

**UKAEA FUS 509**

**EURATOM/UKAEA Fusion**

**Handbook of Activation Data Calculated  
Using EASY-2003**

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July 2004

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# **CONTENTS**

<b>1</b>	<b>INTRODUCTION</b>	<b>1</b>
<b>2</b>	<b>EASY-2003</b>	<b>1</b>
2.1	SAFEPAQ-II	1
2.2	EAF-2003	1
2.3	FISPACT-2003	2
<b>3</b>	<b>NEUTRON SPECTRA</b>	<b>2</b>
<b>4</b>	<b>EXPLANATION OF TABLES AND GRAPHS</b>	<b>5</b>
4.1	GENERAL PROPERTIES	5
4.2	ACTIVATION PROPERTIES	6
4.3	PATHWAY ANALYSES	7
4.4	ACTIVATION GRAPHS	10
4.5	IMPORTANCE DIAGRAMS	11
4.6	TRANSMUTATION GRAPHS	12
4.7	SUMMARY TABLES	13
<b>5</b>	<b>ACKNOWLEDGEMENT</b>	<b>15</b>
<b>6</b>	<b>REFERENCES</b>	<b>15</b>

## **PART 1**

<b>ACTIVATION ANALYSIS OF THE NATURALLY OCCURRING ELEMENTS</b>	<b>17</b>
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## **PART 2**

<b>THE SUMMARY TABLES</b>	<b>507</b>
<b>SUMMARY OF PRIMARY AND SECONDARY NUCLIDES</b>	<b>508</b>
<b>SUMMARY OF MAJOR REACTIONS</b>	<b>521</b>



# **1 INTRODUCTION**

Investigation of the properties of current fusion devices such as JET, planned ones such as ITER, and conceptual power plants such as PPCS, have indicated the need for tools to predict the activation of materials. Considerable effort within the European Fusion Programme has led to the production of the European Activation System (EASY) to provide such a capability. The current version, EASY-2003, consists of: an extensive library of data (EAF-2003) including neutron induced cross sections, decay data and biological hazard coefficients; an inventory code (FISPACT-2003); a development tool (SAFEPAQ-II) used to produce the European Activation File (EAF); and extensive documentation. EASY-2003 is widely distributed and has been used to carry out activation calculations for a large number of materials. However, it was felt that there was also a need for a comprehensive handbook of activation data that could be referred to by materials specialists and designers without the need to run codes. The present report answers this need, and updates and extends the two reports that were produced about eleven years ago [1,2]. Since then the activation field has matured with new versions of the EAF data and FISPACT code, which improve the accuracy of the predictions. In addition, new presentations of the data have been developed, including ‘importance diagrams’ that allow a neutron-spectrum-independent summary of the activation properties of a material to be given. Using these new tools the activation properties of all the naturally occurring elements from Hydrogen to Uranium are presented.

# **2 EASY-2003**

An overview of EASY-2003 is available [3], which describes the various parts that make up the package, and shows how they fit together. Each of these is briefly described below.

## **2.1 SAFEPAQ-II**

SAFEPAQ-II is the software tool used for the maintenance and development of the EAF nuclear data library by UKAEA. Maintenance of the EAF library is a complex procedure: the cross section files need to be evaluated (including choosing which of several data sources to use and adjustment of data), processed (conversion to a common format), compiled into a library, validated (against experimental data and systematics), and documented. Similarly, the decay data files need to be compiled and documented, and all the subsidiary files required as input to the inventory code FISPACT need to be generated in a consistent manner.

Several radical decisions were made when SAFEPAQ-II was designed; these include the use of relational databases rather than text files to store the data and a user-friendly application written in Visual Basic, as well as the choice to run under Windows. Full details are given in the SAFEPAQ-II User manual [4].

## **2.2 EAF-2003**

The EAF-2003 data library is the result of a considerable effort over the last fifteen years by the UKAEA and ECN Petten. The term EAF originally described only the neutron-induced cross section library, but is now used to cover all the nuclear data libraries required for inventory calculations. The libraries contained in EAF-2003 cover:

- Cross section data for neutron-induced reactions
- Uncertainty data for neutron-induced reactions
- Decay data
- Fission yield data
- Biological hazard data
- Legal transport data
- Clearance data
- Charged particle ranges in materials
- Emitted particle spectral data (from neutron-induced reactions)
- Charged particle cross section data
- Gamma absorption data

Further details on the various EAF libraries are available in the cross section report [5], the decay data report [6], and the biological hazard report [7], while summaries of the rest are given in the overview [3].

### **2.3 FISPACT-2003**

FISPACT is an inventory code that has been developed for neutron-induced activation calculations for materials in fusion devices. The current version is FISPACT-2003, which is the culmination of fifteen years of development. It uses external libraries of nuclear data for all relevant nuclides to calculate the number of atoms of each species at a specified time, which can be during an irradiation or after a decay time following shutdown. The various species (nuclides) are formed either by a direct reaction on a starting material, via a series of reactions (some of which can be on radioactive targets), by a decay, by a series of decays, or via a combination of both reactions and decays. The accuracy of the calculated inventory is dependent on the quality of the input nuclear data, i.e. the cross sections and decay properties. The European Activation File (EAF), described above, is the recommended source of data.

The main items of information that must be supplied by the user are: composition and mass of the material to be irradiated, a description of the neutron spectrum, details of the irradiation, which may be either continuous or in a series of pulses, and, for the period following shutdown, a series of decay times at which inventories are required.

The many options available, and the description of the code words used, are fully explained in the FISPACT-2003 User manual [8]. This contains many examples of input, which illustrate how the user can construct input files for any particular type of run.

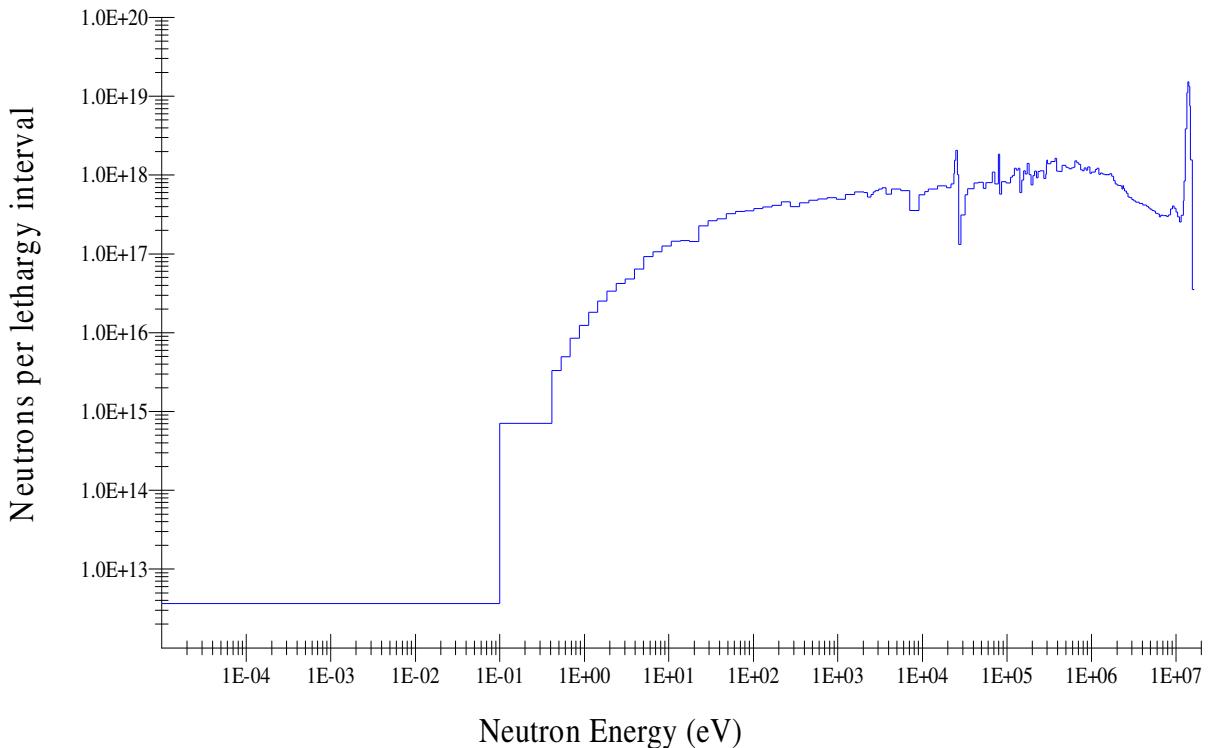
## **3 NEUTRON SPECTRA**

When performing calculations of material activation due to neutron irradiation in FISPACT, the user must supply a neutron spectrum for the incident particles. FISPACT combines this with cross section data in the appropriate group structure, which is determined by the form of the user-supplied spectrum, to produce a 1-group effective cross section library for all the reactions available in EAF. This library is then used directly to perform subsequent activation calculations [8].

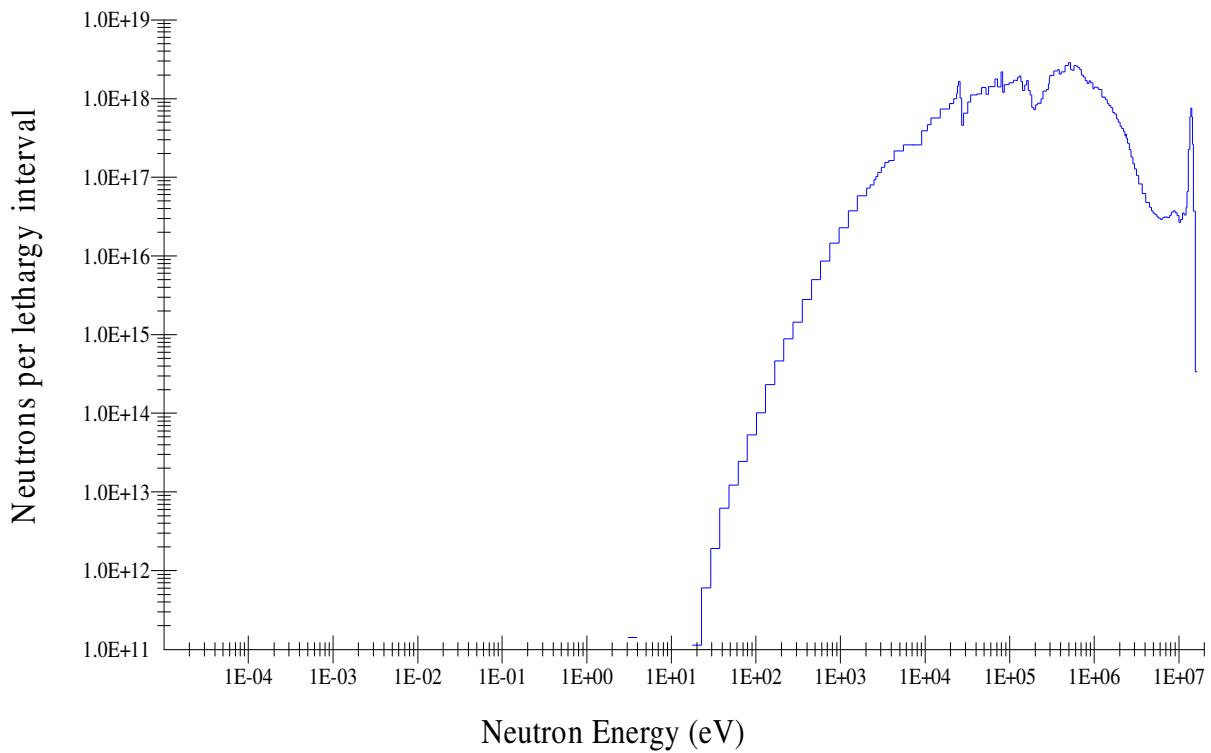
In the calculations performed to produce the activation data presented in this handbook, various neutron spectra are used. In the case of the importance diagrams (see 4.5 for full description), a special set of spectra are used. Each spectrum has neutrons in a single energy group covering the range of energies for the 175-group structure. It is unnecessary to use 175 spectra in practical calculations; forty-two are used with the responses of the missing energies determined by interpolation. Four of these spectrum files are also used to produce the four columns of pathway data, as discussed in 4.3.

The remaining activation calculations are carried out with one of four neutron spectra appropriate to fusion research. Three are taken from the recent Power Plant Conceptual Study (PPCS) study on fusion power plant design studies [9,10,11]. The spectra were calculated for three regions of the plant models, which use various materials for the structure, tritium generation and coolant. The most technologically relevant design was used for each region, thus the first wall spectrum is from Model B, the blanket spectrum from Model C and the shield spectrum from Model A. The three spectra have neutron fluxes of  $1.04 \cdot 10^{15} \text{ ncm}^{-2}\text{s}^{-1}$  for the first wall,  $7.71 \cdot 10^{14} \text{ ncm}^{-2}\text{s}^{-1}$  for the blanket, and  $2.53 \text{ ncm}^{-1}\text{s}^{-1}$  for the shield, with irradiation times of 5, 5, and 25 years respectively. The use of the three spectra means that the activation responses of materials in a range of neutron spectra typical of DT fusion power plants are available. Figure 1, Figure 2, and Figure 3 are graphs of the three spectra, plotted as neutron flux per lethargy interval against energy.

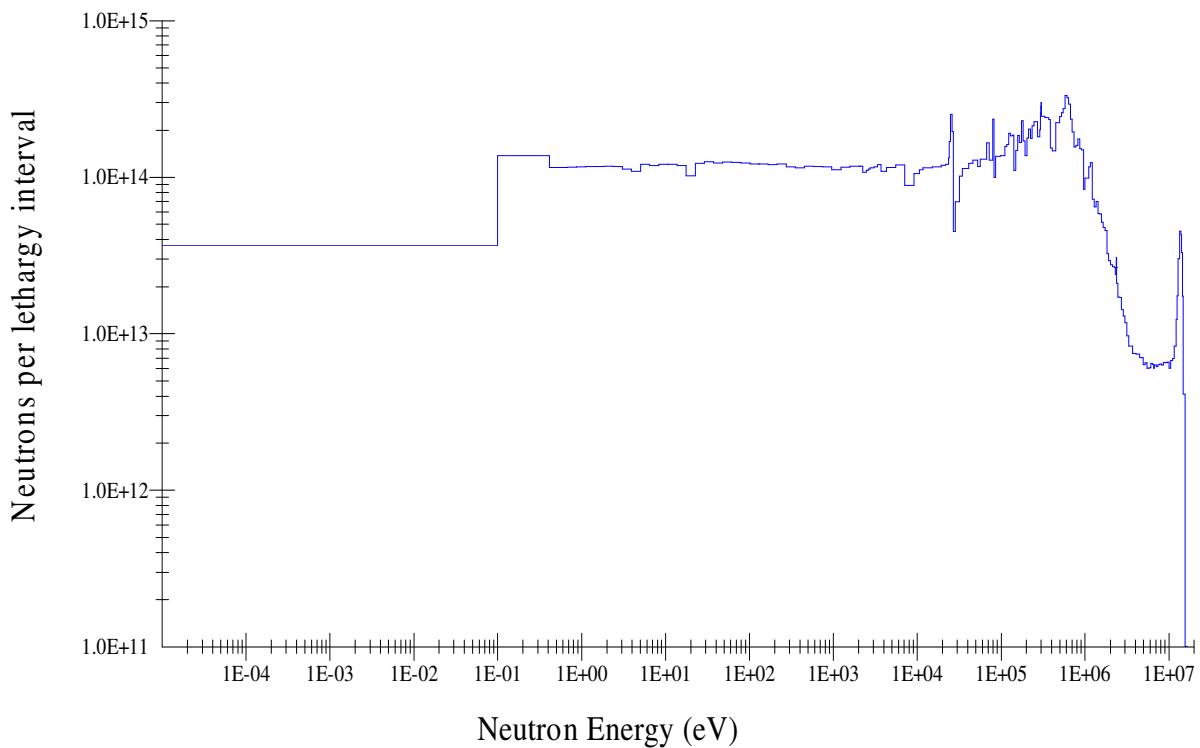
Figure 4 shows the fourth spectra used. In this case a calculated spectrum from an actual fusion device was used, namely the JET (Joint European Torus) experiment. Specifically, it is the spectrum representing the average flux over the vacuum vessel wall on the inboard side of JET [12]. It is for a DD plasma source rather than the DT sources described above and so may be of more interest to experimentalists. It should be noted that this spectrum has much lower fluxes than any of the other three. The details for this spectrum are:  $3.46 \cdot 10^6 \text{ ncm}^{-2}\text{s}^{-1}$ , with an irradiation time of 1 year.



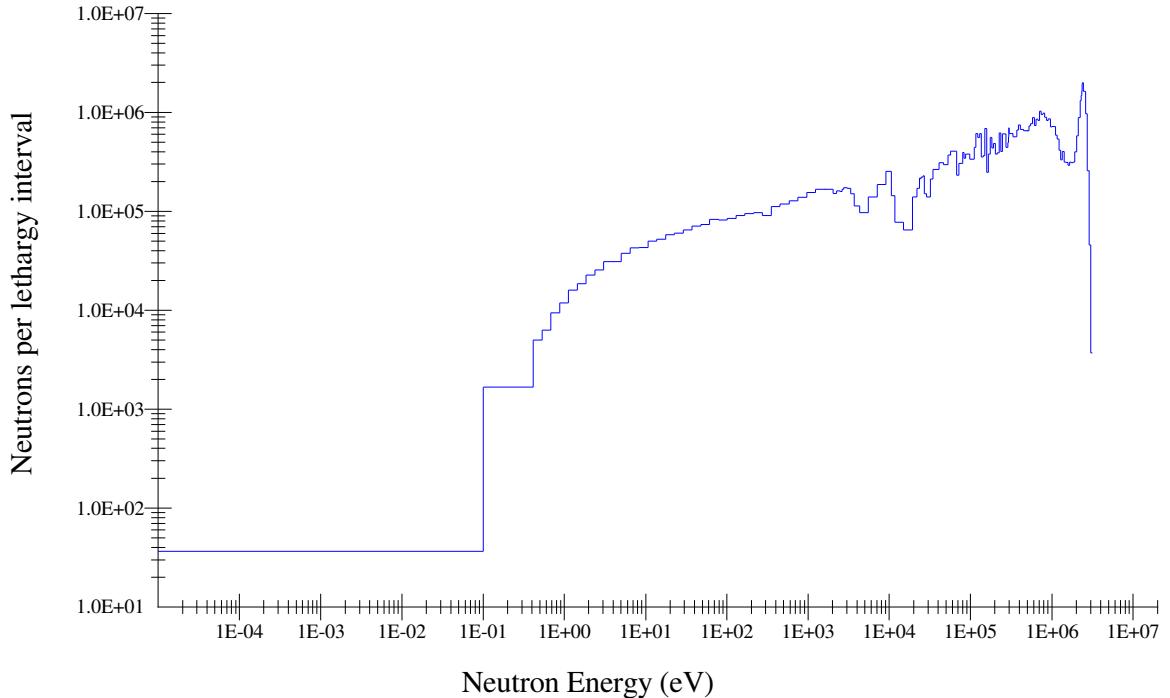
**Figure 1.** Neutron spectrum for the first wall of a conceptual power plant



**Figure 2.** Neutron spectrum for the blanket of a conceptual power plant



**Figure 3.** Neutron spectrum for the shield of a conceptual power plant



**Figure 4.** Neutron spectrum for the vacuum vessel wall on the inboard side of JET

## 4 EXPLANATION OF TABLES AND GRAPHS

The data for each element are split up into a number of sections. These are briefly described below.

### 4.1 GENERAL PROPERTIES

Basic properties of each element are given, including a list of all the naturally occurring isotopes, both stable and radioactive, with the half-lives of the radioactive ones being given in brackets. The properties included in the table are:

- Atomic number
- Crustal abundance in weight parts per million (wppm)
- Melting point in Kelvin at 101.3 kPa (1 atm)
- Boiling point in Kelvin at 101.3 kPa (1 atm)
- Density in  $\text{kgm}^{-3}$
- Thermal Conductivity in  $\text{Wm}^{-1}\text{K}^{-1}$  at 300 K
- Electrical Resistivity in  $\Omega\text{m}$
- Coefficient of linear expansion in  $\text{K}^{-1}$  at 298 K
- Crystal Structure
- Number of stable isotopes
- Mean atomic weight

**Note:** For the number of stable isotopes, figures in brackets indicate the number of isotopes of that particular element that occur naturally, but are also radioactive with long half-lives (as shown in the second column of the table).

The bulk of these data were obtained from the CRC handbook of chemistry and physics [13], together with Nuclear Wallet Cards from the National Nuclear Data Centre (USA) [14], which in the main also takes its data on elemental properties from [13]. Data on the thermal conductivity, electrical resistivity, and crystal structure have mostly been taken directly from the previous version of this handbook [1,2]. Notes relevant for the particular element follow below the table.

## 4.2 ACTIVATION PROPERTIES

The activation table presents the important radionuclides produced by the irradiation of a 1 kg pure sample of an element for 5 years in the first wall neutron spectrum (Figure 1). Data are presented for six activation quantities (the abbreviations used in the tables are shown in brackets, and the units used for these quantities are given):

1 Specific Activity ( <b>Act</b> ) – $\text{Bqkg}^{-1}$	2 Decay Power/Heat Output ( <b>Heat</b> ) – $\text{kWkg}^{-1}$
3 Gamma ( $\gamma$ ) Dose rate ( <b>Dose</b> ) – $\text{Svh}^{-1}$	4 Inhalation dose ( <b>Inh</b> ) – $\text{Svkg}^{-1}$
5 Ingestion dose ( <b>Ing</b> ) – $\text{Svkg}^{-1}$	6 Clearance Index ( <b>Clear</b> ) – no units

The Specific Activity is the activity induced in 1 kg of the material by the neutrons; the Decay Power is the rate of heat production in 1 kg of the material due to the various decay processes. The Gamma Dose rate is the contact dose rate due to a semi-infinite slab of the material [8], the Ingestion and Inhalation doses refer to the dose received by an average person over a 50 year period from the intake of 1 kg of the material [7]. The Clearance Index of a material determines if the material can be disposed of with no special precautions according to IAEA guidelines. If less than 1 then the material can be disposed of or ‘cleared’ as if it were non-radioactive [7].

For each of these six properties data are presented at six different decay times following irradiation. These are: 0 years (immediately after shutdown following the irradiation);  $10^{-5}$  years (5.26 minutes);  $10^{-2}$  years (3.65 days); 1 year; 100 years; and  $10^5$  years. Within the section of the table for each activation property, important radionuclides are listed along with their percentage contribution to the total for the given activation property at each decay time. The nuclides are listed in descending order of contribution for the decay time where they first appear. For example, in Table 1 below, which shows the activation properties of Gallium, in the specific activity section (Act) there are 5 nuclides listed in descending order of contribution at shutdown, with  $^{72}\text{Ga}$  and  $^{70}\text{Ga}$  contributing about 45% each. These two nuclides dominate again after  $10^{-5}$  years, while after a decay time of  $10^{-2}$  years,  $^{71}\text{Ge}$  contributes over 61% with most of the remainder coming from  $^{72}\text{Ga}$  (32%). In the next two time steps  $^3\text{H}$  dominates (78% and 87% respectively). In the last column, which displays the data for a decay time of  $10^5$  years, 4 new nuclides produce all of the activity, and these are listed in the correct descending percentage order of precedence, with  $^{60m}\text{Co}$ ,  $^{60}\text{Fe}$ , and  $^{60}\text{Co}$  each contributing about 30%.

In most cases, nuclides are listed in these tables if their contribution to the total is greater than 1% at any time, except for Uranium and Thorium, where more than 80 radionuclides have contributions greater than 1% for at least one decay time. In these two cases, a decision was made to restrict the overall table to two pages, and so the percentage cut-offs were accordingly adjusted. Furthermore, there are cases where extra nuclides have been included to create symmetry with the adjacent table for any given activation property, as in the case of the Heat Output portion for Gallium in Table 1, where  $^{69}\text{Zn}$  and  $^{71}\text{Ge}$  have been included to match the Specific Activity section.

At the top of each column of percentages for each decay time, the total value of the activation property is given for that time, with units as described earlier. For instance, in the Gallium example, at shutdown after the 5 years of first wall irradiation, the specific activity is  $7.88 \cdot 10^{15} \text{ Bq kg}^{-1}$ . This falls as the decay times increase until, after  $10^5$  years, the activity is just  $5.66 \text{ Bq kg}^{-1}$ .

**Note:** In the case of the Gamma Dose rate percentages, an asterisk (\*) next to the percentage contribution for a given radionuclide indicates that the high-energy  $\beta$  bremsstrahlung radiation correction makes a significant contribution to the percentage. In such cases, the total dose rates (in  $\text{Sv h}^{-1}$ ) are adjusted to include the dose contribution from the bremsstrahlung correction. Further details of this effect and its calculation are given in reference 8.

**Table 1.** Activation properties of Gallium

Act	0	$10^{-5} \text{ y}$	$10^{-2} \text{ y}$	1 y	$100 \text{ y}$	$10^5 \text{ y}$	Heat	0	$10^{-5} \text{ y}$	$10^{-2} \text{ y}$	1 y	$100 \text{ y}$	$10^5 \text{ y}$
Bq kg <sup>-1</sup>	7.88E15	7.24E15	1.48E14	3.40E11	1.16E9	5.66E0	kW kg <sup>-1</sup>	2.35E0	2.27E0	2.60E-2	7.35E-6	1.33E-9	7.5E-16
Ga72	44.71	48.42	32.00				Ga72	77.06	79.34	93.62			
Ga70	44.62	40.84					Ga70	15.60	13.58				
Ga68	7.25	7.47		0.05			Ga68	6.57	6.44		0.67		
Ge71	1.44	1.56	61.34				Ge69	0.30	0.31	5.64			
Ge69	0.52	0.56	5.78				Zn69	0.11	0.10	0.05			
H3			0.19	77.83	87.41		Ge71	0.01	0.01	0.50			
Zn65			0.14	21.98			Zn65			0.08	96.02		
Ni63				0.09	12.59		H3				3.29	69.82	
Co60m						30.26	Ni63				0.01	30.18	
Fe60						30.26	Co60						94.43
Co60						30.19	Fe60						3.19
Ni59						9.27	Co60m						2.30
Dose	0	$10^{-5} \text{ y}$	$10^{-2} \text{ y}$	1 y	$100 \text{ y}$	$10^5 \text{ y}$	Ing	0	$10^{-5} \text{ y}$	$10^{-2} \text{ y}$	1 y	$100 \text{ y}$	$10^5 \text{ y}$
Sv h <sup>-1</sup>	3.02E6	3.00E6	4.09E4	1.25E1	1.44E-9	1.28E-9	Sv kg <sup>-1</sup>	4.06E6	4.03E6	5.63E4	3.03E2	6.44E-2	1.94E-7
Ga72	95.49	95.73	94.55				Ga72	95.37	95.84	92.61			
Ga68	3.77	3.60		0.29			Ga70	2.68	2.28				
Ge69	0.34	0.34	5.22				Ga68	1.41	1.34		0.01		
Ga70	0.23	0.20					Ge69	0.24	0.24	3.65			
Zn71m	0.06	0.06					Ge71	0.03	0.03	1.94			
Zn69m	0.06	0.06	0.05				Zn65	0.02	0.02	1.45	96.23		
Zn65			0.09	99.70			H3			0.02	3.67	66.04	
Ge71			0.08				Ni63				0.01	33.96	
Co60					99.82	99.82	Fe60						96.99
Co60m					0.16	0.17	Co60						2.99
Inh	0	$10^{-5} \text{ y}$	$10^{-2} \text{ y}$	1 y	$100 \text{ y}$	$10^5 \text{ y}$	Clear	0	$10^{-5} \text{ y}$	$10^{-2} \text{ y}$	1 y	$100 \text{ y}$	$10^5 \text{ y}$
Sv kg <sup>-1</sup>	1.97E6	1.95E6	2.94E4	2.36E2	4.53E-1	5.33E-7		1.07E13	1.06E13	1.41E11	2.49E8	3.86E2	5.74E-3
Ga72	94.62	95.11	85.44				Ga72	91.56	92.18	93.05			
Ga70	2.85	2.42					Ga68	5.45	5.23		0.08		
Ga68	1.42	1.36					Ga70	2.35	2.00				
Ge69	0.60	0.60	8.45				Ge69	0.38	0.38	6.05			
Ge71	0.06	0.06	3.40				Zn65	0.01	0.01	0.49	99.89		
Zn65	0.02	0.02	1.56	69.61			Ge71	0.01	0.01	0.31			
H3			0.25	29.14	58.15		H3				0.04	87.41	
Ge68			0.02	1.08			Ni63						12.58
Ni63				0.16	41.85		Co60						99.33
Fe60						90.01	Co60m						0.37
Co60						9.94	Fe60						0.27

### 4.3 PATHWAY ANALYSES

For each element the production pathways for the dominant radionuclides from the element's naturally occurring isotopes are listed. A nuclide's production pathways are presented if it is a 'primary nuclide', and hence appears on one of the importance diagrams (see description in Section 4.5) for the particular element. The meaning of primary nuclide will be discussed later. For each daughter radionuclide the important pathways of production are given, together with their percentage contribution to the total amount of the nuclide

produced, at each of four different neutron energies. Clearly, some pathways have contributions at more than one energy, and in such cases the pathway is listed only once with multiple percentages input on the same row of the table. As a general rule, where many pathways contribute to the production of a particular daughter nuclide, only those contributing more than 1% for at least one of the four different energies are included. Along with the pathways, the half-life of each primary nuclide is also given. For example, in the case of Carbon we have the pathway analysis shown in Table 2. For  $^{15}\text{C}$  it can be seen that this radionuclide has a half-life of 2.449 seconds, and that at all four energies the dominant pathway is  $\text{C}13(\text{n},\gamma)\text{C}14(\text{n},\gamma)\text{C}15$ . At the lowest energy of 0.26 eV it can be seen that there is also a contributing pathway starting from another isotope of Carbon, namely  $^{12}\text{C}$ , and that this pathway,  $\text{C}12(\text{n},\gamma)\text{C}13(\text{n},\gamma)\text{C}14(\text{n},\gamma)\text{C}15$ , contributes 1.1% of the total amount of  $^{15}\text{C}$  produced (the other pathway, starting from  $^{13}\text{C}$ , contributes 98.9%).

**Table 2.** Pathway analysis for Carbon

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
He6	0.808 s	$\text{C}12(\text{n},\alpha)\text{Be}9(\text{n},\alpha)\text{He}6$ $\text{C}13(\text{n},\alpha)\text{Be}10(\text{n},\text{n}\alpha)\text{He}6$				97.8 2.0
Li8	0.838 s	$\text{C}13(\text{n},\text{t})\text{B}11(\text{n},\alpha)\text{Li}8$ $\text{C}12(\text{n},\text{d})\text{B}11(\text{n},\alpha)\text{Li}8$				84.4 15.4
C15	2.449 s	$\text{C}13(\text{n},\gamma)\text{C}14(\text{n},\gamma)\text{C}15$ $\text{C}12(\text{n},\gamma)\text{C}13(\text{n},\gamma)\text{C}14(\text{n},\gamma)\text{C}15$	98.9 1.1	100.0	100.0	99.7 0.1
Be11	13.81 s	$\text{C}13(\text{n},\text{t})\text{B}11(\text{n},\text{p})\text{Be}11$ $\text{C}12(\text{n},\text{d})\text{B}11(\text{n},\text{p})\text{Be}11$ $\text{C}13(\text{n},\alpha)\text{Be}10(\text{n},\gamma)\text{Be}11$				82.4 15.0 2.2
H3	12.33 y	$\text{C}13(\text{n},\gamma)\text{C}14(\beta^-)\text{N}14(\text{n},\text{X})\text{H}1(\text{n},\gamma)\text{H}2(\text{n},\gamma)\text{H}3$ $\text{C}12(\text{n},\alpha)\text{Be}9(\text{n},\text{X})\text{H}3$ $\text{C}13(\text{n},\text{t}2\alpha)\text{H}3$ $\text{C}12(\text{n},\alpha)\text{Be}9(\text{n},\text{t})\text{Li}7(\text{n},\text{n}\alpha)\text{H}3$	95.2	97.1		65.3 33.4 1.0
C14	5730 y	$\text{C}13(\text{n},\gamma)\text{C}14$ $\text{C}12(\text{n},\gamma)\text{C}13(\text{n},\gamma)\text{C}14$	98.9 1.1	100.0	100.0	99.8 0.1
Be10	$1.6 \cdot 10^6$ y	$\text{C}13(\text{n},\alpha)\text{Be}10$ $\text{C}12(\text{n},\gamma)\text{C}13(\text{n},\alpha)\text{Be}10$				99.8 0.1

There are a large number of possible types of reactions and decays that may occur along the production pathway from the parent isotope to the daughter radionuclide. The most common ones in this handbook, with typical examples, are listed below.

## Reactions

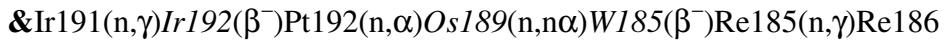
- (n, $\gamma$ ) – neutron absorbed, gamma photon emitted, e.g.  $\text{Li}7(\text{n},\gamma)\text{Li}8$
- (n,2n) – neutron absorbed, two neutrons emitted, e.g.  $\text{N}14(\text{n},2\text{n})\text{N}13$
- (n, $\alpha$ ) – neutron absorbed, alpha particle emitted, e.g.  $\text{Mg}25(\text{n},\alpha)\text{Ne}22$
- (n,p) – neutron absorbed, proton emitted, e.g.  $\text{Si}28(\text{n},\text{p})\text{Al}28$
- (n,n') – neutron absorbed and emitted (inelastic scattering), e.g.  $\text{Xe}129(\text{n},\text{n}')\text{Xe}129\text{m}$
- (n,t) – neutron absorbed, triton emitted (or combination of 2 neutrons and a proton), e.g.  $\text{Fe}55(\text{n},\text{t})\text{Mn}53$
- (n,n $\alpha$ ) – neutron absorbed, alpha particle and neutron emitted, e.g.  $\text{Cl}35(\text{n},\text{n}\alpha)\text{P}31$
- (n,3n) – neutron absorbed, three neutrons emitted, e.g.  $\text{U}238(\text{n},3\text{n})\text{U}236$
- (n,d) – neutron absorbed, deuteron emitted (or a neutron and a proton), e.g.  $\text{Co}59(\text{n},\text{d})\text{Fe}58$

- (n,2p) – neutron absorbed, two protons emitted, e.g. Ca40(n,2p)Ar39
- (n,X) – neutron absorbed, heavy nucleus recoiled (important in the production of  $^3\text{H}$ ), e.g. Be9(n,X)H3

## Decays

- $(\beta^-)$  – beta decay, e.g. Hg205( $\beta^-$ )Tl205
- $(\beta^+)$  – positron decay (including electron capture), e.g. W181( $\beta^+$ )Ta181
- $(\alpha)$  – alpha decay, e.g. Pu236( $\alpha$ )U232
- (IT) – isomeric transition resulting in gamma ray emission, e.g. Na24m(IT)Na24

These reactions and decays can combine to form very long pathways, some of which take up several lines in the pathway analysis tables, so it is important to find ways of limiting the amount of information presented, while still providing a full picture of the production of each radionuclide. Many of the long chain pathways include short-lived isomeric transition nuclides that simply rejoin the main pathway by decaying back to their ground state, e.g. Na24m(IT)Na24. It was decided that pathways that only differed from one another in these isomeric transition (IT) steps, should be summed together, with only the simplest or ‘generic’ pathway, i.e. the one that has no IT steps, displayed in the handbook. In such cases the generic pathway displayed is preceded by an ampersand in bold (**&**), with all the ground state nuclides that have an isomeric (or metastable) state, which is important in the production of the particular radionuclide daughter, printed in italics. Thus, for example, in the case of the production of  $^{186}\text{Re}$  from  $^{191}\text{Ir}$ , we have the generic pathway:



which contributes 73.4% of the total  $^{186}\text{Re}$  production for Iridium. It is displayed in this form in the pathway analysis for Iridium, and it can be seen that Ir192, Os189 and W185 are in italics, indicating that the 73.4% is actually the sum of the contributions from the following 8 pathways, which include the isomeric transitions:

1. Ir191(n, $\gamma$ )Ir192( $\beta^-$ )Pt192(n, $\alpha$ )Os189(n, $\text{n}\alpha$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186 (the basic pathway)
2. Ir191(n, $\gamma$ )Ir192m(IT)Ir192( $\beta^-$ )Pt192(n, $\alpha$ )Os189(n, $\text{n}\alpha$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186
3. Ir191(n, $\gamma$ )Ir192( $\beta^-$ )Pt192(n, $\alpha$ )Os189m(IT)Os189(n, $\text{n}\alpha$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186
4. Ir191(n, $\gamma$ )Ir192( $\beta^-$ )Pt192(n, $\alpha$ )Os189(n, $\text{n}\alpha$ )W185m(IT)W185( $\beta^-$ )Re185(n, $\gamma$ )Re186
5. Ir191(n, $\gamma$ )Ir192m(IT)Ir192( $\beta^-$ )Pt192(n, $\alpha$ )Os189m(IT)Os189(n, $\text{n}\alpha$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186
6. Ir191(n, $\gamma$ )Ir192m(IT)Ir192( $\beta^-$ )Pt192(n, $\alpha$ )Os189(n, $\text{n}\alpha$ )W185m(IT)W185( $\beta^-$ )Re185(n, $\gamma$ )Re186
7. Ir191(n, $\gamma$ )Ir192( $\beta^-$ )Pt192(n, $\alpha$ )Os189m(IT)Os189(n, $\text{n}\alpha$ )W185m(IT)W185( $\beta^-$ )Re185(n, $\gamma$ )Re186
8. Ir191(n, $\gamma$ )Ir192m(IT)Ir192( $\beta^-$ )Pt192(n, $\alpha$ )Os189m(IT)Os189(n, $\text{n}\alpha$ )W185m(IT)W185( $\beta^-$ )Re185(n, $\gamma$ )Re186

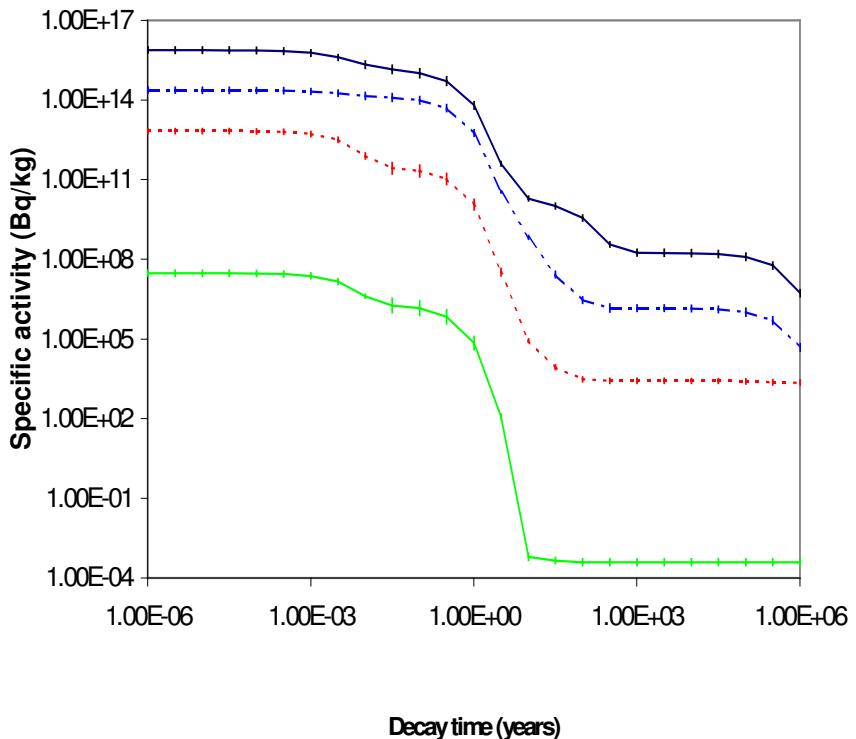
It should be noted that where a metastable nuclide undergoes a reaction or decay, other than an isomeric transition to the ground state, then the pathway involved is displayed separately, and is not included in the generic pathway.

The pathway data were obtained by employing the ability of FISPACT to calculate pathways, full details of which can be found in the User manual [8]. They result from the irradiation of pure samples of the elements for 5 years with the four relevant single-energy neutron spectra described earlier, followed by a series of decay times adding up to  $10^6$  years. The four energies, which are 0.26 eV, 148 eV, 37.6 keV, and 14.7 MeV, were chosen to give a broad picture of the reaction behaviour of the elements when irradiated with neutrons. It should be noted that not all of the primary nuclides are produced at all four of the energies, as can be seen in the cases of  $^6\text{He}$ ,  $^8\text{Li}$ ,  $^{11}\text{Be}$ ,  $^3\text{H}$ , and  $^{10}\text{Be}$  for Carbon in Table 2.

In some cases it has not been possible to find the pathways for given daughter nuclides because the pathways are so long that they exceed the limits of FISPACT (see reference 8 for details). In the standard outputs there may be no pathway data for a nuclide, or there may be only a few of the pathways presented, which do not sum to the total production (100%) for the nuclide. Wherever possible special FISPACT runs with different parameters have been made to find additional pathways so that the total percentage is at least 90%, but in cases where this has not been achieved, notes have been placed within the appropriate part of the table using asterisks (\*) or daggers (†). There are also instances where no pathways have been given because the threshold for the production of a particular radionuclide falls outside the range of energies employed in the pathway analysis, even though it may still appear on the importance diagrams. This is also referred to appropriately within the main body of the handbook. Another complication arises when some of the naturally occurring isotopes are radioactive, in such cases the radionuclides are typically one of the dominant nuclides (at long times) and much of their amount is not formed but is initially present. Such cases are noted in the tables.

#### **4.4 ACTIVATION GRAPHS**

Activation calculations performed using the three neutron spectra for conceptual power plant designs, together with the spectrum calculated for the JET experimental device (see Section 3), are presented in graphical form. For each element, there is a separate graph for all six of the activation properties presented in the activation properties table (see 4.2), with the same units as before. The graphs are colour coded (in the CD-ROM version of this report) to enable distinction between the results from the four different spectra. In each graph the solid dark blue curve represents the data produced from irradiation of the element with neutrons of the first wall spectrum. The dash-dotted blue curve and the dotted red curve represent results for the blanket and shield spectra, respectively. Finally, the solid green curve (always the lowest of the four curves, in case the graphs are being viewed in black-and-white) represents the results of calculations with the JET DD spectrum. Each graph is a log-log plot of the activation property as a function of decay time following irradiation. The decay time ranges from  $10^{-6}$  to  $10^6$  years. The irradiation times used for each spectrum are as stated in Section 3. As with the activation properties, an asterisk, in this case in the title of the dose rate graph, indicates that the contribution from bremsstrahlung is significant. Figure 5 shows, as an example graph, the plot of the specific activity of the metal Tungsten. It shows that the four curves have a similar pattern of variation with the highest activity in the first wall curve, followed by the blanket, shield, and JET DD curves. Note also that error bars have been included for the data on each curve, these represent the uncertainty in the quantity due to uncertainties in the cross section data in the EAF library calculated in the standard FISPACT runs.

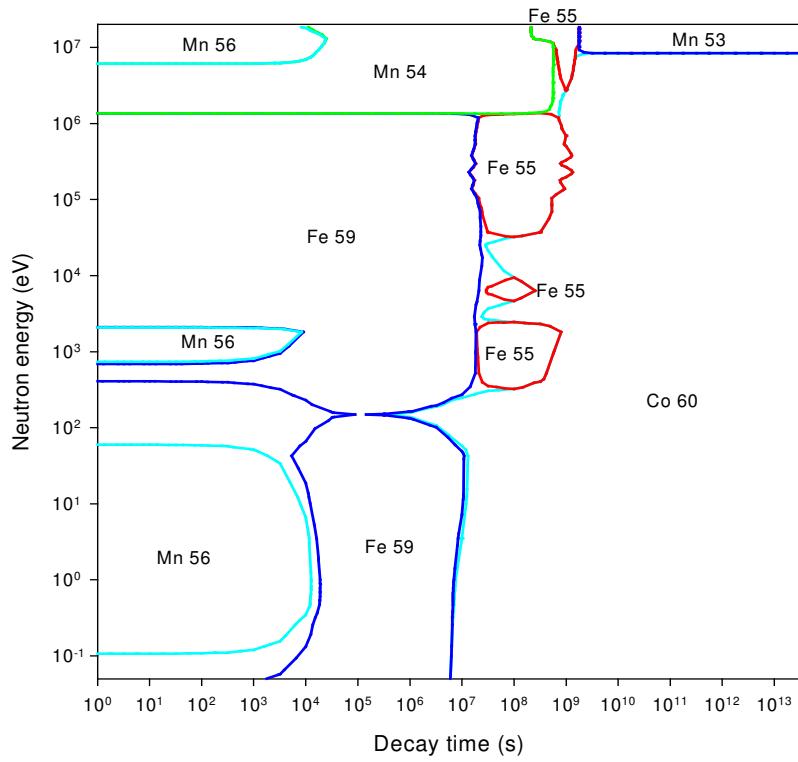


**Figure 5.** The activation graph for the specific activity of Tungsten

**Note:** In the case of the Clearance Index graph, a line indicating a Clearance Index of 1 is also plotted (purple line).

#### 4.5 IMPORTANCE DIAGRAMS

In Section 3 the neutron spectra used for the above calculations are discussed. Neutron spectra are necessary to give results for a particular irradiation, but the motivation for the importance diagrams is to present activation results that do not require the definition of a neutron spectrum. To do this the response of a material to mono-energetic neutrons is considered. Results produced by such calculations allow the most important radionuclides to be identified for each neutron energy. Plotting the regions where a nuclide contributes 50% or more of the total response, at various decay times, gives an importance diagram. A full description of these diagrams is given in reference 15 and examples for various materials can be found in references 16 and 17. Figure 6 shows the dose rate importance diagram for pure iron. In this the various regions shown are labelled by a nuclide, e.g. for decay times  $< 1 \times 10^4$  s and for energies  $> 0.1$  eV and  $< 90$  eV the nuclide  $^{56}\text{Mn}$  is dominant (i.e. it contributes more than 50% of the total dose rate). Note that there are three distinct regions labelled by  $^{56}\text{Mn}$  at these short decay times, at various energies. At other energies  $^{54}\text{Mn}$  or  $^{59}\text{Fe}$  dominate, while at energies  $> 90$  eV and  $< 600$  eV no single nuclide contributes more than 50% for these short decay times. In the latter case it is usual for three nuclides to dominate. It is typical that nuclides dominate at particular decay times giving a vertical band in the diagram (e.g.  $^{55}\text{Fe}$  dominates at about  $1 \times 10^8$  s) although in many cases these bands are split into several distinct regions by a region for another nuclide. Also there is generally a different set of nuclides that dominate at MeV energies from those that dominate at low energy, because of the importance of threshold reactions rather than capture reactions. The importance diagram gives no information on the magnitude of the dose rate (a neutron spectrum is needed for such data), but instead summarises which nuclides will be important at particular decay times, when neutrons of various energies are present. Thus for iron in a hard spectrum, at times  $> 20$  y ( $\sim 6 \times 10^8$  s), Figure 6 shows that  $^{53}\text{Mn}$  would dominate the dose rate, while in a soft spectrum  $^{60}\text{Co}$  would be more important.



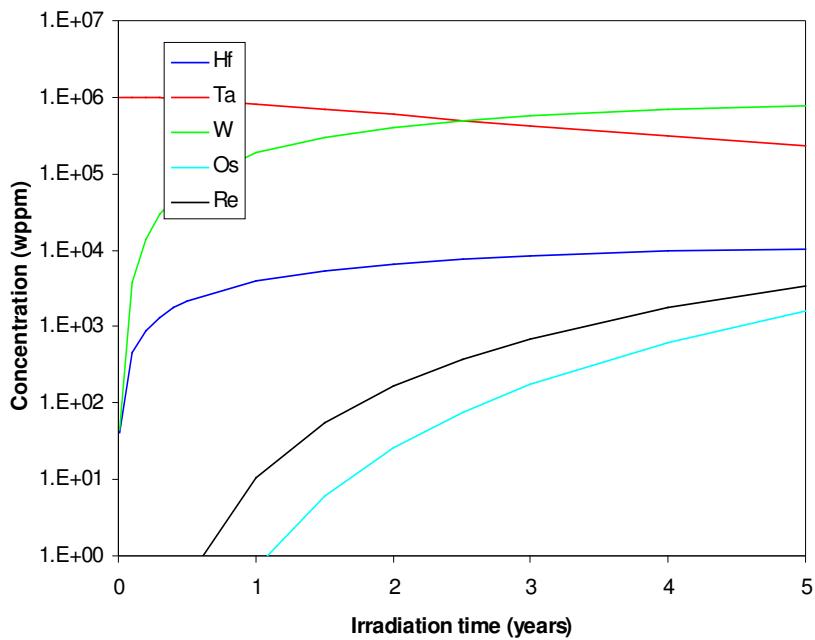
**Figure 6.** Dose rate importance diagram for pure iron

The nuclides shown in the importance diagrams, which appear because they contribute 50% or more of the total quantity in at least one region of the Decay time-Neutron energy plane, are termed ‘primary nuclides’. These are the nuclides which have their production pathways presented in the pathways analysis tables described in 4.3. Of course, other radionuclides are produced during irradiations by mono-energetic neutrons, and those that contribute between 1% and 50% are termed ‘secondary nuclides’. The pathways for these are not listed, but the nuclides themselves are listed in the first table of the Summary section (see Section 4.7 for a full description).

#### 4.6 TRANSMUTATION GRAPHS

The rates of production of the most important transmutation elements, together with the burn-up of the element under consideration, are plotted as a function of time. These results are produced by irradiating the given element with the first wall spectrum described in Section 3. The curve for a particular element is generally only shown if it is produced in concentrations greater than 1 wppm (weight part per million). Exceptions include Hydrogen and Helium, where the boundary was lowered so that the graph had something other than just the starting material on it, and also Uranium and Thorium, where the cut-off was increased so that the graph produced was not overloaded with a huge number of fission products, each with concentrations greater than 1 wppm. Concentrations below this 1 wppm are not included because elements in such small amounts will generally not have any significant effect on material properties.

An example of the type of transmutation graph presented in this handbook is shown in Figure 7, which shows the results for the transmutation of Tantalum (Ta). It can be seen that there is considerable burn-up of the starting material, with the major transmutation product being Tungsten (W). In fact the rate of burn-up is so great that, after around 2.5 years, the concentration of Tungsten (green line) becomes greater than that of Tantalum itself (red line). The other important products are Hafnium (Hf), Osmium (Os), and Rhenium (Re).



**Figure 7.** Transmutation graph for Tantalum

#### 4.7 SUMMARY TABLES

In this section of the handbook two large tables are presented, which summarise some of the important information in a more easily accessible format. The first of these is a table displaying both the primary and secondary nuclides (see definition of these in 4.5) of all elements considered in the handbook. The table takes the form of a list of all the radionuclides that are a primary or secondary nuclide for at least one of the elements in the main body of the handbook. For each of these radionuclides, which are displayed in alphabetical order for easy location, their half-life is given. Two subsequent columns in the table then list the elements for which this nuclide is primary and secondary, respectively. These elements are listed in order of increasing atomic number. For example, the entry for the nuclide  $^{94}\text{Nb}$  has the format shown in Table 3, with appropriate column headings. It shows that there are four elements for which  $^{94}\text{Nb}$  is a primary nuclide, namely Zirconium, Niobium, Molybdenum, and Ruthenium, with seven other elements having this radionuclide as a secondary nuclide. The information on the primary nuclides is the same as that shown in the importance diagrams and pathways analysis for each element, but this table displays it in a more concise form, with the added information on those nuclides that form the next level of importance in the activation of the elements. 754 nuclides, out of a total of 1917 present in EAF-2003, are listed in the table.

**Table 3.** Entry for  $^{94}\text{Nb}$  in the Primary and Secondary nuclides table

Nuclide	$T_{1/2}$	Contributing elements	
		Primary	Secondary
$\text{Nb}^{94}$	$1.999 \cdot 10^4 \text{ y}$	Zr, Nb, Mo, Ru	Y, Rh, Pd, Ag, Cd, In, U

The second summary table displays the important information from the pathway analysis data, which is large and extensive. It presents the major reactions found within the pathway tables, and gives the nuclides that have these reactions as steps in their important production chains. Every primary nuclide listed in the pathway analysis of at least one element has the major reactions from its main pathways of production listed. For each element, a reaction is included if it contributes more than 20% of the total amount of a particular nuclide. So, for example, in Table 2, the pathway data for the production of  $^8\text{Li}$  from the naturally occurring

isotopes of Carbon, lists two pathways that contribute to the production at 14.7 MeV. The first contributes 84.4%, and so the two reactions in the pathway are included in the summary table with  $^8\text{Li}$  shown in the ‘Daughter nuclide’ column. However, the other pathway contributes only 15.4%, and so its two reactions are not included in the table (actually the second reaction is common with the first pathway), unless they are important in the production of other radionuclides, or indeed in the production of  $^8\text{Li}$  from an element other than Carbon. The table displays, as one group, all the major reactions with a single element’s isotopes as the parents, displayed in increasing atomic number of the element. Within the group the reactions are listed in order of increasing mass number of the target nuclide. In the case of generic pathways, only the reactions for the basic pathway, i.e. excluding any isomeric transitions (IT), have been included in the summary table. Thus reactions involving metastable nuclides (e.g.  $^{193\text{m}}\text{Pt}$ ) are only included in the table if they are involved in pathways where they do not decay to the ground state nuclide via an isomeric transition. This can happen if the metastable isomer has a half-life that is long enough to allow time for reactions to occur, or if the isomer has a decay mode that is not an isomeric transition. An example of this can be seen in the production of  $^{77}\text{As}$  from  $^{76}\text{Ge}$ . Both  $^{77}\text{Ge}$  and  $^{77\text{m}}\text{Ge}$  are produced via an  $(n,\gamma)$  reaction from  $^{76}\text{Ge}$ , but while in some cases the  $^{77\text{m}}\text{Ge}$  decays to  $^{77}\text{Ge}$  via an IT reaction, followed by beta decay to  $^{77}\text{As}$ , in other cases the metastable nuclide beta decays directly to  $^{77}\text{As}$ , with both pathways contributing more than 20%. Thus, in the summary table,  $\text{Ge}76(n,\gamma)\text{Ge}77\text{m}$  is included, along with  $\text{Ge}76(n,\gamma)\text{Ge}77$ .

Target nuclides that are stable or naturally occurring are printed in bold. Similarly the product nuclides that are stable are printed in bold. This is an aid to identify reactions that could be measured experimentally. Although some data on radioactive targets are available, these can only be obtained at particular energies typically in a fission reactor environment. Similarly data for stable products are available, but only by employing particle counting techniques rather than the more common activation methods.

The first column of the table lists the major reactions in the order as described above. The second column has a list of all the nuclides whose major production pathways contain the reaction. The third column lists the cross section uncertainty as a percentage of the total cross section. For non-threshold reactions the uncertainty depends upon the neutron spectrum used in the FISPACT calculations. The uncertainty data presented here are for data produced using the first wall spectrum described in Section 3.

Column 4 presents the ‘quality score’ for the reaction. The scores are listed in reference 5, and indicate the agreement of the library data with the experimental database. The meaning of the values are: 0 – no experimental data, 1 – weak disagreement with the differential data, 2 – weak agreement with the differential data, 3 – strong disagreement with the differential data, 4 – strong agreement with the differential data, 5 – discrepant integral and differential data, 6 - agreement between the library and the integral and differential data (validated reaction). The integral data and the results of the validation exercise on EAF-2003 are reported in reference 18. Columns four and five in the table indicate, with a bullet point, whether differential (Diff) and/or integral (Int) experimental data are available to support the data in EAF-2003 for the cross sections of each reaction listed. In cases where a single reaction rather than reactions to the two or three isomeric states is given, if the scores are not the same for all states then all the values are given; thus ‘2/4’ means that the score is 2 for the ground state and 4 for the isomer. In cases where the scores differ from reference 5 (usually as a result of the validation exercise reported in reference 18) this is shown by an asterisk (\*).

## 5 ACKNOWLEDGEMENT

This work was funded jointly by the United Kingdom Engineering and Physical Sciences Research Council and by EURATOM.

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**PART 1:**

**Activation Analysis of the Naturally Occurring  
Elements**

# Hydrogen

## General properties

		1	Isotopes	Isotopic abundances / %	
Atomic number		152	H1	99.985	
Crustal abundance / wppm		14.01	H2	0.015	
Melting point / K		20.28			
Boiling point / K		8.988 $10^{-2}$			
Density / kgm <sup>-3</sup>		1.82 $10^{-1}$			
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>		-			
Electrical resistivity / $\Omega$ m		-			
Coefficient of thermal expansion / K <sup>-1</sup>		HCP			
Crystal structure		2			
Number of stable isotopes		1.0079			
Mean atomic weight					

## Activation properties

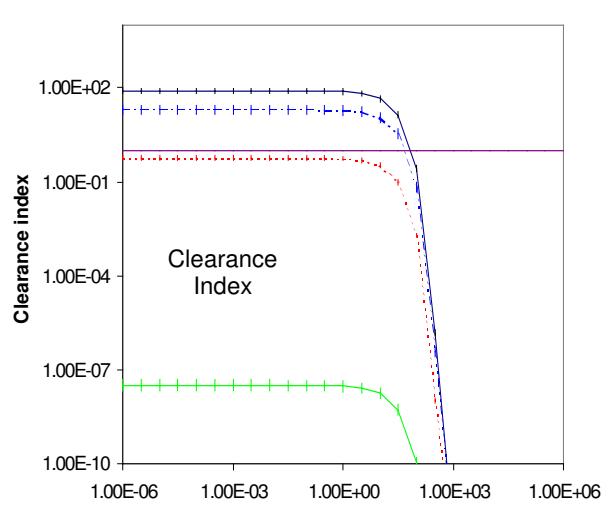
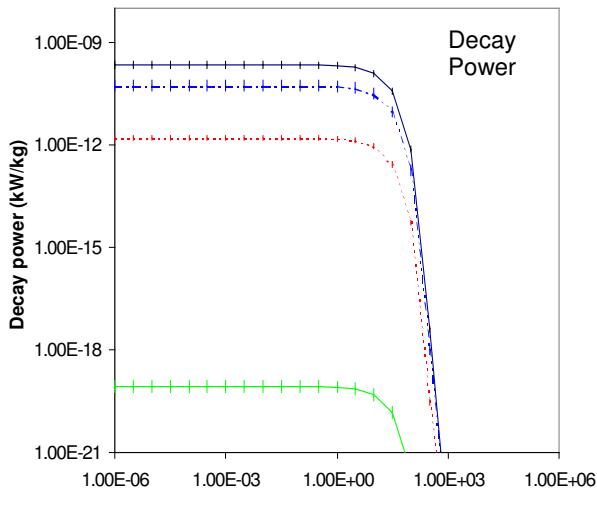
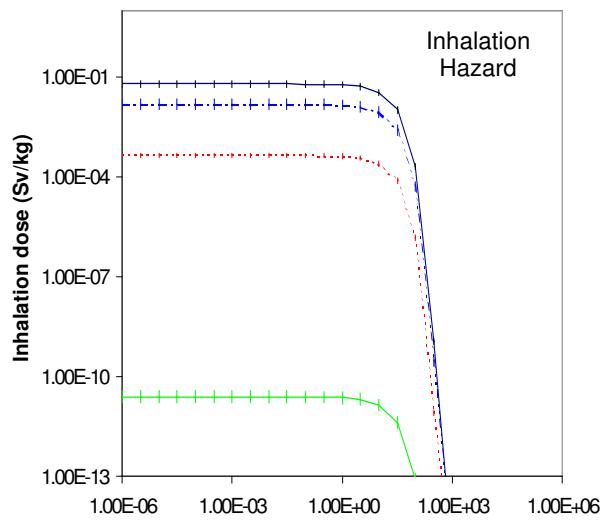
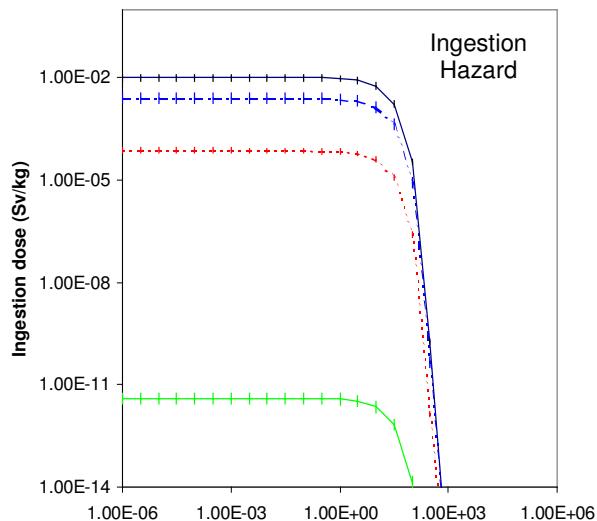
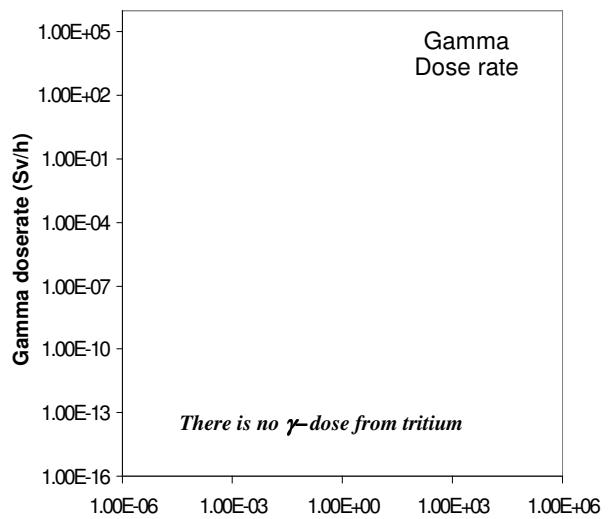
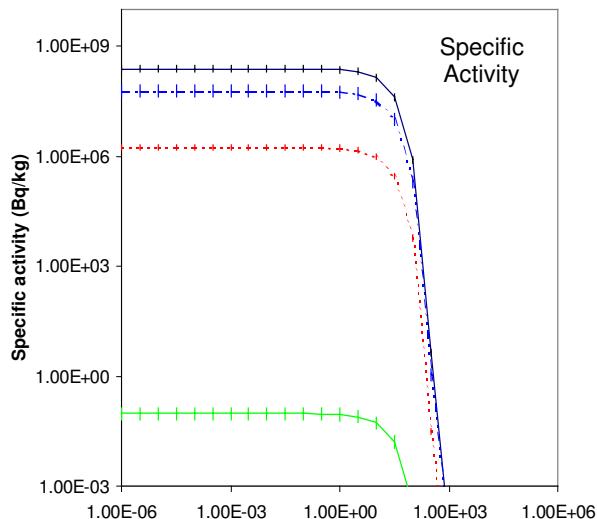
Act	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Heat	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y
Bq kg <sup>-1</sup>	2.41E8	2.41E8	2.41E8	2.28E8	8.74E5	0.00E0	kW kg <sup>-1</sup>	2.21E-10	2.21E-10	2.21E-10	2.09E-10	7.99E-13	0.00E0
H3	100.0	100.0	100.0	100.0	100.0		H3	100.0	100.0	100.0	100.0	100.0	
Dose	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Ing	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y
Sv h <sup>-1</sup>	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	Sv kg <sup>-1</sup>	1.01E-2	1.01E-2	1.01E-2	9.59E-3	3.67E-5	0.00E0
							H3	100.0	100.0	100.0	100.0	100.0	
Inh	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Clear	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y
Sv kg <sup>-1</sup>	6.28E-2	6.28E-2	6.28E-2	5.94E-2	2.27E-4	0.00E0		8.05E1	8.05E1	8.05E1	7.61E1	2.91E-1	0.00E0
H3	100.0	100.0	100.0	100.0	100.0		H3	100.0	100.0	100.0	100.0	100.0	

# Hydrogen

## Pathway analysis

Nuclide	T <sub>½</sub>	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
H3	12.33 y	H1(n, $\gamma$ )H2(n, $\gamma$ )H3 H2(n, $\gamma$ )H3	90.1 1.1	64.9 27.1	10.3 87.6	1.6 98.3

# Hydrogen activation characteristics

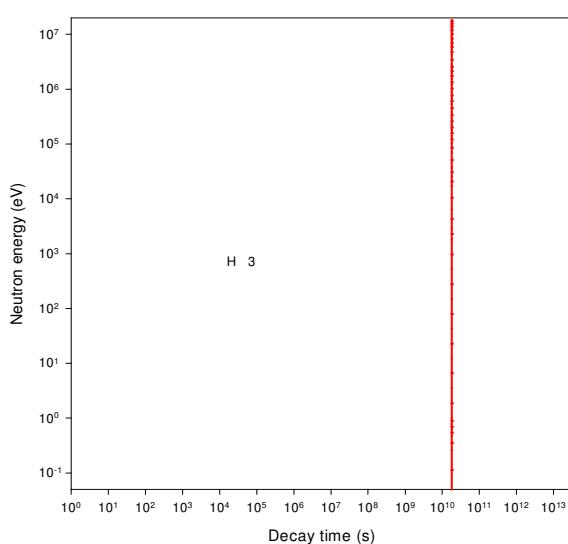


Decay time (years)

Decay time (years)

# Hydrogen importance diagrams & transmutation

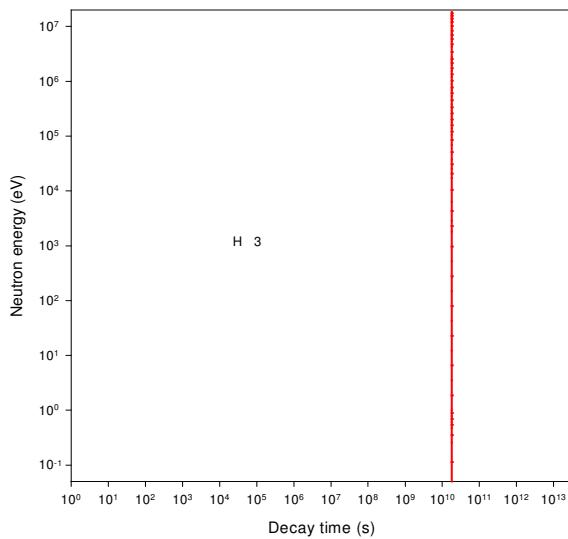
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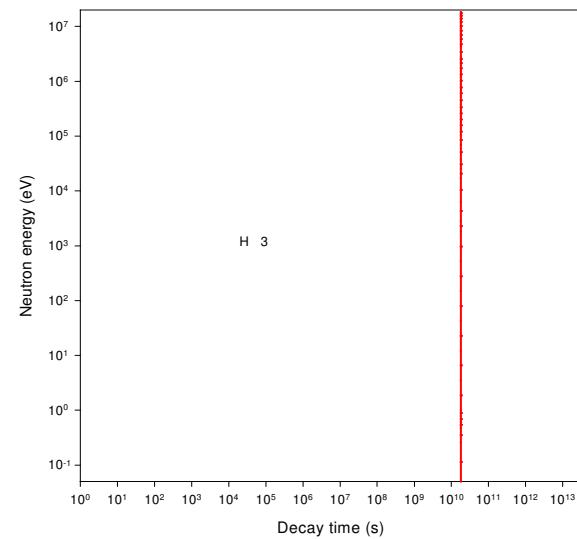
## Dose rate

*There is no  $\gamma$ -dose from tritium*

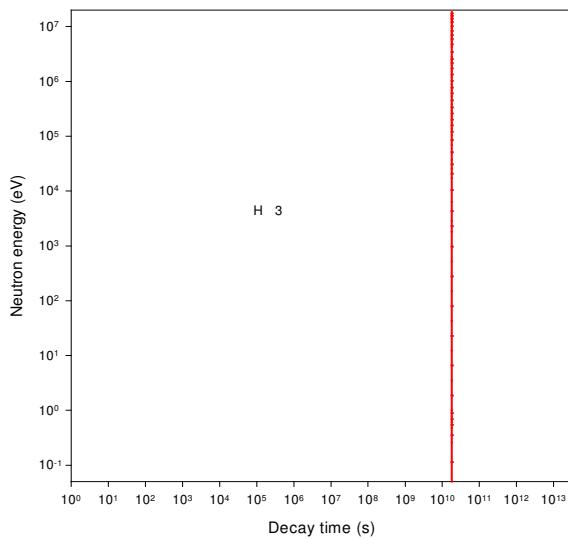
## Heat output



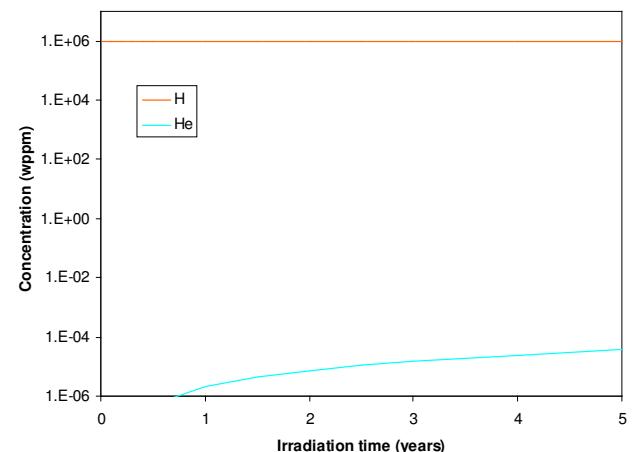
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Helium

## General properties

Atomic number	2	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	8.0 10 <sup>-3</sup>	He3	0.000137
Melting point / K	0.95*	He4	99.999863
Boiling point / K	4.216		
Density / kgm <sup>-3</sup>	1.785 10 <sup>-1</sup>		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	1.52 10 <sup>-1</sup>		
Electrical resistivity /Ωm	-		
Coefficient of thermal expansion / K <sup>-1</sup>	-		
Crystal structure	HCP		
Number of stable isotopes	2		
Mean atomic weight	4.0026		

\* under pressure

## Activation properties

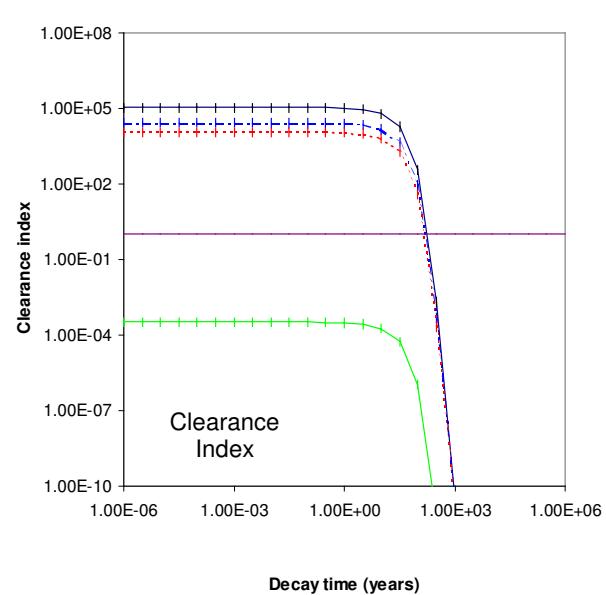
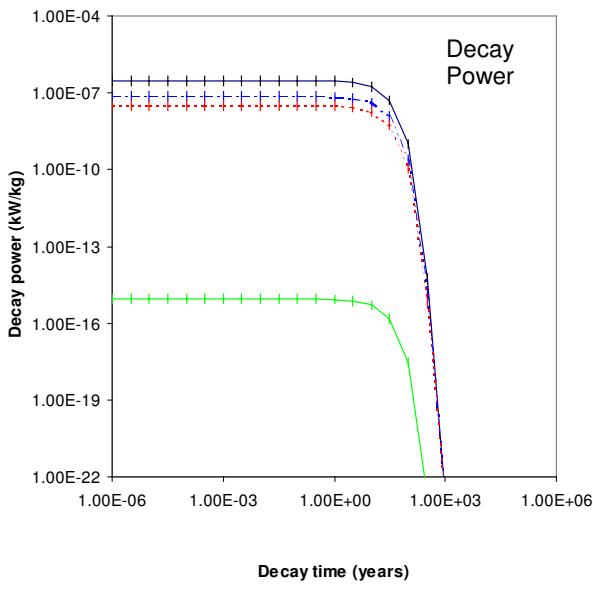
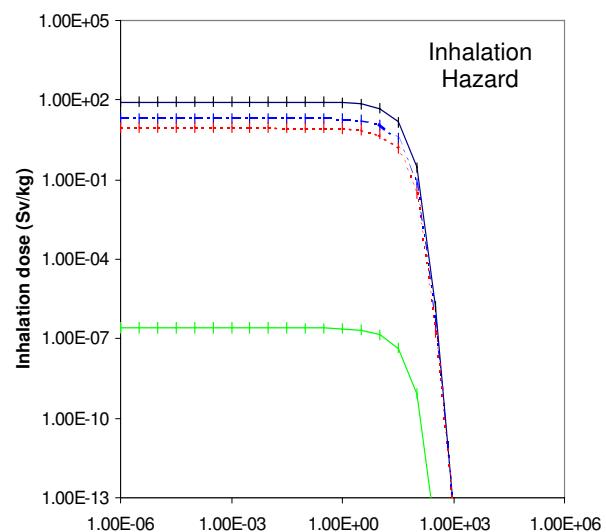
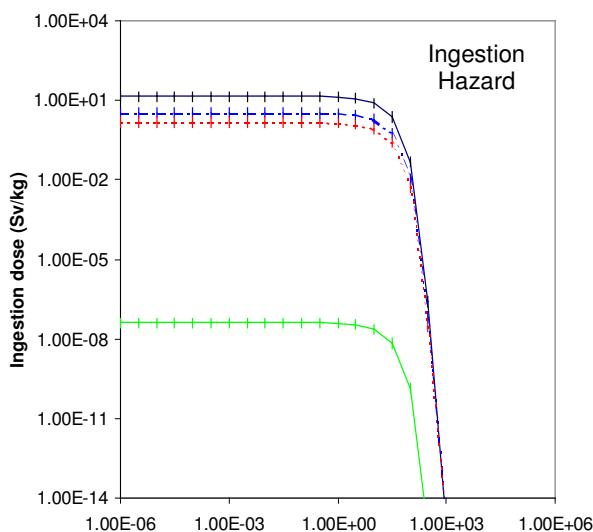
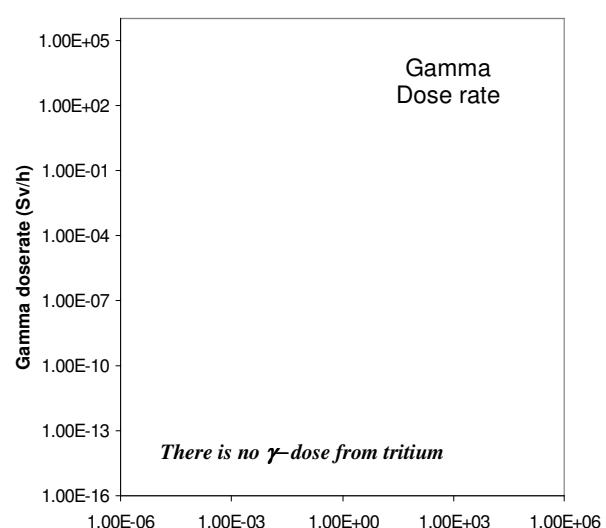
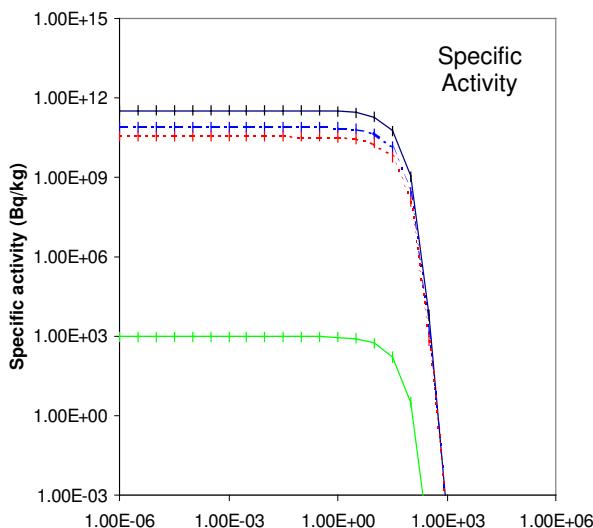
Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	3.31E11	3.31E11	3.31E11	3.13E11	1.20E9	0.0E0	kW kg <sup>-1</sup>	3.03E-7	3.03E-7	3.03E-7	2.86E-7	1.10E-9	0.0E0
H3	100.0	100.0	100.0	100.0	100.0		H3	100.0	100.0	100.0	100.0	100.0	
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	0.0E0	0.0E0	0.0E0	0.0E0	0.0E0	0.0E0	Sv kg <sup>-1</sup>	1.39E1	1.39E1	1.39E1	1.32E1	5.03E-2	0.0E0
							H3	100.0	100.0	100.0	100.0	100.0	
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	8.61E1	8.61E1	8.61E1	8.14E1	3.12E-1	0.0E0		1.10E5	1.10E5	1.10E5	1.04E5	4.00E2	0.0E0
H3	100.0	100.0	100.0	100.0	100.0		H3	100.0	100.0	100.0	100.0	100.0	

# **Helium**

## **Pathway analysis**

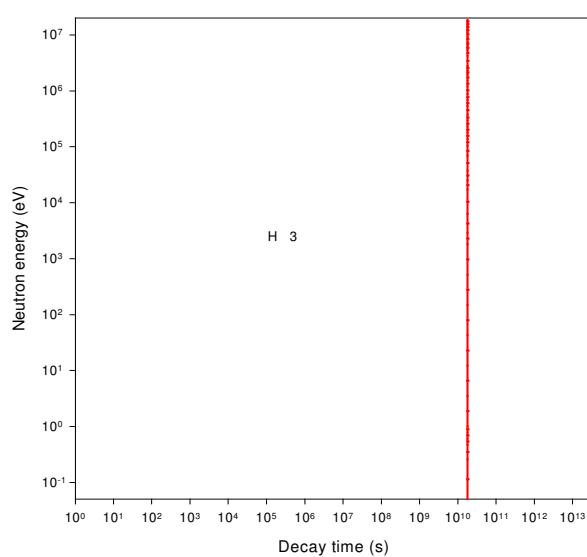
<b>Nuclide</b>	<b>T<sub>½</sub></b>	<b>Pathway</b>	<b>0.26 eV</b>	<b>148 eV</b>	<b>37.6 keV</b>	<b>14.7 MeV</b>
H3	12.33 y	He3(n,p)H3	100.0	100.0	100.0	100.0

# Helium activation characteristics



# Helium importance diagrams & transmutation

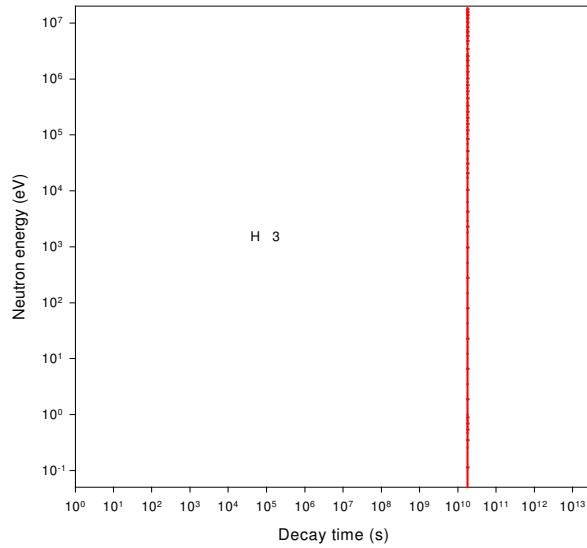
## Activity



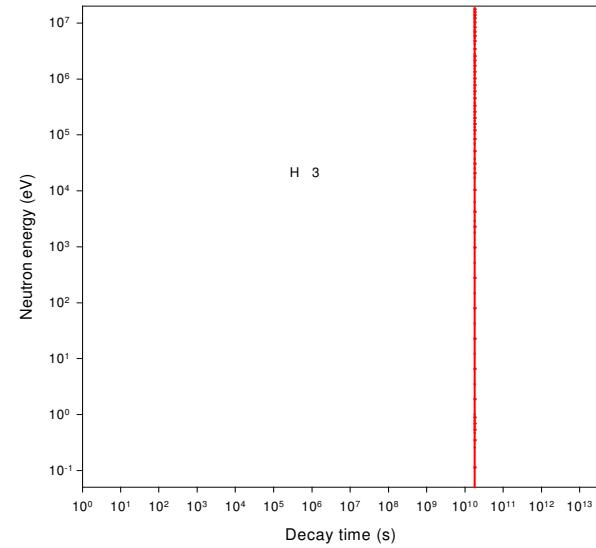
## Dose rate

*There is no  $\gamma$ -dose from tritium*

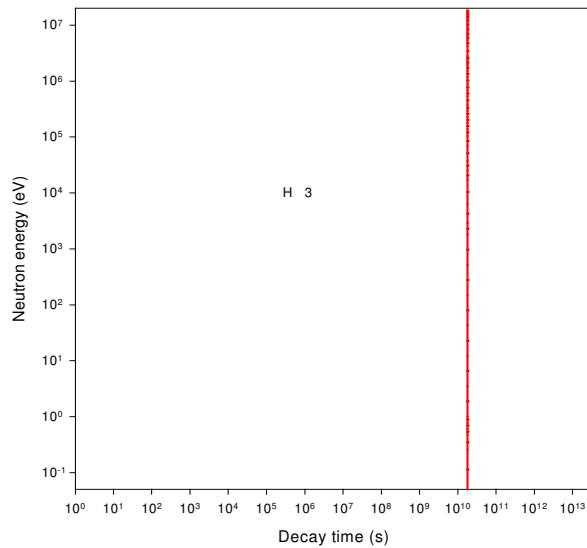
## Heat output



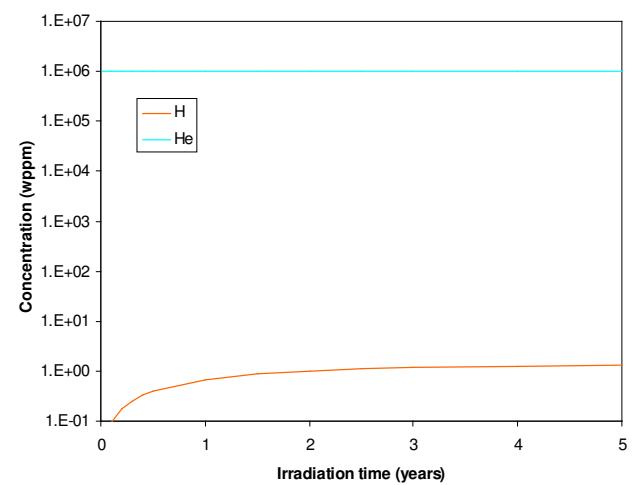
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Lithium

## General properties

Atomic number	3	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	20.0	Li6	7.59
Melting point / K	453.7	Li7	92.41
Boiling point / K	1620		
Density / kgm <sup>-3</sup>	534.0		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	84.7		
Electrical resistivity /Ωm	8.55 10 <sup>8</sup>		
Coefficient of thermal expansion / K <sup>-1</sup>	5.6 10 <sup>-5</sup>		
Crystal structure	BCC		
Number of stable isotopes	2		
Mean atomic weight	6.939		

## Activation properties

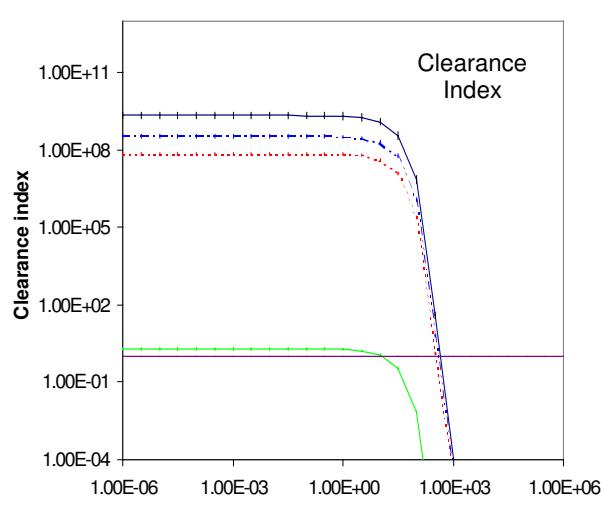
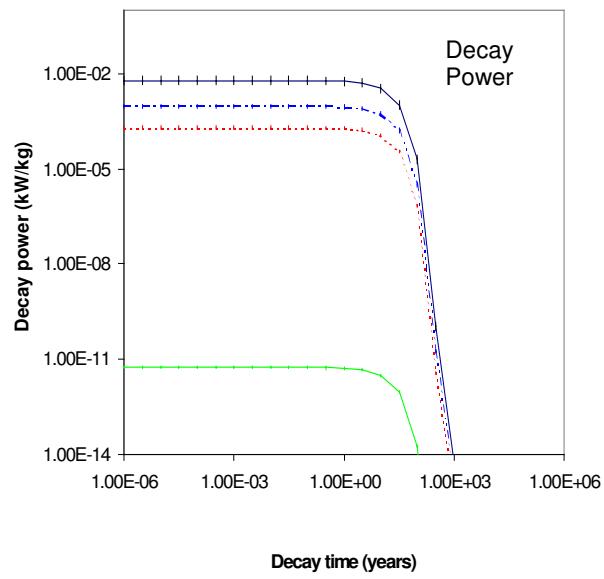
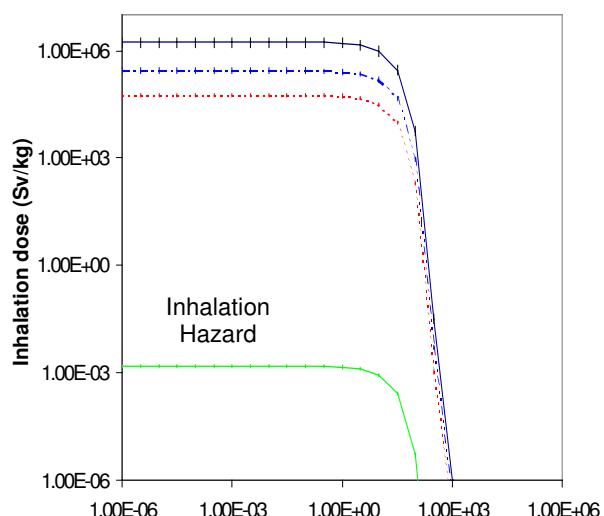
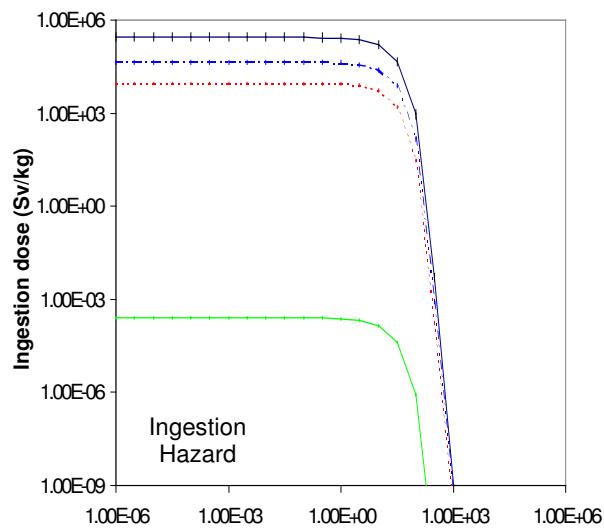
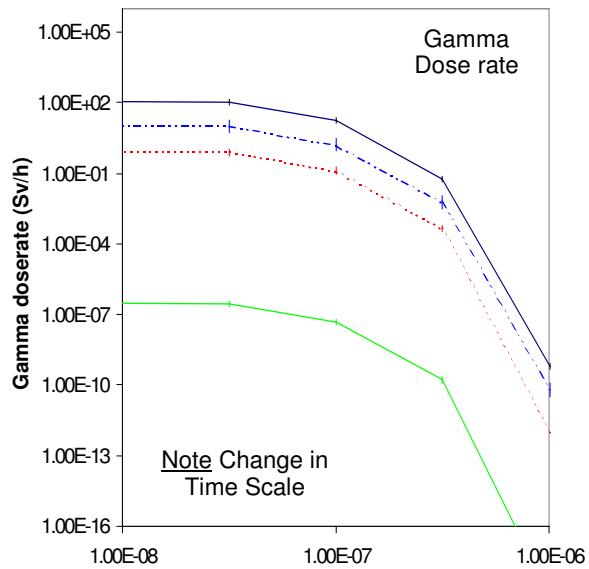
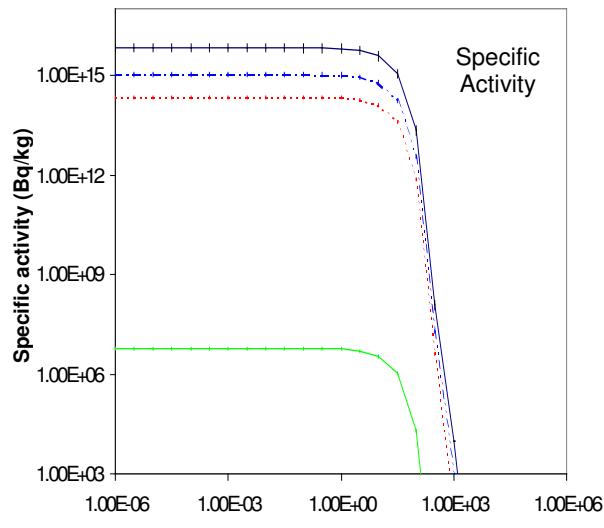
Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	6.65E15	6.57E15	6.57E15	6.21E15	2.38E13	0.00E0	kW kg <sup>-1</sup>	4.59E-2	6.01E-3	6.01E-3	5.68E-3	2.17E-5	0.00E0
H3	98.77	100.0	100.0	100.0	100.0		Li8	50.57					
He6	1.00						He6	36.34					
Li8	0.23						H3	13.09	100.0	100.0	100.0	100.0	100.0
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	2.54E2	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	Sv kg <sup>-1</sup>	2.76E5	2.76E5	2.76E5	2.61E5	9.99E2	0.00E0
Li8	65.55						H3	100.0	100.0	100.0	100.0	100.0	100.0
He6	34.45												
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	1.71E6	1.71E6	1.71E6	1.62E6	6.18E3	0.00E0		2.32E10	2.19E9	2.19E9	2.07E9	7.93E6	0.00E0
H3	100.0	100.0	100.0	100.0	100.0		He6	46.15					
							Li8	44.42					
							H3	9.43	100.0	100.0	100.0	100.0	100.0

# Lithium

## Pathway analysis

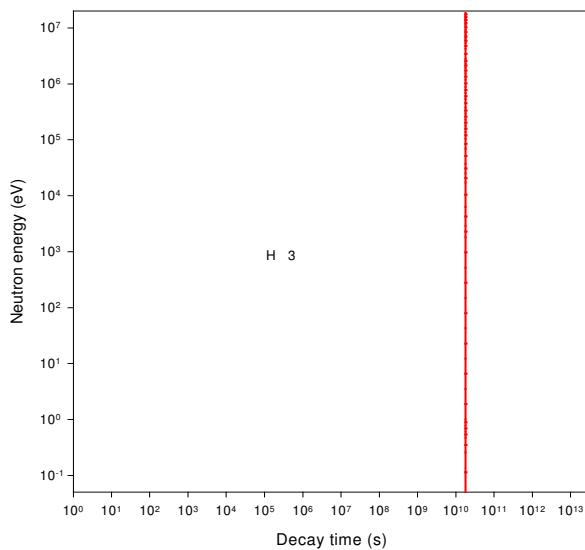
Nuclide	T <sub>½</sub>	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
He6	0.808 s	Li7(n,d)He6 Li6(n,p)He6 Li7(n,2n)Li6(n,p)He6				91.7 7.4 0.8
Li8	0.838 s	Li7(n, $\gamma$ )Li8	100.0	100.0	100.0	100.0
H3	12.33 y	Li6(n, $\alpha$ )H3 Li6(n, $\alpha$ )H3( $\beta^-$ )He3(n,p)H3 Li7(n,n $\alpha$ )H3	75.9 24.1	85.6 14.4	97.8 2.2	0.7 99.1

# Lithium activation characteristics

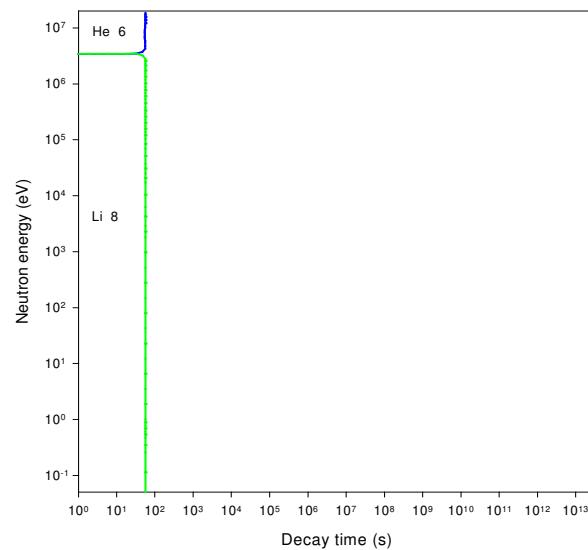


# Lithium importance diagrams & transmutation

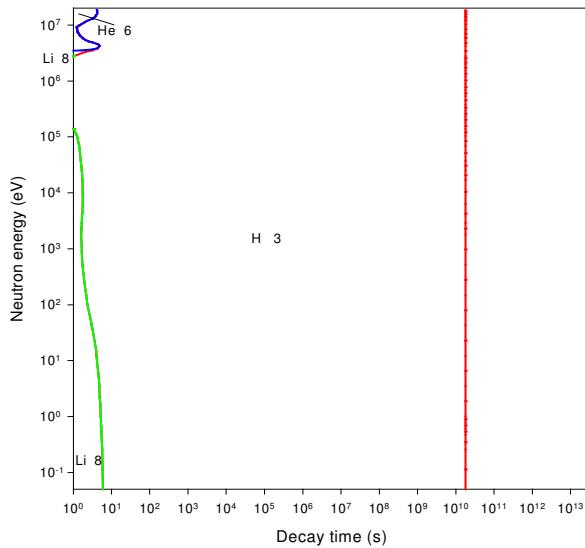
**Activity**



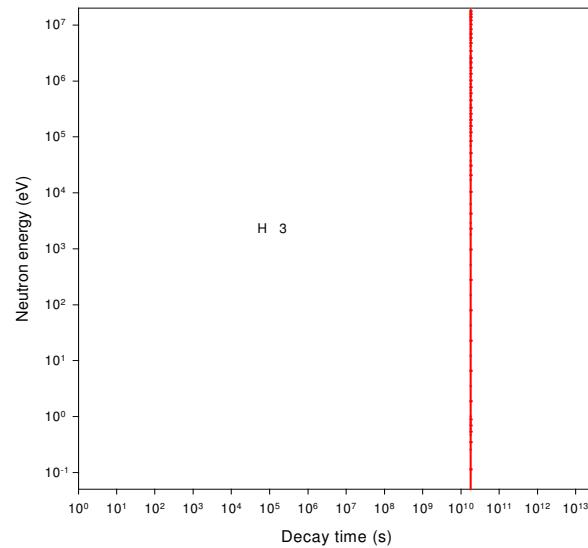
**Dose rate**



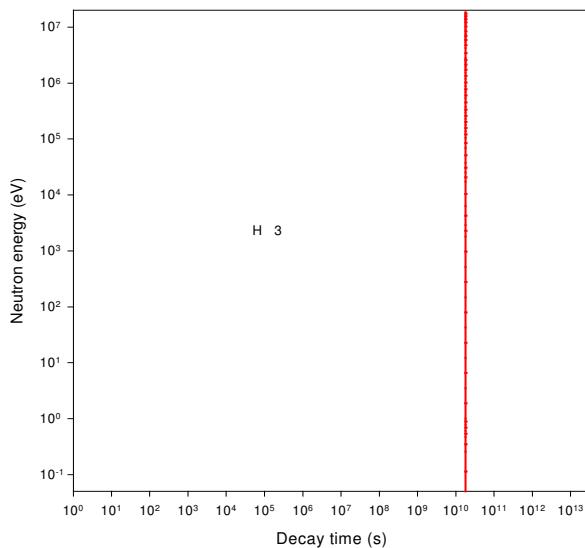
**Heat output**



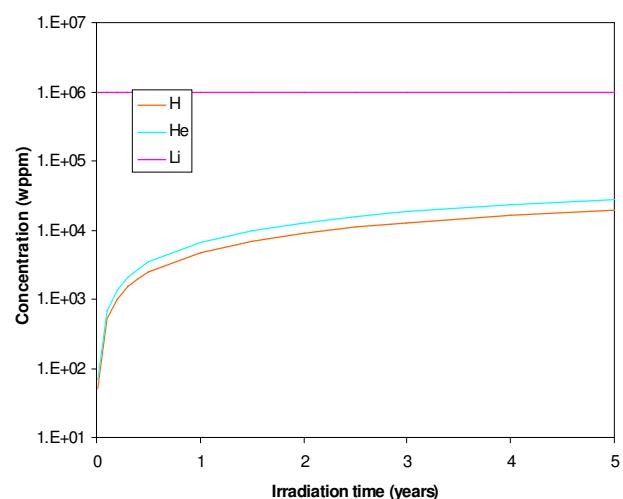
**Ingestion dose**



**Inhalation dose**



**First wall transmutation**



# Beryllium

## General properties

Atomic number	4	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	2.6	Be9	100.0
Melting point / K	1551		
Boiling point / K	3243*		
Density / kgm <sup>-3</sup>	1848		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	200		
Electrical resistivity /Ωm	4.0 10 <sup>-8</sup>		
Coefficient of thermal expansion / K <sup>-1</sup>	1.15 10 <sup>-5</sup>		
Crystal structure	HCP		
Number of stable isotopes	1		
Mean atomic weight	9.0122		

\* under pressure

## Activation properties

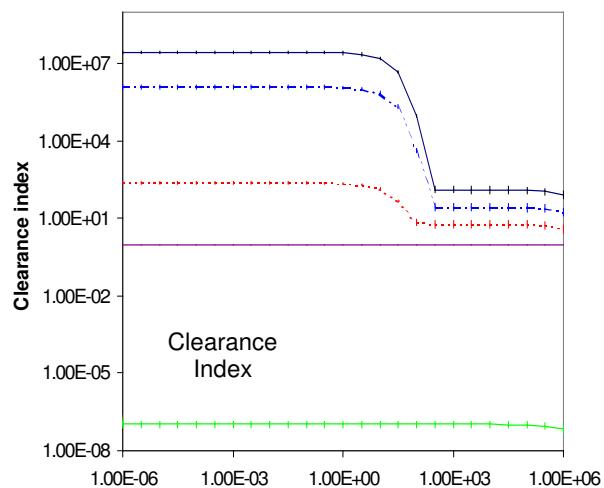
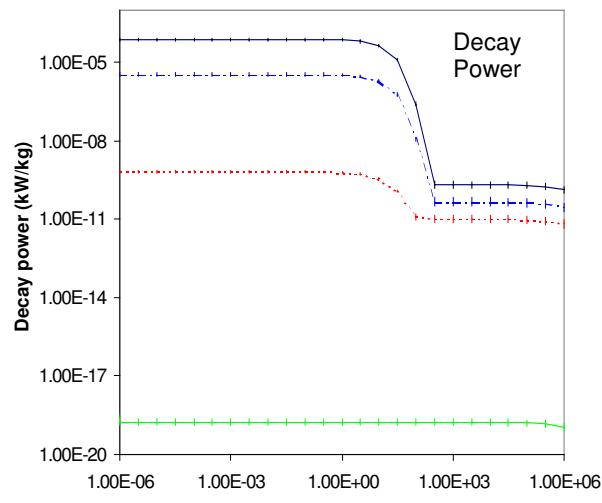
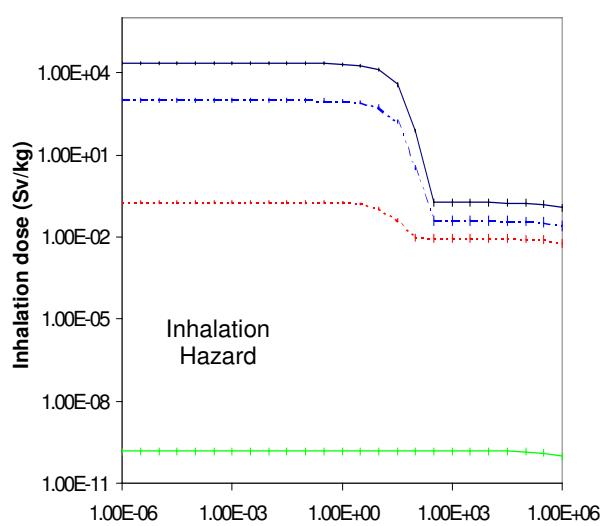
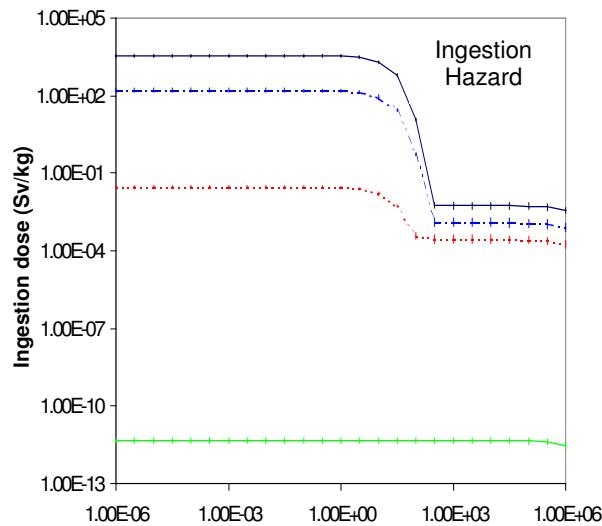
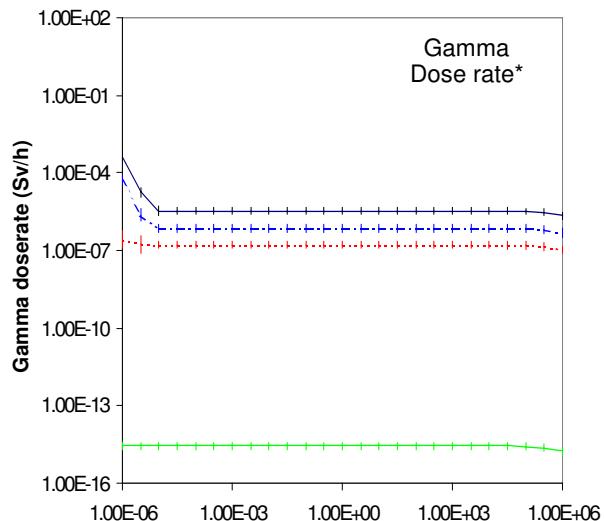
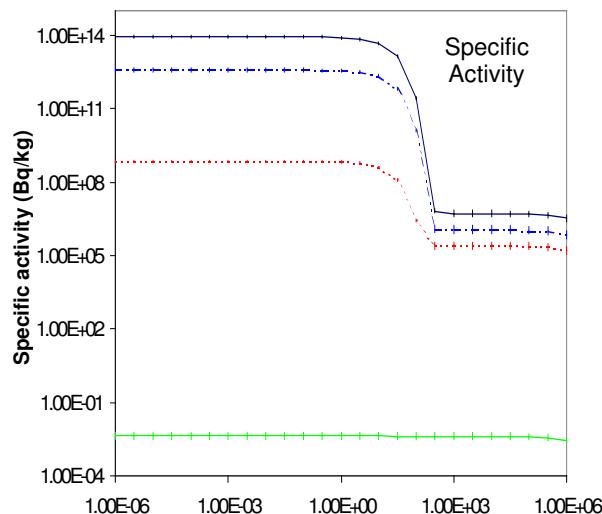
Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	5.54E14	8.38E13	8.37E13	7.92E13	3.03E11	4.92E6	kW kg <sup>-1</sup>	1.18E-1	7.66E-5	7.66E-5	7.24E-5	2.77E-7	1.99E-10
He6	84.80						He6	99.58					
H3	15.12	100.0	100.0	100.0	100.0		H3	0.07	100.0	100.0	100.0	99.92	
Be10						100.0	Be10					0.07	100.0
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	5.77E2	3.38E-6	3.38E-6	3.38E-6	3.38E-6	3.24E-6	Sv kg <sup>-1</sup>	3.53E3	3.52E3	3.52E3	3.33E3	1.27E1	5.42E-3
He6	99.27						H3	99.56	100.0	100.0	100.0	99.95	
Li9	0.72						He6	0.44					
Be10		100.0*	100.0*	100.0*	100.0*	100.0*	Be10					0.04	100.0
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	2.18E4	2.18E4	2.18E4	2.06E4	7.90E1	1.72E-1		7.61E10	2.79E7	2.79E7	2.64E7	1.01E5	1.23E2
H3	99.90	100.0	100.0	100.0	99.77		He6	99.61					
He6	0.10						H3	0.04	100.0	100.0	100.0	99.87	
Be10					0.23	100.0	Be10					0.13	100.0

# Beryllium

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
He6	0.808 s	Be9(n, $\alpha$ )He6 Be9(n,t)Li7(n,d)He6				99.7 0.2
Li8	0.838 s	Be9(n, $\gamma$ )Be10(n, $\gamma$ )Be11( $\beta^-$ $\alpha$ )Li7(n, $\gamma$ )Li8 Be9(n, $\gamma$ )Be10( $\beta^-$ )B10(n, $\alpha$ )Li7(n, $\gamma$ )Li8 Be9(n,t)Li7(n, $\gamma$ )Li8	50.6 49.4	3.1 96.9		100.0
Be11	13.81 s	Be9(n, $\gamma$ )Be10(n, $\gamma$ )Be11	100.0	100.0	100.0	100.0
H3	12.33 y	Be9(n, $\gamma$ )Be10( $\beta^-$ )B10(n,2 $\alpha$ )H3 Be9(n, $\gamma$ )Be10( $\beta^-$ )B10(n,2 $\alpha$ )H3( $\beta^-$ )He3(n,p)H3 Be9(n,X)H3 Be9(n,t)Li7(n,n $\alpha$ )H3	91.7 8.3	94.0 6.0	99.3 0.7	97.5 2.3
Be10	$1.6 \cdot 10^6$ y	Be9(n, $\gamma$ )Be10	100.0	100.0	100.0	100.0

# Beryllium activation characteristics

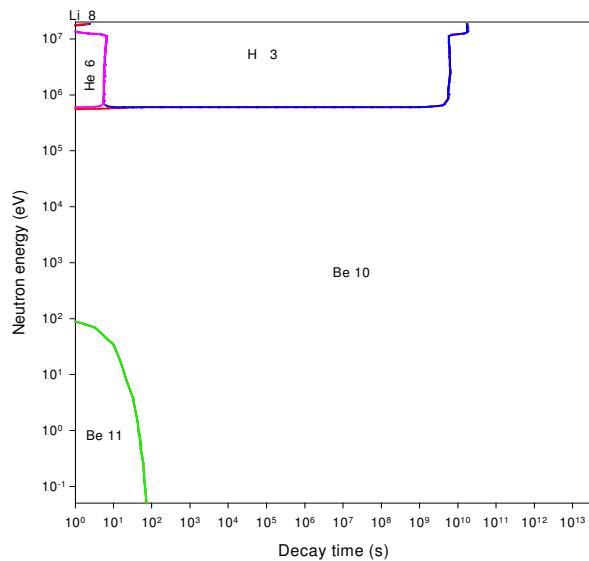


Decay time (years)

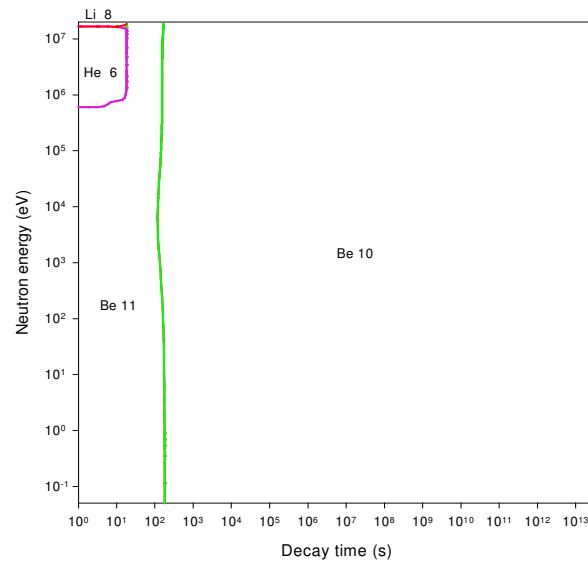
Decay time (years)

# Beryllium importance diagrams & transmutation

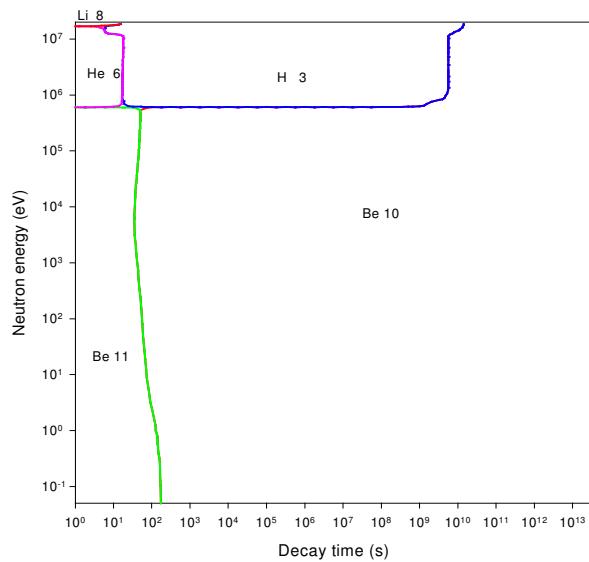
**Activity**



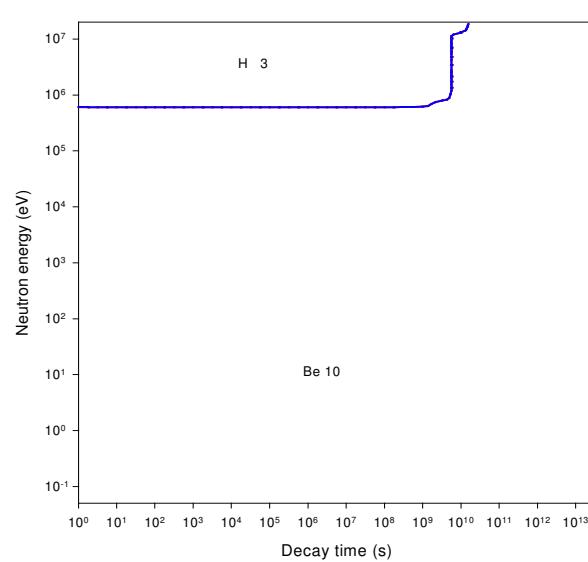
**Dose rate**



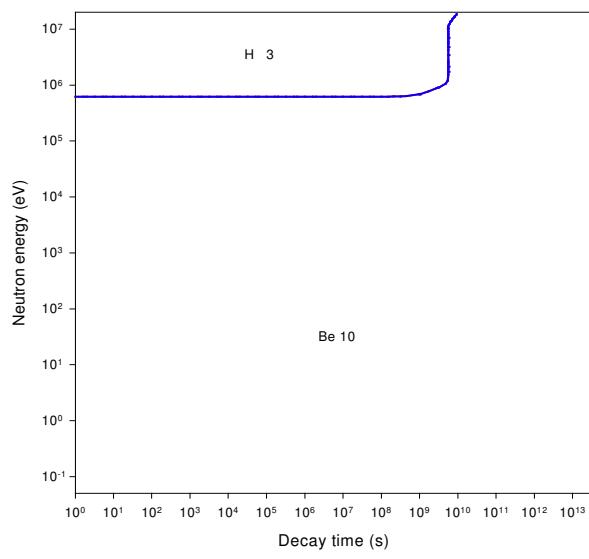
**Heat output**



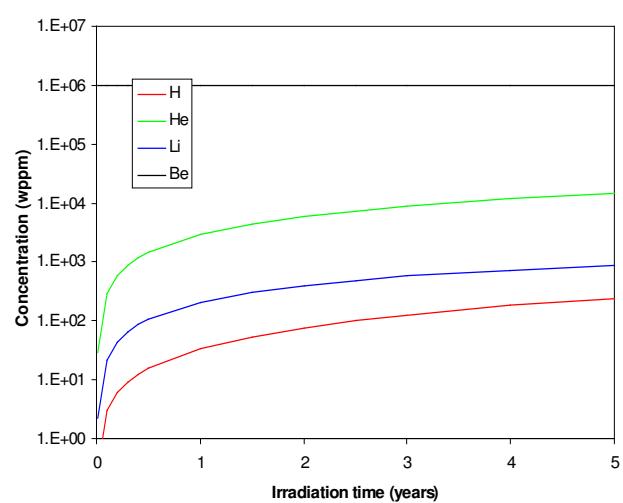
**Ingestion dose**



**Inhalation dose**



**First wall transmutation**



# Boron

## General properties

Atomic number	5	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	10	B10	19.8
Melting point / K	2573	B11	80.2
Boiling point / K	3931		
Density / kgm <sup>-3</sup>	2340		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	27.0		
Electrical resistivity /Ωm	1.80 10 <sup>4</sup>		
Coefficient of thermal expansion / K <sup>-1</sup>	5.0 10 <sup>-5</sup>		
Crystal structure	tetragonal		
Number of stable isotopes	2		
Mean atomic weight	10.811		

## Activation properties

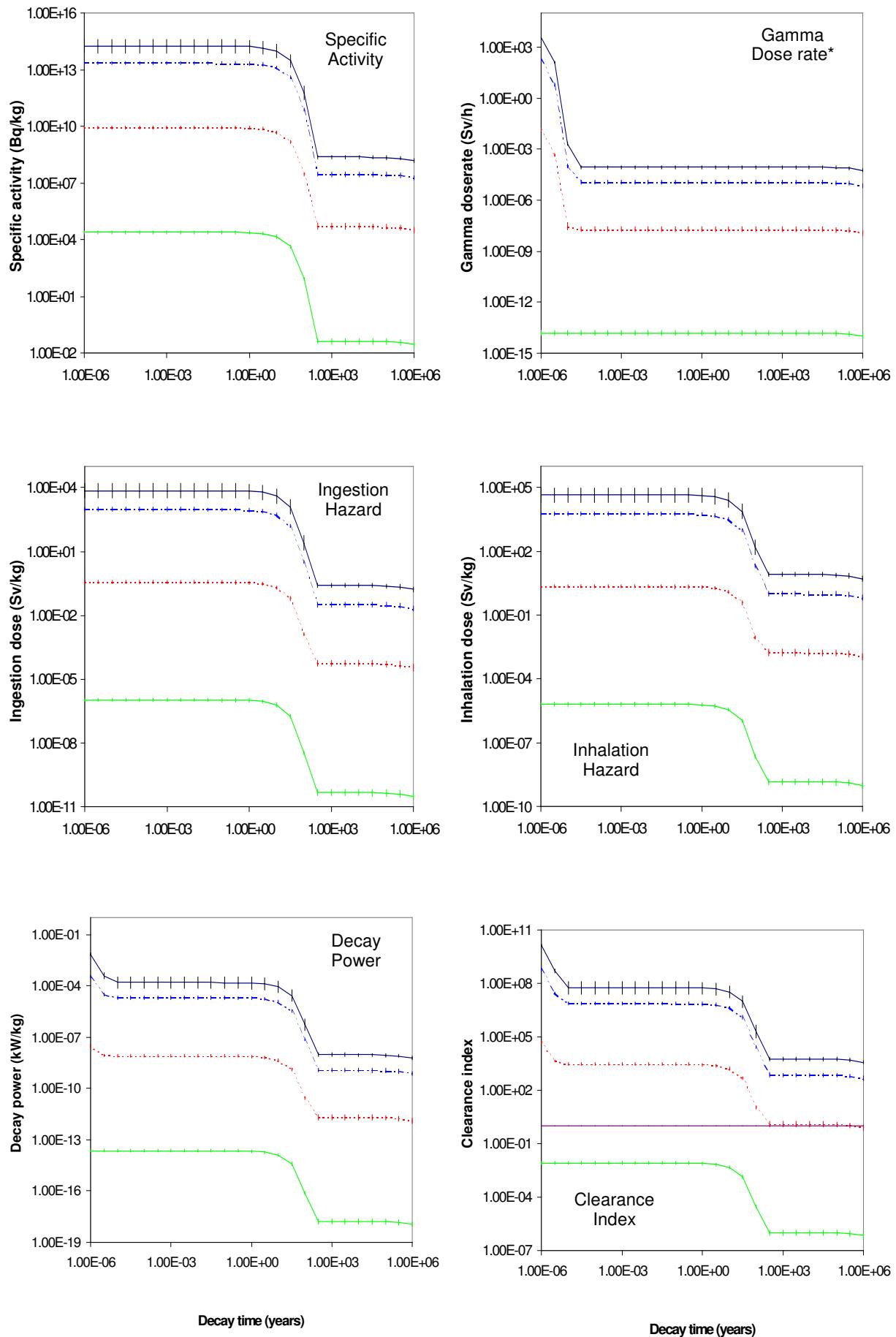
Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	4.38E14	1.72E14	1.72E14	1.63E14	6.23E11	2.21E8	kW kg <sup>-1</sup>	3.70E-1	1.57E-4	1.57E-4	1.49E-4	5.79E-7	8.95E-9
Li8	50.47						Li8	89.62					
H3	39.29	100.0	100.0	100.0	99.96		Be11	9.28					
Be11	8.02						B12	0.53					
He6	1.79						H3	0.04	99.99	99.99	99.99	98.39	
Be10					100.0		Be10		0.01	0.01	0.01	1.61	100.0
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	2.10E4	2.56E-3	8.66E-5	8.66E-5	8.66E-5	8.29E-5	Sv kg <sup>-1</sup>	7.26E3	7.23E3	7.23E3	6.83E3	2.64E1	2.44E-1
Be11	89.26	96.62					H3	99.54	100.0	100.0	100.0	99.04	
Li8	10.49						Li8	0.30					
Be10		3.38*	100.0*	100.0*	100.0*	100.0*	Be10					0.96	100.0
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	4.48E4	4.48E4	4.47E+4	4.23E4	1.70E2	7.75E0		2.16E11	5.74E7	5.73E7	5.42E7	2.13E5	5.54E3
H3	99.93	99.98	99.98	99.98	95.24		Li8	68.13					
Li8	0.03						Be11	30.62	0.02				
Be11	0.02						H3	0.03	99.98	99.99	99.99	97.29	
Be10	0.02	0.02	0.02	0.02	4.76	100.0	Be10		0.01	0.01	0.01	2.71	100.0

# Boron

## Pathway analysis

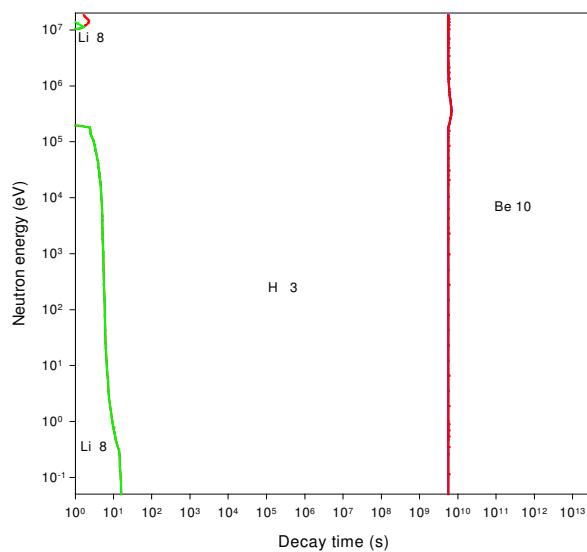
Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
He6	0.808s	B11(n,d)Be10(n,n $\alpha$ )He6 B10(n,n $\alpha$ )Li6(n,p)He6 B11(n,t)Be9(n, $\alpha$ )He6 B10(n,p)Be10(n,n $\alpha$ )He6 B10(n,d)Be9(n, $\alpha$ )He6 B10(n, $\alpha$ )Li7(n,d)He6				26.5 23.0 17.2 15.3 9.8 7.1
Li8	0.838 s	B10(n, $\alpha$ )Li7(n, $\gamma$ )Li8 B11(n, $\alpha$ )Li8	100.0	100.0	100.0	99.9
Be11	13.81 s	B10(n,p)Be10(n, $\gamma$ )Be11 B11(n,p)Be11	100.0	100.0	100.0	100.0
H3	12.33 y	B10(n,2 $\alpha$ )H3 B10(n,2 $\alpha$ )H3( $\beta^-$ )He3(n,p)H3 B11(n,n2 $\alpha$ )H3 B10(n, $\alpha$ )Li7(n,n $\alpha$ )H3 B11(n,2n)B10(n,2 $\alpha$ )H3	75.7 24.3	80.3 19.7	97.6 2.4	56.9  41.5 0.7 0.5
Be10	$1.6 \cdot 10^6$ y	B10(n,p)Be10 B11(n,d)Be10	100.0	100.0	100.0	36.5 63.2

# Boron activation characteristics

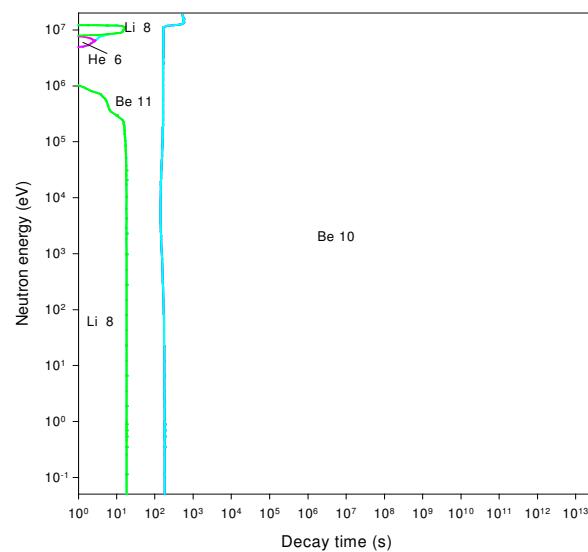


# Boron importance diagrams & transmutation

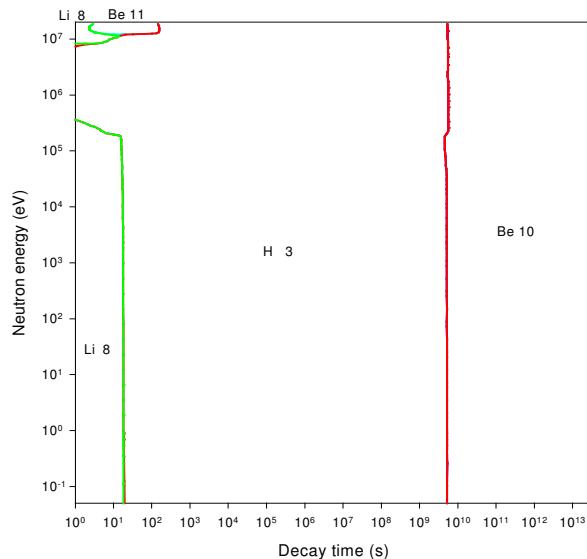
**Activity**



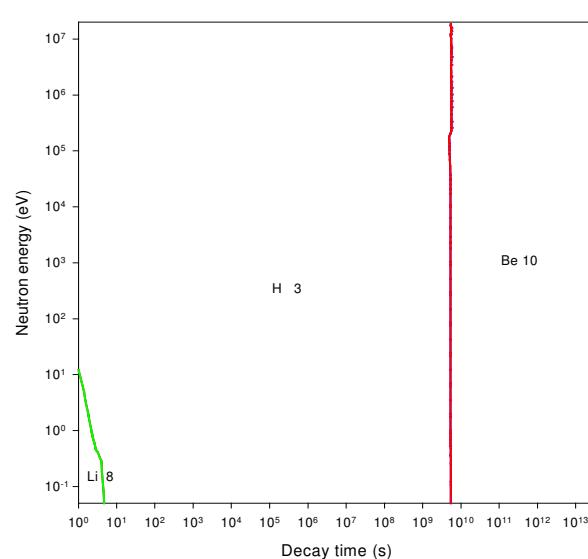
**Dose rate**



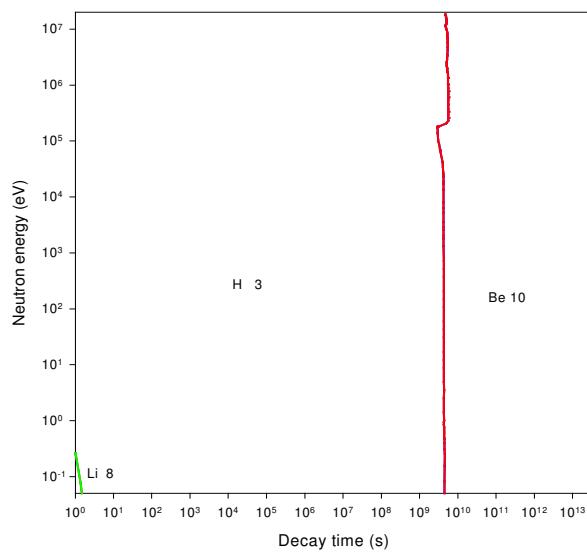
**Heat output**



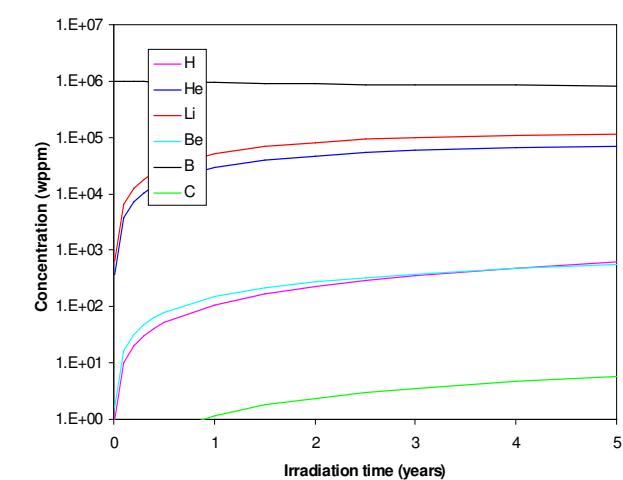
**Ingestion dose**



**Inhalation dose**



**First wall transmutation**



# Carbon

## General properties

		6	Isotopes	Isotopic abundances / %	
Atomic number		480	C12	98.89	
Crustal abundance / wppm		3820 (d)	C13	1.11	
Melting point / K		5100 (subl)	C14	Trace ( $T_{1/2} = 5730$ y)	
Boiling point / K		1400 (a)			
Density / kgm <sup>-3</sup>		2260 (g)			
		3513 (d)			
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>		4.2 (a)			
		5.7-1960 (g)			
Electrical resistivity / Ωm		990-2320 (d)			
Coefficient of thermal expansion / K <sup>-1</sup>		1.357 10 <sup>-5</sup> (g)			
Crystal structure		1.0 10 <sup>11</sup> (d)			
Number of stable isotopes		1.19 10 <sup>-6</sup> (d)			
Mean atomic weight		Hexagonal (g)			
		Cubic (d)			
		2(3)			
		12.011			

(d) = diamond, (g) = graphite, (a) = amorphous, (subl) = sublimes

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	
Bq kg <sup>-1</sup>	4.10E12	1.79E11	1.79E11	1.70E11	7.02E8	1.43E7	kW kg <sup>-1</sup>	3.42E-3	1.65E-7	1.65E-7	1.56E-7	1.49E-9	5.76E-10	
B12	59.75						B12	73.50						
He6	19.65						B13	20.21						
B13	16.17						He6	2.91						
H3	4.38	99.97	99.97	99.97	92.50		H3	0.01	99.45	99.45	99.42	39.73		
C14		0.02	0.02	0.02	5.37		Be10		0.37	0.37	0.39	40.26	100.0	
Be10		0.01	0.01	0.01	2.12	100.0	C14		0.18	0.18	0.19	20.01		
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	
Sv h <sup>-1</sup>	1.15E2	3.79E-6	3.41E-6	3.41E-6	3.41E-6	3.27E-6	Sv kg <sup>-1</sup>	7.61E0	7.57E0	7.57E0	7.16E0	6.55E-2	1.57E-2	
B13	55.68						H3	98.99	99.49	99.49	99.46	41.62		
B12	43.49						He6	0.35						
Be11	0.09	0.36					C14	0.29	0.29	0.29	0.31	33.39		
N13		9.75					Be10	0.22	0.22	0.22	0.23	24.99	100.0	
Be10		89.90*	100.0*	100.0*	100.0*	100.0*	B12	0.12						
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	
Sv kg <sup>-1</sup>	4.74E1	4.74E1	4.73E1	4.48E1	9.08E-1	4.99E-1			2.48E9	6.03E4	6.02E4	5.70E4	7.14E2	3.56E2
H3	98.64	98.43	98.43	98.35	18.58		B12	70.44						
Be10	1.10	1.10	1.10	1.16	57.35	100.0	B13	24.26						
C14	0.47	0.47	0.47	0.49	24.07		He6	5.23						
He6	0.08						H3		99.17	99.17	99.12	30.30		
B12	0.01						Be10		0.62	0.62	0.65	52.10	100.0	
							C14		0.21	0.21	0.22	17.60		

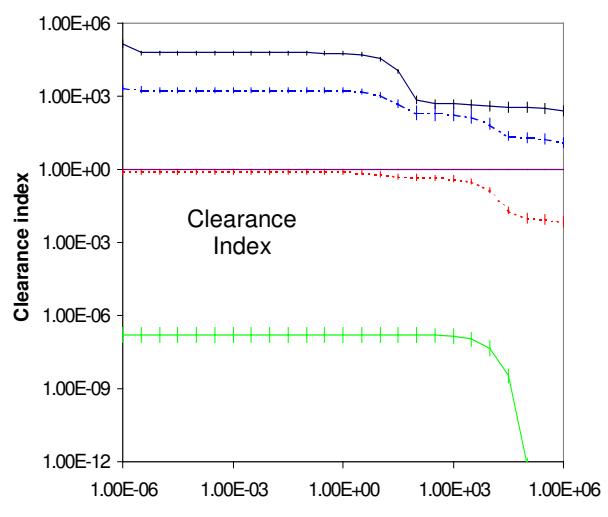
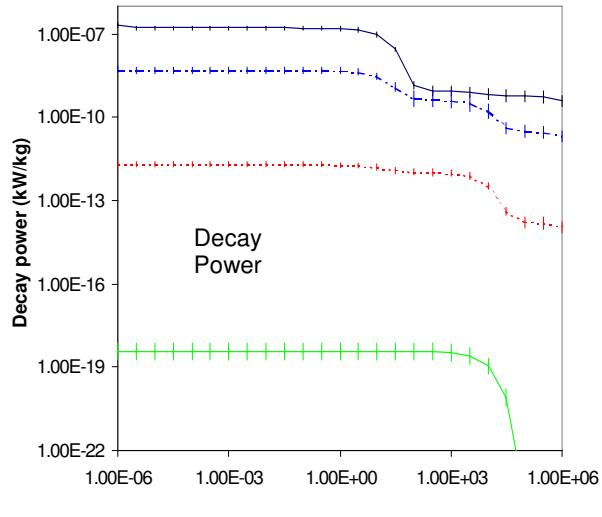
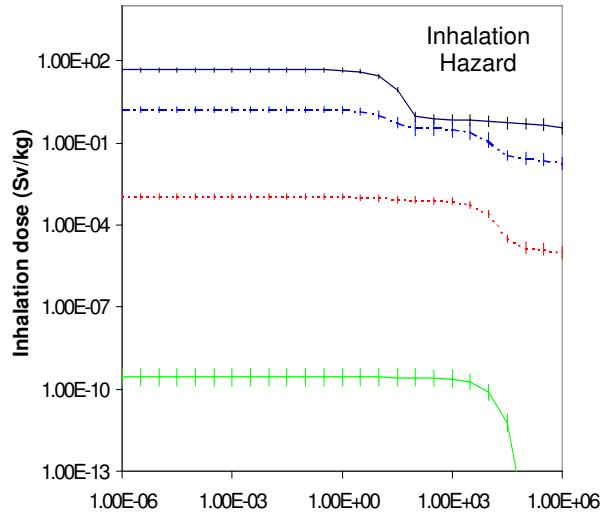
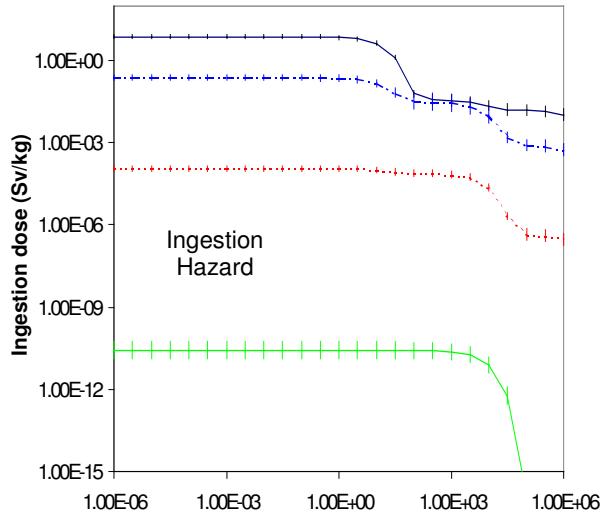
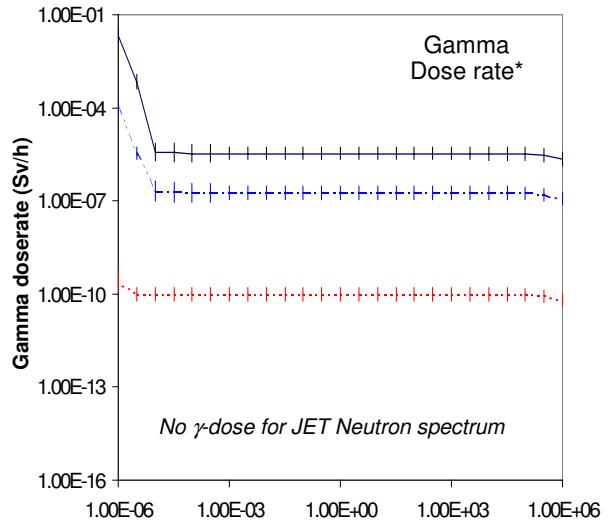
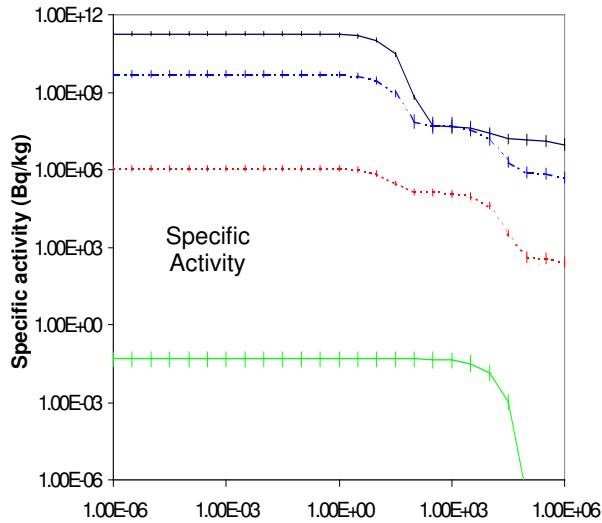
# Carbon

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
B13*	0.017 s	C13(n,p)B13 C12(n, $\gamma$ )C13(n,p)B13				99.8 0.2
B12*	0.020 s	C12(n,p)B12				100.0
He6	0.808 s	C12(n, $\alpha$ )Be9(n, $\alpha$ )He6 C13(n, $\alpha$ )Be10(n,n $\alpha$ )He6				97.8 2.0
Li8	0.838 s	C13(n,t)B11(n, $\alpha$ )Li8 C12(n,d)B11(n, $\alpha$ )Li8				84.4 15.4
C15	2.449 s	C13(n, $\gamma$ )C14(n, $\gamma$ )C15 C12(n, $\gamma$ )C13(n, $\gamma$ )C14(n, $\gamma$ )C15	98.9 1.1	100.0	100.0	99.7 0.1
Be11	13.81 s	C13(n,t)B11(n,p)Be11 C12(n,d)B11(n,p)Be11 C13(n, $\alpha$ )Be10(n, $\gamma$ )Be11				82.4 15.0 2.2
H3	12.33 y	C13(n, $\gamma$ )C14( $\beta^-$ )N14(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 C12(n, $\alpha$ )Be9(n,X)H3 C13(n,t2 $\alpha$ )H3 C12(n, $\alpha$ )Be9(n,t)Li7(n,n $\alpha$ )H3	95.2	97.1		65.3 33.4 1.0
C14	5730 y	C13(n, $\gamma$ )C14 C12(n, $\gamma$ )C13(n, $\gamma$ )C14	98.9 1.1	100.0	100.0	99.8 0.1
Be10	$1.6 \cdot 10^6$ y	C13(n, $\alpha$ )Be10 C12(n, $\gamma$ )C13(n, $\alpha$ )Be10				99.8 0.1

\*Nuclides included in pathway data because of large contributions in Activation properties table, even though they do not appear on any of the importance diagrams.

# Carbon activation characteristics

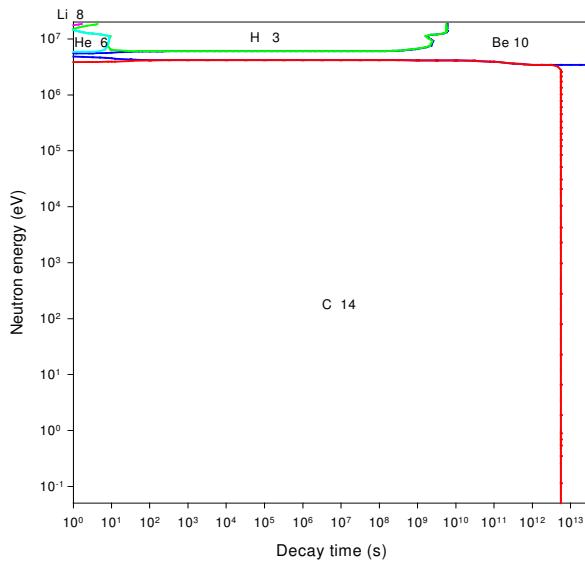


Decay time (years)

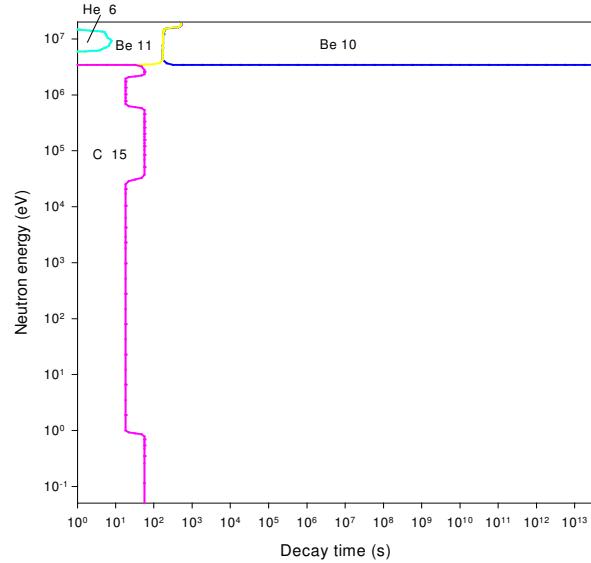
Decay time (years)

# Carbon importance diagrams & transmutation

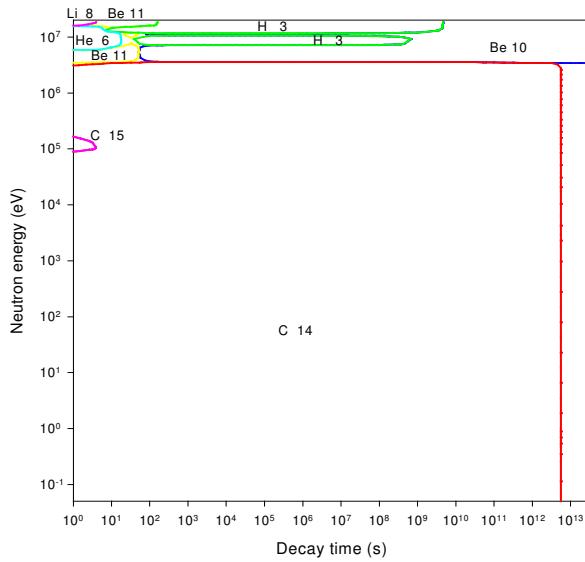
**Activity**



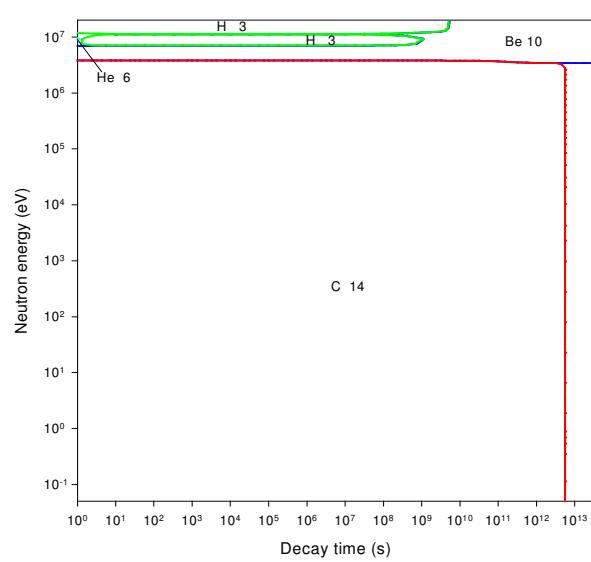
**Dose rate**



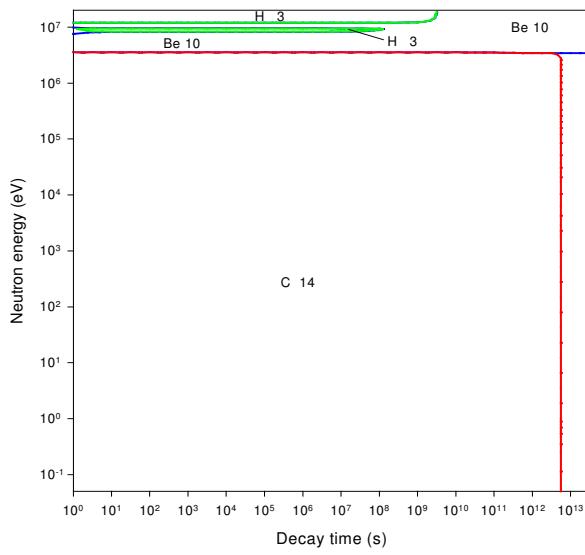
**Heat output**



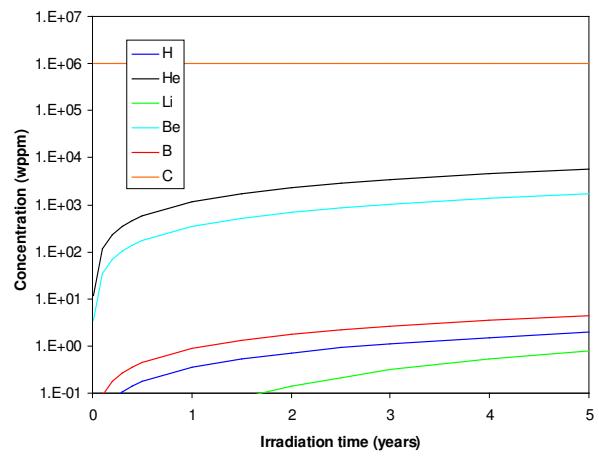
**Ingestion dose**



**Inhalation dose**



**First wall transmutation**



# Nitrogen

## General properties

Atomic number	7	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	25	N14	99.634
Melting point / K	63.29	N15	0.366
Boiling point / K	77.4		
Density / kgm <sup>-3</sup>	1.251		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	2.60 10 <sup>-2</sup>		
Electrical resistivity /Ωm	-		
Coefficient of thermal expansion / K <sup>-1</sup>	-		
Crystal structure	Cubic		
Number of stable isotopes	2		
Mean atomic weight	14.00674		

## Activation properties

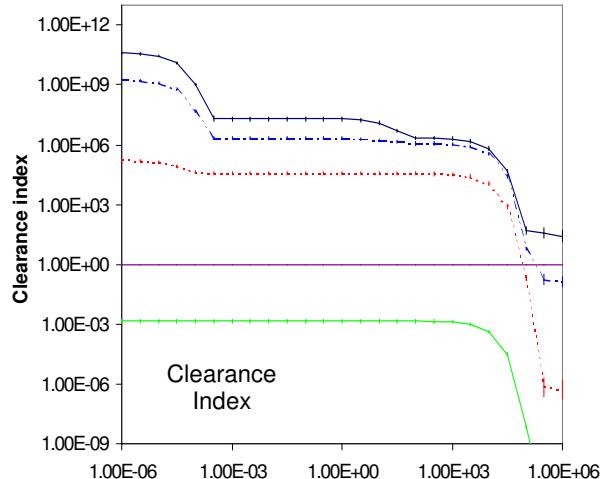
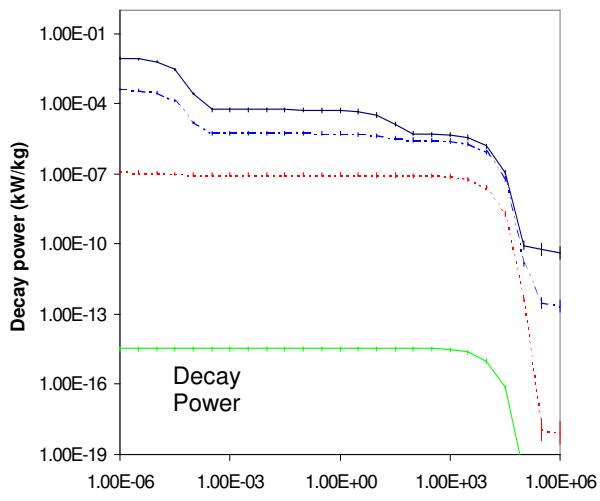
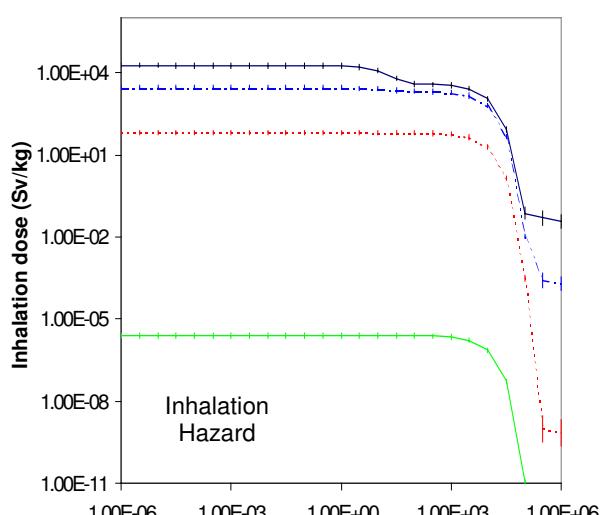
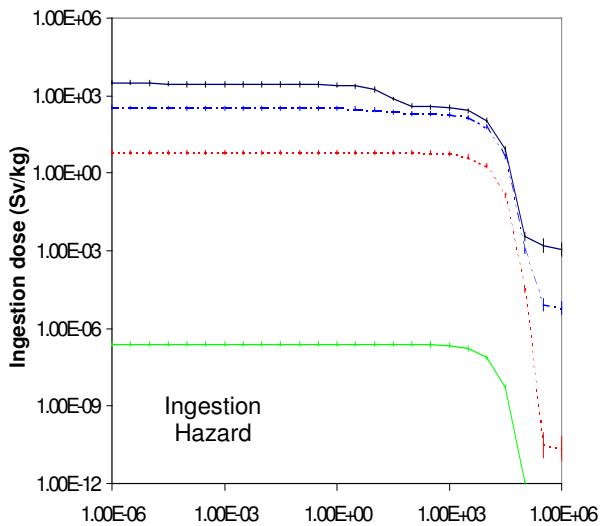
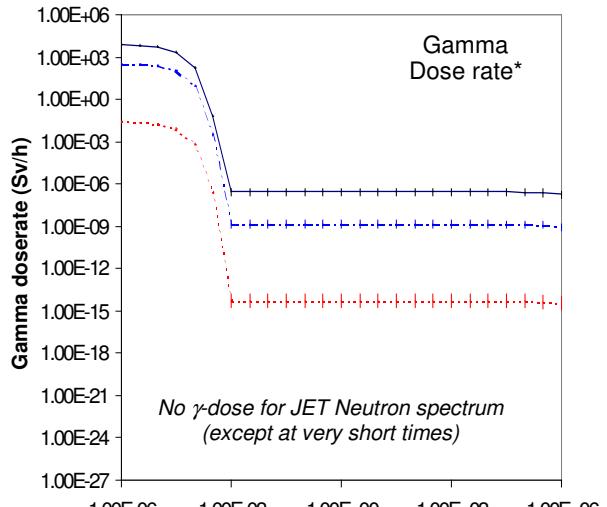
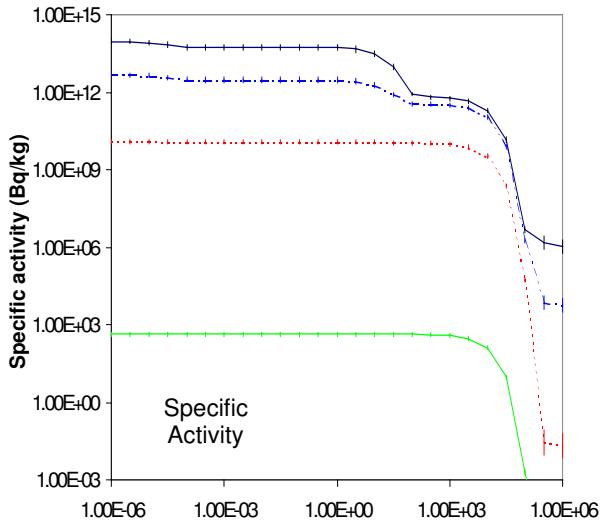
Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	9.65E13	8.16E13	5.55E13	5.25E13	8.54E11	5.26E6	kW kg <sup>-1</sup>	1.31E-2	6.37E-3	5.54E-5	5.27E-5	5.38E-6	9.23E-11
H3	56.81	67.21	98.80	98.74	23.23		N13	69.75	99.13				
N13	38.98	31.98					B12	13.13					
B12	1.73						Li8	10.24					
Li8	0.92						C15	3.68					
C14	0.69	0.81	1.20	1.26	76.77	70.37	Be11	1.89					
C15	0.48						H3	0.38	0.79	90.50	90.01	3.37	
Be11	0.26						C14	0.04	0.08	9.50	9.99	96.62	31.78
Be10						29.64	Be10						68.22
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	8.29E3	5.20E3	2.65E-7	2.65E-7	2.65E-7	2.54E-7	Sv kg <sup>-1</sup>	3.18E3	3.03E3	2.69E3	2.56E3	3.89E2	3.86E-3
N13	90.47	100.0					H3	72.48	76.08	85.67	84.98	2.15	
C15	7.43						N13	15.39	11.21				
Be11	1.48						C14	12.11	12.72	14.33	15.02	97.85	55.59
Be10			100.0*	100.0*	100.0*	100.0*	Be10						44.41
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	1.85E4	1.84E4	1.81E4	1.73E4	3.85E3	7.60E-2		4.46E10	2.81E10	2.05E7	1.95E7	2.25E6	5.13E1
H3	77.22	77.68	78.74	77.79	1.34		N13	90.67	99.93				
C14	20.85	20.97	21.27	22.21	98.66	28.24	C15	3.99					
N13	1.94	1.35					B12	2.67					
Be10						71.76	Li8	1.33					
							Be11	1.07					
							H3	0.04	0.07	89.20	88.65	2.94	
							C14	0.01	0.01	10.80	11.35	97.06	24.05
							Be10						75.95

# Nitrogen

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Li8	0.838 s	N14(n, $\alpha$ )B11(n, $\alpha$ )Li8 N15(n,n $\alpha$ )B11(n, $\alpha$ )Li8				99.7 0.2
C15	2.449 s	N14(n,p)C14(n, $\gamma$ )C15 N15(n,p)C15	100.0	100.0	100.0	0.3 99.7
N16	7.13 s	N14(n, $\gamma$ )N15(n, $\gamma$ )N16 N15(n, $\gamma$ )N16	57.4 42.6	4.0 96.0	0.3 99.7	0.1 99.1
Be11	13.81 s	N14(n, $\alpha$ )B11(n,p)Be11 N14(n,p)C14(n, $\alpha$ )Be11				68.2 31.5
N13	9.965 m	N14(n,2n)N13				100.0
H3	12.33 y	N14(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 N14(n,3 $\alpha$ )H3 N14(n,2 $\alpha$ )Li7(n,n $\alpha$ )H3	93.4	95.2	99.3	95.6 3.4
C14	5730 y	N14(n,p)C14 N15(n,d)C14	100.0	100.0	100.0	99.5 0.5
Be10	$1.6 \cdot 10^6$ y	N14(n,d)C13(n, $\alpha$ )Be10 N14(n, $\alpha$ )B11(n,d)Be10 N14(n,2n)N13( $\beta^+$ )C13(n, $\alpha$ )Be10 N14(n,p)C14(n,n $\alpha$ )Be10 N14(n,n $\alpha$ )B10(n,p)Be10				74.7 13.2 7.2 2.4 1.4

# Nitrogen activation characteristics

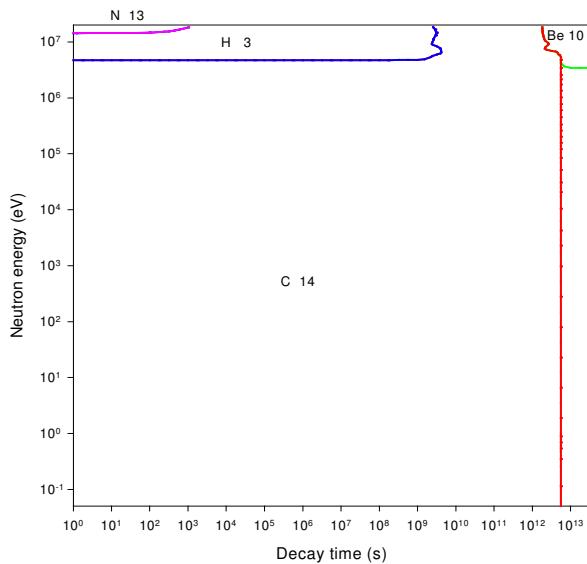


Decay time (years)

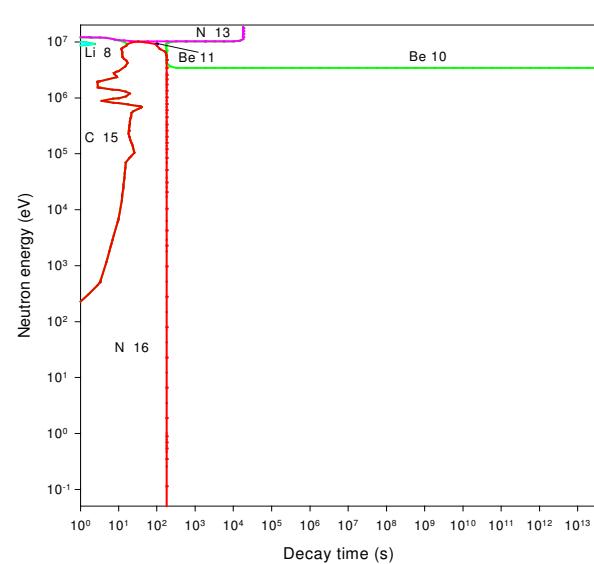
Decay time (years)

# Nitrogen importance diagrams & transmutation

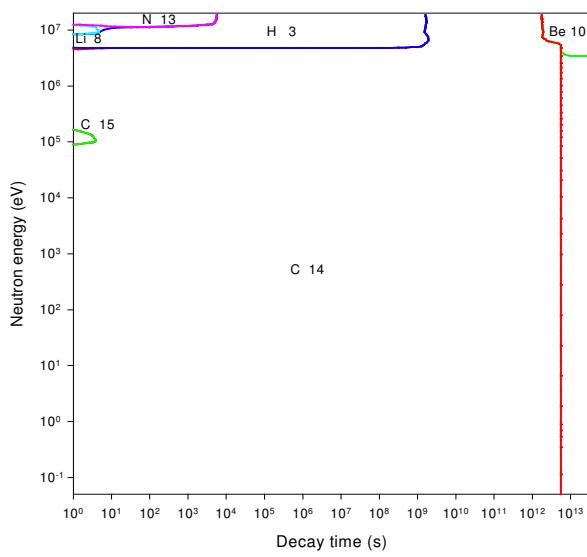
## Activity



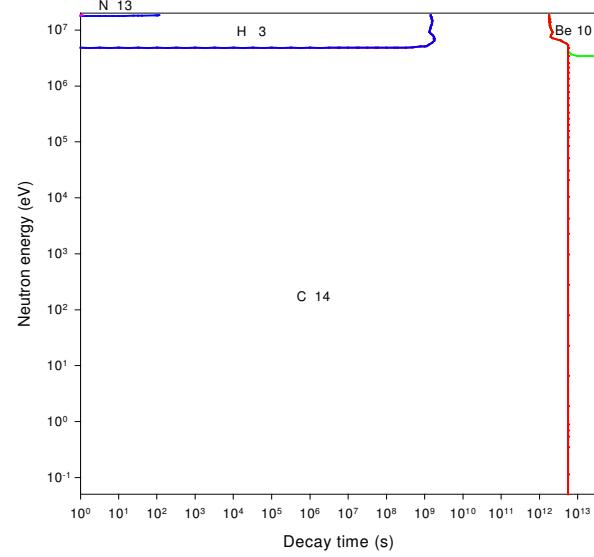
## Dose rate



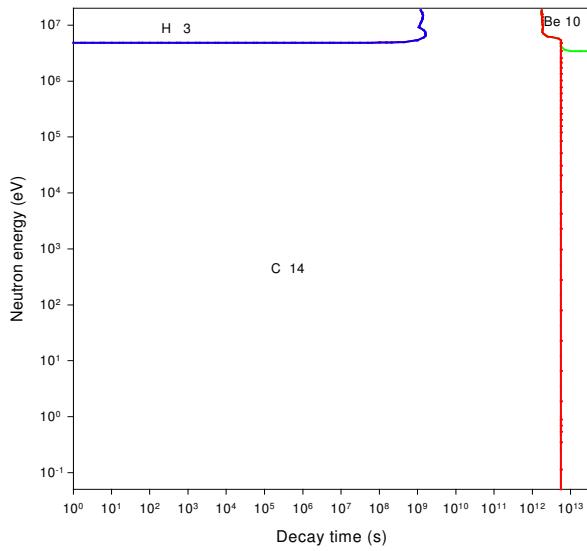
## Heat output



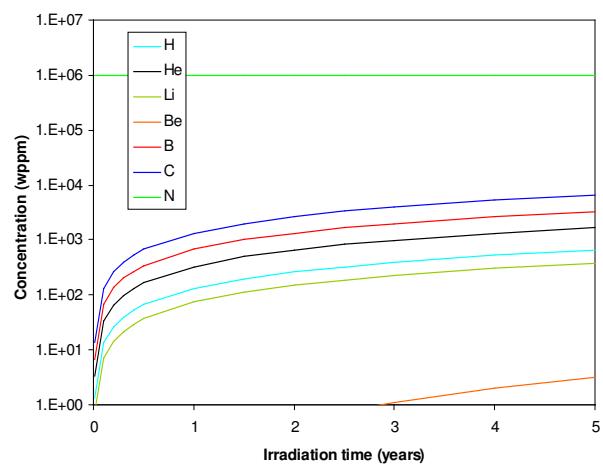
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Oxygen

## General properties

Atomic number	8	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	4.74 10 <sup>5</sup>	O16	99.762
Melting point / K	54.8	O17	0.038
Boiling point / K	90.19	O18	0.200
Density / kgm <sup>-3</sup>	1.429		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	2.67 10 <sup>-1</sup>		
Electrical resistivity /Ωm	-		
Coefficient of thermal expansion / K <sup>-1</sup>	-		
Crystal structure	Rhombic		
Number of stable isotopes	3		
Mean atomic weight	15.9994		

## Activation properties

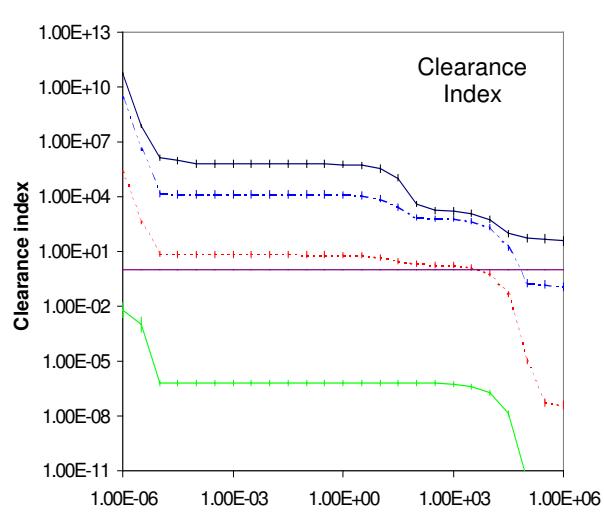
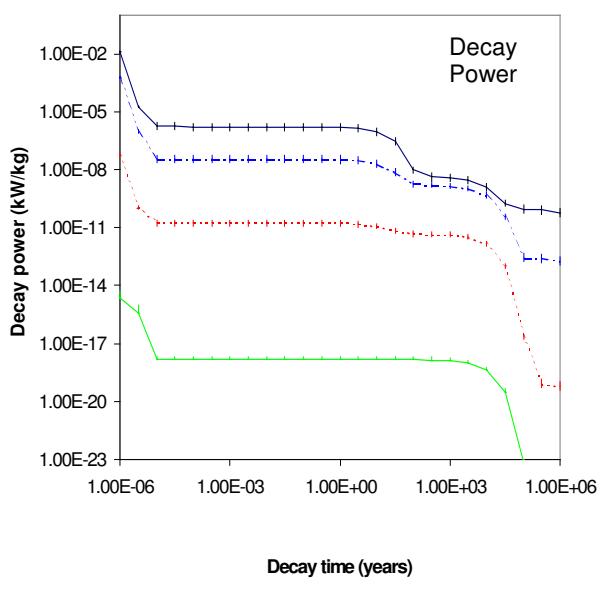
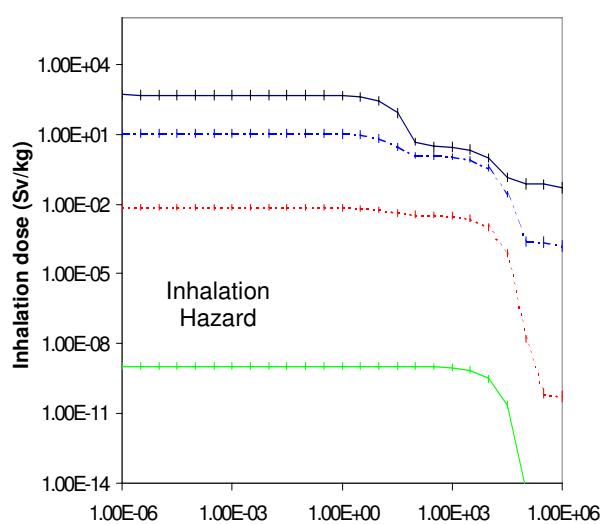
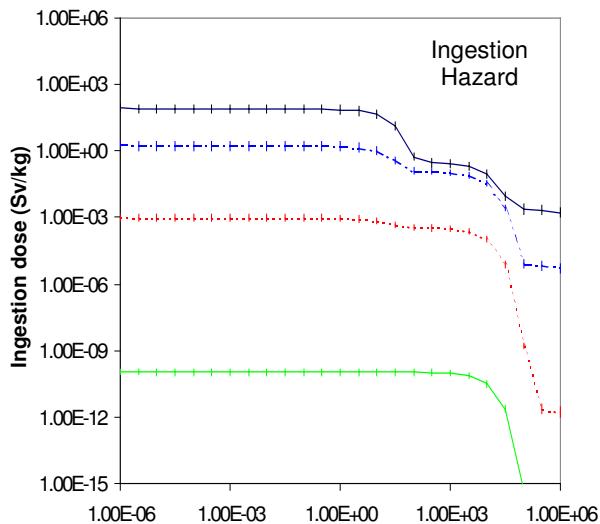
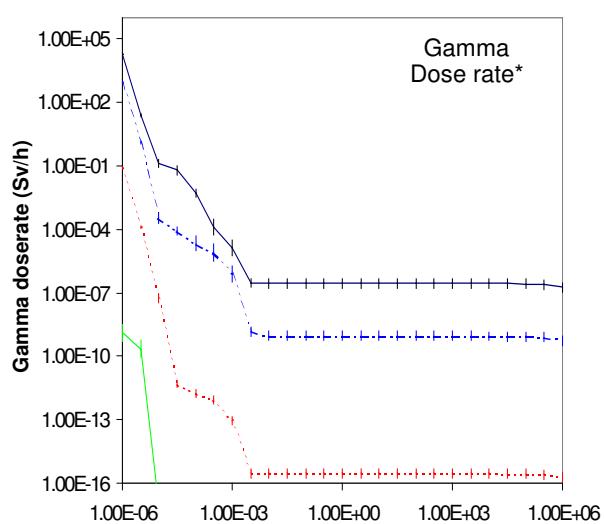
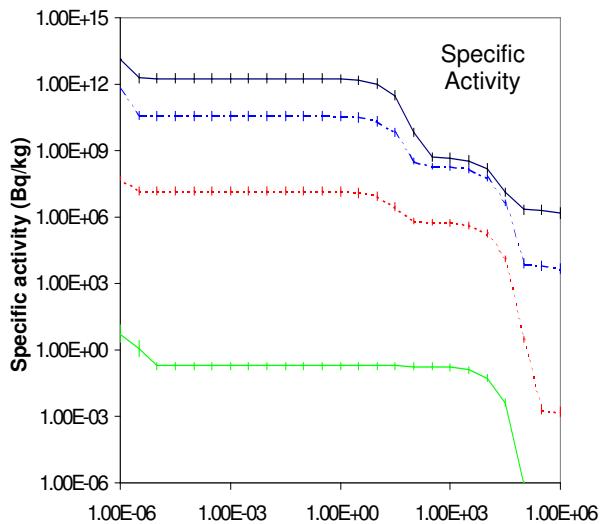
Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	2.42E14	1.83E12	1.83E12	1.73E12	7.16E9	2.20E6	kW kg <sup>-1</sup>	2.80E-1	1.84E-6	1.68E-6	1.59E-6	1.03E-8	8.88E-11
N16	99.01						N16	99.80					
H3	0.76	99.94	99.97	99.97	92.74		H3		90.94	99.74	99.74	59.14	
B13	0.09						N13		8.80				
C14		0.03	0.03	0.03	7.23	0.13	C14		0.23	0.25	0.26	39.96	0.03
Be10					0.03	99.87	Be10		0.01	0.01	0.01	0.90	99.97
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	4.02E5	1.34E-1	2.81E-7	2.81E-7	2.81E-7	2.69E-7	Sv kg <sup>-1</sup>	2.52E2	7.73E1	7.73E1	7.31E1	5.81E-1	2.42E-3
N16	99.95						N16	69.28					
N13		99.62					H3	30.55	99.59	99.60	99.58	47.95	
O19		0.11					C14	0.12	0.39	0.39	0.42	51.61	0.07
Be10			100.0*	100.0*	100.0*	100.0*	Be10					0.43	99.93
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	6.12E2	4.80E2	4.80E2	4.54E2	4.81E0	7.70E-2		1.20E12	1.34E6	6.13E5	5.80E5	3.99E3	5.50E1
H3	77.96	99.35	99.35	99.31	35.90		N16	99.93					
N16	21.52						N13		53.94				
C14	0.50	0.63	0.63	0.67	62.43	0.02	H3		45.73	99.71	99.69	55.39	
Be10	0.01	0.02	0.02	0.02	1.67	99.98	C14		0.13	0.29	0.30	43.18	0.02
N17	0.01						Be10			0.01	0.01	1.44	99.68

# Oxygen

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
C15	2.449 s	O17(n, $\alpha$ )C14(n, $\gamma$ )C15 O16(n, $\gamma$ )O17(n, $\alpha$ )C14(n, $\gamma$ )C15 O16(n,d)N15(n,p)C15 O18(n, $\alpha$ )C15	98.2 1.8	99.9 0.1	99.5 0.5	71.7 28.0
N16	7.13 s	O17(n, $\alpha$ )C14( $\beta^-$ )N14(n, $\gamma$ )N15(n, $\gamma$ )N16 O17(n, $\alpha$ )C14(n, $\gamma$ )C15( $\beta^-$ )N15(n, $\gamma$ )N16 O16(n, $\gamma$ )O17(n, $\alpha$ )C14( $\beta^-$ )N14(n, $\gamma$ )N15(n, $\gamma$ )N16 O16(n,p)N16	92.7 6.3 0.9			99.9
O19	26.91 s	O18(n, $\gamma$ )O19	100.0	100.0	100.0	99.7
O15	2.037 m	Threshold of O16(n,2n)O15 reaction > 15 MeV				
N13	9.965 m	O16(n,d)N15(n,2n)N14(n,2n)N13 O18(n, $\alpha$ )C15( $\beta^-$ )N15(n,2n)N14(n,2n)N13				99.6 0.1
F18	1.828 h	O18(n, $\gamma$ )O19( $\beta^-$ )F19(n,2n)F18				100.0
Na24	14.965 h	O18(n, $\gamma$ )O19( $\beta^-$ )F19(n, $\gamma$ )F20( $\beta^-$ )Ne20(n, $\gamma$ )Ne21(n, $\gamma$ ) Ne22(n, $\gamma$ )Ne23( $\beta^-$ )Na23(n, $\gamma$ )Na24m(IT)Na24 O18(n, $\gamma$ )O19( $\beta^-$ )F19(n, $\gamma$ )F20( $\beta^-$ )Ne20(n, $\gamma$ )Ne21(n, $\gamma$ ) Ne22(n, $\gamma$ )Ne23( $\beta^-$ )Na23(n, $\gamma$ )Na24	76.7 23.3			
H3	12.33 y	O17(n, $\alpha$ )C14( $\beta^-$ )N14(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 O16(n, $\alpha$ )C13(n,t2 $\alpha$ )H3 O16(n,d)N15(n,n3 $\alpha$ )H3 O16(n,n $\alpha$ )C12(n, $\alpha$ )Be9(n,X)H3	95.0	97.1		75.8 20.4 2.3
C14	5730.0 y	O17(n, $\alpha$ )C14 O16(n, $\gamma$ )O17(n, $\alpha$ )C14 O16(n,d)N15(n,d)C14 O18(n,n $\alpha$ )C14 O18(n,2n)O17(n, $\alpha$ )C14	98.2 1.8	99.9 0.1	99.5 0.5	14.1 46.5 35.4 2.4
Be10	$1.6 \cdot 10^6$ y	O16(n, $\alpha$ )C13(n, $\alpha$ )Be10				99.7

# Oxygen activation characteristics

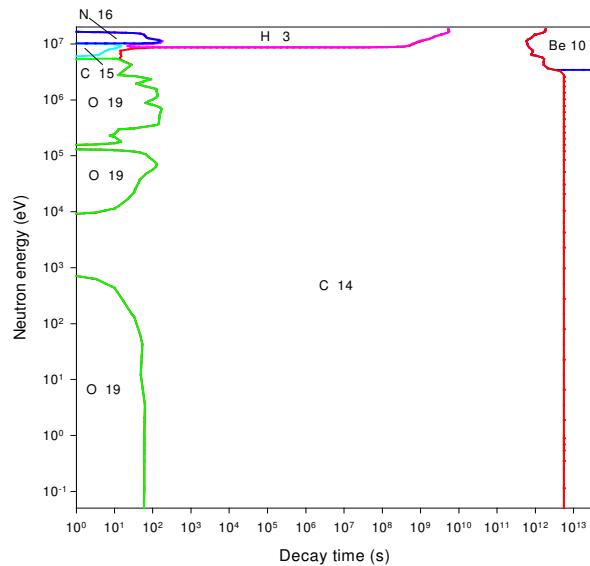


Decay time (years)

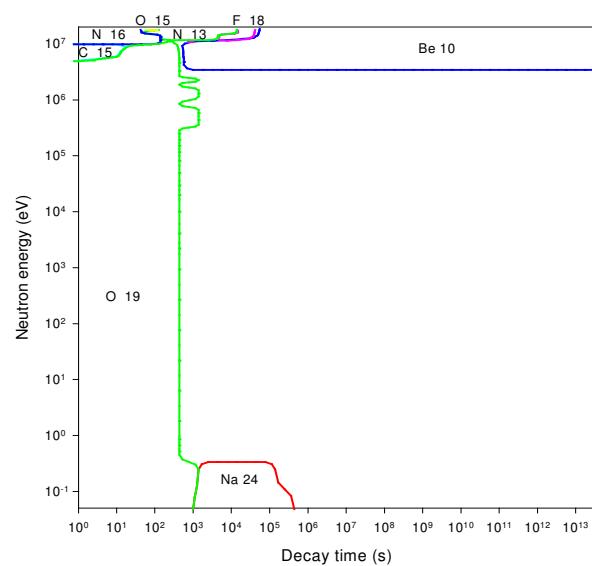
Decay time (years)

# Oxygen importance diagrams & transmutation

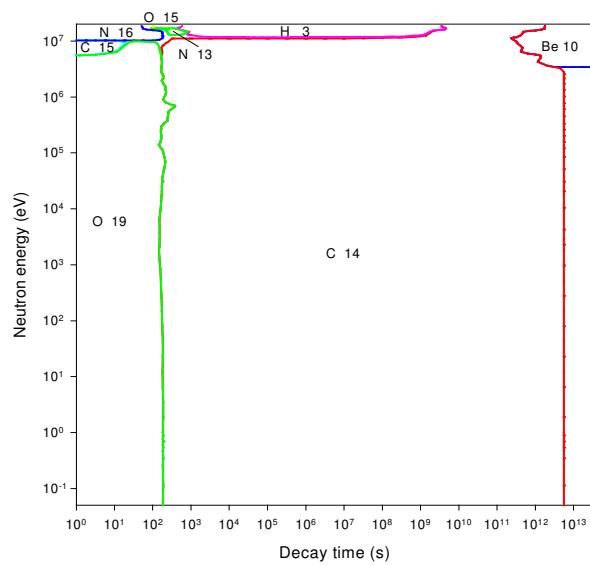
**Activity**



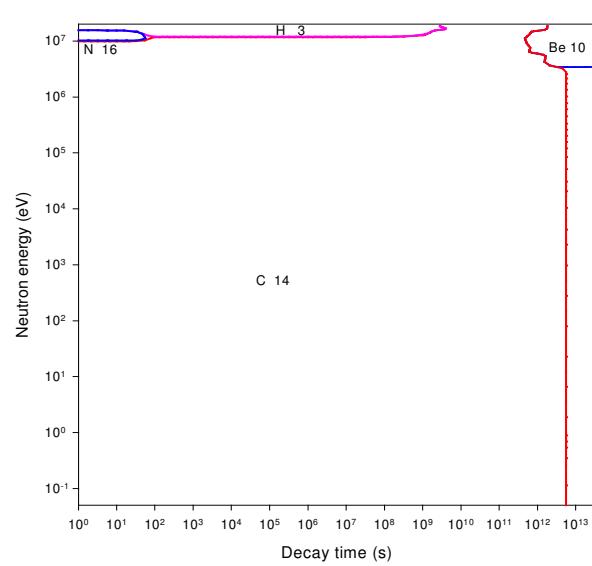
**Dose rate**



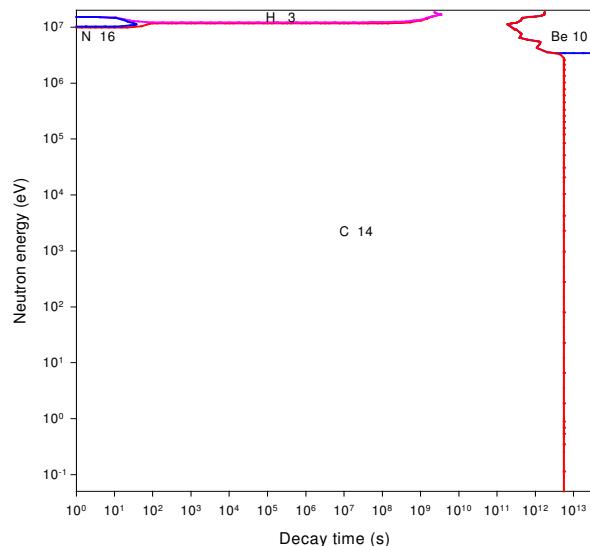
**Heat output**



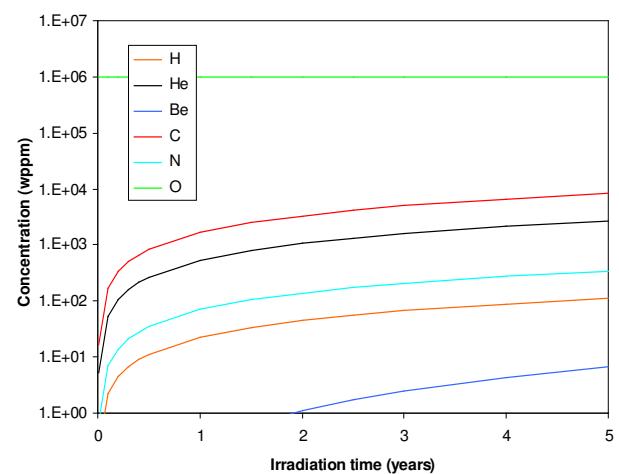
**Ingestion dose**



**Inhalation dose**



**First wall transmutation**



# Fluorine

## General properties

		9	Isotopes	Isotopic abundances / %	
Atomic number		950			
Crustal abundance / wppm		53.53			
Melting point / K		85.01			
Boiling point / K		1.696			
Density / kgm <sup>-3</sup>		2.79 10 <sup>-2</sup>			
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>		-			
Electrical resistivity /Ωm		-			
Coefficient of thermal expansion / K <sup>-1</sup>		Rhombic			
Crystal structure		1			
Number of stable isotopes		18.9984032			
Mean atomic weight					

## Activation properties

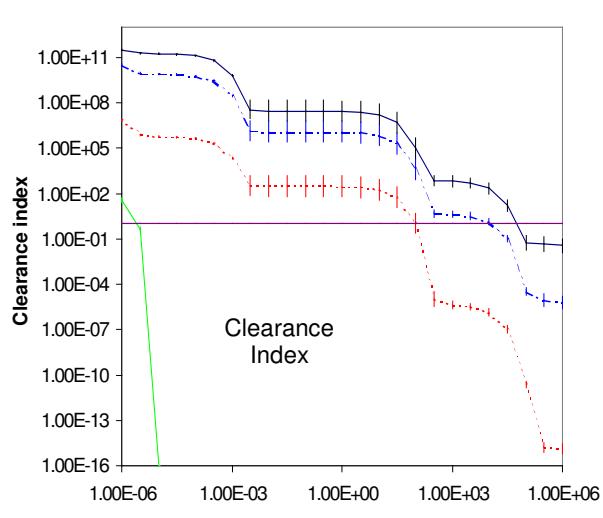
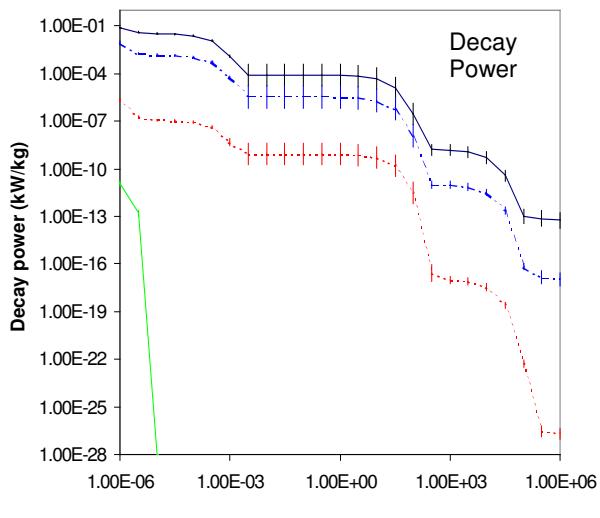
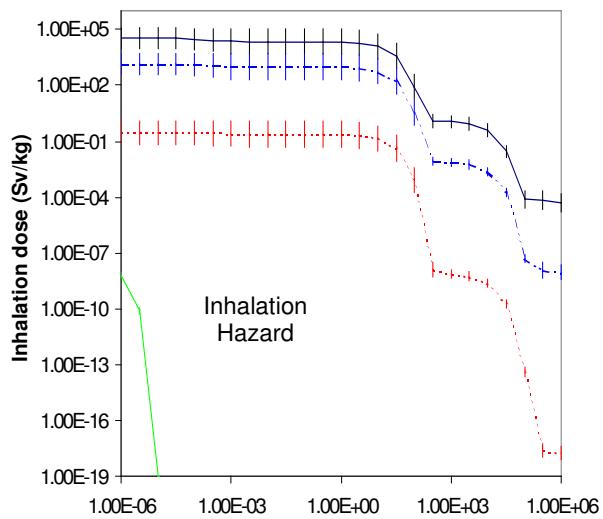
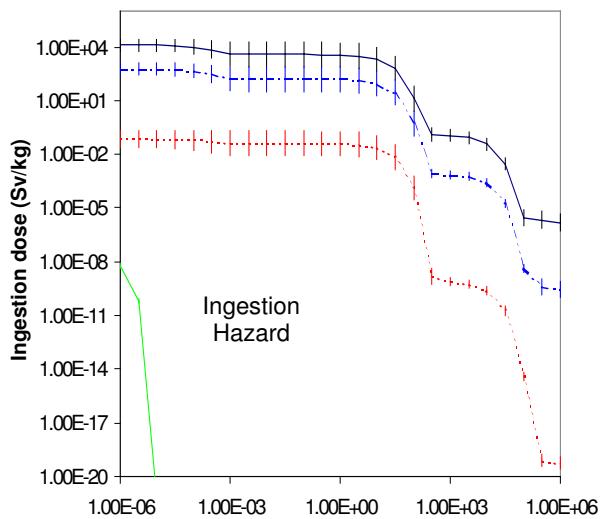
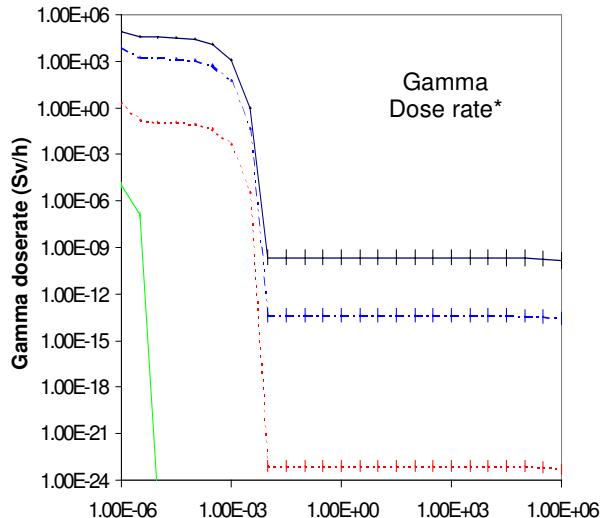
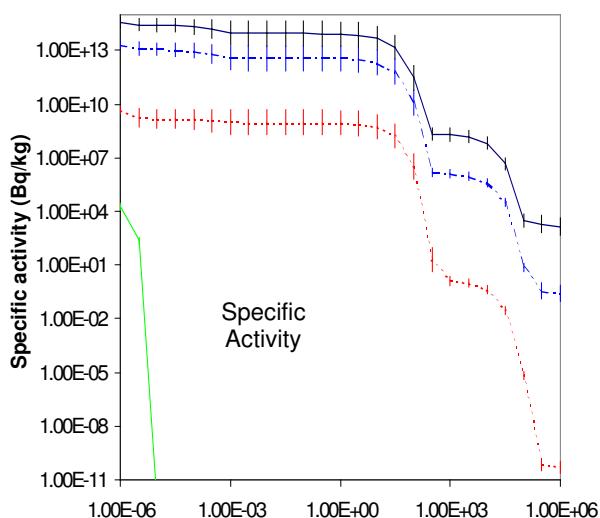
<b>Act</b>	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>	<b>Heat</b>	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>
Bq kg <sup>-1</sup>	7.31E14	2.62E14	8.85E13	8.37E13	3.21E11	3.34E3	kW kg <sup>-1</sup>	4.71E-1	3.42E-2	8.09E-5	7.65E-5	2.95E-7	9.45E-14
N16	42.00						N16	76.20					
F18	24.53	66.20					O19	10.83	0.04				
O19	16.06	0.01					F18	7.49	99.72				
H3	12.11	33.79	100.0	100.0	99.93		F20	5.31					
F20	5.20						H3	0.02	0.24	100.0	100.0	99.41	
C14					0.07	37.24	C14					0.59	10.43
Be10						62.76	Be10						89.57
<b>Dose</b>	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>	<b>Ing</b>	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>
Sv h <sup>-1</sup>	6.21E5	3.53E4	2.22E-10	2.22E-10	2.22E-10	2.12E-10	Sv kg <sup>-1</sup>	1.29E4	1.22E4	3.72E3	3.51E3	1.36E1	3.03E-6
N16	86.19						F18	63.34	69.57				
F18	5.87	99.98					H3	28.92	30.43	100.0	100.0	99.06	
O19	4.85	0.03					N16	1.74					
F20	3.03						C14					0.94	23.83
Be10			100.0*	100.0*	100.0*	100.0*	Be10						76.17
<b>Inh</b>	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>	<b>Clear</b>	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>
Sv kg <sup>-1</sup>	3.39E4	3.32E4	2.30E4	2.18E4	8.46E1	8.06E-5		1.93E12	1.75E11	2.95E7	2.79E7	1.08E5	5.65E-2
H3	67.96	69.22	100.0	100.0	98.49		N16	79.64					
F18	31.24	30.78					F18	9.40	99.96				
N16	0.50						O19	7.17	0.02				
O19	0.27						F20	3.72					
F20	0.04						H3		0.02	100.0	100.0	99.32	
C14			0.01	0.01	1.51	8.95	C14					0.68	7.33
Be10						91.05	Be10						92.67

# Fluorine

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
N16	7.13 s	F19(n, $\alpha$ )N16 F19(n,nt)O16(n,p)N16 F19(n,t)O17(n,d)N16				97.6 1.3 0.3
F20	11.03 s	F19(n, $\gamma$ )F20	100.0	100.0	100.0	98.3
O19	26.91 s	F19(n, $\gamma$ )F20( $\beta^-$ )Ne20(n, $\gamma$ )Ne21(n, $\alpha$ )O18(n, $\gamma$ )O19 F19(n,p)O19	100.0	100.0		100.0
F18	1.828 h	F19(n,2n)F18				99.7
Na24	14.965 h	F19(n, $\gamma$ )F20( $\beta^-$ )Ne20(n, $\gamma$ )Ne21(n, $\gamma$ )Ne22(n, $\gamma$ ) Ne23( $\beta^-$ )Na23(n, $\gamma$ )Na24m(IT)Na24 F19(n, $\gamma$ )F20( $\beta^-$ )Ne20(n, $\gamma$ )Ne21(n, $\gamma$ )Ne22(n, $\gamma$ ) Ne23( $\beta^-$ )Na23(n, $\gamma$ )Na24	76.7 23.3	100.0		
H3	12.33 y	F19(n,X)H3				99.7
C14	5730 y	F19(n,n $\alpha$ )N15(n,d)C14 F19(n,d)O18(n,n $\alpha$ )C14 F19(n,2n)F18( $\beta^+$ )O18(n,n $\alpha$ )C14 F19(n,t)O17(n, $\alpha$ )C14 F19(n,d)O18(n,2n)O17(n, $\alpha$ )C14 F19(n,2n)F18( $\beta^+$ )O18(n,2n)O17(n, $\alpha$ )C14				40.4 30.0 16.0 10.9 1.4 0.7
Be10	$1.6 \cdot 10^6$ y	F19(n,nt)O16(n, $\alpha$ )C13(n, $\alpha$ )Be10 F19(n, $\alpha$ )N16( $\beta^-$ )O16(n, $\alpha$ )C13(n, $\alpha$ )Be10 F19(n,n $\alpha$ )N15(n,t)C13(n, $\alpha$ )Be10 F19(n,t)O17(n,n $\alpha$ )C13(n, $\alpha$ )Be10 F19(n,n $\alpha$ )N15(n,n $\alpha$ )B11(n,d)Be10 F19(n,n $\alpha$ )N15(n,d)C14(n,n $\alpha$ )Be10				58.2 25.3 5.4 4.7 1.8 1.0

# Fluorine activation characteristics

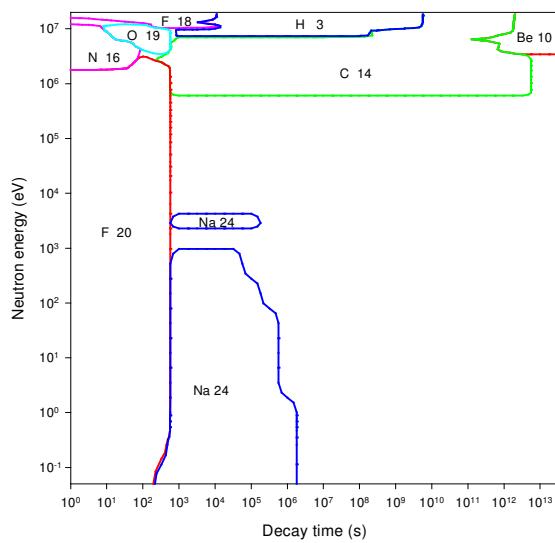


Decay time (years)

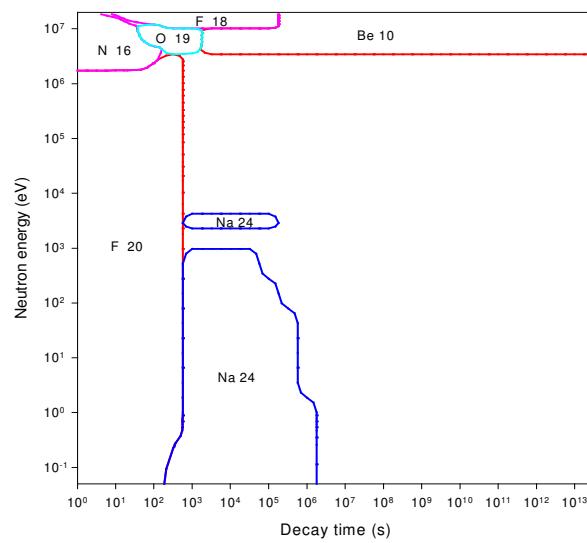
Decay time (years)

# Fluorine importance diagrams & transmutation

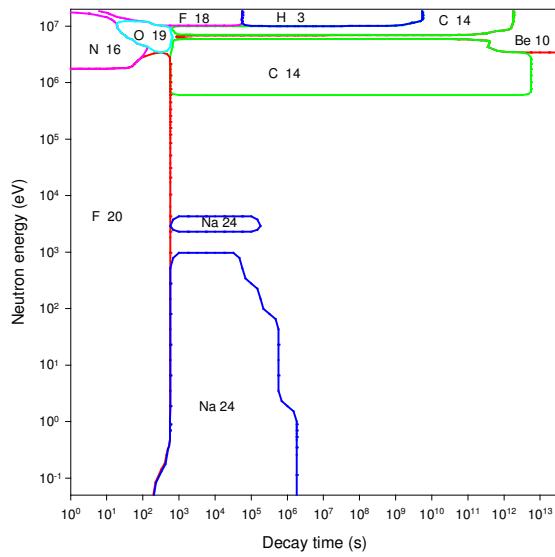
**Activity**



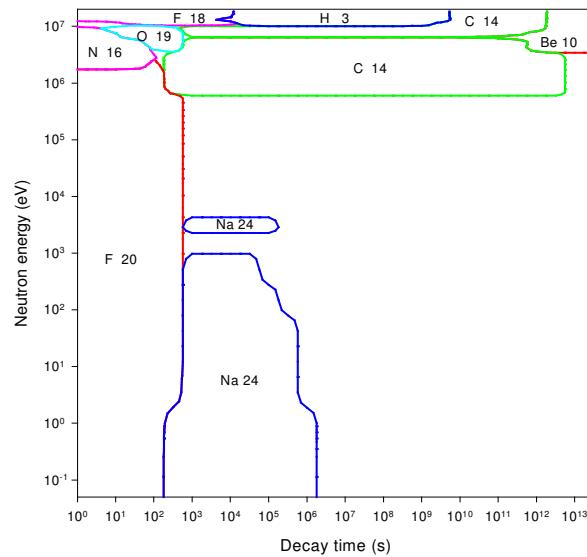
**Dose rate**



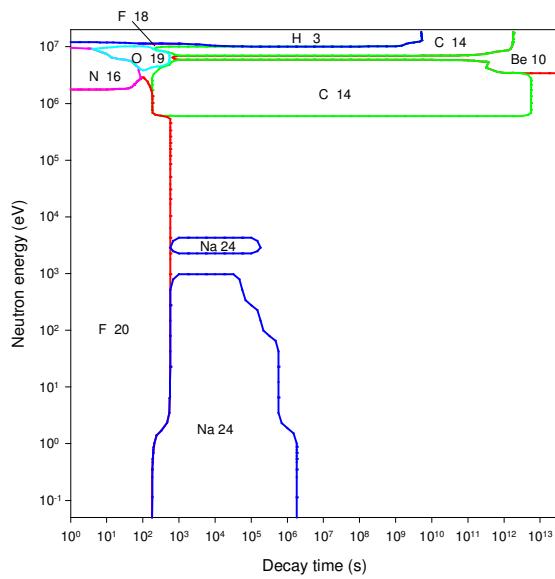
**Heat output**



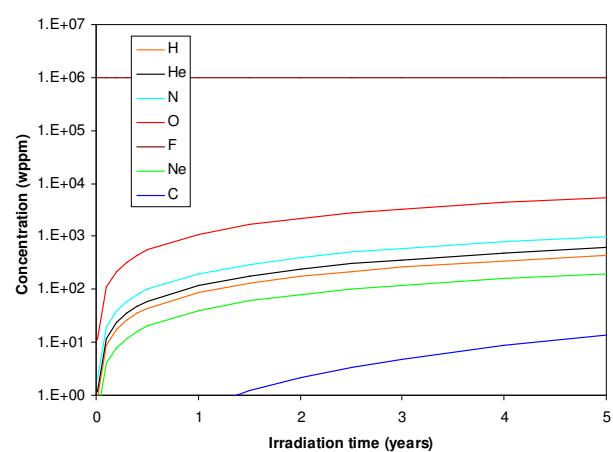
**Ingestion dose**



**Inhalation dose**



**First wall transmutation**



# Neon

## General properties

		10	Isotopes	Isotopic abundances / %	
Atomic number	10	7.0 10 <sup>-5</sup>		Ne20	90.48
Crustal abundance / wppm		24.48	Ne21	0.27	
Melting point / K		27.10	Ne22	9.25	
Boiling point / K		8.999 10 <sup>-1</sup>			
Density / kgm <sup>-3</sup>		4.93 10 <sup>-1</sup>			
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>		-			
Electrical resistivity /Ωm		-			
Coefficient of thermal expansion / K <sup>-1</sup>		FCC			
Crystal structure		3			
Number of stable isotopes		20.1797			
Mean atomic weight					

## Activation properties

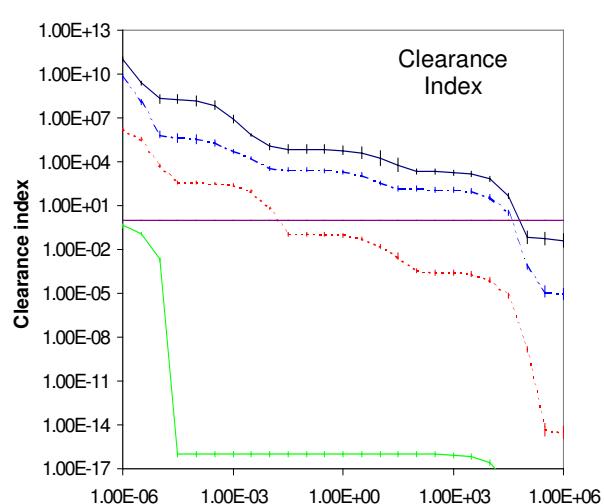
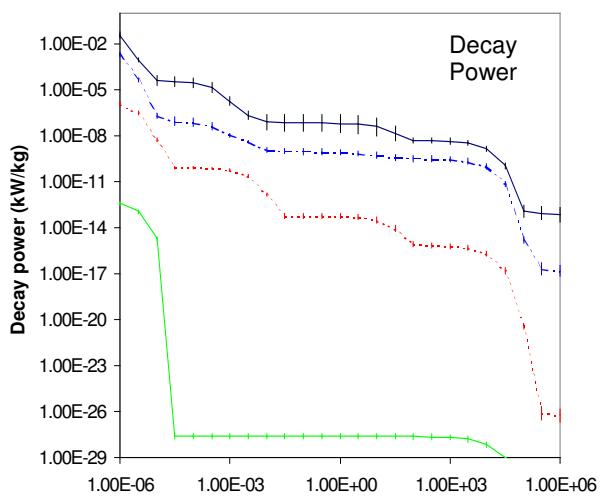
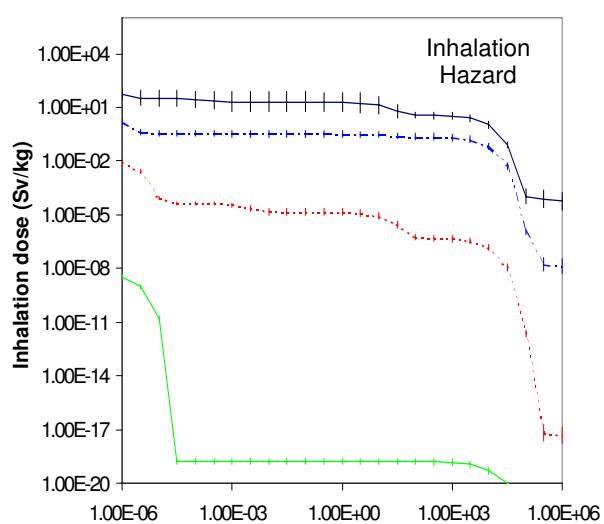
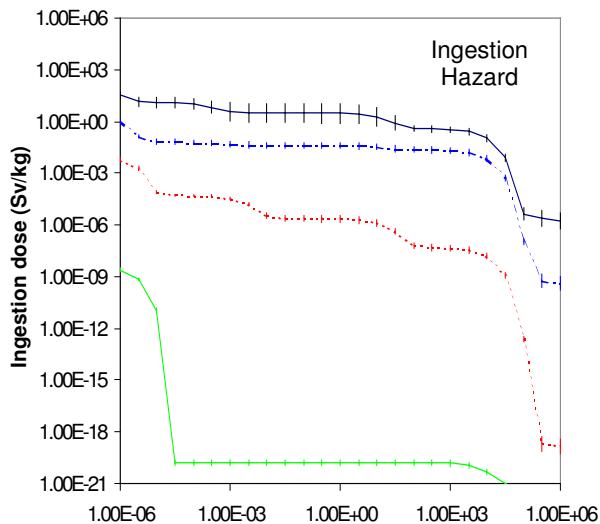
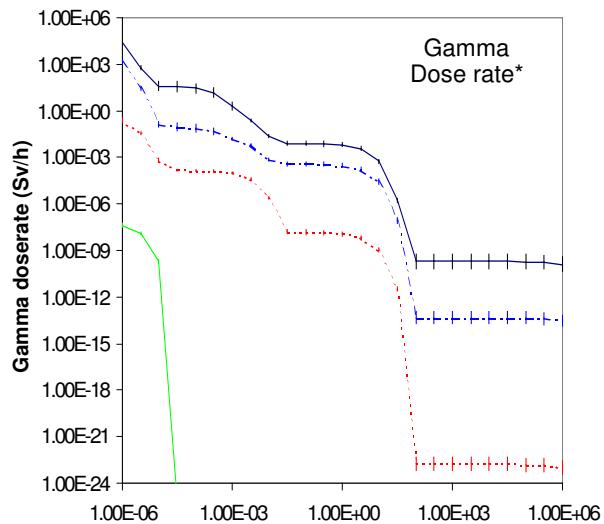
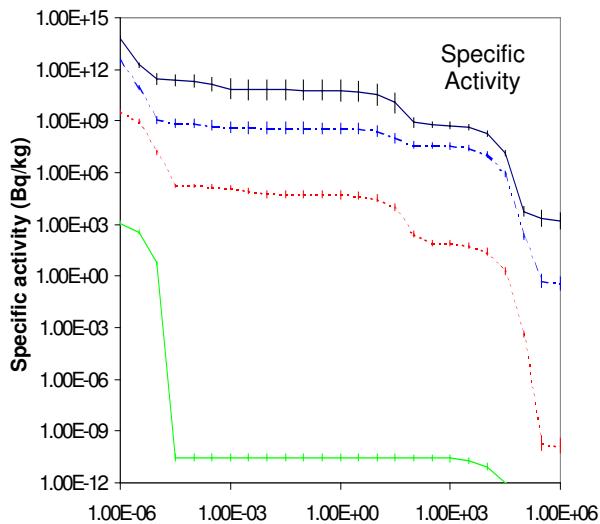
<b>Act</b>	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>	<b>Heat</b>	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>
Bq kg <sup>-1</sup>	4.26E14	2.65E11	6.35E10	6.01E10	8.60E8	6.00E3	kW kg <sup>-1</sup>	2.81E-1	4.09E-5	7.76E-8	6.40E-8	5.22E-9	1.27E-13
F20	94.74						F20	94.43					
O19	2.12	1.01					F22	2.74					
F22	1.40						O19	1.40	2.83				
F21	1.22						Ne23	0.08	1.53				
N16	0.29						F18	0.01	94.17				
Ne23	0.16	0.72					Na24		1.30	11.84			
F18	0.05	73.99					H3		0.14	74.06	85.01	3.99	
H3	0.02	23.77	98.95	98.92	26.49		Na22		0.01	7.57	7.06		
C14		0.24	1.01	1.06	73.51	59.44	C14		0.01	6.53	7.92	96.01	22.33
Be10						40.56	BE10						77.67
<b>Dose</b>	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>	<b>Ing</b>	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>
Sv h <sup>-1</sup>	2.06E5	3.97E1	2.38E-2	6.31E-3	1.99E-10	1.91E-10	Sv kg <sup>-1</sup>	1.35E2	1.30E1	3.07E0	2.91E0	3.76E-1	4.75E-6
F20	92.58						F20	80.54					
F22	5.17						F18	7.34	73.99				
O19	1.08	1.65					O19	6.68	0.02				
N16	0.97						H3	1.95	20.37	86.13	85.94	2.54	
F21	0.18						Ne23	1.00	0.03				
F18	0.02	95.89					C14	0.27	2.86	12.10	12.76	97.46	43.59
Na24		2.27	65.55				Na24	0.23	2.35	0.17			
Na22		0.02	34.45	100.0			Na22	0.04	0.38	1.60	1.30		
Be10					100.0*	100.0*	Be10						56.41
<b>Inh</b>	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>	<b>Clear</b>	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>
Sv kg <sup>-1</sup>	1.77E2	3.18E1	2.01E1	1.92E1	3.72E0	1.06E-4		8.16E11	2.04E8	1.15E5	6.12E4	2.18E3	7.27E-2
F20	75.25						F20	93.54					
H3	9.25	51.37	81.41	80.59	1.59		F22	4.28					
F18	6.75	36.29					O19	1.30	1.54				
O19	3.93	0.01					F18	0.03	96.64				
C14	2.10	11.65	18.47	19.33	98.41	19.54	Na24		1.16	35.54			
Ne23	1.08	0.02					Na22		0.03	44.39	64.12		
F22	0.84						H3		0.01	18.22	32.40	3.48	
N16	0.26						C14			1.85	3.48	96.52	16.35
Be10						80.46	Be10						83.65

# Neon

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
F21	4.32 s	Ne22(n,d)F21 Ne22(n,2n)Ne21(n,p)F21 Ne21(n,p)F21 Ne20(n, $\gamma$ )Ne21(n,p)F21				60.9 27.3 10.7 0.2
F20	11.03 s	Ne21(n, $\alpha$ )O18(n, $\gamma$ )O19( $\beta^-$ )F19(n, $\gamma$ )F20 Ne20(n, $\gamma$ )Ne21(n, $\alpha$ )O18(n, $\gamma$ )O19( $\beta^-$ )F19(n, $\gamma$ )F20 Ne20(n,p)F20	77.3 22.7	99.2 0.8	100.0	99.9
O19	26.91 s	Ne21(n, $\alpha$ )O18(n, $\gamma$ )O19 Ne20(n, $\gamma$ )Ne21(n, $\alpha$ )O18(n, $\gamma$ )O19 Ne22(n, $\alpha$ )O19 Ne20(n,d)F19(n,p)O19	69.1 30.9	98.7 1.3	100.0	91.8 7.7
Ne23	37.2 s	Ne22(n, $\gamma$ )Ne23 Ne21(n, $\gamma$ )Ne22(n, $\gamma$ )Ne23	99.8 0.1	100.0	100.0	99.2
F18	1.828 h	Ne20(n,d)F19(n,2n)F18 Ne22(n, $\alpha$ )O19( $\beta^-$ )F19(n,2n)F18				95.9 3.2
Na24	14.965 h	&Ne22(n, $\gamma$ )Ne23( $\beta^-$ )Na23(n, $\gamma$ )Na24	99.9	100.0	100.0	98.5
Na22	2.603 y	Ne22(n, $\gamma$ )Ne23( $\beta^-$ )Na23(n,2n)Na22				99.9
H3	12.33 y	Ne20(n,d)F19(n,X)H3 Ne22(n,2n)Ne21(n,X)H3 Ne22(n, $\alpha$ )O19( $\beta^-$ )F19(n,X)H3 Ne21(n,X)H3 Ne20(n, $\alpha$ )O17(n,X)H3				89.6 3.2 3.0 2.4 0.8
C14	5730 y	Ne20(n, $\alpha$ )O17(n, $\alpha$ )C14 Ne20(n,d)F19(n,n $\alpha$ )N15(n,d)C14 Ne20(n,n $\alpha$ )O16(n,d)N15(n,d)C14 Ne20(n,d)F19(n,d)O18(n,n $\alpha$ )C14 Ne22(n,n $\alpha$ )O18(n,n $\alpha$ )C14 Ne21(n, $\alpha$ )O18(n,n $\alpha$ )C14				96.3 0.6 0.5 0.5 0.4 0.3
Be10	$1.6 \cdot 10^6$ y	Ne20(n,n $\alpha$ )O16(n, $\alpha$ )C13(n, $\alpha$ )Be10 Ne20(n, $\alpha$ )O17(n,n $\alpha$ )C13(n, $\alpha$ )Be10 Ne20(n, $\alpha$ )O17(n, $\alpha$ )C14(n,n $\alpha$ )Be10				93.2 5.5 0.3

# Neon activation characteristics

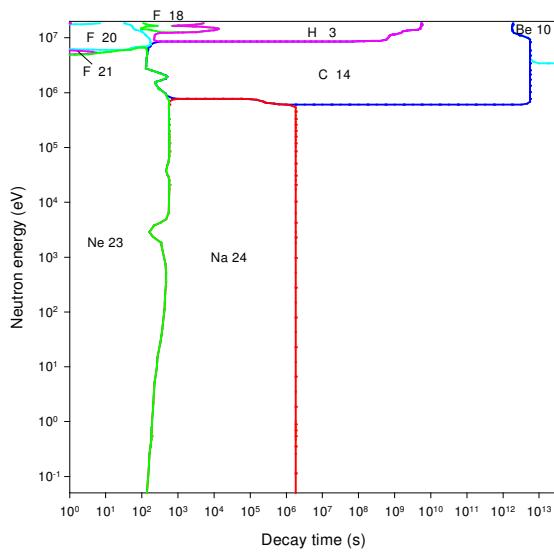


Decay time (years)

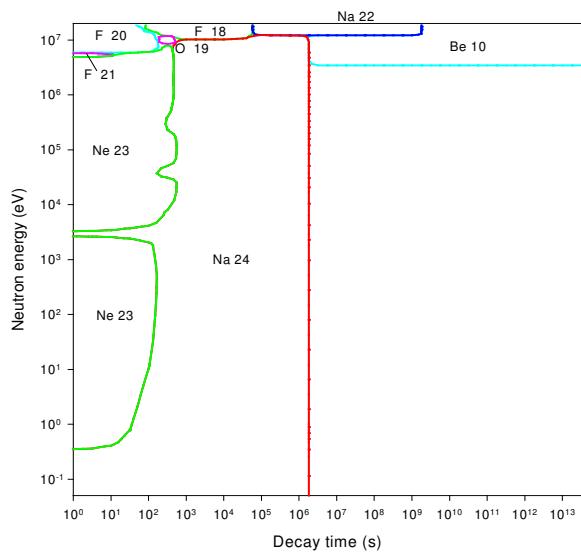
Decay time (years)

# Neon importance diagrams & transmutation

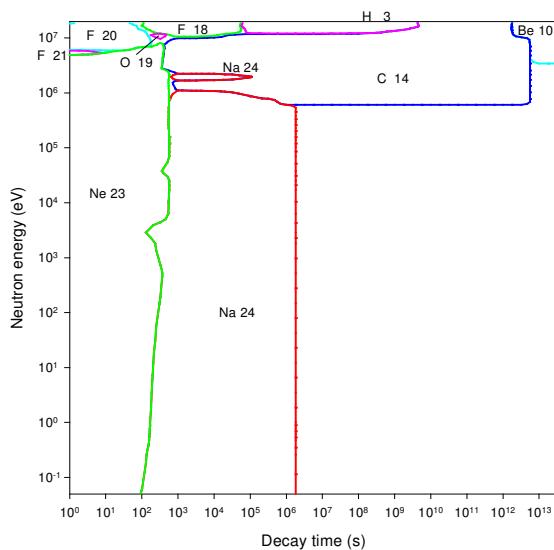
## Activity



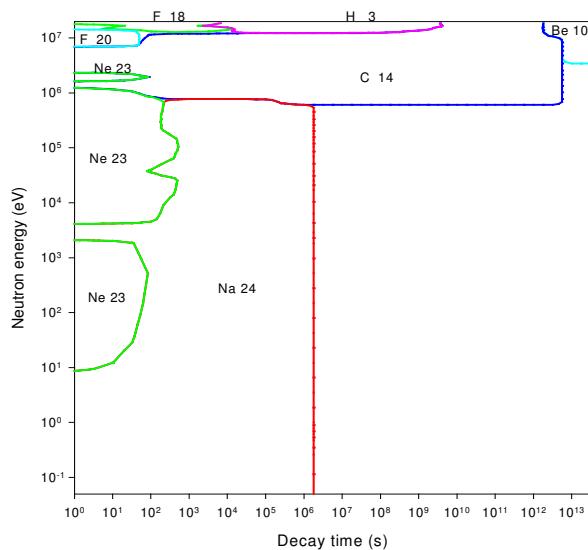
## Dose rate



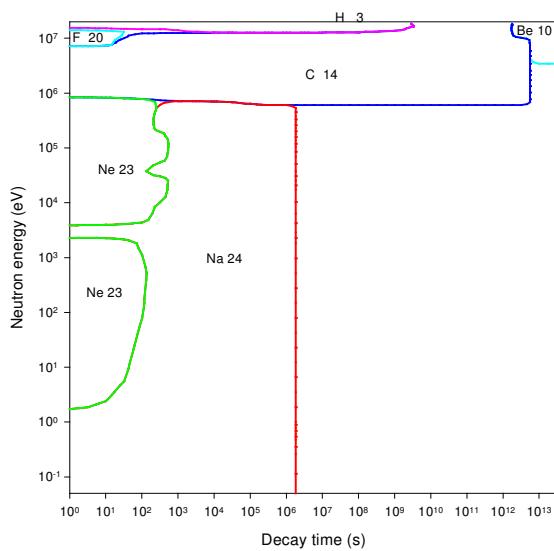
## Heat output



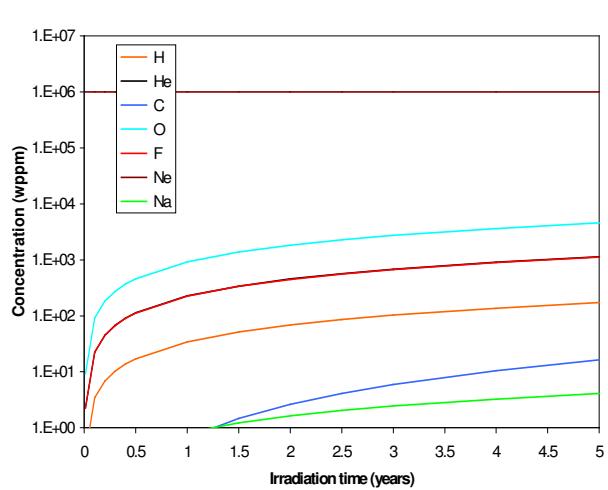
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Sodium

## General properties

		11 2.3 10 <sup>4</sup> 371.0 1156 971 141 4.2 10 <sup>-8</sup> 7.06 10 <sup>-5</sup>	Isotopes Na23	Isotopic abundances / %	
Atomic number	Crustal abundance / wppm			100.0	
Melting point / K					
Boiling point / K					
Density / kgm <sup>-3</sup>					
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>					
Electrical resistivity /Ωm					
Coefficient of thermal expansion / K <sup>-1</sup>					
Crystal structure			hexagonal		
Number of stable isotopes		1			
Mean atomic weight		22.989768			

## Activation properties

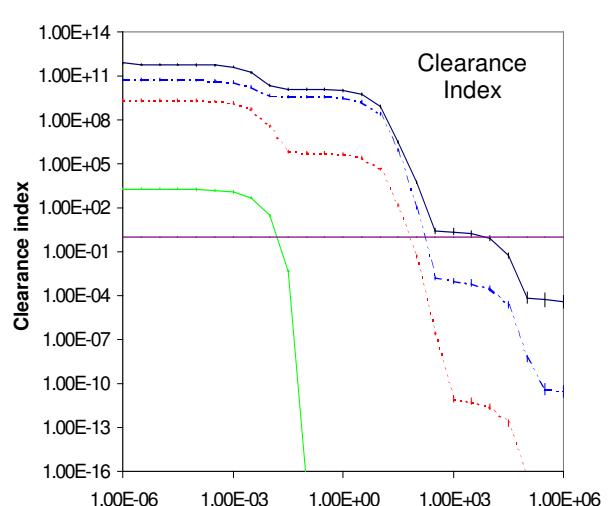
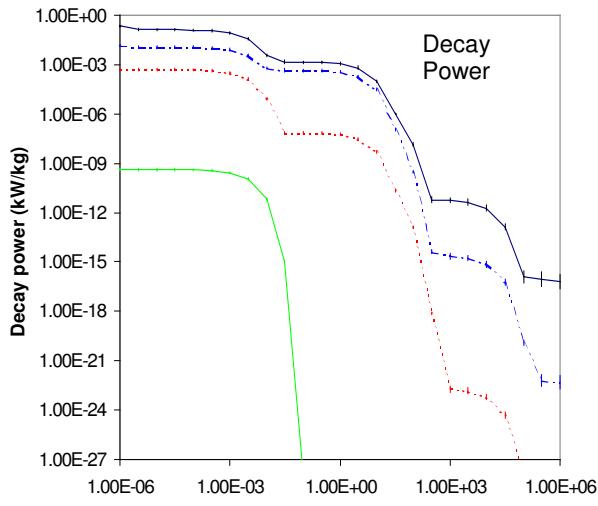
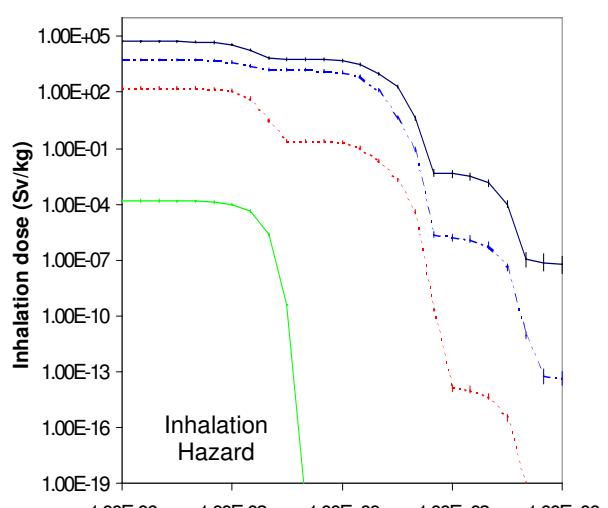
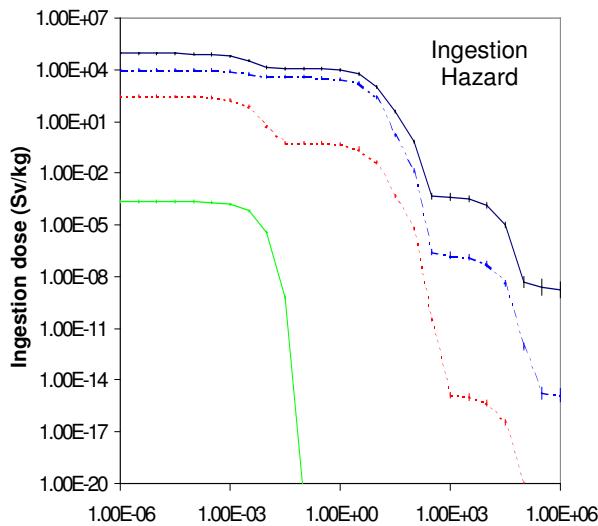
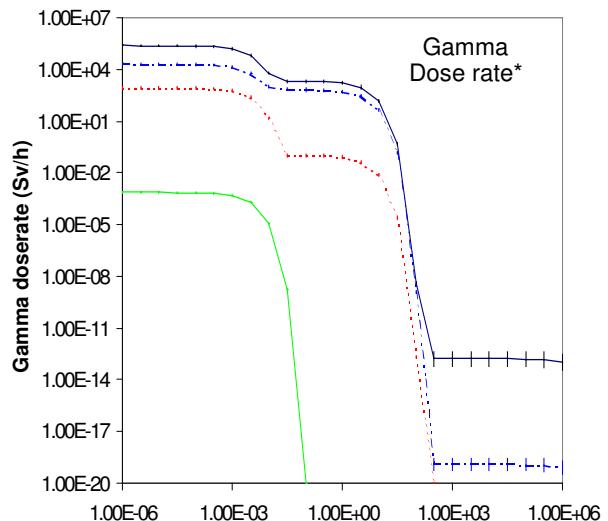
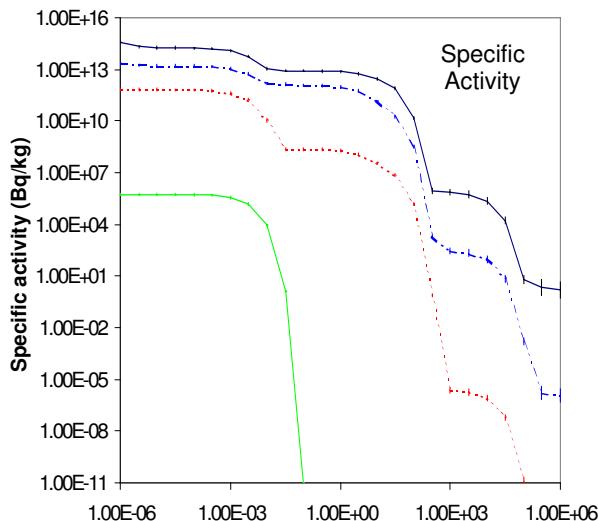
Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.12E15	1.81E14	1.15E13	7.34E12	1.68E10	6.79E0	kW kg <sup>-1</sup>	6.11E-1	1.30E-1	3.71E-3	1.14E-3	1.54E-8	1.30E-16
F20	55.24						F20	66.68					
Ne23	16.67	0.29					Na24	21.17	98.73	60.09			
Na24	15.42	94.99	25.97				Ne23	10.10	0.13				
Na24m	11.81						Na24m	1.68					
H3	0.41	2.56	40.45	59.73	99.99		Na22	0.24	1.14	39.79	99.64		
Na22	0.35	2.13	33.58	40.27			H3			0.11	0.35	99.96	
C14					0.01	65.67	C14					0.04	27.29
Be10						34.33	Be10						72.72
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	5.53E5	2.29E5	6.06E3	1.64E3	1.65E-13	1.58E-13	Sv kg <sup>-1</sup>	8.73E4	8.65E4	1.38E4	9.65E3	7.06E-1	5.15E-9
F20	54.81						Na24	85.01	85.49	9.28			
Na24	41.15	99.05	64.73				Na22	14.15	14.28	89.31	98.09		
Na24m	2.29						Ne23	0.43					
Ne23	1.21	0.01					H3	0.22	0.22	1.41	1.91	99.94	
Na22	0.39	0.94	35.27	100.0			C14					0.07	50.22
Be10					100.0*	100.0*	Be10						49.79
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	5.36E4	5.26E4	7.01E3	4.99E3	4.37E0	1.08E-7		1.89E12	5.86E11	2.28E10	9.86E9	5.60E3	7.32E-5
Na24	87.02	88.17	11.46				F20	61.80					
Na22	9.37	9.53	71.35	77.13			Na24	30.48	97.77	43.61			
H3	2.25	2.29	17.19	22.88	99.90		Ne23	3.53	0.03				
Ne23	0.98						Na24m	3.33					
C14					0.11	24.07	Na22	0.68	2.20	56.39	99.99		
Be10						75.93	H3			0.01	0.02	99.95	
							C14					0.05	20.32
							Be10						79.68

# Sodium

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
F20	11.03 s	Na23(n, $\alpha$ )F20				98.0
Ne23	37.2 s	Na23(n, $\gamma$ )Na24m(IT)Na24( $\beta^-$ )Mg24(n, $\gamma$ )Mg25(n, $\alpha$ ) Ne22(n, $\gamma$ )Ne23 Na23(n, $\gamma$ )Na24( $\beta^-$ )Mg24(n, $\gamma$ )Mg25(n, $\alpha$ )Ne22(n, $\gamma$ ) Ne23 Na23(n,p)Ne23	76.3  23.2	76.3  23.2		100.0
Na24	14.965 h	Na23(n, $\gamma$ )Na24m(IT)Na24 Na23(n, $\gamma$ )Na24	77.1 23.3	76.7 23.3	76.7 23.3	30.5 66.8
P32	14.27 d	&Na23(n, $\gamma$ )Na24( $\beta^-$ )Mg24(n, $\gamma$ )Mg25(n, $\gamma$ )Mg26(n, $\gamma$ ) Mg27( $\beta^-$ )Al27(n, $\gamma$ )Al28( $\beta^-$ )Si28(n, $\gamma$ )Si29(n, $\gamma$ ) Si30(n, $\gamma$ )Si31( $\beta^-$ )P31(n, $\gamma$ )P32	99.3			
Na22	2.603 y	Na23(n,2n)Na22				99.7
H3	12.33 y	Na23(n,X)H3 Na23(n, $n\alpha$ )F19(n,X)H3				97.5 2.0
Si32	330 y	&Na23(n, $\gamma$ )Na24( $\beta^-$ )Mg24(n, $\gamma$ )Mg25(n, $\gamma$ )Mg26(n, $\gamma$ ) Mg27( $\beta^-$ )Al27(n, $\gamma$ )Al28( $\beta^-$ )Si28(n, $\gamma$ )Si29(n, $\gamma$ ) Si30(n, $\gamma$ )Si31(n, $\gamma$ )Si32	99.3			
C14	5730 y	Na23(n, $\alpha$ )F20( $\beta^-$ )Ne20(n, $\alpha$ )O17(n, $\alpha$ )C14 Na23(n, $n\alpha$ )F19(n, $n\alpha$ )N15(n,d)C14 Na23(n, $n\alpha$ )F19(n,d)O18(n, $n\alpha$ )C14 Na23(n, $n\alpha$ )F19(n,2n)F18( $\beta^+$ )O18(n, $n\alpha$ )C14 Na23(n, $n\alpha$ )F19(n,t)O17(n, $\alpha$ )C14 Na23(n,d)Ne22(n, $n\alpha$ )O18(n, $n\alpha$ )C14 Na23(n,t)Ne21(n, $\alpha$ )O18(n, $n\alpha$ )C14 Na23(n,d)Ne22(n,2n)Ne21(n, $\alpha$ )O18(n, $n\alpha$ )C14 Na23(n,2n)Na22(n, $n\alpha$ )F18( $\beta^+$ )O18(n, $n\alpha$ )C14 Na23(n,2n)Na22(n,pa)O18(n, $n\alpha$ )C14 Na23(n,t)Ne21(n, $n\alpha$ )O17(n, $\alpha$ )C14				52.7 13.9 10.3 5.5 3.7 3.6 2.2 1.6 1.4 0.9 0.6
Be10	$1.6 \cdot 10^6$ y	Na23(n, $\alpha$ )F20( $\beta^-$ )Ne20(n, $n\alpha$ )O16(n, $\alpha$ )C13(n, $\alpha$ )Be10 Na23(n, $\alpha$ )F20( $\beta^-$ )Ne20(n, $\alpha$ )O17(n, $n\alpha$ )C13(n, $\alpha$ )Be10 Na23(n, $n\alpha$ )F19(n,nt)O16(n, $\alpha$ )C13(n, $\alpha$ )Be10 Na23(n, $n\alpha$ )F19(n, $\alpha$ )N16( $\beta^-$ )O16(n, $\alpha$ )C13(n, $\alpha$ )Be10				86.1 5.1 4.5 1.9

# Sodium activation characteristics

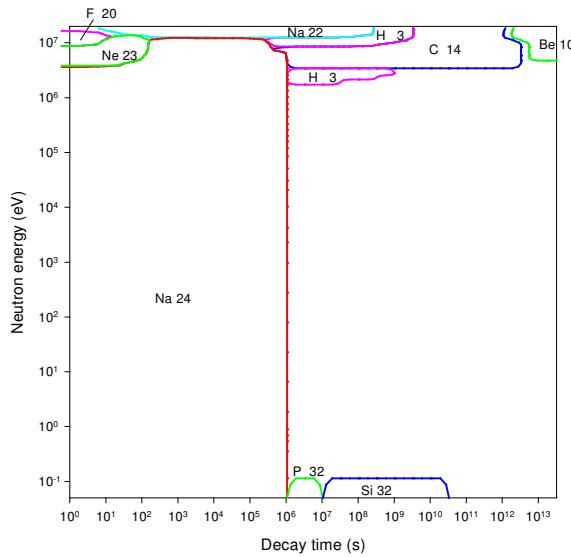


Decay time (years)

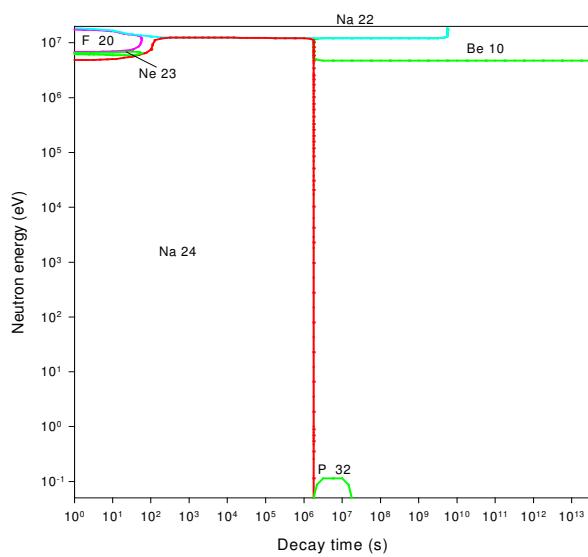
Decay time (years)

# Sodium importance diagrams & transmutation

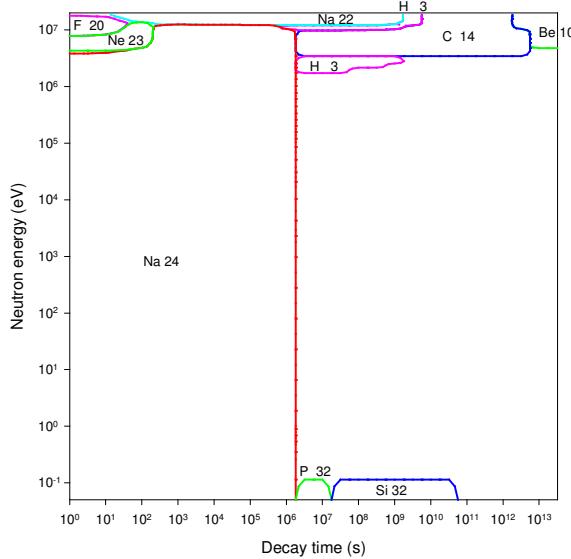
**Activity**



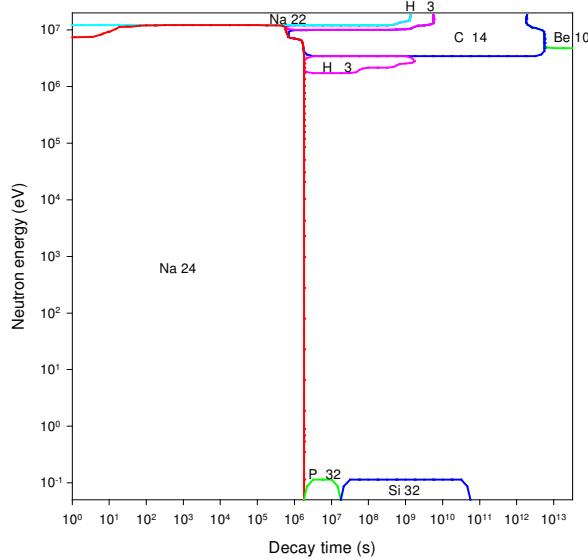
**Dose rate**



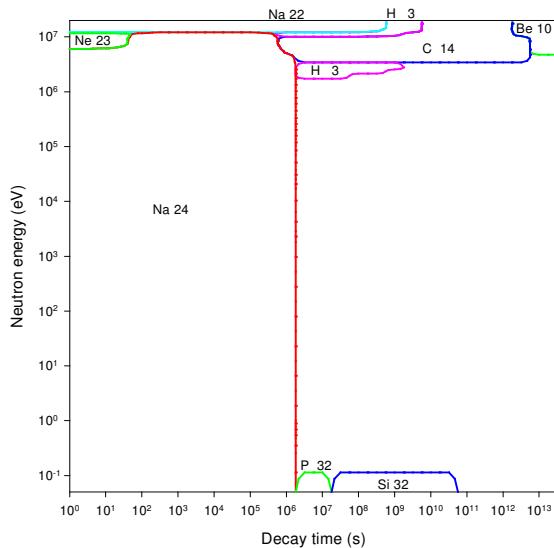
**Heat output**



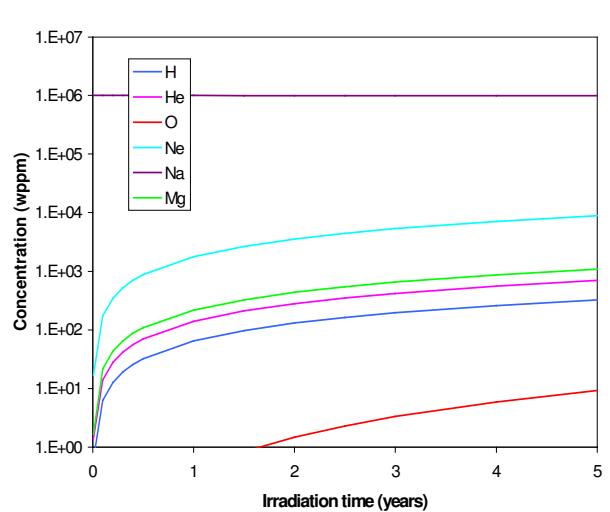
**Ingestion dose**



**Inhalation dose**



**First wall transmutation**



# Magnesium

## General properties

Atomic number	12	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	2.30 10 <sup>4</sup>	Mg24	78.99
Melting point / K	922.0	Mg25	10.00
Boiling point / K	1363	Mg26	11.01
Density / kgm <sup>-3</sup>	1738		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	156		
Electrical resistivity /Ωm	4.38 10 <sup>-8</sup>		
Coefficient of thermal expansion / K <sup>-1</sup>	2.61 10 <sup>-5</sup>		
Crystal structure	HCP		
Number of stable isotopes	3		
Mean atomic weight	24.3050		

## Activation properties

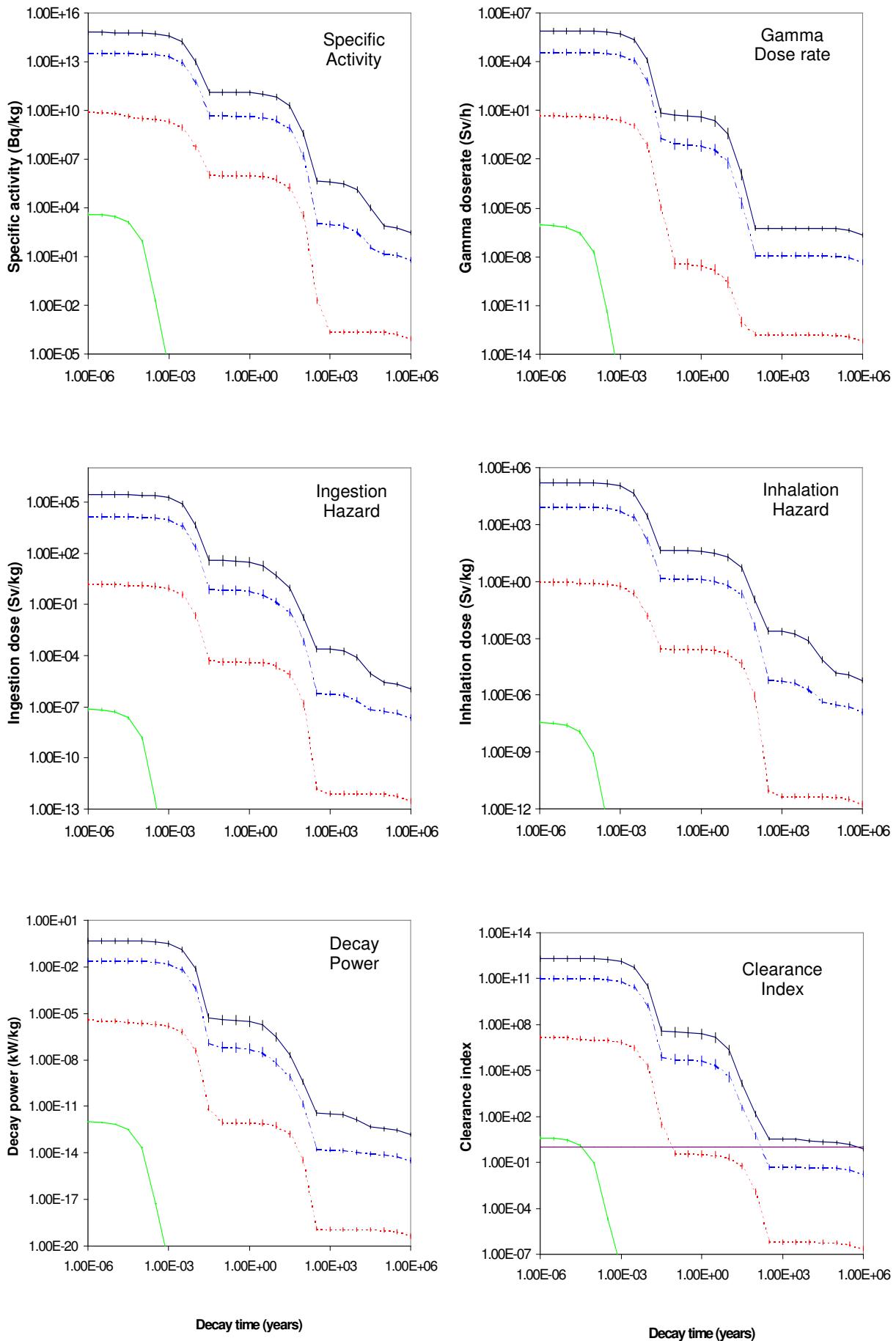
Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	8.65E14	6.13E14	1.07E13	1.24E11	4.45E8	7.26E2	kW kg <sup>-1</sup>	4.99E-1	4.59E-1	7.94E-3	3.01E-6	4.11E-10	3.62E-13
Na24	70.98	99.73	98.77				Na24	92.12	99.91	99.95			
Na24m	22.05						Na24m	2.96					
Na25	3.17	0.11					Na25	1.70	0.05				
Ne23	2.37	0.01					Na26	1.43					
Na26	0.93						Ne23	1.36					
H3	0.01	0.02	1.15	93.88	99.90		Na22			0.05	96.47		
Na22			0.09	6.11			H3				3.53	99.06	
Al26						99.53	C14					0.84	0.01
C14						0.34	Al26					0.10	99.98
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	8.10E5	7.79E5	1.35E4	4.07E0	5.78E-7	5.25E-7	Sv kg <sup>-1</sup>	2.64E5	2.63E5	4.59E3	2.91E1	1.89E-2	2.53E-6
Na24	96.54	99.97	99.96				Na24	99.96	99.98	99.20			
Na24m	2.18						Na22	0.02	0.01	0.69	83.22		
Na26	0.66						H3			0.11	16.78	98.65	
Na22			0.04	100.0			C14					1.34	0.06
Al26					100.0	100.0	Al26					0.02	99.90
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	1.66E5	1.65E5	2.91E3	4.00E1	1.18E-1	1.45E-5		2.19E12	2.04E12	3.53E10	2.53E7	1.52E2	1.95E0
Na24	99.93	99.97	98.46				Na24	93.58	99.94	99.91			
H3	0.02	0.02	1.10	75.4	97.84		Na24m	4.15					
Na22	0.01	0.01	0.44	24.56			Na26	0.92					
C14				0.01	2.14	0.10	Na22			0.09	99.85		
Al26						99.66	H3				0.15	97.63	
Be10						0.24	Al26					1.42	100.0
							C14					0.96	

# Magnesium

## Pathway analysis

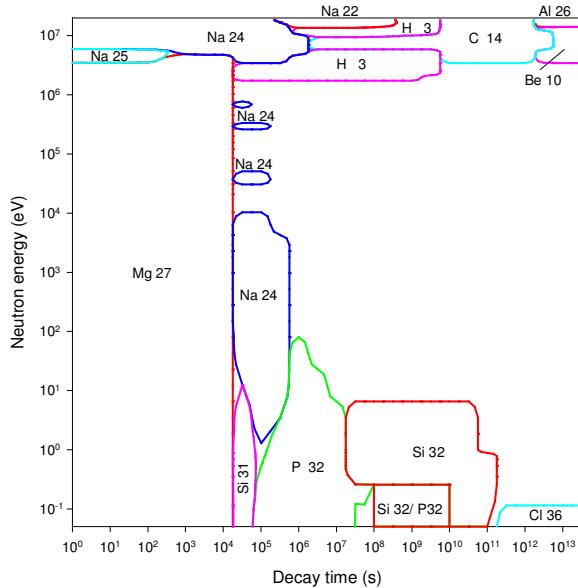
Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Na25	59.6 s	Mg25(n,p)Na25 Mg26(n,2n)Mg25(n,p)Na25 Mg26(n,d)Na25				84.4 8.2 7.2
Mg27	9.46 m	Mg26(n, $\gamma$ )Mg27 Mg25(n, $\gamma$ )Mg26(n, $\gamma$ )Mg27	98.7 1.2	100.0	100.0	98.6
Si31	2.62 h	Mg26(n, $\gamma$ )Mg27( $\beta^-$ )Al27(n, $\gamma$ )Al28( $\beta^-$ )Si28(n, $\gamma$ ) Si29(n, $\gamma$ )Si30(n, $\gamma$ )Si31	99.8	100.0	100.0	
Na24	14.96 h	&Mg25(n, $\alpha$ )Ne22(n, $\gamma$ )Ne23( $\beta^-$ )Na23(n, $\gamma$ )Na24 &Mg24(n,p)Na24 &Mg25(n,d)Na24 &Mg25(n,2n)Mg24(n,p)Na24	99.1	100.0	100.0	94.7 2.5 1.3
P32	14.27 d	Mg26(n, $\gamma$ )Mg27( $\beta^-$ )Al27(n, $\gamma$ )Al28( $\beta^-$ )Si28(n, $\gamma$ ) Si29(n, $\gamma$ )Si30(n, $\gamma$ )Si31( $\beta^-$ )P31(n, $\gamma$ )P32	99.8	100.0		
Na22	2.60 y	Mg24(n,d)Na23(n,2n)Na22 Mg26(n, $\alpha$ )Ne23( $\beta^-$ )Na23(n,2n)Na22 Mg25(n,2n)Mg24(n,d)Na23(n,2n)Na22				92.5 2.6 0.5
H3	12.33 y	Mg25(n,X)H3 Mg24(n,d)Na23(n,X)H3 Mg24(n, $\alpha$ )Ne21(n,X)H3 Mg26(n,2n)Mg25(n,X)H3 Mg26(n, $\alpha$ )Ne23( $\beta^-$ )Na23(n,X)H3				53.1 32.1 8.6 2.6 0.9
Si32	330 y	Mg26(n, $\gamma$ )Mg27( $\beta^-$ )Al27(n, $\gamma$ )Al28( $\beta^-$ )Si28(n, $\gamma$ ) Si29(n, $\gamma$ )Si30(n, $\gamma$ )Si31(n, $\gamma$ )Si32	99.8			
C14	5730 y	Mg24(n, $\alpha$ )Ne20(n, $\alpha$ )O17(n, $\alpha$ )C14 Mg24(n, $\alpha$ )Ne21(n, $\alpha$ )O18(n, $\alpha$ )C14 Mg24(n, $\alpha$ )Ne21(n, $\alpha$ )O17(n, $\alpha$ )C14 Mg25(n, $\alpha$ )Ne21(n, $\alpha$ )O18(n, $\alpha$ )C14 Mg24(n, $\alpha$ )Ne21(n, $\alpha$ )O18(n,2n)O17(n, $\alpha$ )C14				43.2 39.4 11.1 1.1 1.4
Cl36	$3.1 \cdot 10^5$ y	Mg26(n, $\gamma$ )Mg27( $\beta^-$ )Al27(n, $\gamma$ )Al28( $\beta^-$ )Si28(n, $\gamma$ ) Si29(n, $\gamma$ )Si30(n, $\gamma$ )Si31( $\beta^-$ )P31(n, $\gamma$ )P32( $\beta^-$ )S32(n, $\gamma$ ) S33(n, $\gamma$ )S34(n, $\gamma$ )S35( $\beta^-$ )Cl35(n, $\gamma$ )Cl36	94.6			
Al26	$7.2 \cdot 10^5$ y	Mg26(n, $\gamma$ )Mg27( $\beta^-$ )Al27(n,2n)Al26				99.9
Be10	$1.6 \cdot 10^6$ y	Mg24(n, $\alpha$ )Ne20(n, $\alpha$ )O16(n, $\alpha$ )C13(n, $\alpha$ )Be10 Mg24(n, $\alpha$ )Ne20(n, $\alpha$ )O17(n, $\alpha$ )C13(n, $\alpha$ )Be10 Mg24(n, $\alpha$ )Ne21(n, $\alpha$ )O17(n, $\alpha$ )C13(n, $\alpha$ )Be10				89.5 5.3 1.4

# Magnesium activation characteristics

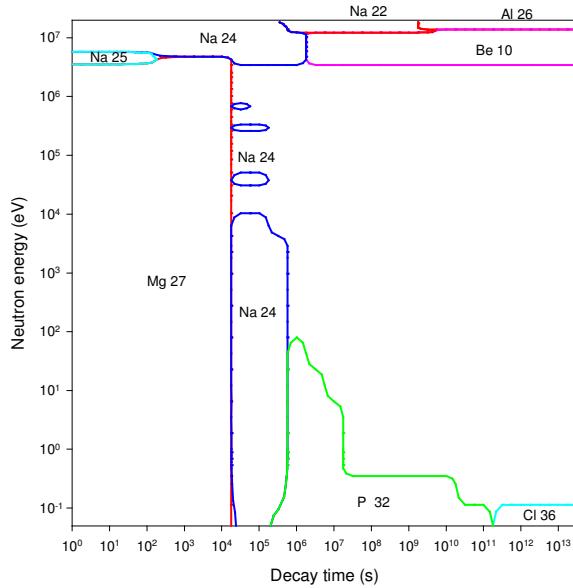


# Magnesium importance diagrams & transmutation

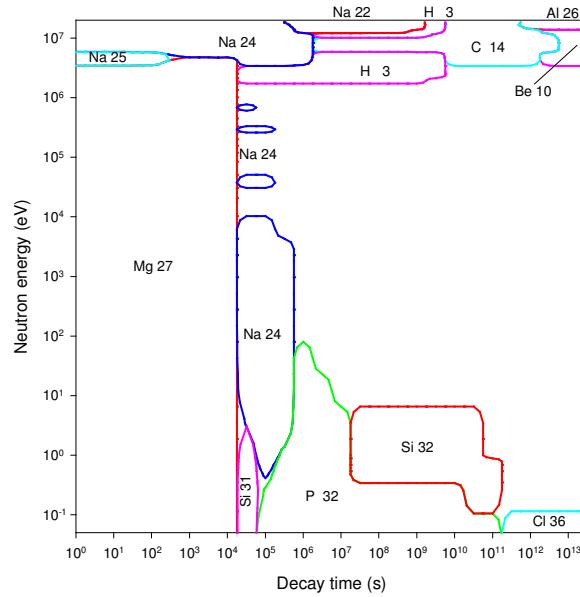
## Activity



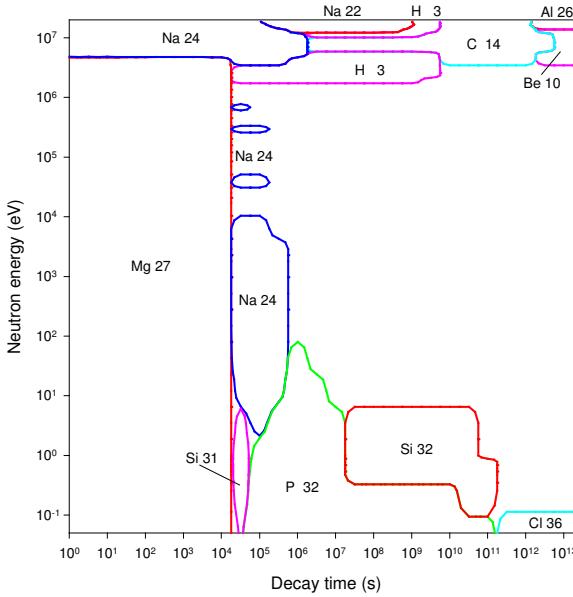
## Dose rate



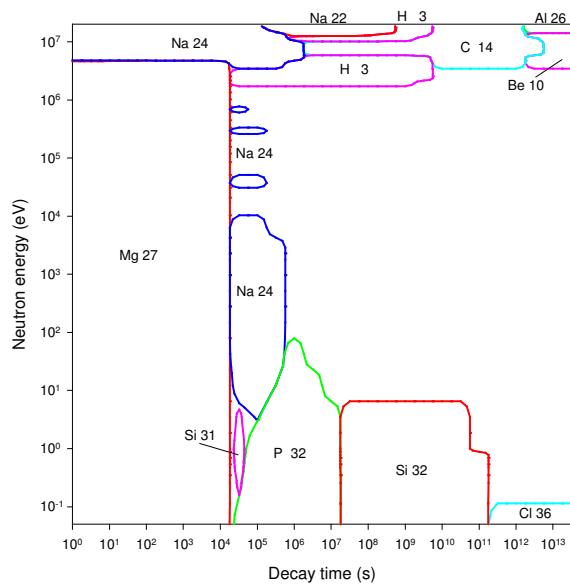
## Heat output



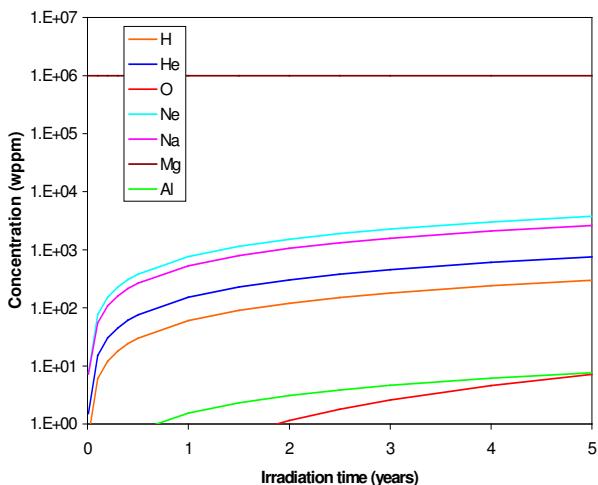
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Aluminium

## General properties

		13 8.20 10 <sup>4</sup> 933.5 2740 2698 237 2.655 10 <sup>2</sup> 2.303 10 <sup>-5</sup>	Isotopes Al27	Isotopic abundances / %	
Atomic number	13			100.0	
Crustal abundance / wppm	8.20 10 <sup>4</sup>				
Melting point / K	933.5				
Boiling point / K	2740				
Density / kgm <sup>-3</sup>	2698				
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	237				
Electrical resistivity / Ωm	2.655 10 <sup>2</sup>				
Coefficient of thermal expansion / K <sup>-1</sup>	2.303 10 <sup>-5</sup>				
Crystal structure	FCC				
Number of stable isotopes	1				
Mean atomic weight	26.98154				

## Activation properties

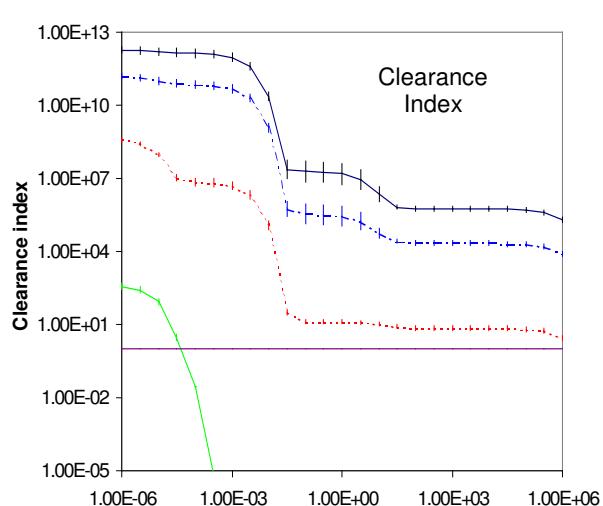
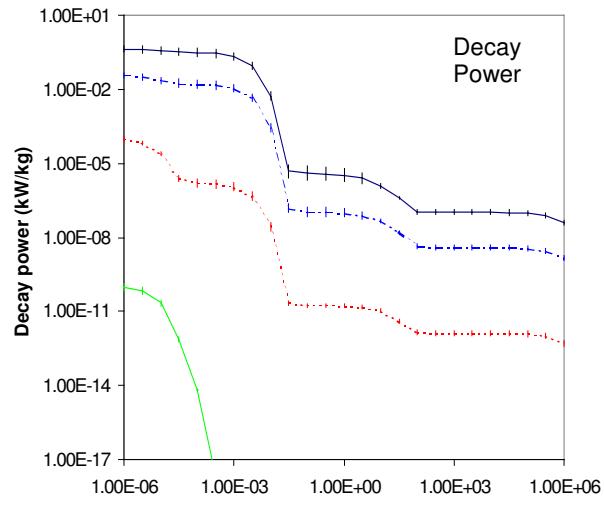
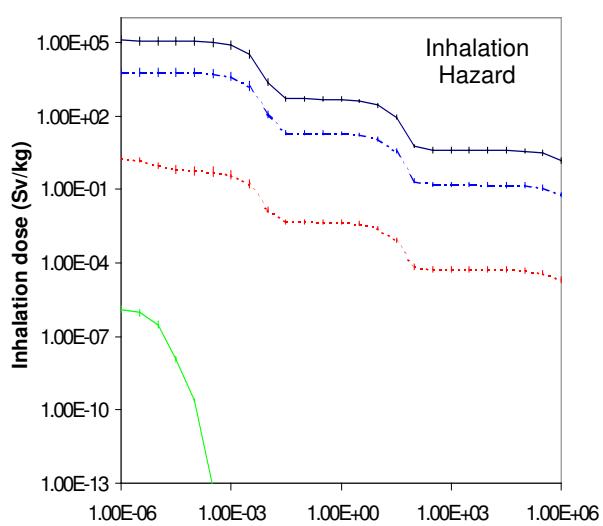
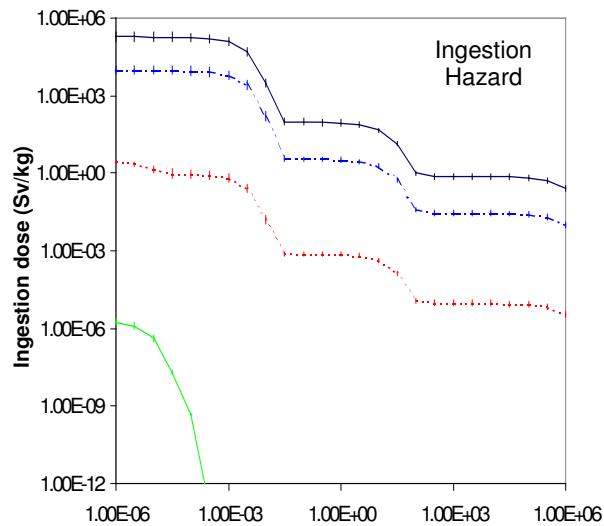
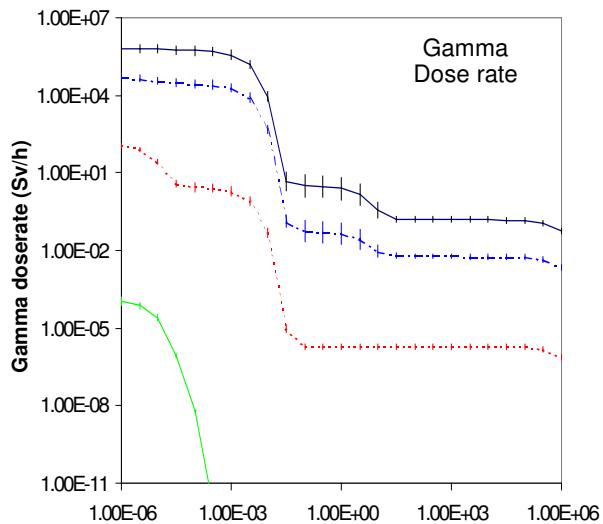
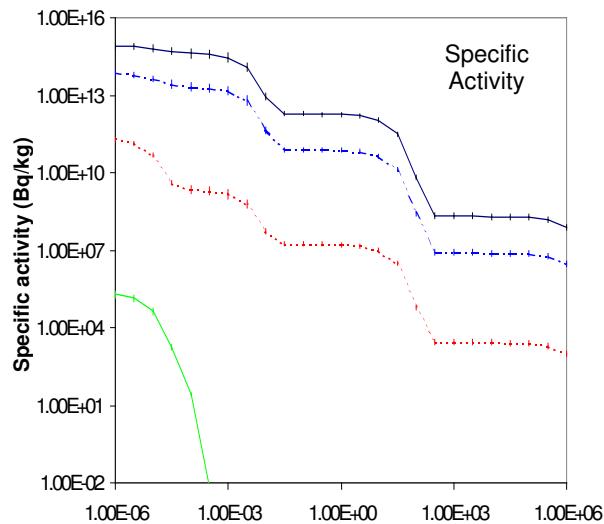
Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	9.40E14	6.47E14	9.23E12	1.78E12	6.99E9	1.87E8	kW kg <sup>-1</sup>	4.44E-1	3.78E-1	5.51E-3	3.35E-6	1.09E-7	9.36E-8
Na24	45.34	65.63	79.63				Na24	71.88	84.19	99.93			
Mg27	32.15	31.78					Mg27	17.38	13.90				
Na24m	14.08						Al28	8.26	1.91				
Al28	8.06	2.30					Na24m	2.31					
H3	0.20	0.29	20.31	99.75	97.06		Al26m	0.07					
Al26m	0.09						Na22			0.04	48.45		
Al26	0.01	0.02	1.09	0.01	2.94	100.0	H3			0.03	48.47	5.68	
Na22			0.06	0.24			Al26				3.08	94.32	100.0
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	6.80E5	6.08E5	9.57E3	2.48E0	1.53E-1	1.39E-1	Sv kg <sup>-1</sup>	1.89E5	1.86E5	3.26E3	8.87E1	1.01E0	6.55E-1
Na24	81.61	90.83	99.97				Na24	96.71	97.89	97.02			
Mg27	10.27	7.81					Mg27	2.87	1.98				
Al28	6.22	1.37					Al28	0.37	0.07				
Na24m	1.85						H3	0.04	0.04	2.42	83.95	28.34	
Na22			0.03	93.82			Na22	0.01	0.01	0.54	15.54		
Al26				6.18	100.0	100.0	Al26			0.02	0.81	71.66	100.0
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	1.19E5	1.17E5	2.48E3	4.71E2	5.88E0	3.74E0		1.93E12	1.65E12	2.45E10	1.52E7	5.59E5	5.05E5
Na24	96.82	97.87	79.92				Na24	73.48	85.80	99.92			
Mg27	2.34	1.62					Mg27	15.63	12.46				
Al28	0.42	0.08					Al28	7.54	1.74				
H3	0.41	0.42	19.63	97.96	30.00		Na24m	3.26					
Na22	0.01	0.01	0.29	1.17			Na22			0.08	92.47		
Al26			0.17	0.88	70.00	100.0	H3				3.88	0.41	
							Al26				3.65	99.60	100.0

# Aluminium

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Al28	2.242 m	Al27(n, $\gamma$ )Al28	100.0	100.0	100.0	95.4
Mg27	9.46 m	Al27(n,p)Mg27				100.0
Si31	2.62 h	Al27(n, $\gamma$ )Al28( $\beta^-$ )Si28(n, $\gamma$ )Si29(n, $\gamma$ )Si30(n, $\gamma$ )Si31	100.0	100.0	100.0	98.7
Na24	14.96 h	&Al27(n, $\alpha$ )Na24				96.6
P32	14.27 d	Al27(n, $\gamma$ )Al28( $\beta^-$ )Si28(n, $\gamma$ )Si29(n, $\gamma$ )Si30(n, $\gamma$ ) Si31( $\beta^-$ )P31(n, $\gamma$ )P32 Al27(n, $\gamma$ )Al28( $\beta^-$ )Si28(n, $\gamma$ )Si29(n, $\gamma$ )Si30(n, $\gamma$ ) Si31(n, $\gamma$ )Si32( $\beta^-$ )P32	100.0	100.0	99.5 0.5	98.6
Na22	2.60 y	Al27(n,2n)Al26(n,n $\alpha$ )Na22 Al27(n,n $\alpha$ )Na23(n,2n)Na22 Al27(n, $\alpha$ )Na24( $\beta^-$ )Mg24(n,d)Na23(n,2n)Na22				82.4 15.5 0.8
H3	12.33 y	Al27(n,X)H3 Al27(n,n $\alpha$ )Na23(n,X)H3				99.0 0.3
Si32	330 y	Al27(n, $\gamma$ )Al28( $\beta^-$ )Si28(n, $\gamma$ )Si29(n, $\gamma$ )Si30(n, $\gamma$ )Si31(n, $\gamma$ ) Si32	100.0	100.0	100.0	
C14	5730 y	&Al27(n, $\alpha$ )Na24( $\beta^-$ )Mg24(n,n $\alpha$ )Ne20(n, $\alpha$ )O17(n, $\alpha$ )C14 &Al27(n, $\alpha$ )Na24( $\beta^-$ )Mg24(n, $\alpha$ )Ne21(n, $\alpha$ )O18(n,n $\alpha$ )C14 &Al27(n, $\alpha$ )Na24( $\beta^-$ )Mg24(n, $\alpha$ )Ne21(n,n $\alpha$ )O17(n, $\alpha$ )C14 Al27(n,n $\alpha$ )Na23(n, $\alpha$ )F20( $\beta^-$ )Ne20(n, $\alpha$ )O17(n, $\alpha$ )C14 Al27(n,2n)Al26(n,n $\alpha$ )Na22(n,n $\alpha$ )F18( $\beta^+$ )O18(n,n $\alpha$ )C14 Al27(n,n $\alpha$ )Na23(n,n $\alpha$ )F19(n,n $\alpha$ )N15(n,d)C14 Al27(n,n $\alpha$ )Na23(n,n $\alpha$ )F19(n,d)O18(n, $\alpha$ )C14 Al27(n,2n)Al26(n,n $\alpha$ )Na22(n,n $\alpha$ )F18( $\beta^+$ )O18(n,n $\alpha$ )C14				36.2 33.1 9.3 7.8 3.9 2.1 1.5 1.2
Cl36	$3.0 \cdot 10^5$ y	Al27(n, $\gamma$ )Al28( $\beta^-$ )Si28(n, $\gamma$ )Si29(n, $\gamma$ )Si30(n, $\gamma$ )Si31( $\beta^-$ ) P31(n, $\gamma$ )P32( $\beta^-$ )S32(n, $\gamma$ )S33(n, $\gamma$ )S34(n, $\gamma$ )S35( $\beta^-$ )Cl35(n, $\gamma$ ) Cl36	95.1			
Al26	$7.2 \cdot 10^5$ y	Al27(n,2n)Al26				99.5
Be10	$1.6 \cdot 10^6$ y	&Al27(n, $\alpha$ )Na24( $\beta^-$ )Mg24(n,n $\alpha$ )Ne20(n,n $\alpha$ )O16(n, $\alpha$ ) C13(n, $\alpha$ )Be10 Al27(n,n $\alpha$ )Na23(n, $\alpha$ )F20( $\beta^-$ )Ne20(n,n $\alpha$ )O16(n, $\alpha$ ) C13(n, $\alpha$ )Be10 &Al27(n, $\alpha$ )Na24( $\beta^-$ )Mg24(n,n $\alpha$ )Ne20(n, $\alpha$ )O17(n,n $\alpha$ ) C13(n, $\alpha$ )Be10 &Al27(n, $\alpha$ )Na24( $\beta^-$ )Mg24(n, $\alpha$ )Ne21(n,n $\alpha$ )O17(n,n $\alpha$ ) C13(n, $\alpha$ )Be10			73.3 15.8 4.3 1.1	

# Aluminium activation characteristics

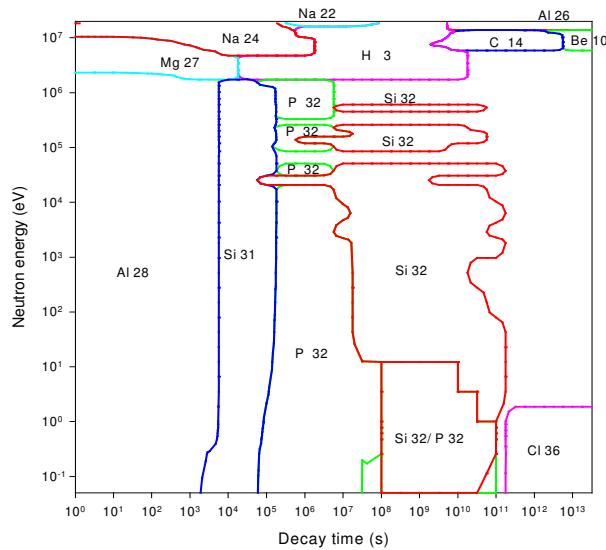


Decay time (years)

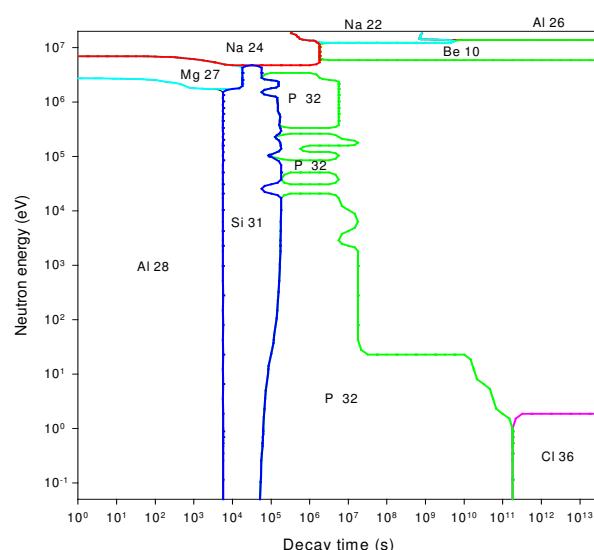
Decay time (years)

# Aluminium importance diagrams & transmutation

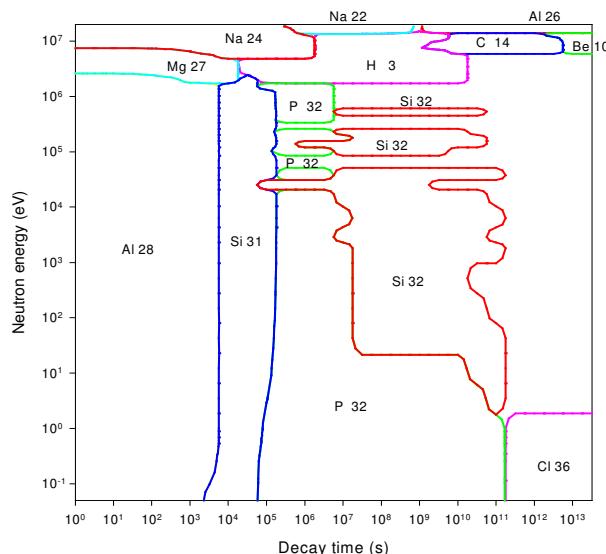
## Activity



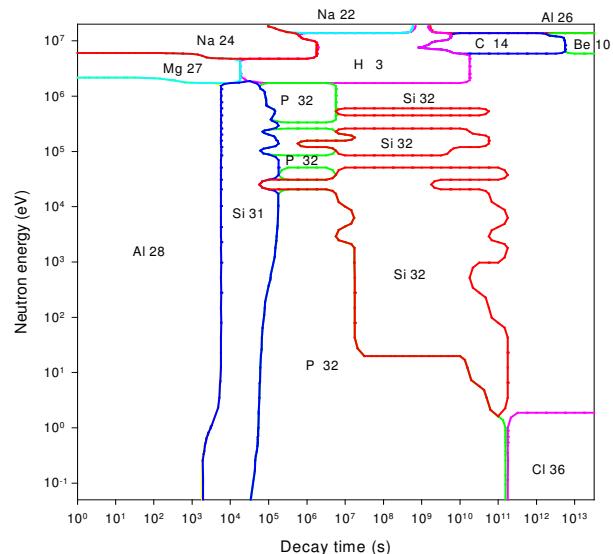
## Dose rate



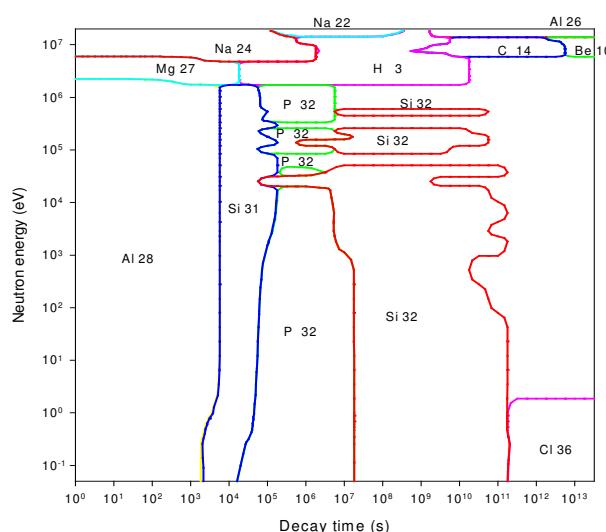
## Heat output



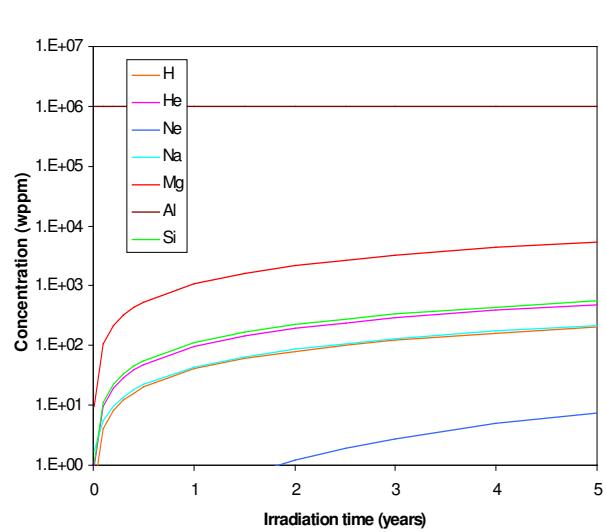
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Silicon

## General properties

Atomic number	14	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	2.77 10 <sup>5</sup>	Si28	92.230
Melting point / K	1683	Si29	4.683
Boiling point / K	2628	Si30	3.087
Density / kgm <sup>-3</sup>	2329		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	148		
Electrical resistivity /Ωm	1.0 10 <sup>-3</sup>		
Coefficient of thermal expansion / K <sup>-1</sup>	4.2 10 <sup>-6</sup>		
Crystal structure	cubic		
Number of stable isotopes	3		
Mean atomic weight	28.0855		

## Activation properties

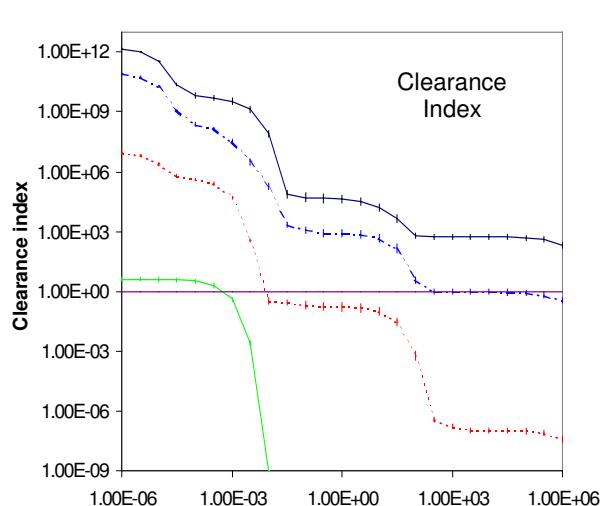
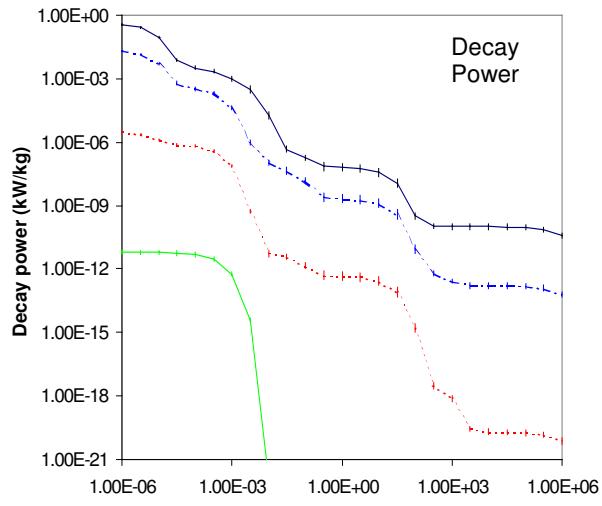
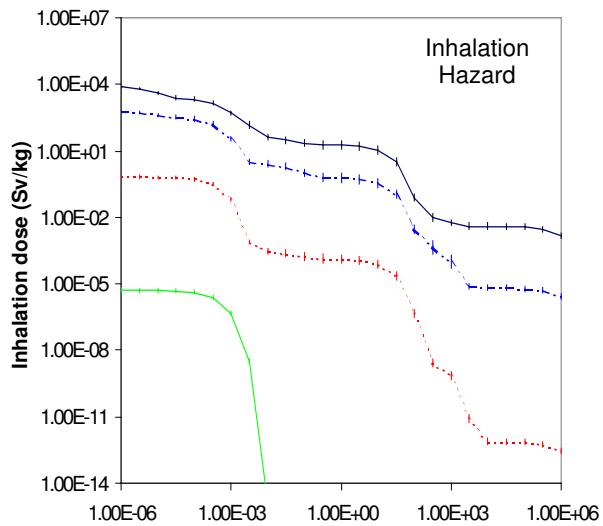
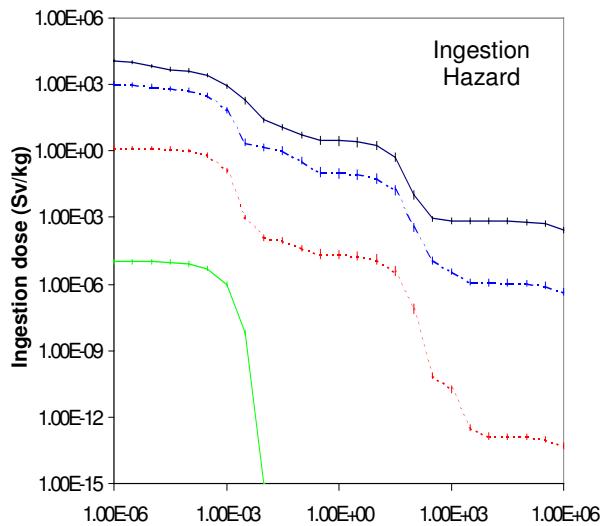
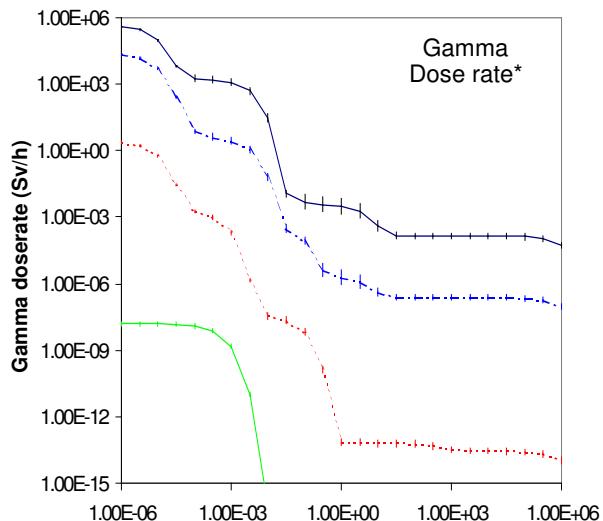
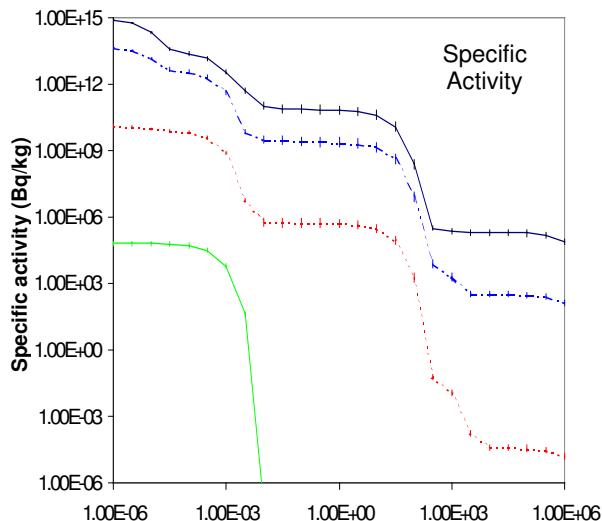
Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	9.29E14	2.15E14	1.03E11	6.83E10	2.62E8	1.85E5	kW kg <sup>-1</sup>	4.37E-1	9.18E-2	1.97E-5	6.48E-8	3.51E-10	9.24E-11
Al28	93.16	79.14					Al28	95.73	89.66				
Si31	2.87	12.13					Al29	1.86	5.07				
Al29	2.32	5.74					Al30	1.08					
Mg27	0.77	2.25					Si31	0.58	2.71				
Al30	0.55						Mg27	0.42	1.35				
Na24	0.16	0.68	24.73				Na24	0.25	1.20	96.80			
Na25	0.12	0.01					P32			2.85	0.02	2.73	
H3	0.01	0.03	70.36	99.99	99.86		H3			0.34	96.44	68.06	
P32			4.91		0.03		Na22			0.02	3.38		
Al26					0.08	100.0	Al26				0.16	28.96	100.0
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	4.84E5	9.93E4	3.19E1	3.18E-3	1.46E-4	1.33E-4	Sv kg <sup>-1</sup>	1.35E4	6.73E3	2.61E1	2.89E0	1.20E-2	6.46E-4
Al28	96.38	92.23					Al28	59.13	23.25				
Al29	1.73	4.82					Si31	31.71	61.98				
Al30	1.15						Na24	4.70	9.37	41.88			
Na24	0.38	1.85	99.98				Al29	3.36	3.85				
Mg27	0.33	1.09					Mg27	0.95	1.30				
Na25	0.02						P32	0.11	0.22	46.39	0.01	1.73	
Na22			0.01	95.41			H3	0.02	0.05	11.64	99.33	91.91	
Al26				4.59	99.99	100.0	Al26				0.03	5.95	100.0
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	8.65E3	3.85E3	4.28E1	1.78E1	8.19E-2	3.69E-3		1.73E12	3.57E11	8.47E7	4.24E4	6.38E2	4.99E2
Al28	66.05	29.18					Al28	96.24	91.72				
Si31	24.38	53.54					Al29	1.83	5.09				
Na24	4.60	10.29	16.02				Al30	1.09					
Al29	3.73	4.81					Mg27	0.41	1.36				
Mg27	0.76	1.16					Na24	0.28	1.37	99.92			
P32	0.24	0.53	40.03		0.36		Si31	0.10	0.46				
H3	0.22	0.49	43.89	99.87	83.09		Na22			0.03	44.93		
Si32				0.03	0.07	11.58	H3			0.03	53.77	13.68	
Al26			0.01	0.02	4.97	100.0	Al26				1.30	86.19	100.0

# Silicon

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Al28	2.242 m	Si28(n,p)Al28 Si29(n,2n)Si28(n,p)Al28 Si29(n,d)Al28				99.3 0.3 0.3
Al29	6.56 m	Si29(n,p)Al29 Si30(n,d)Al29 Si30(n,2n)Si29(n,p)Al29 Si28(n, $\gamma$ )Si29(n,p)Al29				95.9 2.1 1.7 0.2
Si31	2.62 h	Si30(n, $\gamma$ )Si31 Si29(n, $\gamma$ )Si30(n, $\gamma$ )Si31	98.8 1.1	100.0	98.9 1.1	97.7
Na24	14.96 h	&Si28(n,d)Al27(n, $\alpha$ )Na24 &Si28(n, $\alpha$ )Mg25(n,d)Na24 &Si28(n,n $\alpha$ )Mg24(n,p)Na24 &Si28(n, $\alpha$ )Mg25(n,2n)Mg24(n,p)Na24 &Si30(n, $\alpha$ )Mg27( $\beta^-$ )Al27(n, $\alpha$ )Na24				53.1 23.7 12.3 6.2 0.9
P32	14.27 d	Si30(n, $\gamma$ )Si31( $\beta^-$ )P31(n, $\gamma$ )P32 Si29(n, $\gamma$ )Si30(n, $\gamma$ )Si31( $\beta^-$ )P31(n, $\gamma$ )P32 Si30(n, $\gamma$ )Si31(n, $\gamma$ )Si32( $\beta^-$ )P32	99.4 0.5	100.0	99.0 0.5 0.5	97.9
Na22	2.60 y	Si28(n,d)Al27(n,2n)Al26(n,n $\alpha$ )Na22 Si28(n,n $\alpha$ )Mg24(n,d)Na23(n,2n)Na22 Si28(n,d)Al27(n,n $\alpha$ )Na23(n,2n)Na22 Si28(n, $\alpha$ )Mg25(n,2n)Mg24(n,d)Na23(n,2n)Na22 Si29(n, $\alpha$ )Mg26(n, $\alpha$ )Ne23( $\beta^-$ )Na23(n,2n)Na22 Si28(n, $\alpha$ )Mg25(n,t)Na23(n,2n)Na22				58.1 19.3 10.8 5.2 1.4 1.2
H3	12.33 y	Si29(n,X)H3 Si28(n,d)Al27(n,X)H3 Si28(n, $\alpha$ )Mg25(n,X)H3				72.0 15.3 10.2
Si32	330 y	Si30(n, $\gamma$ )Si31(n, $\gamma$ )Si32 Si29(n, $\gamma$ )Si30(n, $\gamma$ )Si31(n, $\gamma$ )Si32 Si30(n, $\gamma$ )Si31( $\beta^-$ )P31(n, $\gamma$ )P32(n,p)Si32	99.4 0.5	100.0	99.5 0.5	72.1 26.5
C14	5730 y	Si28(n, $\alpha$ )Mg25(n,n $\alpha$ )Ne21(n, $\alpha$ )O18(n,n $\alpha$ )C14 Si28(n,n $\alpha$ )Mg24(n,n $\alpha$ )Ne20(n, $\alpha$ )O17(n, $\alpha$ )C14 Si28(n,n $\alpha$ )Mg24(n, $\alpha$ )Ne21(n, $\alpha$ )O18(n,n $\alpha$ )C14 Si28(n, $\alpha$ )Mg25(n,n $\alpha$ )Ne21(n,n $\alpha$ )O17(n, $\alpha$ )C14 Si28(n,n $\alpha$ )Mg24(n, $\alpha$ )Ne21(n,n $\alpha$ )O17(n, $\alpha$ )C14 Si28(n, $\alpha$ )Mg25(n, $\alpha$ )Ne22(n,n $\alpha$ )O18(n,n $\alpha$ )C14 Si28(n, $\alpha$ )Mg25(n,2n)Mg24(n,n $\alpha$ )Ne20(n, $\alpha$ )O17(n, $\alpha$ )C14 Si28(n, $\alpha$ )Mg25(n,2n)Mg24(n, $\alpha$ )Ne21(n, $\alpha$ )O18(n,n $\alpha$ )C14 Si28(n, $\alpha$ )Mg25(n, $\alpha$ )Ne22(n,2n)Ne21(n, $\alpha$ )O18(n,n $\alpha$ )C14				31.9 18.2 16.6 9.0 4.7 3.7 3.7 3.4 1.3
Cl36	$3.02 \cdot 10^5$ y	Si30(n, $\gamma$ )Si31( $\beta^-$ )P31(n, $\gamma$ )P32( $\beta^-$ )S32(n, $\gamma$ )S33(n, $\gamma$ ) S34(n, $\gamma$ )S35( $\beta^-$ )Cl35(n, $\gamma$ )Cl36 Si30(n, $\gamma$ )Si31( $\beta^-$ )P31(n, $\gamma$ )P32(n, $\gamma$ )P33( $\beta^-$ )S33(n, $\gamma$ )S34(n, $\gamma$ ) S35( $\beta^-$ )Cl35(n, $\gamma$ )Cl36	96.5 3.2	96.3 3.4		
Al26	$7.2 \cdot 10^5$ y	Si28(n,d)Al27(n,2n)Al26 Si30(n, $\alpha$ )Mg27( $\beta^-$ )Al27(n,2n)Al26				96.6 1.6
Be10	$1.6 \cdot 10^6$ y	Si28(n,n $\alpha$ )Mg24(n,n $\alpha$ )Ne20(n,n $\alpha$ )O16(n, $\alpha$ )C13(n, $\alpha$ )Be10 Si28(n, $\alpha$ )Mg25(n,2n)Mg24(n,n $\alpha$ )Ne20(n,n $\alpha$ )O16(n, $\alpha$ )C13(n, $\alpha$ )Be10 Si28(n,n $\alpha$ )Mg24(n,n $\alpha$ )Ne20(n, $\alpha$ )O17(n,n $\alpha$ )C13(n, $\alpha$ )Be10 Si28(n, $\alpha$ )Mg25(n,n $\alpha$ )Ne21(n,n $\alpha$ )O17(n,n $\alpha$ )C13(n, $\alpha$ )Be10 Si28(n,n $\alpha$ )Mg24(n, $\alpha$ )Ne21(n,n $\alpha$ )O17(n,na)C13(n, $\alpha$ )Be10				71.5 12.2 4.2 2.1 1.1

# Silicon activation characteristics

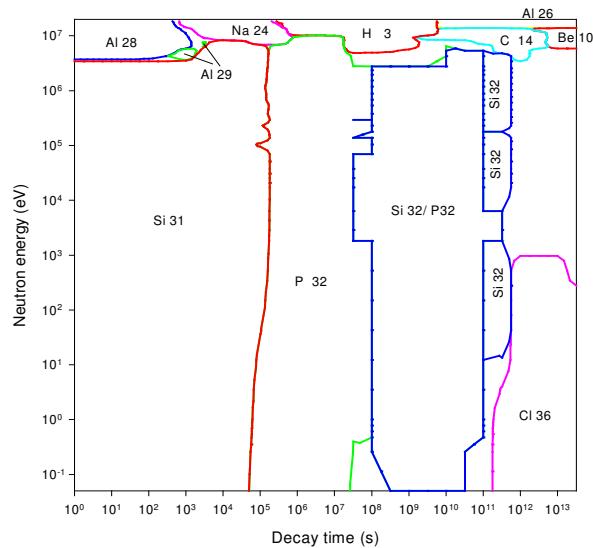


Decay time (years)

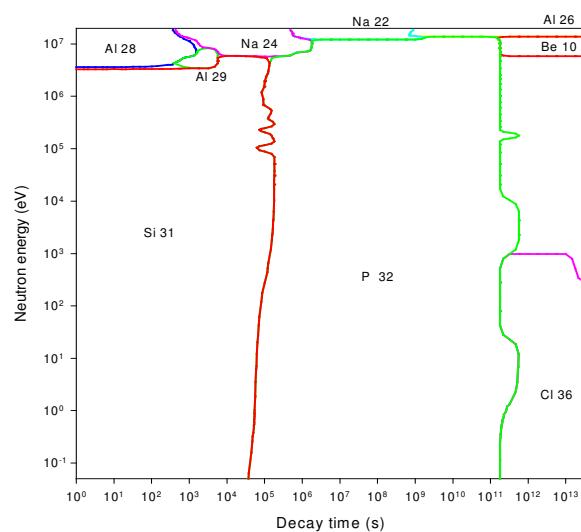
Decay time (years)

# Silicon importance diagrams & transmutation

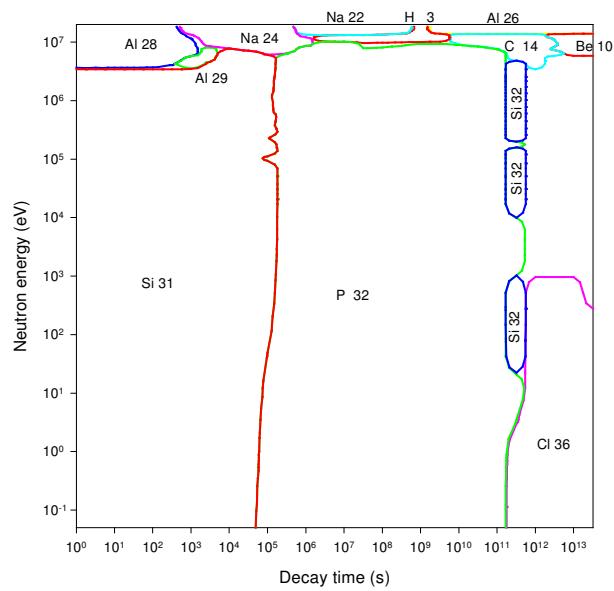
## Activity



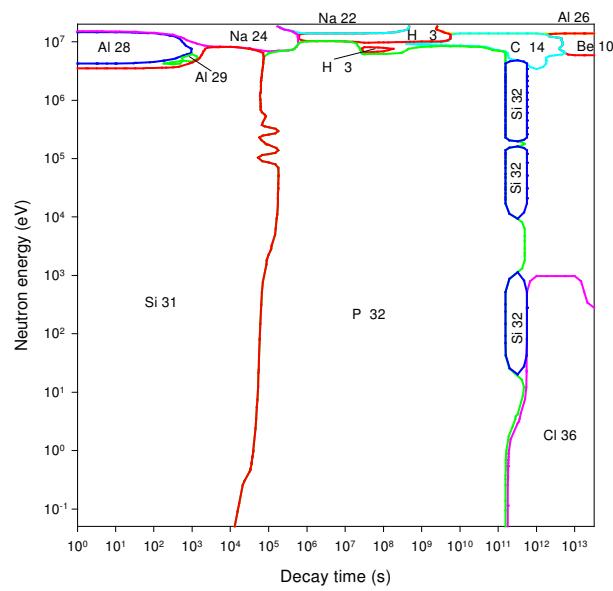
## Dose rate



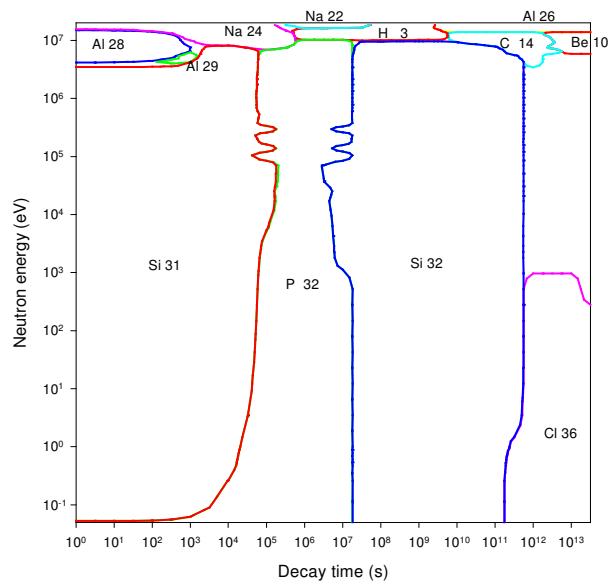
## Heat output



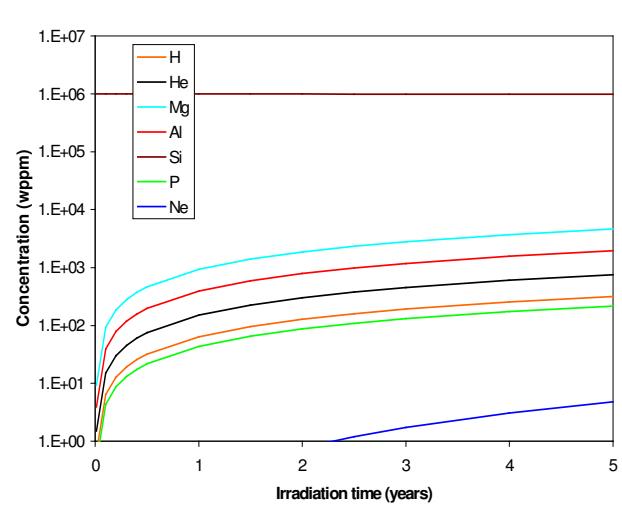
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Phosphorus

## General properties

		15 1.00 10 <sup>3</sup> 317.3 553 1820 2.35 10 <sup>-1</sup> 1.0 10 <sup>9</sup> 1.245 10 <sup>-4</sup> cubic 1 30.973761	Isotopes P31	Isotopic abundances / %	
Atomic number	Crustal abundance / wppm			100.0	
Melting point / K					
Boiling point / K					
Density / kgm <sup>-3</sup>					
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>					
Electrical resistivity / Ωm					
Coefficient of thermal expansion / K <sup>-1</sup>					
Crystal structure					
Number of stable isotopes					
Mean atomic weight					

## Activation properties

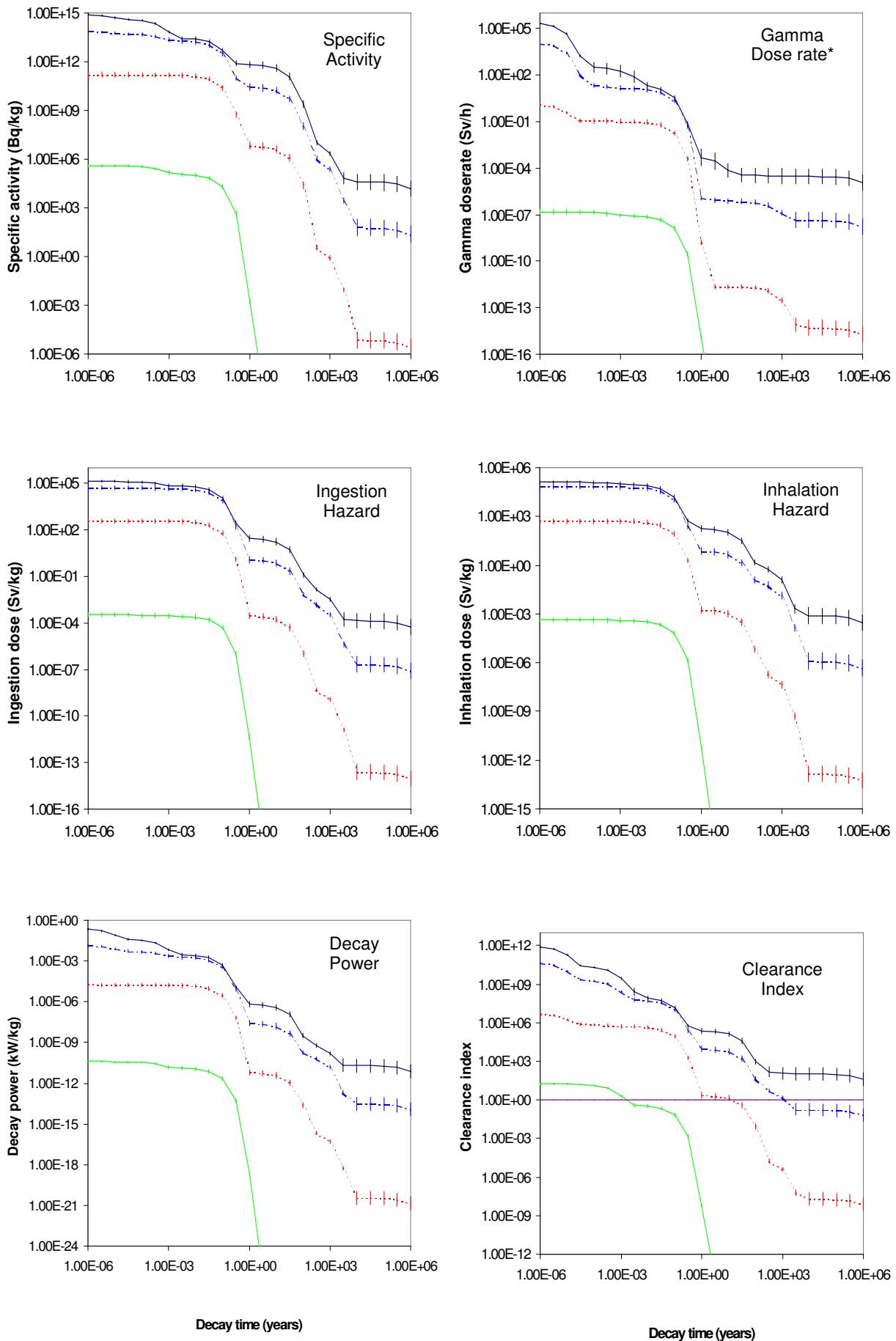
Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	8.72E14	5.10E14	2.42E13	6.84E11	2.63E9	3.64E4	kW kg <sup>-1</sup>	2.54E-1	8.27E-2	2.62E-3	6.27E-7	3.32E-9	1.82E-11
Al28	48.26	16.24					Al28	80.37	48.43				
Si31	46.11	77.12					Si31	15.15	45.38				
P32	3.22	5.50	97.00		0.28		P30	2.92	2.08				
P30	2.15	0.86					P32	1.23	3.78	99.89	0.17	25.05	
Mg27	0.09	0.10					H3			0.03	99.76	72.02	
H3	0.08	0.14	2.99	100.0	99.43		Si32				0.02	2.33	
Al26					100.0		Al26					0.60	100.0
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	2.38E5	4.71E4	2.04E1	4.71E-4	3.49E-5	2.69E-5	Sv kg <sup>-1</sup>	1.36E5	1.31E5	5.64E4	2.88E1	1.32E-1	1.27E-4
Al28	97.92	97.13					P32	49.57	51.35	99.94	0.08	13.58	
P30	1.62	1.90					Si31	47.38	47.96				
Na24	0.09	0.45	18.2				Al28	2.85	0.58				
P32		0.01	82.8*	1.47*	15.21*		H3	0.02	0.02	0.05	99.89	83.15	
Na22				92.24			Si32				0.02	3.17	
Al26				6.29	84.79	100.0	Al26					0.11	100.0
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	1.31E5	1.27E5	8.01E4	1.79E2	1.53E0	7.28E-4		8.60E11	1.90E11	8.82E7	2.31E5	1.06E3	9.84E1
P32	73.07	74.93	99.76	0.02	1.66		Al28	94.14	83.75				
Si31	24.34	24.39					Si31	2.92	12.93				
Al28	2.13	0.43					P30	2.54	2.67				
P30	0.27	0.07					Na24	0.07	0.29	10.88			
H3	0.14	0.15	0.24	99.41	44.50		P32	0.01	0.05	88.84	0.01	2.36	
Na24	0.04	0.04					H3			0.27	98.77	82.65	
Si32				0.57	53.79		Al26				0.05	10.26	100.0
Al26					0.05	100.0	Si32				0.03	4.72	

# Phosphorus

## Pathway analysis

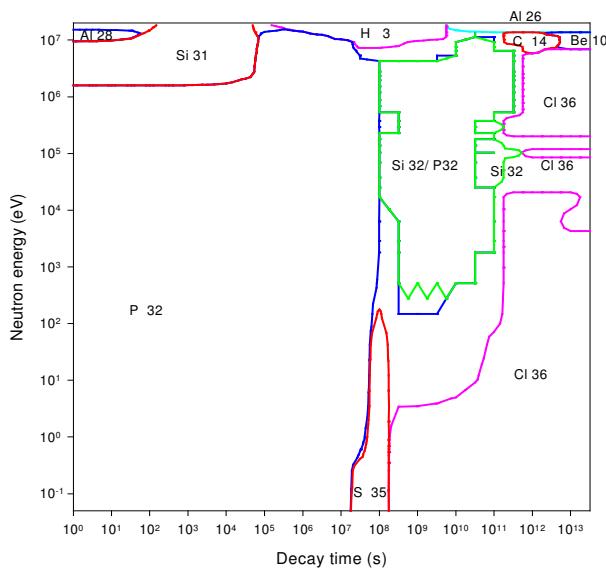
Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Al28	2.24 m	P31(n, $\alpha$ )Al28				95.1
P30	2.50 m	P31(n,2n)P30				98.7
Si31	2.62 h	P31(n, $\gamma$ )P32( $\beta^-$ )S32(n, $\gamma$ )S33(n, $\alpha$ )Si30(n, $\gamma$ )Si31 P31(n, $\gamma$ )P32(n, $\gamma$ )P33( $\beta^-$ )S33(n, $\alpha$ )Si30(n, $\gamma$ )Si31 P31(n,p)Si31 P31(n, $\gamma$ )P32( $\beta^-$ )S32(n, $\alpha$ )Si29(n, $\gamma$ )Si30(n, $\gamma$ )Si31	97.6 1.7 0.7	97.5 1.7 0.7	17.9 1.1 81.0	100.0
Na24	14.96 h	&P31(n,n $\alpha$ )Al27(n, $\alpha$ )Na24 &P31(n, $\alpha$ )Al28( $\beta^-$ )Si28(n,d)Al27(n, $\alpha$ )Na24 &P31(n,d)Si30(n, $\alpha$ )Mg27( $\beta^-$ )Al27(n, $\alpha$ )Na24 &P31(n, $\alpha$ )Al28( $\beta^-$ )Si28(n, $\alpha$ )Mg25(n,d)Na24				89.7 3.3 1.9 1.5
P32	14.27 d	P31(n, $\gamma$ )P32	100.0	100.0	100.0	95.5
S35	87.5 d	P31(n, $\gamma$ )P32( $\beta^-$ )S32(n, $\gamma$ )S33(n, $\gamma$ )S34(n, $\gamma$ )S35 P31(n, $\gamma$ )P32(n, $\gamma$ )P33( $\beta^-$ )S33(n, $\gamma$ )S34(n, $\gamma$ )S35 P31(n, $\gamma$ )P32(n, $\gamma$ )P33(n, $\gamma$ )P34( $\beta^-$ )S34(n, $\gamma$ )S35	97.7 1.8	98.1 1.9	92.6 5.9 1.5	95.1 3.2 0.1
Na22	2.60 y	P31(n,n $\alpha$ )Al27(n,2n)Al26(n,n $\alpha$ )Na22 P31(n,n $\alpha$ )Al27(n,n $\alpha$ )Na23(n,2n)Na22 P31(n, $\alpha$ )Al28( $\beta^-$ )Si28(n,d)Al27(n,2n)Al26(n,n $\alpha$ )Na22				79.6 14.9 1.5
H3	12.33 y	P31(n,X)H3				98.4
Si32	330 y	P31(n, $\gamma$ )P32(n,p)Si32 P31(n, $\gamma$ )P32( $\beta^-$ )S32(n, $\gamma$ )S33(n, $\alpha$ )Si30(n, $\gamma$ )Si31(n, $\gamma$ )Si32 P31(n,p)Si31(n, $\gamma$ )Si32	72.2 27.8	100.0	100.0	96.8 1.8
C14	5730 y	P31(n, $\alpha$ )Al28( $\beta^-$ )Si28(n, $\alpha$ )Mg25(n,n $\alpha$ )Ne21(n, $\alpha$ )O18(n,n $\alpha$ )C14 &P31(n,n $\alpha$ )Al27(n, $\alpha$ )Na24( $\beta^-$ )Mg24(n,n $\alpha$ )Ne20(n, $\alpha$ )O17(n, $\alpha$ )C14 &P31(n,n $\alpha$ )Al27(n, $\alpha$ )Na24( $\beta^-$ )Mg24(n, $\alpha$ )Ne21(n, $\alpha$ )O18(n,n $\alpha$ )C14 P31(n, $\alpha$ )Al28( $\beta^-$ )Si28(n,n $\alpha$ )Mg24(n,n $\alpha$ )Ne20(n, $\alpha$ )O17(n, $\alpha$ )C14 P31(n, $\alpha$ )Al28( $\beta^-$ )Si28(n,n $\alpha$ )Mg24(n, $\alpha$ )Ne21(n, $\alpha$ )O18(n,n $\alpha$ )C14 P31(n, $\alpha$ )Al28( $\beta^-$ )Si28(n,n $\alpha$ )Mg25(n,n $\alpha$ )Ne21(n,n $\alpha$ )O17(n, $\alpha$ )C14 &P31(n,n $\alpha$ )Al27(n, $\alpha$ )Na24( $\beta^-$ )Mg24(n, $\alpha$ )Ne21(n,n $\alpha$ )O17(n, $\alpha$ )C14 P31(n,n $\alpha$ )Al27(n,n $\alpha$ )Na23(n, $\alpha$ )F20( $\beta^-$ )Ne20(n, $\alpha$ )O17(n, $\alpha$ )C14 P31(n,n $\alpha$ )Al27(n, $\alpha$ )Na24( $\beta^-$ )Mg24(n, $\alpha$ )Ne21(n,n $\alpha$ )O17(n, $\alpha$ )C14 P31(n, $\alpha$ )Al28( $\beta^-$ )Si28(n,n $\alpha$ )Mg24(n, $\alpha$ )Ne21(n,n $\alpha$ )O17(n, $\alpha$ )C14 P31(n, $\alpha$ )Al28( $\beta^-$ )Si28(n,n $\alpha$ )Mg25(n,n $\alpha$ )Ne22(n,n $\alpha$ )O18(n,n $\alpha$ )C14 P31(n, $\alpha$ )Al28( $\beta^-$ )Si28(n,n $\alpha$ )Mg25(n,2n)Mg24(n,n $\alpha$ )Ne20(n, $\alpha$ )O17(n, $\alpha$ )C14 P31(n, $\alpha$ )Al28( $\beta^-$ )Si28(n,n $\alpha$ )Mg25(n,2n)Mg24(n, $\alpha$ )Ne21(n, $\alpha$ )O18(n,n $\alpha$ )C14 P31(n,n $\alpha$ )Al27(n,n $\alpha$ )Na23(n,n $\alpha$ )F19(n,n $\alpha$ )N15(n,d)C14				17.7 16.8 15.3 10.1 9.2 5.0 4.3 3.6 3.0 2.6 2.0 1.7 1.6 1.0
Cl36	$3.0 \cdot 10^5$ y	P31(n, $\gamma$ )P32( $\beta^-$ )S32(n, $\gamma$ )S33(n, $\gamma$ )S34(n, $\gamma$ )S35( $\beta^-$ ) Cl35(n, $\gamma$ )Cl36 P31(n, $\gamma$ )P32(n, $\gamma$ )P33( $\beta^-$ )S33(n, $\gamma$ )S34(n, $\gamma$ )S35( $\beta^-$ ) Cl35(n, $\gamma$ )Cl36	97.3 2.7	97.0 2.9		93.7 5.0
Al26	$7.2 \cdot 10^5$ y	P31(n,n $\alpha$ )Al27(n,2n)Al26 P31(n, $\alpha$ )Al28( $\beta^-$ )Si28(n,d)Al27(n,2n)Al26 P31(n,d)Si30(n, $\alpha$ )Mg27( $\beta^-$ )Al27(n,2n)Al26				95.4 2.3 1.4
Be10	$1.6 \cdot 10^6$ y	&P31(n,n $\alpha$ )Al27(n, $\alpha$ )Na24( $\beta^-$ )Mg24(n,n $\alpha$ )Ne20(n,n $\alpha$ ) O16(n, $\alpha$ )C13(n, $\alpha$ )Be10 P31(n, $\alpha$ )Al28( $\beta^-$ )Si28(n,n $\alpha$ )Mg24(n,n $\alpha$ )Ne20(n,n $\alpha$ ) O16(n, $\alpha$ )C13(n, $\alpha$ )Be10 P31(n,n $\alpha$ )Al27(n,n $\alpha$ )Na23(n, $\alpha$ )F20( $\beta^-$ )Ne20(n,n $\alpha$ ) O16(n, $\alpha$ )C13(n, $\alpha$ )Be10 P31(n, $\alpha$ )Al28( $\beta^-$ )Si28(n, $\alpha$ )Mg25(n,2n)Mg24(n,n $\alpha$ ) Ne20(n,n $\alpha$ )O16(n, $\alpha$ )C13(n, $\alpha$ )Be10 &P31(n,n $\alpha$ )Al27(n, $\alpha$ )Na24( $\beta^-$ )Mg24(n,n $\alpha$ )Ne20(n, $\alpha$ ) O17(n,n $\alpha$ )C13(n, $\alpha$ )Be10 P31(n, $\alpha$ )Al28( $\beta^-$ )Si28(n,n $\alpha$ )Mg24(n,n $\alpha$ )Ne20(n, $\alpha$ ) O17(n,n $\alpha$ )C13(n, $\alpha$ )Be10				45.7 27.6 9.9 4.0 2.7 1.6

# Phosphorus activation characteristics

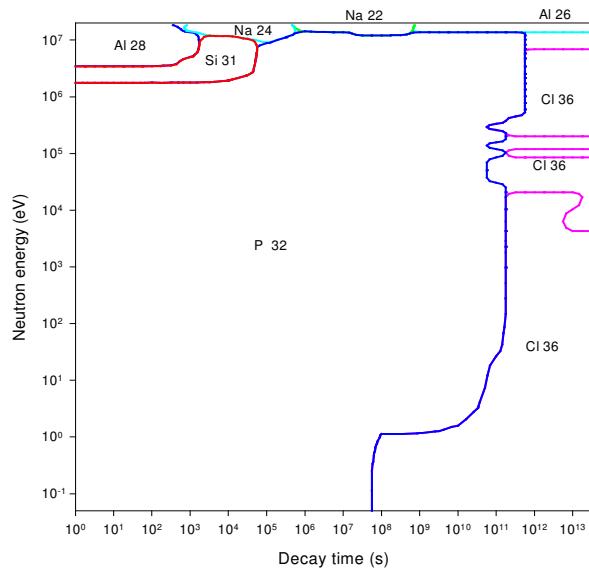


# Phosphorus importance diagrams & transmutation

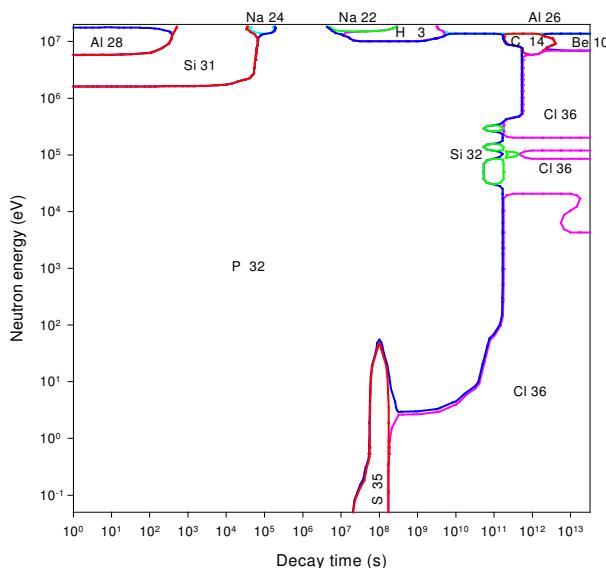
## Activity



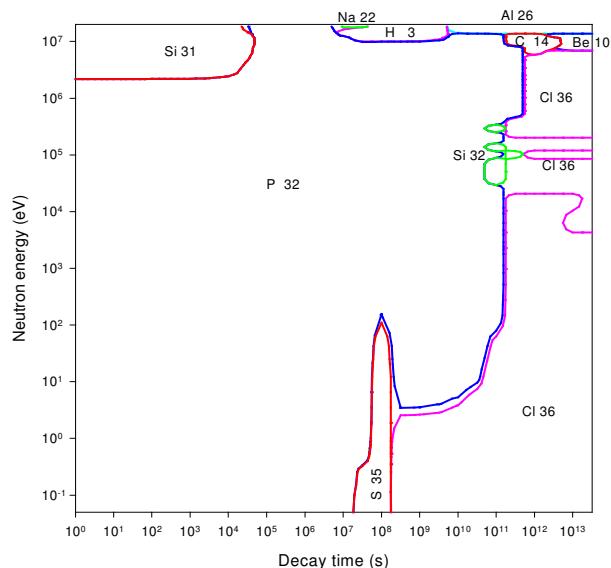
## Dose rate



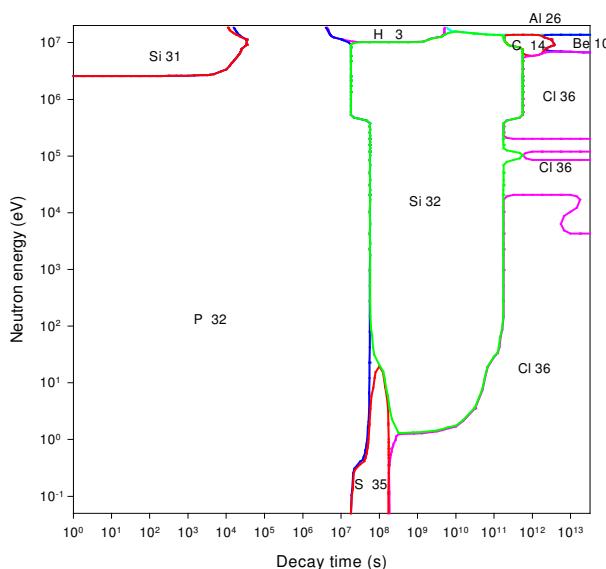
## Heat output



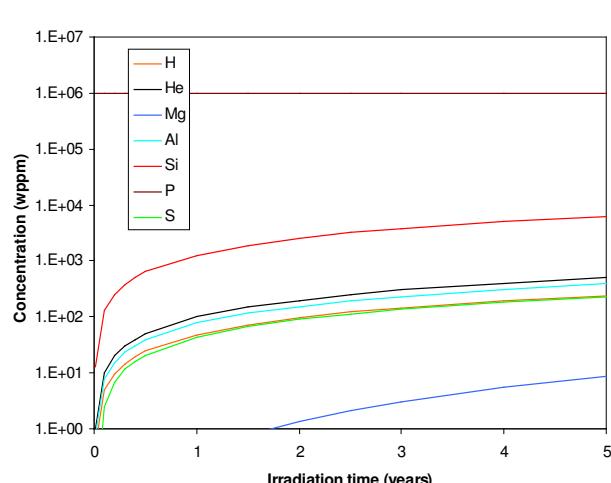
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Sulphur

## General properties

Atomic number	16	Isotopes	Isotopic abundances / %	
Crustal abundance / wppm	260	S32	95.02	
Melting point / K	386.0	S33	0.75	
Boiling point / K	717.8	S34	4.21	
Density / kgm <sup>-3</sup>	2070	S36	0.02	
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	2.69 10 <sup>-1</sup>			
Electrical resistivity /Ωm	2.0 10 <sup>15</sup>			
Coefficient of thermal expansion / K <sup>-1</sup>	7.433 10 <sup>-5</sup>			
Crystal structure	orthorhombic			
Number of stable isotopes	4			
Mean atomic weight	32.066			

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.01E15	9.94E14	8.07E14	4.10E11	2.19E9	1.07E5	kW kg <sup>-1</sup>	1.17E-1	1.10E-1	8.90E-2	8.98E-7	5.47E-8	4.29E-12
P32	94.5	95.98	99.04	0.14	20.06		P32	91.06	96.44	99.90	6.94	89.47	
Si31	2.93	2.91					P34	3.63					
P34	0.99						Si31	2.42	2.50				
P33	0.69	0.70	0.78	0.08			Al28	1.75	0.36				
Al28	0.42	0.08					S35	0.01	0.01	0.01	57.06		
S35	0.12	0.12	0.14	15.98			H3				34.93	2.20	
H3	0.04	0.04	0.05	83.67	59.88		Si32				0.63	8.33	
Si32				0.13	20.06		Cl36					0.01	97.73
Cl36					0.01	99.82	Al26						2.27
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	5.19E3	1.74E3	5.13E2	3.68E-4	2.82E-4	1.43E-7	Sv kg <sup>-1</sup>	2.30E6	2.30E6	1.92E6	6.66E1	1.36E0	9.96E-5
Al28	43.54	25.58					P32	99.68	99.69	99.88	2.02	77.78	
Al29	21.98	37.69					Si31	0.21	0.20				
P32	11.79*	35.24*	99.99*	97.53*	99.94*		S35	0.04	0.04	0.05	75.76		
P34	2.03						H3				21.64	4.06	
Na22				2.42			Si32				0.46	18.15	
Al26				0.04	0.05	97.44	Cl36					0.01	99.32
Cl36						2.56*	Al26						0.69
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	3.26E6	3.26E6	2.73E6	2.76E2	5.02E1	7.80E-4		2.39E10	9.21E9	2.71E9	1.44E5	4.84E3	8.81E-1
P32	99.53	99.53	99.57	0.69	2.98		Al28	33.89	17.30				
P33	0.32	0.32	0.35	0.18			P34	24.69					
Si31	0.07	0.07					Al29	18.14	27.02				
S35	0.07	0.07	0.08	45.16			P32	13.31	34.55	98.20	1.30	30.31	
H3				32.36	0.68		Si31	7.73	19.61				
Si32				21.61	96.34		P33	0.22	0.58	1.78	1.74		
Cl36					99.50	S35				0.01	15.14		
Al26					0.05	H3					79.28	9.05	
						Si32					2.50	60.62	
						Al26						0.01	59.77
						Cl36						0.01	40.23

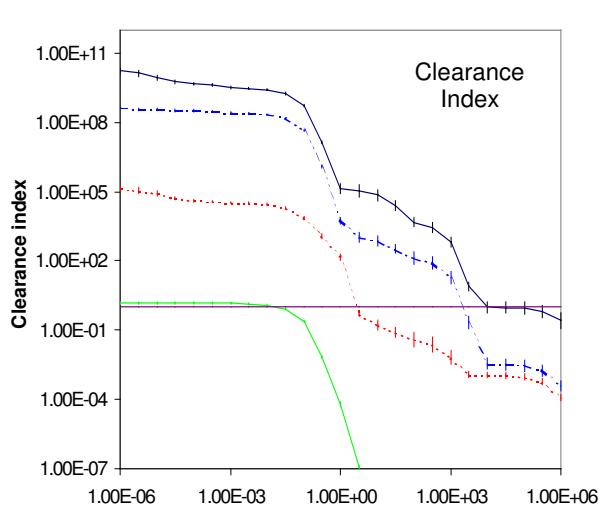
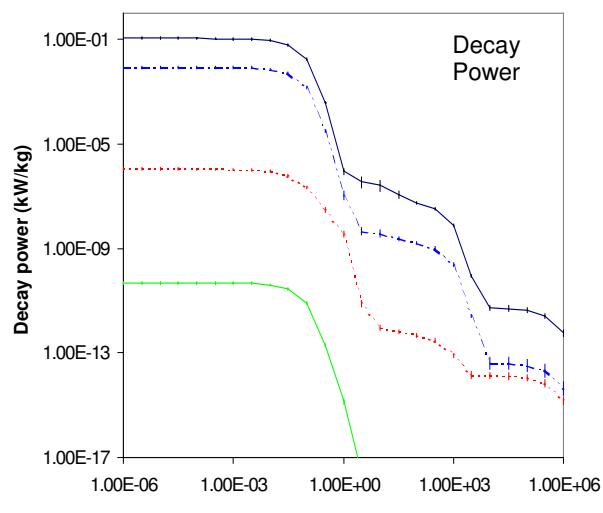
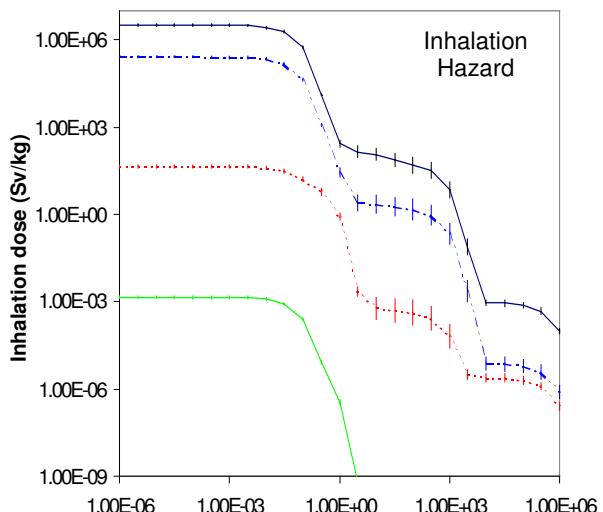
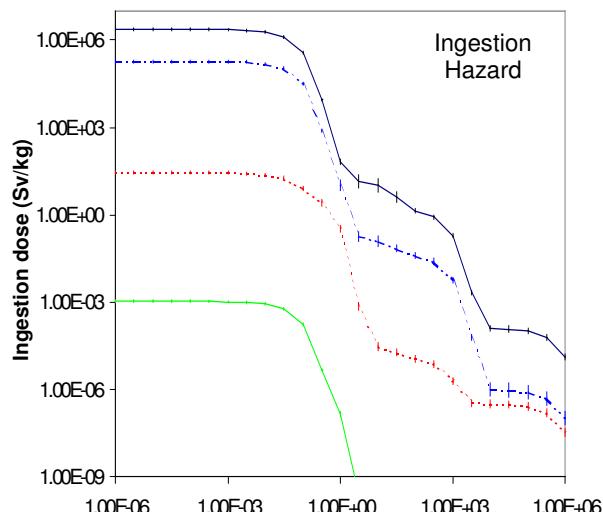
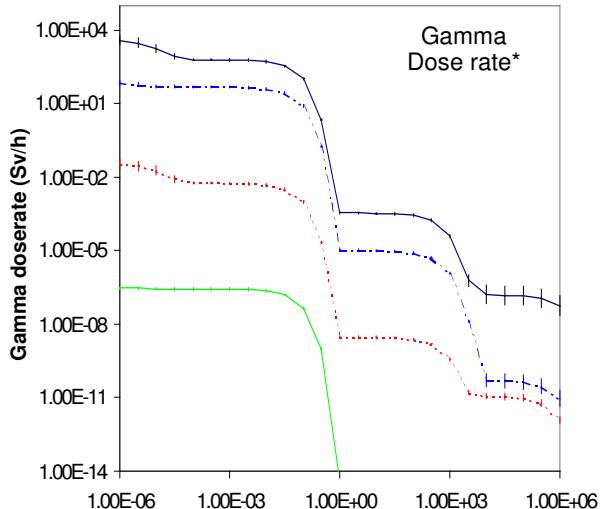
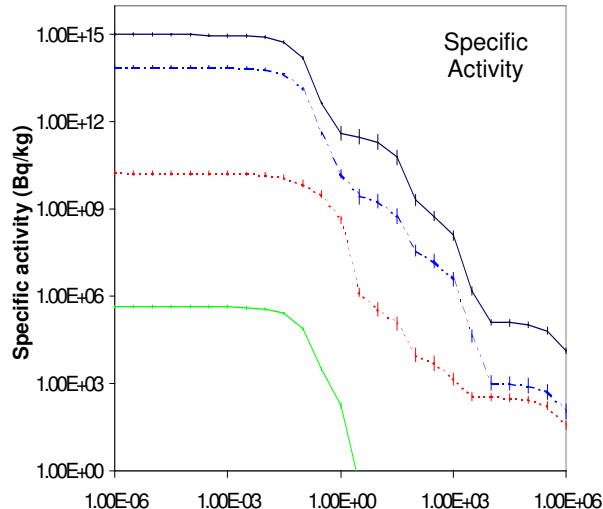
# Sulphur

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Al28	2.24 m	S32(n,d)P31(n, $\alpha$ )Al28 S32(n,n $\alpha$ )Si28(n,p)Al28 S32(n, $\alpha$ )Si29(n,d)Al28 S32(n, $\alpha$ )Si29(n,2n)Si28(n,p)Al28				55.5 31.3 5.1 2.6
S37	4.99 m	S36(n, $\gamma$ )S37	99.5	100.0	100.0	99.2
Al29	6.56 m	S32(n, $\alpha$ )Si29(n,p)Al29				97.1
Cl38	37.2 m	&S34(n, $\gamma$ )S35( $\beta^-$ )Cl35(n, $\gamma$ )Cl36(n, $\gamma$ )Cl37(n, $\gamma$ )Cl38 S36(n, $\gamma$ )S37( $\beta^-$ )Cl37(n, $\gamma$ )Cl38 S36(n, $\gamma$ )S37( $\beta^-$ )Cl37(n, $\gamma$ )Cl38m(IT)Cl38	97.1 2.4 0.3	87.7 11.9	88.1 11.9	47.6 51.6
Si31	2.62 h	S32(n, $\gamma$ )S33(n, $\alpha$ )Si30(n, $\gamma$ )Si31 S33(n, $\alpha$ )Si30(n, $\gamma$ )Si31 S32(n, $\alpha$ )Si29(n, $\gamma$ )Si30(n, $\gamma$ )Si31 S34(n, $\alpha$ )Si31 S32(n,2p)Si31 S32(n,d)P31(n,p)Si31	69.8 29.7	6.4 93.6	0.4 98.0 1.6	38.1 32.1 26.0
Na24	14.96 h	&S32(n,n $\alpha$ )Si28(n,d)Al27(n, $\alpha$ )Na24 &S32(n,d)P31(n,n $\alpha$ )Al27(n, $\alpha$ )Na24 &S32(n,n $\alpha$ )Si28(n, $\alpha$ )Mg25(n,d)Na24 &S32(n,n $\alpha$ )Si28(n,n $\alpha$ )Mg24(n,p)Na24 &S32(n,n $\alpha$ )Si28(n, $\alpha$ )Mg25(n,2n)Mg24(n,p)Na24 &S32(n, $\alpha$ )Si29(n,2n)Si28(n,d)Al27(n, $\alpha$ )Na24 &S32(n, $\alpha$ )Si29(n,t)Al27(n, $\alpha$ )Na24 &S34(n,n $\alpha$ )Si30(n, $\alpha$ )Mg27( $\beta^-$ )Al27(n, $\alpha$ )Na24				32.0 29.6 14.5 7.4 2.5 1.8 1.7 1.2
P32	14.27 d	S32(n, $\gamma$ )S33(n, $\alpha$ )Si30(n, $\gamma$ )Si31( $\beta^-$ )P31(n, $\gamma$ )P32 S33(n, $\alpha$ )Si30(n, $\gamma$ )Si31( $\beta^-$ )P31(n, $\gamma$ )P32 S34(n, $\gamma$ )S35( $\beta^-$ )Cl35(n, $\alpha$ )P32 S32(n,p)P32	55.0 35.4 9.1	0.2 4.2 95.6	0.2 99.8	99.6
P33	25.4 d	S32(n, $\gamma$ )S33(n,p)P33 S33(n,p)P33 S34(n,d)P33 S34(n,2n)S33(n,p)P33	83.8 17.7	12.0 88.3	0.7 99.3	52.0 44.4 1.5
S35	87.5 d	S34(n, $\gamma$ )S35 S32(n, $\gamma$ )S33(n, $\gamma$ )S34(n, $\gamma$ )S35 S36(n,2n)S35 S36(n,d)P35( $\beta^-$ )S35	97.7 0.9	100.0	100.0	13.8 82.3 1.6
Na22	2.60 y	S32(n, $\alpha$ )Si29(n, $\alpha$ )Mg26(n, $\alpha$ )Ne23( $\beta^-$ )Na23(n,2n)Na22 S32(n,n $\alpha$ )Si28(n,d)Al27(n,2n)Al26(n,n $\alpha$ )Na22 S32(n,d)P31(n,n $\alpha$ )Al27(n,2n)Al26(n,n $\alpha$ )Na22 S32(n,n $\alpha$ )Si28(n,n $\alpha$ )Mg24(n,d)Na23(n,2n)Na22 S32(n,n $\alpha$ )Si28(n,d)Al27(n,n $\alpha$ )Na23(n,2n)Na22 S32(n,d)P31(n,n $\alpha$ )Al27(n,n $\alpha$ )Na23(n,2n)Na22 S32(n,n $\alpha$ )Si28(n, $\alpha$ )Mg25(n,2n)Mg24(n,d)Na23(n,2n)Na22 S32(n, $\alpha$ )Si29(n,t)Al27(n,2n)Al26(n,n $\alpha$ )Na22				27.8 23.6 21.8 7.8 4.4 4.0 1.7 1.3
H3	12.33 y	S34(n, $\gamma$ )S35( $\beta^-$ )Cl35(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 S32(n, $\gamma$ )S33(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 S33(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 S34(n, $\gamma$ )S35( $\beta^-$ )Cl35(n, $\gamma$ )Cl36(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 S32(n, $\alpha$ )Si29(n,X)H3 S32(n,d)P31(n,X)H3 S32(n,X)H3 S33(n,X)H3 S32(n,X)He3(n,p)H3 S34(n,X)H3	49.9 22.7 19.0 2.7	0.5 3.2 91.6	0.2 99.2	38.7 23.0 18.7 7.3 6.5 2.4

Si32	330 y	S32(n, $\gamma$ )S33(n, $\alpha$ )Si30(n, $\gamma$ )Si31(n, $\gamma$ )Si32 S33(n, $\alpha$ )Si30(n, $\gamma$ )Si31(n, $\gamma$ )Si32 S34(n, $\gamma$ )S35(n, $\alpha$ )Si32 S32(n, $\alpha$ )Si29(n, $\gamma$ )Si30(n, $\gamma$ )Si31(n, $\gamma$ )Si32 S32(n,p)P32(n,p)Si32 S33(n,2p)Si32 S36(n,n $\alpha$ )Si32	60.7 38.7 0.2	0.9 20.8 78.3	0.2 90.0 8.8 1.0	63.0 29.3 5.5
Cl36	$3.0 \cdot 10^5$ y	S34(n, $\gamma$ )S35( $\beta^-$ )Cl35(n, $\gamma$ )Cl36 S36(n,2n)S35( $\beta^-$ )Cl35(n, $\gamma$ )Cl36 S36(n, $\gamma$ )S37( $\beta^-$ )Cl37(n,2n)Cl36	99.6	100.0	100.0	8.5 52.1 38.1
Al26	$7.2 \cdot 10^5$ y	S32(n,n $\alpha$ )Si28(n,d)Al27(n,2n)Al26 S32(n,d)P31(n,n $\alpha$ )Al27(n,2n)Al26 S32(n, $\alpha$ )Si29(n,t)Al27(n,2n)Al26 S32(n, $\alpha$ )Si29(n,2n)Si28(n,d)Al27(n,2n)Al26 S34(n,n $\alpha$ )Si30(n, $\alpha$ )Mg27( $\beta^-$ )Al27(n,2n)Al26				46.1 42.5 2.5 1.9 1.7

# Sulphur activation characteristics

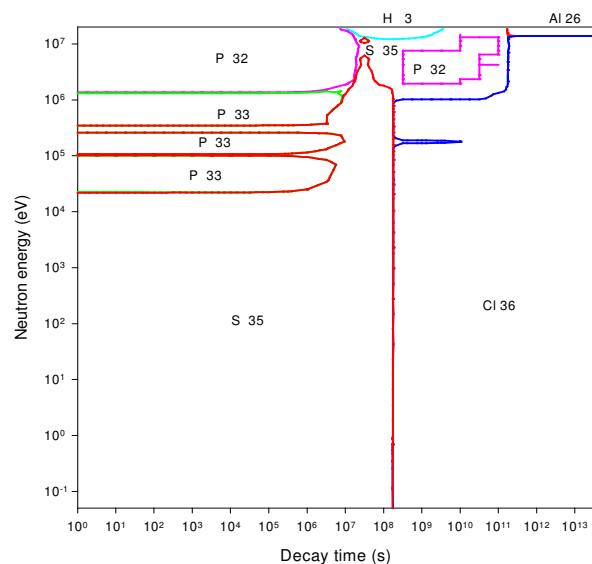


Decay time (years)

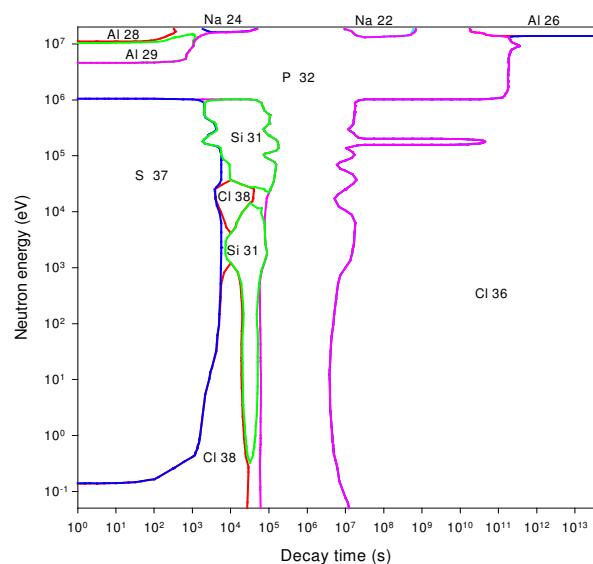
Decay time (years)

# Sulphur importance diagrams & transmutation

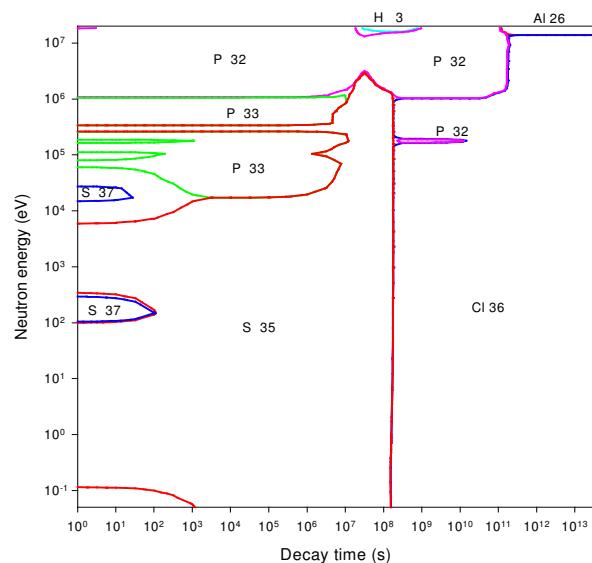
## Activity



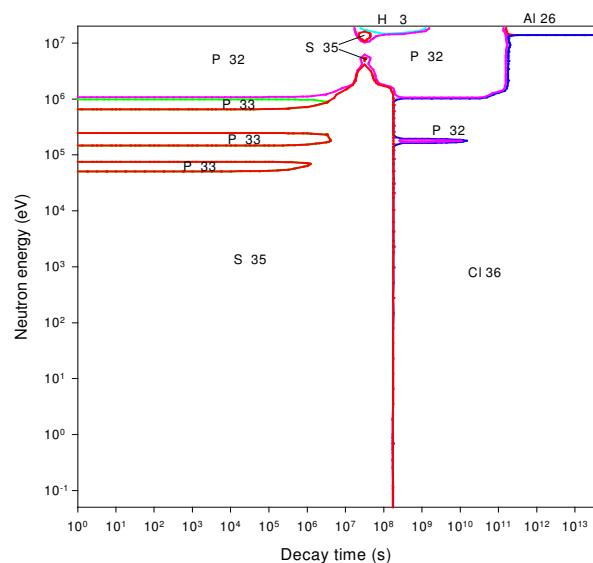
## Dose rate



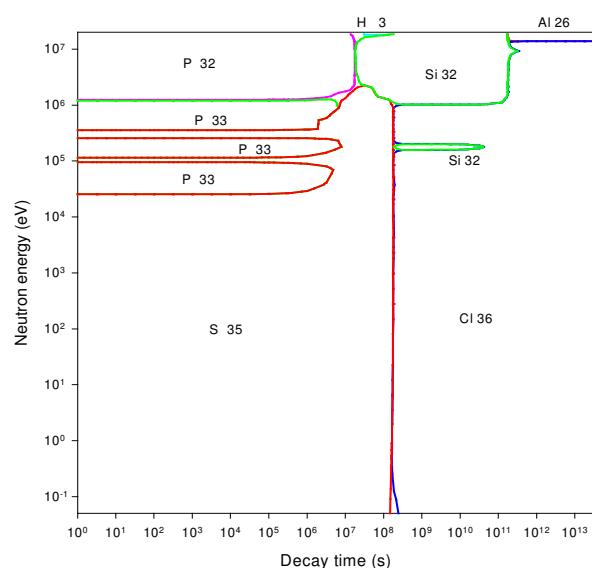
## Heat output



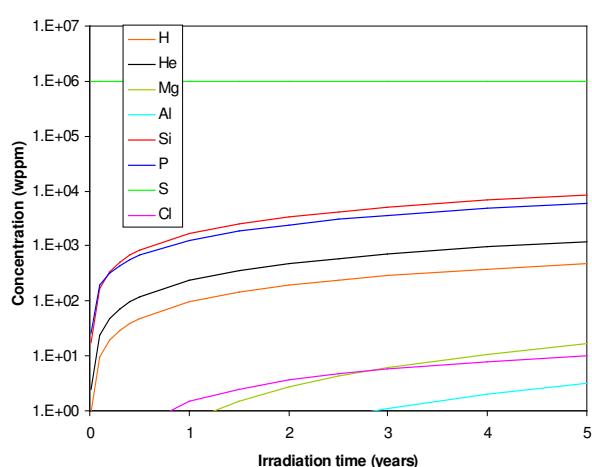
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Chlorine

## General properties

Atomic number	17	Isotopes	Isotopic abundances / %	
Crustal abundance / wppm	130	Cl35	75.77	
Melting point / K	172.2	Cl37	24.23	
Boiling point / K	239.2			
Density / kgm <sup>-3</sup>	3.214			
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	8.9 10 <sup>-3</sup>			
Electrical resistivity /Ωm	-			
Coefficient of thermal expansion / K <sup>-1</sup>	-			
Crystal structure	tetragonal			
Number of stable isotopes	2			
Mean atomic weight	35.4527			

## Activation properties

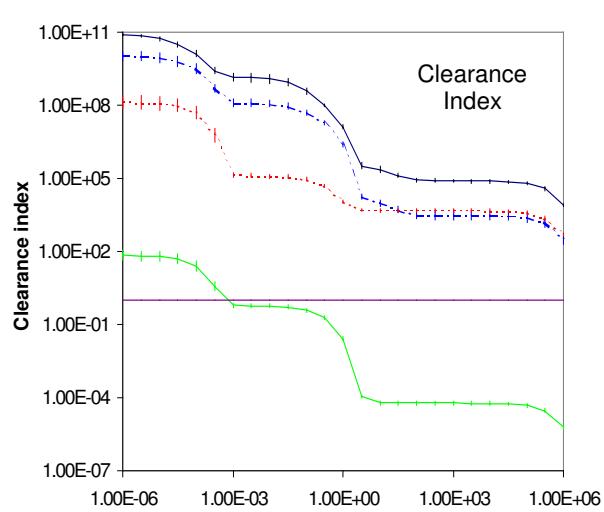
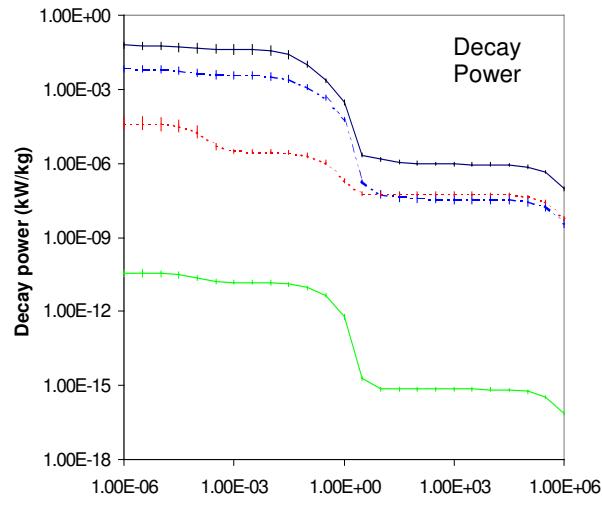
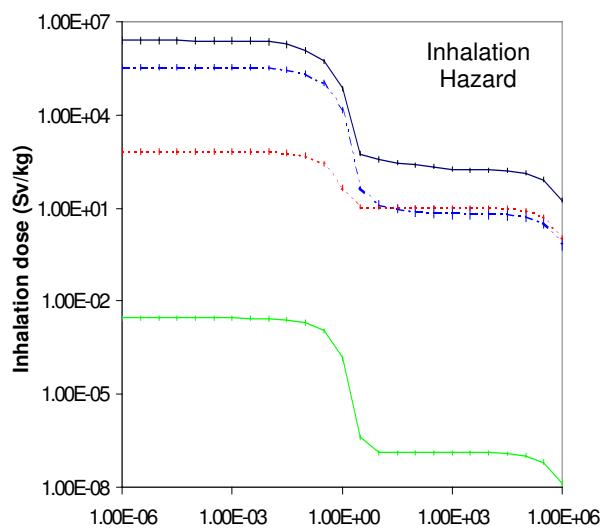
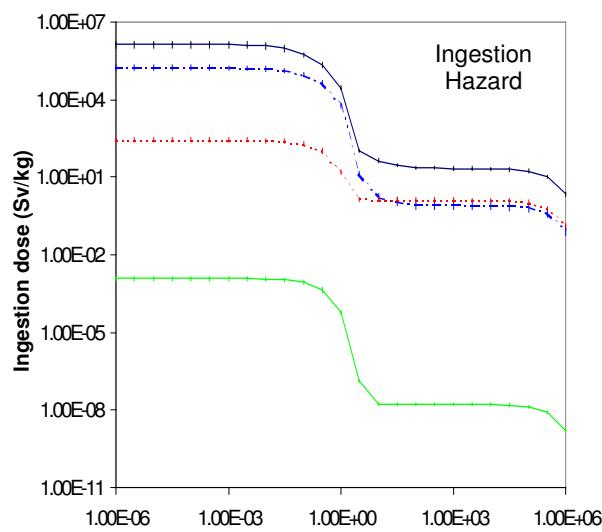
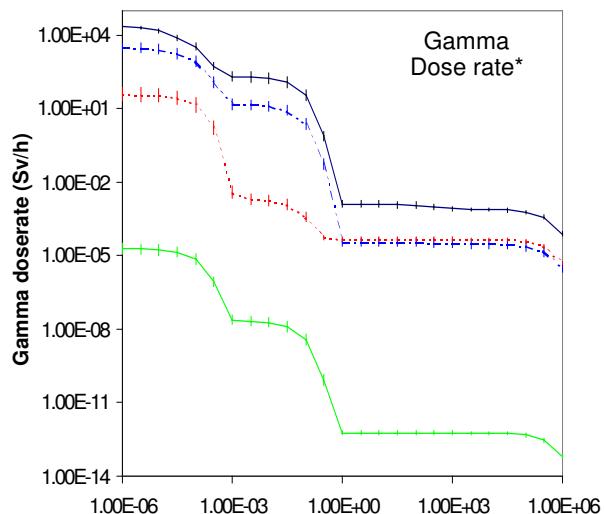
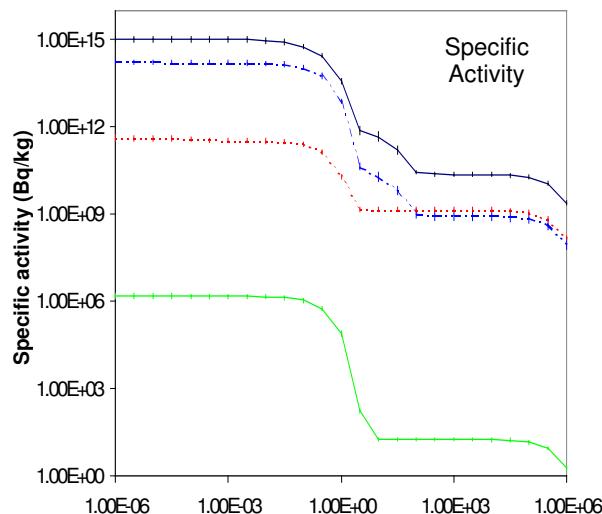
Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.11E15	1.07E15	9.68E14	3.95E13	2.74E10	1.86E10	kW kg <sup>-1</sup>	7.22E-2	5.54E-2	3.66E-2	3.04E-4	9.98E-7	7.33E-7
S35	63.18	65.36	70.14	98.05			P32	51.63	67.34	85.24	0.03	6.97	
P32	30.30	31.34	28.99		2.28		S37	12.44	7.82				
P34	1.92						P34	12.41					
S37	1.36	0.68					S35	7.57	9.88	14.50	99.44		
P33	0.75	0.78	0.78				Cl38	7.02	8.30				
H3	0.07	0.07	0.08	1.89	10.41		Cl34	4.93	2.37				
Cl36				0.06	84.95	100.0	Cl34m	3.34	3.89				
Si32					2.28		Cl36				0.30	92.04	100.0
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	2.76E4	1.54E4	1.75E2	1.26E-3	1.16E-3	6.16E-4	Sv kg <sup>-1</sup>	1.35E6	1.35E6	1.20E6	2.99E4	2.37E1	1.73E1
S37	53.79	46.24					P32	59.72	59.73	56.21	0.01	6.34	
Cl38	17.75	28.73					S35	39.96	39.97	43.63	99.81		
Cl34m	12.59	20.07					P33	0.15	0.15	0.15			
P34	8.41						H3				0.11	0.51	
Cl34	5.41	3.56					Cl36				0.07	91.46	100.0
P32	0.76*	1.35*	100.0*	38.56*	33.59*		Si32					1.48	
Cl36				61.37*	66.37*	100.0*	Ar39					0.22	
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	2.48E6	2.48E6	2.26E6	7.40E4	2.47E2	1.36E2		9.98E10	5.37E10	1.22E9	1.32E7	8.53E4	6.20E4
S35	53.51	53.52	57.18	99.38			S37	45.66	40.89				
P32	45.92	45.91	42.29		0.86		Cl38	17.22	29.03				
P33	0.50	0.50	0.50				Cl34m	12.73	21.12				
Cl38	0.02	0.02					P34	12.53					
H3	0.01	0.01	0.01	0.26	0.30		Cl34	8.95	6.14				
Cl36	0.01	0.01	0.01	0.23	68.85	100.0	P32	1.12	2.08		0.02	2.44	
Si32				0.11	27.85		S35	0.23	0.43			97.45	
Ar39				0.01	2.14		H3					1.88	1.12
							Cl36					0.59	91.00
							Si32					0.01	4.89

# Chlorine

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
S37	4.99 m	Cl35(n, $\gamma$ )Cl36(n,p)S36(n, $\gamma$ )S37 Cl35(n,p)S35(n, $\gamma$ )S36(n, $\gamma$ )S37 Cl37(n,p)S37	98.8 0.6	99.3 0.4	3.7 96.1	99.9
Cl34m	32.1 m	Cl35(n,2n)Cl34m				98.1
Cl38	37.2 m	Cl37(n, $\gamma$ )Cl38 Cl35(n, $\gamma$ )Cl36(n, $\gamma$ )Cl37(n, $\gamma$ )Cl38 Cl37(n, $\gamma$ )Cl38m(IT)Cl38 Cl35(n, $\gamma$ )Cl36(n, $\gamma$ )Cl37(n, $\gamma$ )Cl38m(IT)Cl38	40.3 47.5 5.4 6.4	88.0 11.9	88.1 11.9	47.3 51.3
Ar41	1.8267 h	&Cl37(n, $\gamma$ )Cl38( $\beta^-$ )Ar38(n, $\gamma$ )Ar39(n, $\gamma$ )Ar40(n, $\gamma$ )Ar41 &Cl35(n, $\gamma$ )Cl36(n, $\gamma$ )Cl37(n, $\gamma$ )Cl38( $\beta^-$ )Ar38(n, $\gamma$ ) Ar39(n, $\gamma$ )Ar40(n, $\gamma$ )Ar41	77.6 25.3	100.0	100.0	99.3
K42	12.37 h	&Cl37(n, $\gamma$ )Cl38( $\beta^-$ )Ar38(n, $\gamma$ )Ar39(n, $\gamma$ )Ar40(n, $\gamma$ ) Ar41( $\beta^-$ )K41(n, $\gamma$ )K42 &Cl35(n, $\gamma$ )Cl36(n, $\gamma$ )Cl37(n, $\gamma$ )Cl38( $\beta^-$ )Ar38(n, $\gamma$ ) Ar39(n, $\gamma$ )Ar40(n, $\gamma$ )Ar41( $\beta^-$ )K41(n, $\gamma$ )K42	83.9 16.0	100.0		
P32	14.27 d	Cl35(n, $\alpha$ )P32 Cl37(n,2n)Cl36(n,n $\alpha$ )P32	96.2	99.9	100.0	93.6 1.3
S35	87.5 d	Cl35(n,p)S35 Cl37(n,d)S36(n,2n)S35 Cl37(n,2n)Cl36(n,d)S35	100.0	99.9	100.0	95.1 2.5 1.7
Na22	2.60 y	Cl35(n,n $\alpha$ )P31(n,n $\alpha$ )Al27(n,2n)Al26(n,n $\alpha$ )Na22 Cl35(n,n $\alpha$ )P31(n,n $\alpha$ )Al27(n,n $\alpha$ )Na23(n,2n)Na22 Cl35(n,d)S34(n,n $\alpha$ )Si30(n, $\alpha$ )Mg27( $\beta^-$ )Al27(n,2n) Al26(n,n $\alpha$ )Na22 Cl35(n, $\alpha$ )P32( $\beta^-$ )S32(n, $\alpha$ )Si29(n, $\alpha$ )Mg26(n, $\alpha$ ) Ne23( $\beta^-$ )Na23(n,2n)Na22 Cl35(n, $\alpha$ )P32( $\beta^-$ )S32(n,n $\alpha$ )Si28(n,d)Al27(n,2n) Al26(n,n $\alpha$ )Na22 Cl35(n, $\alpha$ )P32( $\beta^-$ )S32(n,d)P31(n,n $\alpha$ )Al27(n,2n) Al26(n,n $\alpha$ )Na22 Cl35(n,d)S34(n, $\alpha$ )Si31( $\beta^-$ )P31(n,n $\alpha$ )Al27(n,2n) Al26(n,n $\alpha$ )Na22 Cl35(n, $\alpha$ )P32( $\beta^-$ )S32(n,n $\alpha$ )Si28(n,n $\alpha$ )Mg24(n,d) Na23(n,2n)Na22 Cl35(n,d)S34(n,n $\alpha$ )Si30(n, $\alpha$ )Mg27( $\beta^-$ )Al27(n,n $\alpha$ ) Na23(n,2n)Na22				52.0 9.7 6.2  5.8  5.0  4.6  3.1  1.6  1.1
H3	12.33 y	Cl35(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Cl35(n, $\gamma$ )Cl36(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Cl35(n,X)H3 Cl37(n,X)H3	86.1 6.3	94.9 0.3	99.3	71.8 27.1
Ar39	269 y	&Cl37(n, $\gamma$ )Cl38( $\beta^-$ )Ar38(n, $\gamma$ )Ar39 &Cl35(n, $\gamma$ )Cl36(n, $\gamma$ )Cl37(n, $\gamma$ )Cl38( $\beta^-$ )Ar38(n, $\gamma$ )Ar39	66.8 33.1	100.0	100.0	99.4
Si32	330 y	Cl35(n,p)S35(n, $\alpha$ )Si32 Cl35(n, $\alpha$ )P32(n,p)Si32 Cl37(n,d)S36(n,n $\alpha$ )Si32 Cl37(n,d)S36(n,2n)S35(n, $\alpha$ )Si32 Cl37(n,2n)Cl36(n,p $\alpha$ )Si32 Cl37(n,2n)Cl36(n,p)S36(n,n $\alpha$ )Si32	100.0	100.0	99.7 0.3	56.0 11.7 27.8 0.7 0.7 0.7
Cl36	$3.0 \cdot 10^5$ y	Cl35(n, $\gamma$ )Cl36 Cl37(n,2n)Cl36	98.9	100.0	100.0	0.4 99.5

# Chlorine activation characteristics

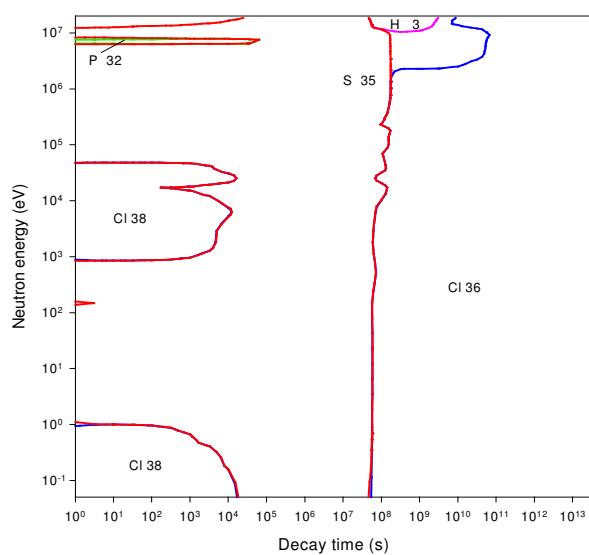


Decay time (years)

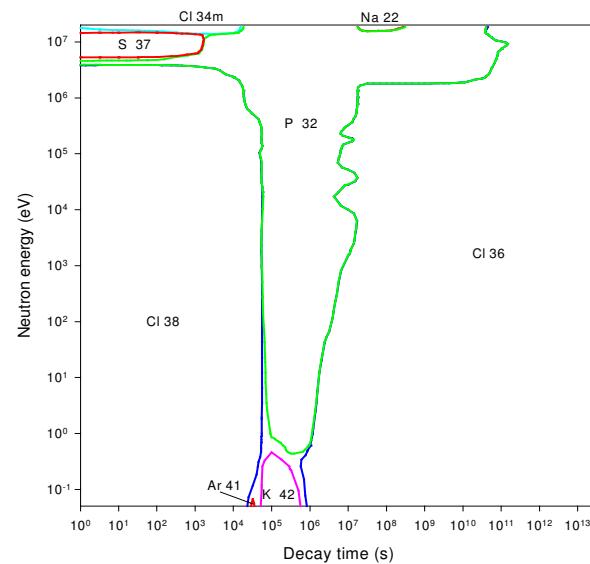
Decay time (years)

# Chlorine importance diagrams & transmutation

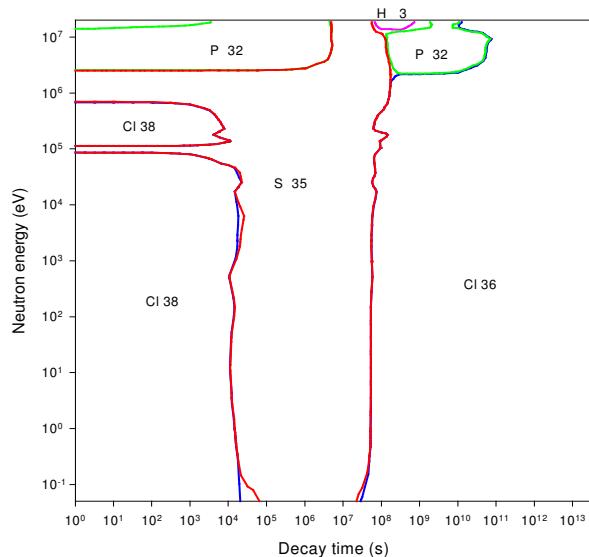
## Activity



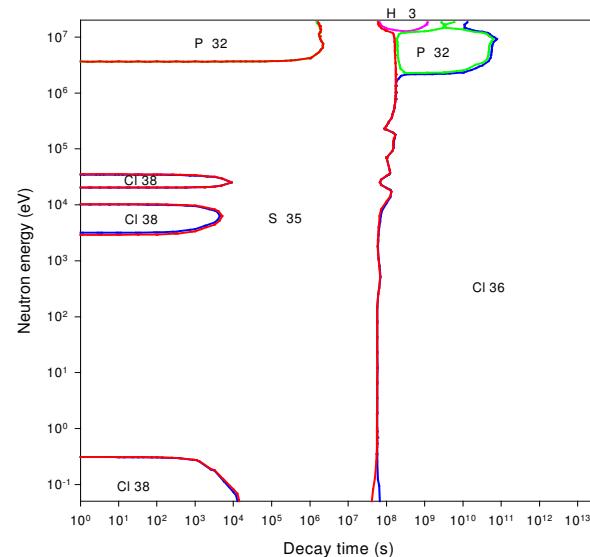
## Dose rate



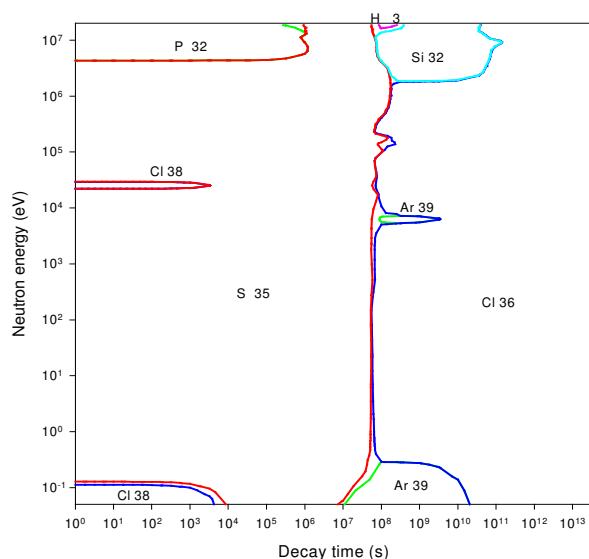
## Heat output



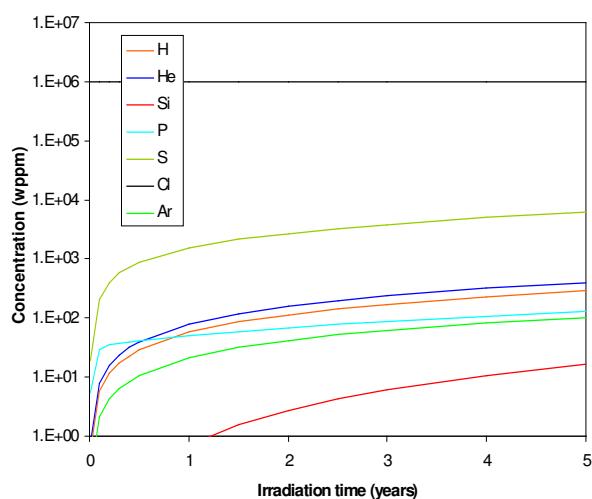
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Argon

## General properties

Atomic number Crustal abundance / wppm Melting point / K Boiling point / K Density / kgm <sup>-3</sup> Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup> Electrical resistivity /Ωm Coefficient of thermal expansion / K <sup>-1</sup> Crystal structure Number of stable isotopes Mean atomic weight	18	Isotopes Ar36 Ar38 Ar40	Isotopic abundances / % 0.3365 0.0632 99.6003
	1.2		
	83.78		
	87.29		
	1.784		
	1.77 10 <sup>-2</sup>		
	-		
	-		
	FCC		
	3		

## Activation properties

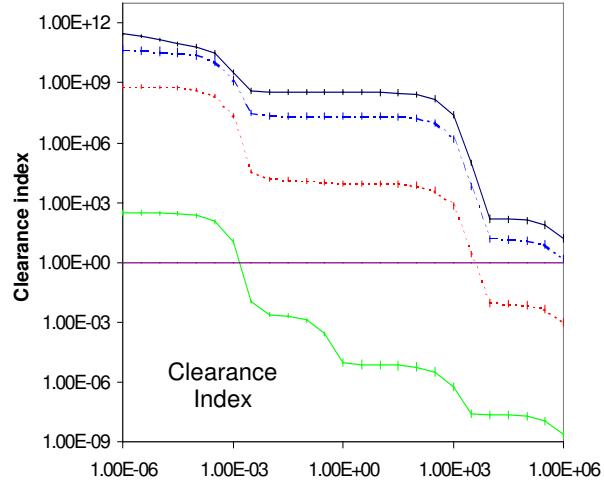
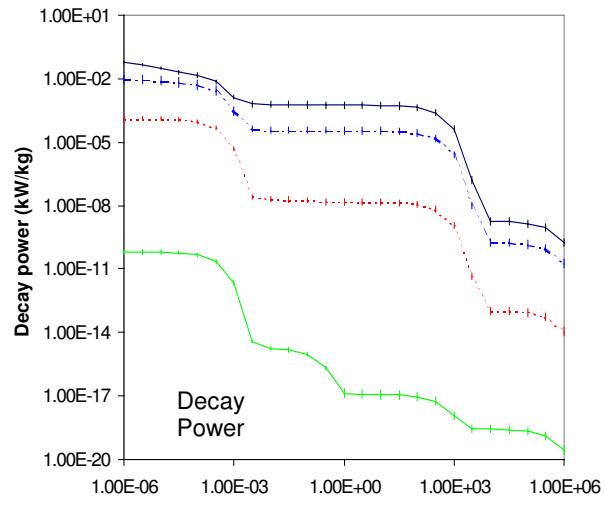
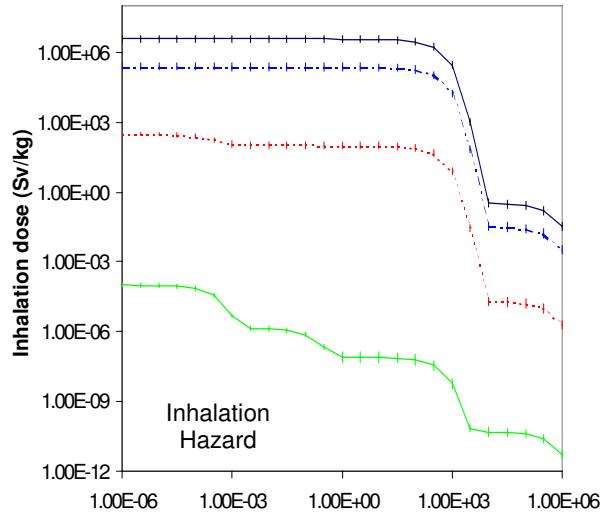
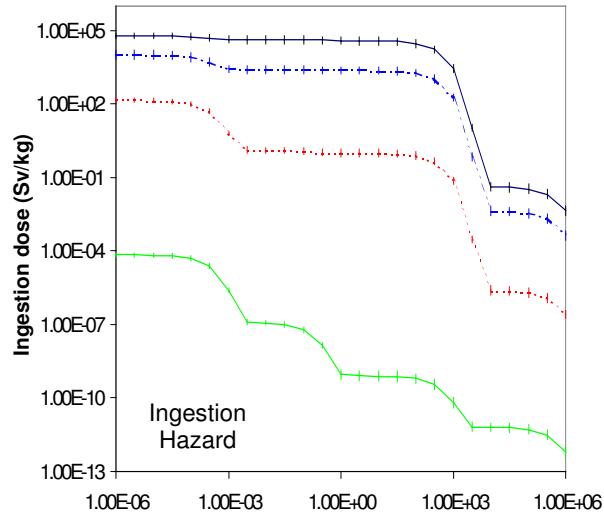
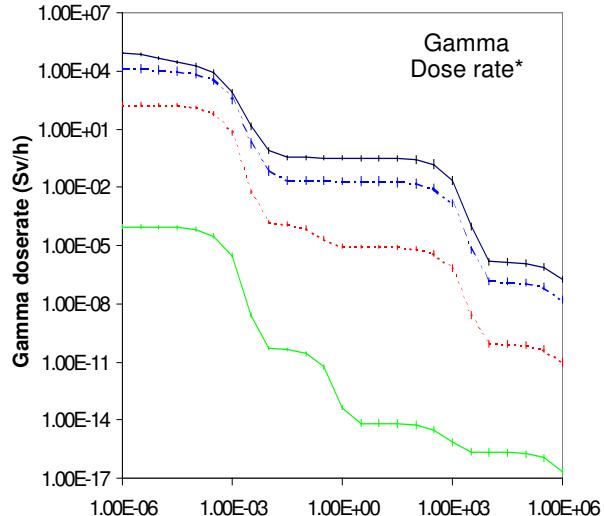
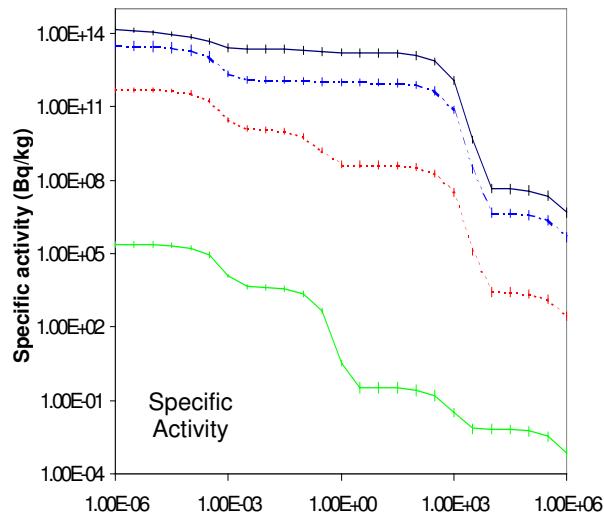
Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.56E14	1.07E14	2.22E13	1.61E13	1.22E13	3.72E7	kW kg <sup>-1</sup>	6.84E-2	3.09E-2	6.01E-4	5.56E-4	4.29E-4	1.46E-9
Ar41	39.90	56.41					Cl40	43.46	6.47				
Cl40	21.21	2.08					Ar41	25.48	54.64				
S37	18.36	12.92					S37	25.02	26.72				
Ar39	10.16	14.84	71.38	98.03	99.99		Cl39	2.93	6.09				
Cl39	3.53	4.84					Cl38	1.77	3.55				
S35	3.37	4.93	23.01	1.81			Ar39	0.81	1.80	92.36	99.58	100.0	
Cl38	1.60	2.12					K42	0.26	0.58	0.22			
Ar37	0.79	1.16	5.19	0.01			S35	0.06	0.13	6.65	0.41		
Cl36						99.94	P32	0.01	0.02	0.62			
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	1.03E5	4.44E4	8.18E-1	3.25E-1	2.52E-1	1.24E-6	Sv kg <sup>-1</sup>	6.26E4	6.15E4	4.21E4	3.81E4	2.94E4	3.45E-2
Cl40	43.65	6.81					Ar39	60.71	61.84	90.36	99.41	100.0	
S37	28.96	32.41					Ar41	29.82	29.38				
Ar41	23.64	53.11					S35	6.46	6.58	9.35	0.59		
Cl39	2.30	5.01					Cl39	0.75	0.71				
Cl38	1.20	2.53					S37	0.69	0.34				
P32	0.06	0.14*	2.57*	0.01*	0.01*		Cl38	0.48	0.44				
K42			55.94*	0.01*			K42	0.45	0.45	0.01			
Ar39			39.80*	99.98*	99.99*		P32	0.15	0.16	0.19			
Ar37			1.69				Cl36						99.98
Cl36						97.74*							
K40						2.22							
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	3.84E6	3.84E6	3.81E6	3.79E6	2.94E6	2.71E-1		3.22E11	1.44E11	3.49E8	3.44E8	2.66E8	1.24E2
Ar39	99.02	99.05	99.73	99.98	100.0		Cl40	42.87	6.45				
Ar41	0.68	0.66					S37	26.99	29.10				
S35	0.26	0.26	0.26	0.02			Ar41	25.81	55.89				
Cl36						100.0	Cl39	2.64	5.53				
							Cl38	1.27	2.59				
							Ar39	0.11	0.24	98.64	99.97	100.0	

# Argon

## Pathway analysis

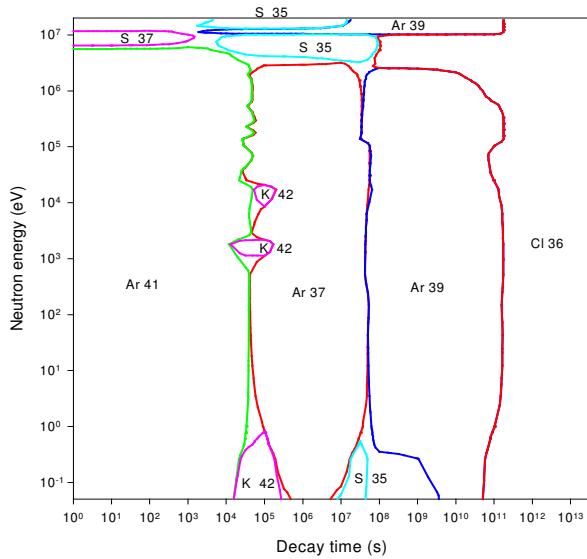
Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
S37	4.99 m	Ar36(n, $\gamma$ )Ar37(n, $\alpha$ )S34(n, $\gamma$ )S35(n, $\gamma$ )S36(n, $\gamma$ )S37 Ar36(n, $\gamma$ )Ar37(n, $\alpha$ )S34(n, $\gamma$ )S35( $\beta^-$ )Cl35(n, $\gamma$ ) Cl36(n,p)S36(n, $\gamma$ )S37 Ar36(n,p)Cl36(n,p)S36(n, $\gamma$ )S37 Ar36(n,p)Cl36( $\beta^+$ )S36(n, $\gamma$ )S37 Ar40(n, $\alpha$ )S37	65.7 28.8  5.1	3.4  96.4 0.2	96.2 3.4	99.3
Cl38	37.2 m	Ar36(n, $\gamma$ )Ar37( $\beta^+$ )Cl37(n, $\gamma$ )Cl38 Ar36(n, $\gamma$ )Ar37( $\beta^+$ )Cl37(n, $\gamma$ )Cl38m(IT)Cl38 Ar36(n, $\gamma$ )Ar37(n,p)Cl37(n, $\gamma$ )Cl38 Ar36(n, $\gamma$ )Ar37(n,p)Cl37(n, $\gamma$ )Cl38m(IT)Cl38 <b>&amp;Ar40(n,2n)Ar39(n,d)Cl38</b> <b>&amp;Ar40(n,2n)Ar39(n,2n)Ar38(n,p)Cl38</b>	78.0 10.5 9.9 1.3	87.8 11.9 0.3	88.1 11.9	95.2 2.6
Cl39	55.6 m	Ar40(n, $\gamma$ )Ar41( $\beta^-$ )K41(n, $\gamma$ )K42(n, $\alpha$ )Cl39 Ar40(n,2n)Ar39(n,p)Cl39 Ar40(n,d)Cl39	100.0	100.0		80.2 19.4
Ar41	1.827 h	Ar40(n, $\gamma$ )Ar41	100.0	100.0	100.0	99.0
K42	12.37 h	Ar40(n, $\gamma$ )Ar41( $\beta^-$ )K41(n, $\gamma$ )K42	100.0	100.0	100.0	98.5
P32	14.27 d	Ar36(n, $\gamma$ )Ar37(n, $\alpha$ )S34(n, $\gamma$ )S35( $\beta^-$ )Cl35(n, $\alpha$ )P32 Ar36(n, $\alpha$ )S33(n, $\alpha$ )Si30(n, $\gamma$ )Si31( $\beta^-$ )P31(n, $\gamma$ )P32 Ar40(n,2n)Ar39(n, $\alpha$ )S35( $\beta^-$ )Cl35(n, $\alpha$ )P32 Ar36(n,d)Cl35(n, $\alpha$ )P32 Ar36(n, $\alpha$ )S32(n,p)P32 Ar40(n, $\alpha$ )S36(n,2n)S35( $\beta^-$ )Cl35(n, $\alpha$ )P32 Ar36(n,p)Cl36(n, $\alpha$ )P32 Ar36(n, $\alpha$ )S33(n,d)P32 Ar36(n,p $\alpha$ )P32 Ar40(n, $\alpha$ )S37( $\beta^-$ )Cl37(n,2n)Cl36(n, $\alpha$ )P32	98.4 1.6	99.8 0.2	99.9	71.4 7.8 5.5 4.5 3.4 1.7 1.3 1.2
P33	25.4 d	Ar36(n, $\alpha$ )S33(n,p)P33 Ar40(n, $\alpha$ )S36(n, $\alpha$ )Si33( $\beta^-$ )P33 Ar40(n, $\alpha$ )S37( $\beta^-$ )Cl37(n, $\alpha$ )P33 Ar36(n,p)Cl36(n, $\alpha$ )P33 Ar40(n,2n)Ar39(n, $\alpha$ )S36(n, $\alpha$ )Si33( $\beta^-$ )P33 Ar40(n, $\alpha$ )S37( $\beta^-$ )Cl37(n,2n)Cl36(n, $\alpha$ )P33 Ar40(n,2n)Ar39(n,2n)Ar38(n, $\alpha$ )S34(n,d)P33 Ar38(n, $\alpha$ )S34(n,d)P33	100.0	100.0	100.0	11.1 35.2 24.8 10.5 4.2 3.8 3.2 1.0
Ar37	35.04 d	Ar36(n, $\gamma$ )Ar37 Ar40(n,2n)Ar39(n,2n)Ar38(n,2n)Ar37 <b>&amp;Ar40(n,2n)Ar39(n,d)Cl38(<math>\beta^-</math>)Ar38(n,2n)Ar37</b> Ar38(n,2n)Ar37	99.8	100.0	100.0	75.3 15.6 7.7
Sc46	83.79 d	<b>&amp;Ar40(n,<math>\gamma</math>)Ar41(<math>\beta^-</math>)K41(n,<math>\gamma</math>)K42(<math>\beta^-</math>)Ca42(n,<math>\gamma</math>)</b> Ca43(n, $\gamma$ )Ca44(n, $\gamma$ )Ca45( $\beta^-$ )Sc45(n, $\gamma$ )Sc46	99.6	99.5	99.9	
S35	87.5 d	Ar36(n, $\gamma$ )Ar37(n, $\alpha$ )S34(n, $\gamma$ )S35 Ar40(n,2n)Ar39(n, $\alpha$ )S35 Ar40(n, $\alpha$ )S36(n,2n)S35 Ar40(n,2n)Ar39(n,2n)Ar38(n, $\alpha$ )S35	99.3	100.0	100.0	90.0 5.8 1.1
Ar42	33.0 y	Ar40(n, $\gamma$ )Ar41(n, $\gamma$ )Ar42 Ar40(n, $\gamma$ )Ar41( $\beta^-$ )K41(n, $\gamma$ )K42(n,p)Ar42	100.0	100.0	100.0	97.6 1.8
Ar39	269 y	Ar38(n, $\gamma$ )Ar39 Ar36(n, $\gamma$ )Ar37( $\beta^+$ )Cl37(n, $\gamma$ )Cl38( $\beta^-$ )Ar38(n, $\gamma$ )Ar39 Ar40(n,2n)Ar39	99.3 0.4	100.0	100.0	99.1
Cl36	$3.0 \cdot 10^5$ y	Ar36(n, $\gamma$ )Ar37(n, $\alpha$ )S34(n, $\gamma$ )S35( $\beta^-$ )Cl35(n, $\gamma$ )Cl36 Ar36(n,p)Cl36 Ar40(n, $\alpha$ )S37( $\beta^-$ )Cl37(n,2n)Cl36 Ar40(n,2n)Ar39( $\beta^-$ )K39(n, $\alpha$ )Cl36	92.4 7.6	99.9	100.0	69.4 25.9 2.8

# Argon activation characteristics

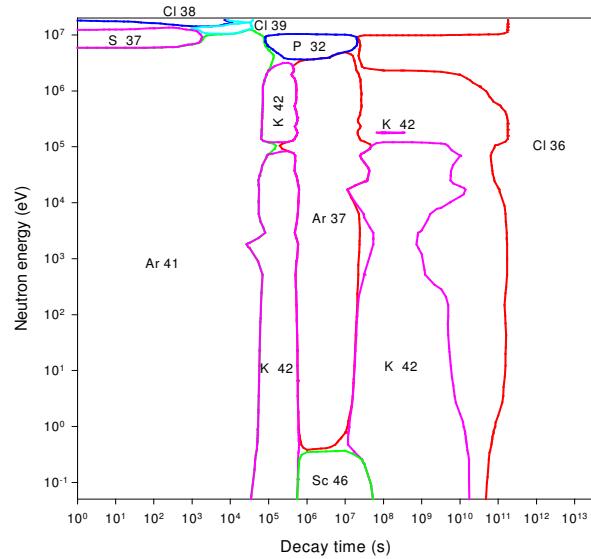


# Argon importance diagrams & transmutation

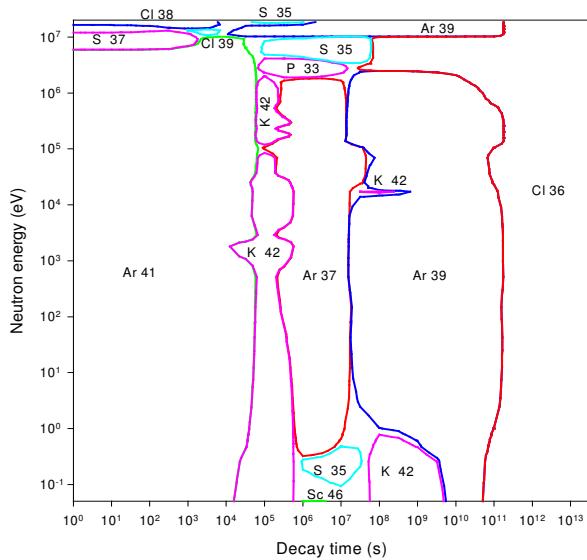
## Activity



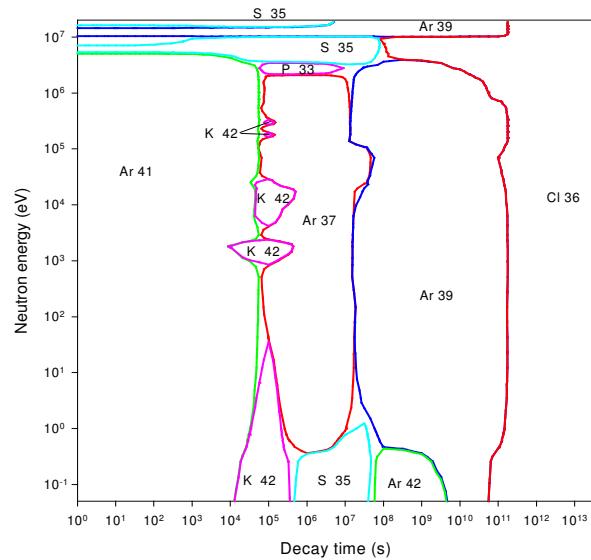
## Dose rate



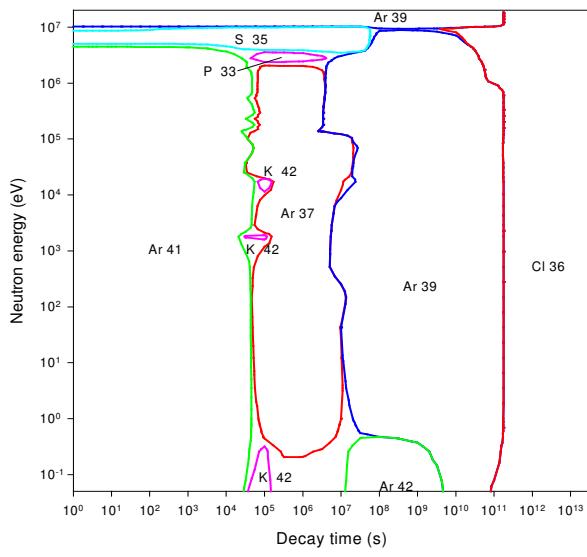
## Heat output



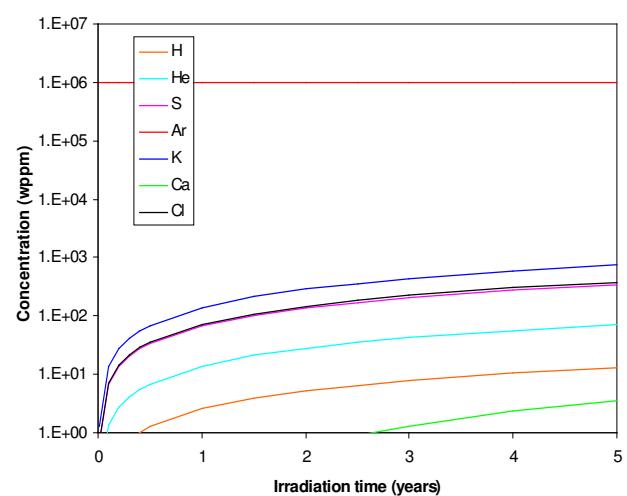
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Potassium

## General properties

Atomic number	19	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	2.09 10 <sup>4</sup>	K39	93.2581
Melting point / K	336.5	K40	0.0117 ( $T_{1/2} = 1.3 \cdot 10^9$ y)
Boiling point / K	1032	K41	6.7302
Density / kgm <sup>-3</sup>	862		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	102		
Electrical resistivity /Ωm	6.15 10 <sup>-8</sup>		
Coefficient of thermal expansion / K <sup>-1</sup>	8.3 10 <sup>-5</sup>		
Crystal structure	BCC		
Number of stable isotopes	2(3)		
Mean atomic weight	39.0983		

## Activation properties

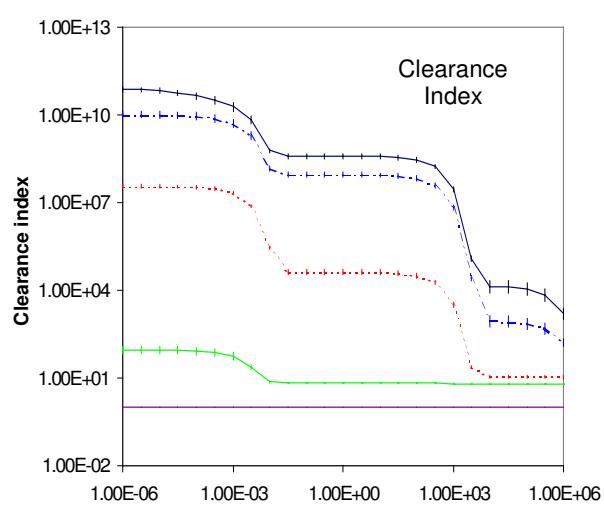
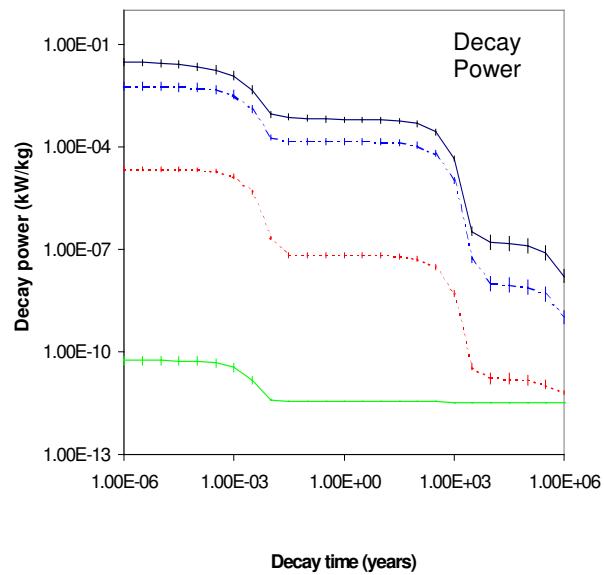
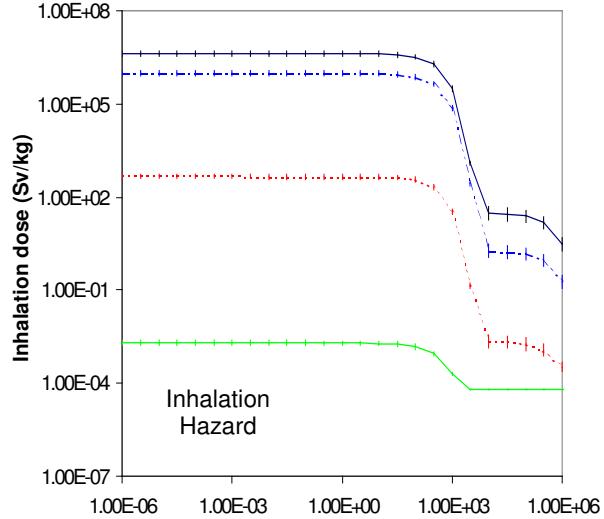
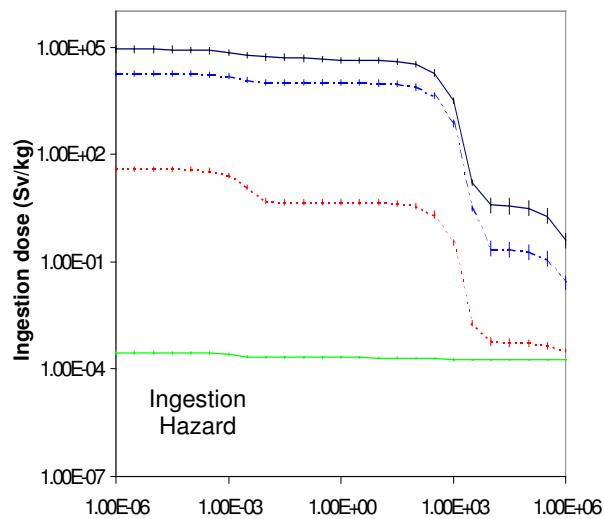
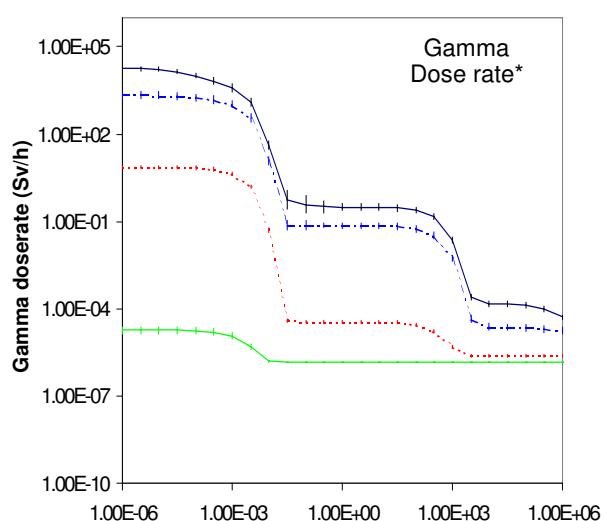
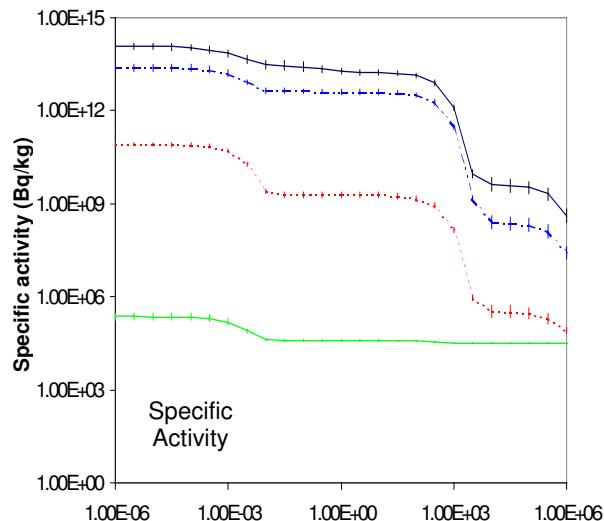
Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.28E14	1.20E14	3.08E13	1.84E13	1.37E13	3.32E9	kW kg <sup>-1</sup>	3.13E-2	2.85E-2	9.05E-4	6.24E-4	4.80E-4	1.31E-7
K42	53.01	55.90	1.62				K42	59.43	64.81	15.11			
Ar39	13.89	14.72	57.54	96.26	99.97		Cl38	14.22	14.13				
S35	8.05	8.53	32.39	3.10			K38	9.59	6.51				
Ar41	7.33	7.51					Ar41	8.38	8.89				
Cl38	7.21	6.92					Cl39	2.64	2.71				
K38	3.34	2.19					Ar39	1.99	2.18	68.67	99.24	99.97	
Cl38m	2.22						K38m	1.42					
Cl39	1.78	1.76					Cl38m	0.98					
Ar37	1.14	1.21	4.39	0.01			S35	0.26	0.28	8.63	0.71		
P32	0.51	0.54	1.77				P32	0.23	0.25	6.71			
P33	0.50	0.53	1.89				P33	0.03	0.03	0.79			
Cl36			0.01	0.02	0.03	99.76	Cl36			0.02	0.03	0.03	99.93
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	1.93E4	1.64E4	4.49E1	3.13E-1	2.43E-1	1.32E-4	Sv kg <sup>-1</sup>	8.56E4	8.52E4	5.19E4	4.29E4	3.29E4	3.09E0
K42	31.15*	36.51*	98.60*	0.07	0.01		Ar39	49.72	49.96	81.92	98.96	99.99	
Cl38	21.91	23.39					K42	34.01	34.00	0.41			
K38	19.65	14.33					S35	9.24	9.29	14.79	1.02		
Ar41	17.60	20.05					Ar41	3.28	3.19				
Cl39	4.68	5.17					P32	1.83	1.83	2.52			
Cl38m	2.24						Cl38	1.29	1.18				
Cl40	1.07	0.08					Cl39	0.23	0.21				
Ar39			0.70*	99.87*	99.92*		K38	0.18	0.18	0.27			
Cl36				0.04*	0.05*	71.12*	Cl36	0.01	0.01	0.01	0.01	0.01	99.79
K40				0.01	0.01	28.78*	K40						0.17
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	4.29E6	4.29E6	4.28E6	4.25E6	3.29E6	2.42E1		7.92E10	6.78E10	6.12E8	3.85E8	2.98E8	1.12E4
Ar39	99.17	99.17	99.48	99.97	100.0		K42	37.15	43.20	35.36			
S35	0.46	0.46	0.44	0.03			Cl38	19.04	20.18				
K42	0.19	0.19					K38	17.93	12.98				
P32	0.05	0.05	0.04				Ar41	15.75	17.81				
Cl36					99.99		Cl39	4.40	4.82				
							Cl38m	2.39					
							K38m	1.32					
							Ar39	0.49	0.57	62.94	99.94	100.0	
							Cl36						98.42
							K40						1.53

# Potassium

## Pathway analysis

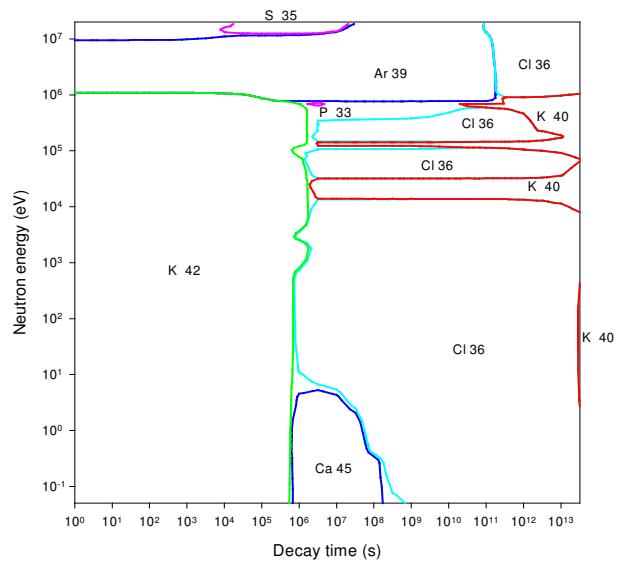
Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
K38	7.61 m	K39(n,2n)K38				100.0
Cl38	37.2 m	&K39(n, $\gamma$ )K40(n, $\alpha$ )Cl37(n, $\gamma$ )Cl38 &K39(n, $\alpha$ )Cl36(n, $\gamma$ )Cl37(n, $\gamma$ )Cl38 &K40(n, $\alpha$ )Cl37(n, $\gamma$ )Cl38 &K39(n,p)Ar39(n,d)Cl38 &K41(n, $\alpha$ )Cl38 &K39(n,d)Ar38(n,p)Cl38 &K39(n,p)Ar39(n,2n)Ar38(n,p)Cl38	95.0 4.9	93.7 0.5 5.7	75.8 24.2	57.3 20.0 18.4 1.6
Ar41	1.827 h	K39(n, $\gamma$ )K40(n,p)Ar40(n, $\gamma$ )Ar41 K40(n,p)Ar40(n, $\gamma$ )Ar41 K41(n,p)Ar41	99.9 0.1	94.2 5.8	75.8 24.2	100.0
K42	12.37 h	K39(n, $\gamma$ )K40(n, $\gamma$ )K41(n, $\gamma$ )K42 K41(n, $\gamma$ )K42	52.9 46.9	0.2 99.8	100.0	96.7
P32	14.27 d	K39(n, $\alpha$ )Cl36( $\beta^-$ )Ar36(n, $\gamma$ )Ar37(n, $\alpha$ )S34(n,g)S35( $\beta^-$ ) Cl35(n, $\alpha$ )P32 K39(n, $\alpha$ )Cl36(n,n $\alpha$ )P32 K39(n,n $\alpha$ )Cl35(n, $\alpha$ )P32 K39(n,p)Ar39(n,n $\alpha$ )S35( $\beta^-$ )Cl35(n, $\alpha$ )P32 K39(n, $\alpha$ )Cl36(n,2n)Cl35(n, $\alpha$ )P32 K39(n,p $\alpha$ )S35( $\beta^-$ )Cl35(n, $\alpha$ )P32	99.1			63.6 24.9 3.7 3.3 1.5
P33	25.4 d	K39(n, $\alpha$ )Cl36(n, $\alpha$ )P33 K39(n,d)Ar38(n,n $\alpha$ )S34(n,d)P33 K41(n,n $\alpha$ )Cl37(n,n $\alpha$ )P33	99.3	100.0	100.0	95.8 1.4 1.4
Ar37	35.04 d	K39(n, $\alpha$ )Cl36( $\beta^-$ )Ar36(n, $\gamma$ )Ar37 K39(n,d)Ar38(n,2n)Ar37 K39(n,p)Ar39(n,2n)Ar38(n,2n)Ar37 K39(n,t)Ar37 K39(n,2n)K38( $\beta^+$ )Ar38(n,2n)Ar37	100.0	100.0	100.0	86.4 7.0 2.8 2.1
Sc46	83.79 d	&K41(n, $\gamma$ )K42( $\beta^-$ )Ca42(n, $\gamma$ )Ca43(n, $\gamma$ )Ca44(n, $\gamma$ ) Ca45( $\beta^-$ )Sc45(n, $\gamma$ )Sc46 &K39(n, $\gamma$ )K40(n, $\gamma$ )K41(n, $\gamma$ )K42( $\beta^-$ )Ca42(n, $\gamma$ ) Ca43(n, $\gamma$ )Ca44(n, $\gamma$ )Ca45( $\beta^-$ )Sc45(n, $\gamma$ )Sc46	91.1 8.5	99.6	99.9	98.8
S35	87.5 d	K39(n, $\alpha$ )Cl36( $\beta^-$ )Ar36(n, $\gamma$ )Ar37(n, $\alpha$ )S34(n, $\gamma$ )S35 K39(n,p)Ar39(n,n $\alpha$ )S35 K39(n, $\alpha$ )Cl36(n,d)S35 K39(n,p $\alpha$ )S35 K39(n,d)Ar38(n, $\alpha$ )S35 K39(n,n $\alpha$ )Cl35(n,p)S35	99.6	100.0	100.0	59.5 11.9 11.9 8.9 3.4
Ca45	162.7 d	K41(n, $\gamma$ )K42( $\beta^-$ )Ca42(n, $\gamma$ )Ca43(n, $\gamma$ )Ca44(n, $\gamma$ )Ca45 K39(n, $\gamma$ )K40(n, $\gamma$ )K41(n, $\gamma$ )K42( $\beta^-$ )Ca42(n, $\gamma$ )Ca43(n, $\gamma$ ) Ca44(n, $\gamma$ )Ca45	87.7 11.9	99.7	99.9	99.1
Ar42	33.0 y	K39(n, $\gamma$ )K40(n,p)Ar40(n, $\gamma$ )Ar41(n, $\gamma$ )Ar42 K40(n,p)Ar40(n, $\gamma$ )Ar41(n, $\gamma$ )Ar42 K41(n, $\gamma$ )K42(n,p)Ar42 K41(n,p)Ar41(n, $\gamma$ )Ar42	99.8 0.2	91.1 8.3 0.5	26.2 12.5 61.3	81.7 16.8
Ar39	269 y	&K39(n, $\gamma$ )K40(n, $\alpha$ )Cl37(n, $\gamma$ )Cl38( $\beta^-$ )Ar38(n, $\gamma$ )Ar39 &K39(n, $\alpha$ )Cl36(n, $\gamma$ )Cl37(n, $\gamma$ )Cl38( $\beta^-$ )Ar38(n, $\gamma$ )Ar39 &K40(n, $\alpha$ )Cl37(n, $\gamma$ )Cl38( $\beta^-$ )Ar38(n, $\gamma$ )Ar39 K39(n,p)Ar39	95.4 4.4 0.2	17.4 0.1 2.0 78.0	100.0	99.3
Cl36	$3.0 \cdot 10^5$ y	K39(n, $\alpha$ )Cl36	100.0	100.0	100.0	99.5
K40	$1.28 \cdot 10^9$ y	K39(n, $\gamma$ )K40 K41(n,2n)K40 (*Remaining percentage originates from K40 present in starting material)	100.0	97.1*	86.2*	2.2* 94.2*

# Potassium activation characteristics

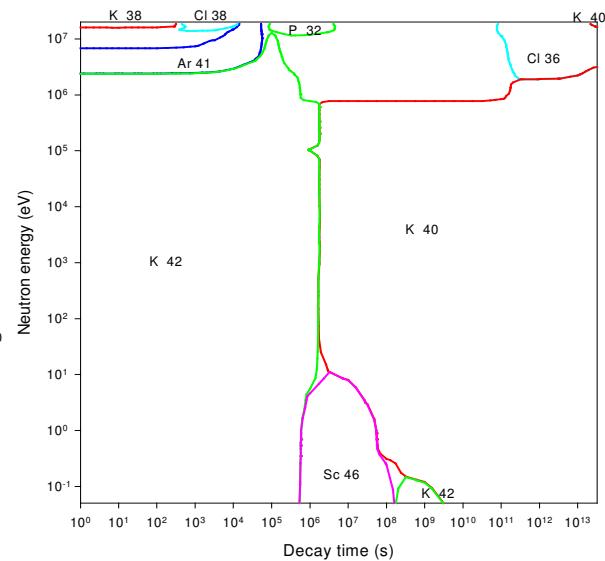


# Potassium importance diagrams & transmutation

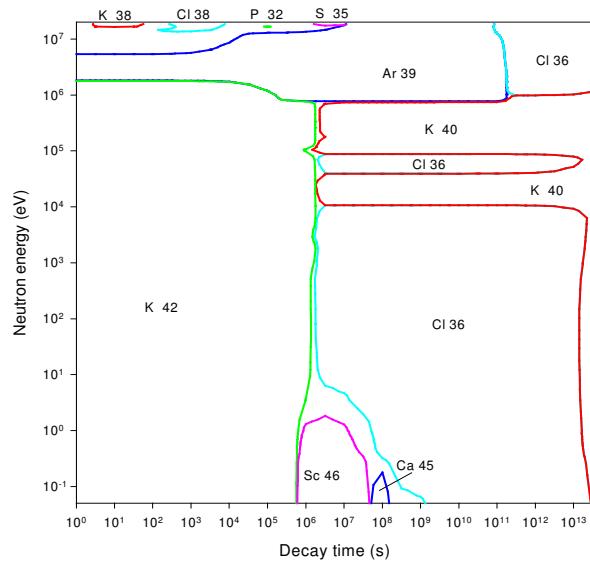
## Activity



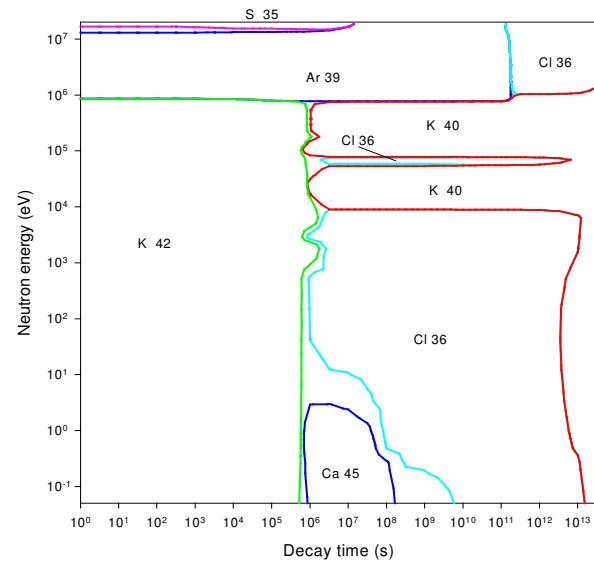
## Dose rate



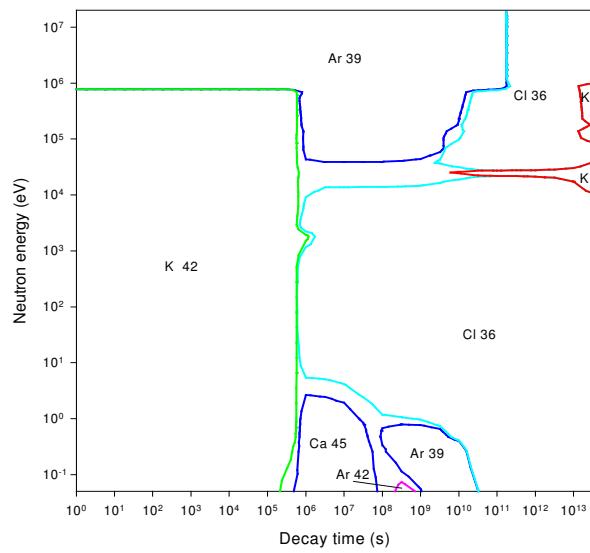
## Heat output



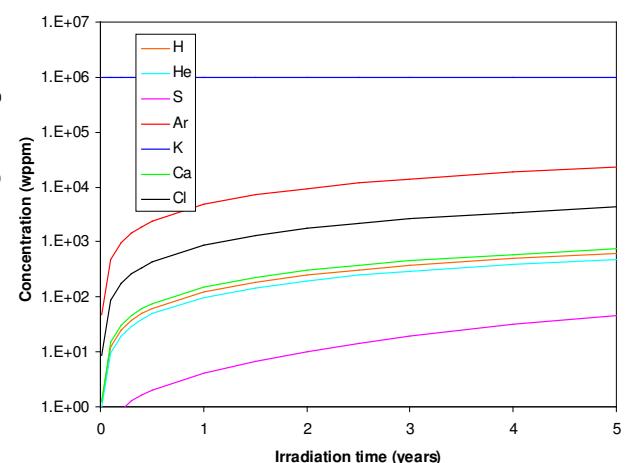
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Calcium

## General properties

		20	Isotopes	Isotopic abundances / %	
Atomic number				Ca40	96.941
Crustal abundance / wppm		4.10 10 <sup>4</sup>		Ca42	0.647
Melting point / K		1112		Ca43	0.135
Boiling point / K		1757		Ca44	2.086
Density / kgm <sup>-3</sup>		1550		Ca46	0.004
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>		200		Ca48	0.187
Electrical resistivity /Ωm		3.43 10 <sup>-8</sup>			
Coefficient of thermal expansion / K <sup>-1</sup>		2.2 10 <sup>-5</sup>			
Crystal structure		FCC			
Number of stable isotopes		6			
Mean atomic weight		40.078			

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	4.46E14	4.45E14	4.06E14	1.65E12	5.86E11	1.15E9	kW kg <sup>-1</sup>	4.23E-3	3.67E-3	7.98E-4	3.25E-5	2.04E-5	3.79E-9
Ar37	95.94	96.19	98.01	18.90			K44	24.77	24.2				
Sc47	0.74	0.74	0.70				K42	20.18	23.13	0.79	0.02		
Ca47	0.74	0.74	0.46				Ca47	17.50	20.15	53.12			
K42	0.70	0.70	0.01				Ar41	8.04	8.96				
Ca45	0.45	0.45	0.48	25.57			Ar37	4.34	5.00	21.41	0.41		
K44	0.38	0.33					P34	3.72					
Ar41	0.27	0.26					S37	3.59	1.99				
Ar39	0.17	0.17	0.19	45.63	99.53		Cl38	3.49	3.65				
S35	0.07	0.07	0.08	1.05			Sc47	3.39	3.90	15.47			
H3	0.03	0.03	0.04	8.61	0.09		K38	2.27	1.62				
Ca41				0.13	0.36	93.26	K43	2.22	2.55	0.76			
Cl36				0.01	0.02	6.53	Ca49	1.81	1.37				
K40						0.21	Ar39	0.62	0.72	3.31	80.99	99.97	
							Ca45	0.58	0.67	33.05	16.03		
							Sc46	0.27	0.31	1.40	1.72		
							Cl36				0.01	0.02	78.22
							Ca41					0.01	14.88
							K40						6.90
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	3.71E3	3.19E3	5.96E2	8.55E-1	9.70E-3	1.26E-4	Sv kg <sup>-1</sup>	2.47E4	2.46E4	1.93E4	2.14E3	1.40E3	2.88E-1
K44	31.59	31.17					Ar37	48.57	48.67	57.88	0.41		
Ca47	25.45	29.59	90.78				Ca47	21.33	21.37	15.64			
Ar41	11.55	13.00					Ar39	7.34	7.35	9.40	84.53	99.96	
K42	7.24*	8.39*	0.33	0.20	2.24		Sc47	7.23	7.25	7.97			
S37	6.38	3.57					Ca45	5.75	5.76	7.25	14.01		
Cl38	3.68	3.88					K42	5.42	5.41	0.05			
Ca49	3.19	2.44					Ar41	1.48	1.43				
K38	3.19	2.30					S35	0.98	0.98	1.22	0.63		
K43	2.34	2.72	0.95				K44	0.58	0.50				
P34	1.05						K43	0.47	0.47	0.04			
Cl39	1.01	1.10					Sc46	0.21	0.21	0.26	0.12		
Sc47	0.83	0.97	4.45				Ca41				0.02	0.03	70.61
Sc46	0.46	0.54	2.80	98.06			Cl36					0.01	24.22
Ar39				1.41*	96.29*		K40						5.17
K40				0.01	1.11*	85.36*							
Ca41					0.33	13.09							
Cl36					0.03*	1.54*							

Inh	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>	Clear	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>
Sv kg <sup>-1</sup>	3.28E5	3.28E5	3.15E5	1.82E5	1.40E5	7.46E-1		1.50E10	1.30E10	2.77E9	2.01E7	1.27E7	1.52E3
Ar39	55.14	55.15	57.50	99.03	100.0		K44	29.31	28.64				
Ar37	39.12	39.12	37.95	0.05			Ca47	24.18	27.84	74.60			
Ca45	2.25	2.25	2.31	0.86			Ar41	10.83	12.07				
Ca47	2.11	2.10	1.26				K42	9.05	10.37	0.36	0.04	0.01	
Sc47	0.74	0.74	0.66				S37	5.15	2.86				
S35	0.18	0.18	0.18	0.02			Cl38	3.35	3.50				
Ar41	0.16	0.15					K43	3.07	3.53	1.07			
K42	0.11	0.11					K38	3.05	2.18				
Sc46	0.07	0.07	0.07	0.01			Sc47	2.76	3.18	12.81			
Cl36					73.47		Ca49	2.55	1.94				
Ca41					25.85		Ar37	1.59	1.83	7.97	0.86		
K40					0.68		P34	1.47					
							Cl39	0.99	1.07				
							Sc46	0.46	0.53	2.41	16.74		
							Ar39	0.11	0.13	0.59	81.39	99.97	
							Ca41				0.01	0.01	50.49
							K40						33.01
							Cl36						16.51

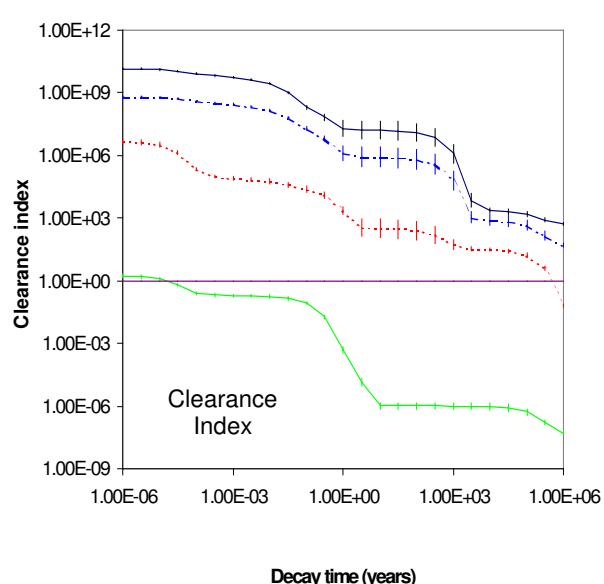
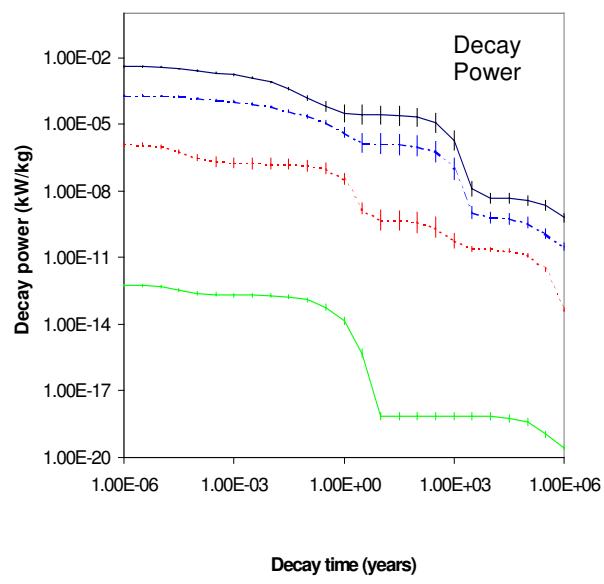
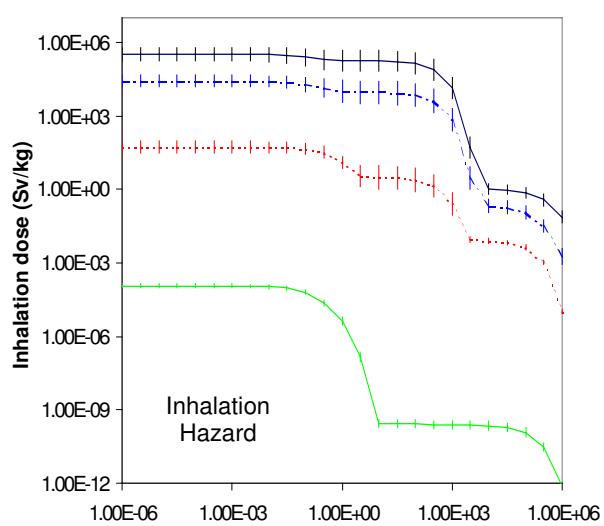
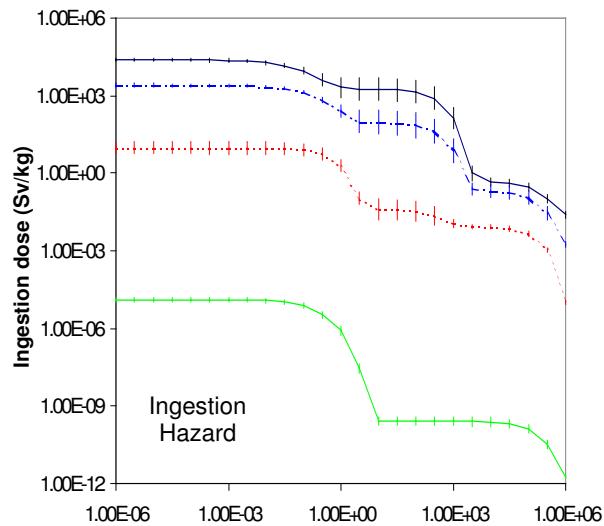
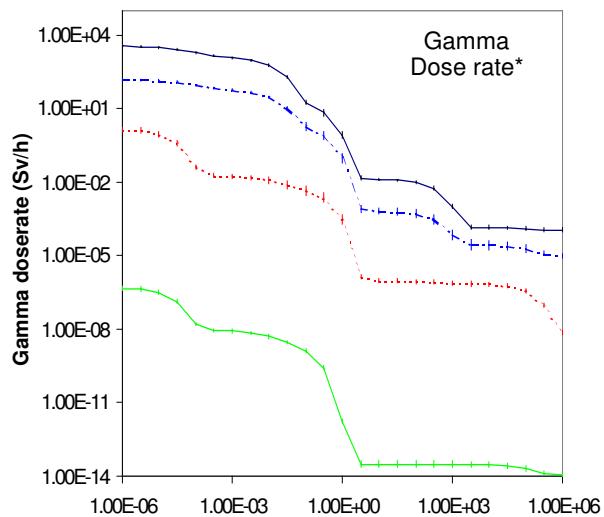
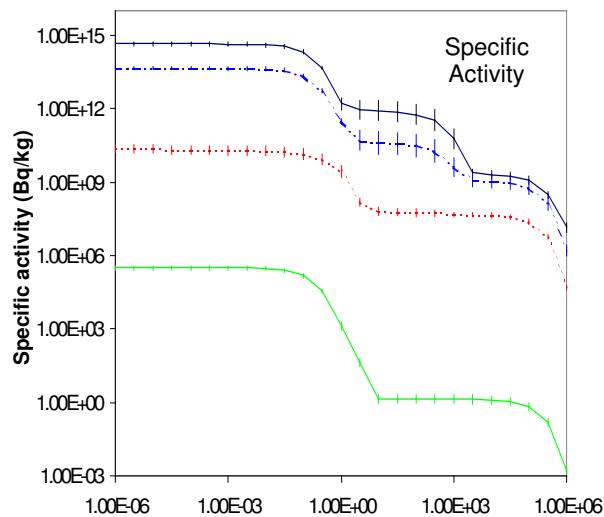
# Calcium

## Pathway analysis

Nuclide	T <sub>1/2</sub>	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
S37	4.99 m	Ca40(n, $\alpha$ )Ar37(n, $\alpha$ )S34(n, $\gamma$ )S35(n, $\gamma$ )S36(n, $\gamma$ )S37 Ca40(n, $\alpha$ )Ar37(n, $\alpha$ )S34(n, $\gamma$ )S35( $\beta^-$ )Cl35(n, $\gamma$ ) Cl36(n,p)S36(n, $\gamma$ )S37 Ca40(n, $\alpha$ )Ar37( $\beta^+$ )Cl37(n,p)S37 Ca40(n,p)K40(n, $\alpha$ )Cl37(n,p)S37	69.9 29.7	99.3		97.1 1.8
K38	7.61 m	Ca40(n,d)K39(n,2n)K38 Ca40(n,t)K38				78.2 21.3
Ca49	8.72 m	Ca48(n, $\gamma$ )Ca49	100.0	100.0	100.0	99.9
Cl38	37.2 m	&Ca40(n, $\alpha$ )Ar37( $\beta^+$ )Cl37(n, $\gamma$ )Cl38 &Ca40(n, $\alpha$ )Ar37(n,p)Cl37(n, $\gamma$ )Cl38 &Ca40(n,2p)Ar39(n,d)Cl38 &Ca40(n,d)K39(n,p)Ar39(n,d)Cl38 &Ca40(n,d)K39(n,d)Ar38(n,p)Cl38 &Ca40(n,p)K40(n,d)Ar39(n,d)Cl38 &Ca40(n,2p)Ar39(n,2n)Ar38(n,p)Cl38	88.5 11.2	99.6 0.4	100.0	62.4 19.8 6.3 4.1 1.7
K42	12.37 h	Ca40(n, $\gamma$ )Ca41(n,p)K41(n, $\gamma$ )K42 Ca40(n, $\gamma$ )Ca41( $\beta^+$ )K41(n, $\gamma$ )K42 Ca42(n,p)K42 Ca44(n,2n)Ca43(n,d)K42 Ca43(n,d)K42	93.6 6.4	30.1 69.0	4.7 95.3	93.5 3.1 1.5
K43	22.2 h	Ca40(n, $\gamma$ )Ca41(n,p)K41(n, $\gamma$ )K42(n, $\gamma$ )K43 Ca40(n, $\gamma$ )Ca41( $\beta^+$ )K41(n, $\gamma$ )K42(n, $\gamma$ )K43 &Ca44(n, $\gamma$ )Ca45( $\beta^-$ )Sc45(n, $\gamma$ )Sc46(n, $\alpha$ )K43 Ca44(n,2n)Ca43(n,p)K43 Ca43(n,p)K43 Ca44(n,d)K43	93.7 6.4	29.7 69.1 1.2	4.6 93.3 2.1	63.0 29.8 6.8
Ca47	4.538 d	Ca44(n, $\gamma$ )Ca45(n, $\gamma$ )Ca46(n, $\gamma$ )Ca47 Ca46(n, $\gamma$ )Ca47 Ca48(n,2n)Ca47	77.1 22.2	0.5 99.5	100.0	99.8
Ar37	35.04 d	Ca40(n, $\alpha$ )Ar37	100.0	100.0	100.0	99.3
Sc46	83.79 d	&Ca44(n, $\gamma$ )Ca45( $\beta^-$ )Sc45(n, $\gamma$ )Sc46 &Ca43(n, $\gamma$ )Ca44(n, $\gamma$ )Ca45( $\beta^-$ )Sc45(n, $\gamma$ )Sc46 &Ca48(n,2n)Ca47( $\beta^-$ )Sc47( $\beta^-$ )Ti47(n,d)Sc46 &Ca48(n,2n)Ca47( $\beta^-$ )Sc47( $\beta^-$ )Ti47(n,2n) Ti46(n,p)Sc46 &Ca48(n,2n)Ca47( $\beta^-$ )Sc47(n,2n)Sc46	98.6 1.3	100.0	100.0	94.0 2.6 1.8
S35	87.5 d	Ca40(n, $\alpha$ )Ar37(n, $\alpha$ )S34(n, $\gamma$ )S35 Ca40(n,2p)Ar39(n,n $\alpha$ )S35 Ca40(n,d)K39(n,p)Ar39(n,n $\alpha$ )S35 Ca40(n,d)K39(n,p $\alpha$ )S35 Ca40(n,p)K40(n,d)Ar39(n,n $\alpha$ )S35 Ca40(n, $\alpha$ )Ar37( $\beta^+$ )Cl37(n,d)S36(n,2n)S35 Ca40(n,d)K39(n, $\alpha$ )Cl36(n,d)S35 Ca40(n,n $\alpha$ )Ar36(n,2p)S35 Ca40(n,d)K39(n,d)Ar38(n, $\alpha$ )S35 Ca40(n, $\alpha$ )Ar37( $\beta^+$ )Cl37(n,2n)Cl36(n,d)S35 Ca40(n,p $\alpha$ )Cl36(n,d)S35 Ca40(n,p)K40(n,n $\alpha$ )Cl36(n,d)S35 Ca40(n, $\alpha$ )Ar37( $\beta^+$ )Cl37(n,t)S35	99.3	100.0	100.0	51.4 15.3 6.0 3.1 3.1 3.0 2.8 2.3 2.2 1.6 1.2 1.1
Ca45	162.7 d	Ca44(n, $\gamma$ )Ca45 Ca43(n, $\gamma$ )Ca44(n, $\gamma$ )Ca45 Ca46(n,2n)Ca45 Ca48(n, $\alpha$ )Ar45( $\beta^-$ )K45( $\beta^-$ )Ca45	97.7 2.1	99.9	100.0	25.8 69.7 3.0

H3	12.33 y	Ca40(n, $\alpha$ )Ar37(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Ca40(n, $\gamma$ )Ca41(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Ca40(n,X)H3 Ca40(n, $\alpha$ )Ar37( $\beta^+$ )Cl37(n,X)H3 Ca40(n,d)K39(n,X)H3 Ca40(n,X)He3(n,p)H3 Ca44(n,2n)Ca43(n,X)H3 Ca40(n,2p)Ar39(n,X)H3 Ca43(n,X)H3	53.8 41.0	80.1 15.4	86.4 12.2	77.8 8.4 4.3 1.8 1.7 1.6 1.5
Ar39	269 y	Ca40(n, $\gamma$ )Ca41(n, $\alpha$ )Ar38(n, $\gamma$ )Ar39 Ca40(n, $\alpha$ )Ar37( $\beta^+$ )Cl37(n, $\gamma$ )Cl38( $\beta^-$ )Ar38(n, $\gamma$ )Ar39 Ca40(n, $\alpha$ )Ar37(n, $\gamma$ )Ar38(n, $\gamma$ )Ar39 Ca42(n, $\alpha$ )Ar39 Ca40(n,2p)Ar39 Ca40(n,d)K39(n,p)Ar39 Ca40(n,p)K40(n,d)Ar39	93.6 4.7 0.4	83.2 12.8 1.4 0.9	100.0	71.2 22.6 4.7
Ca41	$1.03 \cdot 10^5$ y	Ca40(n, $\gamma$ )Ca41 Ca42(n,2n)Ca41	100.0	100.0	100.0	10.9 87.2
Cl36	$3.0 \cdot 10^5$ y	Ca40(n, $\alpha$ )Ar37(n, $\alpha$ )S34(n, $\gamma$ )S35( $\beta^-$ )Cl35(n, $\gamma$ )Cl36 Ca42(n, $\alpha$ )Ar39( $\beta^-$ )K39(n, $\alpha$ )Cl36 Ca40(n,d)K39(n, $\alpha$ )Cl36 Ca40(n, $\alpha$ )Ar37( $\beta^+$ )Cl37(n,2n)Cl36 Ca40(n,p $\alpha$ )Cl36 Ca40(n,p)K40(n,n $\alpha$ )Cl36 Ca40(n,n $\alpha$ )Ar36(n,p)Cl36 Ca40(n, $\alpha$ )Ar37(n,d)Cl36	100.0	100.0	91.5 8.5	35.9 25.6 18.2 13.7 4.5 1.6
K40	$1.28 \cdot 10^9$ y	Ca40(n, $\gamma$ )Ca41(n, $\alpha$ )Ar38(n, $\gamma$ )Ar39( $\beta^-$ )K39(n, $\gamma$ )K40 &Ca40(n, $\alpha$ )Ar37( $\beta^+$ )Cl37(n, $\gamma$ )Cl38( $\beta^-$ )Ar38(n, $\gamma$ ) Ar39( $\beta^-$ )K39(n, $\gamma$ )K40 Ca40(n, $\alpha$ )Ar37(n, $\gamma$ )Ar38(n, $\gamma$ )Ar39( $\beta^-$ )K39(n, $\gamma$ )K40 Ca42(n, $\alpha$ )Ar39( $\beta^-$ )K39(n, $\gamma$ )K40 Ca40(n,p)K40	93.6 5.1 0.6	79.7 13.2 2.5 4.5	100.0	99.9

# Calcium activation characteristics

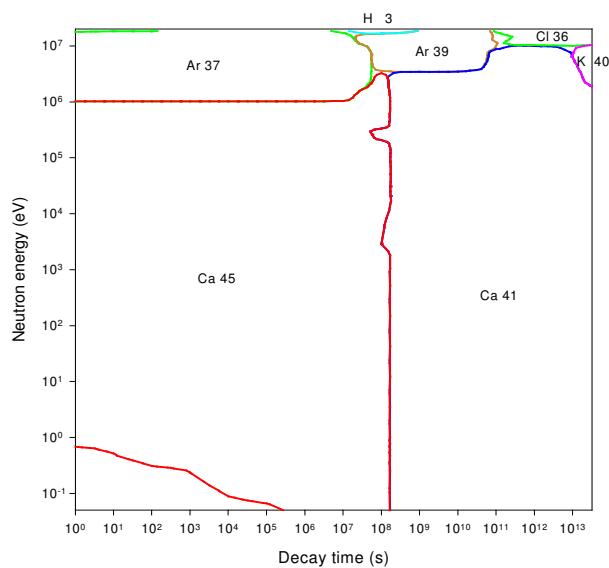


Decay time (years)

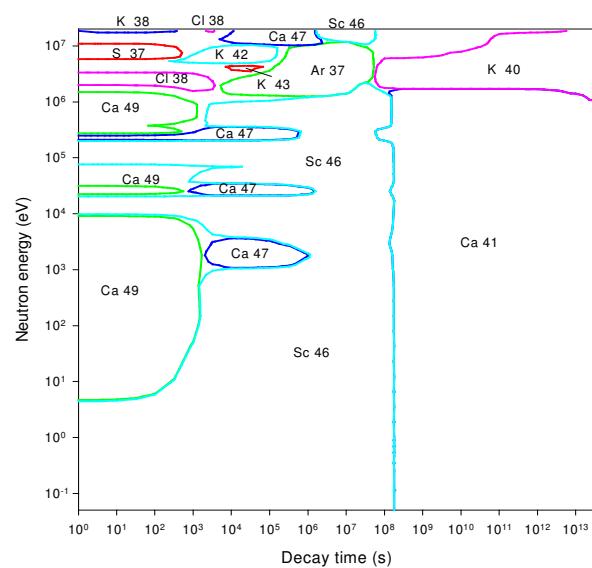
Decay time (years)

# Calcium importance diagrams & transmutation

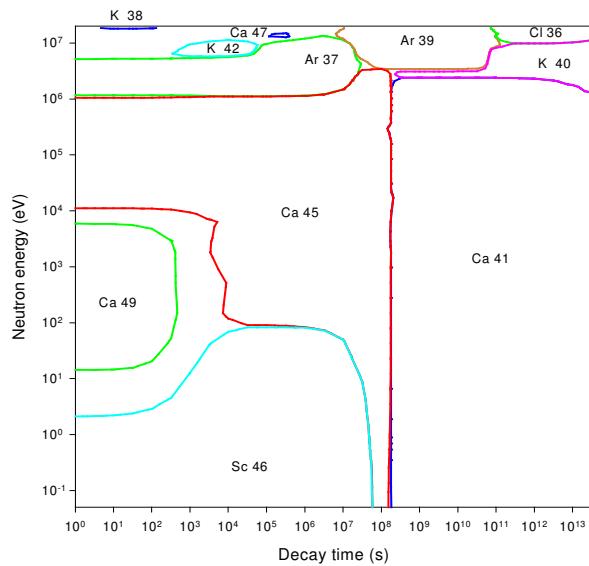
## Activity



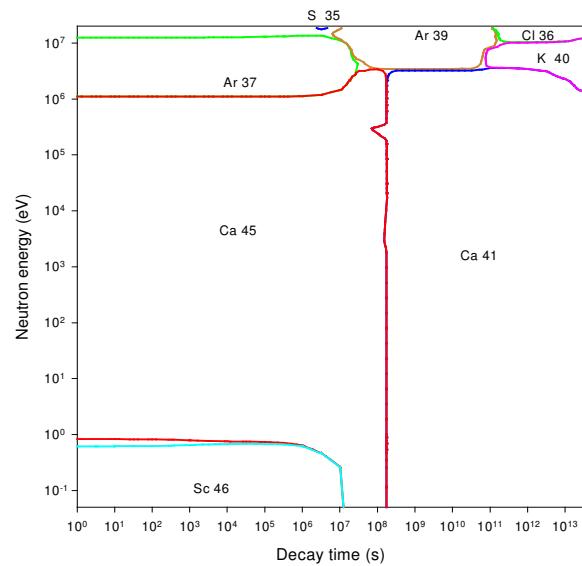
## Dose rate



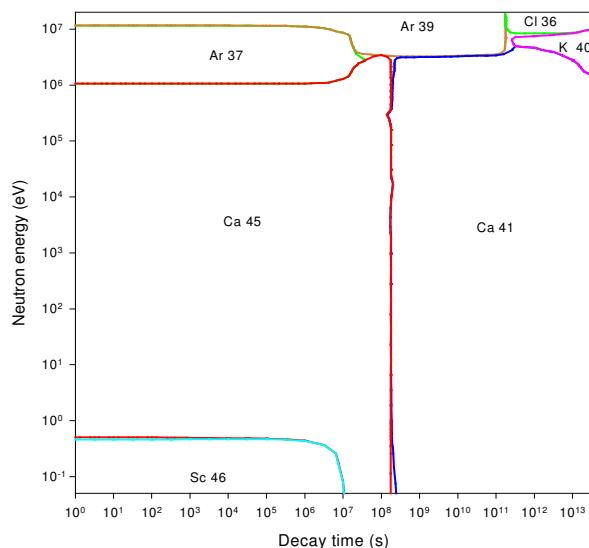
## Heat output



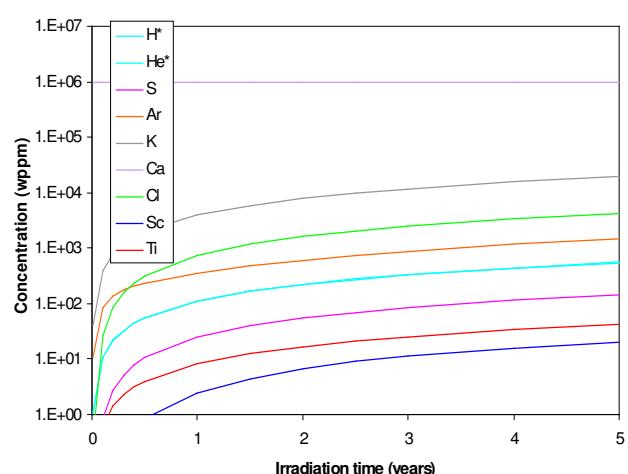
## Ingestion dose



## Inhalation dose



## First wall transmutation



\*Graphs for He and H are indistinguishable

# Scandium

## General properties

		21	Isotopes	Isotopic abundances / %	
Crustal abundance / wppm		22	Sc45	100.0	
Melting point / K		1814			
Boiling point / K		3103			
Density / kgm <sup>-3</sup>		2989			
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>		15.8			
Electrical resistivity /Ωm		6.10 10 <sup>-7</sup>			
Coefficient of thermal expansion / K <sup>-1</sup>		1.02 10 <sup>-5</sup>			
Crystal structure		HCP			
Number of stable isotopes		1			
Mean atomic weight		44.95591			

## Activation properties

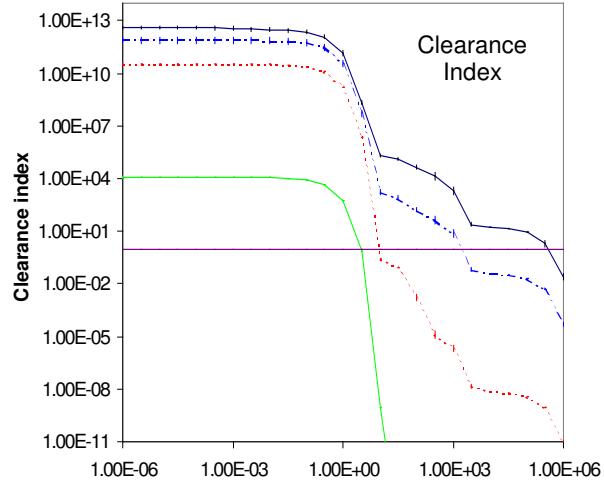
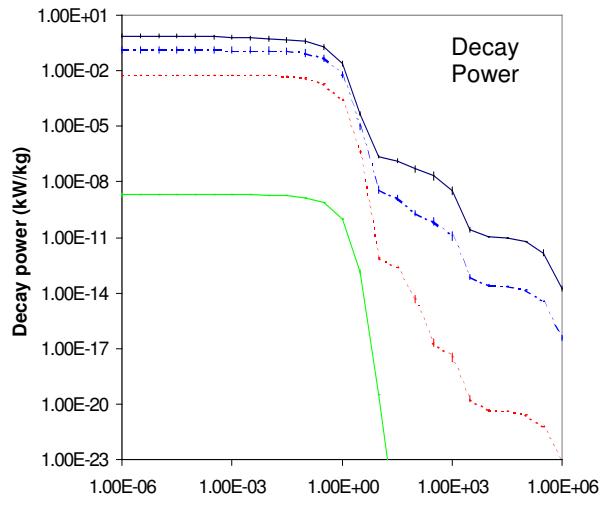
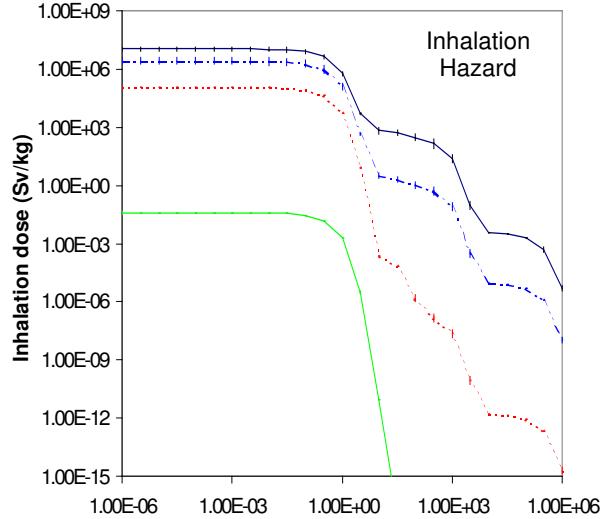
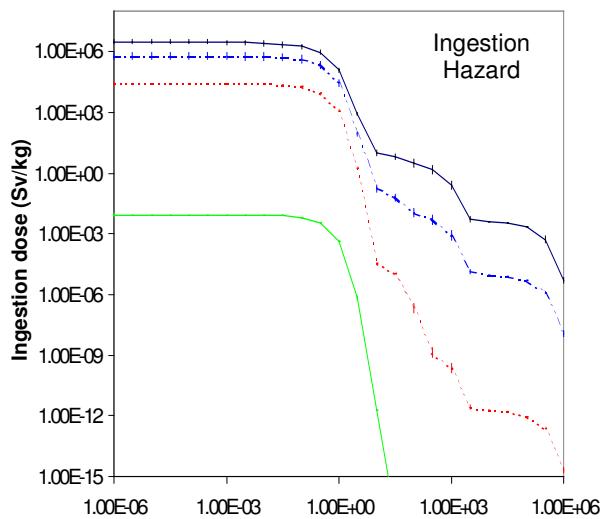
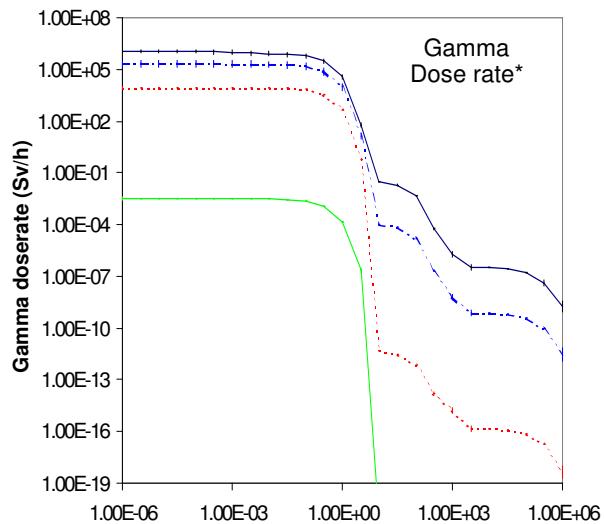
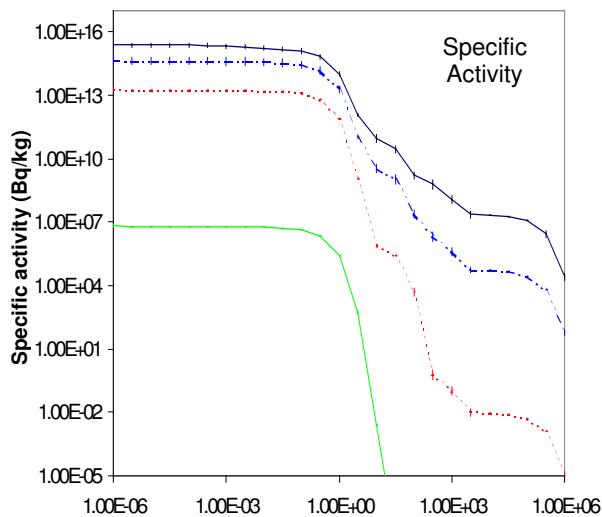
Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	5.03E15	2.39E15	1.73E15	1.02E14	1.71E9	1.18E7	kW kg <sup>-1</sup>	7.75E-1	7.54E-1	5.32E-1	2.53E-2	5.24E-8	6.20E-12
Sc45m	39.0						Sc46	66.19	67.97	93.55	98.62		
Sc46	29.97	63.02	84.70	72.18			Sc44	26.03	26.48	5.51			
Sc46m	13.29						K42	3.91	4.00	0.04		26.98	
Sc44	9.15	19.07	3.87				Sc46m	1.96					
Sc44m	3.58	7.52	3.70				Sc44m	1.15	1.18	0.59			
Ca45	2.66	5.58	7.61	27.68			Sc45m	0.37					
K42	2.19	4.59	0.05		3.02		Ca45	0.21	0.22	0.31	1.38		
H3		0.01	0.01	0.14	32.70		Ar39					68.36	
Ar39					59.91		Ar42					3.67	
Ar42					3.02		H3					0.97	
Ca41					1.35	100.0	Ca41					0.02	99.80
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	1.08E6	1.08E6	8.32E5	3.99E4	4.76E-3	1.75E-7	Sv kg <sup>-1</sup>	3.00E6	3.00E6	2.47E6	1.30E5	2.97E0	2.24E-3
Sc46	75.49	76.01	95.44	100.0			Sc46	75.41	75.47	89.01	84.62		
Sc44	22.26	22.20	4.21		0.01		Sc44m	14.41	14.41	6.22			
K42	0.94	0.94	0.01		99.62*		Sc44	5.37	5.33	0.95			
Sc44m	0.72	0.73	0.33				Ca45	3.16	3.17	3.79	15.36		
Sc46m	0.45						K42	1.58	1.58	0.01		0.75	
K44	0.09	0.07					Ar39					82.70	
Ca41					0.01	99.17	Ar42					15.62	
K40						0.82	Ca41					0.15	99.98
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	1.11E7	1.11E7	1.05E7	6.05E5	2.96E2	2.12E-3		4.25E12	4.17E12	3.15E12	1.50E11	4.60E4	8.41E0
Sc46	92.38	92.39	94.40	82.63			Sc46	72.48	73.76	94.80	100.0		
Ca45	4.45	4.45	4.62	17.24			Sc44	23.58	23.77	4.62			
Sc44m	2.27	2.27	0.85				Sc46m	1.43					
Sc44	0.75	0.74	0.11				Sc44m	1.18	1.20	0.56			
Ar42				0.07	17.19		K42	1.13	1.14	0.01		48.65	
Ar39				0.05	82.76		Ar39					48.30	
Ca41						99.92	Ar42					2.60	
							Ca41					0.04	99.92

# Scandium

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Sc45m	0.316 s	Sc45(n,n')Sc45m			100.0	99.3
Sc44	3.927 h	Sc45(n,2n)Sc44 Sc45(n,2n)Sc44m(IT)Sc44			61.6 37.7	
K42	12.37 h	Sc45(n, $\alpha$ )K42 Sc45(n,d)Ca44(n,2n)Ca43(n,d)K42			96.4 0.1	
Sc44m	2.442 d	Sc45(n,2n)Sc44m			99.3	
Sc46	83.79 d	Sc45(n, $\gamma$ )Sc46 Sc45(n, $\gamma$ )Sc46m(IT)Sc46	55.6 44.4	55.6 44.4	55.6 44.4	66.3 29.9
Ca45	162.7 d	Sc45(n,p)Ca45	99.0	99.9	100.0	99.8
Co60	5.272 y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0			
H3	12.33 y	Sc45(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Sc45(n, $\gamma$ )Sc46(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Sc45(n, $\gamma$ )Sc46m(IT)Sc46(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 &Sc45(n, $\gamma$ )Sc46(n, $\gamma$ )Sc47( $\beta^-$ )Ti47(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Sc45(n,X)H3 Sc45(n,d)Ca44(n,2n)Ca43(n,X)H3	82.8 4.8 3.8 1.2	95.1	99.3	97.7 0.9
Ar42	33.0 y	Sc45(n,p)Ca45(n, $\alpha$ )Ar42 Sc45(n,d)Ca44(n,h)Ar42 Sc45(n,2n)Sc44( $\beta^+$ )Ca44(n,h)Ar42				93.2 3.4 1.3
Ar39	269.0 y	Sc45(n, $\alpha$ )K42( $\beta^-$ )Ca42(n, $\alpha$ )Ar39 Sc45(n,d)Ca44(n,2n)Ca43(n,n $\alpha$ )Ar39 &Sc45(n,2n)Sc44( $\beta^+$ )Ca44(n,2n)Ca43(n,n $\alpha$ )Ar39				89.5 4.1 2.5
Ca41	$1.03 \cdot 10^5$ y	Sc45(n, $\alpha$ )K42( $\beta^-$ )Ca42(n,2n)Ca41 Sc45(n,d)Ca44(n,2n)Ca43(n,2n)Ca42(n,2n)Ca41				99.1 0.5
Cl36	$3.0 \cdot 10^5$ y	Sc45(n,n $\alpha$ )K41(n,n $\alpha$ )Cl37(n,2n)Cl36 Sc45(n, $\alpha$ )K42( $\beta^-$ )Ca42(n,2n)Ca41(n,d)K40(n,n $\alpha$ )Cl36 Sc45(n,n $\alpha$ )K41(n,2n)K40(n,n $\alpha$ )Cl36 Sc45(n,d)Ca44(n, $\alpha$ )Ar41( $\beta^-$ )K41(n,n $\alpha$ )Cl37(n,2n)Cl36 Sc45(n, $\alpha$ )K42( $\beta^-$ )Ca42(n,n $\alpha$ )Ar38(n,2n)Ar37( $\beta^+$ ) Cl37(n,2n)Cl36 Sc45(n,d)Ca44(n, $\alpha$ )Ar41( $\beta^-$ )K41(n,2n)K40(n,n $\alpha$ )Cl36 Sc45(n, $\alpha$ )K42( $\beta^-$ )Ca42(n,2n)Ca41(n,n $\alpha$ )Ar37( $\beta^+$ ) Cl37(n,2n)Cl36 Sc45(n, $\alpha$ )K42( $\beta^-$ )Ca42(n,n $\alpha$ )Ar38(n,d)Cl37(n,2n)Cl36 &Sc45(n,2n)Sc44( $\beta^+$ )Ca44(n, $\alpha$ )Ar41( $\beta^-$ )K41(n,n $\alpha$ ) Cl37(n,2n)Cl36 &Sc45(n,2n)Sc44( $\beta^+$ )Ca44(n, $\alpha$ )Ar41( $\beta^-$ )K41(n,2n) K40(n,n $\alpha$ )Cl36 Sc45(n, $\alpha$ )K42( $\beta^-$ )Ca42(n,d)K41(n,n $\alpha$ )Cl37(n,2n)Cl36 Sc45(n, $\alpha$ )K42( $\beta^-$ )Ca42(n,d)K41(n,2n)K40(n,n $\alpha$ )Cl36 Sc45(n, $\alpha$ )K42( $\beta^-$ )Ca42(n,2n)Ca41(n,p $\alpha$ )Cl37(n,2n)Cl36				23.3 17.9 17.6 5.9 5.1  4.4 4.3  3.9 3.6  2.7  2.6 2.0 1.4
Fe60	$1.5 \cdot 10^6$ y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0			
K40	$1.28 \cdot 10^9$ y	Sc45(n, $\alpha$ )K42( $\beta^-$ )Ca42(n,2n)Ca41(n,d)K40 Sc45(n,n $\alpha$ )K41(n,2n)K40 Sc45(n,d)Ca44(n, $\alpha$ )Ar41( $\beta^-$ )K41(n,2n)K40 Sc45(n, $\alpha$ )K42( $\beta^-$ )Ca42(n,d)K41(n,2n)K40 Sc45(n,2n)Sc44( $\beta^+$ )Ca44(n, $\alpha$ )Ar41( $\beta^-$ )K41(n,2n)K40 Sc45(n,2n)Sc44m(n,n $\alpha$ )K40				43.3 32.2 10.8 4.8 4.1 1.0

# Scandium activation characteristics

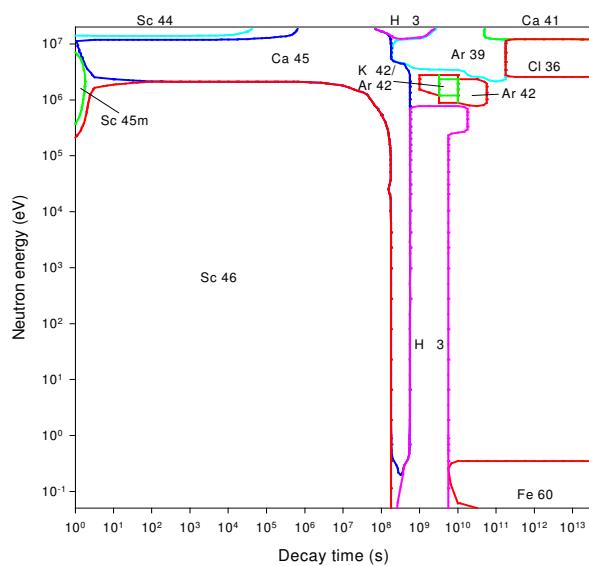


Decay time (years)

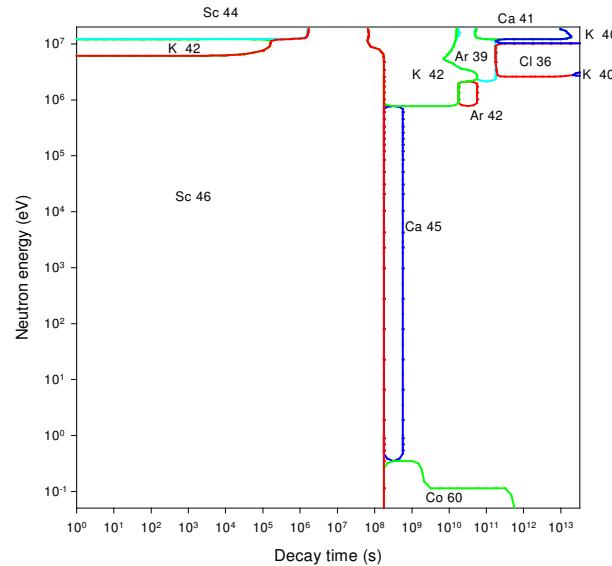
Decay time (years)

# Scandium importance diagrams & transmutation

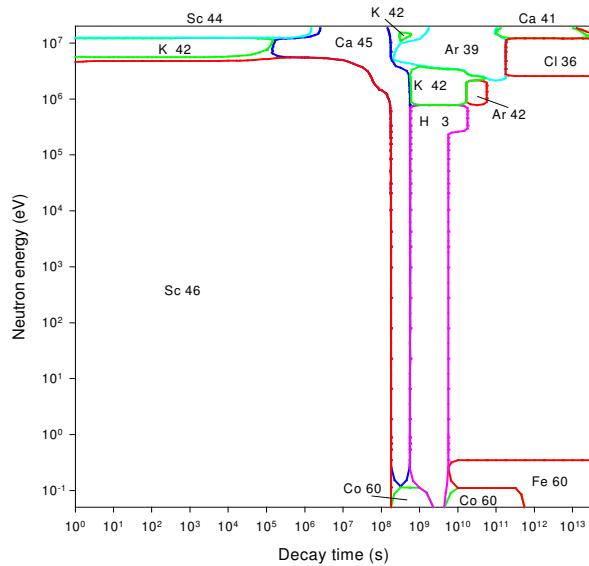
## Activity



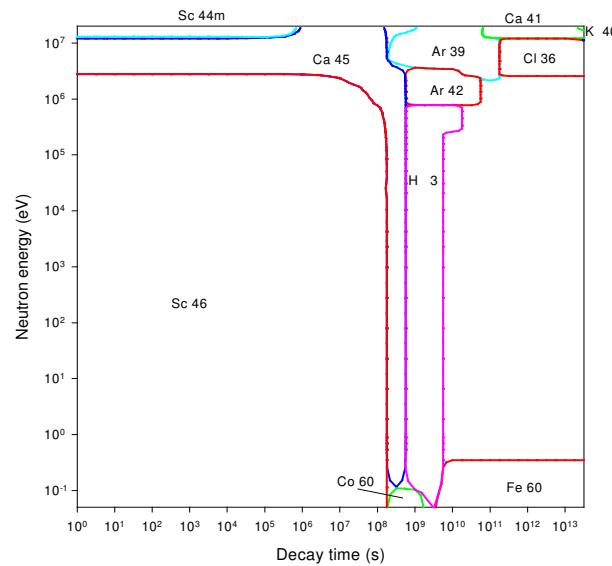
## Dose rate



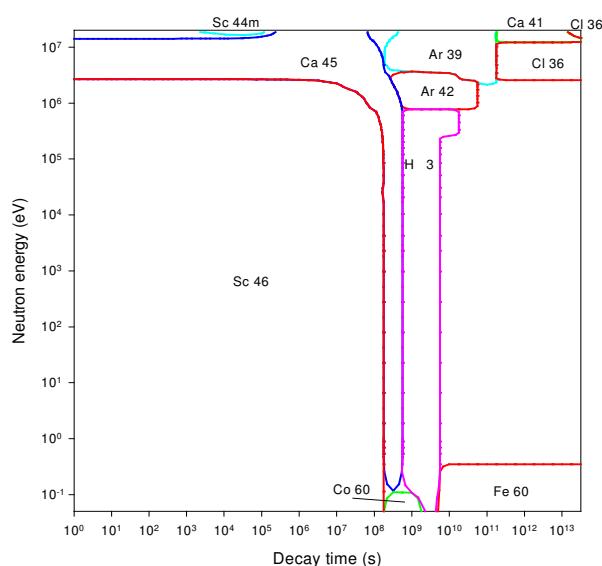
## Heat output



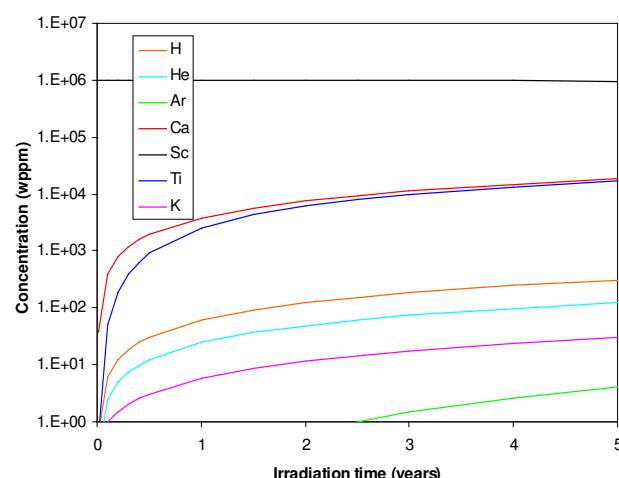
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Titanium

## General properties

	22	Isotopes	Isotopic abundances / %
Atomic number	5.65 10 <sup>3</sup>	Ti46	8.25
Crustal abundance / wppm	1941	Ti47	7.44
Melting point / K	3560	Ti48	73.72
Boiling point / K	4540	Ti49	5.41
Density / kgm <sup>-3</sup>	21.9	Ti50	5.18
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	4.2 10 <sup>-7</sup>		
Electrical resistivity /Ωm	8.60 10 <sup>-6</sup>		
Coefficient of thermal expansion / K <sup>-1</sup>	HCP		
Crystal structure	5		
Number of stable isotopes	47.867		
Mean atomic weight			

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	2.82E14	2.46E14	1.46E14	1.30E13	2.86E8	1.22E5	kW kg <sup>-1</sup>	7.49E-2	7.36E-2	3.25E-2	1.05E-3	6.45E-9	6.42E-14
Sc48	31.36	35.93	15.11				Sc48	67.51	68.62	38.67			
Sc46	19.69	22.59	36.99	20.75			Sc46	25.19	25.64	56.28	87.85		
Ca45	17.26	19.80	32.92	78.78			Sc47	2.58	2.62	2.83			
Sc47	15.78	18.09	14.54				Sc50	1.19	0.14				
Sc45m	7.61						Ca45	0.80	0.82	1.82	12.14		
Sc46m	4.51						Ti45	0.76	0.75				
Sc49	1.43	1.54					Sc49	0.71	0.68				
Ti45	1.01	1.13					Ca47	0.23	0.23	0.30			
K42	0.05	0.05			6.36		K42	0.05	0.05			77.37	
H3	0.02	0.03	0.04	0.47	81.55		H3				0.01	3.30	
Ar42					6.36		Ar42					10.51	
Ar39					5.64		Ar39					8.75	
Ca41					0.08	100.0	Ca41						99.94
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	1.17E5	1.16E5	5.09E4	1.49E3	1.71E-3	1.66E-9	Sv kg <sup>-1</sup>	2.95E5	2.94E5	1.64E5	1.13E4	2.20E-1	2.32E-5
Sc48	71.54	72.17	40.90				Sc48	50.98	50.96	22.73			
Sc46	26.17	26.44	58.36	100.0			Sc46	28.24	28.26	49.10	35.74		
Sc50	0.90	0.11					Ca45	11.72	11.73	20.68	64.22		
Ti45	0.44	0.44					Sc47	8.15	8.15	6.95			
Sc47	0.36	0.36	0.26				K42	0.02	0.02			3.55	
Sc44	0.23	0.23	0.08		0.27		H3				0.02	4.45	
Ca47	0.20	0.20	0.26				Ar42				0.01	74.38	
K42	0.01	0.01			99.70*		Ar39					17.58	
Ca41					99.72	Ca41						0.02	100.0
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	6.90E5	6.89E5	5.84E5	5.65E4	2.19E1	2.20E-5		4.24E11	4.19E11	1.86E11	5.52E9	8.78E3	8.72E-2
Sc46	54.71	54.73	62.67	32.53			Sc48	69.50	70.29	39.31			
Ca45	26.11	26.11	30.34	67.18			Sc46	26.71	27.05	58.92	99.94		
Sc48	14.10	14.09	4.14				Sc47	1.31	1.33	1.42			
Sc47	4.71	4.71	2.65				K42	0.01	0.01			90.08	
Ca47	0.23	0.23	0.15				Ar42					4.82	
Ar42	0.02	0.02	0.03	0.26	82.08		Ar39					3.99	
Ar39				0.01	17.63		H3					0.89	
Ca41					99.98	Ca41							99.97

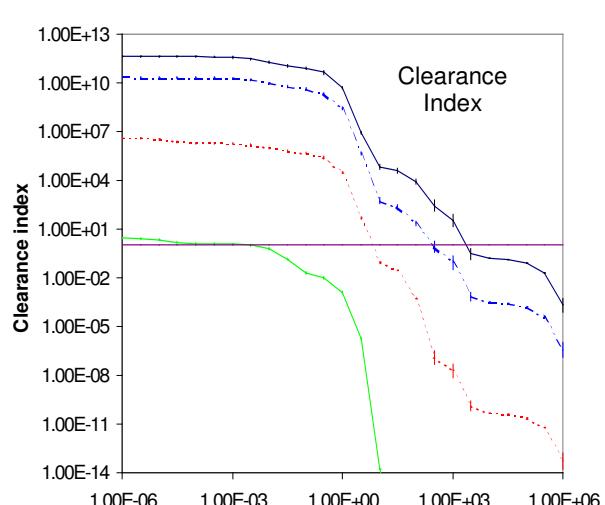
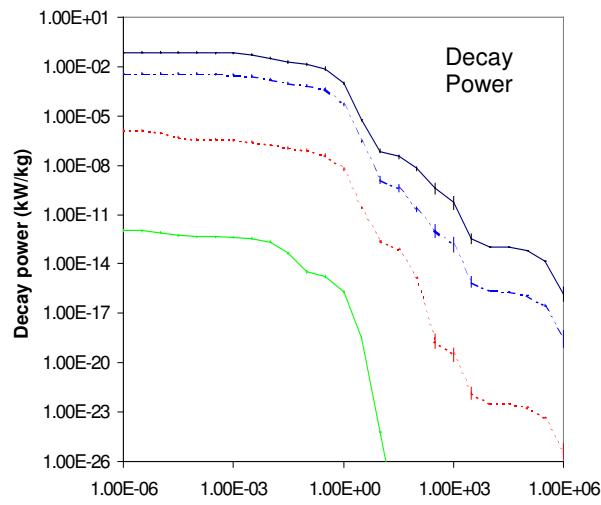
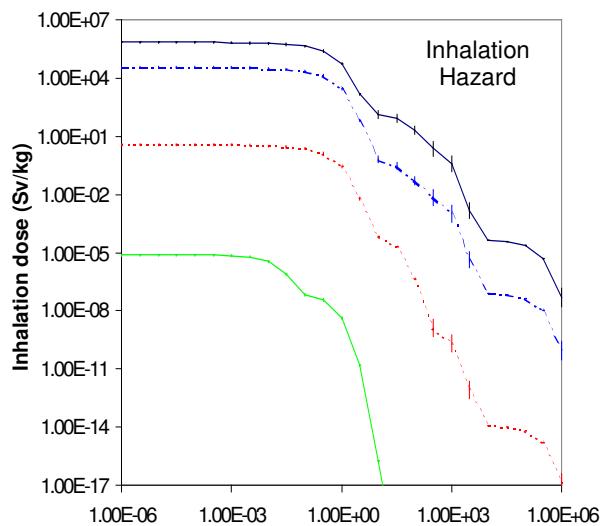
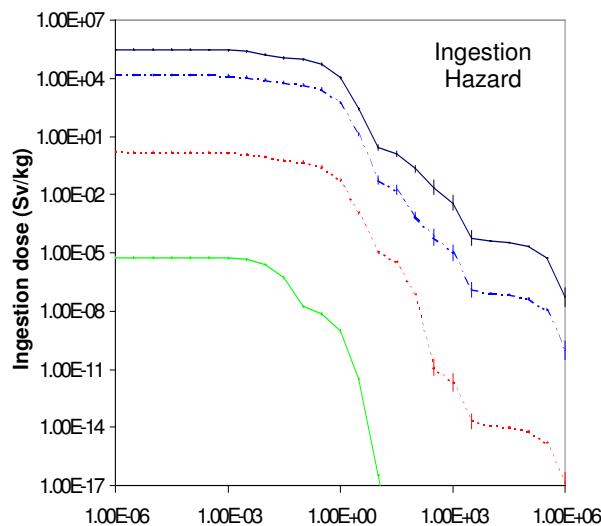
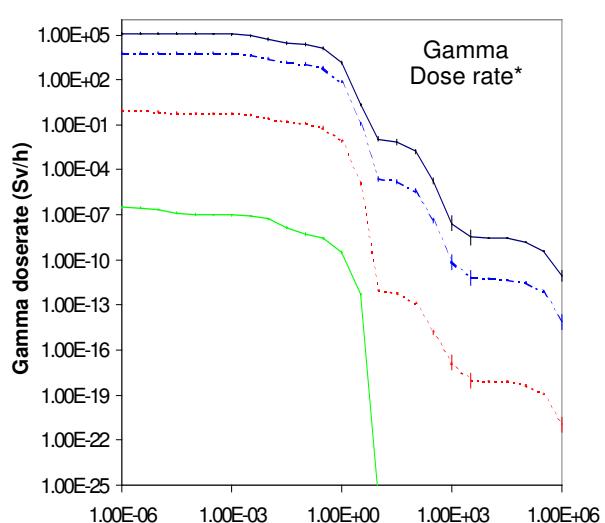
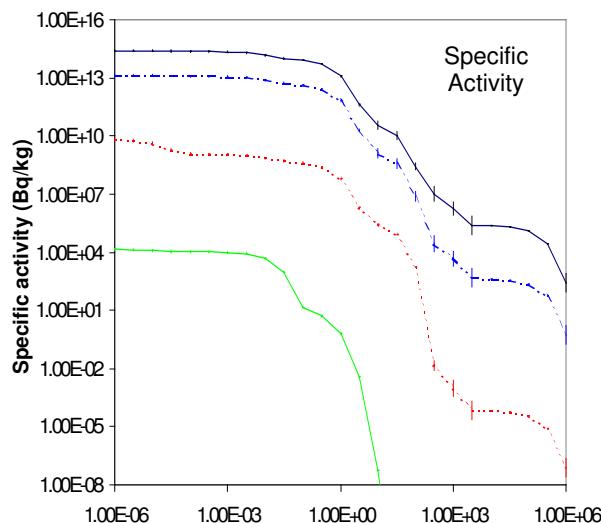
# Titanium

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
V52	3.745 m	Ti50(n, $\gamma$ )Ti51( $\beta^-$ )V51(n, $\gamma$ )V52 Ti48(n, $\gamma$ )Ti49(n, $\gamma$ )Ti50(n, $\gamma$ )Ti51( $\beta^-$ )V51(n, $\gamma$ )V52 Ti49(n, $\gamma$ )Ti50(n, $\gamma$ )Ti51( $\beta^-$ )V51(n, $\gamma$ )V52	78.6 14.9 6.5	99.9 0.1 0.1	99.9 0.1 0.1	99.3
Ti51	5.8 m	Ti50(n, $\gamma$ )Ti51 Ti48(n, $\gamma$ )Ti49(n, $\gamma$ )Ti50(n, $\gamma$ )Ti51 Ti49(n, $\gamma$ )Ti50(n, $\gamma$ )Ti51	60.6 30.0 9.2	99.7 0.3 0.2	99.8 0.2	99.3
Mn56	2.579 h	Ti50(n, $\gamma$ )Ti51( $\beta^-$ )V51(n, $\gamma$ )V52( $\beta^-$ )Cr52(n, $\gamma$ )Cr53(n, $\gamma$ ) Cr54(n, $\gamma$ )Cr55( $\beta^-$ )Mn55(n, $\gamma$ )Mn56 Ti49(n, $\gamma$ )Ti50(n, $\gamma$ )Ti51( $\beta^-$ )V51(n, $\gamma$ )V52( $\beta^-$ )Cr52(n, $\gamma$ ) Cr53(n, $\gamma$ )Cr54(n, $\gamma$ )Cr55( $\beta^-$ )Mn55(n, $\gamma$ )Mn56 Ti48(n, $\gamma$ )Ti49(n, $\gamma$ )Ti50(n, $\gamma$ )Ti51( $\beta^-$ )V51(n, $\gamma$ )V52( $\beta^-$ ) Cr52(n, $\gamma$ )Cr53(n, $\gamma$ )Cr54(n, $\gamma$ )Cr55( $\beta^-$ )Mn55(n, $\gamma$ )Mn56	94.5  2.7  2.8	100.0		
K42	12.37 h	&Ti46(n,d)Sc45(n, $\alpha$ )K42 Ti48(n, $\alpha$ )Ca45( $\beta^-$ )Sc45(n, $\alpha$ )K42 Ti46(n,2n)Ti45( $\beta^+$ )Sc45(n, $\alpha$ )K42 Ti46(n, $\alpha$ )Ca43(n,d)K42 Ti46(n,n $\alpha$ )Ca42(n,p)K42				45.4 37.1 5.3 2.4 3.8
Sc48	1.820 d	Ti47(n,p)Sc47(n, $\gamma$ )Sc48 Ti48(n, $\gamma$ )Ti49(n, $\alpha$ )Ca46(n, $\gamma$ )Ca47( $\beta^-$ )Sc47(n, $\gamma$ )Sc48 Ti46(n, $\gamma$ )Ti47(n,p)Sc47(n, $\gamma$ )Sc48 Ti49(n, $\alpha$ )Ca46(n, $\gamma$ )Ca47( $\beta^-$ )Sc47(n, $\gamma$ )Sc48 Ti48(n,p)Sc48 Ti49(n,d)Sc48 Ti49(n,2n)Ti48(n,p)Sc48	82.4 10.3 4.0 3.2	99.7 0.1 0.1	99.5 0.4	97.2 1.5 1.1
Sc47	3.346 d	Ti47(n,p)Sc47 Ti48(n, $\gamma$ )Ti49(n, $\alpha$ )Ca46(n, $\gamma$ )Ca47( $\beta^-$ )Sc47 Ti46(n, $\gamma$ )Ti47(n,p)Sc47 Ti49(n, $\alpha$ )Ca46(n, $\gamma$ )Ca47( $\beta^-$ )Sc47 Ti48(n,d)Sc47 Ti48(n,2n)Ti47(n,p)Sc47 Ti50(n, $\alpha$ )Ca47( $\beta^-$ )Sc47	82.4 10.4 4.0 3.2	99.7 0.1 0.1	99.5 0.4	27.9 47.5 21.0 1.3
Ca47	4.538 d	Ti48(n, $\gamma$ )Ti49(n, $\alpha$ )Ca46(n, $\gamma$ )Ca47 Ti49(n, $\alpha$ )Ca46(n, $\gamma$ )Ca47 Ti50(n, $\alpha$ )Ca47	76.6 23.4	9.9 90.1	5.7 94.3	99.5
Fe59	44.502 d	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0			
Sc46	83.79 d	&Ti47(n, $\alpha$ )Ca44(n, $\gamma$ )Ca45( $\beta^-$ )Sc45(n, $\gamma$ )Sc46 Ti46(n, $\gamma$ )Ti47(n, $\alpha$ )Ca44(n, $\gamma$ )Ca45( $\beta^-$ )Sc45(n, $\gamma$ )Sc46 &Ti46(n,p)Sc46 &Ti47(n,d)Sc46 &Ti48(n,2n)Ti47(n,d)Sc46 &Ti47(n,2n)Ti46(n,p)Sc46	98.5 0.8	100.0	99.9	58.7 21.3 15.2 1.2
Ca45	162.7 d	Ti47(n, $\alpha$ )Ca44(n, $\gamma$ )Ca45 Ti46(n, $\gamma$ )Ti47(n, $\alpha$ )Ca44(n, $\gamma$ )Ca45 Ti48(n, $\alpha$ )Ca45 Ti49(n,2n)Ti48(n, $\alpha$ )Ca45 &Ti46(n,d)Sc45(n,p)Ca45	97.9 2.1	99.9	99.8 0.2	95.9 0.9 0.7
Co60	5.272 y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0			
H3	12.33 y	Ti47(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Ti46(n, $\gamma$ )Ti47(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Ti47(n,X)H3 Ti48(n,2n)Ti47(n,X)H3 Ti49(n,X)H3 Ti46(n,X)H3 Ti48(n,d)Sc47( $\beta^-$ )Ti47(n,X)H3	92.3 1.1	95.2	99.2 0.1	58.1 23.0 12.5 2.3 1.1
Ar42	33.0 y	Ti48(n, $\alpha$ )Ca45(n, $\alpha$ )Ar42				97.6

Ni63	99.0 y	Very long pathways of ( $n,\gamma$ ), ( $\beta^-$ )	100.0			
Ar39	269.0 y	Ti46( $n,\alpha$ )Ca42( $n,\alpha$ )Ar39 Ti46( $n,\alpha$ )Ca43( $n,\alpha$ )Ar39 Ti46( $n,\alpha$ )Ca43( $n,\alpha$ )Ar40( $n,2n$ )Ar39 Ti46( $n,\alpha$ )Ca43( $n,2n$ )Ca42( $n,\alpha$ )Ar39 &Ti46( $n,d$ )Sc45( $n,\alpha$ )K42( $\beta^-$ )Ca42( $n,\alpha$ )Ar39 Ti48( $n,\alpha$ )Ca45( $\beta^-$ )Sc45( $n,\alpha$ )K42( $\beta^-$ )Ca42( $n,\alpha$ )Ar39 Ti47( $n,\alpha$ )Ca43( $n,\alpha$ )Ar39				39.6 34.7 4.9 4.6 4.4 2.9 1.5
Ca41	$1.03 \cdot 10^5$ y	Ti46( $n,\alpha$ )Ca42( $n,2n$ )Ca41 Ti46( $n,\alpha$ )Ca43( $n,2n$ )Ca42( $n,2n$ )Ca41 &Ti46( $n,d$ )Sc45( $n,\alpha$ )K42( $\beta^-$ )Ca42( $n,2n$ )Ca41 Ti48( $n,\alpha$ )Ca45( $\beta^-$ )Sc45( $n,\alpha$ )K42( $\beta^-$ )Ca42( $n,2n$ )Ca41				72.9 8.5 8.1 5.3
Cl36	$3.0 \cdot 10^5$ y	Ti46( $n,\alpha$ )Ca42( $n,2n$ )Ca41( $n,d$ )K40( $n,\alpha$ )Cl36 Ti46( $n,\alpha$ )Ca42( $n,\alpha$ )Ar38( $n,2n$ )Ar37( $\beta^+$ )Cl37( $n,2n$ )Cl36 Ti46( $n,\alpha$ )Ca42( $n,2n$ )Ca41( $n,\alpha$ )Ar37( $\beta^+$ )Cl37( $n,2n$ )Cl36 Ti46( $n,\alpha$ )Ca42( $n,\alpha$ )Ar38( $n,d$ )Cl37( $n,2n$ )Cl36 Ti47( $n,\alpha$ )Ca44( $n,\alpha$ )Ar41( $\beta^-$ )K41( $n,\alpha$ )Cl37( $n,2n$ )Cl36 Ti46( $n,\alpha$ )Ca42( $n,d$ )K41( $n,\alpha$ )Cl37( $n,2n$ )Cl36 Ti47( $n,\alpha$ )Ca44( $n,\alpha$ )Ar41( $\beta^-$ )K41( $n,2n$ )K40( $n,\alpha$ )Cl36 Ti46( $n,\alpha$ )Ca42( $n,d$ )K41( $n,2n$ )K40( $n,\alpha$ )Cl36 &Ti46( $n,d$ )Sc45( $n,\alpha$ )K41( $n,\alpha$ )Cl37( $n,2n$ )Cl36 &Ti46( $n,d$ )Sc45( $n,\alpha$ )K41( $n,2n$ )K40( $n,\alpha$ )Cl36 Ti46( $n,\alpha$ )Ca42( $n,2n$ )Ca41( $n,p\alpha$ )Cl37( $n,2n$ )Cl36 Ti46( $n,\alpha$ )Ca43( $n,2n$ )Ca42( $n,2n$ )Ca41( $n,d$ )K40( $n,\alpha$ )Cl36 &Ti46( $n,d$ )Sc45( $n,\alpha$ )K42( $\beta^-$ )Ca42( $n,2n$ )Ca41( $n,d$ )K40( $n,\alpha$ )Cl36 Ti48( $n,\alpha$ )Ca45( $\beta^-$ )Sc45( $n,\alpha$ )K41( $n,\alpha$ )Cl37( $n,2n$ )Cl36 Ti48( $n,\alpha$ )Ca45( $\beta^-$ )Sc45( $n,\alpha$ )K41( $n,2n$ )K40( $n,\alpha$ )Cl36 Ti48( $n,\alpha$ )Ca45( $\beta^-$ )Sc45( $n,\alpha$ )K42( $\beta^-$ )Ca42( $n,2n$ )Ca41( $n,d$ ) K40( $n,\alpha$ )Cl36 *Plus many other similar pathways				27.3 7.8 6.5 6.0 4.7 4.0 3.6 3.0 2.9 2.2 2.2 1.9 1.8 1.7 1.3 1.0 22.1*
Fe60	$1.5 \cdot 10^6$ y	Very long pathways of ( $n,\gamma$ ), ( $\beta^-$ )	100.0			
K40	$1.3 \cdot 10^9$ y	Ti46( $n,\alpha$ )Ca42( $n,2n$ )Ca41( $n,d$ )K40 Ti47( $n,\alpha$ )Ca44( $n,\alpha$ )Ar41( $\beta^-$ )K41( $n,2n$ )K40 Ti46( $n,\alpha$ )Ca42( $n,d$ )K41( $n,2n$ )K40 Ti46( $n,\alpha$ )Ca43( $n,2n$ )Ca42( $n,2n$ )Ca41( $n,d$ )K40 &Ti46( $n,d$ )Sc45( $n,\alpha$ )K42( $\beta^-$ )Ca42( $n,2n$ )Ca41( $n,d$ )K40 &Ti46( $n,d$ )Sc45( $n,\alpha$ )K41( $n,2n$ )K40 Ti48( $n,\alpha$ )Ca45( $\beta^-$ )Sc45( $n,\alpha$ )K41( $n,2n$ )K40 Ti48( $n,\alpha$ )Ca45( $\beta^-$ )Sc45( $n,\alpha$ )K42( $\beta^-$ )Ca42( $n,2n$ )Ca41( $n,d$ ) K40 Ti48( $n,2n$ )Ti47( $n,\alpha$ )Ca44( $n,\alpha$ )Ar41( $\beta^-$ )K41( $n,2n$ )K40 &Ti46( $n,d$ )Sc45( $n,d$ )Ca44( $n,\alpha$ )Ar41( $\beta^-$ )K41( $n,2n$ )K40 *Plus many other similar pathways				54.3 7.1 6.1 4.7 4.5 4.5 2.9 2.7 1.4 1.1 10.7*

# Titanium activation characteristics

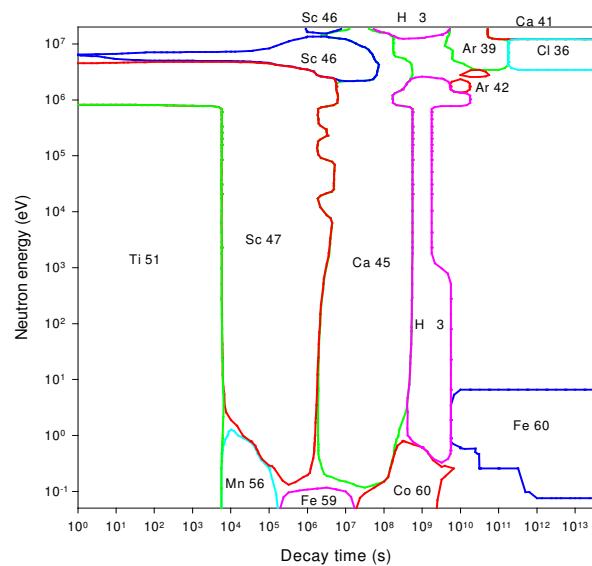


Decay time (years)

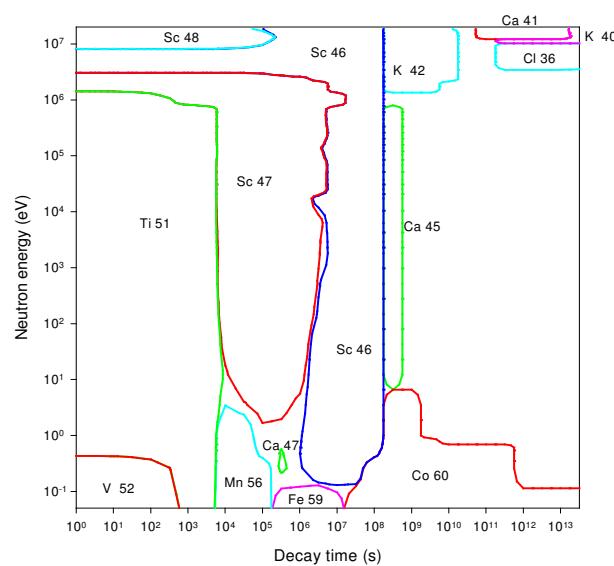
Decay time (years)

# Titanium importance diagrams & transmutation

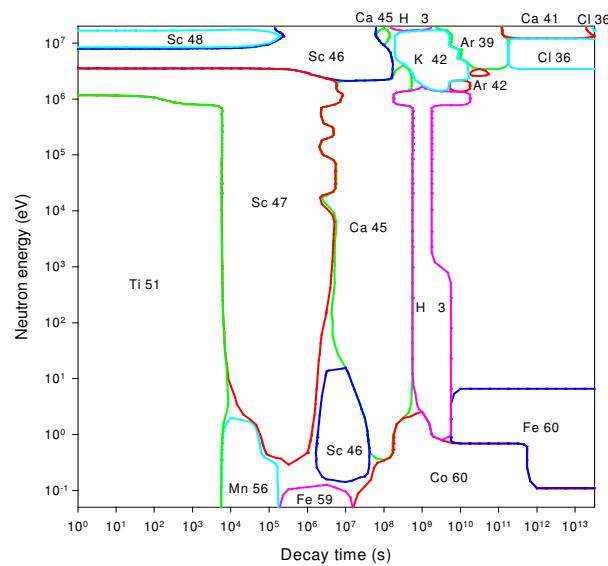
## Activity



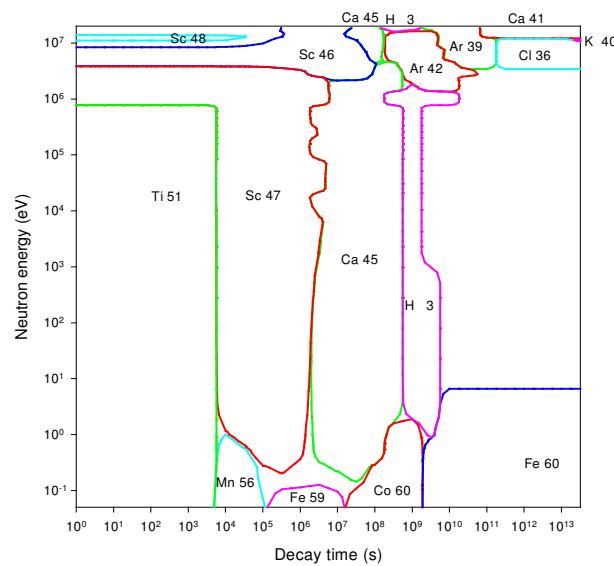
## Dose rate



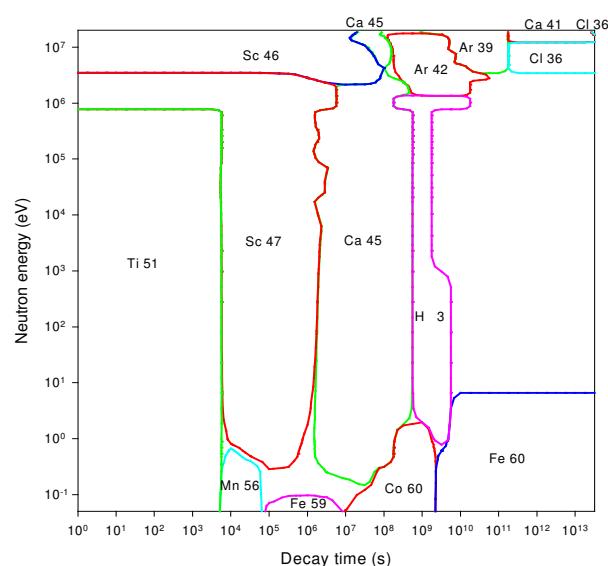
## Heat output



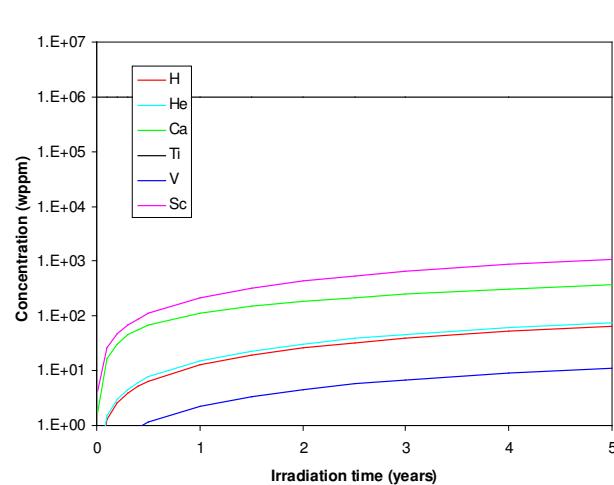
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Vanadium

## General properties

		23	Isotopes	Isotopic abundances / %	
Atomic number		120	V50	0.25 ( $T_{1/2} = 1.4893 \cdot 10^{17}$ y)	
Crustal abundance / wppm		2183	V51	99.75	
Melting point / K		3680			
Boiling point / K		6110			
Density / kgm <sup>-3</sup>		30.7			
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>		2.48 $10^{-7}$			
Electrical resistivity / $\Omega$ m		8.4 $10^{-6}$			
Coefficient of thermal expansion / K <sup>-1</sup>		BCC			
Crystal structure		1(2)			
Number of stable isotopes		50.9415			
Mean atomic weight					

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	5.84E14	2.51E14	1.40E13	2.06E12	4.31E7	2.05E-1	kW kg <sup>-1</sup>	2.25E-1	9.61E-2	3.81E-3	1.65E-6	4.06E-11	3.95E-18
V52	84.28	74.09					V52	88.17	77.89				
Ti51	9.81	12.17					Sc48	6.75	15.77	99.06			
Sc48	4.54	10.56	47.18				Ti51	5.04	6.28				
V49	0.75	1.76	31.24	99.22			V49			0.08	89.82		
Cr51	0.51	1.19	19.46	0.02			Sc46			0.06	6.38		
Sc47	0.09	0.20	1.74				Ca45			0.01	3.07		
Ca45		0.01	0.14	0.20			H3				0.62	97.10	
H3		0.01	0.09	0.55	99.98		K42					2.55	
Ca41						89.25	V50						97.56
V50						10.75	Ca41						2.44
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	2.46E5	1.09E5	6.38E3	6.21E-1	3.66E-7	7.57E-12	Sv kg <sup>-1</sup>	5.34E4	4.87E4	1.16E4	4.07E1	1.84E-3	1.43E-10
V52	87.96	74.69					Sc48	84.49	92.62	96.87			
Sc48	10.40	23.35	99.56				V52	12.91	5.35				
Ti51	1.60	1.92					Ti51	1.61	0.94				
Sc50	0.01						Sc47	0.50	0.55	1.13			
Cr51	0.01	0.02	0.25	0.30			V49	0.15	0.16	0.68	90.51		
Sc46			0.05	28.00			Ca45	0.03	0.03	0.12	7.15		
V49			0.01	71.70			Sc46	0.02	0.02	0.08	1.14		
K42					99.85*		H3				1.16	98.07	
Ar42					0.15*		Ar42					1.84	
V50						99.76	V50						75.65
Ca41						0.24	Ca41						24.35
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	3.52E4	3.20E4	7.84E3	8.98E1	1.49E-2	2.14E-10		8.84E11	3.93E11	2.22E10	3.31E6	1.61E1	2.41E-5
Sc48	83.05	91.11	92.65				V52	87.01	73.93				
V52	12.88	5.35					Sc48	10.01	22.48	99.28			
Ti51	1.79	1.05					Ti51	2.95	3.53				
Sc47	1.03	1.14	2.27				Cr51	0.01	0.03	0.41	0.32		
V49	0.43	0.47	1.90	77.47			Sc47	0.01	0.02	0.14			
Cr51	0.31	0.35	1.29	0.01			Sc46			0.06	19.14		
Ca45	0.20	0.22	0.90	16.88			V49			0.03	80.38		
Sc46	0.12	0.14	0.54	2.35			H3				0.11	89.26	
H3	0.01	0.01	0.04	3.26	74.97		K42					10.20	
Ar42					25.00		Ar42					0.54	
V50						84.57	V50						99.46
Ca41						15.42	Ca41						0.54

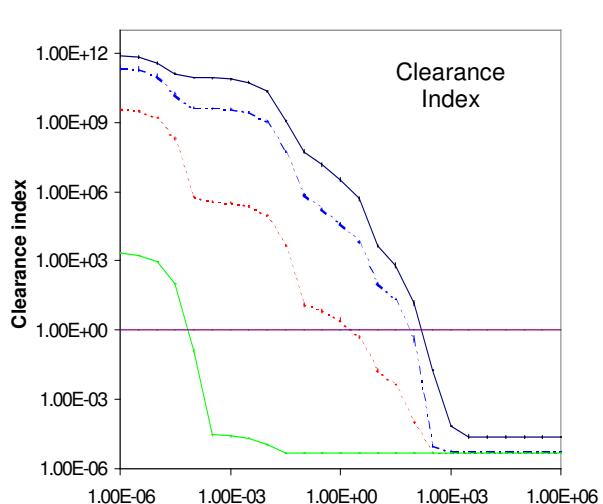
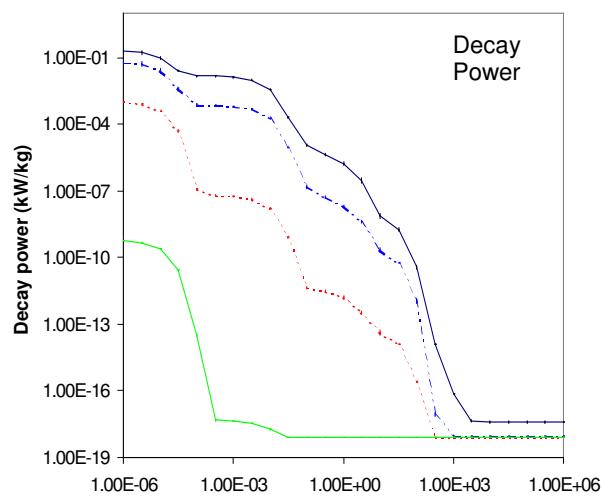
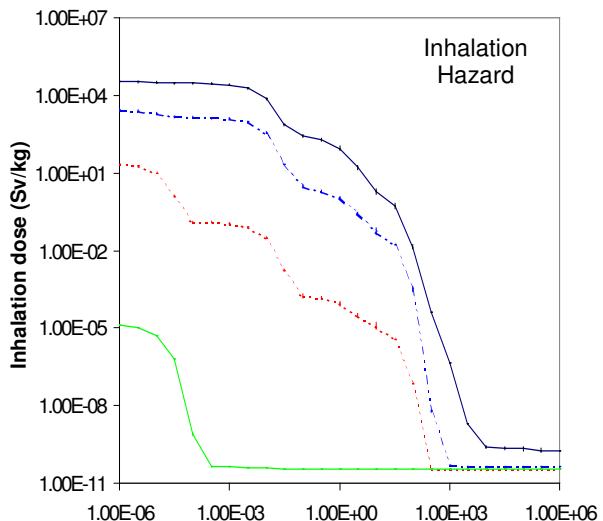
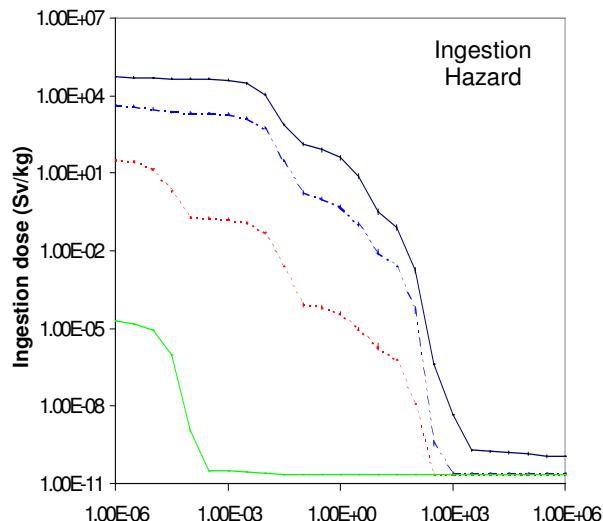
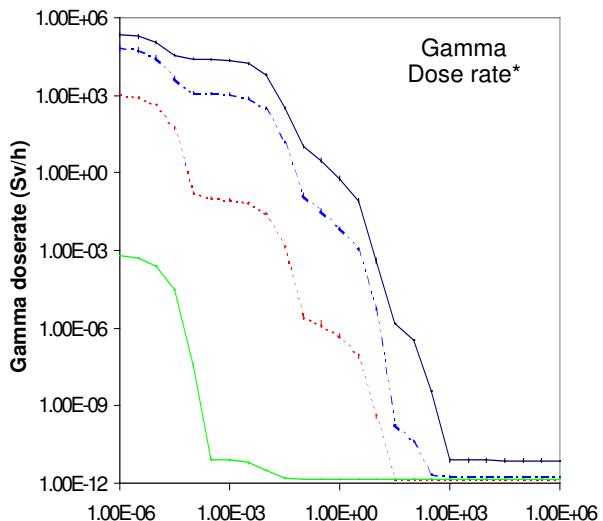
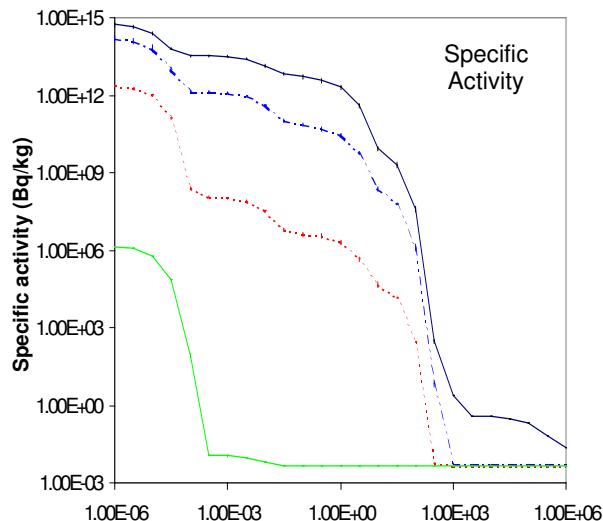
# Vanadium

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
V52	3.745 m	V51(n, $\gamma$ )V52 V50(n, $\gamma$ )V51(n, $\gamma$ )V52	99.7 0.3	99.8 0.2	100.0	98.3
Ti51	5.8 m	V50(n,p)Ti50(n, $\gamma$ )Ti51 V51(n,p)Ti51	100.0	100.0	100.0	100.0
Mn56	2.579 h	V51(n, $\gamma$ )V52( $\beta^-$ )Cr52(n, $\gamma$ )Cr53(n, $\gamma$ )Cr54(n, $\gamma$ )Cr55( $\beta^-$ ) Mn55(n, $\gamma$ )Mn56	99.9	99.8	100.0	
K42	12.37 h	V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n, $\alpha$ )Ca45( $\beta^-$ )Sc45(n, $\alpha$ )K42				90.9
Sc48	1.8196 d	V50(n, $\alpha$ )Sc47(n, $\gamma$ )Sc48 V51(n, $\alpha$ )Sc48	100.0		100.0	98.2
Sc47	3.346 d	V50(n, $\alpha$ )Sc47 V51(n,2n)V50(n, $\alpha$ )Sc47 V51(n,d)Ti50(n, $\alpha$ )Ca47( $\beta^-$ )Sc47 V51(n,n $\alpha$ )Sc47 V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n,d)Sc47	99.3	100.0	100.0	2.1 83.6 5.0 4.7 2.7
Fe59	44.502 d	V51(n, $\gamma$ )V52( $\beta^-$ )Cr52(n, $\gamma$ )Cr53(n, $\gamma$ )Cr54(n, $\gamma$ )Cr55( $\beta^-$ ) Mn55(n, $\gamma$ )Mn56( $\beta^-$ )Fe56(n, $\gamma$ )Fe57(n, $\gamma$ )Fe58(n, $\gamma$ )Fe59	99.9	99.8		
Sc46	83.79 d	&V51(n,2n)V50(n,n $\alpha$ )Sc46 &V51(n,2n)V50(n,2n)V49(n, $\alpha$ )Sc46 &V51(n,2n)V50(n, $\alpha$ )Sc47( $\beta^-$ )Ti47(n,d)Sc46 &V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n,2n)Ti47(n,d)Sc46 &V51(n,n $\alpha$ )Sc47( $\beta^-$ )Ti47(n,d)Sc46 &V50(n,2n)V49(n, $\alpha$ )Sc46 &V50(n, $\alpha$ )Sc47( $\beta^-$ )Ti47(n,d)Sc46				44.4 29.0 10.9 7.8 1.3 1.0 0.6
Ca45	162.7 d	V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n, $\alpha$ )Ca45 V51(n,2n)V50(n,2n)V49( $\beta^+$ )Ti49(n,2n)Ti48(n, $\alpha$ )Ca45 V51(n,2n)V50(n,d)Ti49(n,2n)Ti48(n, $\alpha$ )Ca45				93.2 1.5 1.2
V49	330.0 d	V51(n,2n)V50(n,2n)V49 V50(n,2n)V49				96.6 3.2
Co60	5.272 y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ ), see Fe59	100.0			
H3	12.33 y	V50(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 V51(n,X)H3 V51(n,2n)V50(n,X)H3	92.7	93.7	99.3	94.5 2.7
Ar42	33.0 y	V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n, $\alpha$ )Ca45(n, $\alpha$ )Ar42 V51(n,2n)V50(n,d)Ti49(n,2n)Ti48(n, $\alpha$ )Ca45(n, $\alpha$ )Ar42				96.3 0.6
Ni63	99.0 y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ ), see Fe59	100.0			
Ar39	269.0 y	V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n, $\alpha$ )Ca45( $\beta^-$ )Sc45(n, $\alpha$ )K42( $\beta^-$ )Ca42(n, $\alpha$ )Ar39 V51(n,2n)V50(n, $\alpha$ )Sc47( $\beta^-$ )Ti47(n,n $\alpha$ )Ca43(n,n $\alpha$ )Ar39 V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n,2n)Ti47(n,n $\alpha$ )Ca43(n,n $\alpha$ )Ar39 &V51(n,2n)V50(n,n $\alpha$ )Sc46( $\beta^-$ )Ti46(n,n $\alpha$ )Ca42(n, $\alpha$ )Ar39 &V51(n,2n)V50(n,n $\alpha$ )Sc46( $\beta^-$ )Ti46(n, $\alpha$ )Ca43(n,n $\alpha$ )Ar39 V51(n,2n)V50(n, $\alpha$ )Sc47( $\beta^-$ )Ti47(n, $\alpha$ )Ca44(n,2n)Ca43(n,n $\alpha$ )Ar39 V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n,2n)Ti47(n, $\alpha$ )Ca44(n,2n)Ca43(n,n $\alpha$ )Ar39 V51(n,n $\alpha$ )Sc47( $\beta^-$ )Ti47(n,n $\alpha$ )Ca43(n,n $\alpha$ )Ar39 &V51(n,2n)V50(n,2n)V49(n, $\alpha$ )Sc46( $\beta^-$ )Ti46(n,n $\alpha$ )Ca42(n, $\alpha$ )Ar39 &V51(n,2n)V50(n,2n)V49(n, $\alpha$ )Sc46( $\beta^-$ )Ti46(n, $\alpha$ )Ca43(n,n $\alpha$ )Ar39 V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n, $\alpha$ )Ca45(n,2n)Ca44(n,2n)Ca43(n,n $\alpha$ )Ar39 V51(n,2n)V50(n, $\alpha$ )Sc47( $\beta^-$ )Ti47(n,2n)Ti46(n,n $\alpha$ )Ca42(n, $\alpha$ )Ar39 V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n, $\alpha$ )Ca45( $\beta^-$ )Sc45(n,d) Ca44(n,2n)Ca43(n,n $\alpha$ )Ar39				41.2 8.2 5.9 4.4 3.8 3.2 2.3 1.9 1.8 1.5 1.3 1.0 1.0 22.5*
		*Plus many other similar pathways				

Ca41	$1.03 \cdot 10^5$ y	V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n, $\alpha$ )Ca45( $\beta^-$ )Sc45(n, $\alpha$ )K42( $\beta^-$ )Ca42(n,2n)Ca41 <b>&amp;V51(n,2n)V50(n,n<math>\alpha</math>)Sc46(<math>\beta^-</math>)Ti46(n,n<math>\alpha</math>)Ca42(n,2n)Ca41</b> <b>&amp;V51(n,2n)V50(n,2n)V49(n,<math>\alpha</math>)Sc46(<math>\beta^-</math>)Ti46(n,n<math>\alpha</math>)Ca42(n,2n)Ca41</b> V51(n,2n)V50(n, $\alpha$ )Sc47( $\beta^-$ )Ti47(n,2n)Ti46(n,n $\alpha$ )Ca42(n,2n)Ca41 V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n,2n)Ti47(n,2n)Ti46(n,n $\alpha$ )Ca42(n,2n)Ca41 V51(n,2n)V50(n, $\alpha$ )Sc47( $\beta^-$ )Ti47(n,n $\alpha$ )Ca43(n,2n)Ca42(n,2n)Ca41 *Plus many other similar pathways				73.1 7.9 3.1 1.7 1.2 1.2 11.8*
Fe60	$1.5 \cdot 10^6$ y	V51(n, $\gamma$ )V52( $\beta^-$ )Cr52(n, $\gamma$ )Cr53(n, $\gamma$ )Cr54(n, $\gamma$ )Cr55( $\beta^-$ ) Mn55(n, $\gamma$ )Mn56( $\beta^-$ )Fe56(n, $\gamma$ )Fe57(n, $\gamma$ )Fe58(n, $\gamma$ )Fe59(n, $\gamma$ ) Fe60	100.0			
V50	$1.5 \cdot 10^{17}$ y	V51(n,2n)V50 Nuclide also present in starting material	100.0	100.0	100.0	97.3 2.7

# Vanadium activation characteristics

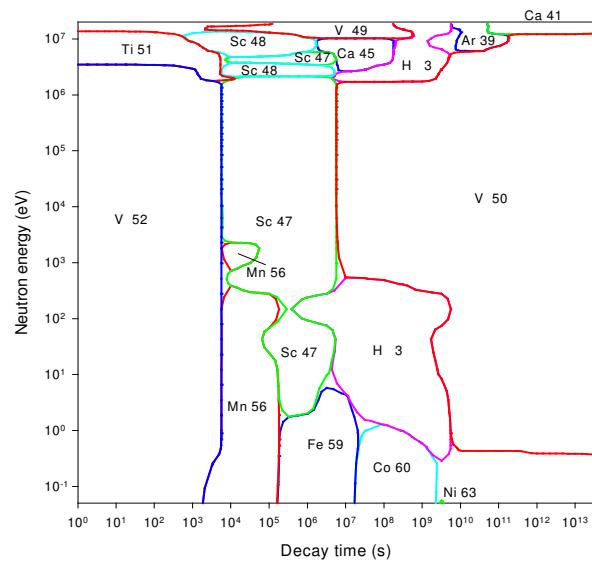


Decay time (years)

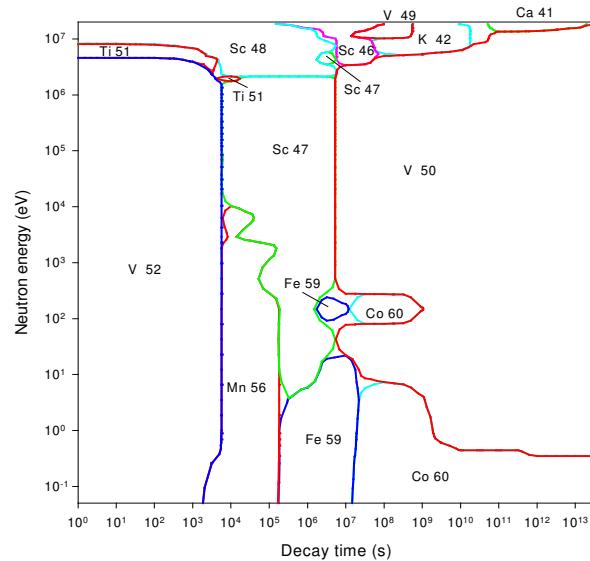
Decay time (years)

# Vanadium importance diagrams & transmutation

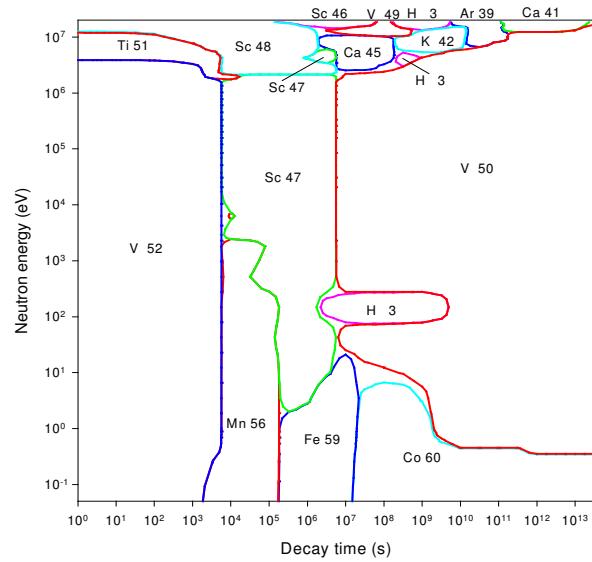
## Activity



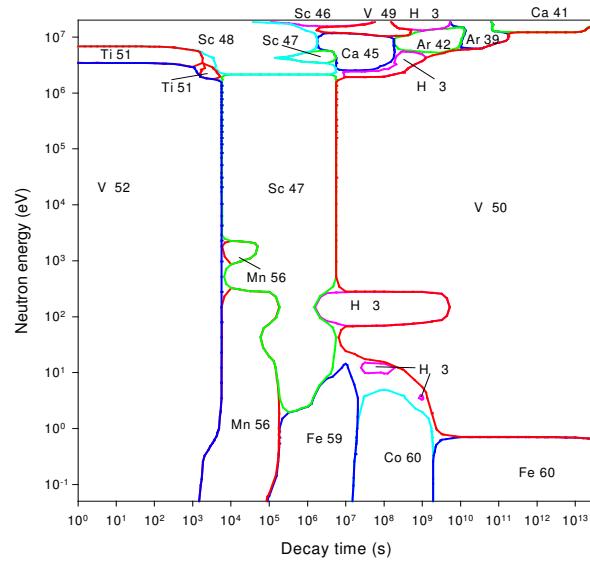
## Dose rate



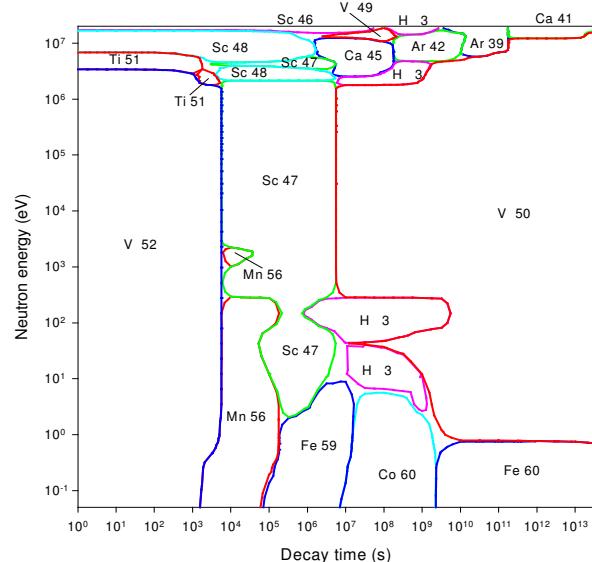
## Heat output



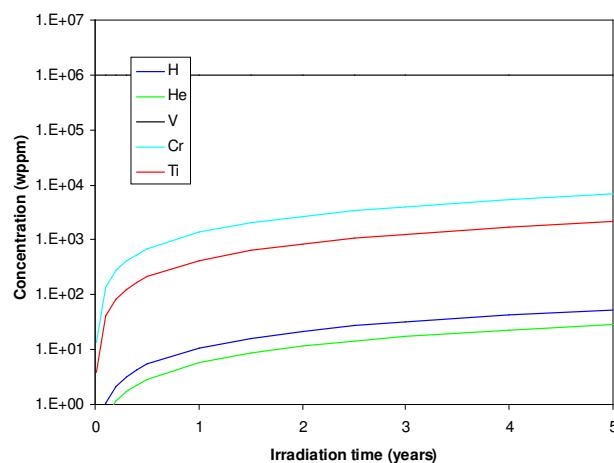
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Chromium

## General properties

Atomic number	24	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	102	Cr50	4.345
Melting point / K	2180	Cr52	83.789
Boiling point / K	2944	Cr53	9.501
Density / kgm <sup>-3</sup>	7190	Cr54	2.365
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	93.7		
Electrical resistivity /Ωm	1.27 10 <sup>-7</sup>		
Coefficient of thermal expansion / K <sup>-1</sup>	4.9 10 <sup>-6</sup>		
Crystal structure	BCC		
Number of stable isotopes	4		
Mean atomic weight	51.9961		

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	5.72E14	4.86E14	3.99E14	7.54E12	1.03E8	9.40E0	kW kg <sup>-1</sup>	5.64E-2	2.22E-2	2.30E-3	6.61E-6	9.43E-11	8.14E-18
Cr51	73.40	86.40	95.97	0.60			V52	88.94	85.25				
V52	21.79	9.69					V53	4.50	1.20				
V49	2.81	3.31	4.00	98.97			Cr51	4.37	11.08	97.74	4.00		
V53	1.35	0.17					Cr49	0.43	1.01				
Cr55	0.17	0.07					Sc48	0.21	0.52	1.26			
Cr49	0.17	0.18					V49	0.02	0.05	0.50	81.93		
Ti51	0.16	0.10					Sc46	0.01	0.02	0.18	3.11		
Sc48	0.04	0.04	0.01				Mn54		0.01	0.07	10.57		
H3	0.01	0.01	0.01	0.36	100.0		H3				0.37	99.96	
Mn53					94.68		Mn53					95.00	
Co60					5.31		Ca41					3.22	
V50					0.01		V50					1.76	
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	5.91E4	2.32E4	2.21E3	3.12E0	9.46E-9	2.87E-12	Sv kg <sup>-1</sup>	1.85E4	1.74E4	1.50E4	1.42E2	4.33E-3	3.66E-10
V52	90.25	89.94					Cr51	86.07	91.68	97.12	1.21		
Cr51	3.97	10.12	96.95	8.09			V52	9.41	3.79				
V53	3.83	1.03					Sc48	1.87	1.99	0.57			
V54	1.14	0.04					V49	1.56	1.66	1.92	94.67		
Sc48	0.32	0.82	2.15				Cr49	0.31	0.30				
Sc46	0.01	0.03	0.30	10.61			V48	0.12	0.13	0.12			
V49	0.01	0.01	0.14	44.77			Sc46	0.10	0.11	0.12	0.64		
Mn54		0.01	0.12	36.52			Mn54	0.05	0.05	0.06	2.60		
K42					99.40*		H3	0.01	0.01	0.01	0.80	99.97	
Mn53					0.03	88.92	Mn53					72.97	
V50						9.58	Ca41					25.92	
Ca41						1.50	V50					1.10	
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	1.77E4	1.69E4	1.49E4	2.75E2	2.69E-2	5.77E-10		2.22E11	9.06E10	1.31E10	2.97E7	3.44E1	1.74E-5
Cr51	87.75	91.63	95.00	0.61			V52	87.62	81.20				
V52	6.48	2.56					Cr51	6.30	15.45	97.82	5.06		
V49	3.09	3.23	3.64	92.31			V53	3.95	1.02				
Sc48	1.26	1.32	0.37				V54	1.03	0.03				
Sc46	0.48	0.50	0.55	1.49			Cr49	0.47	1.05				
Sc47	0.17	0.18	0.10				Sc48	0.31	0.75	1.29			
V48	0.15	0.15	0.15				Mn54	0.02	0.04	0.30	58.17		
Mn54	0.10	0.10	0.12	2.83			Sc46	0.01	0.03	0.19	4.14		
H3	0.04	0.04	0.05	2.55	99.54		V49	0.01	0.02	0.16	32.60		
Ar42					0.37		H3				0.03	99.86	
Mn53					83.25		Mn53					92.83	
Ca41					15.56		V50					5.12	
V50					1.17		Ca41					2.05	

# Chromium

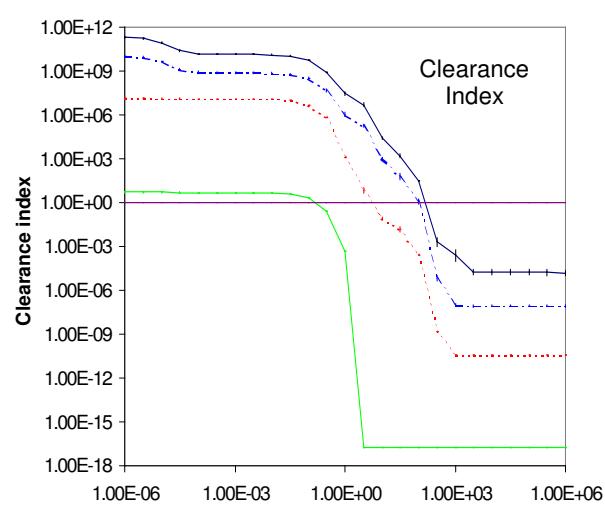
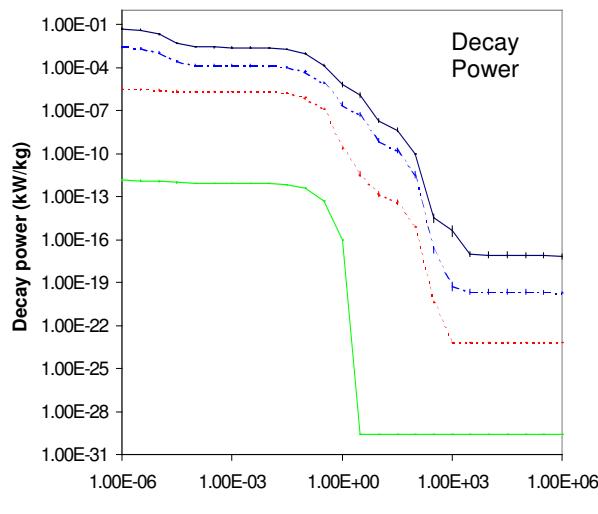
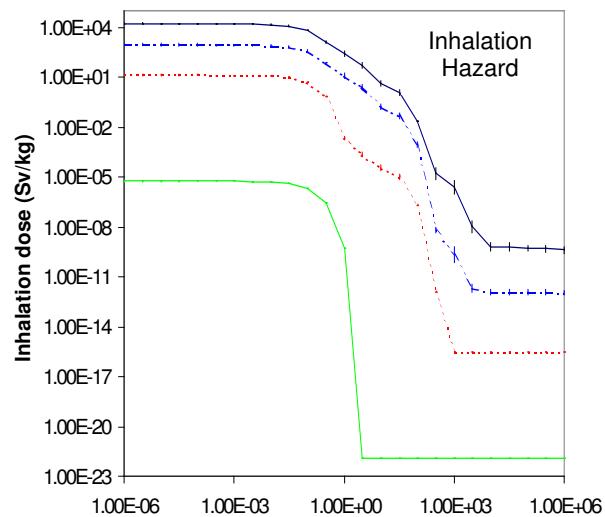
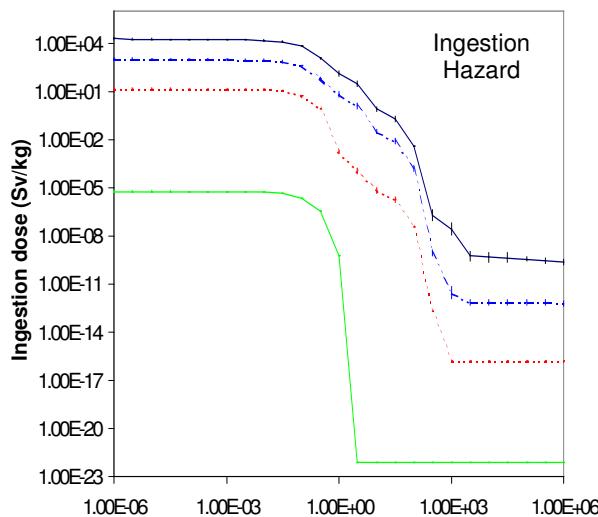
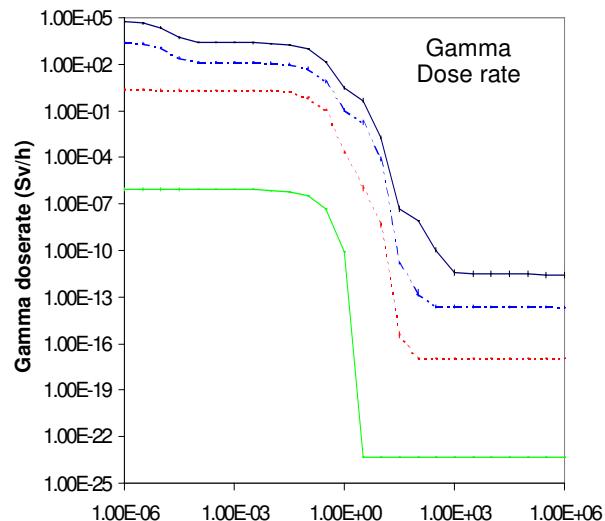
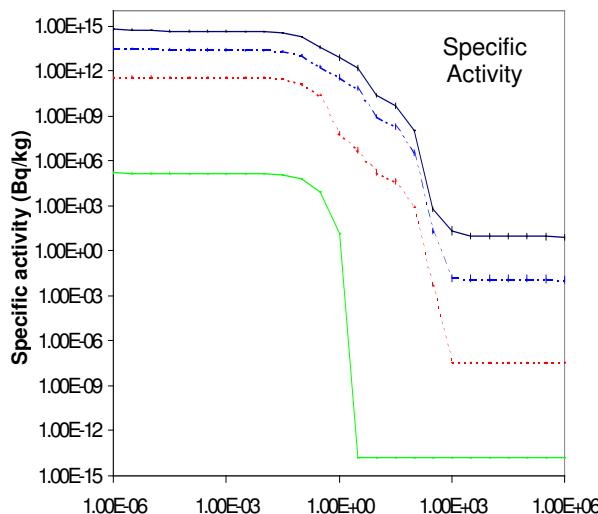
## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Cr55	3.54 m	Cr53(n, $\gamma$ )Cr54(n, $\gamma$ )Cr55 Cr54(n, $\gamma$ )Cr55 Cr52(n, $\gamma$ )Cr53(n, $\gamma$ )Cr54(n, $\gamma$ )Cr55	61.6 21.0 17.5	12.3 87.6 99.3	0.7 99.3	99.1
V52	3.745 m	Cr50(n, $\gamma$ )Cr51( $\beta^+$ )V51(n, $\gamma$ )V52 Cr52(n,p)V52 Cr53(n,d)V52 Cr53(n,2n)Cr52(n,p)V52	100.0	100.0	100.0	95.9 2.0 1.9
Mn56	2.579 h	Cr53(n, $\gamma$ )Cr54(n, $\gamma$ )Cr55( $\beta^-$ )Mn55(n, $\gamma$ )Mn56 Cr54(n, $\gamma$ )Cr55( $\beta^-$ )Mn55(n, $\gamma$ )Mn56 Cr52(n, $\gamma$ )Cr53(n, $\gamma$ )Cr54(n, $\gamma$ )Cr55( $\beta^-$ )Mn55(n, $\gamma$ )Mn56	59.1 29.8 11.1	6.6 93.3 99.7	0.3 99.7	99.0
K42	12.37 h	Cr52(n, $\alpha$ )Ti49(n,2n)Ti48(n, $\alpha$ )Ca45( $\beta^-$ )Sc45(n, $\alpha$ )K42 &Cr50(n,n $\alpha$ )Ti46(n,d)Sc45(n, $\alpha$ )K42 Cr52(n, $\alpha$ )Ti49(n, $\alpha$ )Ca46(n,2n)Ca45( $\beta^-$ )Sc45(n, $\alpha$ )K42 &Cr50(n, $\alpha$ )Ti47(n,2n)Ti46(n,d)Sc45(n, $\alpha$ )K42 &Cr50(n, $\alpha$ )Ti47(n,t)Sc45(n, $\alpha$ )K42 Cr50(n,d)V49( $\beta^+$ )Ti49(n,2n)Ti48(n, $\alpha$ )Ca45( $\beta^-$ )Sc45(n, $\alpha$ )K42 Cr52(n,2n)Cr51( $\beta^+$ )V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n, $\alpha$ )Ca45( $\beta^-$ ) Sc45(n, $\alpha$ )K42 &Cr50(n, $\alpha$ )Ti47(n,d)Sc46( $\beta^-$ )Ti46(n,d)Sc45(n, $\alpha$ )K42 &Cr50(n,d)V49(n, $\alpha$ )Sc46( $\beta^-$ )Ti46(n,d)Sc45(n, $\alpha$ )K42 Cr50(n,d)V49(n,d)Ti48(n, $\alpha$ )Ca45( $\beta^-$ )Sc45(n, $\alpha$ )K42 Cr50(n,n $\alpha$ )Ti46(n,2n)Ti45( $\beta^+$ )Sc45(n, $\alpha$ )K42 Cr50(n, $\alpha$ )Ti47(n,n $\alpha$ )Ca43(n,d)K42 Cr52(n,n $\alpha$ )Ti48(n, $\alpha$ )Ca45( $\beta^-$ )Sc45(n, $\alpha$ )K42 Cr50(n,d)V49( $\beta^+$ )Ti49(n, $\alpha$ )Ca46(n,2n)Ca45( $\beta^-$ )Sc45(n, $\alpha$ )K42 Cr50(n,n $\alpha$ )Ti46(n,n $\alpha$ )Ca42(n,p)K42 Cr52(n,d)V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n, $\alpha$ )Ca45( $\beta^-$ )Sc45(n, $\alpha$ )K42 &Cr50(n, $\alpha$ )Ti47(n,d)Sc46(n,2n)Sc45(n, $\alpha$ )K42 Cr52(n,2n)Cr51(n, $\alpha$ )Ti48(n, $\alpha$ )Ca45( $\beta^-$ )Sc45(n, $\alpha$ )K42 Cr50(n, $\alpha$ )Ti47(n, $\alpha$ )Ca44(n,2n)Ca43(n,d)K42 *Plus many other similar pathways				22.8 16.9 8.0 5.9 5.2 4.3 4.2 3.0 2.1 2.1 2.0 1.8 1.6 1.5 1.4 1.3 1.1 1.1 1.1 12.6*
Sc48	1.820 d	Cr52(n,2n)Cr51( $\beta^+$ )V51(n, $\alpha$ )Sc48 Cr52(n,d)V51(n, $\alpha$ )Sc48 Cr52(n, $\alpha$ )Ti49(n,d)Sc48 Cr50(n,d)V49( $\beta^+$ )Ti49(n,d)Sc48 Cr52(n, $\alpha$ )Ti49(n,2n)Ti48(n,p)Sc48				68.4 20.0 5.1 1.4 1.7
Sc47	3.346 d	Cr50(n, $\alpha$ )Ti47(n,p)Sc47 Cr52(n,2n)Cr51( $\beta^+$ )V51(n,2n)V50(n, $\alpha$ )Sc47 Cr50(n,p)V50(n, $\alpha$ )Sc47 Cr52(n,d)V51(n,2n)V50(n, $\alpha$ )Sc47 Cr52(n, $\alpha$ )Ti49(n,2n)Ti48(n,d)Sc47 Cr53(n, $\alpha$ )Ti50(n, $\alpha$ )Ca47( $\beta^-$ )Sc47 Cr52(n,2n)Cr51( $\beta^+$ )V51(n,n $\alpha$ )Sc47 Cr52(n, $\alpha$ )Ti49(n,t)Sc47 Cr52(n,2n)Cr51( $\beta^+$ )V51(n,d)Ti50(n, $\alpha$ )Ca47( $\beta^-$ )Sc47				33.8 21.6 19.1 6.5 3.7 2.7 2.5 1.7 1.2
Cr51	27.706 d	Cr50(n, $\gamma$ )Cr51 Cr52(n,2n)Cr51 Cr53(n,2n)Cr52(n,2n)Cr51	100.0	99.9	100.0	96.7 1.9

Sc46	83.79 d	&Cr50(n, $\alpha$ )Ti47(n,d)Sc46 &Cr50(n,d)V49(n, $\alpha$ )Sc46 &Cr50(n,n $\alpha$ )Ti46(n,p)Sc46 &Cr50(n,2n)Cr49( $\beta^+$ )V49(n, $\alpha$ )Sc46 &Cr50(n, $\alpha$ )Ti47(n,2n)Ti46(n,p)Sc46				59.8 22.8 3.5 2.6 1.7	
Ca45	162.7 d	Cr52(n, $\alpha$ )Ti49(n,2n)Ti48(n, $\alpha$ )Ca45 Cr52(n, $\alpha$ )Ti49(n, $\alpha$ )Ca46(n,2n)Ca45 Cr50(n,d)V49( $\beta^+$ )Ti49(n,2n)Ti48(n, $\alpha$ )Ca45 Cr52(n,2n)Cr51( $\beta^+$ )V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n, $\alpha$ )Ca45 Cr50(n,d)V49( $\beta^+$ )Ti49(n, $\alpha$ )Ca46(n,2n)Ca45 Cr50(n,d)V49(n,d)Ti48(n, $\alpha$ )Ca45 Cr52(n,d)V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n, $\alpha$ )Ca45 Cr52(n,n $\alpha$ )Ti48(n, $\alpha$ )Ca45 Cr52(n,2n)Cr51(n, $\alpha$ )Ti48(n, $\alpha$ )Ca45 Cr50(n, $\alpha$ )Ti47(n,2p)Ca46(n,2n)Ca45 Cr50(n,2n)Cr49( $\beta^+$ )V49( $\beta^+$ )Ti49(n,2n)Ti48(n, $\alpha$ )Ca45				44.4 15.5 9.8 8.4 3.4 3.4 2.5 2.2 1.5 1.2 1.1	
V49	330.0 d	Cr50(n,d)V49 Cr50(n,2n)Cr49( $\beta^+$ )V49 Cr50(n,p)V50(n,2n)V49 Cr52(n,2n)Cr51( $\beta^+$ )V51(n,2n)V50(n,2n)V49				83.1 9.3 3.4 3.1	
Co60	5.2717 y	&Cr54(n, $\gamma$ )Cr55( $\beta^-$ )Mn55(n, $\gamma$ )Mn56( $\beta^-$ )Fe56(n, $\gamma$ ) Fe57(n, $\gamma$ )Fe58(n, $\gamma$ )Fe59( $\beta^-$ )Co59(n, $\gamma$ )Co60 &Cr53(n, $\gamma$ )Cr54(n, $\gamma$ )Cr55( $\beta^-$ )Mn55(n, $\gamma$ )Mn56( $\beta^-$ ) Fe56(n, $\gamma$ )Fe57(n, $\gamma$ )Fe58(n, $\gamma$ )Fe59( $\beta^-$ )Co59(n, $\gamma$ )Co60 &Cr52(n, $\gamma$ )Cr53(n, $\gamma$ )Cr54(n, $\gamma$ )Cr55( $\beta^-$ )Mn55(n, $\gamma$ )Mn56 ( $\beta^-$ )Fe56(n, $\gamma$ )Fe57(n, $\gamma$ )Fe58(n, $\gamma$ )Fe59( $\beta^-$ )Co59(n, $\gamma$ )Co60	58.7  38.9  2.4	97.7  2.2  	99.9		
H3	12.33 y	Cr50(n, $\gamma$ )Cr51(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Cr53(n,X)H3 Cr52(n,X)H3 Cr50(n,X)H3 Cr54(n,X)H3 Cr52(n,2n)Cr51(n,X)H3 Cr52(n, $\alpha$ )Ti49(n,X)H3 Cr54(n,2n)Cr53(n,X)H3 Cr52(n,2n)Cr51( $\beta^+$ )V51(n,X)H3		93.2			56.1 27.1 4.8 2.6 2.3 1.7 1.3 1.3
Ar42	33.0 y	Cr52(n, $\alpha$ )Ti49(n,2n)Ti48(n, $\alpha$ )Ca45(n, $\alpha$ )Ar42 Cr52(n, $\alpha$ )Ti49(n, $\alpha$ )Ca46(n,2n)Ca45(n, $\alpha$ )Ar42 Cr50(n,d)V49( $\beta^+$ )Ti49(n,2n)Ti48(n, $\alpha$ )Ca45(n, $\alpha$ )Ar42 Cr52(n,2n)Cr51( $\beta^+$ )V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n, $\alpha$ )Ca45(n, $\alpha$ )Ar42 Cr50(n,d)V49(n,d)Ti48(n, $\alpha$ )Ca45(n, $\alpha$ )Ar42 Cr52(n,n $\alpha$ )Ti48(n, $\alpha$ )Ca45(n, $\alpha$ )Ar42 Cr50(n,d)V49( $\beta^+$ )Ti49(n, $\alpha$ )Ca46(n,2n)Ca45(n, $\alpha$ )Ar42 Cr52(n,d)V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n, $\alpha$ )Ca45(n, $\alpha$ )Ar42 Cr52(n,2n)Cr51(n, $\alpha$ )Ti48(n, $\alpha$ )Ca45(n, $\alpha$ )Ar42 Cr50(n, $\alpha$ )Ti47(n,2p)Ca46(n,2n)Ca45(n, $\alpha$ )Ar42				44.2 15.5 8.4 8.1 4.1 3.1 2.9 2.5 2.2 1.2	
Ni63	99.0 y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )		100.0	100.0		

Ar39	269.0 y	$\text{Cr50(n,}\alpha\text{)Ti47(n,n}\alpha\text{)Ca43(n,n}\alpha\text{)Ar39}$ $\text{Cr50(n,n}\alpha\text{)Ti46(n,n}\alpha\text{)Ca42(n,}\alpha\text{)Ar39}$ $\text{Cr50(n,n}\alpha\text{)Ti46(n,}\alpha\text{)Ca43(n,n}\alpha\text{)Ar39}$ $\text{Cr50(n,}\alpha\text{)Ti47(n,}\alpha\text{)Ca44(n,2n)Ca43(n,n}\alpha\text{)Ar39}$ $\text{Cr50(n,}\alpha\text{)Ti47(n,2n)Ti46(n,n}\alpha\text{)Ca42(n,}\alpha\text{)Ar39}$ $\text{Cr50(n,}\alpha\text{)Ti47(n,2n)Ti46(n,}\alpha\text{)Ca43(n,n}\alpha\text{)Ar39}$ $\text{Cr50(n,}\alpha\text{)Ti47(n,n}\alpha\text{)Ca43(n,}\alpha\text{)Ar40(n,2n)Ar39}$ $\text{Cr50(n,}\alpha\text{)Ti47(n,n}\alpha\text{)Ca43(n,2n)Ca42(n,}\alpha\text{)Ar39}$ $\text{Cr50(n,}\alpha\text{)Ti47(n,}\alpha\text{)Ca44(n,n}\alpha\text{)Ar40(n,2n)Ar39}$ $\&\text{Cr50(n,}\alpha\text{)Ti47(n,d)Sc46(\beta^-)Ti46(n,n}\alpha\text{)Ca42(n,}\alpha\text{)Ar39}$ $\&\text{Cr50(n,}\alpha\text{)Ti47(n,d)Sc46(\beta^-)Ti46(n,}\alpha\text{)Ca43(n,n}\alpha\text{)Ar39}$ $\&\text{Cr50(n,d)V49(n,}\alpha\text{)Sc46(\beta^-)Ti46(n,n}\alpha\text{)Ca42(n,}\alpha\text{)Ar39}$ $\text{Cr50(n,n}\alpha\text{)Ti46(n,}\alpha\text{)Ca43(n,}\alpha\text{)Ar40(n,2n)Ar39}$ $\text{Cr50(n,n}\alpha\text{)Ti46(n,}\alpha\text{)Ca43(n,2n)Ca42(n,}\alpha\text{)Ar39}$ $\&\text{Cr50(n,d)V49(n,}\alpha\text{)Sc46(\beta^-)Ti46(n,}\alpha\text{)Ca43(n,n}\alpha\text{)Ar39}$ $\&\text{Cr50(n,n}\alpha\text{)Ti46(n,d)Sc45(n,}\alpha\text{)K42(\beta^-)Ca42(n,}\alpha\text{)Ar39}$ $\text{Cr50(n,}\alpha\text{)Ti47(n,}\alpha\text{)Ca44(n,2n)Ca43(n,}\alpha\text{)Ar40(n,2n)Ar39}$ $\text{Cr50(n,}\alpha\text{)Ti47(n,}\alpha\text{)Ca44(n,2n)Ca43(n,2n)Ca42(n,}\alpha\text{)Ar39}$				25.6 14.6 12.7 12.4 3.8 3.3 2.7 2.6 2.2 1.8 1.6 1.4 1.3 1.3 1.2 1.2 1.1 1.0
Ca41	$1.03 \cdot 10^5$ y	$\text{Cr50(n,n}\alpha\text{)Ti46(n,n}\alpha\text{)Ca42(n,2n)Ca41}$ $\text{Cr50(n,}\alpha\text{)Ti47(n,2n)Ti46(n,n}\alpha\text{)Ca42(n,2n)Ca41}$ $\text{Cr50(n,}\alpha\text{)Ti47(n,n}\alpha\text{)Ca43(n,2n)Ca42(n,2n)Ca41}$ $\&\text{Cr50(n,}\alpha\text{)Ti47(n,d)Sc46(\beta^-)Ti46(n,n}\alpha\text{)Ca42(n,2n)Ca41}$ $\&\text{Cr50(n,d)V49(n,}\alpha\text{)Sc46(\beta^-)Ti46(n,n}\alpha\text{)Ca42(n,2n)Ca41}$ $\text{Cr50(n,n}\alpha\text{)Ti46(n,}\alpha\text{)Ca43(n,2n)Ca42(n,2n)Ca41}$ $\&\text{Cr50(n,n}\alpha\text{)Ti46(n,d)Sc45(n,}\alpha\text{)K42(\beta^-)Ca42(n,2n)Ca41}$ $\text{Cr50(n,}\alpha\text{)Ti47(n,}\alpha\text{)Ca44(n,2n)Ca43(n,2n)Ca42(n,2n)Ca41}$ $\text{Cr52(n,}\alpha\text{)Ti49(n,2n)Ti48(n,}\alpha\text{)Ca45(\beta^-)Sc45(n,}\alpha\text{)}$ $\text{K42(\beta^-)Ca42(n,2n)Ca41}$ $\&\text{Cr50(n,}\alpha\text{)Ti47(n,t)Sc45(n,}\alpha\text{)K42(\beta^-)Ca42(n,2n)Ca41}$ *Plus many other similar pathways				45.0 11.7 7.9 5.6 4.4 3.9 3.7 3.1 2.5 1.1 11.1*
Fe60	$1.5 \cdot 10^6$ y	$\text{Cr54(n,}\gamma\text{)Cr55(\beta^-)Mn55(n,}\gamma\text{)Mn56(\beta^-)Fe56(n,}\gamma\text{)$ $\text{Fe57(n,}\gamma\text{)Fe58(n,}\gamma\text{)Fe59(n,}\gamma\text{)Fe60}$ $\text{Cr53(n,}\gamma\text{)Cr54(n,}\gamma\text{)Cr55(\beta^-)Mn55(n,}\gamma\text{)Mn56(\beta^-)}$ $\text{Fe56(n,}\gamma\text{)Fe57(n,}\gamma\text{)Fe58(n,}\gamma\text{)Fe59(n,}\gamma\text{)Fe60}$ $\text{Cr52(n,}\gamma\text{)Cr53(n,}\gamma\text{)Cr54(n,}\gamma\text{)Cr55(\beta^-)Mn55(n,}\gamma\text{)}$ $\text{Mn56(\beta^-)Fe56(n,}\gamma\text{)Fe57(n,}\gamma\text{)Fe58(n,}\gamma\text{)Fe59(n,}\gamma\text{)Fe60}$	56.2 41.0 2.8	97.8 2.2 0.1	99.9	
Mn53	$3.68 \cdot 10^6$ y	$\text{Cr54(n,}\gamma\text{)Cr55(\beta^-)Mn55(n,2n)Mn54(n,2n)Mn53}$				99.9
K40	$1.28 \cdot 10^9$ y	$\text{Cr50(n,}\alpha\text{)Ti47(n,}\alpha\text{)Ca44(n,}\alpha\text{)Ar41(\beta^-)K41(n,2n)K40}$ $\text{Cr50(n,n}\alpha\text{)Ti46(n,n}\alpha\text{)Ca42(n,2n)Ca41(n,d)K40}$ $\text{Cr50(n,}\alpha\text{)Ti47(n,2n)Ti46(n,n}\alpha\text{)Ca42(n,2n)Ca41(n,d)K40}$ $\text{Cr50(n,}\alpha\text{)Ti47(n,n}\alpha\text{)Ca43(n,2n)Ca42(n,2n)Ca41(n,d)K40}$ $\text{Cr50(n,n}\alpha\text{)Ti46(n,n}\alpha\text{)Ca42(n,d)K41(n,2n)K40}$ $\&\text{Cr50(n,}\alpha\text{)Ti47(n,d)Sc46(\beta^-)Ti46(n,n}\alpha\text{)Ca42(n,2n)}$ Ca41(n,d)K40 *Plus many other similar pathways				69.2 11.1 2.3 1.5 1.2 1.0 13.7*
V50	$1.5 \cdot 10^{17}$ y	$\text{Cr52(n,2n)Cr51(\beta^+)V51(n,2n)V50}$ $\text{Cr50(n,p)V50}$ $\text{Cr52(n,d)V51(n,2n)V50}$ $\text{Cr52(n,2n)Cr51(n,d)V50}$				44.9 39.6 13.4 1.2

# Chromium activation characteristics

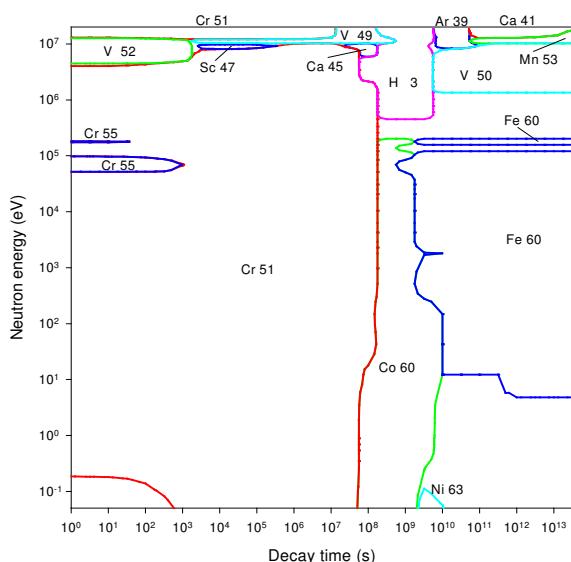


Decay time (years)

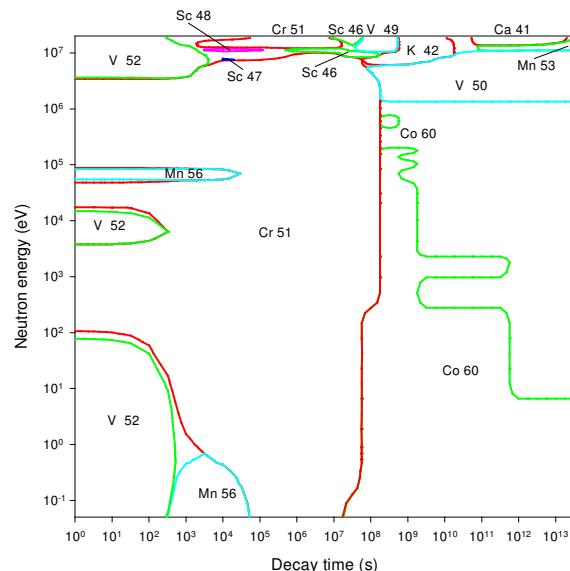
Decay time (years)

# Chromium importance diagrams & transmutation

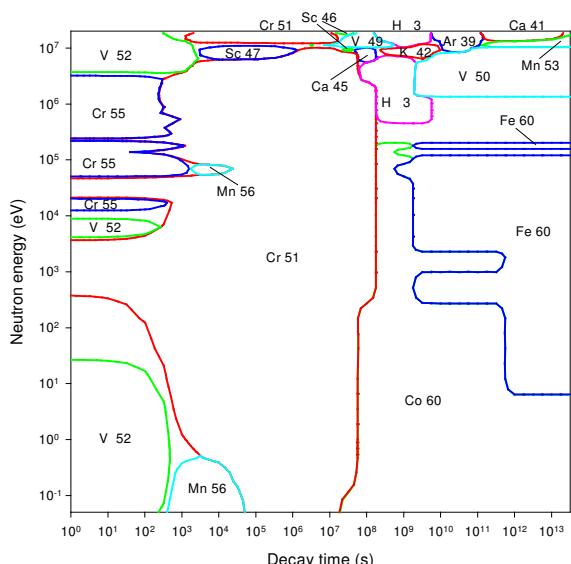
## Activity



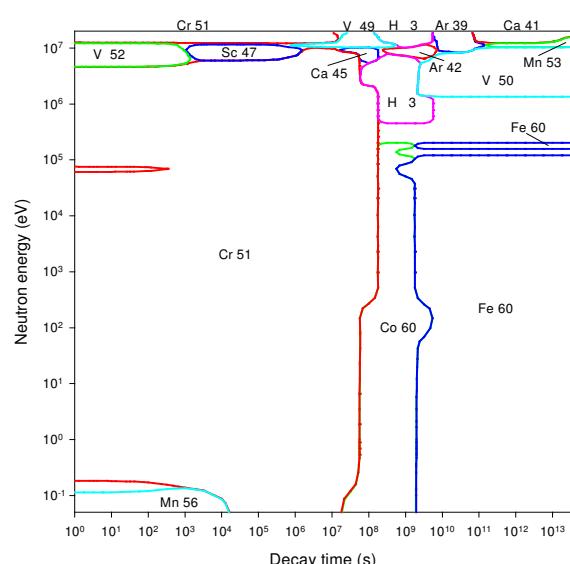
## Dose rate



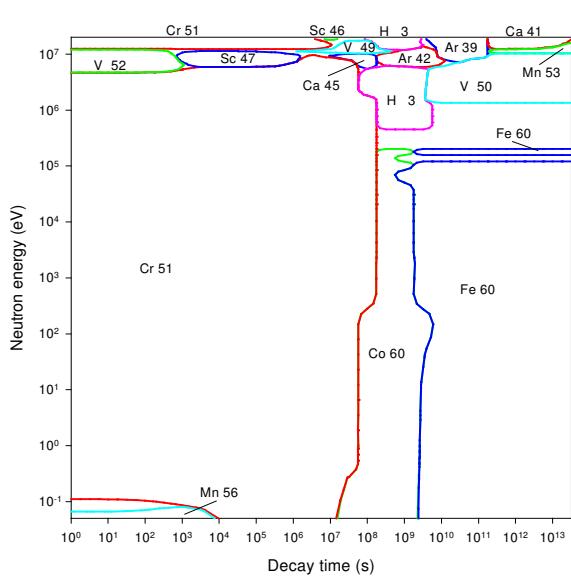
## Heat output



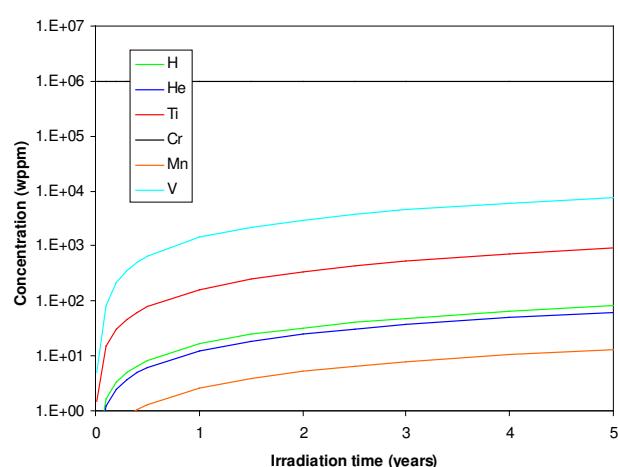
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Manganese

## General properties

Atomic number	25	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	950	Mn55	100.0
Melting point / K	1519		
Boiling point / K	2234		
Density / kgm <sup>-3</sup>	7440		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	7.82		
Electrical resistivity /Ωm	1.85 10 <sup>-6</sup>		
Coefficient of thermal expansion / K <sup>-1</sup>	2.17 10 <sup>-5</sup>		
Crystal structure	BCC		
Number of stable isotopes	1		
Mean atomic weight	54.93805		

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	4.30E15	4.16E15	1.10E15	4.99E14	1.28E9	1.58E6	kW kg <sup>-1</sup>	1.42E0	1.38E0	1.47E-1	6.58E-2	1.17E-9	1.37E-12
Mn56	71.85	72.44					Mn56	87.81	88.58				
Mn54	25.57	26.39	98.79	97.93			Mn54	10.40	10.74	99.99	99.99		
Cr55	1.43	0.53					V52	1.00	0.39				
Fe55	0.30	0.31	1.16	2.00			Cr55	0.76	0.28				
H3	0.01	0.01	0.03	0.07	99.87		H3					99.88	
Mn53					0.13	100.0	Mn53					0.12	100.0
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	1.82E6	1.78E6	2.42E5	1.09E5	4.12E-7	4.04E-7	Sv kg <sup>-1</sup>	1.56E6	1.54E6	7.78E5	3.50E5	5.36E-2	4.73E-5
Mn56	85.75	85.94					Mn54	50.11	50.70	99.45	99.05		
Mn54	13.39	13.74	100.0	100.0			Mn56	49.58	49.01				
V52	0.84	0.33					Fe55	0.27	0.28	0.54	0.94		
Mn53					99.77	100.0	H3					99.91	
Co60					0.23		Mn53					0.09	100.0
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	2.03E6	2.02E6	1.64E6	7.40E5	3.31E-1	8.51E-5		9.24E12	9.07E12	3.63E12	1.63E12	4.28E2	2.87E0
Mn54	81.23	81.58	99.39	98.95			Mn56	59.68	59.37				
Mn56	18.26	17.92					Mn54	39.64	40.37	100.0	99.99		
Fe55	0.49	0.49	0.60	1.04			V52	0.60	0.23				
H3	0.01	0.01	0.01	0.01	99.97		H3					99.32	
Mn53					0.03	99.99	Mn53					0.68	100.0

# Manganese

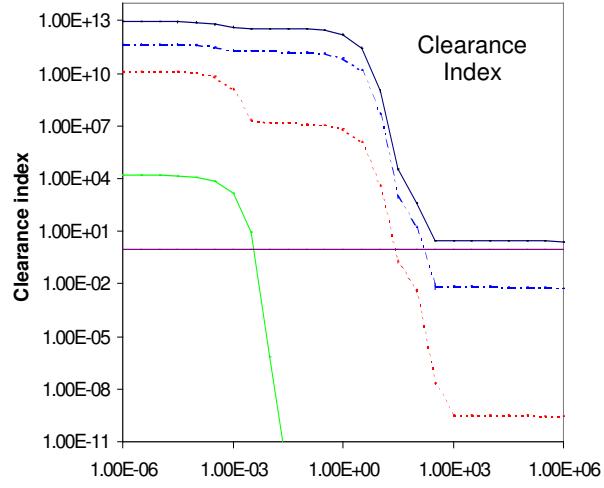
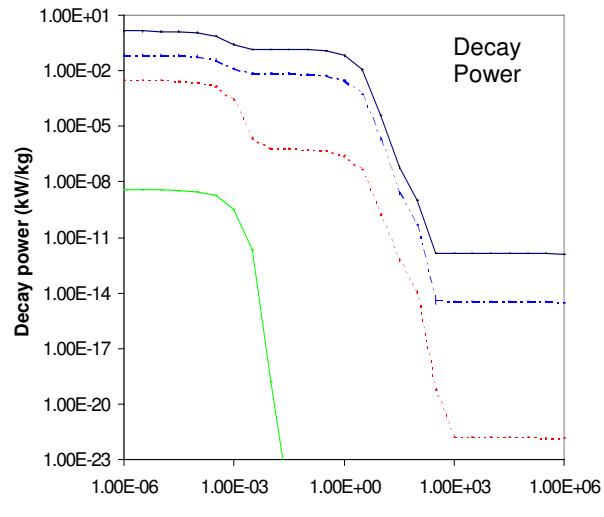
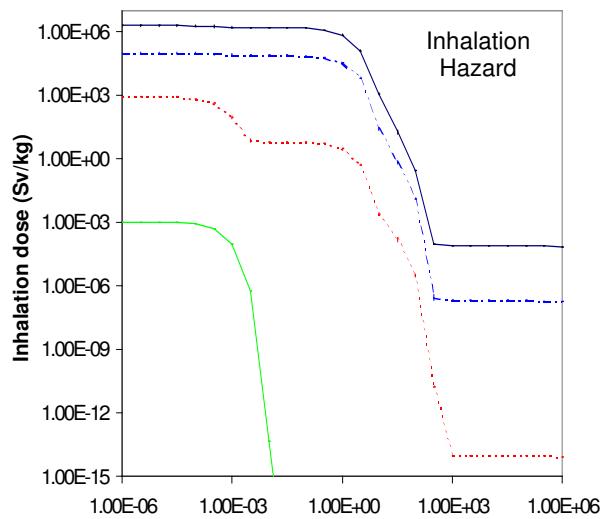
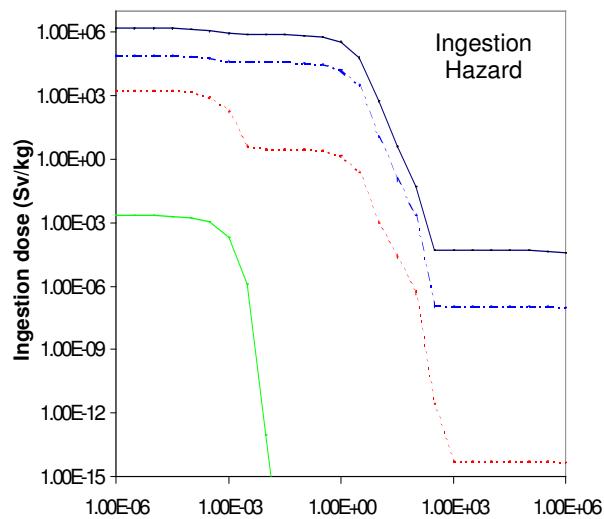
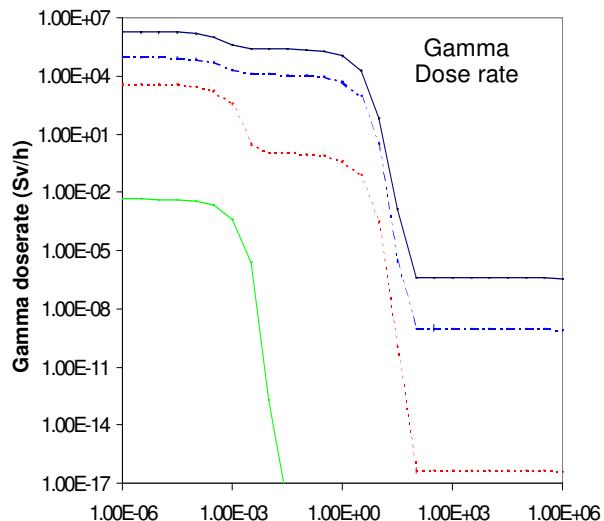
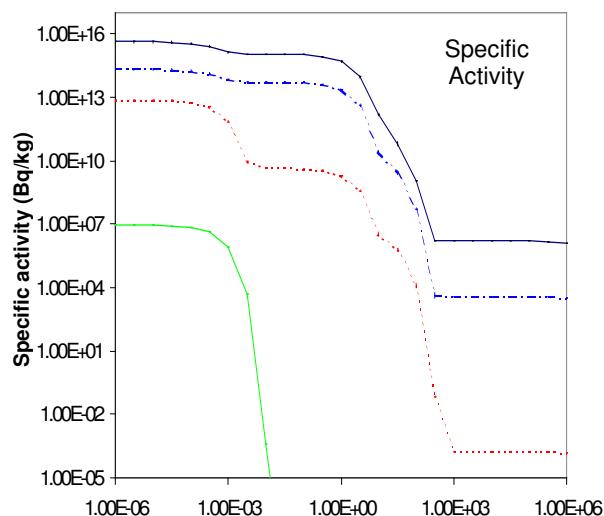
## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Cr55	3.54 m	Mn55(n, $\gamma$ )Mn56( $\beta^-$ )Fe56(n, $\alpha$ )Cr53(n, $\gamma$ )Cr54(n, $\gamma$ )Cr55 Mn55(n, $\gamma$ )Mn56( $\beta^-$ )Fe56(n, $\gamma$ )Fe57(n, $\alpha$ )Cr54(n, $\gamma$ )Cr55 Mn55(n,p)Cr55	84.4 15.6	88.0 12.0	49.1 50.9	99.8
V52	3.745 m	Mn55(n, $\alpha$ )V52				97.5
Mn56	2.579 h	Mn55(n, $\gamma$ )Mn56	100.0	100.0	100.0	97.8
K42	12.37 h	Mn55(n, $\alpha$ )V52( $\beta^-$ )Cr52(n, $\alpha$ )Ti49(n,2n)Ti48(n, $\alpha$ ) Ca45( $\beta^-$ )Sc45(n, $\alpha$ )K42 Mn55(n,n $\alpha$ )V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n, $\alpha$ )Ca45( $\beta^-$ )Sc45(n, $\alpha$ )K42 Mn55(n, $\alpha$ )V52( $\beta^-$ )Cr52(n, $\alpha$ )Ti49(n, $\alpha$ )Ca46(n,2n) Ca45( $\beta^-$ )Sc45(n, $\alpha$ )K42 Mn55(n,2n)Mn54(n, $\alpha$ )V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n, $\alpha$ ) Ca45( $\beta^-$ )Sc45(n, $\alpha$ )K42 Mn55(n, $\alpha$ )V52( $\beta^-$ )Cr52(n,n $\alpha$ )Ti48(n, $\alpha$ )Ca45( $\beta^-$ )Sc45(n, $\alpha$ )K42 Mn55(n, $\alpha$ )V52( $\beta^-$ )Cr52(n,2n)Cr51(n, $\alpha$ )Ti48(n, $\alpha$ ) Ca45( $\beta^-$ )Sc45(n, $\alpha$ )K42 Mn55(n, $\alpha$ )V52( $\beta^-$ )Cr52(n,d)V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n, $\alpha$ ) Ca45( $\beta^-$ )Sc45(n, $\alpha$ )K42 *Plus many other similar pathways			28.2 26.6 9.9 8.9 2.7 1.8 1.6 12.2*	
Sc48	1.820 d	Mn55(n,n $\alpha$ )V51(n, $\alpha$ )Sc48 Mn55(n,2n)Mn54(n, $\alpha$ )V51(n, $\alpha$ )Sc48 Mn55(n, $\alpha$ )V52( $\beta^-$ )Cr52(n,2n)Cr51( $\beta^+$ )V51(n, $\alpha$ )Sc48 Mn55(n,2n)Mn54( $\beta^+$ )Cr54(n, $\alpha$ )Ti51( $\beta^-$ )V51(n, $\alpha$ )Sc48 Mn55(n, $\alpha$ )V52( $\beta^-$ )Cr52(n,d)V51(n, $\alpha$ )Sc48 Mn55(n,d)Cr54(n, $\alpha$ )Ti51( $\beta^-$ )V51(n, $\alpha$ )Sc48 Mn55(n, $\alpha$ )V52( $\beta^-$ )Cr52(n, $\alpha$ )Ti49(n,d)Sc48				39.4 19.7 17.5 12.6 5.2 1.4 1.3
Sc47	3.346 d	Mn55(n,2n)Mn54(n,n $\alpha$ )V50(n, $\alpha$ )Sc47 Mn55(n,n $\alpha$ )V51(n,2n)V50(n, $\alpha$ )Sc47 Mn55(n,2n)Mn54( $\beta^+$ )Cr54(n,n $\alpha$ )Ti50(n, $\alpha$ )Ca47( $\beta^-$ )Sc47 Mn55(n,2n)Mn54(n,2n)Mn53(n, $\alpha$ )V50(n, $\alpha$ )Sc47 Mn55(n,2n)Mn54( $\beta^+$ )Cr54(n,2n)Cr53(n, $\alpha$ )Ti50(n, $\alpha$ )Ca47( $\beta^-$ )Sc47 Mn55(n,2n)Mn54(n, $\alpha$ )V51(n,2n)V50(n, $\alpha$ )Sc47 Mn55(n, $\alpha$ )V52( $\beta^-$ )Cr52(n,2n)Cr51( $\beta^+$ )V51(n,2n)V50(n, $\alpha$ )Sc47 Mn55(n,2n)Mn54( $\beta^+$ )Cr54(n, $\alpha$ )Ti51( $\beta^-$ )V51(n,2n)V50(n, $\alpha$ )Sc47 Mn55(n,n $\alpha$ )V51(n,n $\alpha$ )Sc47 Mn55(n, $\alpha$ )V52( $\beta^-$ )Cr52(n,d)V51(n,2n)V50(n, $\alpha$ )Sc47 Mn55(n,d)Cr54(n,n $\alpha$ )Ti50(n, $\alpha$ )Ca47( $\beta^-$ )Sc47 Mn55(n,d)Cr54(n,2n)Cr53(n, $\alpha$ )Ti50(n, $\alpha$ )Ca47( $\beta^-$ )Sc47			27.7 15.0 11.7 9.8 7.8 6.2 4.3 2.7 1.7 1.3 1.3 1.0	
Ca47	4.538 d	Mn55(n,2n)Mn54( $\beta^+$ )Cr54(n,n $\alpha$ )Ti50(n, $\alpha$ )Ca47 Mn55(n,2n)Mn54( $\beta^+$ )Cr54(n,2n)Cr53(n, $\alpha$ )Ti50(n, $\alpha$ )Ca47 Mn55(n,d)Cr54(n,n $\alpha$ )Ti50(n, $\alpha$ )Ca47 Mn55(n,d)Cr54(n,2n)Cr53(n, $\alpha$ )Ti50(n, $\alpha$ )Ca47 Mn55(n,n $\alpha$ )V51(n,d)Ti50(n, $\alpha$ )Ca47 Mn55(n,2n)Mn54(n,d)Cr53(n, $\alpha$ )Ti50(n, $\alpha$ )Ca47 Mn55(n,t)Cr53(n, $\alpha$ )Ti50(n, $\alpha$ )Ca47 Mn55(n,2n)Mn54(n, $\alpha$ )V51(n,d)Ti50(n, $\alpha$ )Ca47 Mn55(n,2n)Mn54(n,p $\alpha$ )Ti50(n, $\alpha$ )Ca47			47.1 32.3 5.1 4.1 3.3 2.0 1.4 1.3 1.1	
Fe59	44.502 d	Mn55(n, $\gamma$ )Mn56( $\beta^-$ )Fe56(n, $\gamma$ )Fe57(n, $\gamma$ )Fe58(n, $\gamma$ )Fe59	100.0	100.0	100.0	99.3

Sc46	83.79 d	$\&Mn55(n,2n)Mn54(n,n\alpha)V50(n,n\alpha)Sc46$ $\&Mn55(n,2n)Mn54(n,n\alpha)V50(n,2n)V49(n,\alpha)Sc46$ $\&Mn55(n,n\alpha)V51(n,2n)V50(n,n\alpha)Sc46$ $\&Mn55(n,2n)Mn54(n,2n)Mn53(n,\alpha)V50(n,n\alpha)Sc46$ $\&Mn55(n,n\alpha)V51(n,2n)V50(n,2n)V49(n,\alpha)Sc46$ $\&Mn55(n,2n)Mn54(n,\alpha)V51(n,2n)V50(n,n\alpha)Sc46$ $\&Mn55(n,2n)Mn54(n,n\alpha)V50(n,\alpha)Sc47(\beta^-)Ti47(n,d)Sc46$ $\&Mn55(n,2n)Mn54(n,2n)Mn53(n,\alpha)V50(n,2n)V49(n,\alpha)Sc46$ $\&Mn55(n,\alpha)V52(\beta^-)Cr52(n,2n)Cr51(\beta^+)V51(n,2n)V50(n,n\alpha)Sc46$ $\&Mn55(n,2n)Mn54(n,\alpha)V51(n,2n)V50(n,2n)V49(n,\alpha)Sc46$ $\&Mn55(n,\alpha)V52(\beta^-)Cr54(n,\alpha)Ti51(\beta^-)V51(n,2n)V50(n,n\alpha)Sc46$ $\&Mn55(n,n\alpha)V51(n,\alpha)Sc47(\beta^-)Ti47(n,d)Sc46$ $\&Mn55(n,\alpha)V52(\beta^-)Cr52(n,\alpha)Ti49(n,2n)Ti48(n,2n)Ti47(n,d)Sc46$ $\&Mn55(n,\alpha)V52(\beta^-)Cr52(n,2n)Cr51(\beta^+)V51(n,2n)$ $V50(n,2n)V49(n,\alpha)Sc46$ $\&Mn55(n,n\alpha)V51(n,\alpha)Sc48(\beta^-)Ti48(n,2n)Ti47(n,d)Sc46$ $\&Mn55(n,2n)Mn54(\beta^+)Cr54(n,n\alpha)Ti50(n,\alpha)Ca47(\beta^-)$ $Sc47(\beta^-)Ti47(n,d)Sc46$ $\&Mn55(n,2n)Mn54(n,2n)Mn53(n,\alpha)V50(n,\alpha)Sc47(\beta^-)$ $Ti47(n,d)Sc46$ $\&Mn55(n,\alpha)V52(\beta^-)Cr52(n,d)V51(n,2n)V50(n,n\alpha)Sc46$				22.3 13.4 11.5 7.4 6.2 4.6 4.5 3.6 3.1 2.3 1.9 1.9 1.5 1.4 1.4 1.2 1.0 1.0
Ca45	162.7 d	$Mn55(n,\alpha)V52(\beta^-)Cr52(n,\alpha)Ti49(n,2n)Ti48(n,\alpha)Ca45$ $Mn55(n,n\alpha)V51(n,\alpha)Sc48(\beta^-)Ti48(n,\alpha)Ca45$ $Mn55(n,\alpha)V52(\beta^-)Cr52(n,\alpha)Ti49(n,\alpha)Ca46(n,2n)Ca45$ $Mn55(n,2n)Mn54(n,\alpha)V51(n,\alpha)Sc48(\beta^-)Ti48(n,\alpha)Ca45$ $Mn55(n,\alpha)V52(\beta^-)Cr52(n,2n)Cr51(\beta^+)V51(n,\alpha)Sc48(\beta^-)$ $Ti48(n,\alpha)Ca45$ $Mn55(n,2n)Mn54(\beta^+)Cr54(n,\alpha)Ti51(\beta^-)V51(n,\alpha)$ $Sc48(\beta^-)Ti48(n,\alpha)Ca45$ $Mn55(n,\alpha)V52(\beta^-)Cr52(n,n\alpha)Ti48(n,\alpha)Ca45$ $Mn55(n,\alpha)V52(\beta^-)Cr52(n,d)V51(n,\alpha)Sc48(\beta^-)Ti48(n,\alpha)Ca45$ $Mn55(n,\alpha)V52(\beta^-)Cr52(n,2n)Cr51(n,\alpha)Ti48(n,\alpha)Ca45$ $Mn55(n,2n)Mn54(\beta^+)Cr54(n,n\alpha)Ti50(n,2n)Ti49(n,2n)$ $Ti48(n,\alpha)Ca45$				31.9 22.8 11.2 8.9 5.9  3.6  2.3 1.8 1.6 1.2
Mn54	312.3 d	Mn55(n,2n)Mn54				99.6
Co60	5.272 y	$\&Mn55(n,\gamma)Mn56(\beta^-)Fe56(n,\gamma)Fe57(n,\gamma)Fe58(n,\gamma)$ $Fe59(\beta^-)Co59(n,\gamma)Co60$	100.0	100.0	100.0	99.6
H3	12.33 y	Mn55(n,X)H3				98.7
Ar42	33.0 y	$Mn55(n,\alpha)V52(\beta^-)Cr52(n,\alpha)Ti49(n,2n)Ti48(n,\alpha)Ca45(n,\alpha)Ar42$ $Mn55(n,n\alpha)V51(n,\alpha)Sc48(\beta^-)Ti48(n,\alpha)Ca45(n,\alpha)Ar42$ $Mn55(n,\alpha)V52(\beta^-)Cr52(n,\alpha)Ti49(n,\alpha)Ca46(n,2n)Ca45(n,\alpha)Ar42$ $Mn55(n,2n)Mn54(n,\alpha)V51(n,\alpha)Sc48(\beta^-)Ti48(n,\alpha)Ca45(n,\alpha)Ar42$ $Mn55(n,\alpha)V52(\beta^-)Cr52(n,2n)Cr51(\beta^+)V51(n,\alpha)Sc48(\beta^-)$ $Ti48(n,\alpha)Ca45(n,\alpha)Ar42$ $Mn55(n,2n)Mn54(\beta^+)Cr54(n,\alpha)Ti51(\beta^-)V51(n,\alpha)$ $Sc48(\beta^-)Ti48(n,\alpha)Ca45(n,\alpha)Ar42$ $Mn55(n,\alpha)V52(\beta^-)Cr52(n,n\alpha)Ti48(n,\alpha)Ca45(n,\alpha)Ar42$ $Mn55(n,\alpha)V52(\beta^-)Cr52(n,2n)Cr51(n,\alpha)Ti48(n,\alpha)Ca45(n,\alpha)Ar42$ $Mn55(n,\alpha)V52(\beta^-)Cr52(n,d)V51(n,\alpha)Sc48(\beta^-)Ti48(n,\alpha)Ca45(n,\alpha)Ar42$				29.9 28.0 10.5 9.4 5.3  2.9  2.8 1.9 1.7
Ni63	99.0 y	$\&Mn55(n,\gamma)Mn56(\beta^-)Fe56(n,\gamma)Fe57(n,\gamma)Fe58(n,\gamma)Fe59$ $(\beta^-)Co59(n,\gamma)Co60(n,\gamma)Co61(\beta^-)Ni61(n,\gamma)Ni62(n,\gamma)Ni63$ $\&Mn55(n,\gamma)Mn56(\beta^-)Fe56(n,\gamma)Fe57(n,\gamma)Fe58(n,\gamma)Fe59$ $(\beta^-)Co59(n,\gamma)Co60(\beta^-)Ni60(n,\gamma)Ni61(n,\gamma)Ni62(n,\gamma)Ni63$ $Mn55(n,\gamma)Mn56(\beta^-)Fe56(n,\gamma)Fe57(n,\gamma)Fe58(n,\gamma)Fe59$ $(n,\gamma)Fe60(n,\gamma)Fe61(\beta^-)Co61(\beta^-)Ni61(n,\gamma)Ni62(n,\gamma)Ni63$	86.1  9.5  4.3	93.1  6.7	100.0	

Ar39	269.0 y	Mn55(n,n $\alpha$ )V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n, $\alpha$ )Ca45( $\beta^-$ )Sc45(n, $\alpha$ )K42( $\beta^-$ )Ca42(n, $\alpha$ )Ar39 Mn55(n,2n)Mn54(n,n $\alpha$ )V50(n, $\alpha$ )Sc47( $\beta^-$ )Ti47(n,n $\alpha$ )Ca43(n,n $\alpha$ )Ar39 &Mn55(n,2n)Mn54(n,n $\alpha$ )V50(n,n $\alpha$ )Sc46( $\beta^-$ )Ti46(n,n $\alpha$ )Ca42(n,n $\alpha$ )Ar39 &Mn55(n,2n)Mn54(n,n $\alpha$ )V50(n,n $\alpha$ )Sc46( $\beta^-$ )Ti46(n, $\alpha$ )Ca43(n,n $\alpha$ )Ar39 Mn55(n,n $\alpha$ )V51(n,2n)V50(n, $\alpha$ )Sc47( $\beta^-$ )Ti47(n,n $\alpha$ )Ca43(n,n $\alpha$ )Ar39 Mn55(n,2n)Mn54(n,n $\alpha$ )V50(n, $\alpha$ )Sc47( $\beta^-$ )Ti47(n, $\alpha$ )Ca44(n,2n)Ca43(n,n $\alpha$ )Ar39 Mn55(n, $\alpha$ )V52( $\beta^-$ )Cr52(n, $\alpha$ )Ti49(n, $\alpha$ )Ca46(n, $\alpha$ ) Ar43( $\beta^-$ )K43( $\beta^-$ )Ca43(n,n $\alpha$ )Ar39 Mn55(n,n $\alpha$ )V51(n,2n)Ti48(n,n $\alpha$ )Ca45( $\beta^-$ ) Sc47( $\beta^-$ )Ti47(n,n $\alpha$ )Ca43(n,n $\alpha$ )Ar39 Mn55(n,n $\alpha$ )V51(n,2n)V50(n,n $\alpha$ )Sc46( $\beta^-$ )Ti46(n,n $\alpha$ )Ca43(n,n $\alpha$ )Ar39 Mn55(n,n $\alpha$ )V52( $\beta^-$ )Cr52(n,n $\alpha$ )Ti48(n,n $\alpha$ )Ca45( $\beta^-$ ) Sc45(n, $\alpha$ )K42( $\beta^-$ )Ca42(n, $\alpha$ )Ar39 &Mn55(n,2n)Mn54(n,n $\alpha$ )V50(n,2n)V49(n, $\alpha$ )Sc46( $\beta^-$ ) Ti46(n, $\alpha$ )Ca43(n,n $\alpha$ )Ar39 Mn55(n,2n)Mn54(n,2n)Mn53(n, $\alpha$ )V50(n, $\alpha$ )Sc47( $\beta^-$ ) Ti47(n,n $\alpha$ )Ca43(n,n $\alpha$ )Ar39 Mn55(n,n $\alpha$ )V51(n,2n)V50(n,n $\alpha$ )Sc46( $\beta^-$ )Ti46(n, $\alpha$ )Ca43(n,n $\alpha$ )Ar39 *Plus many other similar pathways				12.1 7.4 3.9 3.4 2.6 2.5 2.0 1.9 1.4 1.4 1.3 1.3 1.2 1.2 1.1 1.1 54.2*
Cl36	$3.07 \cdot 10^5$ y	Mn55(n,n $\alpha$ )V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n, $\alpha$ )Ca45( $\beta^-$ ) Sc45(n,n $\alpha$ )K41(n,n $\alpha$ )Cl37(n,2n)Cl36 Mn55(n,n $\alpha$ )V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n, $\alpha$ )Ca45( $\beta^-$ ) Sc45(n,n $\alpha$ )K41(n,2n)K40(n,n $\alpha$ )Cl36 Mn55(n,n $\alpha$ )V51(n,n $\alpha$ )Sc47( $\beta^-$ )Ti47(n, $\alpha$ )Ca44(n, $\alpha$ ) Ar41( $\beta^-$ )K41(n,n $\alpha$ )Cl37(n,2n)Cl36 *Many other paths involving (n, $\alpha$ ), (n,n $\alpha$ ) and $\beta^-$				5.5 4.2 1.0 89.3*
Fe60	$1.5 \cdot 10^6$ y	Mn55(n, $\gamma$ )Mn56( $\beta^-$ )Fe56(n, $\gamma$ )Fe57(n, $\gamma$ )Fe58(n, $\gamma$ ) Fe59(n, $\gamma$ )Fe60	100.0	100.0	100.0	98.8
Mn53	$3.68 \cdot 10^6$ y	Mn55(n,2n)Mn54(n,2n)Mn53				99.8
K40	$1.28 \cdot 10^9$ y	Mn55(n,2n)Mn54(n,n $\alpha$ )V50(n, $\alpha$ )Sc47( $\beta^-$ )Ti47(n, $\alpha$ ) Ca44(n, $\alpha$ )Ar41( $\beta^-$ )K41(n,2n)K40 Mn55(n,n $\alpha$ )V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n, $\alpha$ )Ca45( $\beta^-$ )Sc45(n,n $\alpha$ )K41(n,2n)K40 Mn55(n, $\alpha$ )V52( $\beta^-$ )Cr52(n, $\alpha$ )Ti49(n,2n)Ti48(n, $\alpha$ ) Ca45( $\beta^-$ )Sc45(n,n $\alpha$ )K41(n,2n)K40 Mn55(n,n $\alpha$ )V51(n,2n)V50(n, $\alpha$ )Sc47( $\beta^-$ )Ti47(n, $\alpha$ ) Ca44(n, $\alpha$ )Ar41( $\beta^-$ )K41(n,2n)K40 Mn55(n,2n)Mn54(n, $\alpha$ )V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n, $\alpha$ ) Ca45( $\beta^-$ )Sc45(n,n $\alpha$ )K41(n,2n)K40 Mn55(n, $\alpha$ )V52( $\beta^-$ )Cr52(n, $\alpha$ )Ti49(n, $\alpha$ )Ca46(n,2n) Ca45( $\beta^-$ )Sc45(n,n $\alpha$ )K41(n,2n)K40 Mn55(n,n $\alpha$ )V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n, $\alpha$ )Ca45(n,2n) Ca44(n, $\alpha$ )Ar41( $\beta^-$ )K41(n,2n)K40 &Mn55(n,2n)Mn54(n,n $\alpha$ )V50(n,n $\alpha$ )Sc46( $\beta^-$ )Ti46(n,n $\alpha$ ) Ca42(n,2n)Ca41(n,d)K40 Mn55(n,n $\alpha$ )V51(n,n $\alpha$ )Sc47( $\beta^-$ )Ti47(n, $\alpha$ )Ca44(n, $\alpha$ )Ar41( $\beta^-$ )K41(n,2n)K40 Mn55(n,n $\alpha$ )V51(n, $\alpha$ )Sc48( $\beta^-$ )Ti48(n,n $\alpha$ )Ca44(n, $\alpha$ )Ar41( $\beta^-$ )K41(n,2n)K40 *Plus many other similar pathways				13.1 8.3 6.0 4.3 3.1 2.2 2.1 1.9 1.9 1.5 1.0 54.6*
V50	$1.5 \cdot 10^{17}$ y	Mn55(n,2n)Mn54(n,n $\alpha$ )V50 Mn55(n,n $\alpha$ )V51(n,2n)V50 Mn55(n,2n)Mn54(n,2n)Mn53(n, $\alpha$ )V50 Mn55(n,2n)Mn54(n, $\alpha$ )V51(n,2n)V50 Mn55(n, $\alpha$ )V52( $\beta^-$ )Cr52(n,2n)Cr51( $\beta^+$ )V51(n,2n)V50 Mn55(n,2n)Mn54( $\beta^+$ )Cr54(n, $\alpha$ )Ti51( $\beta^-$ )V51(n,2n)V50 Mn55(n, $\alpha$ )V52( $\beta^-$ )Cr52(n,d)V51(n,2n)V50				40.8 22.0 14.5 9.1 6.3 4.0 1.9

# Manganese activation characteristics

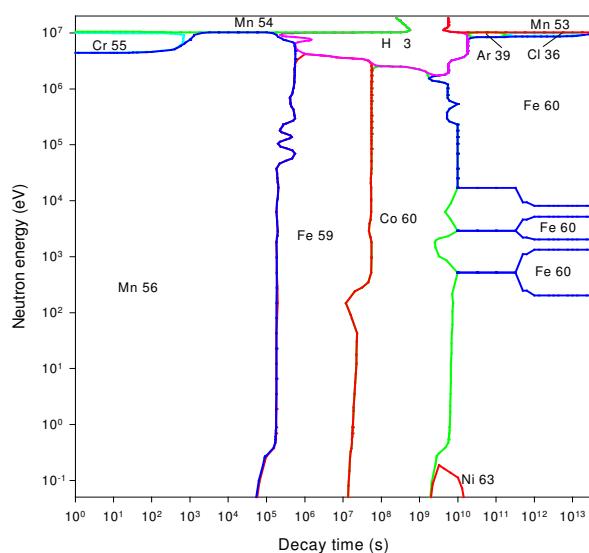


Decay time (years)

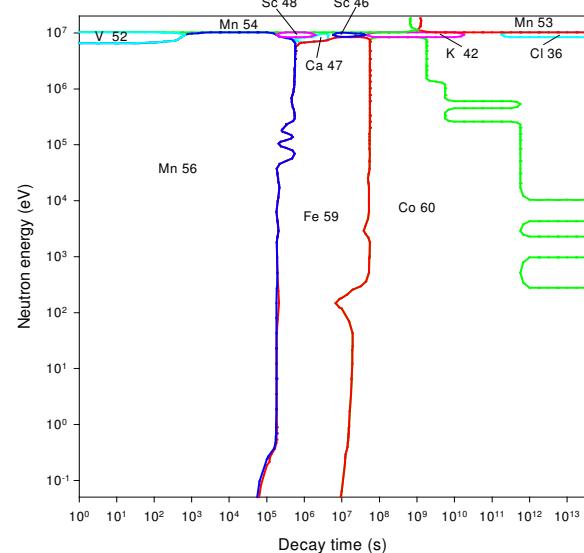
Decay time (years)

# Manganese importance diagrams & transmutation

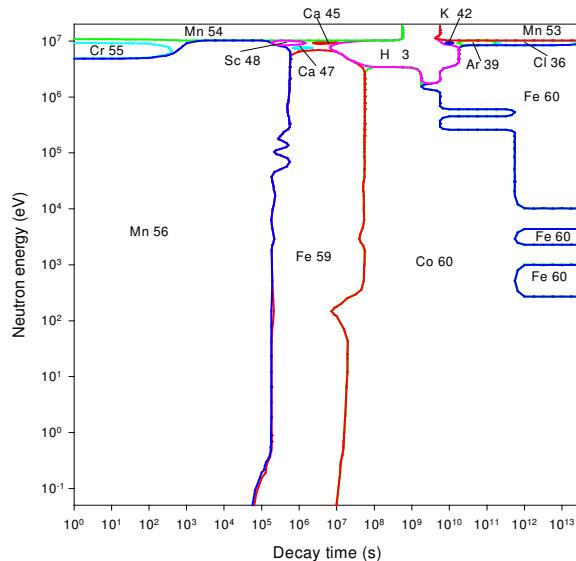
## Activity



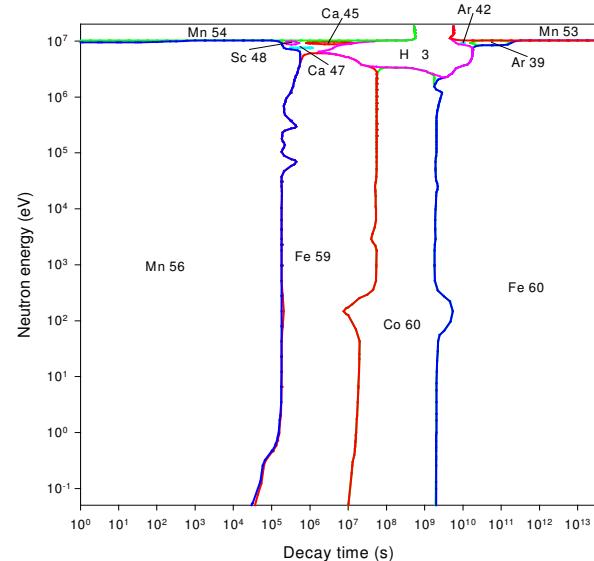
## Dose rate



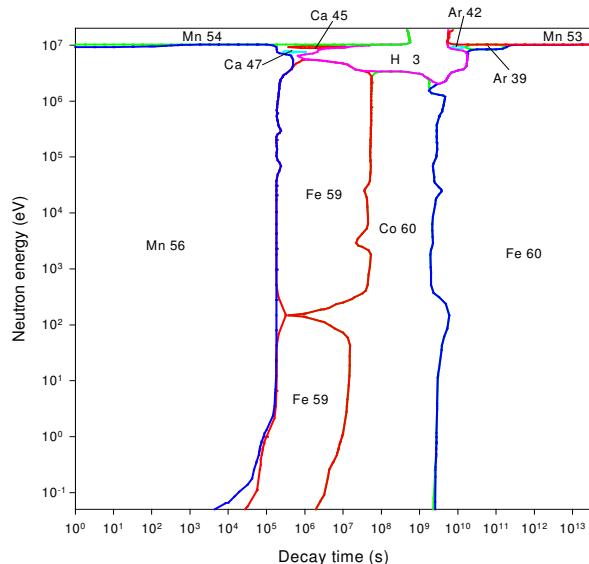
## Heat output



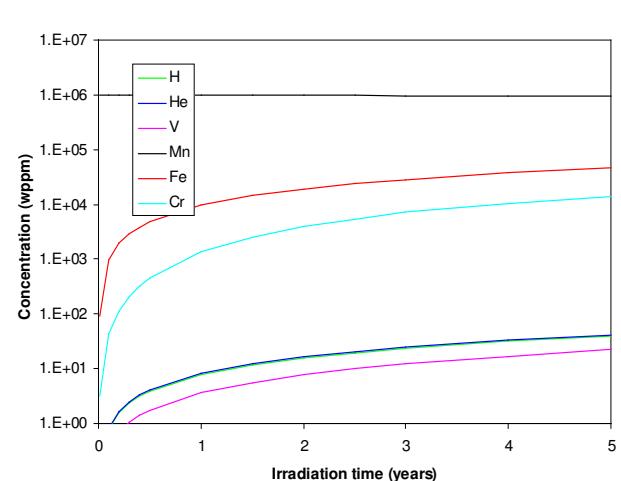
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Iron

## General properties

		26	Isotopes	Isotopic abundances / %	
Atomic number		5.63 10 <sup>4</sup>	Fe54	5.845	
Crustal abundance / wppm		1811	Fe56	91.754	
Melting point / K		3134	Fe57	2.119	
Boiling point / K		7874	Fe58	0.282	
Density / kgm <sup>-3</sup>		80.2			
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>		9.71 10 <sup>-8</sup>			
Electrical resistivity /Ωm		1.18 10 <sup>-5</sup>			
Coefficient of thermal expansion / K <sup>-1</sup>		BCC			
Crystal structure		4			
Number of stable isotopes		55.845			
Mean atomic weight					

## Activation properties

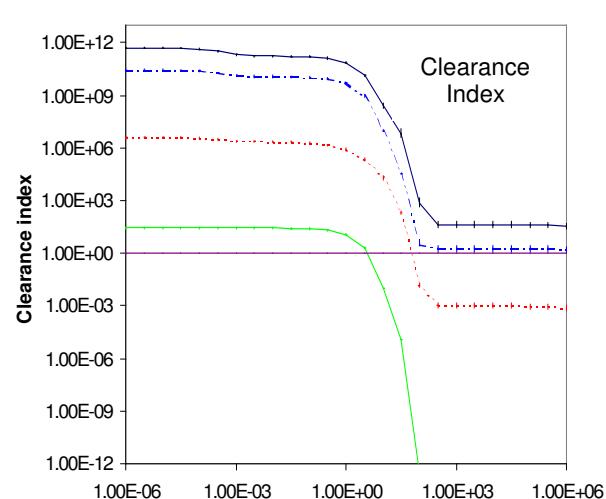
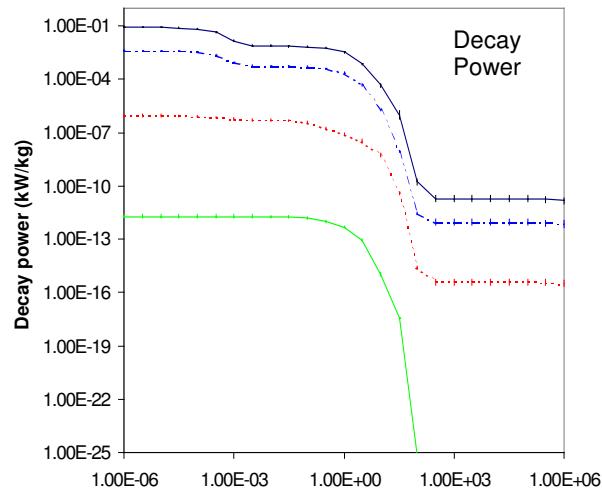
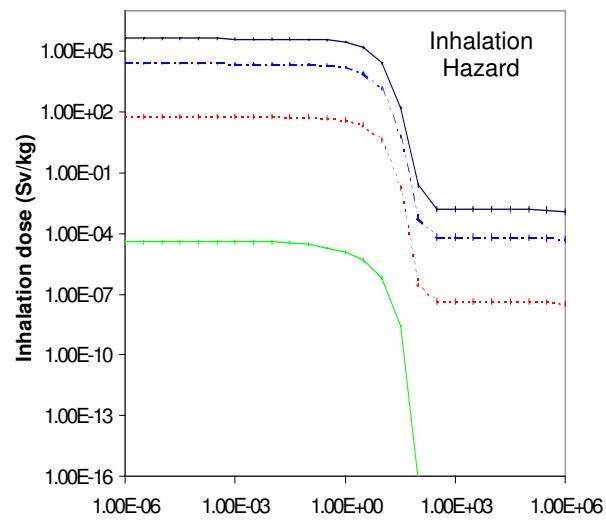
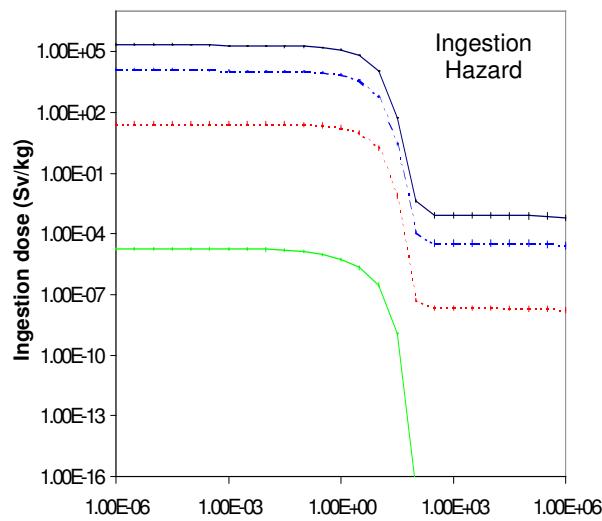
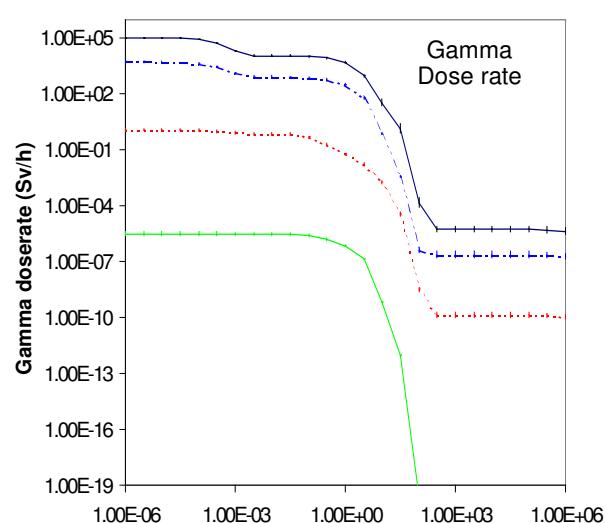
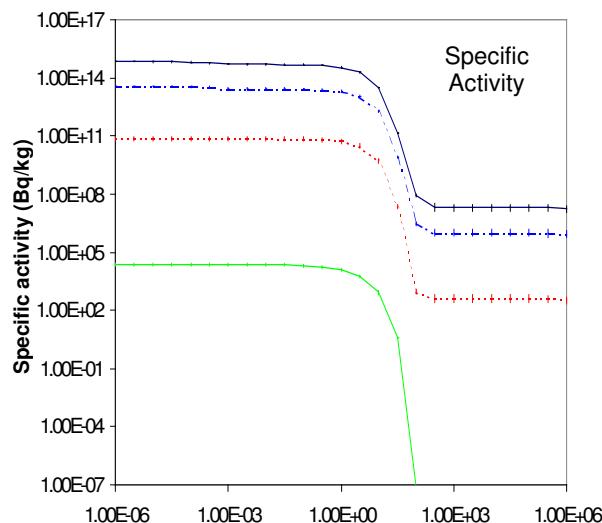
Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	6.81E14	6.73E14	4.82E14	3.51E14	9.35E7	2.02E7	kW kg <sup>-1</sup>	8.65E-2	8.39E-2	7.60E-3	3.39E-3	1.89E-10	1.82E-11
Fe55	62.15	62.91	87.66	93.54			Mn56	89.97	90.59				
Mn56	28.25	27.93					Mn54	7.89	8.14	89.07	89.45		
Mn54	7.45	7.54	10.44	6.42			Fe55	0.46	0.48	5.24	9.14		
Cr51	1.20	1.22	1.55				Fe59	0.38	0.39	4.09	0.03		
Co60	0.02	0.02	0.03	0.03	0.27	0.01	Co60	0.06	0.06	0.70	1.38	55.30	3.36
H3				0.01	77.68		H3					35.19	
Mn53					22.04	99.97	Mn53					9.49	96.44
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	1.07E5	1.05E5	1.17E4	5.06E3	1.84E-4	5.54E-6	Sv kg <sup>-1</sup>	2.28E5	2.26E5	1.79E5	1.25E5	4.69E-3	7.75E-4
Mn56	88.67	88.61					Fe55	61.40	61.71	78.05	86.86		
Mn54	10.26	10.49	93.28	96.63			Mn56	21.14	20.75				
Fe59	0.49	0.51	4.28	0.04			Mn54	15.83	15.91	20.01	12.83		
Fe55	0.11	0.11	0.97	1.74			Fe59	1.24	1.25	1.50	0.01		
V52	0.10	0.04					Co60	0.19	0.19	0.24	0.31	18.16	0.65
Co60	0.09	0.09	0.78	1.59	97.52	19.05	H3					65.03	
Mn52	0.06	0.06	0.32				Mn53					13.18	78.39
Mn53					2.48	80.90	Fe60					3.62	20.95
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	4.36E5	4.35E5	4.11E5	2.90E5	2.82E-2	1.55E-3		5.17E11	5.08E11	1.70E11	7.66E10	8.97E2	4.17E1
Fe55	74.80	74.89	79.14	87.14			Mn56	66.43	66.06				
Mn54	17.46	17.48	18.37	11.65			Mn54	32.69	33.28	98.40	98.08		
Mn56	5.30	5.18					Fe55	0.27	0.28	0.83	1.43		
Fe59	1.44	1.44	1.44	0.01			Fe59	0.10	0.10	0.29			
Co60	0.91	0.91	0.93	1.20	27.54	2.94	Co60	0.08	0.08	0.25	0.49	93.12	11.75
H3					66.97		Cr51	0.05	0.05	0.15			
Mn53					3.95	70.40	Mn53					4.18	88.16
Fe60					1.53	26.61	H3					2.70	

# Iron

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Mn56	2.579 h	Fe54(n, $\gamma$ )Fe55( $\beta^+$ )Mn55(n, $\gamma$ )Mn56 Fe56(n,p)Mn56 Fe57(n,d)Mn56 Fe57(n,2n)Fe56(n,p)Mn56	100.0	100.0	100.0	98.9 0.7 0.4
Fe59	44.502 d	Fe56(n, $\gamma$ )Fe57(n, $\gamma$ )Fe58(n, $\gamma$ )Fe59 Fe57(n, $\gamma$ )Fe58(n, $\gamma$ )Fe59 Fe58(n, $\gamma$ )Fe59	67.1 17.9 15.0	0.3 2.7 97.0	2.5 97.4	98.5
Mn54	312.3 d	Fe54(n,p)Mn54 Fe56(n,2n)Fe55( $\beta^+$ )Mn55(n,2n)Mn54 Fe56(n,d)Mn55(n,2n)Mn54 Fe56(n,2n)Fe55(n,2n)Fe54(n,p)Mn54	100.0	100.0	100.0	40.6 37.5 19.0 0.6
Fe55	2.735 y	Fe54(n, $\gamma$ )Fe55 Fe56(n,2n)Fe55 Fe57(n,2n)Fe56(n,2n)Fe55	100.0	100.0	100.0	98.7 0.2
Co60	5.272 y	&Fe56(n, $\gamma$ )Fe57(n, $\gamma$ )Fe58(n, $\gamma$ )Fe59( $\beta^-$ )Co59(n, $\gamma$ )Co60 &Fe58(n, $\gamma$ )Fe59( $\beta^-$ )Co59(n, $\gamma$ )Co60 &Fe57(n, $\gamma$ )Fe58(n, $\gamma$ )Fe59( $\beta^-$ )Co59(n, $\gamma$ )Co60	42.2 38.3 19.5	98.4 1.5	99.1 0.9	99.7
H3	12.33 y	Fe54(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Fe54(n, $\gamma$ )Fe55(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Fe56(n,X)H3 Fe56(n,2n)Fe55(n,X)H3 Fe57(n,X)H3 Fe56(n,2n)Fe55( $\beta^+$ )Mn55(n,X)H3 Fe56(n,d)Mn55(n,X)H3 Fe54(n,X)H3 Fe54(n,d)Mn53(n,X)H3 Fe56(n, $\alpha$ )Cr53(n,X)H3	90.8 2.5	95.1	99.3	38.8 28.9 10.5 7.8 4.7 4.3 1.9 1.4
Ni63	99.0 y	&Fe58(n, $\gamma$ )Fe59( $\beta^-$ )Co59(n, $\gamma$ )Co60(n, $\gamma$ )Co61( $\beta^-$ ) Ni61(n, $\gamma$ )Ni62(n, $\gamma$ )Ni63 &Fe56(n, $\gamma$ )Fe57(n, $\gamma$ )Fe58(n, $\gamma$ )Fe59( $\beta^-$ )Co59(n, $\gamma$ ) Co60(n, $\gamma$ )Co61( $\beta^-$ )Ni61(n, $\gamma$ )Ni62(n, $\gamma$ )Ni63 &Fe57(n, $\gamma$ )Fe58(n, $\gamma$ )Fe59( $\beta^-$ )Co59(n, $\gamma$ )Co60(n, $\gamma$ ) Co61( $\beta^-$ )Ni61(n, $\gamma$ )Ni62(n, $\gamma$ )Ni63 &Fe58(n, $\gamma$ )Fe59( $\beta^-$ )Co59(n, $\gamma$ )Co60( $\beta^-$ )Ni60(n, $\gamma$ ) Ni61(n, $\gamma$ )Ni62(n, $\gamma$ )Ni63 Fe58(n, $\gamma$ )Fe59(n, $\gamma$ )Fe60(n, $\gamma$ )Fe61( $\beta^-$ )Co61( $\beta^-$ ) Ni61(n, $\gamma$ )Ni62(n, $\gamma$ )Ni63 &Fe56(n, $\gamma$ )Fe57(n, $\gamma$ )Fe58(n, $\gamma$ )Fe59( $\beta^-$ )Co59(n, $\gamma$ ) Co60( $\beta^-$ )Ni60(n, $\gamma$ )Ni61(n, $\gamma$ )Ni62(n, $\gamma$ )Ni63 &Fe57(n, $\gamma$ )Fe58(n, $\gamma$ )Fe59( $\beta^-$ )Co59(n, $\gamma$ )Co60( $\beta^-$ ) Ni60(n, $\gamma$ )Ni61(n, $\gamma$ )Ni62(n, $\gamma$ )Ni63	55.0 15.4 12.9 9.5 2.0 1.9 1.9	88.9 0.5 0.4 10.3 4.0 10.9 11.1	84.6 0.4 11.1	76.6
Fe60	$1.5 \cdot 10^6$ y	Fe56(n, $\gamma$ )Fe57(n, $\gamma$ )Fe58(n, $\gamma$ )Fe59(n, $\gamma$ )Fe60 Fe58(n, $\gamma$ )Fe59(n, $\gamma$ )Fe60 Fe57(n, $\gamma$ )Fe58(n, $\gamma$ )Fe59(n, $\gamma$ )Fe60 &Fe58(n, $\gamma$ )Fe59( $\beta^-$ )Co59(n, $\gamma$ )Co60(n,p)Fe60	48.5 32.1 19.3	100.0	100.0	96.1 3.3
Mn53	$3.68 \cdot 10^6$ y	Fe54(n,d)Mn53 Fe54(n,2n)Fe53( $\beta^+$ )Mn53 Fe54(n,p)Mn54(n,2n)Mn53				95.0 2.1 1.1

# Iron activation characteristics

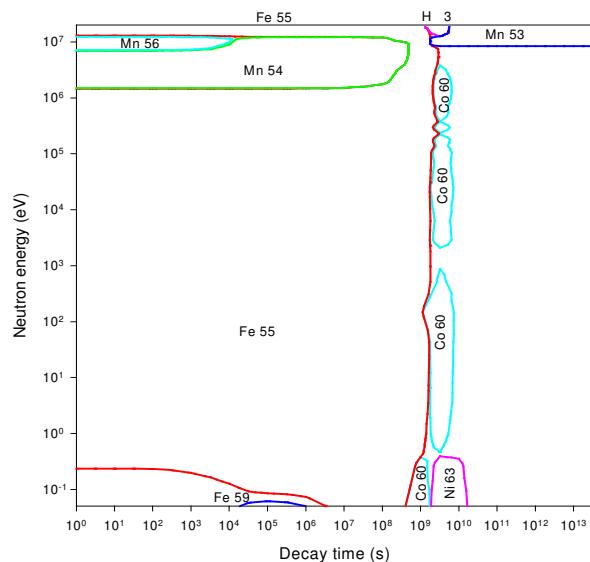


Decay time (years)

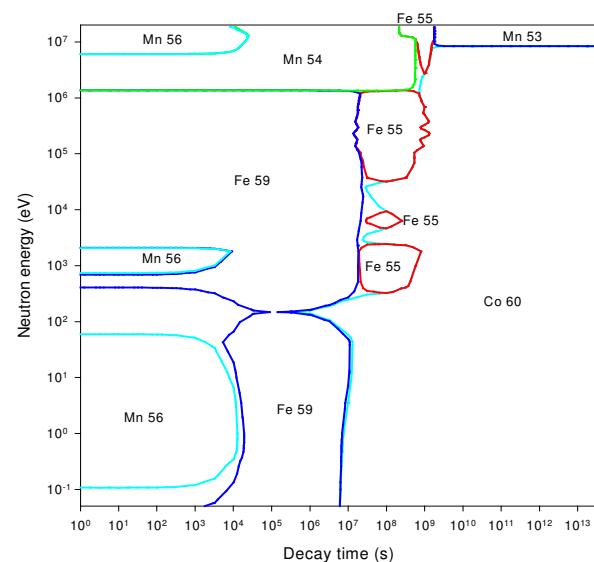
Decay time (years)

# Iron importance diagrams & transmutation

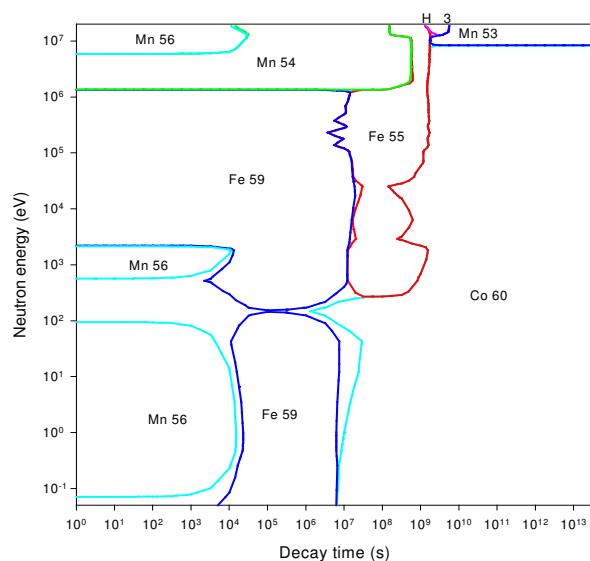
## Activity



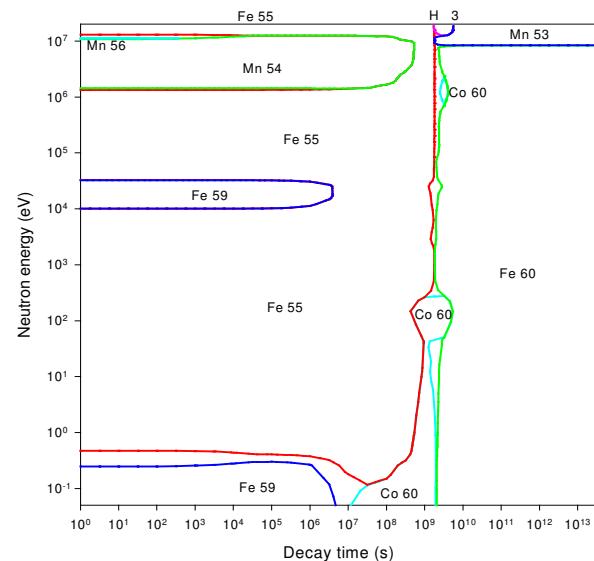
## Dose rate



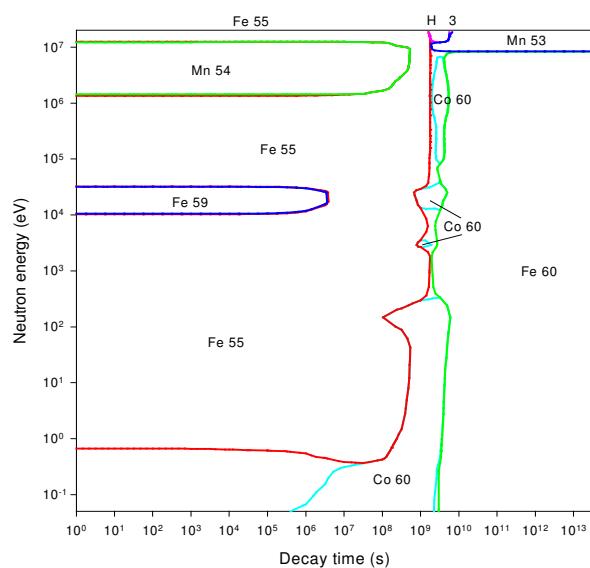
## Heat output



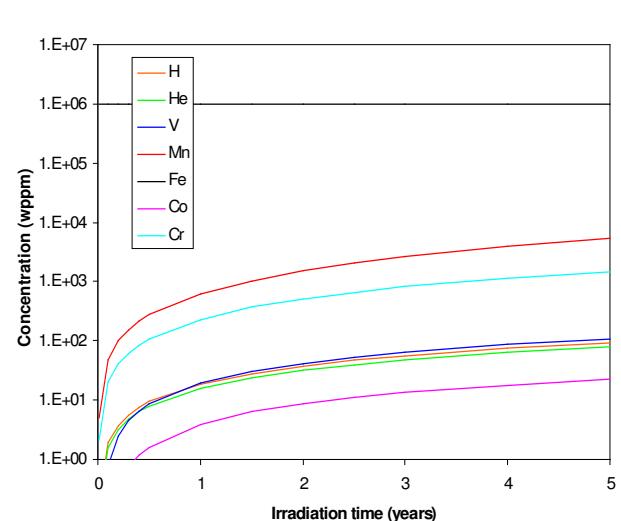
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Cobalt

## General properties

Atomic number	27	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	25	Co59	100.0
Melting point / K	1768		
Boiling point / K	3200		
Density / kgm <sup>-3</sup>	8900		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	100.0		
Electrical resistivity /Ωm	6.24 10 <sup>-8</sup>		
Coefficient of thermal expansion / K <sup>-1</sup>	1.336 10 <sup>-5</sup>		
Crystal structure	BCC		
Number of stable isotopes	1		
Mean atomic weight	58.9332		

## Activation properties

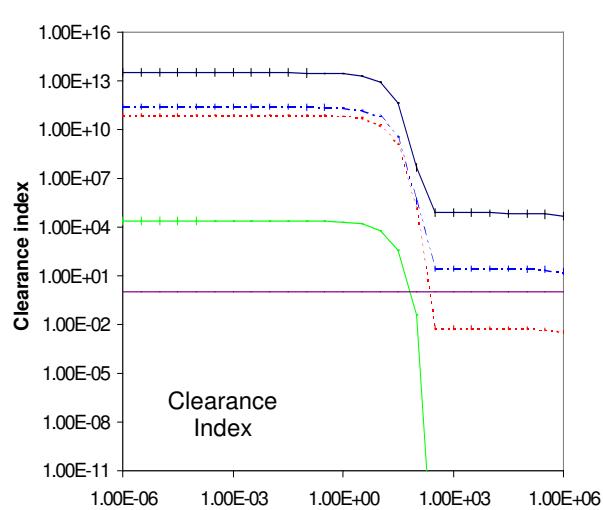
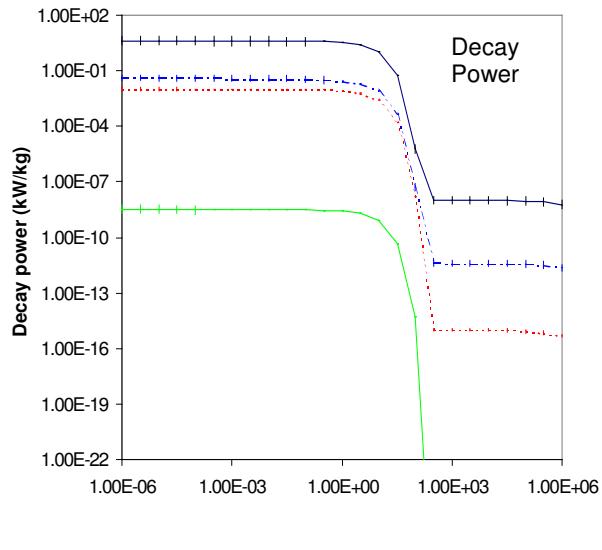
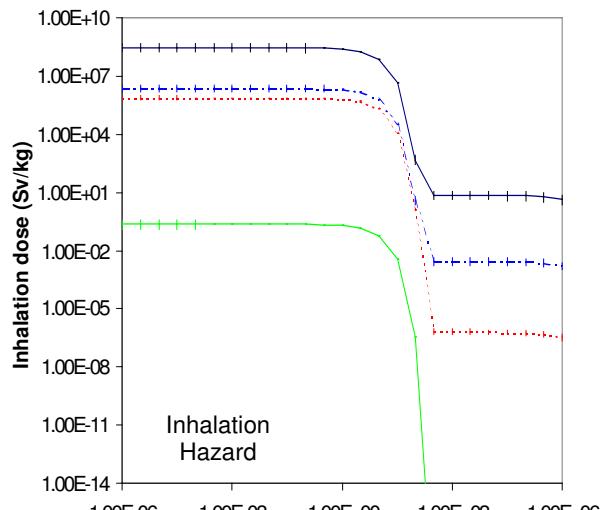
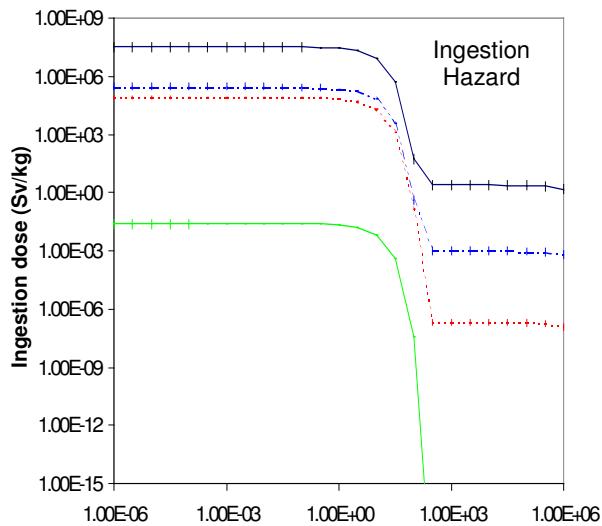
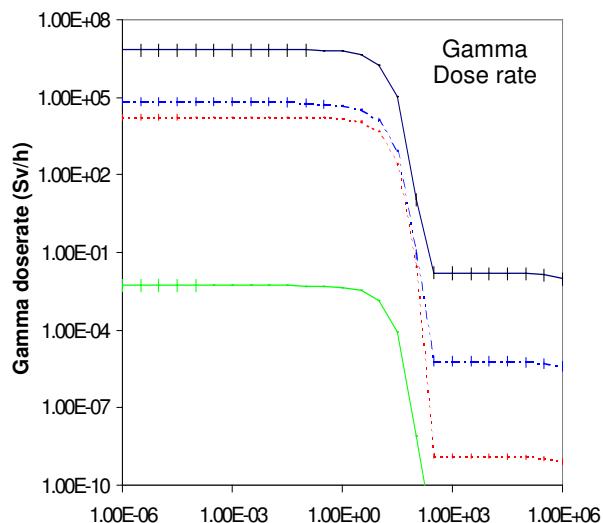
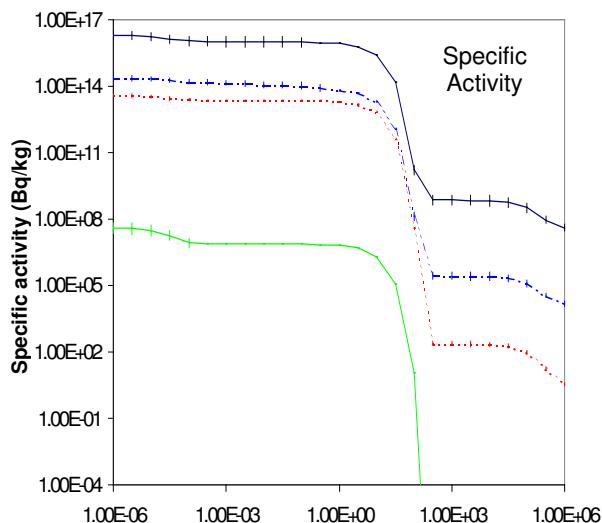
Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	2.01E16	1.73E16	9.76E15	8.18E15	1.92E10	3.27E8	kW kg <sup>-1</sup>	4.11E0	4.08E0	3.95E0	3.41E0	7.57E-6	9.25E-9
Co60m	46.91	38.47			0.11	6.21	Co60	94.45	95.17	98.07	99.94	99.98	91.38
Co60	46.28	53.76	95.36	99.86	94.46	6.20	Co60m	2.33	1.66				2.23
Co58m	2.23	2.58	0.01				Co58	1.58	1.59	1.59	0.05		
Co61	2.06	2.30					Co61	0.89	0.87				
Co58	1.99	2.31	3.98	0.14			Fe59	0.34	0.35	0.34			
Ni59					3.45	81.38	Mn56	0.33	0.33				
H3					1.71		Ni59					0.01	3.31
Fe60					0.11	6.21	Fe60						3.09
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	6.93E6	6.92E6	6.88E6	5.94E6	1.32E1	1.49E-2	Sv kg <sup>-1</sup>	3.22E7	3.22E7	3.20E7	2.78E7	6.42E1	2.32E0
Co60	97.74	97.80	98.28	99.95	99.99	99.19	Co60	98.50	98.51	98.75	99.97	96.26	2.97
Co58	1.44	1.44	1.40	0.05			Co58	0.92	0.92	0.90	0.03		
Fe59	0.33	0.33	0.32				Fe59	0.38	0.38	0.36			
Co60m	0.19	0.13				0.19	Fe60					3.65	96.30
Ni59						0.63	Ni59					0.07	0.72
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	2.90E8	2.90E8	2.89E8	2.53E8	5.70E2	6.44E0		3.14E13	3.14E13	3.12E13	2.72E13	6.06E7	6.89E4
Co60	99.60	99.60	99.63	99.99	98.88	9.76	Co60	98.74	98.87	99.52	99.99	100.0	98.19
Co58	0.29	0.29	0.28	0.01			Co58	0.42	0.43	0.42	0.01		
Fe60					1.05	88.42	Co60m	0.38	0.27				0.37
Ni59					0.05	1.82	Ni59						1.17

# Cobalt

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Co60m	10.47 m	Co59(n, $\gamma$ )Co60m Co59(n, $\gamma$ )Co60(n,n')Co60m Co59(n, $\gamma$ )Co60( $\beta^-$ )Ni60(n,p)Co60m	100.0	100.0	100.0	96.8 1.0 0.3
Fe59	44.502 d	&Co59(n, $\gamma$ )Co60(n, $\gamma$ )Co61( $\beta^-$ )Ni61(n, $\alpha$ )Fe58(n, $\gamma$ )Fe59 &Co59(n, $\gamma$ )Co60( $\beta^-$ )Ni60(n, $\gamma$ )Ni61(n, $\alpha$ )Fe58(n, $\gamma$ )Fe59 Co59(n, $\gamma$ )Co60m( $\beta^-$ )Ni60(n, $\gamma$ )Ni61(n, $\alpha$ )Fe58(n, $\gamma$ )Fe59 &Co59(n, $\gamma$ )Co60(n, $\alpha$ )Mn57( $\beta^-$ )Fe57(n, $\gamma$ )Fe58(n, $\gamma$ )Fe59 Co59(n,p)Fe59 Co59(n,2n)Co58m(IT)Co58( $\beta^+$ )Fe58(n, $\gamma$ )Fe59	79.2 20.6 0.2	83.4 16.4 0.1	82.2 16.0 0.9	99.8 0.1
Co58	70.86 d	&Co59(n,2n)Co58				99.3
Mn54	312.3 d	Co59(n,n $\alpha$ )Mn55(n,2n)Mn54 &Co59(n,2n)Co58(n,n $\alpha$ )Mn54 &Co59(n,2n)Co58( $\beta^+$ )Fe58(n, $\alpha$ )Cr55( $\beta^-$ )Mn55(n,2n)Mn54 Co59(n, $\alpha$ )Mn56( $\beta^-$ )Fe56(n,2n)Fe55( $\beta^+$ )Mn55(n,2n)Mn54 &Co59(n,2n)Co58(n, $\alpha$ )Mn55(n,2n)Mn54 Co59(n,d)Fe58(n, $\alpha$ )Cr55( $\beta^-$ )Mn55(n,2n)Mn54 Co59(n, $\alpha$ )Mn56( $\beta^-$ )Fe56(n,d)Mn55(n,2n)Mn54				44.0 41.8 5.5 2.1 2.1 1.7 1.5
Co60	5.272 y	Co59(n, $\gamma$ )Co60m(IT)Co60 Co59(n, $\gamma$ )Co60	55.6 44.4	55.6 44.4	55.6 44.4	47.7 51.7
H3	12.33 y	Co59(n, $\gamma$ )Co60m(IT)Co60(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Co59(n, $\gamma$ )Co60(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Co59(n,X)H3 Co59(n,2n)Co58m(IT)Co58( $\beta^+$ )Fe58(n,X)H3	47.0 37.6	53.0 42.3		96.5 1.1
Ni63	99.0 y	&Co59(n, $\gamma$ )Co60(n, $\gamma$ )Co61( $\beta^-$ )Ni61(n, $\gamma$ )Ni62(n, $\gamma$ )Ni63 &Co59(n, $\gamma$ )Co60( $\beta^-$ )Ni60(n, $\gamma$ )Ni61(n, $\gamma$ )Ni62(n, $\gamma$ )Ni63 Co59(n, $\gamma$ )Co60m( $\beta^-$ )Ni60(n, $\gamma$ )Ni61(n, $\gamma$ )Ni62(n, $\gamma$ )Ni63	81.3 18.5 0.2	86.7 13.2 0.1	86.1 13.8 0.2	84.2 15.2 0.2
Ni59	$7.6 \cdot 10^4$ y	Co59(n, $\gamma$ )Co60( $\beta^-$ )Ni60(n,2n)Ni59 Co59(n, $\gamma$ )Co60m(IT)Co60( $\beta^-$ )Ni60(n,2n)Ni59 Co59(n, $\gamma$ )Co60m( $\beta^-$ )Ni60(n,2n)Ni59				51.5 47.6 0.6
Fe60	$1.5 \cdot 10^6$ y	&Co59(n, $\gamma$ )Co60(n, $\gamma$ )Co61( $\beta^-$ )Ni61(n, $\alpha$ )Fe58(n, $\gamma$ ) Fe59(n, $\gamma$ )Fe60 &Co59(n, $\gamma$ )Co60( $\beta^-$ )Ni60(n, $\gamma$ )Ni61(n, $\alpha$ )Fe58(n, $\gamma$ ) Fe59(n, $\gamma$ )Fe60 &Co59(n, $\gamma$ )Co60(n,p)Fe60 Co59(n,p)Fe59(n, $\gamma$ )Fe60	71.5 14.3 14.1		100.0	100.0 93.1 6.6
Mn53	$3.68 \cdot 10^6$ y	&Co59(n,2n)Co58(n,n $\alpha$ )Mn54(n,2n)Mn53 Co59(n,n $\alpha$ )Mn55(n,2n)Mn54(n,2n)Mn53 Co59(n, $\alpha$ )Mn56( $\beta^-$ )Fe56(n,2n)Fe55(n,2n)Fe54(n,d) Mn53 &Co59(n,2n)Co58( $\beta^+$ )Fe58(n, $\alpha$ )Cr55( $\beta^-$ )Mn55(n,2n) Mn54(n,2n)Mn53 &Co59(n,2n)Co58(n,2n)Co57(n,n $\alpha$ )Mn53 &Co59(n,2n)Co58(n, $\alpha$ )Mn55(n,2n)Mn54(n,2n)Mn53				53.6 32.5 1.9 2.7 3.2 1.4

# Cobalt activation characteristics

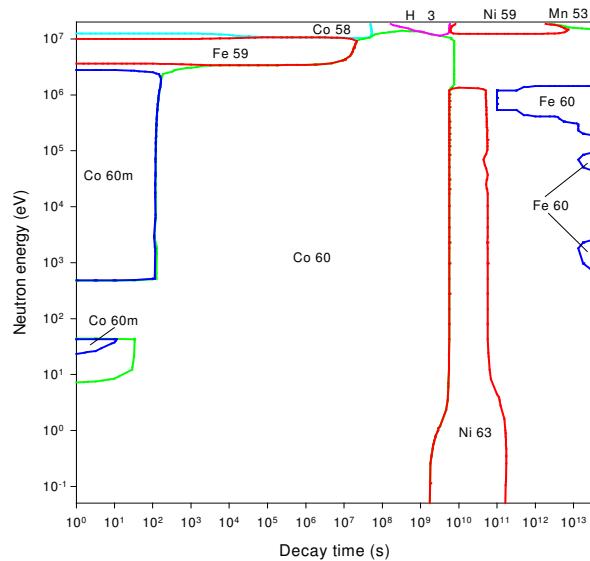


Decay time (years)

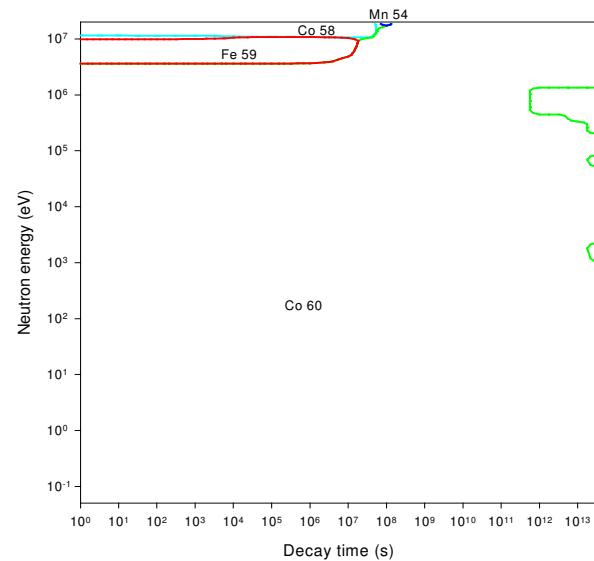
Decay time (years)

# Cobalt importance diagrams & transmutation

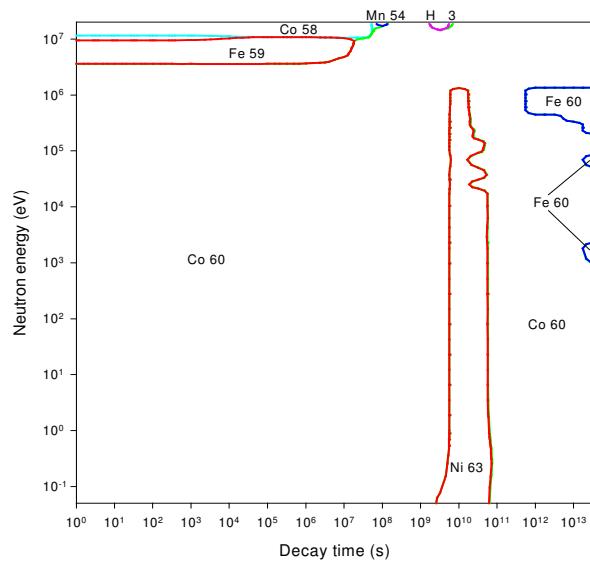
## Activity



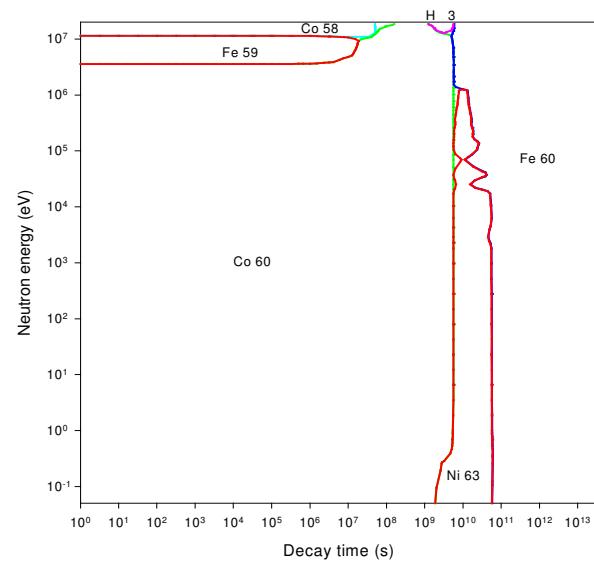
## Dose rate



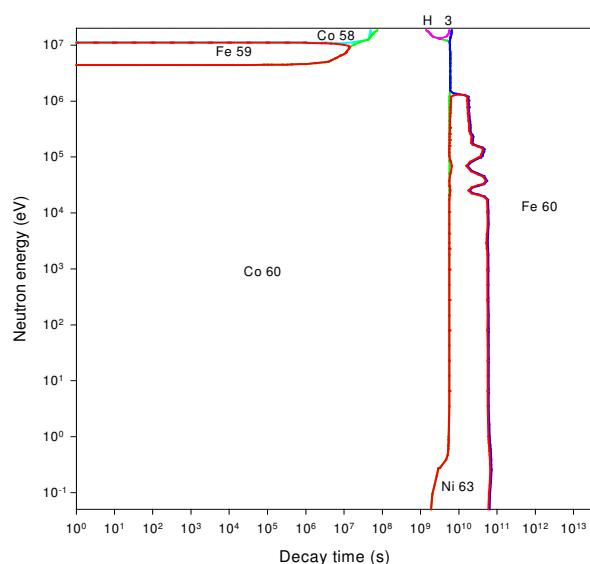
## Heat output



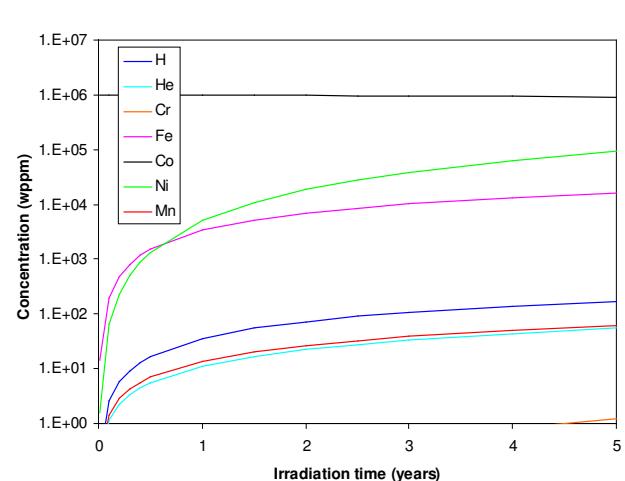
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Nickel

## General properties

Atomic number	28	Isotopes	Isotopic abundances / %	
Crustal abundance / wppm	84	Ni58	68.077	
Melting point / K	1728	Ni60	26.223	
Boiling point / K	3186	Ni61	1.140	
Density / kgm <sup>-3</sup>	8902	Ni62	3.634	
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	90.7	Ni64	0.926	
Electrical resistivity /Ωm	6.84 10 <sup>-8</sup>			
Coefficient of thermal expansion / K <sup>-1</sup>	1.34 10 <sup>-5</sup>			
Crystal structure	FCC			
Number of stable isotopes	5			
Mean atomic weight	58.69			

## Activation properties

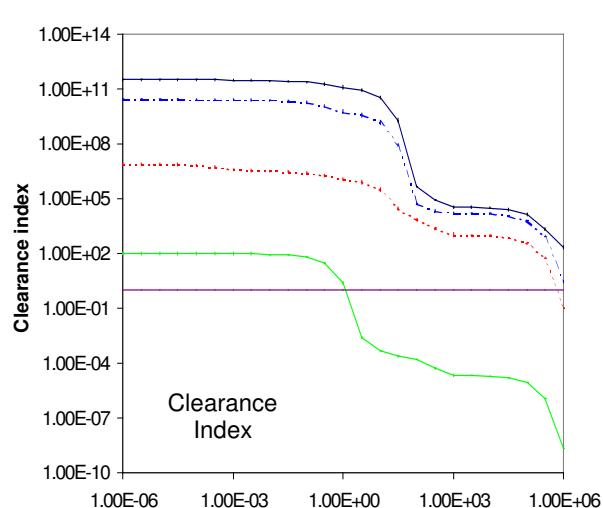
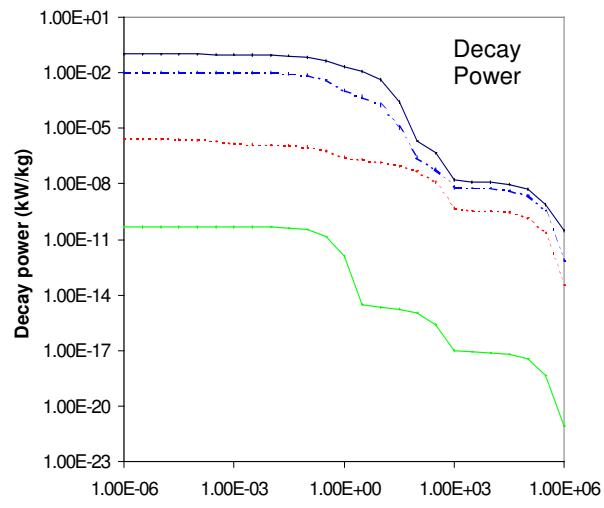
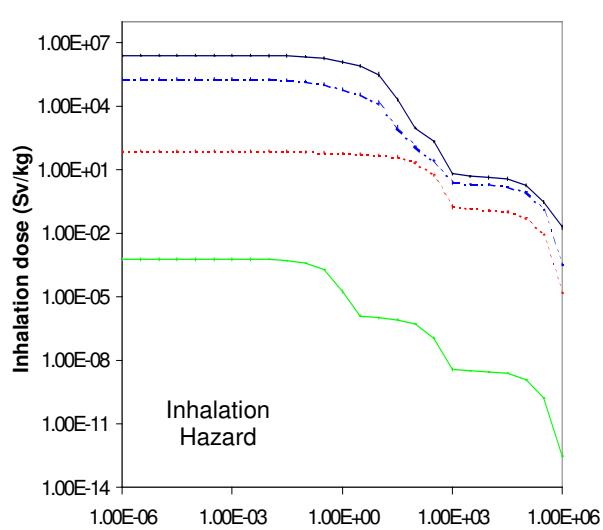
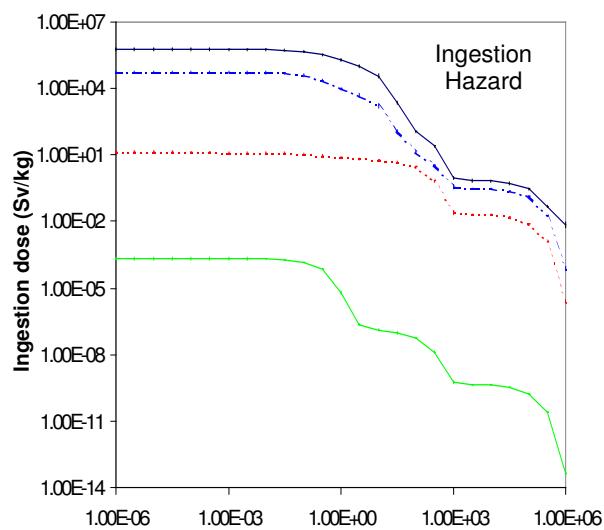
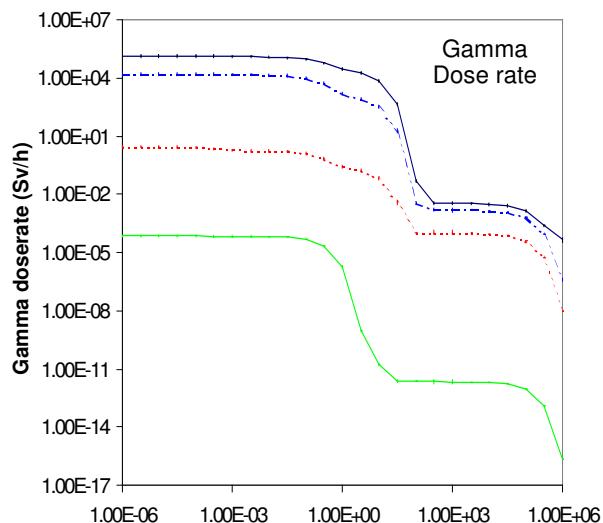
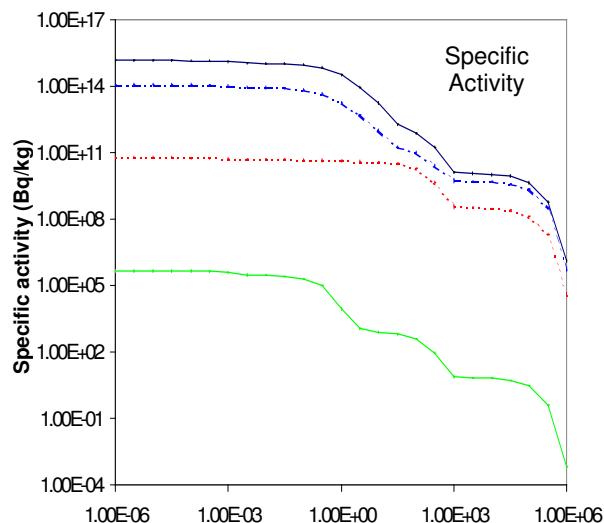
Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.46E15	1.44E15	1.06E15	3.40E14	7.57E11	4.49E9	kW kg <sup>-1</sup>	1.02E-1	1.01E-1	8.81E-2	2.12E-2	2.09E-6	5.20E-9
Co57	40.36	40.93	55.32	68.45			Co58	56.12	56.80	62.81	7.60		
Co58	24.09	24.43	32.30	2.92			Co60	15.78	15.97	18.19	66.37	1.50	0.75
Co58m	20.85	21.00	0.03				Co57	13.40	13.56	15.33	25.33		
Fe55	5.42	5.50	7.48	18.10			Ni57	8.08	8.16	1.70			
Co60m	3.58	2.56					Co58m	1.20	1.21				
Co60	2.63	2.67	3.64	9.93	0.01		Fe59	1.16	1.17	1.26	0.02		
Ni57	1.65	1.67	0.42				Mn56	1.06	1.05				
Ni63	0.10	0.10	0.14	0.44	98.51		Ni63			0.01	0.02	97.88	
Ni59					1.48	99.99	Ni59					0.61	99.20
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	1.34E5	1.33E5	1.18E5	2.80E4	5.58E-2	1.41E-3	Sv kg <sup>-1</sup>	5.85E5	5.85E5	5.49E5	1.92E5	1.13E2	2.94E-1
Co58	62.60	62.96	68.91	8.45			Co58	44.63	44.64	46.09	3.83		
Co60	20.03	20.14	22.72	84.05	94.00	4.64	Co60	22.40	22.40	23.83	59.79	0.23	0.11
Ni57	9.43	9.46	1.95				Co57	21.22	21.22	22.40	25.46		
Co57	3.70	3.72	4.16	6.97			Fe55	4.48	4.48	4.76	10.58		
Fe59	1.38	1.38	1.48	0.02			Ni57	3.60	3.59	0.70			
Mn56	0.95	0.94					Fe59	1.73	1.73	1.74	0.02		
Co56	0.53	0.53	0.58	0.10			Co58m	1.25	1.25				
Co62m	0.45	0.35					Ni63	0.04	0.04	0.04	0.12	99.14	
Mn54	0.17	0.18	0.20	0.37			Ni59					0.62	96.36
Ni59					6.00	95.35	Fe60					0.01	3.53
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	2.64E6	2.64E6	2.59E6	1.35E6	9.76E2	2.01E0		3.34E11	3.31E11	2.79E11	1.26E11	5.33E5	1.39E4
Co60	45.30	45.30	46.07	77.49	0.24	0.15	Co60	38.41	38.79	46.06	89.63	47.02	2.25
Co58	28.10	28.10	27.73	1.55			Co58	35.17	35.51	40.93	2.64		
Co57	22.41	22.41	22.62	17.23			Ni57	14.17	14.29	3.10			
Fe55	2.32	2.32	2.35	3.51			Co57	5.89	5.95	7.01	6.18		
Fe59	0.85	0.85	0.82	0.01			Mn56	1.42	1.40				
Ni63	0.07	0.07	0.08	0.14	99.25		Mn54	1.10	1.11	1.31	1.31		
Ni59					0.50	98.54	Ni63					46.63	
Fe60						1.32	Ni59					6.35	97.73

# Nickel

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Ni65	2.52 h	Ni62(n, $\gamma$ )Ni63(n, $\gamma$ )Ni64(n, $\gamma$ )Ni65 Ni64(n, $\gamma$ )Ni65 Ni61(n, $\gamma$ )Ni62(n, $\gamma$ )Ni63(n, $\gamma$ )Ni64(n, $\gamma$ )Ni65 Ni60(n, $\gamma$ )Ni61(n, $\gamma$ )Ni62(n, $\gamma$ )Ni63(n, $\gamma$ )Ni64(n, $\gamma$ )Ni65	58.4 38.4 1.3 1.7	0.6 99.4	100.0	99.6
Cu64	12.702 h	Ni62(n, $\gamma$ )Ni63( $\beta^-$ )Cu63(n, $\gamma$ )Cu64 Ni61(n, $\gamma$ )Ni62(n, $\gamma$ )Ni63( $\beta^-$ )Cu63(n, $\gamma$ )Cu64 Ni60(n, $\gamma$ )Ni61(n, $\gamma$ )Ni62(n, $\gamma$ )Ni63( $\beta^-$ )Cu63(n, $\gamma$ )Cu64 Ni64(n, $\gamma$ )Ni65( $\beta^-$ )Cu65(n,2n)Cu64 Ni64(n,2n)Ni63( $\beta^-$ )Cu63(n, $\gamma$ )Cu64	94.8 2.1 2.9	100.0	100.0	93.2 6.2
Co58	70.86 d	Ni58(n,p)Co58 Ni58(n,p)Co58m(IT)Co58 Ni60(n,d)Co59(n,2n)Co58m(IT)Co58 Ni60(n,d)Co59(n,2n)Co58	81.3 18.5	50.0 50.0	50.0 50.0	45.3 51.0 1.8 0.8
Co57	271.79 d	Ni58(n,d)Co57 Ni58(n,2n)Ni57( $\beta^+$ )Co57				94.5 5.4
Fe55	2.735 y	Ni58(n, $\alpha$ )Fe55 Ni58(n,d)Co57( $\beta^+$ )Fe57(n,2n)Fe56(n,2n)Fe55 Ni58(n,d)Co57(n,d)Fe56(n,2n)Fe55	100.0	100.0	100.0	97.2 1.2 0.5
Co60	5.272 y	&Ni58(n, $\gamma$ )Ni59(n,p)Co59(n, $\gamma$ )Co60 &Ni58(n, $\gamma$ )Ni59( $\beta^+$ )Co59(n, $\gamma$ )Co60 &Ni60(n,p)Co60 &Ni61(n,d)Co60	99.9	99.9	98.9 1.1	98.2 1.0
Ni63	99.0 y	Ni62(n, $\gamma$ )Ni63 Ni60(n, $\gamma$ )Ni61(n, $\gamma$ )Ni62(n, $\gamma$ )Ni63 Ni61(n, $\gamma$ )Ni62(n, $\gamma$ )Ni63 Ni64(n,2n)Ni63 Ni64(n,d)Co63( $\beta^-$ )Ni63	88.3 7.1 3.7	99.9	99.9	0.3  99.2 0.4
Ni59	$7.6 \cdot 10^4$ y	Ni58(n, $\gamma$ )Ni59 Ni60(n,2n)Ni59 Ni61(n,2n)Ni60(n,2n)Ni59	100.0	100.0	100.0	0.4 99.2 0.3
Fe60	$1.5 \cdot 10^6$ y	Ni58(n, $\gamma$ )Ni59(n, $\alpha$ )Fe56(n, $\gamma$ )Fe57(n, $\gamma$ )Fe58(n, $\gamma$ ) Fe59(n, $\gamma$ )Fe60 Ni60(n, $\gamma$ )Ni61(n, $\alpha$ )Fe58(n, $\gamma$ )Fe59(n, $\gamma$ )Fe60 Ni61(n, $\alpha$ )Fe58(n, $\gamma$ )Fe59(n, $\gamma$ )Fe60 Ni62(n, $\gamma$ )Ni63(n, $\alpha$ )Fe60 Ni58(n, $\gamma$ )Ni59(n, $\alpha$ )Fe56(n, $\gamma$ )Fe57(n, $\gamma$ )Fe58(n, $\gamma$ ) Fe59(n, $\gamma$ )Fe60 &Ni58(n, $\gamma$ )Ni59(n,p)Co59(n, $\gamma$ )Co60(n,p)Fe60 &Ni60(n,p)Co60(n,p)Fe60 Ni64(n,2n)Ni63(n, $\alpha$ )Fe60 Ni64(n,n $\alpha$ )Fe60	99.8 0.1 0.1 82.2 5.1 4.1	0.3 8.1 0.6 99.1		87.1 8.0 3.3
Mn53	$3.68 \cdot 10^6$ y	Ni58(n,n $\alpha$ )Fe54(n,d)Mn53 Ni58(n,d)Co57(n,n $\alpha$ )Mn53 Ni58(n, $\alpha$ )Fe55(n,2n)Fe54(n,d)Mn53 Ni58(n,d)Co57(n, $\alpha$ )Mn54(n,2n)Mn53 Ni58(n, $\alpha$ )Fe55( $\beta^+$ )Mn55(n,2n)Mn54(n,2n)Mn53 Ni58(n, $\alpha$ )Fe55(n,t)Mn53 Ni58(n,2n)Ni57( $\beta^+$ )Co57(n,n $\alpha$ )Mn53 Ni58(n,d)Co57(n,2n)Co56(n, $\alpha$ )Mn53 Ni58(n,p $\alpha$ )Mn54(n,2n)Mn53 Ni58(n,n $\alpha$ )Fe54(n,2n)Fe53( $\beta^+$ )Mn53				43.7 32.0 6.8 4.4 3.5 2.2 1.8 1.4 1.1 1.0

# Nickel activation characteristics

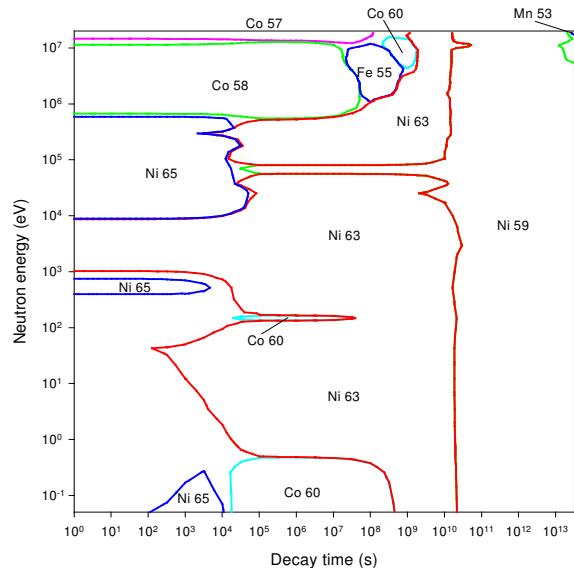


Decay time (years)

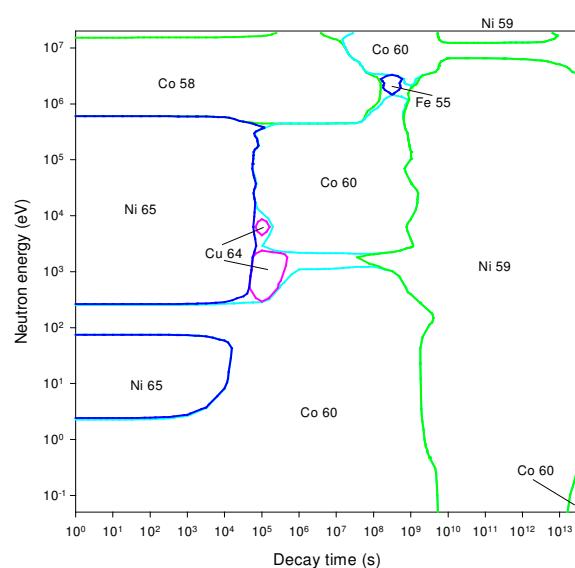
Decay time (years)

# Nickel importance diagrams & transmutation

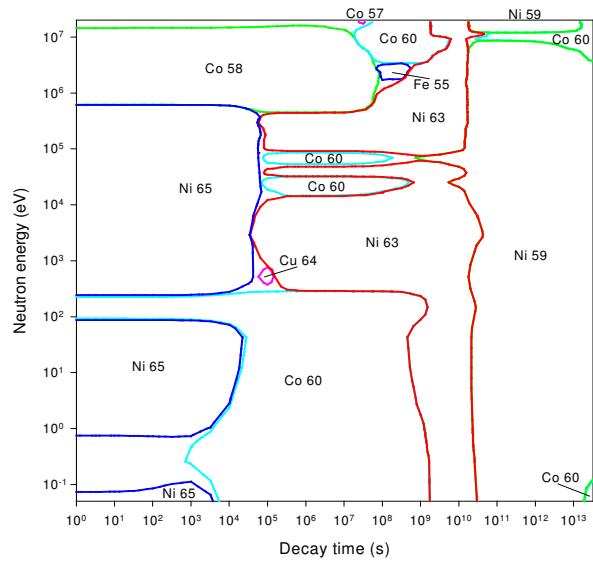
## Activity



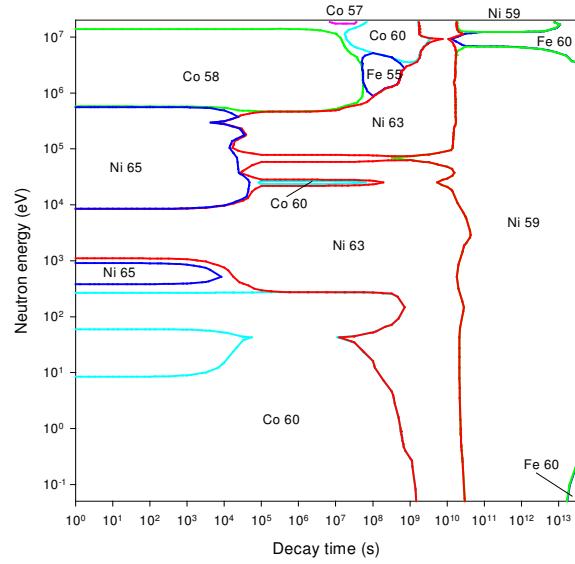
## Dose rate



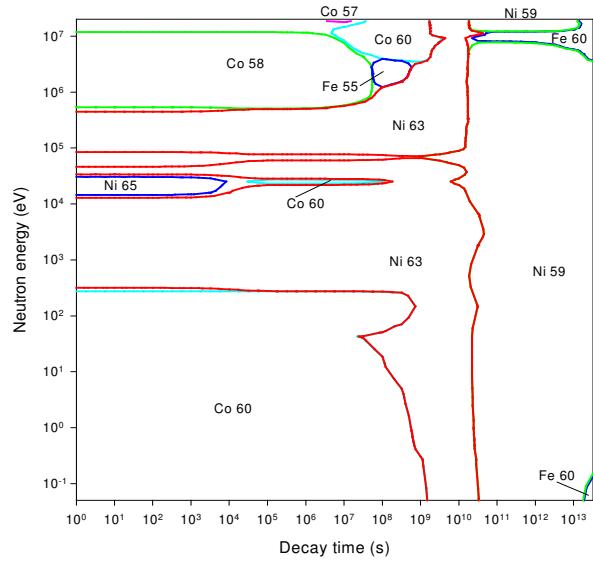
## Heat output



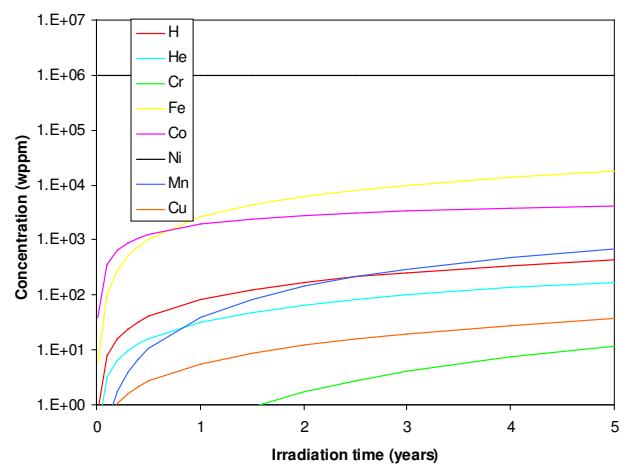
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Copper

## General properties

Atomic number	29	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	60	Cu63	69.17
Melting point / K	1357.8	Cu65	30.83
Boiling point / K	2925		
Density / kgm <sup>-3</sup>	8960		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	401		
Electrical resistivity /Ωm	1.673 10 <sup>8</sup>		
Coefficient of thermal expansion / K <sup>-1</sup>	1.65 10 <sup>-5</sup>		
Crystal structure	FCC		
Number of stable isotopes	2		
Mean atomic weight	63.546		

## Activation properties

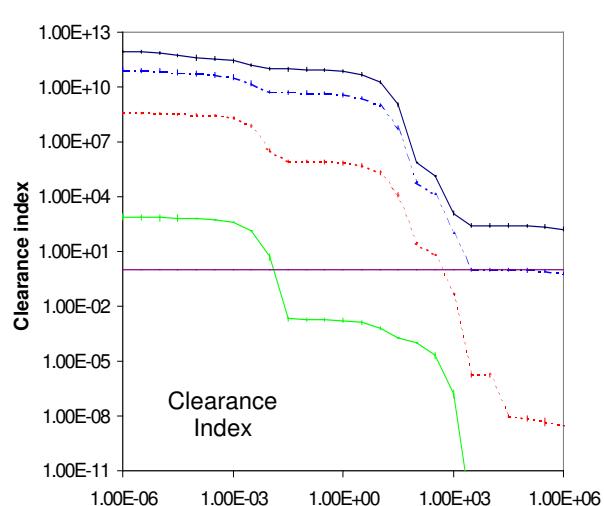
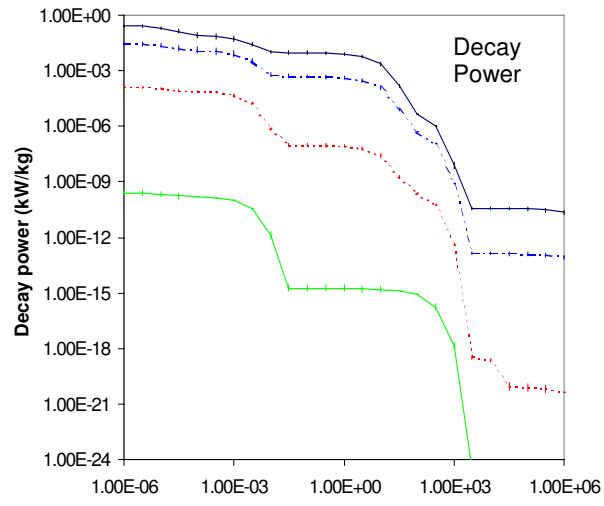
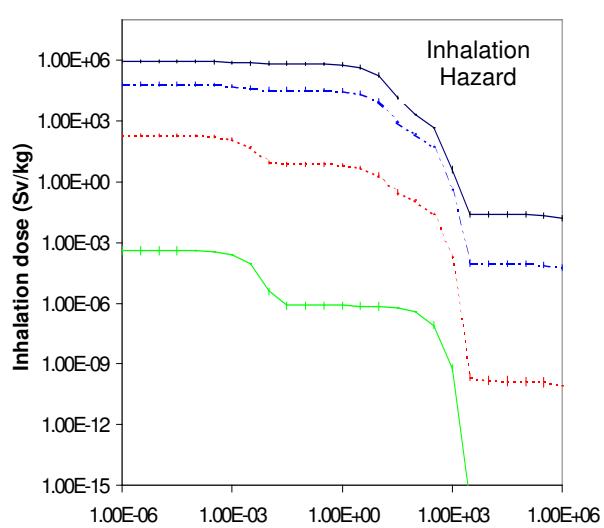
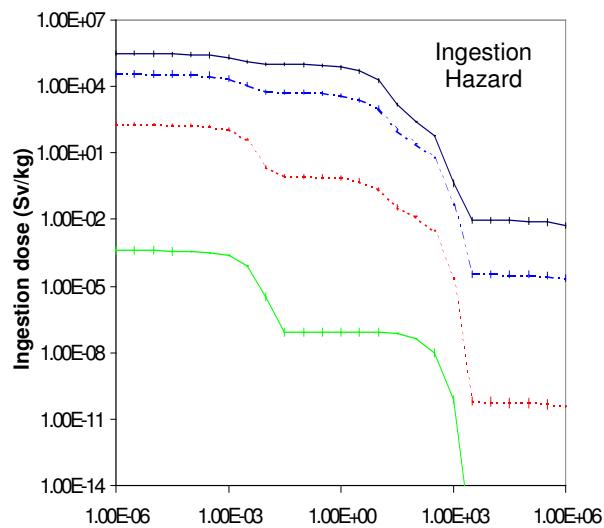
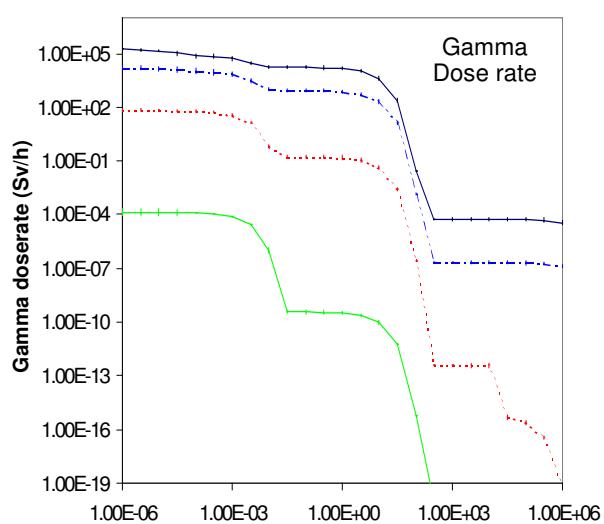
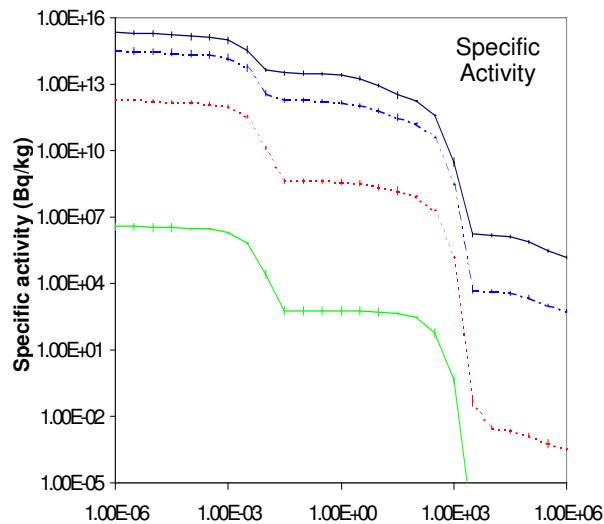
Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	2.18E15	1.93E15	4.47E13	2.50E13	1.75E12	7.94E5	kW kg <sup>-1</sup>	2.83E-1	2.13E-1	1.03E-2	8.13E-3	4.82E-6	3.38E-11
Cu64	68.24	76.78	27.85				Cu62	53.74	49.06				
Cu62	18.93	14.72					Cu64	26.71	35.27	6.10			
Cu66	9.68	5.35					Cu66	13.80	8.96	6.10			
Co60	0.99	1.12	48.27	75.84		9.47	Co60	3.19	4.23	86.99	97.20	0.37	92.68
Co60m	0.68	0.54				9.50	Ni65	0.83	1.07				
Ni65	0.57	0.63					Zn65	0.22	0.29	5.87	2.68		
Zn65	0.30	0.34	14.36	9.21			Co60m	0.05	0.05				2.26
Ni63	0.16	0.18	7.87	13.99	99.95		Ni63		0.01	0.09	0.12	99.62	
Ni59						71.53	Fe60						3.13
Fe60						9.50	Ni59						1.93
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	1.72E5	1.41E5	1.74E4	1.42E4	3.07E-2	5.50E-5	Sv kg <sup>-1</sup>	3.10E5	3.00E5	1.01E5	7.40E4	2.62E2	8.58E-3
Cu62	49.59	41.68					Cu64	57.62	59.37	1.48			
Cu64	34.13	41.49	2.81				Co60	23.71	24.54	72.49	87.13	0.06	2.98
Co60	9.17	11.20	90.27	97.35	100.0	99.53	Zn65	8.16	8.45	24.74	12.14		
Cu66	2.72	1.63					Cu62	8.12	5.79				
Co62m	1.47	1.38					Cu66	1.09	0.55				
Ni65	1.17	1.40					Ni65	0.72	0.73				
Zn65	0.62	0.75	6.00	2.64			Ni63	0.17	0.18	0.52	0.71	99.93	
Fe59	0.08	0.10	0.77				Fe60						96.60
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	8.89E5	8.82E5	6.91E5	5.97E5	2.27E3	2.37E-2		9.31E11	7.56E11	9.61E10	7.09E10	7.24E5	2.54E2
Co60	75.41	75.99	96.81	98.38	0.06	9.84	Cu62	50.42	42.74				
Cu64	20.10	20.16	0.22				Cu64	32.65	40.03	2.65			
Cu62	1.77	1.22					Cu60	7.74	9.54	74.90	89.17	19.44	98.68
Zn65	1.61	1.62	2.04	0.85			Cu66	4.28	2.58				
Ni63	0.52	0.52	0.66	0.76	99.93		Zn65	2.32	2.86	22.28	10.83		
Fe59	0.19	0.19	0.23				Co62m	0.95	0.90				
Fe60						89.10	Ni65	0.95	1.00				
Ni59						1.05	Ni63						80.51

# Copper

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Cu66	5.1 m	Cu65(n, $\gamma$ )Cu66 Cu63(n, $\gamma$ )Cu64( $\beta^+$ )Ni64(n, $\gamma$ )Ni65( $\beta^-$ )Cu65(n, $\gamma$ )Cu66 Cu63(n, $\gamma$ )Cu64(n, $\gamma$ )Cu65(n, $\gamma$ )Cu66 Cu63(n, $\gamma$ )Cu64( $\beta^-$ )Zn64(n, $\gamma$ )Zn65( $\beta^+$ )Cu65(n, $\gamma$ )Cu66	97.1 2.1 0.5 0.3	100.0	100.0	98.5
Cu62	9.75 m	Cu63(n,2n)Cu62 Cu65(n,2n)Cu64( $\beta^-$ )Zn64(n,d)Cu63(n,2n)Cu62				99.8 0.1
Cu64	12.702 h	Cu63(n, $\gamma$ )Cu64 Cu65(n,2n)Cu64	100.0	100.0	100.0	0.6 98.0
Zn65	244.26 d	Cu63(n, $\gamma$ )Cu64( $\beta^-$ )Zn64(n, $\gamma$ )Zn65 Cu65(n, $\gamma$ )Cu66( $\beta^-$ )Zn66(n,2n)Zn65 Cu65(n,2n)Cu64( $\beta^-$ )Zn64(n, $\gamma$ )Zn65	100.0	100.0	100.0	0.3 52.1 47.5
Co60	5.272 y	Cu63(n, $\alpha$ )Co60 Cu63(n, $\alpha$ )Co60m(IT)Co60 Cu63(n,2n)Cu62( $\beta^+$ )Ni62(n,2n)Ni61(n,d)Co60m(IT)Co60	50.1 49.9	50.1 49.9	50.1 49.9	71.8 27.5 0.1
Ni63	99.0 y	Cu63(n,p)Ni63 Cu65(n, $\gamma$ )Cu66( $\beta^-$ )Zn66(n, $\alpha$ )Ni63 Cu65(n,2n)Cu64( $\beta^+$ )Ni64(n,2n)Ni63 Cu65(n,d)Ni64(n,2n)Ni63	98.0 2.0	100.0	100.0	70.8 26.6 1.7
Ni59	$7.6 \cdot 10^4$ y	&Cu63(n, $\alpha$ )Co60( $\beta^-$ )Ni60(n,2n)Ni59 Cu63(n,2n)Cu62( $\beta^+$ )Ni62(n,2n)Ni61(n,2n)Ni60(n,2n) Ni59 Cu65(n,2n)Cu64( $\beta^-$ )Zn64(n,n $\alpha$ )Ni60(n,2n)Ni59 Cu63(n,d)Ni62(n,2n)Ni61(n,2n)Ni60(n,2n)Ni59				78.9 7.7 7.5 4.2
Kr81	$2.1 \cdot 10^5$ y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0			
Fe60	$1.5 \cdot 10^6$ y	Cu63(n, $\gamma$ )Cu64( $\beta^-$ )Zn64(n, $\alpha$ )Ni61(n, $\alpha$ )Fe58(n, $\gamma$ )Fe59 (n, $\gamma$ )Fe60 Cu63(n,p)Ni63(n, $\alpha$ )Fe60 &Cu63(n, $\alpha$ )Co60(n,p)Fe60 Cu65(n,2n)Cu64( $\beta^+$ )Ni64(n,2n)Ni63(n, $\alpha$ )Fe60 Cu65(n,2n)Cu64( $\beta^+$ )Ni64(n,n $\alpha$ )Fe60	53.3 46.3	99.9	99.7	29.1 57.7 7.3 4.4

# Copper activation characteristics

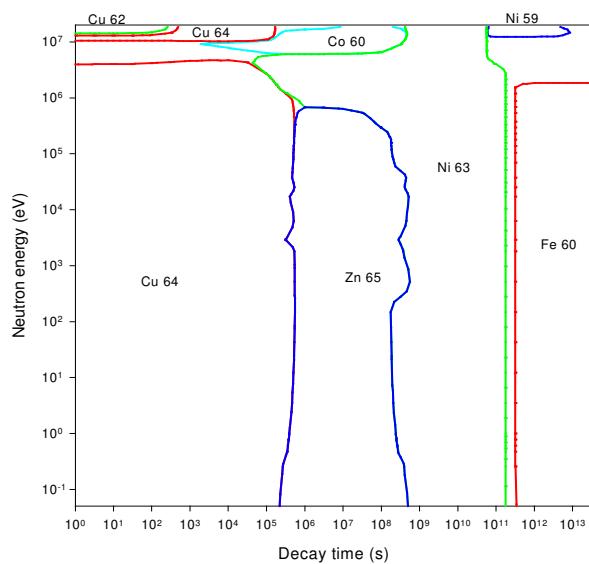


Decay time (years)

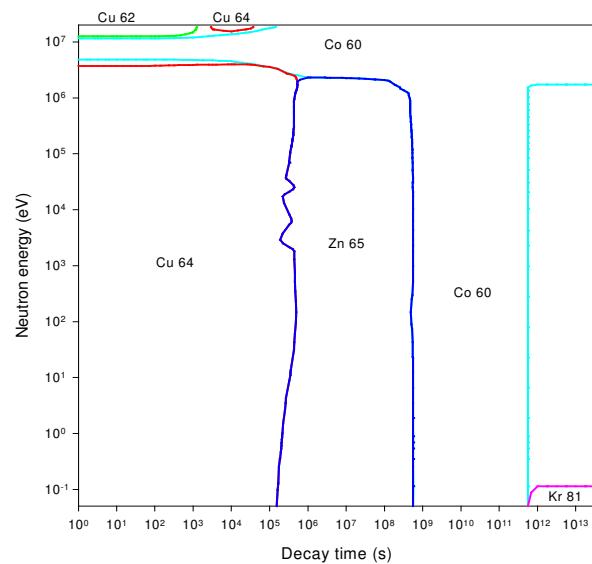
Decay time (years)

# Copper importance diagrams & transmutation

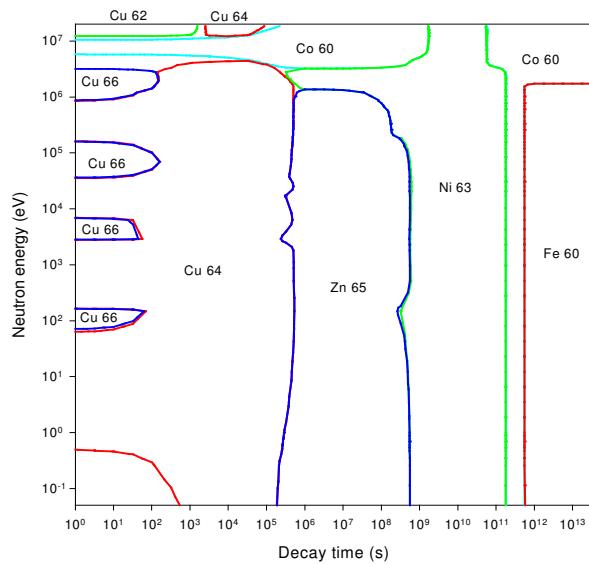
## Activity



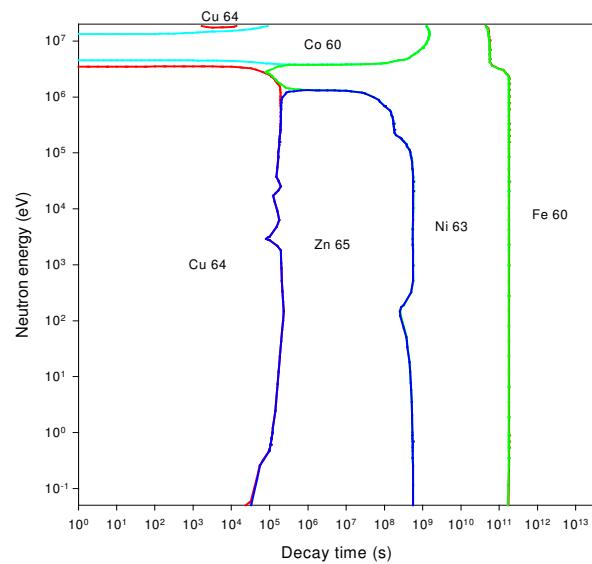
## Dose rate



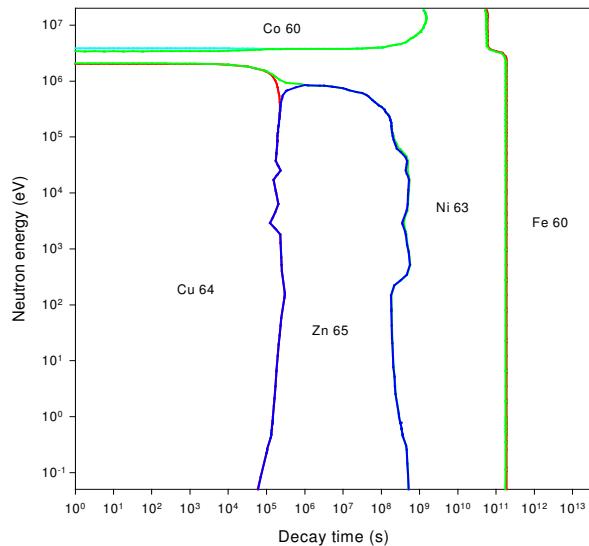
## Heat output



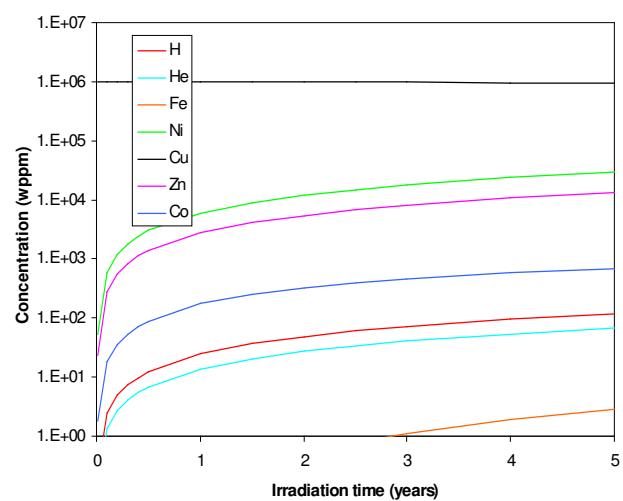
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Zinc

## General properties

Atomic number	30	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	70	Zn64	48.63
Melting point / K	692.7	Zn66	27.90
Boiling point / K	1180	Zn67	4.10
Density / kgm <sup>-3</sup>	7133	Zn68	18.75
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	116	Zn70	0.62
Electrical resistivity /Ωm	5.916 10 <sup>8</sup>		
Coefficient of thermal expansion / K <sup>-1</sup>	3.02 10 <sup>-5</sup>		
Crystal structure	HCP		
Number of stable isotopes	5		
Mean atomic weight	65.39		

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.04E15	9.95E14	4.41E14	1.57E14	2.34E11	2.99E6	kW kg <sup>-1</sup>	1.03E-1	9.41E-2	4.15E-2	1.49E-2	6.44E-7	5.40E-12
Zn65	42.32	44.39	99.08	99.58			Zn65	40.56	44.33	99.40	99.52		
Zn69	21.91	21.70	0.07				Zn63	22.29	22.16				
Cu64	19.02	19.86	0.38				Zn69	11.43	11.80	0.04			
Zn63	6.78	6.47					Cu64	9.78	10.64	0.20			
Cu66	3.52	1.81					Cu66	6.60	3.53				
Ga70	2.19	1.93					Ga70	2.32	2.13				
Zn69m	2.18	2.28	0.06				Cu62	1.67	1.25				
Cu62	0.45	0.32					Zn69m	1.55	1.69	0.05			
Ga68	0.41	0.40					Cu68	1.36	0.24				
Ni65	0.29	0.29					Ga68	1.12	1.16				
Cu67	0.26	0.27	0.23				Co60	0.08	0.09	0.19	0.47	0.03	34.57
Ni63	0.05	0.05	0.11	0.30	99.96		Ni63				0.01	99.96	
Co60	0.02	0.02	0.04	0.11		0.15	Ni59						63.41
Ni59						99.55	Fe60						1.17
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	1.02E5	9.88E4	7.08E4	2.54E4	2.76E-4	4.00E-6	Sv kg <sup>-1</sup>	1.77E6	1.77E6	1.71E6	6.11E5	3.51E1	6.97E-4
Zn65	69.77	72.23	99.66	99.52			Zn65	97.27	97.36	99.92	99.90		
Zn63	16.00	15.07					Cu64	1.35	1.34	0.01			
Cu64	7.56	7.78	0.09				Zn69m	0.42	0.42	0.01			
Zn69m	1.87	1.93	0.03				Co60	0.04	0.04	0.04	0.09		2.19
Cu68	1.00	0.16					Ni63				0.01	99.98	
Co60	0.14	0.14	0.20	0.48	99.32	80.99	Fe60						70.87
Ni59					0.68	18.87	Ni59						26.95
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	1.02E6	1.02E6	9.69E5	3.50E5	3.05E2	2.71E-3		1.64E12	1.62E12	1.46E12	5.23E11	7.94E4	2.41E1
Zn65	95.22	95.32	99.23	98.33			Zn65	89.68	90.72	99.92	99.89		
Cu64	2.34	2.33	0.02				Zn63	5.14	4.72				
Zn69	0.63	0.59					Cu64	2.47	2.49	0.02			
Zn69m	0.60	0.60	0.01				Zn69m	0.58	0.58	0.01			
Co60	0.58	0.58	0.61	1.49		5.13	Zn69	0.45	0.43				
Ni63	0.06	0.06	0.06	0.17	99.99		Co60	0.04	0.04	0.04	0.11	1.59	62.05
Ni59						48.45	Ni63					98.34	
Fe60						46.43	Ni59					0.03	37.55

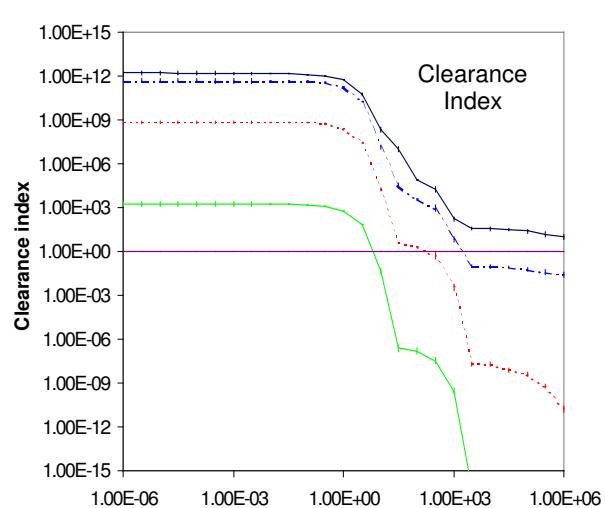
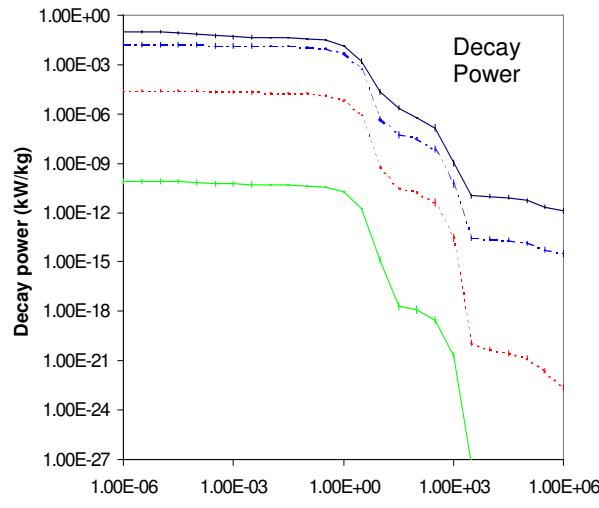
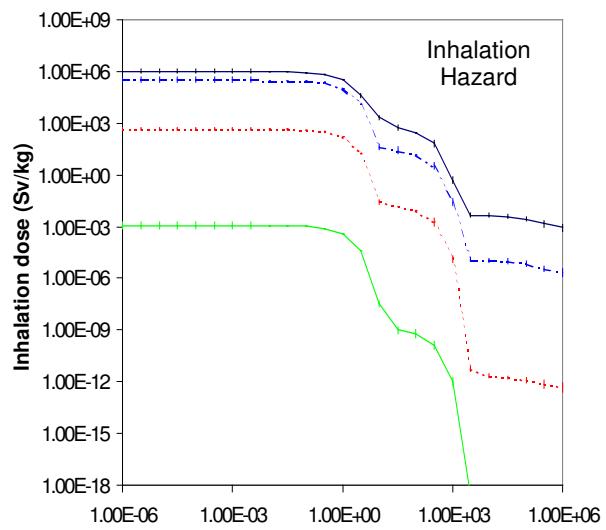
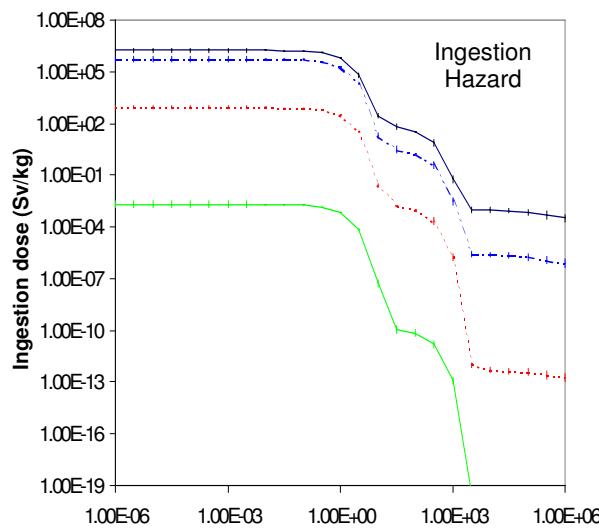
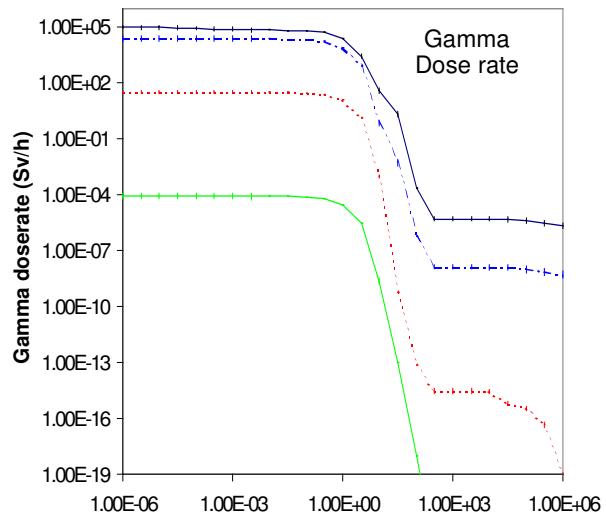
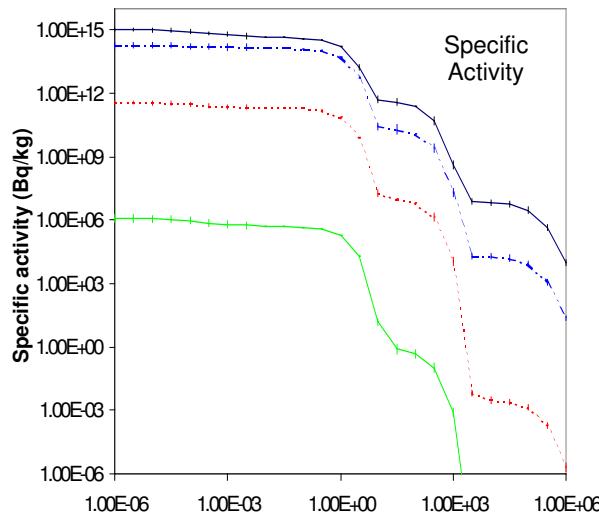
# Zinc

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Ga70	21.14 m	&Zn68(n, $\gamma$ )Zn69( $\beta^-$ )Ga69(n, $\gamma$ )Ga70 &Zn67(n, $\gamma$ )Zn68(n, $\gamma$ )Zn69( $\beta^-$ )Ga69(n, $\gamma$ )Ga70 Zn66(n, $\gamma$ )Zn67(n, $\gamma$ )Zn68(n, $\gamma$ )Zn69( $\beta^-$ )Ga69(n, $\gamma$ )Ga70 &Zn70(n,2n)Zn69( $\beta^-$ )Ga69(n, $\gamma$ )Ga70 Zn70(n, $\gamma$ )Zn71m( $\beta^-$ )Ga71(n,2n)Ga70 &Zn70(n, $\gamma$ )Zn71( $\beta^-$ )Ga71(n,2n)Ga70	95.0 4.4 0.6	99.6 0.4	99.8 0.2	48.2 29.8 20.3
Zn63	38.4 m	Zn64(n,2n)Zn63 Zn66(n,2n)Zn65( $\beta^+$ )Cu65(n,2n)Cu64( $\beta^-$ )Zn64(n,2n)Zn63 Zn66(n,2n)Zn65(n,2n)Zn64(n,2n)Zn63				98.7 0.1 0.1
Zn69	57.0 m	Zn68(n, $\gamma$ )Zn69 Zn68(n, $\gamma$ )Zn69m(IT)Zn69 &Zn67(n, $\gamma$ )Zn68(n, $\gamma$ )Zn69 &Zn66(n, $\gamma$ )Zn67(n, $\gamma$ )Zn68(n, $\gamma$ )Zn69 Zn70(n,2n)Zn69m(IT)Zn69 Zn70(n,2n)Zn69	83.0 7.5 7.8 1.7	90.9 8.2 0.8 0.4	91.3 8.2 0.4	0.8 1.2 50.0 47.2
Cu64	12.702 h	Zn66(n, $\alpha$ )Ni63( $\beta^-$ )Cu63(n, $\gamma$ )Cu64 Zn64(n, $\alpha$ )Ni61(n, $\gamma$ )Ni62(n, $\gamma$ )Ni63( $\beta^-$ )Cu63(n, $\gamma$ )Cu64 Zn64(n, $\gamma$ )Zn65(n, $\gamma$ )Zn66(n, $\alpha$ )Ni63( $\beta^-$ )Cu63(n, $\gamma$ )Cu64 Zn64(n,p)Cu64 Zn66(n,2n)Zn65( $\beta^+$ )Cu65(n,2n)Cu64 Zn66(n,d)Cu65(n,2n)Cu64	96.7 1.4 1.3 0.6	11.9 88.1	1.5 98.5	
Zn69m	13.76 h	Zn68(n, $\gamma$ )Zn69m Zn67(n, $\gamma$ )Zn68(n, $\gamma$ )Zn69m Zn66(n, $\gamma$ )Zn67(n, $\gamma$ )Zn68(n, $\gamma$ )Zn69m Zn70(n,2n)Zn69m Zn70(n,2n)Zn69( $\beta^-$ )Ga69(n,p)Zn69m	90.5 7.8 1.7	99.1 0.9	99.5 0.5	2.3 96.9 0.3
Zn65	244.26 d	Zn64(n, $\gamma$ )Zn65 Zn66(n,2n)Zn65 Zn67(n,2n)Zn66(n,2n)Zn65 Zn68(n,2n)Zn67(n,2n)Zn66(n,2n)Zn65	100.0	100.0	100.0	0.2 96.1 2.1 0.6
Co60	5.272 y	&Zn64(n, $\alpha$ )Ni61(n, $\alpha$ )Fe58(n, $\gamma$ )Fe59( $\beta^-$ )Co59(n, $\gamma$ ) Co60 &Zn66(n, $\alpha$ )Ni63( $\beta^-$ )Cu63(n, $\alpha$ )Co60 &Zn64(n,d)Cu63(n, $\alpha$ )Co60 &Zn64(n,n $\alpha$ )Ni60(n,p)Co60 &Zn64(n,2n)Zn63( $\beta^+$ )Cu63(n, $\alpha$ )Co60 &Zn64(n, $\alpha$ )Ni61(n,d)Co60	100.0	99.1 0.9	0.6 98.7	
Ni63	99.0 y	Zn66(n, $\alpha$ )Ni63 Zn64(n, $\alpha$ )Ni61(n, $\gamma$ )Ni62(n, $\gamma$ )Ni63 Zn64(n, $\gamma$ )Zn65(n, $\gamma$ )Zn66(n, $\alpha$ )Ni63 Zn64(n,p)Cu64( $\beta^+$ )Ni64(n,2n)Ni63 Zn64(n,d)Cu63(n,p)Ni63 Zn67(n,n $\alpha$ )Ni63 Zn64(n,2n)Zn63( $\beta^+$ )Cu63(n,p)Ni63 Zn64(n,2p)Ni63 Zn66(n,2n)Zn65( $\beta^+$ )Cu65(n,2n)Cu64( $\beta^+$ )Ni64(n,2n)Ni63 Zn68(n,2n)Zn67(n,n $\alpha$ )Ni63	94.7 2.9 2.3	100.0	100.0	46.8 28.1 8.9 4.7 2.5 2.2 2.1 1.6
Ni59	$7.6 \cdot 10^4$ y	Zn64(n,n $\alpha$ )Ni60(n,2n)Ni59 Zn64(n, $\alpha$ )Ni61(n,2n)Ni60(n,2n)Ni59				96.9 2.3
Kr81	$2.1 \cdot 10^5$ y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0			
Se79	$6.0 \cdot 10^5$ y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0			

Fe60	$1.5 \cdot 10^6$ y	Zn64(n, $\alpha$ )Ni61(n, $\alpha$ )Fe58(n, $\gamma$ )Fe59(n, $\gamma$ )Fe60 Zn66(n, $\alpha$ )Ni63(n, $\alpha$ )Fe60 Zn64(n,p)Cu64( $\beta^+$ )Ni64(n,2n)Ni63(n, $\alpha$ )Fe60 <b>&amp;Zn64(n,d)Cu63(n,<math>\alpha</math>)Co60(n,p)Fe60</b> Zn64(n,p)Cu64( $\beta^+$ )Ni64(n,n $\alpha$ )Fe60 Zn64(n,d)Cu63(n,p)Ni63(n, $\alpha$ )Fe60 <b>&amp;Zn64(n,n<math>\alpha</math>)Ni60(n,p)Co60(n,p)Fe60</b> Zn67(n,n $\alpha$ )Ni63(n, $\alpha$ )Fe60 <b>&amp;Zn64(n,2n)Zn63(<math>\beta^+</math>)Cu63(n,<math>\alpha</math>)Co60(n,p)Fe60</b> Zn64(n,2p)Ni63(n, $\alpha$ )Fe60 Zn64(n,2n)Zn63( $\beta^+$ )Cu63(n,p)Ni63(n, $\alpha$ )Fe60	99.3 0.6	0.3 99.7	100.0	39.2 15.7 10.3 9.6 5.0 4.7 4.0 2.8 1.9 1.4
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# Zinc activation characteristics

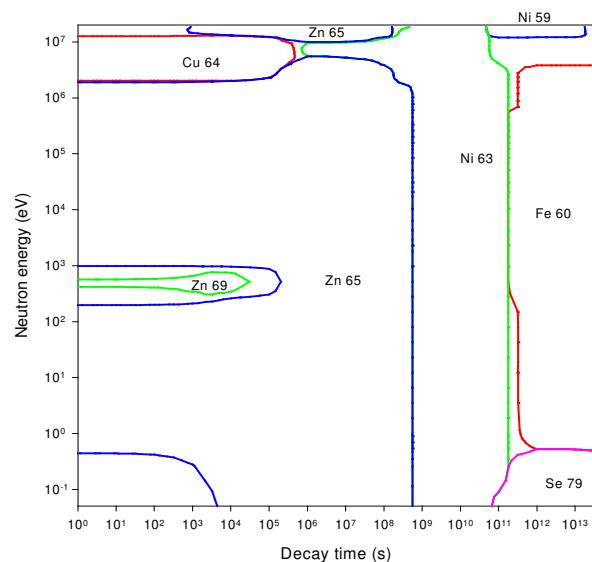


Decay time (years)

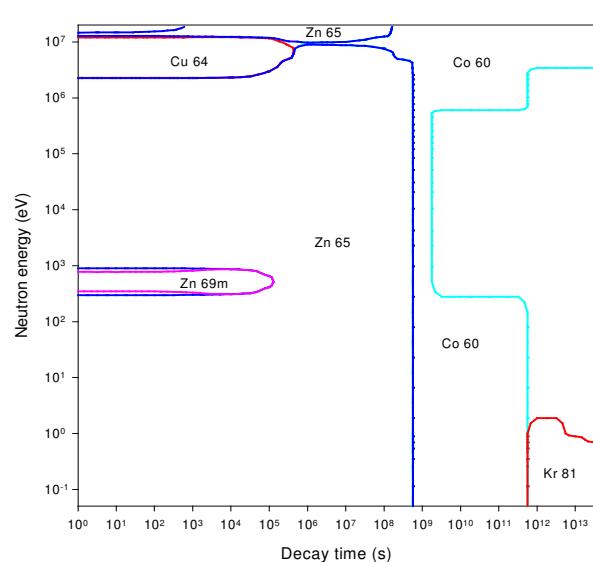
Decay time (years)

# Zinc importance diagrams & transmutation

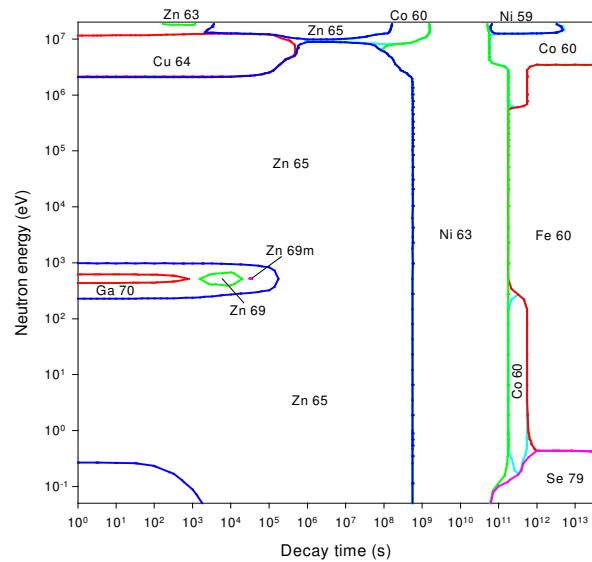
## Activity



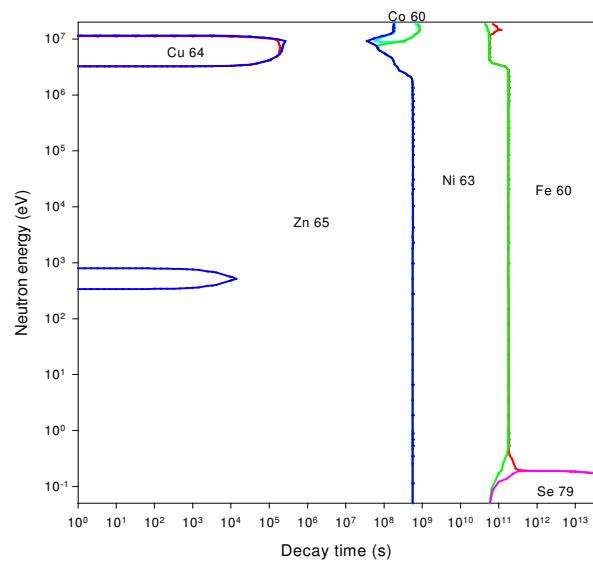
## Dose rate



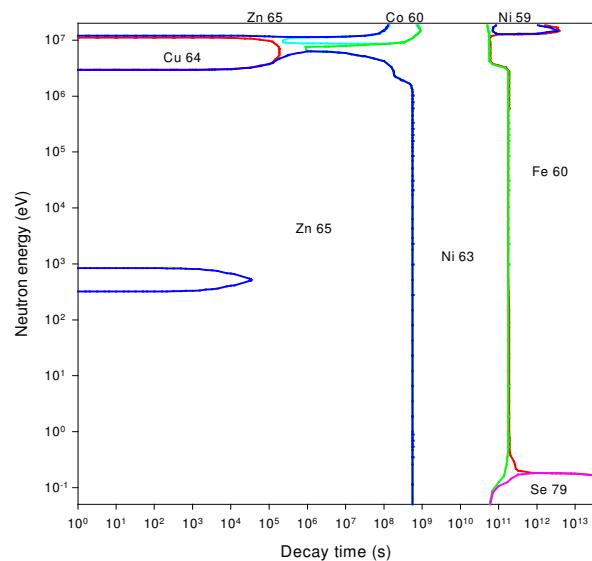
## Heat output



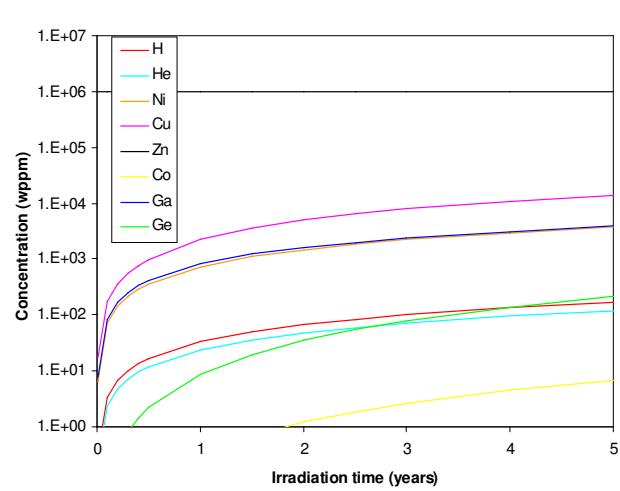
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Gallium

## General properties

Atomic number	31	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	19	Ga69	60.108
Melting point / K	302.9	Ga71	39.892
Boiling point / K	2477		
Density / kgm <sup>-3</sup>	5904		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	40.6		
Electrical resistivity /Ωm	2.7 10 <sup>-7</sup>		
Coefficient of thermal expansion / K <sup>-1</sup>	1.2 10 <sup>-5</sup>		
Crystal structure	Orthorhombic		
Number of stable isotopes	2		
Mean atomic weight	69.723		

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	7.88E15	7.24E15	1.48E14	3.40E11	1.16E9	5.66E0	kW kg <sup>-1</sup>	2.35E0	2.27E0	2.60E-2	7.35E-6	1.33E-9	7.54E-16
Ga72	44.71	48.42	32.00				Ga72	77.06	79.34	93.62			
Ga70	44.62	40.84					Ga70	15.60	13.58				
Ga68	7.25	7.47		0.05			Ga68	6.57	6.44		0.67		
Ge71	1.44	1.56	61.34				Ge69	0.30	0.31	5.64			
Ge69	0.52	0.56	5.78				Zn69	0.11	0.10	0.05			
H3			0.19	77.83	87.41		Ge71	0.01	0.01	0.50			
Zn65			0.14	21.98			Zn65			0.08	96.02		
Ni63				0.09	12.59		H3				3.29	69.82	
Co60m						30.26	Ni63				0.01	30.18	
Fe60						30.26	Co60						94.43
Co60						30.19	Fe60						3.19
Ni59						9.27	Co60m						2.30
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	3.02E6	3.00E6	4.09E4	1.25E1	1.44E-9	1.28E-9	Sv kg <sup>-1</sup>	4.06E6	4.03E6	5.63E4	3.03E2	6.44E-2	1.94E-7
Ga72	95.49	95.73	94.55				Ga72	95.37	95.84	92.61			
Ga68	3.77	3.60		0.29			Ga70	2.68	2.28				
Ge69	0.34	0.34	5.22				Ga68	1.41	1.34		0.01		
Ga70	0.23	0.20					Ge69	0.24	0.24	3.65			
Zn71m	0.06	0.06					Ge71	0.03	0.03	1.94			
Zn69m	0.06	0.06	0.05				Zn65	0.02	0.02	1.45	96.23		
Zn65			0.09	99.70			H3			0.02	3.67	66.04	
Ge71			0.08				Ni63				0.01	33.96	
Co60					99.82	99.82	Fe60						96.99
Co60m					0.16	0.17	Co60						2.99
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	1.97E6	1.95E6	2.94E4	2.36E2	4.53E-1	5.33E-7		1.07E13	1.06E13	1.41E11	2.49E8	3.86E2	5.74E-3
Ga72	94.62	95.11	85.44				Ga72	91.56	92.18	93.05			
Ga70	2.85	2.42					Ga68	5.45	5.23		0.08		
Ga68	1.42	1.36					Ga70	2.35	2.00				
Ge69	0.60	0.60	8.45				Ge69	0.38	0.38	6.05			
Ge71	0.06	0.06	3.40				Zn65	0.01	0.01	0.49	99.89		
Zn65	0.02	0.02	1.56	69.61			Ge71	0.01	0.01	0.31			
H3			0.25	29.14	58.15		H3				0.04	87.41	
Ge68			0.02	1.08			Ni63					12.58	
Ni63				0.16	41.85		Co60						99.33
Fe60						90.01	Co60m						0.37
Co60						9.94	Fe60						0.27

# Gallium

## Pathway analysis

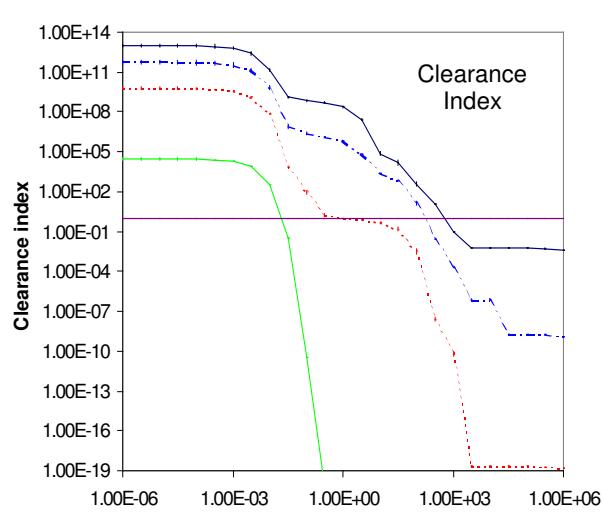
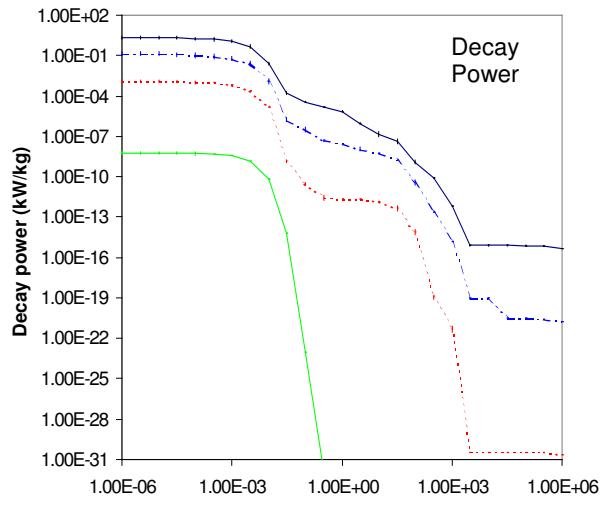
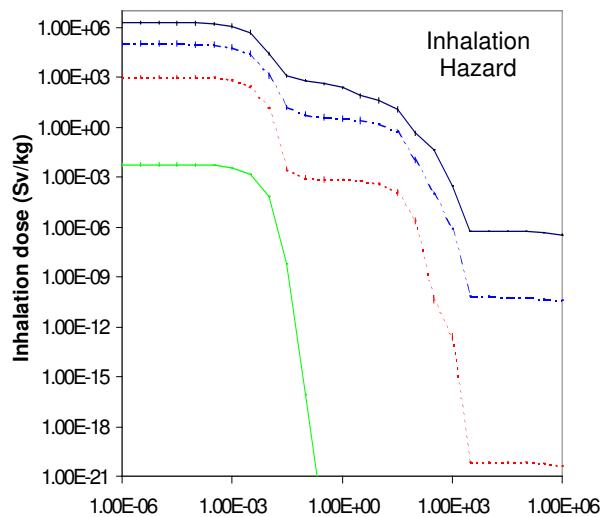
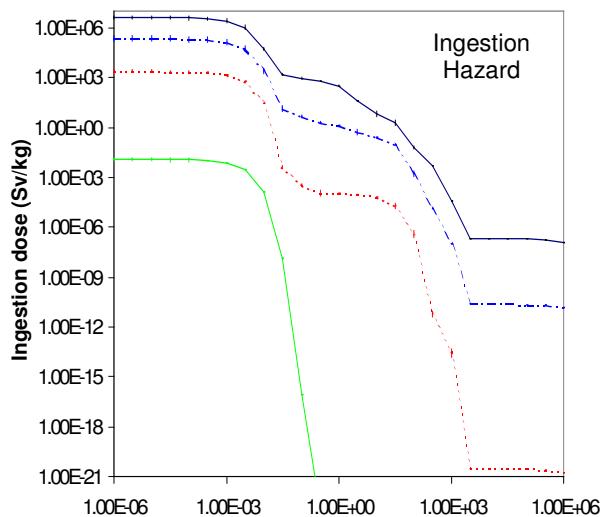
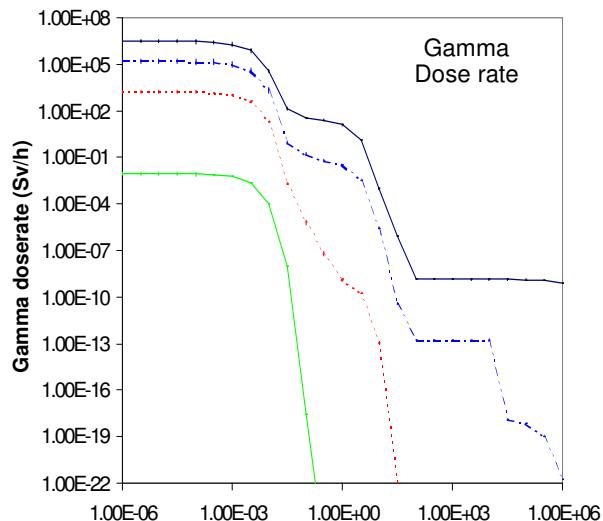
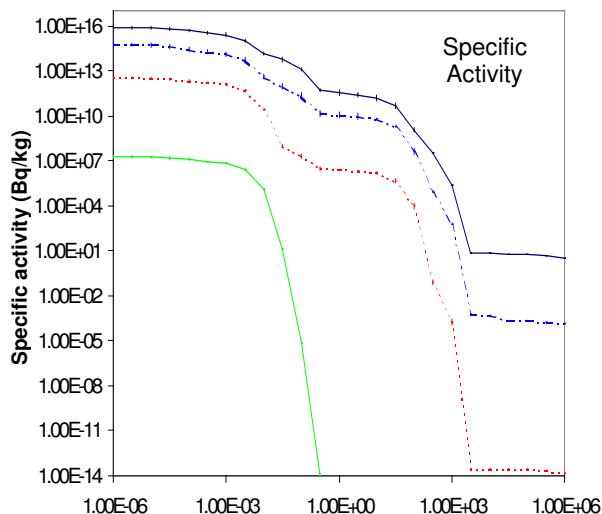
Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Ga70	21.14 m	Ga69(n, $\gamma$ )Ga70 Ga71(n,2n)Ga70	100.0	100.0	100.0	98.4
Zn69	57.0 m	&Ga71(n, $\gamma$ )Ga72( $\beta^-$ )Ge72(n, $\alpha$ )Zn69 &Ga71(n, $\alpha$ )Cu68( $\beta^-$ )Zn68(n, $\gamma$ )Zn69 &Ga71(n, $\alpha$ )Cu68m( $\beta^-$ )Zn68(n, $\gamma$ )Zn69 &Ga69(n,p)Zn69 &Ga71(n,d)Zn70(n,2n)Zn69 &Ga71(n,t)Zn69 &Ga71(n,2n)Ga70( $\beta^+$ )Zn70(n,2n)Zn69	81.7 16.0 1.4	94.8 4.8 0.4	87.9 11.2 0.9	91.8 3.1 2.5 1.1
Ga68	1.127 h	Ga69(n,2n)Ga68 Ga71(n,2n)Ga70( $\beta^-$ )Ge70(n,2n)Ge69( $\beta^+$ )Ga69(n,2n)Ga68				98.6 0.5
Zn69m	13.76 h	Ga71(n, $\gamma$ )Ga72( $\beta^-$ )Ge72(n, $\alpha$ )Zn69m &Ga71(n, $\alpha$ )Cu68( $\beta^-$ )Zn68(n, $\gamma$ )Zn69m Ga71(n, $\alpha$ )Cu68m( $\beta^-$ )Zn68(n, $\gamma$ )Zn69m Ga69(n,p)Zn69m Ga71(n,d)Zn70(n,2n)Zn69m Ga71(n,t)Zn69m Ga71(n,2n)Ga70( $\beta^+$ )Zn70(n,2n)Zn69m Ga71(n,2n)Ga70( $\beta^-$ )Ge70(n,2n)Ge69( $\beta^+$ )Ga69(n,p)Zn69m	96.0 3.1	99.2 0.8	97.9 2.0 0.1	93.2 2.7 1.5 1.0 0.5
Ga72	14.1 h	Ga71(n, $\gamma$ )Ga72 Ga69(n, $\gamma$ )Ga70( $\beta^-$ )Ge70(n, $\gamma$ )Ge71( $\beta^+$ )Ga71(n, $\gamma$ )Ga72	97.8 2.2	100.0	100.0	99.0
Ge69	1.627 d	Ga71(n,2n)Ga70( $\beta^-$ )Ge70(n,2n)Ge69				99.9
Cu67	2.579 d	Ga69(n, $\gamma$ )Ga70( $\beta^-$ )Ge70(n, $\alpha$ )Zn67(n,p)Cu67 Ga69(n, $\alpha$ )Cu66( $\beta^-$ )Zn66(n, $\gamma$ )Zn67(n,p)Cu67 Ga71(n,n $\alpha$ )Cu67 Ga69(n,2n)Ga68( $\beta^+$ )Zn68(n,2n)Zn67(n,p)Cu67 Ga69(n,2n)Ga68( $\beta^+$ )Zn68(n,d)Cu67 Ga69(n,d)Zn68(n,2n)Zn67(n,p)Cu67 Ga69(n,d)Zn68(n,d)Cu67	64.9 35.1	85.7 14.3	84.5 15.5	66.8 17.3 11.2 1.5 0.9
Ge71	11.435 d	Ga69(n, $\gamma$ )Ga70( $\beta^-$ )Ge70(n, $\gamma$ )Ge71 Ga71(n,2n)Ga70( $\beta^-$ )Ge70(n, $\gamma$ )Ge71 Ga71(n, $\gamma$ )Ga72( $\beta^-$ )Ge72(n,2n)Ge71	100.0	100.0	100.0	55.0 44.8
Fe59	44.502 d	Ga69(n, $\alpha$ )Cu65(n, $\alpha$ )Co62m( $\beta^-$ )Ni62(n, $\alpha$ )Fe59 &Ga69(n, $\alpha$ )Cu65(n, $\alpha$ )Co62( $\beta^-$ )Ni62(n, $\alpha$ )Fe59 Ga69(n, $\alpha$ )Cu66( $\beta^-$ )Zn66(n,n $\alpha$ )Ni62(n, $\alpha$ )Fe59 Ga69(n,2n)Ga68( $\beta^+$ )Zn68(n,2n)Zn67(n,n $\alpha$ )Ni63(n,n $\alpha$ )Fe59 Ga69(n, $\alpha$ )Cu66( $\beta^-$ )Zn66(n, $\alpha$ )Ni63(n,n $\alpha$ )Fe59 Ga69(n,2n)Ga68( $\beta^+$ )Zn68(n,2n)Zn67(n,n $\alpha$ )Ni63(n,2n)Ni62(n, $\alpha$ )Fe59 Ga69(n, $\alpha$ )Cu66( $\beta^-$ )Zn66(n, $\alpha$ )Ni63(n,2n)Ni62(n, $\alpha$ )Fe59 Ga69(n,n $\alpha$ )Cu65(n,2n)Cu64( $\beta^+$ )Ni64(n,2n)Ni63(n,2n) Ni62(n, $\alpha$ )Fe59 Ga69(n, $\alpha$ )Cu66( $\beta^-$ )Zn66(n, $\alpha$ )Ni63(n, $\alpha$ )Fe60(n,2n)Fe59 Ga69(n,2n)Ga68( $\beta^+$ )Zn68(n,n $\alpha$ )Ni64(n,2n)Ni63(n,n $\alpha$ )Fe59 Ga69(n, $\alpha$ )Cu66( $\beta^-$ )Zn66(n,2n)Zn65(n, $\alpha$ )Ni62(n, $\alpha$ )Fe59 Ga69(n,2n)Ga68( $\beta^+$ )Zn68(n,n $\alpha$ )Ni64(n,2n)Ni63(n,2n) Ni62(n, $\alpha$ )Fe59 Ga69(n,n $\alpha$ )Cu65(n,2n)Cu64( $\beta^+$ )Ni64(n,2n)Ni63(n, $\alpha$ ) Fe60(n,2n)Fe59 Ga69(n,2n)Ga68( $\beta^+$ )Zn68(n,2n)Zn67(n,2n) Zn66(n,n $\alpha$ )Ni62(n, $\alpha$ )Fe59 Ga71(n,2n)Ga70( $\beta^-$ )Ge70(n,n $\alpha$ )Zn66(n,n $\alpha$ )Ni62(n, $\alpha$ )Fe59				13.7 11.8 9.9 9.8 6.4 6.3 5.5 3.8 2.7 2.4 2.4 2.3 2.3 1.5 1.0 1.0 1.0

\*Plus many other similar pathways

Zn65	244.26 d	Ga69(n, $\alpha$ )Cu66( $\beta^-$ )Zn66(n, $\alpha$ )Ni63( $\beta^-$ )Cu63(n, $\gamma$ ) Cu64( $\beta^-$ )Zn64(n, $\gamma$ )Zn65 Ga69(n, $\alpha$ )Cu66( $\beta^-$ )Zn66(n,2n)Zn65 Ga69(n,2n)Ga68( $\beta^+$ )Zn68(n,2n)Zn67(n,2n)Zn66(n,2n)Zn65 Ga71(n,2n)Ga70( $\beta^-$ )Ge70(n,n $\alpha$ )Zn66(n,2n)Zn65 Ga69(n,d)Zn68(n,2n)Zn67(n,2n)Zn66(n,2n)Zn65	100.0			75.1 11.6 10.2 1.0
Co60	5.272 y	&Ga69(n,n $\alpha$ )Cu65(n,2n)Cu64( $\beta^-$ )Zn64(n,d)Cu63(n, $\alpha$ )Co60 &Ga69(n,n $\alpha$ )Cu65(n,2n)Cu64( $\beta^-$ )Zn64(n,n $\alpha$ )Ni60(n,p)Co60 &Ga69(n,n $\alpha$ )Cu65(n,2n)Cu64( $\beta^-$ )Zn64(n,2n) Zn63( $\beta^+$ )Cu63(n, $\alpha$ )Co60 &Ga69(n,n $\alpha$ )Cu65(n,n $\alpha$ )Co61( $\beta^-$ )Ni61(n,d)Co60 &Ga69(n, $\alpha$ )Cu66( $\beta^-$ )Zn66(n,2n)Zn65(n,n $\alpha$ )Ni61(n,d)Co60 &Ga69(n,n $\alpha$ )Cu65(n,2n)Cu64( $\beta^-$ )Zn64(n, $\alpha$ )Ni61(n,d)Co60 &Ga69(n, $\alpha$ )Cu66( $\beta^-$ )Zn66(n,2n)Zn65(n,2n)Zn64(n,d) Cu63(n, $\alpha$ )Co60 &Ga69(n, $\alpha$ )Cu66( $\beta^-$ )Zn66(n, $\alpha$ )Ni63( $\beta^-$ )Cu63(n, $\alpha$ )Co60 &Ga69(n,2n)Ga68( $\beta^+$ )Zn68(n,2n)Zn67(n,n $\alpha$ ) Ni63( $\beta^-$ )Cu63(n, $\alpha$ )Co60 &Ga69(n,n $\alpha$ )Cu65(n,2n)Cu64(n,n $\alpha$ )Co60 *Plus many other similar pathways				36.9 16.9 10.2  5.8 5.0 2.4 2.0  1.8 1.7  1.1 16.2*
Kr85	10.73 y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0			
H3	12.33 y	Ga71(n, $\gamma$ )Ga72(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Ga69(n, $\gamma$ )Ga70( $\beta^-$ )Ge70(n, $\gamma$ )Ge71(n,X)H1(n, $\gamma$ ) H2(n, $\gamma$ )H3 Ga69(n,X)H3 Ga71(n,X)H3	59.0 34.4			52.9 46.1
Ni63	99.0 y	Ga69(n, $\alpha$ )Cu66( $\beta^-$ )Zn66(n, $\alpha$ )Ni63 Ga69(n,2n)Ga68( $\beta^+$ )Zn68(n,2n)Zn67(n,n $\alpha$ )Ni63 Ga69(n,n $\alpha$ )Cu65(n,2n)Cu64( $\beta^+$ )Ni64(n,2n)Ni63 Ga69(n,2n)Ga68( $\beta^+$ )Zn68(n,n $\alpha$ )Ni64(n,2n)Ni63 Ga69(n,d)Zn68(n,2n)Zn67(n,n $\alpha$ )Ni63 Ga71(n,2n)Ga70( $\beta^-$ )Ge70(n,n $\alpha$ )Zn66(n, $\alpha$ )Ni63 Ga69(n,2n)Ga68( $\beta^+$ )Zn68(n,2n)Zn67(n,2n)Zn66(n, $\alpha$ )Ni63 Ga69(n,2n)Ga68( $\beta^+$ )Zn68(n,2n)Zn67(n, $\alpha$ )Ni64(n,2n)Ni63 Ga71(n,n $\alpha$ )Cu67( $\beta^-$ )Zn67(n,n $\alpha$ )Ni63 Ga69(n,2n)Ga68( $\beta^+$ )Zn68(n,2n)Zn67(n, $\alpha$ )Ni64(n,2n)Ni63	100.0	100.0	100.0	23.2 36.6 14.1 8.7 3.1 2.5 2.4 1.4 1.4 1.0
Ni59	$7.6 \cdot 10^4$ y	Ga69(n,n $\alpha$ )Cu65(n,2n)Cu64( $\beta^-$ )Zn64(n,n $\alpha$ )Ni60(n,2n)Ni59 Ga69(n, $\alpha$ )Cu66( $\beta^-$ )Zn66(n,2n)Zn65(n,2n)Zn64(n,n $\alpha$ ) Ni60(n,2n)Ni59 Ga69(n,n $\alpha$ )Cu65(n,n $\alpha$ )Co61( $\beta^-$ )Ni61(n,2n)Ni60(n,2n)Ni59 Ga69(n, $\alpha$ )Cu66( $\beta^-$ )Zn66(n,2n)Zn65(n,n $\alpha$ )Ni61(n,2n) Ni60(n,2n)Ni59 Ga69(n,2n)Ga68( $\beta^+$ )Zn68(n, $\alpha$ )Ni65( $\beta^-$ )Cu65(n,2n) Cu64( $\beta^-$ )Zn64(n,n $\alpha$ )Ni60(n,2n)Ni59 Ga69(n, $\alpha$ )Cu66( $\beta^-$ )Zn66(n,2n)Zn65( $\beta^+$ )Cu65(n,2n) Cu64( $\beta^-$ )Zn64(n,n $\alpha$ )Ni60(n,2n)Ni59 Ga69(n,n $\alpha$ )Cu65(n,2n)Cu64( $\beta^-$ )Zn64(n, $\alpha$ )Ni61(n,2n) Ni60(n,2n)Ni59				80.3 4.2  3.5 2.6  2.1  1.9  1.1
Kr81	$2.1 \cdot 10^5$ y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0			
Se79	$6.0 \cdot 10^5$ y	&Ga71(n, $\gamma$ )Ga72( $\beta^-$ )Ge72(n, $\gamma$ )Ge73(n, $\gamma$ )Ge74(n, $\gamma$ ) Ge75( $\beta^-$ )As75(n, $\gamma$ )As76( $\beta^-$ )Se76(n, $\gamma$ )Se77(n, $\gamma$ ) Se78(n, $\gamma$ )Se79 &Ga71(n, $\gamma$ )Ga72(n, $\gamma$ )Ga73( $\beta^-$ )Ge73(n, $\gamma$ )Ge74(n, $\gamma$ ) Ge75( $\beta^-$ )As75(n, $\gamma$ )As76( $\beta^-$ )Se76(n, $\gamma$ )Se77(n, $\gamma$ ) Se78(n, $\gamma$ )Se79	96.5 3.9	15.7 72.5	97.2 1.2	

Fe60	$1.5 \cdot 10^6$ y	$\text{Ga69(n,2n)Ga68}(\beta^+)\text{Zn68(n,2n)Zn67(n,n}\alpha\text{)Ni63(n,}\alpha\text{)Fe60}$ $\text{Ga69(n,}\alpha\text{)Cu66}(\beta^-)\text{Zn66(n,}\alpha\text{)Ni63(n,}\alpha\text{)Fe60}$ $\text{Ga69(n,}\alpha\text{)Cu65(n,2n)Cu64}(\beta^+)\text{Ni64(n,2n)Ni63(n,}\alpha\text{)Fe60}$ $\text{Ga69(n,n}\alpha\text{)Cu65(n,2n)Cu64}(\beta^+)\text{Ni64(n,n}\alpha\text{)Fe60}$ $\text{Ga69(n,2n)Ga68}(\beta^+)\text{Zn68(n,n}\alpha\text{)Ni64(n,2n)Ni63(n,}\alpha\text{)Fe60}$ $\text{Ga69(n,2n)Ga68}(\beta^+)\text{Zn68(n,n}\alpha\text{)Ni64(n,n}\alpha\text{)Fe60}$ $\text{Ga69(n,d)Zn68(n,2n)Zn67(n,n}\alpha\text{)Ni63(n,}\alpha\text{)Fe60}$ $\text{Ga71(n,2n)Ga70}(\beta^-)\text{Ge70(n,n}\alpha\text{)Zn66(n,}\alpha\text{)Ni63(n,}\alpha\text{)Fe60}$ $\text{Ga69(n,2n)Ga68}(\beta^+)\text{Zn68(n,2n)Zn67(n,2n)Zn66(n,}\alpha\text{)}$ $\text{Ni63(n,}\alpha\text{)Fe60}$ $\text{Ga71(n,n}\alpha\text{)Cu67}(\beta^-)\text{Zn67(n,n}\alpha\text{)Ni63(n,}\alpha\text{)Fe60}$ $\text{Ga69(n,t)Zn67(n,n}\alpha\text{)Ni63(n,}\alpha\text{)Fe60}$	28.2 23.9 10.9 8.8 6.7 5.5 2.4 1.9 1.5 1.4 1.0
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# Gallium activation characteristics

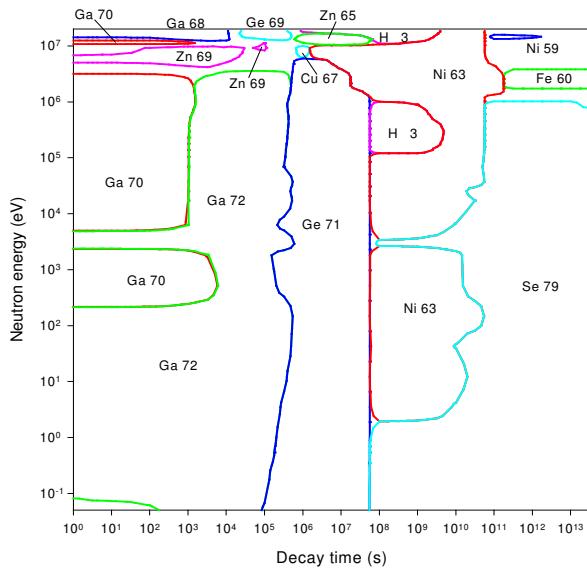


Decay time (years)

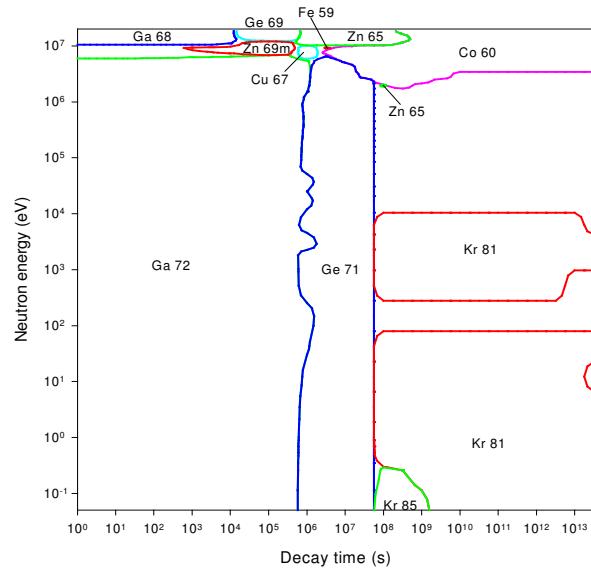
Decay time (years)

# Gallium importance diagrams & transmutation

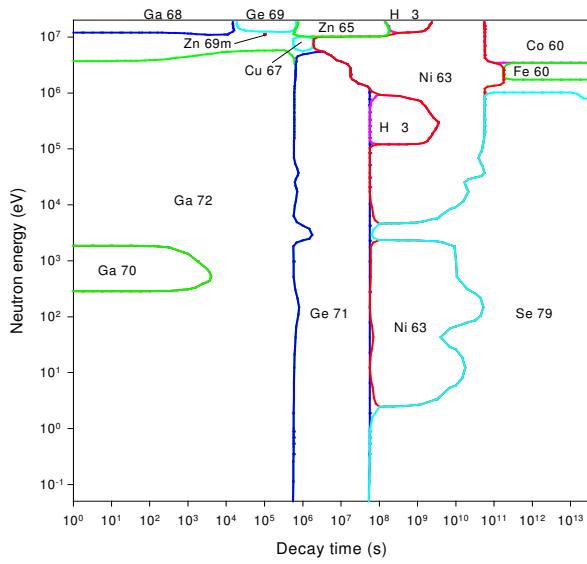
## Activity



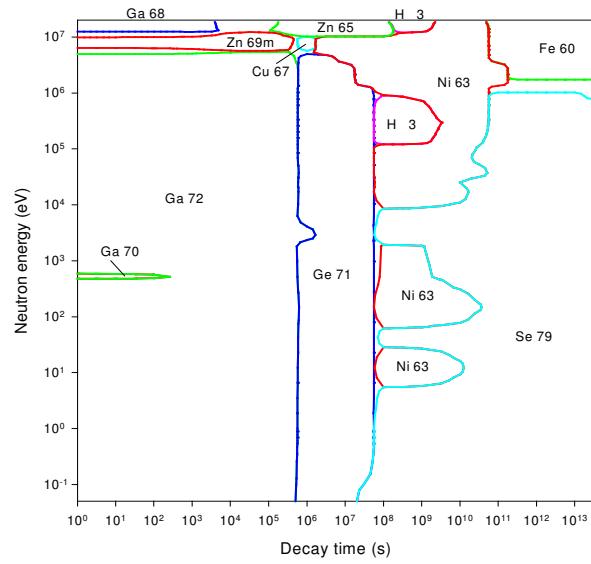
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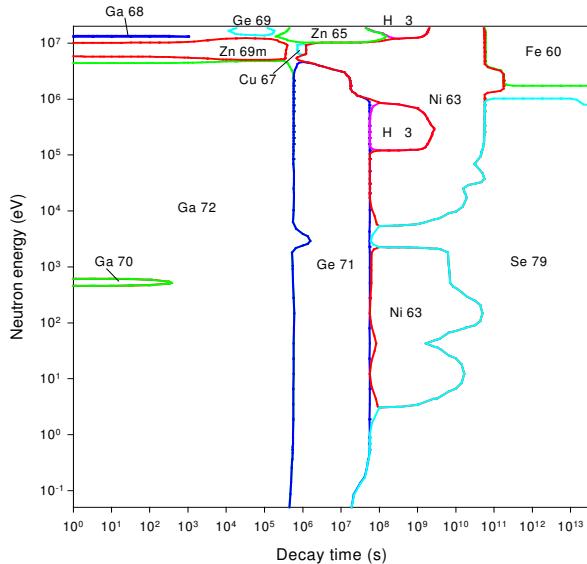
## Heat output



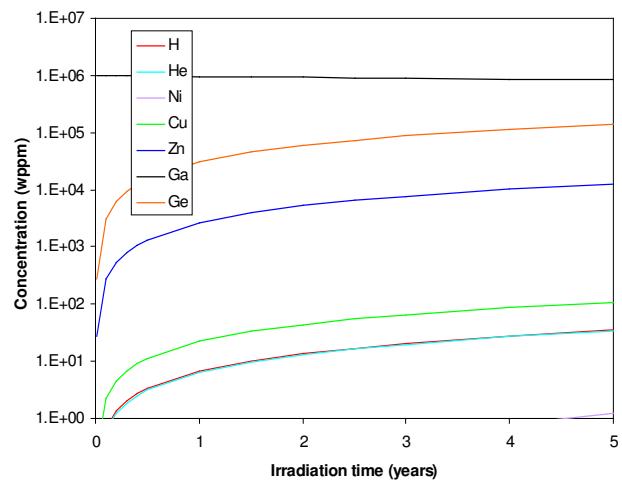
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Germanium

## General properties

		32	Isotopes	Isotopic abundances / %	
Atomic number	1.5			Ge70	20.37
Crustal abundance / wppm	1211.4		Ge72	27.31	
Melting point / K	3106		Ge73	7.76	
Boiling point / K	5323		Ge74	36.73	
Density / kgm <sup>-3</sup>	59.9		Ge76	7.83	
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	4.6 10 <sup>-1</sup>				
Electrical resistivity /Ωm	5.57 10 <sup>-6</sup>				
Coefficient of thermal expansion / K <sup>-1</sup>	Cubic				
Crystal structure	5				
Number of stable isotopes	72.64				
Mean atomic weight					

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	
Bq kg <sup>-1</sup>	1.34E15	9.28E14	3.46E14	1.78E11	1.59E8	1.01E5	kW kg <sup>-1</sup>	1.17E-1	1.05E-1	7.39E-3	1.24E-5	3.47E-10	8.51E-13	
Ge71	28.12	40.54	87.04				Ga72	36.76	41.02	8.01				
Ge73m	19.69	0.30					Ge69	16.68	18.66	55.98				
Ge75	13.57	18.82					Ge75	11.29	12.17					
Ge69	8.55	12.30	6.97				As76	10.89	12.18	17.22				
Ge75m	7.76	0.11					Ge77	4.88	5.44	0.36				
Ga72	6.28	9.01	0.33				Ga70	4.14	3.91					
As76	4.00	5.75	1.54				Ge77m	3.58	0.06					
Ga70	3.49	4.23					Ga74	2.84	2.04					
As77	3.02	4.36	2.95				Ge73m	2.40	0.03					
Ge77m	1.81	0.04					Ge75m	1.97	0.02					
Ge77	1.56	2.23	0.03				As77	1.29	1.45	5.18				
Ga74	0.39	0.36					Ga68	0.67	0.71	0.01	1.40			
Zn69	0.31	0.43	0.01				Ge71	0.46	0.52	5.88				
As74	0.25	0.35	0.82				As74	0.46	0.52	6.34				
Se75		0.10	0.25	60.64			Se75		0.06	0.77	56.39			
Zn65			0.05	31.08			Zn65			0.20	42.08			
H3				7.32	31.25		H3					0.10	13.13	
Ni63				0.12	68.68		Ni63					0.01	86.62	
Se79					0.07	99.99	Se79						0.26	99.94
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	
Sv h <sup>-1</sup>	1.17E5	1.14E5	8.23E3	1.41E1	9.49E-10	8.81E-10	Sv kg <sup>-1</sup>	2.53E5	2.51E5	2.99E4	4.97E2	1.88E-2	2.93E-4	
Ga72	59.04	60.40	11.52				Ga72	36.56	36.62	4.23				
Ge69	24.55	25.19	73.75				As76	33.86	33.98	28.44				
As76	4.72	4.84	6.68				Ge69	10.86	10.91	19.36				
Ge77	4.22	4.32	0.28				As77	6.40	6.44	13.65				
Ga74	4.04	2.66					Ge75	3.30	3.20					
Ge75	0.66	0.66					Ge77	2.72	2.72	0.11				
Ga68	0.49	0.48		0.91			Ge71	1.79	1.80	12.10				
As74	0.45	0.47	5.58				As74	1.69	1.70	12.37				
Zn71m	0.45	0.46					Se75	0.92	0.93	7.62	56.36			
Ge71	0.11	0.11	1.23				Zn65	0.24	0.24	2.01	43.33			
Se75	0.03	0.03	0.46	33.25			H3					0.11	11.12	
Zn65		0.02	0.31	65.84			Ni63					0.01	87.23	
Co60					99.79	99.80	Se79						1.66	99.96

Inh	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>	Clear	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>
Sv kg <sup>-1</sup>	1.62E5	1.61E5	2.64E4	2.75E2	1.56E-1	6.87E-4		4.64E11	4.38E11	3.50E10	2.26E8	5.36E1	5.35E-1
Ga72	27.41	27.45	2.31				Ga72	50.31	52.98	9.13			
As76	24.37	24.46	14.91				Ge69	24.66	26.04	68.87			
Ge69	20.42	20.51	26.51				As76	6.07	6.41	7.99			
As77	9.71	9.76	15.08				Ge77	5.10	5.37	0.31			
Ge77	4.74	4.74	0.14				Ga74	3.49	2.37				
As74	4.24	4.27	22.65				Ge75	3.01	3.06				
Ge75	4.03	3.89					Ge75m	1.49	0.02				
Ge71	2.55	2.56	12.57				Ga68	0.64	0.64	0.01	0.29		
Se75	0.72	0.72	4.32	51.04			As74	0.54	0.58	6.25			
Ga70	0.46	0.39					Ge71	0.39	0.41	4.10			
Zn65	0.21	0.21	1.29	44.27			Zn65	0.11	0.12	1.47	81.38		
Ge68		0.01	0.09	3.27			Se75		0.08	0.96	18.32		
H3			0.01	1.23	8.30		Ni63					68.00	
Ni63				0.10	91.23		H3					30.94	
Se79					0.47	99.94	Se79					1.05	99.26

# Germanium

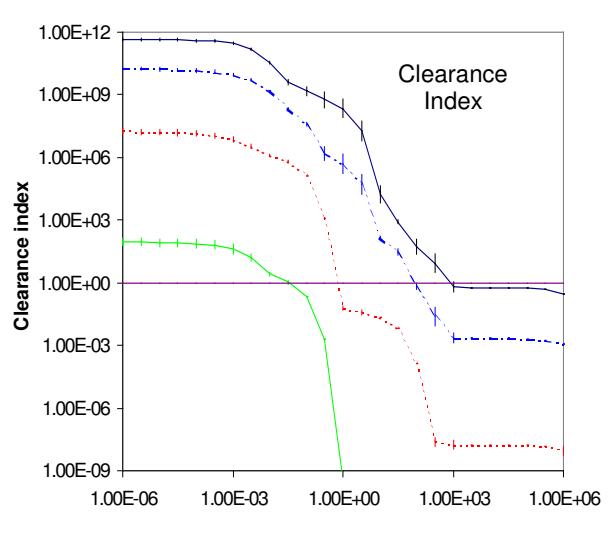
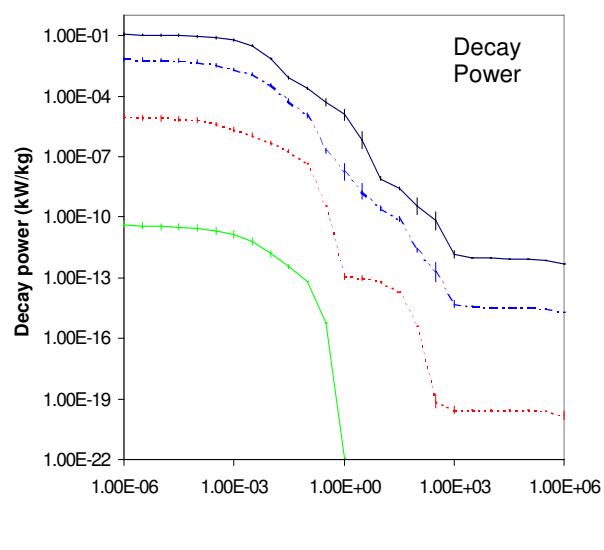
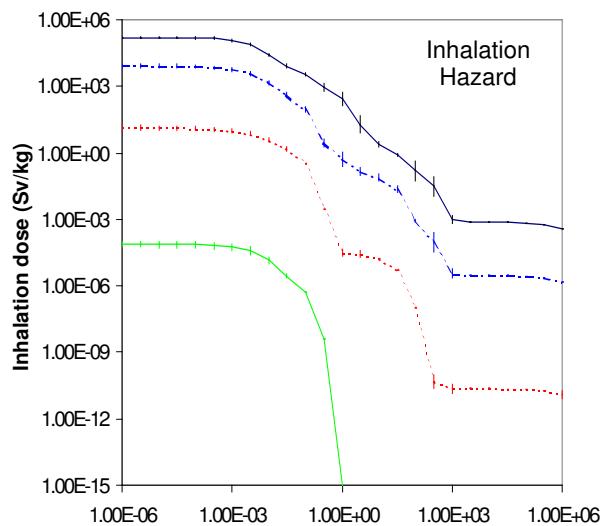
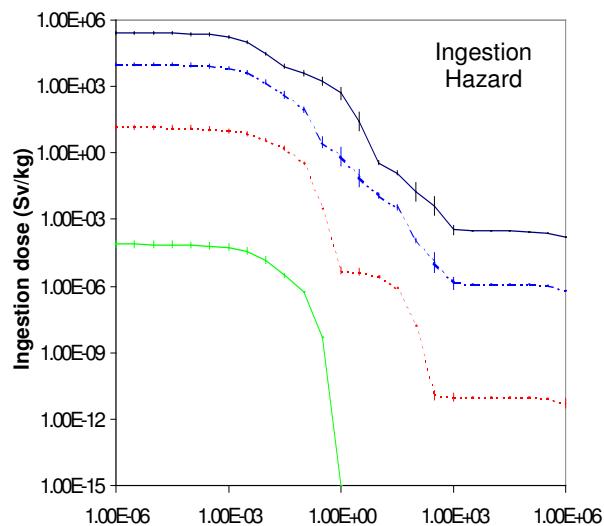
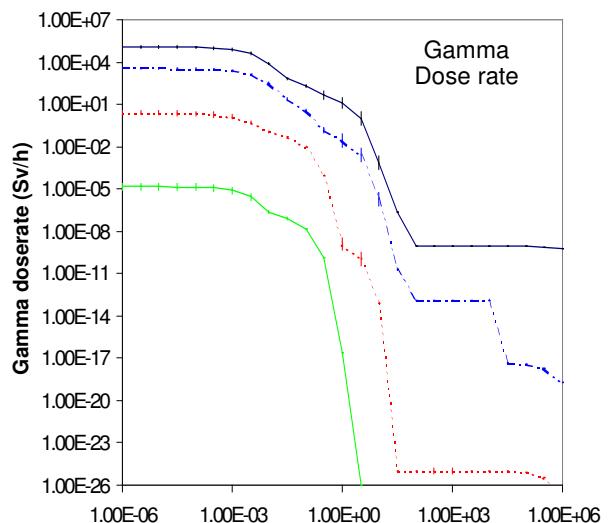
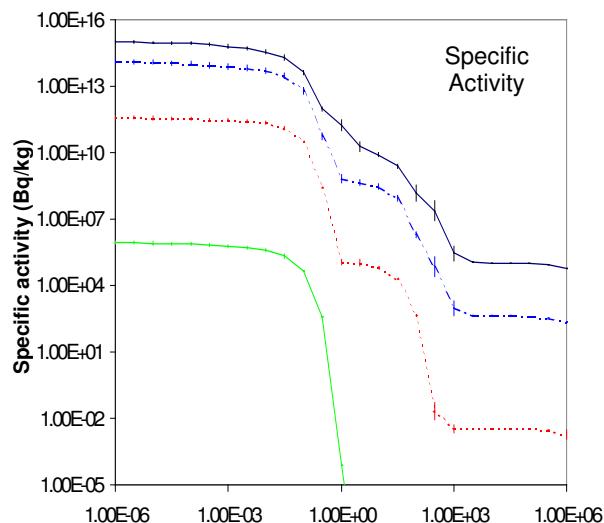
## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Ga70	21.14 m	Ge72(n, $\alpha$ )Zn69( $\beta^-$ )Ga69(n, $\gamma$ )Ga70 Ge72(n, $\alpha$ )Zn69m(IT)Zn69( $\beta^-$ )Ga69(n, $\gamma$ )Ga70 Ge72(n,2n)Ge71( $\beta^+$ )Ga71(n,2n)Ga70 Ge70(n,p)Ga70 Ge73(n,2n)Ge72(n,2n)Ge71( $\beta^+$ )Ga71(n,2n)Ga70 Ge72(n,d)Ge71(n,2n)Ga70	49.4 49.4	50.0 50.0	50.0 50.0	68.7 26.4 1.9 1.3
Ge75	1.380 h	&Ge74(n, $\gamma$ )Ge75 &Ge73(n, $\gamma$ )Ge74(n, $\gamma$ )Ge75 &Ge72(n, $\gamma$ )Ge73(n, $\gamma$ )Ge74(n, $\gamma$ )Ge75 &Ge76(n,2n)Ge75	86.3 12.1 1.5	98.1 1.8 0.8	99.2	100.0
Ge77	11.3 h	Ge76(n, $\gamma$ )Ge77 Ge76(n, $\gamma$ )Ge77m(IT)Ge77	77.8 22.2	77.8 22.2	77.8 22.2	94.0 6.0
Ga72	14.1 h	Ge70(n, $\gamma$ )Ge71( $\beta^+$ )Ga71(n, $\gamma$ )Ga72 Ge72(n,p)Ga72 Ge73(n,2n)Ge72(n,p)Ga72 Ge73(n,d)Ga72 &Ge74(n,2n)Ge73(n,d)Ga72 &Ge74(n,2n)Ge73(n,2n)Ge72(n,p)Ga72 &Ge76(n,2n)Ge75( $\beta^-$ )As75(n, $\alpha$ )Ga72	100.0	100.0	100.0	84.8 4.8 3.3 2.8 2.0 1.3
As76	1.097 d	&Ge74(n, $\gamma$ )Ge75( $\beta^-$ )As75(n, $\gamma$ )As76 &Ge73(n, $\gamma$ )Ge74(n, $\gamma$ )Ge75( $\beta^-$ )As75(n, $\gamma$ )As76 &Ge76(n,2n)Ge75( $\beta^-$ )As75(n, $\gamma$ )As76	91.5 7.8	99.0 1.0	99.6 0.4	0.2 97.1
As77	1.618 d	&Ge76(n, $\gamma$ )Ge77( $\beta^-$ )As77 Ge76(n, $\gamma$ )Ge77m( $\beta^-$ )As77 &Ge74(n, $\gamma$ )Ge75( $\beta^-$ )As75(n, $\gamma$ )As76(n, $\gamma$ )As77	51.1 48.4 0.5	51.4 48.6	51.4 48.6	79.7 19.7
Ge69	1.627 d	Ge70(n,2n)Ge69 Ge72(n,2n)Ge71( $\beta^+$ )Ga71(n,2n)Ga70( $\beta^-$ )Ge70(n,2n)Ge69				97.1 1.5
Ge71	11.435 d	Ge70(n, $\gamma$ )Ge71 Ge72(n,2n)Ge71 Ge73(n,2n)Ge72(n,2n)Ge71 &Ge74(n,2n)Ge73(n,2n)Ge72(n,2n)Ge71		99.8	100.0	100.0 91.9 5.2 2.1
As74	17.78 d	&Ge76(n,2n)Ge75( $\beta^-$ )As75(n,2n)As74				99.4
Zn65	244.26 d	Ge70(n,n $\alpha$ )Zn66(n,2n)Zn65 Ge70(n, $\alpha$ )Zn67(n,2n)Zn66(n,2n)Zn65 Ge70(n,2n)Ge69( $\beta^+$ )Ga69(n, $\alpha$ )Cu66( $\beta^-$ )Zn66(n,2n)Zn65				92.6 3.6 1.3
Co60	5.272 y	&Ge70(n,n $\alpha$ )Zn66(n,2n)Zn65(n,n $\alpha$ )Ni61(n,d)Co60 &Ge70(n,n $\alpha$ )Zn66(n,2n)Zn65(n,2n)Zn64(n,d)Cu63(n, $\alpha$ )Co60 &Ge70(n,n $\alpha$ )Zn66(n, $\alpha$ )Ni63( $\beta^-$ )Cu63(n, $\alpha$ )Co60 &Ge70(n,n $\alpha$ )Zn66(n,2n)Zn65(n,2n)Zn64(n,n $\alpha$ )Ni60(n,p)Co60 &Ge70(n,n $\alpha$ )Zn66(n,2n)Zn65( $\beta^+$ )Cu65(n,2n)Cu64( $\beta^-$ ) Zn64(n,d)Cu63(n, $\alpha$ )Co60 &Ge70(n,n $\alpha$ )Zn66(n,n $\alpha$ )Ni62(n,2n)Ni61(n,d)Co60 &Ge70(n, $\alpha$ )Zn67(n,n $\alpha$ )Ni63( $\beta^-$ )Cu63(n, $\alpha$ )Co60 &Ge70(n,n $\alpha$ )Zn66(n,2n)Zn65(n,n $\alpha$ )Ni61(n,2n)Ni60(n,p)Co60 &Ge70(n,n $\alpha$ )Zn66(n,2n)Zn65(n,2n)Zn64(n,2n) Zn63( $\beta^+$ )Cu63(n, $\alpha$ )Co60 &Ge70(n,n $\alpha$ )Zn66(n,2n)Zn65( $\beta^+$ )Cu65(n,2n)Cu64( $\beta^-$ ) Zn64(n,n $\alpha$ )Ni60(n,p)Co60 &Ge70(n,2n)Ge69( $\beta^+$ )Ga69(n,n $\alpha$ )Cu65(n,2n)Cu64( $\beta^-$ ) Zn64(n,d)Cu63(n, $\alpha$ )Co60 &Ge70(n,n $\alpha$ )Zn66(n,d)Cu65(n,2n)Cu64( $\beta^-$ )Zn64(n,d)Cu63(n, $\alpha$ )Co60 &Ge70(n,n $\alpha$ )Zn66(n, $\alpha$ )Ni63(n,2n)Ni62(n,2n)Ni61(n,d)Co60 &Ge70(n,n $\alpha$ )Zn66(n,2n)Zn65( $\beta^+$ )Cu65(n,n $\alpha$ )Co61( $\beta^-$ )Ni61(n,d)Co60				29.4 11.6 10.6 5.3 5.2 3.7 3.7 3.3 3.2 2.4 1.5 1.3 1.3 1.2 16.2*

\*Plus other similar pathways

Kr85	10.73 y	Very long pathways of $(n,\gamma)$ , $(\beta^-)$	100.0			
H3	12.33 y	Ge70( $n,\gamma$ )Ge71( $n,X$ )H1( $n,\gamma$ )H2( $n,\gamma$ )H3 <b>&amp;Ge76(<math>n,\gamma</math>)Ge77(<math>\beta^-</math>)As77(<math>\beta^-</math>)Se77(<math>n,X</math>)H1(<math>n,\gamma</math>)H2(<math>n,\gamma</math>)H3</b> Ge76( $n,\gamma$ )Ge77m( $\beta^-$ )As77( $\beta^-$ )Se77( $n,X$ )H1( $n,\gamma$ )H2( $n,\gamma$ )H3 Ge74( $n,\gamma$ )Ge75( $\beta^-$ )As75( $n,\gamma$ )As76( $\beta^-$ )Se76( $n,\gamma$ ) Se77( $n,X$ )H1( $n,\gamma$ )H2( $n,\gamma$ )H3 Ge72( $n,2n$ )Ge71( $\beta^+$ )Ga71( $n,X$ )H3 Ge73( $n,X$ )H3 Ge70( $n,X$ )H3 Ge70( $n,2n$ )Ge69( $\beta^+$ )Ga69( $n,X$ )H3 <b>&amp;Ge74(<math>n,2n</math>)Ge73(<math>n,X</math>)H3</b> Ge72( $n,X$ )H3 Ge74( $n,X$ )H3 Ge70( $n,d$ )Ga69( $n,X$ )H3 <b>&amp;Ge76(<math>n,2n</math>)Ge75(<math>\beta^-</math>)As75(<math>n,X</math>)H3</b>	63.0 10.2 9.6 4.8 26.3 21.7 10.7 10.4 9.2 6.8 5.3 3.0 2.8			
Ni63	99.0 y	Ge70( $n,n\alpha$ )Zn66( $n,\alpha$ )Ni63 Ge70( $n,\alpha$ )Zn67( $n,n\alpha$ )Ni63 Ge70( $n,\alpha$ )Zn67( $n,2n$ )Zn66( $n,\alpha$ )Ni63 Ge70( $n,n\alpha$ )Zn66( $n,2n$ )Zn65( $\beta^+$ )Cu65( $n,2n$ )Cu64( $\beta^+$ ) Ni64( $n,2n$ )Ni63 Ge70( $n,\alpha$ )Zn67( $n,\alpha$ )Ni64( $n,2n$ )Ni63				66.7 23.2 2.1 1.3 1.2
Kr81	$2.1 \cdot 10^5$ y	<b>&amp;Ge76(<math>n,\gamma</math>)Ge77(<math>\beta^-</math>)As77(<math>\beta^-</math>)Se77(<math>n,\gamma</math>)Se78(<math>n,\gamma</math>)Se79m(<math>\beta^-</math>)Br79(<math>n,\gamma</math>)Br80(<math>\beta^-</math>)Kr80(<math>n,\gamma</math>)Kr81</b> <b>&amp;Ge76(<math>n,\gamma</math>)Ge77m(<math>\beta^-</math>)As77(<math>\beta^-</math>)Se77(<math>n,\gamma</math>)Se78(<math>n,\gamma</math>)Se79m(<math>\beta^-</math>)Br79(<math>n,\gamma</math>)Br80(<math>\beta^-</math>)Kr80(<math>n,\gamma</math>)Kr81</b> <b>&amp;Ge74(<math>n,\gamma</math>)Ge75(<math>\beta^-</math>)As75(<math>n,\gamma</math>)As76(<math>\beta^-</math>)Se76(<math>n,\gamma</math>)Se77(<math>n,\gamma</math>)Se78(<math>n,\gamma</math>)Se79m(<math>\beta^-</math>)Br79(<math>n,\gamma</math>)Br80(<math>\beta^-</math>)Kr80(<math>n,\gamma</math>)Kr81</b> <b>&amp;Ge76(<math>n,\gamma</math>)Ge77(<math>\beta^-</math>)As77(<math>n,\gamma</math>)As78(<math>\beta^-</math>)Se78(<math>n,\gamma</math>)Se79m(<math>\beta^-</math>)Br79(<math>n,\gamma</math>)Br80(<math>\beta^-</math>)Kr80(<math>n,\gamma</math>)Kr81</b> <b>&amp;Ge76(<math>n,\gamma</math>)Ge77m(<math>\beta^-</math>)As77(<math>n,\gamma</math>)As78(<math>\beta^-</math>)Se78(<math>n,\gamma</math>)Se79m(<math>\beta^-</math>)Br79(<math>n,\gamma</math>)Br80(<math>\beta^-</math>)Kr80(<math>n,\gamma</math>)Kr81</b>	36.2 34.2 28.7 0.1 0.1	47.0 44.5 4.6 4.3	51.5 48.6 0.2 0.2	
Se79	$6.0 \cdot 10^5$ y	<b>&amp;Ge74(<math>n,\gamma</math>)Ge75(<math>\beta^-</math>)As75(<math>n,\gamma</math>)As76(<math>\beta^-</math>)Se76(<math>n,\gamma</math>)Se77(<math>n,\gamma</math>)Se78(<math>n,\gamma</math>)Se79</b> <b>&amp;Ge76(<math>n,\gamma</math>)Ge77(<math>\beta^-</math>)As77(<math>\beta^-</math>)Se77(<math>n,\gamma</math>)Se78(<math>n,\gamma</math>)Se79</b> <b>&amp;Ge76(<math>n,\gamma</math>)Ge77m(<math>\beta^-</math>)As77(<math>\beta^-</math>)Se77(<math>n,\gamma</math>)Se78(<math>n,\gamma</math>)Se79</b> <b>&amp;Ge73(<math>n,\gamma</math>)Ge74(<math>n,\gamma</math>)Ge75(<math>\beta^-</math>)As75(<math>n,\gamma</math>)As76(<math>\beta^-</math>)Se76(<math>n,\gamma</math>)Se77(<math>n,\gamma</math>)Se78(<math>n,\gamma</math>)Se79</b> <b>&amp;Ge76(<math>n,\gamma</math>)Ge77(<math>\beta^-</math>)As77(<math>n,\gamma</math>)As78(<math>\beta^-</math>)Se78(<math>n,\gamma</math>)Se79</b> <b>&amp;Ge76(<math>n,\gamma</math>)Ge77m(<math>\beta^-</math>)As77(<math>n,\gamma</math>)As78(<math>\beta^-</math>)Se78(<math>n,\gamma</math>)Se79</b>	41.6 29.1 27.5 1.4 2.7 2.6	48.6 45.9 4.3	51.4 48.5 0.2 0.2	80.2 19.8
Fe60	$1.5 \cdot 10^6$ y	Ge70( $n,n\alpha$ )Zn66( $n,\alpha$ )Ni63( $n,\alpha$ )Fe60 Ge70( $n,\alpha$ )Zn67( $n,n\alpha$ )Ni63( $n,\alpha$ )Fe60 Ge70( $n,\alpha$ )Zn67( $n,2n$ )Zn66( $n,\alpha$ )Ni63( $n,\alpha$ )Fe60				67.1 23.5 1.6

# Germanium activation characteristics

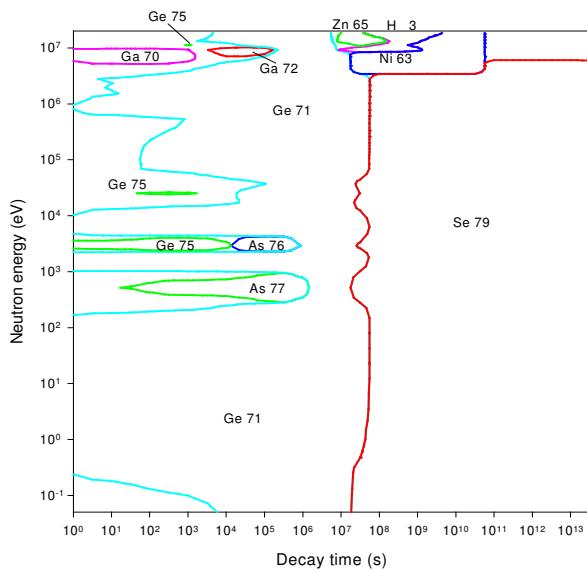


Decay time (years)

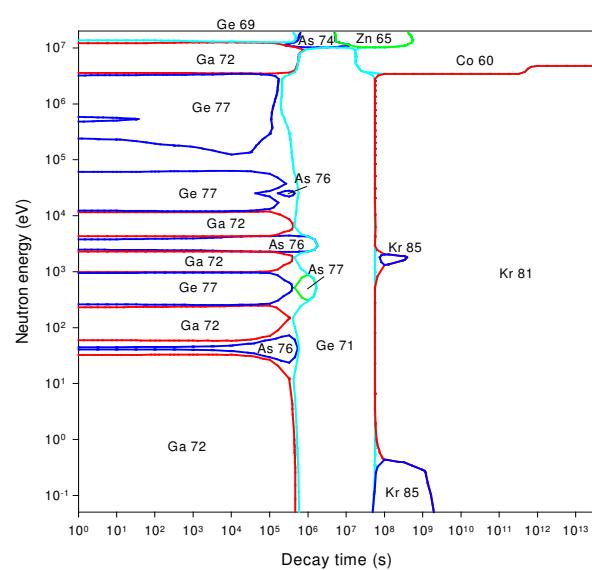
Decay time (years)

# Germanium importance diagrams & transmutation

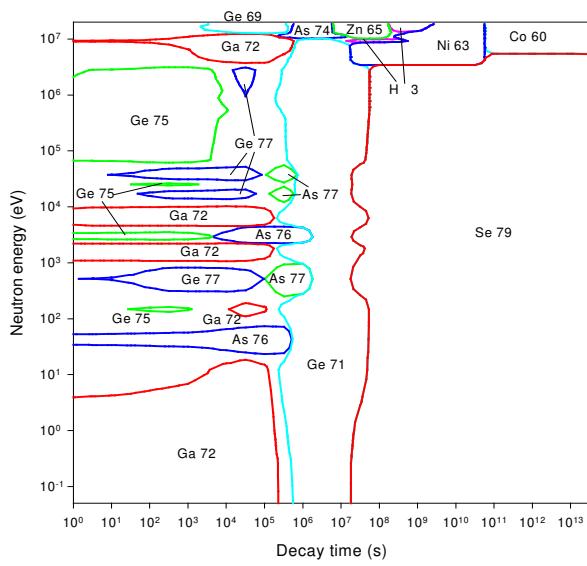
## Activity



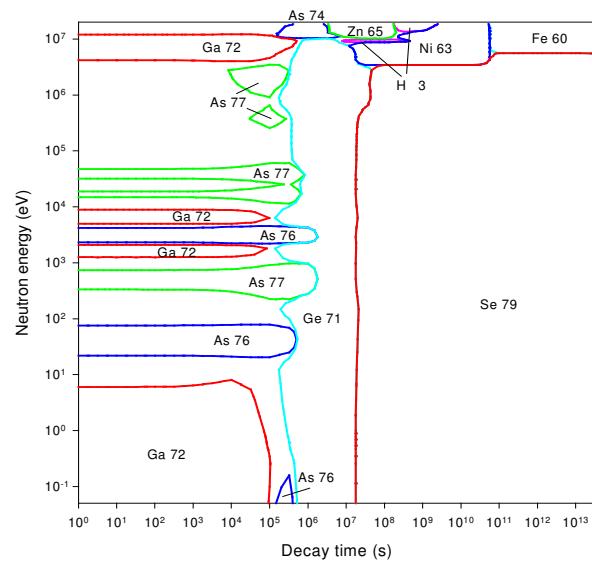
## Dose rate



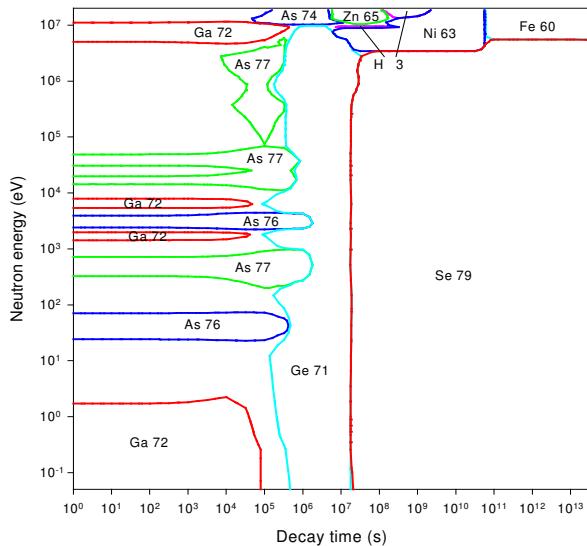
## Heat output



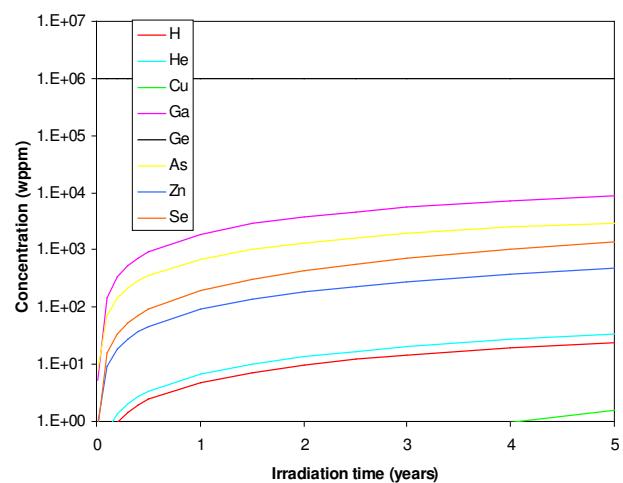
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Arsenic

## General properties

		33 1.8 1090 887 (sublimes) 5730 50 2.6 10 <sup>-7</sup> 4.7 10 <sup>-6</sup> rhombohedral 1 74.9216	Isotopes As75	Isotopic abundances / %	
Atomic number	Crustal abundance / wppm			100.0	
Melting point / K					
Boiling point / K					
Density / kgm <sup>-3</sup>					
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>					
Electrical resistivity / Ωm					
Coefficient of thermal expansion / K <sup>-1</sup>					
Crystal structure					
Number of stable isotopes					
Mean atomic weight					

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.41E16	1.36E16	2.33E15	5.21E13	3.09E8	1.08E6	kW kg <sup>-1</sup>	3.14E0	3.12E0	4.33E-1	3.37E-3	2.91E-10	9.09E-12
As76	88.02	90.80	52.90				As76	94.46	94.79	68.12			
As74	5.49	5.68	28.79				As74	4.06	4.08	25.51			
Se75	3.06	3.17	18.13	99.70			Se75	0.89	0.90	6.33	99.97		
Se77m	2.95						Se77m	0.34					
H3			0.15	99.63			H3					96.68	
Se79					0.37	100.00	Se79					3.32	100.00
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	1.43E6	1.42E6	2.52E5	2.20E3	3.24E-12	2.33E-12	Sv kg <sup>-1</sup>	2.20E7	2.19E7	3.94E6	1.35E5	1.63E-2	3.13E-3
As76	89.29	89.40	50.23				As76	90.25	90.23	50.01			
As74	8.69	8.72	42.63				Se75	5.10	5.11	27.85	99.99		
Se75	1.28	1.29	7.10	99.99			As74	4.57	4.58	22.11			
Ga72	0.57	0.57	0.04				H3					79.54	
Kr81					99.91	100.00	Se79					20.46	100.00
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	1.14E7	1.13E7	2.87E6	6.76E4	8.78E-2	7.33E-3		7.35E12	7.30E12	1.33E12	2.00E10	1.09E2	5.68E0
As76	80.68	80.65	31.75				As76	88.71	89.16	48.87			
As74	14.28	14.31	49.04				As74	8.09	8.15	38.86			
Se75	4.93	4.94	19.12	99.85			Se75	2.26	2.27	12.24	99.99		
As77	0.03	0.03	0.03				Se77m	0.51					
As73	0.02	0.02	0.06	0.12			Ga72	0.37	0.37	0.03			
H3				0.03	91.12		H3					94.45	
Se79					8.88	100.00	Se79					5.56	100.00

# Arsenic

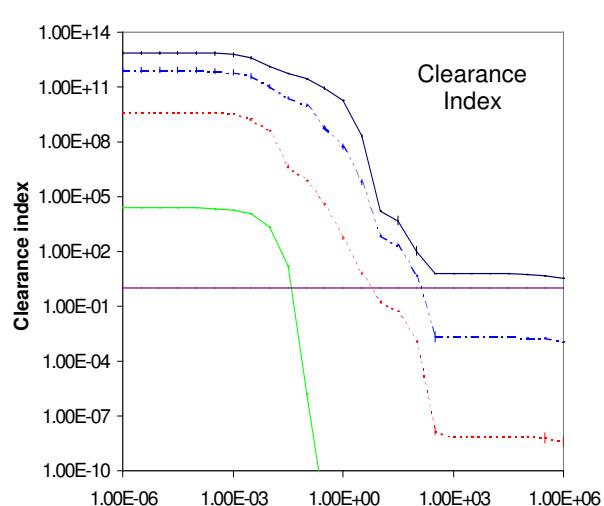
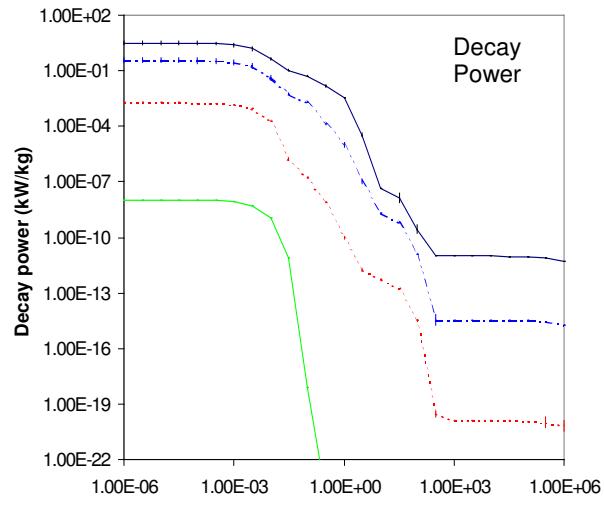
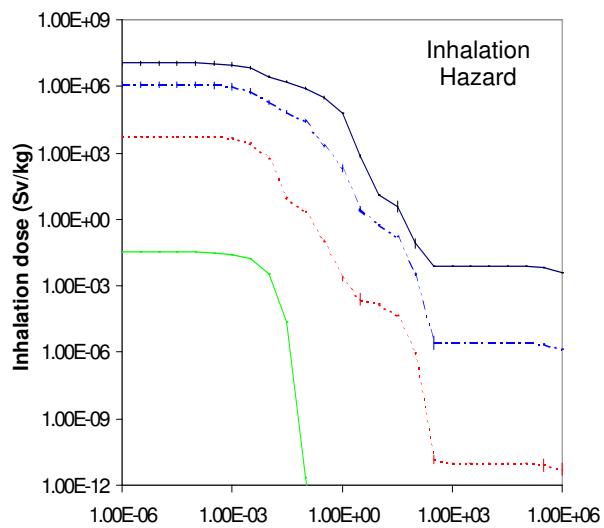
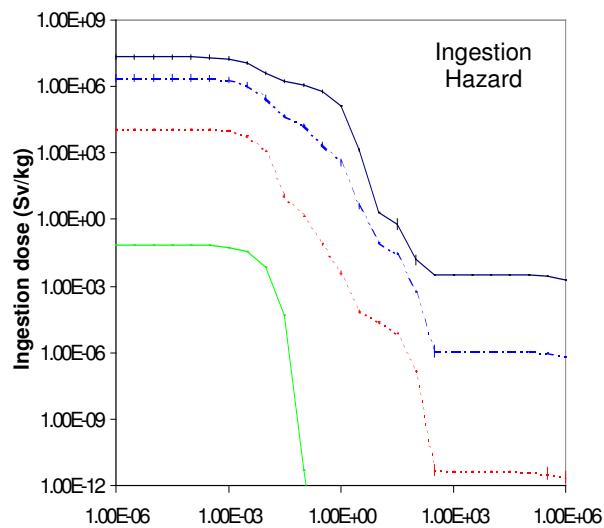
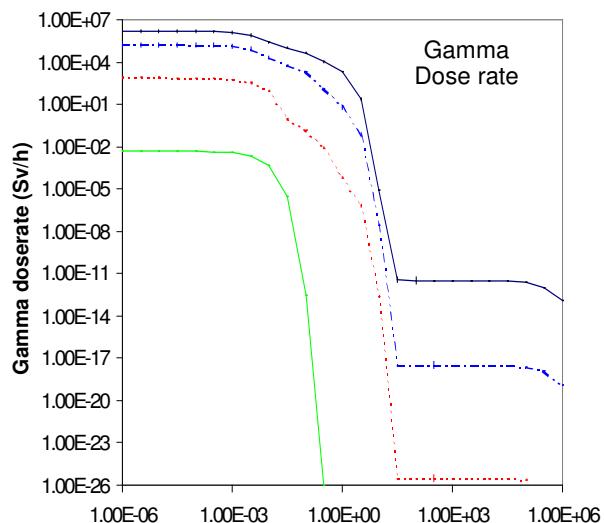
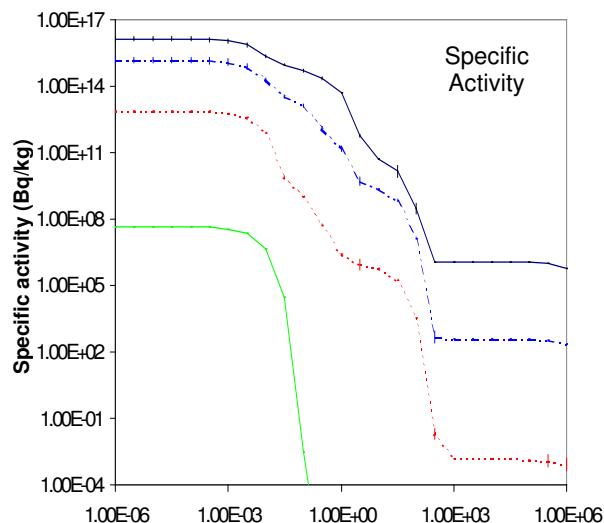
## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Se77m	17.36 s	As75(n, $\gamma$ )As76( $\beta^-$ )Se76(n, $\gamma$ )Se77m As75(n, $\gamma$ )As76( $\beta^-$ )Se76(n, $\gamma$ )Se77(n,n')Se77m	100.0	100.0	100.0	96.5 1.1
Se79m	3.9 m	&As75(n, $\gamma$ )As76( $\beta^-$ )Se76(n, $\gamma$ )Se77(n, $\gamma$ )Se78(n, $\gamma$ )Se79m As75(n, $\gamma$ )As76(n, $\gamma$ )As77( $\beta^-$ )Se77(n, $\gamma$ )Se78(n, $\gamma$ )Se79m	99.9 0.1	94.9 5.1	99.4 0.6	98.9 0.1
Ge75	1.3797 h	&As75(n, $\gamma$ )As76( $\beta^-$ )Se76(n, $\gamma$ )Se77(n, $\alpha$ )Ge74(n, $\gamma$ )Ge75 &As75(n, $\gamma$ )As76(n, $\gamma$ )As77( $\beta^-$ )Se77(n, $\alpha$ )Ge74(n, $\gamma$ )Ge75 &As75(n, $\gamma$ )As76( $\beta^-$ )Se76(n, $\gamma$ )Se77(n, $\gamma$ )Se78(n, $\alpha$ )Ge75 &As75(n,p)Ge75 &As75(n,2n)As74( $\beta^+$ )Ge74(n, $\gamma$ )Ge75	99.9 0.1	94.8 5.1	43.7 55.7	99.4 0.3
Ga72	14.1 h	As75(n, $\alpha$ )Ga72 &As75(n,2n)As74( $\beta^+$ )Ge74(n,2n)Ge73(n,d)Ga72 As75(n,2n)As74( $\beta^+$ )Ge74(n,2n)Ge73(n,2n)Ge72(n,p)Ga72	100.0	100.0	100.0	97.9 0.5 0.1
As76	1.0967 d	As75(n, $\gamma$ )As76	100.0	100.0	100.0	98.8
Br82	1.4717 d	&As75(n, $\gamma$ )As76( $\beta^-$ )Se76(n, $\gamma$ )Se77(n, $\gamma$ )Se78(n, $\gamma$ ) Se79(n, $\gamma$ )Se80(n, $\gamma$ )Se81( $\beta^-$ )Br81(n, $\gamma$ )Br82 &As75(n, $\gamma$ )As76(n, $\gamma$ )As77( $\beta^-$ )Se77(n, $\gamma$ )Se78(n, $\gamma$ ) Se79(n, $\gamma$ )Se80(n, $\gamma$ )Se81( $\beta^-$ )Br81(n, $\gamma$ )Br82	96.8	88.2 8.3	95.5 1.5	
As77	1.6179 d	As75(n, $\gamma$ )As76(n, $\gamma$ )As77 &As75(n, $\gamma$ )As76( $\beta^-$ )Se76(n, $\gamma$ )Se77(n,p)As77	99.3	100.0	100.0	12.2 87.5
Ge71	11.435 d	As75(n,2n)As74( $\beta^-$ )Se74(n, $\alpha$ )Ge71 As75(n, $\alpha$ )Ga72( $\beta^-$ )Ge72(n,2n)Ge71 &As75(n,2n)As74( $\beta^+$ )Ge74(n,2n)Ge73(n,2n) Ge72(n,2n)Ge71 &As75(n,2n)As74( $\beta^-$ )Se74(n,2n)Se73( $\beta^+$ )As73( $\beta^+$ ) Ge73(n,2n)Ge72(n,2n)Ge71 As75(n,2n)As74( $\beta^-$ )Se74(n,d)As73( $\beta^+$ )Ge73(n,2n) Ge72(n,2n)Ge71				44.4 36.7 12.6  1.7  1.5
As74	17.78 d	As75(n,2n)As74				98.7
As73	80.301 d	&As75(n,2n)As74( $\beta^-$ )Se74(n,2n)Se73( $\beta^+$ )As73 As75(n,2n)As74( $\beta^-$ )Se74(n,d)As73 As75(n,2n)As74( $\beta^-$ )Se74(n,2n)Se73m( $\beta^+$ )As73 As75(n,2n)As74(n,2n)As73				45.5 40.5 7.9 5.9
Se75	119.64 d	As75(n, $\gamma$ )As76( $\beta^-$ )Se76(n,2n)Se75 As75(n,2n)As74( $\beta^-$ )Se74(n, $\gamma$ )Se75				60.4 39.4
Zn65	244.26 d	As75(n,2n)As74( $\beta^-$ )Se74(n,n $\alpha$ )Ge70(n,n $\alpha$ )Zn66(n,2n)Zn65 As75(n,n $\alpha$ )Ga71(n,2n)Ga70( $\beta^-$ )Ge70(n,n $\alpha$ )Zn66(n,2n)Zn65 As75(n,2n)As74(n,n $\alpha$ )Ga70( $\beta^-$ )Ge70(n,n $\alpha$ )Zn66(n,2n)Zn65 As75(n,2n)As74( $\beta^-$ )Se74(n,n $\alpha$ )Ge70(n, $\alpha$ )Zn67(n,2n) Zn66(n,2n)Zn65 As75(n,2n)As74( $\beta^-$ )Se74(n, $\alpha$ )Ge71( $\beta^+$ )Ga71(n,2n) Ga70( $\beta^-$ )Ge70(n,n $\alpha$ )Zn66(n,2n)Zn65 As75(n, $\alpha$ )Ga72( $\beta^-$ )Ge72(n,2n)Ge71( $\beta^+$ )Ga71(n,2n) Ga70( $\beta^-$ )Ge70(n,n $\alpha$ )Zn66(n,2n)Zn65				76.5 11.6 2.8 1.6  1.4  1.2

Co60	5.2717 y	<p><b>&amp;As75(n,2n)As74(<math>\beta^-</math>)Se74(n,n<math>\alpha</math>)Ge70(n,n<math>\alpha</math>)</b></p> <p>Zn66(n,2n)Zn65(n,n<math>\alpha</math>)Ni61(n,d)<i>Co60</i></p> <p><b>&amp;As75(n,2n)As74(<math>\beta^-</math>)Se74(n,n<math>\alpha</math>)Ge70(n,n<math>\alpha</math>)</b></p> <p>Zn66(n,<math>\alpha</math>)Ni63(<math>\beta^-</math>)Cu63(n,<math>\alpha</math>)<i>Co60</i></p> <p><b>&amp;As75(n,2n)As74(<math>\beta^-</math>)Se74(n,n<math>\alpha</math>)Ge70(n,n<math>\alpha</math>)</b></p> <p>Zn66(n,2n)Zn65(n,n<math>\alpha</math>)Ni61(n,d)<i>Co60</i></p> <p><b>&amp;As75(n,2n)As74(<math>\beta^-</math>)Se74(n,n<math>\alpha</math>)Ge70(n,n<math>\alpha</math>)</b></p> <p>Zn66(n,2n)Zn65(n,2n)Zn64(n,p)<i>Co60</i></p> <p><b>&amp;As75(n,2n)As74(<math>\beta^-</math>)Se74(n,n<math>\alpha</math>)Ge70(n,<math>\alpha</math>)</b></p> <p>Zn67(n,n<math>\alpha</math>)Ni63(<math>\beta^-</math>)Cu63(n,<math>\alpha</math>)<i>Co60</i></p> <p><b>&amp;As75(n,2n)As74(<math>\beta^-</math>)Se74(n,n<math>\alpha</math>)Ge70(n,n<math>\alpha</math>)</b></p> <p>Zn66(n,n<math>\alpha</math>)Ni62(n,2n)Ni61(n,d)<i>Co60</i></p> <p><b>&amp;As75(n,2n)As74(n,n<math>\alpha</math>)Ga70(<math>\beta^-</math>)Ge70(n,n<math>\alpha</math>)</b></p> <p>Zn66(n,2n)Zn65(n,2n)Zn64(n,d)Cu63(n,<math>\alpha</math>)<i>Co60</i></p> <p><b>&amp;As75(n,2n)As74(<math>\beta^-</math>)Se74(n,n<math>\alpha</math>)Ge70(n,n<math>\alpha</math>)Zn66(n,2n)</b></p> <p>Zn65(<math>\beta^+</math>)Cu65(n,2n)Cu64(<math>\beta^-</math>)Zn64(n,d)Cu63(n,<math>\alpha</math>)<i>Co60</i></p> <p><b>&amp;As75(n,2n)As74(<math>\beta^-</math>)Se74(n,n<math>\alpha</math>)Ge70(n,n<math>\alpha</math>)</b></p> <p>Zn66(n,2n)Zn65(n,n<math>\alpha</math>)Ni61(n,2n)Ni60(n,p)<i>Co60</i></p> <p><b>&amp;As75(n,2n)As74(<math>\beta^-</math>)Se74(n,n<math>\alpha</math>)Ge70(n,n<math>\alpha</math>)Zn66(n,2n)</b></p> <p>Zn65(n,2n)Zn64(n,2n)Zn63(<math>\beta^+</math>)Cu63(n,<math>\alpha</math>)<i>Co60</i></p> <p><b>&amp;As75(n,2n)As74(n,n<math>\alpha</math>)Ga70(<math>\beta^-</math>)Ge70(n,n<math>\alpha</math>)</b></p> <p>Zn66(n,2n)Zn65(n,n<math>\alpha</math>)Ni61(n,d)<i>Co60</i></p> <p><b>&amp;As75(n,n<math>\alpha</math>)Ga71(n,n<math>\alpha</math>)Cu67(<math>\beta^-</math>)Zn67(n,n<math>\alpha</math>)</b></p> <p>Ni63(<math>\beta^-</math>)Cu63(n,<math>\alpha</math>)<i>Co60</i></p> <p><b>&amp;As75(n,n<math>\alpha</math>)Ga71(n,2n)Ga70(<math>\beta^-</math>)Ge70(n,n<math>\alpha</math>)</b></p> <p>Zn66(n,2n)Zn65(n,2n)Zn64(n,d)Cu63(n,<math>\alpha</math>)<i>Co60</i></p> <p>*Plus other pathways involving (n,n<math>\alpha</math>), (n,<math>\alpha</math>), (<math>\beta^-</math>), etc</p>				28.8
Kr85	10.73 y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0			
H3	12.33 y	<p><b>&amp;As75(n,<math>\gamma</math>)As76(<math>\beta^-</math>)Se76(n,<math>\gamma</math>)Se77(n,X)H1(n,<math>\gamma</math>)</b></p> <p>H2(n,<math>\gamma</math>)H3</p> <p>As75(n,<math>\gamma</math>)As76(n,X)H1(n,<math>\gamma</math>)H2(n,<math>\gamma</math>)H3</p> <p>As75(n,<math>\gamma</math>)As76(n,<math>\gamma</math>)As77(<math>\beta^-</math>)Se77(n,X)H1(n,<math>\gamma</math>)H2(n,<math>\gamma</math>)H3</p> <p>As75(n,X)H3</p> <p>As75(n,2n)As74(<math>\beta^-</math>)Se74(n,X)H3</p>	95.1 0.9 0.2			
Ni63	99.0 y	<p>As75(n,2n)As74(<math>\beta^-</math>)Se74(n,n<math>\alpha</math>)Ge70(n,n<math>\alpha</math>)Zn66(n,<math>\alpha</math>)Ni63</p> <p>As75(n,2n)As74(<math>\beta^-</math>)Se74(n,n<math>\alpha</math>)Ge70(n,<math>\alpha</math>)Zn67(n,n<math>\alpha</math>)Ni63</p> <p>As75(n,n<math>\alpha</math>)Ga71(n,2n)Ga70(<math>\beta^-</math>)Ge70(n,n<math>\alpha</math>)Zn66(n,<math>\alpha</math>)Ni63</p> <p>As75(n,n<math>\alpha</math>)Ga71(n,n<math>\alpha</math>)Cu67(<math>\beta^-</math>)Zn67(n,n<math>\alpha</math>)Ni63</p> <p>As75(n,n<math>\alpha</math>)Ga71(n,2n)Ga70(<math>\beta^-</math>)Ge70(n,<math>\alpha</math>)Zn67(n,n<math>\alpha</math>)Ni63</p> <p>As75(n,2n)As74(n,n<math>\alpha</math>)Ga70(<math>\beta^-</math>)Ge70(n,n<math>\alpha</math>)Zn66(n,<math>\alpha</math>)Ni63</p> <p>*Plus many other similar pathways</p>			50.5 17.7 7.7 5.6 2.7 2.1 13.7*	



# Arsenic activation characteristics

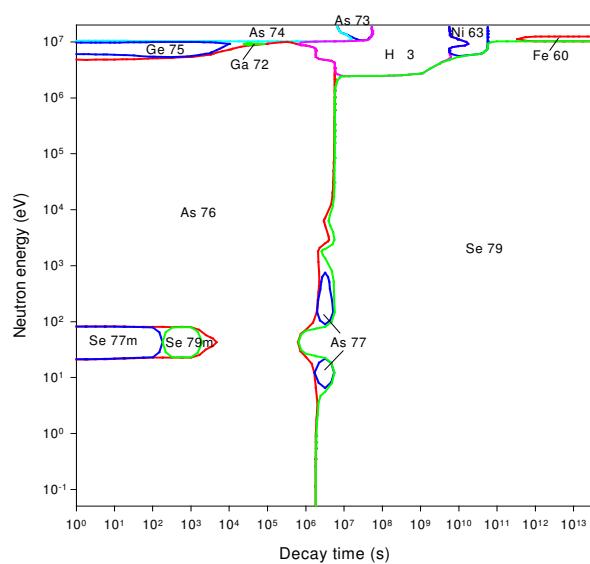


Decay time (years)

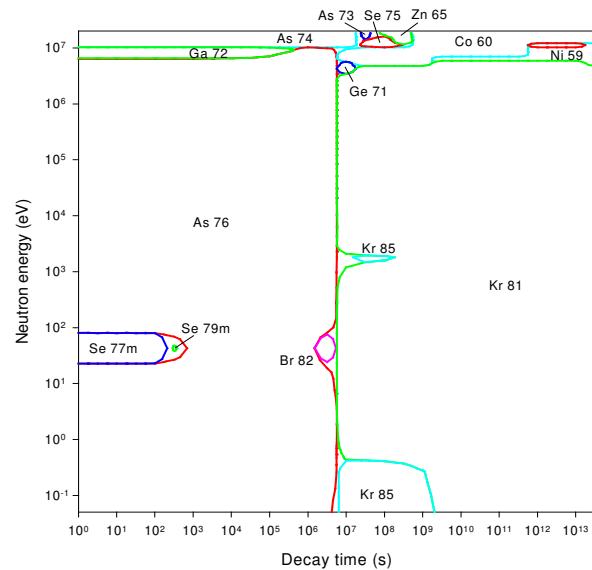
Decay time (years)

# Arsenic importance diagrams & transmutation

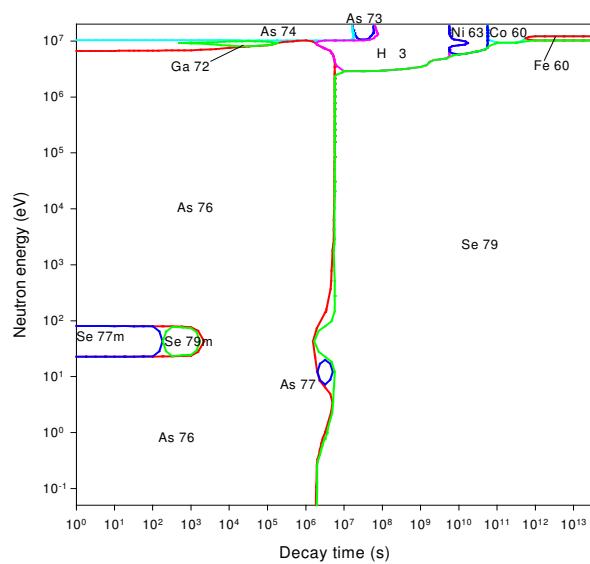
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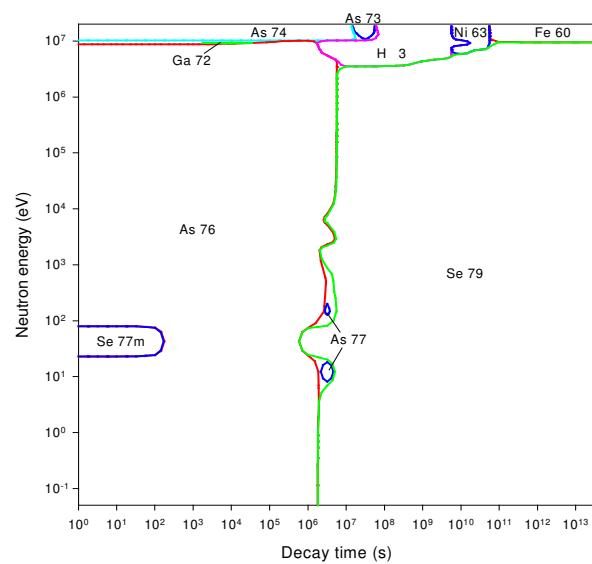
## Dose rate



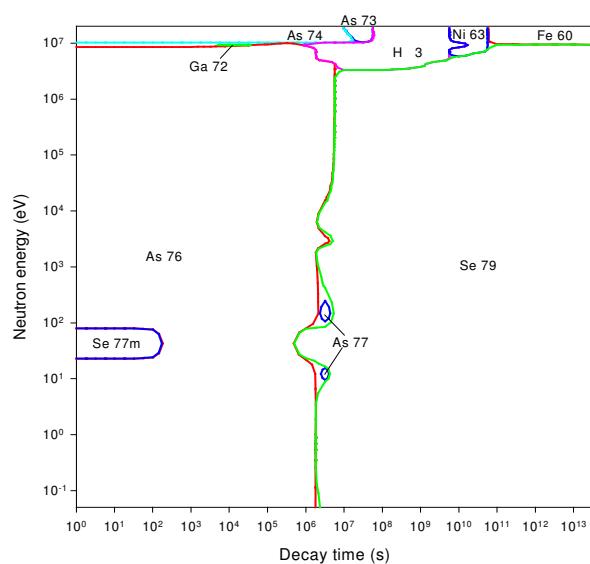
## Heat output



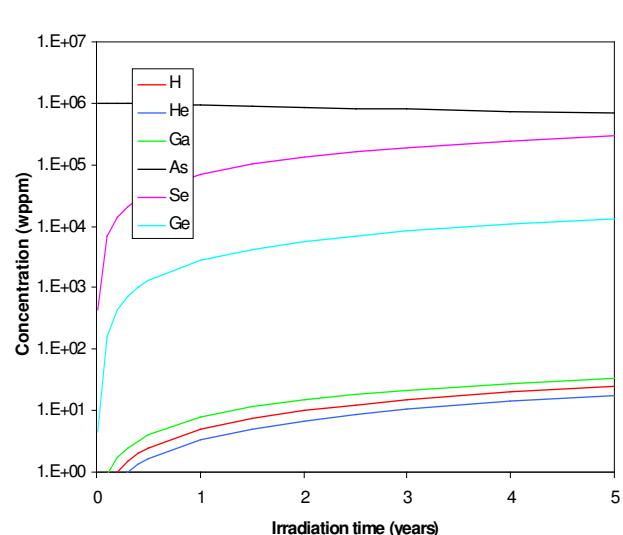
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Selenium

## General properties

	34	Isotopes	Isotopic abundances / %
Atomic number	5.0 10 <sup>-2</sup>	Se74	0.89
Crustal abundance / wppm	494	Se76	9.37
Melting point / K	958.1	Se77	7.63
Boiling point / K	4790	Se78	23.77
Density / kgm <sup>-3</sup>	2.04	Se80	49.61
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	1.0 10 <sup>-2</sup>	Se82	8.73 ( $T_{1/2} = 1.3943 \cdot 10^{20}$ y)
Electrical resistivity /Ωm	3.69 10 <sup>-5</sup>		
Coefficient of thermal expansion / K <sup>-1</sup>	Hexagonal		
Crystal structure	5(6)		
Number of stable isotopes	78.96		
Mean atomic weight			

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	
Bq kg <sup>-1</sup>	1.84E15	1.05E15	2.17E14	2.24E13	2.82E9	2.60E9	kW kg <sup>-1</sup>	1.41E-1	1.16E-1	2.26E-2	1.45E-3	2.34E-8	2.19E-8	
Se79m	24.09	16.65					Br82	27.55	33.33	30.79				
Se77m	23.32						Se81	21.62	23.30					
Se81	16.66	26.02					As76	19.90	24.03	12.32				
Se75	10.06	17.65	83.59	99.78			Se75	8.55	10.35	52.11	99.97			
Se81m	6.67	10.98					Se77m	7.76						
As76	6.35	11.11	5.36				Se79m	4.84	2.31					
Br82	4.72	8.28	7.19				As80	2.85						
Br82m	4.39	4.23					Se81m	1.45	1.64					
Kr83m	0.92	1.57					As78	1.38	1.60					
As74	0.39	0.68	2.85				As74	0.83	1.01	4.51				
H3			0.01	0.06	1.70		Br80	0.62	0.69					
Se79				0.01	97.80	99.68	Se79					99.23	99.92	
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	
Sv h <sup>-1</sup>	8.97E4	8.54E4	2.09E4	9.47E2	3.24E-6	1.24E-6	Sv kg <sup>-1</sup>	7.45E5	7.43E5	5.08E5	5.81E4	8.01E0	7.52E0	
Br82	67.97	71.39	52.44				Se75	64.63	64.81	92.94	99.96			
As76	13.65	14.31	5.83				As76	25.09	25.10	3.66				
Se75	8.76	9.21	36.87	100.0			Br82	6.30	6.31	1.66				
Se77m	2.17						As74	1.24	1.25	1.58				
As78	2.01	2.03					Se81	1.11	0.99					
As80	1.48						Se81m	0.87	0.82					
As74	1.29	1.36	4.83				As77	0.33	0.33	0.11				
Kr81					53.10	100.0	As78	0.13	0.13					
Kr85					46.90*		Se79				0.01	99.86	99.98	
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	
Sv kg <sup>-1</sup>	4.14E5	4.12E5	2.69E5	2.95E4	1.96E1	1.77E1			4.66E11	4.05E11	1.22E11	8.59E9	1.47E4	1.37E4
Se75	58.23	58.41	87.66	98.35			Br82	49.11	56.46	33.72				
As76	20.91	20.93	3.20				Se75	15.30	17.59	57.30	99.99			
Br82	13.24	13.28	3.66				As76	13.21	15.16	5.02				
As74	3.62	3.63	4.82				Se77m	8.38						
Se81m	1.51	1.43					Se81	4.70	4.82					
Se81	1.11	0.99					Se79m	2.12	0.96					
As77	0.58	0.58	0.20				As80	1.86						
Kr85	0.11	0.11	0.17	1.46	3.66		As78	1.46	1.61					
Se79			0.01	0.06	95.45	99.34	As74	1.18	1.35	3.90				
Kr81					0.83	0.66	Se79					98.78	99.53	

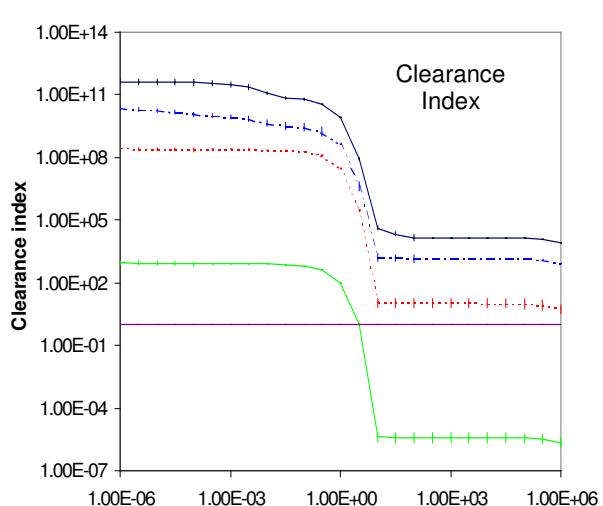
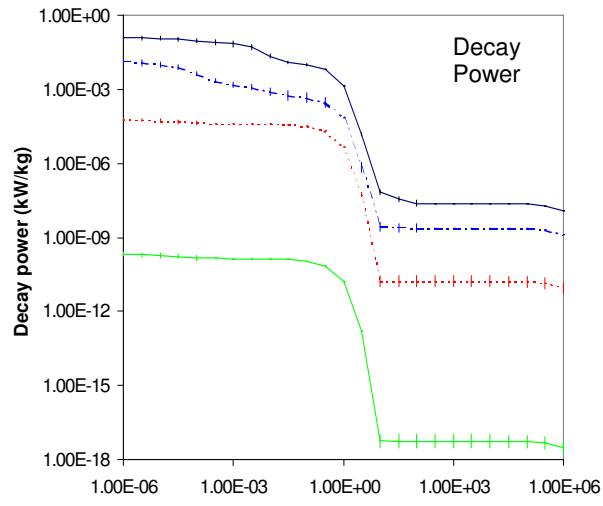
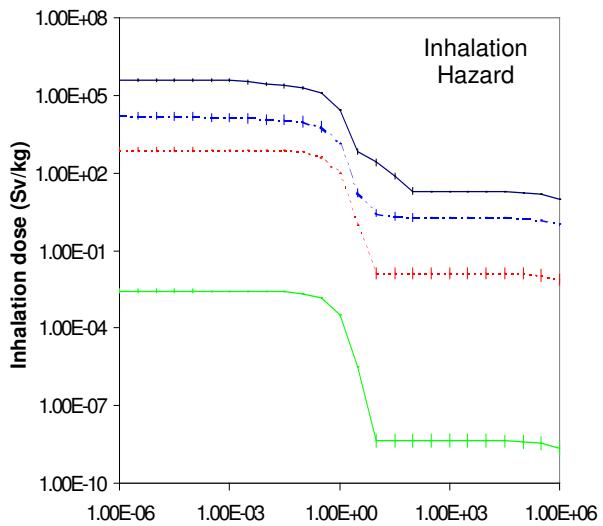
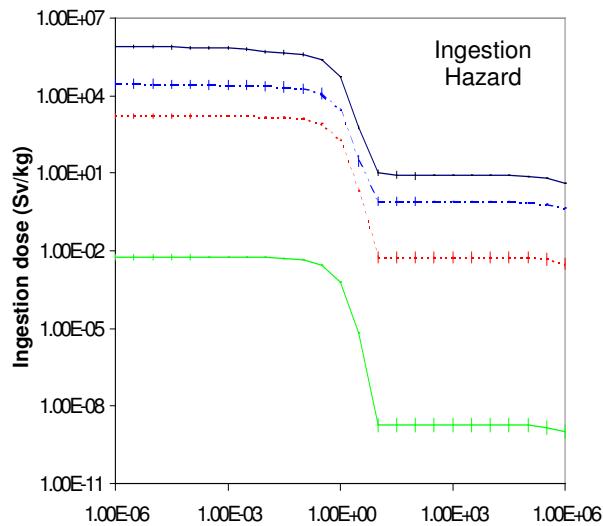
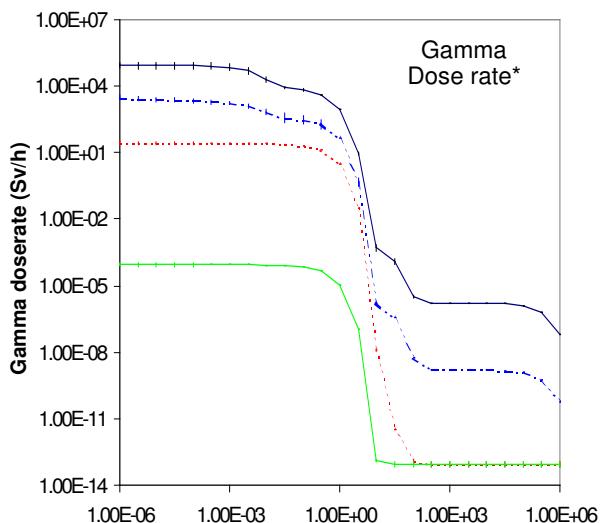
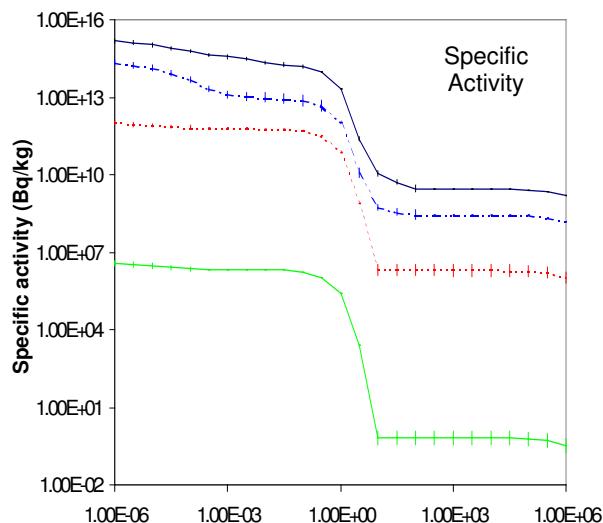
# Selenium

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV	
Se77m	17.36 s	Se74(n, $\gamma$ )Se75(n, $\gamma$ )Se76(n, $\gamma$ )Se77m Se76(n, $\gamma$ )Se77m Se74(n, $\gamma$ )Se75( $\beta^+$ )As75(n, $\gamma$ )As76( $\beta^-$ )Se76(n, $\gamma$ )Se77m Se78(n,2n)Se77m Se77(n,n')Se77m <b>&amp;Se80(n,2n)Se79(n,2n)Se78(n,2n)Se77m</b> Se78(n,2n)Se77(n,n')Se77m	41.7 39.1 19.2	100.0	100.0		81.5 9.7 3.2 1.3
Se81	18.5 m	Se80(n, $\gamma$ )Se81 Se80(n, $\gamma$ )Se81m(IT)Se81 Se78(n, $\gamma$ )Se79m(IT)Se79(n, $\gamma$ )Se80(n, $\gamma$ )Se81 <b>&amp;Se82(n,2n)Se81</b>	84.3 15.2 0.3	84.8 15.2	84.7 15.3	0.1 0.2 99.0	
As76	1.097 d	Se74(n, $\gamma$ )Se75( $\beta^+$ )As75(n, $\gamma$ )As76 Se76(n,p)As76 Se77(n,d)As76 Se77(n,2n)Se76(n,p)As76 <b>&amp;Se78(n,2n)Se77(n,d)As76</b> <b>&amp;Se78(n,2n)Se77(n,2n)Se76(n,p)As76</b>		100.0	100.0	100.0 69.3 11.8 9.6 6.1 2.4	
Br82	1.472 d	<b>&amp;Se80(n,<math>\gamma</math>)Se81(<math>\beta^-</math>)Br81(n,<math>\gamma</math>)Br82</b> <b>&amp;Se82(n,2n)Se81(<math>\beta^-</math>)Br81(n,<math>\gamma</math>)Br82</b> <b>&amp;Se82(n,<math>\gamma</math>)Se83(<math>\beta^-</math>)Br83(<math>\beta^-</math>)Kr83(n,d)Br82</b>	99.9	100.0	100.0	0.2 98.7 0.4	
As74	17.78 d	Se76(n,2n)Se75( $\beta^+$ )As75(n,2n)As74 Se74(n,p)As74 Se77(n,2n)Se76(n,2n)Se75( $\beta^+$ )As75(n,2n)As74 Se76(n,d)As75(n,2n)As74 <b>&amp;Se78(n,<math>\alpha</math>)Ge75(<math>\beta^-</math>)As75(n,2n)As74</b>				79.6 7.3 5.0 2.9 2.1	
As73	80.301 d	<b>&amp;Se74(n,2n)Se73(<math>\beta^+</math>)As73</b> Se74(n,d)As73 Se74(n,2n)Se73m( $\beta^+$ )As73 Se76(n,2n)Se75( $\beta^+$ )As75(n,2n)As74( $\beta^-$ )Se74(n,d)As73 <b>&amp;Se76(n,2n)Se75(n,2n)Se74(n,2n)Se73(<math>\beta^+</math>)As73</b>				45.4 40.3 7.9 1.2 1.3	
Se75	119.64 d	Se74(n, $\gamma$ )Se75 Se76(n,2n)Se75 Se77(n,2n)Se76(n,2n)Se75 <b>&amp;Se78(n,2n)Se77(n,2n)Se76(n,2n)Se75</b> Se77(n,d)As76( $\beta^-$ )Se76(n,2n)Se75	100.0	100.0	100.0	85.7 10.8 2.5 0.1	
Zn65	244.26 d	Se74(n,n $\alpha$ )Ge70(n,n $\alpha$ )Zn66(n,2n)Zn65 Se74(n,n $\alpha$ )Ge70(n, $\alpha$ )Zn67(n,2n)Zn66(n,2n)Zn65 Se74(n, $\alpha$ )Ge71( $\beta^+$ )Ga71(n,2n)Ga70( $\beta^-$ )Ge70(n,n $\alpha$ ) Zn66(n,2n)Zn65				90.7 2.4 2.2	

Co60	5.272 y	<b>&amp;Se74(n,nα)Ge70(n,nα)Zn66(n,2n)Zn65(n,nα)</b> <b>Ni61(n,d)Co60</b> <b>&amp;Se74(n,nα)Ge70(n,nα)Zn66(n,α)Ni63(β⁻)</b> <b>Cu63(n,α)Co60</b> <b>&amp;Se74(n,nα)Ge70(n,nα)Zn66(n,2n)Zn65(n,2n)</b> <b>Zn64(n,d)Cu63(n,α)Co60</b> <b>&amp;Se74(n,nα)Ge70(n,nα)Zn66(n,2n)Zn65(n,2n)</b> <b>Zn64(n,nα)Ni60(n,p)Co60</b> <b>&amp;Se74(n,nα)Ge70(n,α)Zn67(n,nα)Ni63(β⁻)Cu63(n,α)Co60</b> <b>&amp;Se74(n,nα)Ge70(n,nα)Zn66(n,nα)Ni62(n,2n)</b> <b>Ni61(n,d)Co60</b> <b>&amp;Se74(n,nα)Ge70(n,nα)Zn66(n,2n)Zn65(n,nα)</b> <b>Ni61(n,2n)Ni60(n,p)Co60</b> <b>&amp;Se74(n,nα)Ge70(n,nα)Zn66(n,2n)Zn65(n,2n)</b> <b>Zn64(n,2n)Zn63(β⁺)Cu63(n,α)Co60</b> <b>&amp;Se74(n,nα)Ge70(n,nα)Zn66(n,α)Ni63(n,2n)</b> <b>Ni62(n,2n)Ni61(n,d)Co60</b> <b>&amp;Se74(n,nα)Ge70(n,nα)Zn66(n,d)Cu65(n,2n)</b> <b>Cu64(β⁻)Zn64(n,d)Cu63(n,α)Co60</b> <b>&amp;Se74(n,nα)Ge70(n,nα)Zn66(n,2n)Zn65(β⁺)</b> <b>Cu65(n,nα)Co61(β⁻)Ni61(n,d)Co60</b> <i>*Plus many other similar pathways</i>				33.0 10.7 10.5 4.8 3.8 3.7 3.0 2.9 1.1 1.1 1.0 24.4*
Kr85	10.73 y	<b>&amp;Se80(n,γ)Se81(β⁻)Br81(n,γ)Br82(β⁻)Kr82(n,γ)</b> <b>Kr83(n,γ)Kr84(n,γ)Kr85</b> <b>&amp;Se82(n,γ)Se83m(β⁻)Br83(β⁻)Kr83(n,γ)Kr84(n,γ)Kr85</b> <b>&amp;Se82(n,γ)Se83(β⁻)Br83(β⁻)Kr83(n,γ)Kr84(n,γ)Kr85</b> <b>&amp;Se80(n,γ)Se81(β⁻)Br81(n,γ)Br82m(β⁻)Kr82(n,γ)</b> <b>Kr83(n,γ)Kr84(n,γ)Kr85</b> <b>&amp;Se80(n,γ)Se81(β⁻)Br81(n,γ)Br82(n,γ)Br83(β⁻)</b> <b>Kr83(n,γ)Kr84(n,γ)Kr85</b>	54.8 38.1 5.7 1.0 0.2	11.7 63.2 9.4 13.0 15.2		24.5 75.3
H3	12.33 y	<b>Se77(n,X)H1(n,γ)H2(n,γ)H3</b> <b>&amp;Se76(n,γ)Se77(n,X)H1(n,γ)H2(n,γ)H3</b> <b>&amp;Se74(n,γ)Se75(n,γ)Se76(n,γ)Se77(n,X)H1(n,γ)</b> <b>H2(n,γ)H3</b> <b>Se74(n,γ)Se75(n,X)H1(n,γ)H2(n,γ)H3</b> <b>Se77(n,X)H3</b> <b>&amp;Se80(n,2n)Se79(n,X)H3</b> <b>&amp;Se78(n,2n)Se77(n,X)H3</b> <b>Se80(n,X)H3</b> <b>Se78(n,X)H3</b> <b>Se76(n,X)H3</b> <b>&amp;Se82(n,2n)Se81(β⁻)Br81(n,X)H3</b> <b>Se76(n,2n)Se75(β⁺)As75(n,X)H3</b> <b>Se76(n,2n)Se75(n,X)H3</b>	49.7 41.5 1.3 0.5	90.4 4.8 0.6 0.1		36.1 26.9 9.4 7.3 5.7 3.8 3.3 2.5 1.7
Kr81	$2.1 \cdot 10^5$ y	<b>&amp;Se78(n,γ)Se79m(β⁻)Br79(n,γ)Br80(β⁻)Kr80(n,γ)Kr81</b> <b>&amp;Se77(n,γ)Se78(n,γ)Se79m(β⁻)Br79(n,γ)Br80(β⁻)</b> <b>Kr80(n,γ)Kr81</b> <b>&amp;Se76(n,γ)Se77(n,γ)Se78(n,γ)Se79m(β⁻)Br79(n,γ)</b> <b>Br80(β⁻)Kr80(n,γ)Kr81</b> <b>&amp;Se82(n,2n)Se81(β⁻)Br81(n,2n)Br80(β⁻)Kr80(n,γ)Kr81</b> <b>&amp;Se82(n,2n)Se81(β⁻)Br81(n,γ)Br82(β⁻)Kr82(n,2n)Kr81</b> <b>&amp;Se82(n,γ)Se83(β⁻)Br83(β⁻)Kr83(n,2n)Kr82(n,2n)Kr81</b> <b>&amp;Se82(n,γ)Se83m(β⁻)Br83(β⁻)Kr83(n,2n)Kr82(n,2n)Kr81</b>	77.4 12.5 9.7	98.7 1.0 0.4		40.1 33.1 19.5 6.4
Se79	$6.0 \cdot 10^5$ y	<b>&amp;Se78(n,γ)Se79</b> <b>&amp;Se77(n,γ)Se78(n,γ)Se79</b> <b>&amp;Se76(n,γ)Se77(n,γ)Se78(n,γ)Se79</b> <b>Se80(n,2n)Se79</b> <b>Se80(n,2n)Se79m(IT)Se79</b> <b>Se80(n,d)As79(β⁻)Se79m(IT)Se79</b>	67.5 15.9 15.9	97.6 2.2 0.1	99.0 1.0	84.3 15.1 0.2

# Selenium activation characteristics

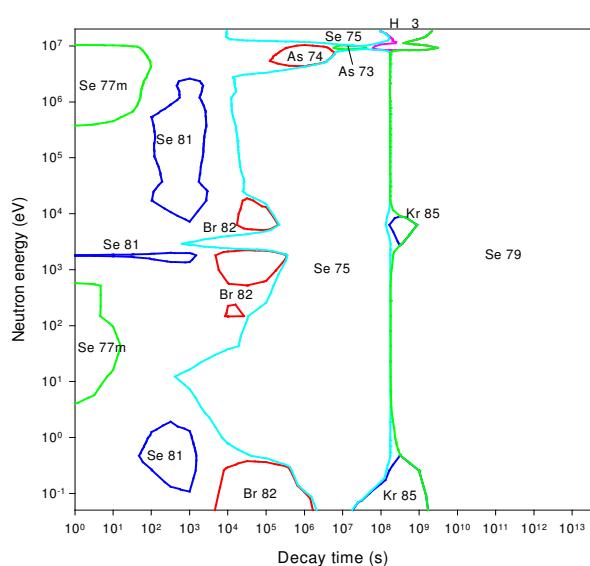


Decay time (years)

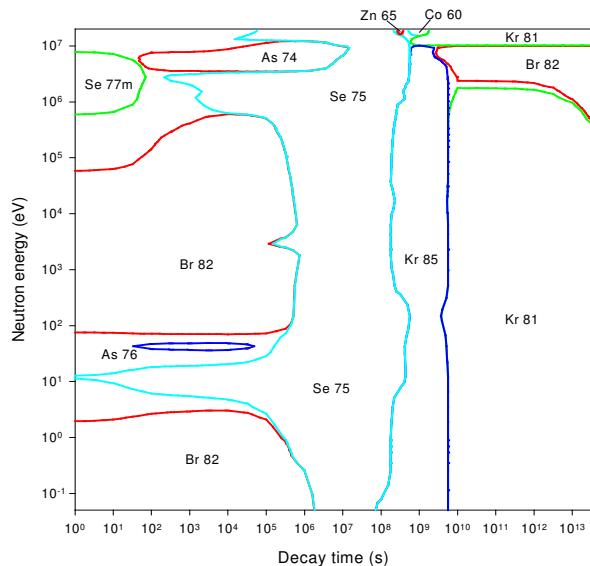
Decay time (years)

# Selenium importance diagrams & transmutation

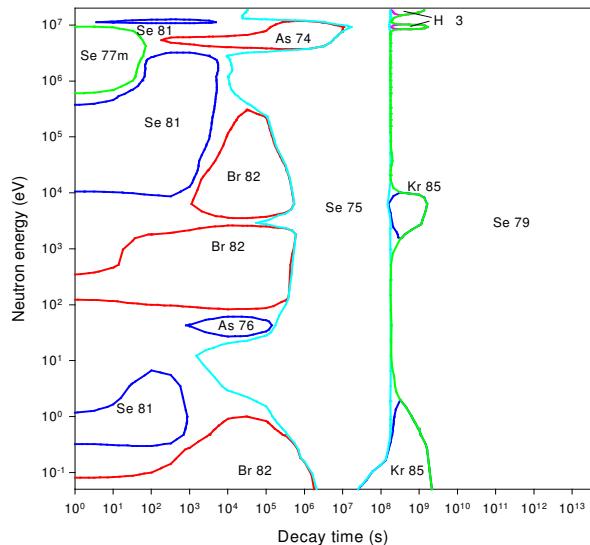
## Activity



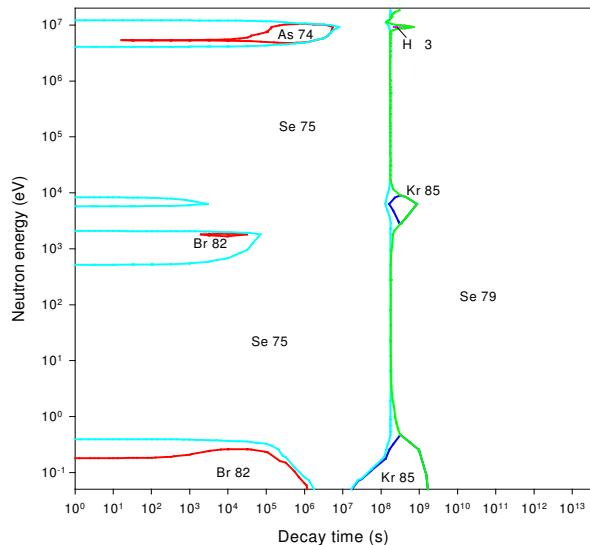
## Dose rate



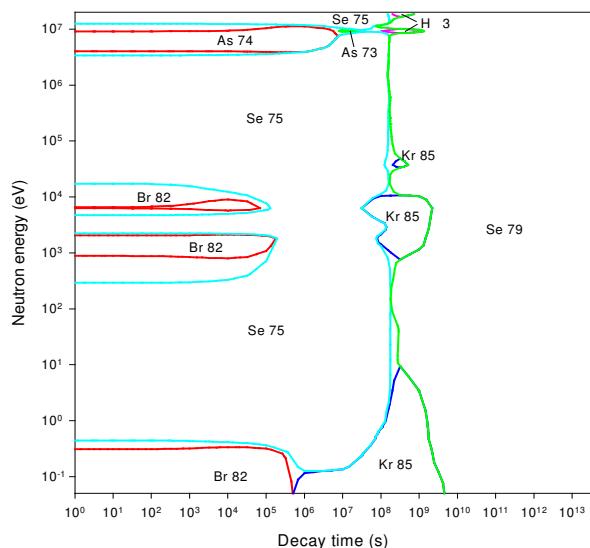
## Heat output



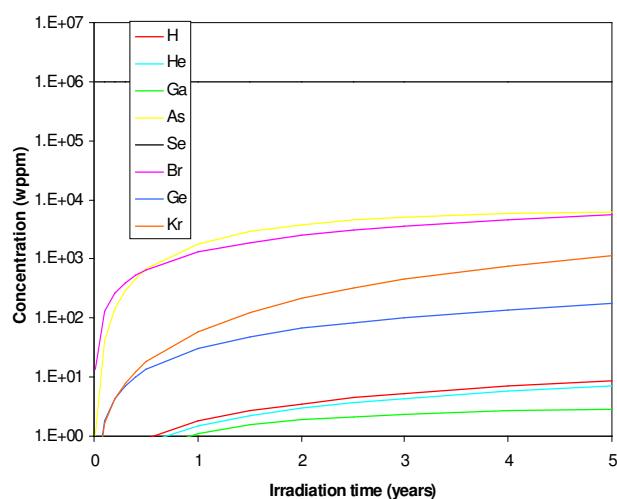
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Bromine

## General properties

Atomic number	35	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	2.4	Br79	50.69
Melting point / K	266.0	Br81	49.31
Boiling point / K	332.0		
Density / kgm <sup>-3</sup>	3120		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	1.22 10 <sup>-1</sup>		
Electrical resistivity /Ωm	-		
Coefficient of thermal expansion / K <sup>-1</sup>	-		
Crystal structure	orthorhombic		
Number of stable isotopes	2		
Mean atomic weight	79.904		

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	2.53E16	1.99E16	1.01E15	3.98E11	3.25E10	2.29E10	kW kg <sup>-1</sup>	3.77E0	3.50E0	4.37E-1	1.25E-5	8.55E-8	4.75E-8
Br80	33.75	36.95					Br82	64.40	69.35	99.71			
Br82	21.54	27.43	97.36				Br80	29.06	26.92				
Br82m	20.03	14.02					Br78	1.99	1.22				
Br80m	8.47	10.64					Br82m	1.69	1.00				
Kr83m	7.53	9.28					Kr81m	1.16					
Kr81m	5.65						Br80m	0.78	0.83				
Br79m	0.95						Kr83m	0.34	0.35				
Kr79	0.57	0.73	2.54				Kr85				93.97	22.91	
Kr85			0.03	72.82	1.49		Se75				4.98		
Se75			0.01	2.41			Kr81				0.52	75.68	98.07
H3			0.01	16.77	0.79		H3				0.49	0.27	
Kr81				7.96	97.37	99.53	Se79				0.01	1.14	1.93
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	3.97E6	3.91E6	6.73E5	5.54E-1	4.69E-3	3.19E-3	Sv kg <sup>-1</sup>	3.62E6	3.57E6	5.53E5	8.44E2	6.14E0	3.51E0
Br82	94.38	95.76	99.81				Br82	81.34	82.48	95.48			
Br80	3.73	3.25					Br80	7.32	6.38				
Br78	1.23	0.71					Br80m	6.52	6.52				
Kr81m	0.23						Kr79	3.60	3.64	4.15			
Se75				70.43			Kr85	0.02	0.02	0.16	96.14	22.07	
Kr85				27.84*	5.49*		Se75	0.01	0.01	0.04	2.96		
Kr81				0.80	94.51	100.00	Kr81				0.53	72.28	90.99
Rb84				0.79			Se79				0.04	5.47	9.01
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	3.99E6	3.96E6	7.31E5	7.58E4	5.70E2	3.20E2		1.63E13	1.57E13	2.58E12	1.18E7	2.57E5	1.76E5
Br82	86.18	86.62	84.33				Br82	87.90	91.06	99.73			
Kr79	4.72	4.74	4.54				Br80	7.81	6.96				
Br80m	4.09	4.06					Br78	1.58	0.93				
Kr85	2.02	2.03	10.99	99.38	22.06		Kr81m	1.20					
Br80	2.02	1.74					Kr85				66.31	5.08	
Kr83m	0.48	0.47					Se75				31.25		
Kr81	0.01	0.01	0.06	0.59	77.79	99.77	Kr81				2.06	94.65	99.68

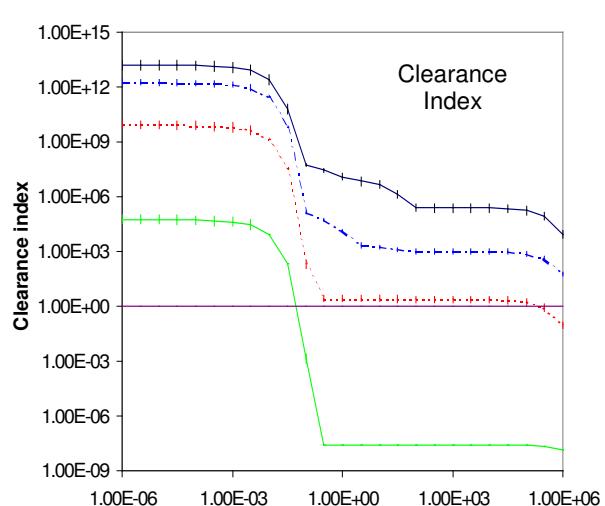
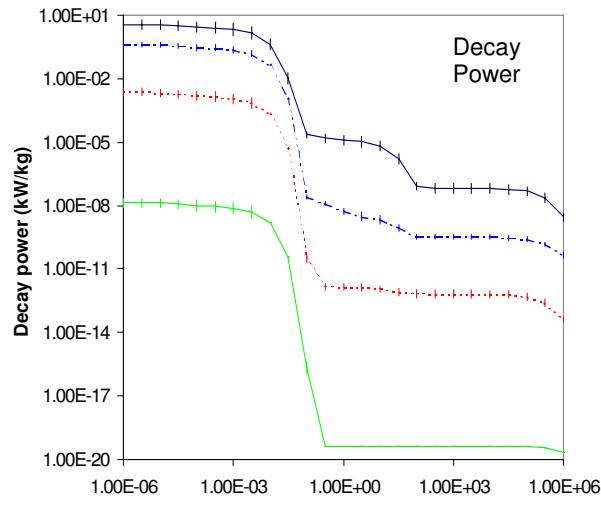
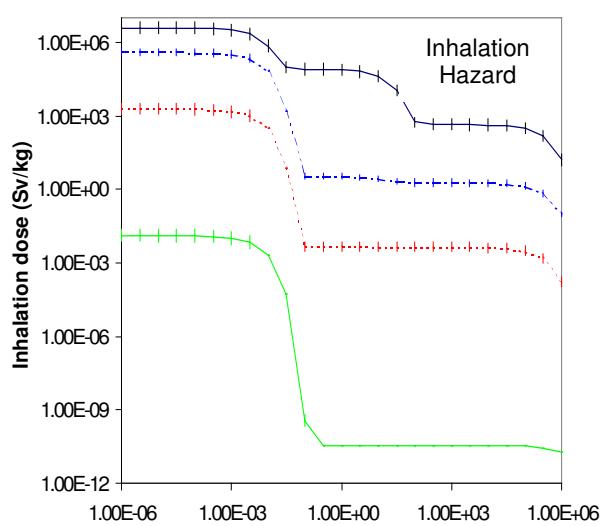
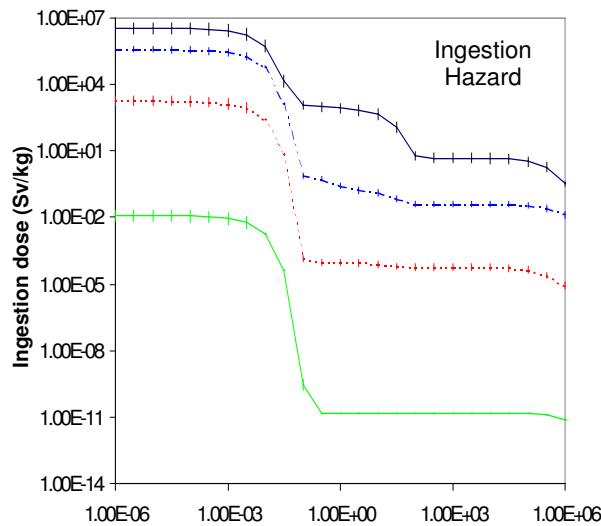
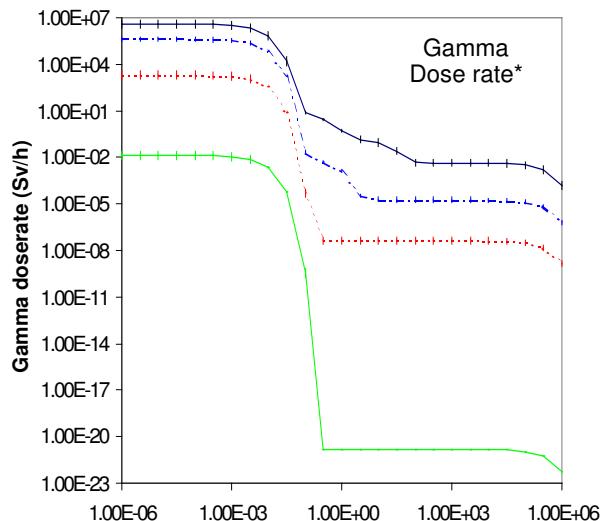
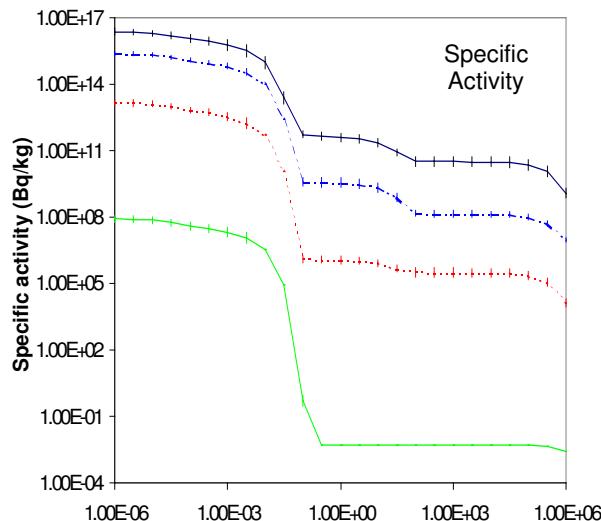
# Bromine

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Br79m	4.88 s	Br79(n,n')Br79m <b>&amp;Br81(n,2n)Br80(<math>\beta^-</math>)Kr80(n,d)Br79m</b> <b>&amp;Br81(n,2n)Br80(<math>\beta^-</math>)Kr80(n,2n)Kr79(<math>\beta^+</math>)Br79(n,n')Br79m</b>				95.0 3.7 1.1
Br78	6.46 m	Br79(n,2n)Br78 <b>&amp;Br81(n,2n)Br80(<math>\beta^-</math>)Kr80(n,2n)Kr79(<math>\beta^+</math>)Br79(n,2n)Br78</b>				98.7 1.1
Br80	17.6 m	Br79(n, $\gamma$ )Br80 Br79(n, $\gamma$ )Br80m(IT)Br80 <b>&amp;Br81(n,2n)Br80</b>	76.3 23.7	76.8 23.2	76.7 23.3	100.0
Se81	18.5 m	<b>&amp;Br79(n,<math>\gamma</math>)Br80(<math>\beta^+</math>)Se80(n,<math>\gamma</math>)Se81</b> <b>&amp;Br81(n,p)Se81</b>	99.3	96.4	96.4	100.0
Br80m	4.41 h	Br79(n, $\gamma$ )Br80m Br81(n,2n)Br80m	100.0	100.0	100.0	99.1
As76	1.097 d	Br79(n, $\alpha$ )As76 <b>&amp;Br79(n,2n)Br78(<math>\beta^+</math>)Se78(n,2n)Se77(n,d)As76</b> <b>&amp;Br81(n,2n)Br80(<math>\beta^-</math>)Kr80(n,2n)Kr79(<math>\beta^+</math>)Br79(n,<math>\alpha</math>)As76</b>	100.0	100.0	100.0	96.2 1.1 1.1
Kr79	1.46 d	<b>&amp;Br81(n,2n)Br80(<math>\beta^-</math>)Kr80(n,2n)Kr79</b>				99.7
Br82	1.472 d	Br81(n, $\gamma$ )Br82m(IT)Br82 Br81(n, $\gamma$ )Br82 <b>&amp;Br79(n,<math>\gamma</math>)Br80(<math>\beta^+</math>)Se80(n,<math>\gamma</math>)Se81(<math>\beta^-</math>)Br81(n,<math>\gamma</math>)Br82</b>	90.6 9.3 0.1	89.3 9.2 1.3	90.6 9.4	47.4 51.7
As74	17.78 d	Br79(n,n $\alpha$ )As75(n,2n)As74 Br79(n, $\alpha$ )As76( $\beta^-$ )Se76(n,2n)Se75( $\beta^+$ )As75(n,2n)As74 <b>&amp;Br79(n,2n)Br78(<math>\beta^+</math>)Se78(n,<math>\alpha</math>)Ge75(<math>\beta^-</math>)As75(n,2n)As74</b> <b>&amp;Br79(n,2n)Br78(<math>\beta^+</math>)Se78(n,2n)Se77(n,2n)Se76(n,2n)</b> Se75( $\beta^+$ )As75(n,2n)As74 <b>&amp;Br79(n,d)Se78(n,<math>\alpha</math>)Ge75(<math>\beta^-</math>)As75(n,2n)As74</b>				60.8 16.9 15.3 2.6 2.0
Rb86	18.63 d	<b>&amp;Br81(n,<math>\gamma</math>)Br82(<math>\beta^-</math>)Kr82(n,<math>\gamma</math>)Kr83(n,<math>\gamma</math>)Kr84(n,<math>\gamma</math>)</b> Kr85m( $\beta^-$ )Rb85(n, $\gamma$ )Rb86 <b>&amp;Br79(n,<math>\gamma</math>)Br80(<math>\beta^-</math>)Kr80(n,<math>\gamma</math>)Kr81(n,<math>\gamma</math>)Kr82(n,<math>\gamma</math>)</b> Kr83(n, $\gamma$ )Kr84(n, $\gamma$ )Kr85m( $\beta^-$ )Rb85(n, $\gamma$ )Rb86 <b>&amp;Br81(n,<math>\gamma</math>)Br82(<math>\beta^-</math>)Kr82(n,<math>\gamma</math>)Kr83(n,<math>\gamma</math>)Kr84(n,<math>\gamma</math>)</b> Kr85( $\beta^-$ )Rb85(n, $\gamma$ )Rb86 <b>&amp;Br81(n,<math>\gamma</math>)Br82m(<math>\beta^-</math>)Kr82(n,<math>\gamma</math>)Kr83(n,<math>\gamma</math>)Kr84(n,<math>\gamma</math>)</b> Kr85m( $\beta^-$ )Rb85(n, $\gamma$ )Rb86 <b>&amp;Br81(n,<math>\gamma</math>)Br82(n,<math>\gamma</math>)Br83(<math>\beta^-</math>)Kr83(n,<math>\gamma</math>)Kr84(n,<math>\gamma</math>)</b> Kr85m( $\beta^-$ )Rb85(n, $\gamma$ )Rb86 <b>&amp;Br81(n,<math>\gamma</math>)Br82(n,<math>\gamma</math>)Br83(<math>\beta^-</math>)Kr83(n,<math>\gamma</math>)Kr84(n,<math>\gamma</math>)</b> Kr85( $\beta^-$ )Rb85(n, $\gamma$ )Rb86	82.5 11.6 2.9 1.8 0.3	47.5 1.4 2.7 0.9 47.3 2.1	92.8	78.3 18.4 2.0 2.2
Se75	119.64 d	Br79(n, $\alpha$ )As76( $\beta^-$ )Se76(n,2n)Se75 <b>&amp;Br79(n,2n)Br78(<math>\beta^+</math>)Se78(n,2n)Se77(n,2n)Se76(n,2n)Se75</b> <b>&amp;Br79(n,d)Se78(n,2n)Se77(n,2n)Se76(n,2n)Se75</b> <b>&amp;Br81(n,2n)Br80(<math>\beta^-</math>)Kr80(n,n<math>\alpha</math>)Se76(n,2n)Se75</b>				71.1 21.9 2.8 2.8
Kr85	10.73 y	<b>&amp;Br81(n,<math>\gamma</math>)Br82(<math>\beta^-</math>)Kr82(n,<math>\gamma</math>)Kr83(n,<math>\gamma</math>)Kr84(n,<math>\gamma</math>)Kr85</b> <b>&amp;Br79(n,<math>\gamma</math>)Br80(<math>\beta^-</math>)Kr80(n,<math>\gamma</math>)Kr81(n,<math>\gamma</math>)Kr82(n,<math>\gamma</math>)</b> Kr83(n, $\gamma$ )Kr84(n, $\gamma$ )Kr85 <b>&amp;Br81(n,<math>\gamma</math>)Br82m(<math>\beta^-</math>)Kr82(n,<math>\gamma</math>)Kr83(n,<math>\gamma</math>)Kr84(n,<math>\gamma</math>)Kr85</b> <b>&amp;Br81(n,<math>\gamma</math>)Br82(n,<math>\gamma</math>)Br83(<math>\beta^-</math>)Kr83(n,<math>\gamma</math>)Kr84(n,<math>\gamma</math>)Kr85</b>	85.1 12.8 1.9 0.2	50.5 1.1 2.0 48.4	95.9	98.6 1.0 0.4
H3	12.33 y	Br79(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 <b>&amp;Br79(n,<math>\gamma</math>)Br80(<math>\beta^-</math>)Kr80(n,<math>\gamma</math>)Kr81(n,X)H1(n,<math>\gamma</math>)</b> H2(n, $\gamma$ )H3 Br79(n,X)H3 Br81(n,X)H3 <b>&amp;Br81(n,2n)Br80(<math>\beta^-</math>)Kr80(n,X)H3</b>	92.1 1.0	95.1	99.5	60.9 37.5 0.3



# Bromine activation characteristics

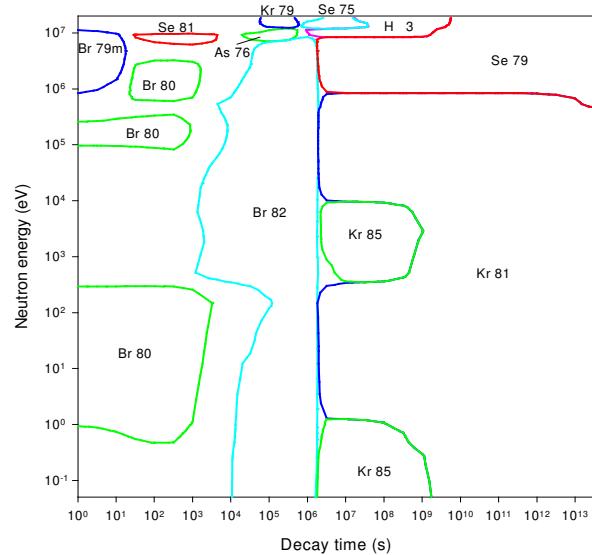


Decay time (years)

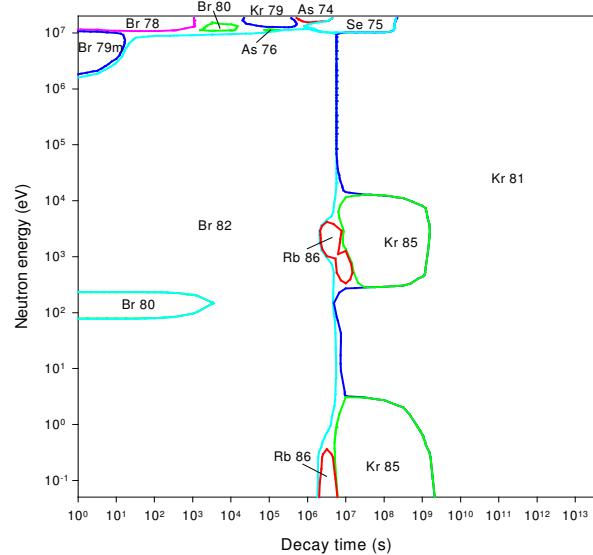
Decay time (years)

# Bromine importance diagrams & transmutation

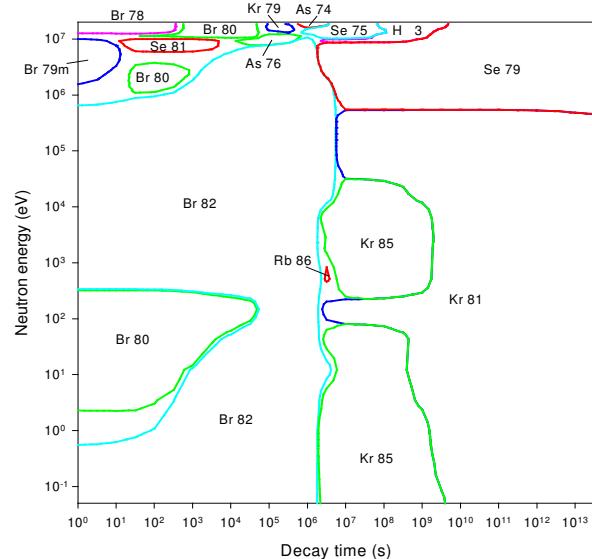
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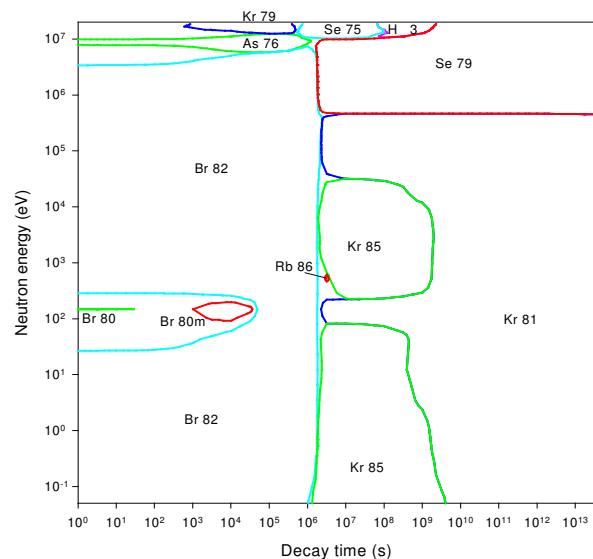
## Dose rate



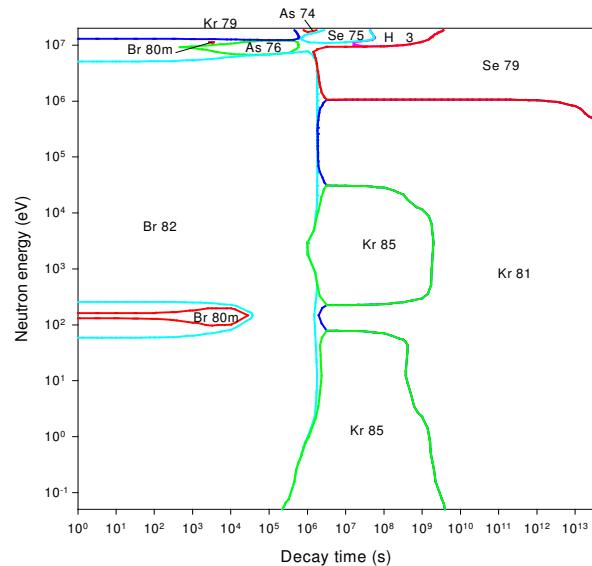
## Heat output



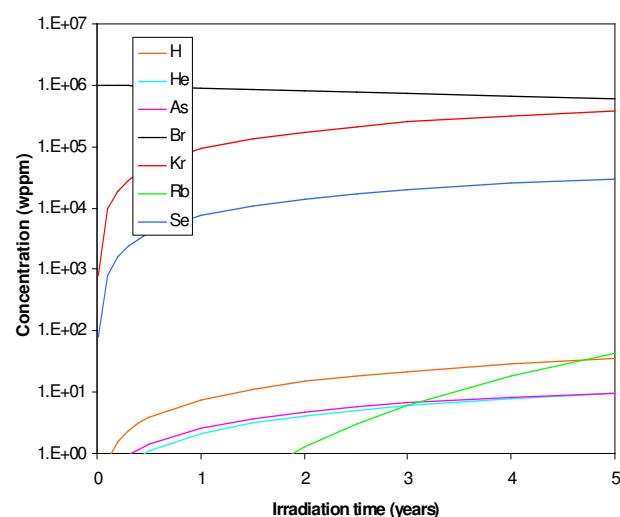
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Krypton

## General properties

		36	Isotopes	Isotopic abundances / %	
Atomic number				Kr78	0.35
Crustal abundance / wppm	1.0 10 <sup>-5</sup>		Kr80	2.25	
Melting point / K	116.6		Kr82	11.60	
Boiling point / K	120.8		Kr83	11.50	
Density / kgm <sup>-3</sup>	3.749		Kr84	57.00	
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	9.49 10 <sup>-3</sup>		Kr86	17.30	
Electrical resistivity /Ωm	-				
Coefficient of thermal expansion / K <sup>-1</sup>	-				
Crystal structure	FCC				
Number of stable isotopes	6				
Mean atomic weight	83.80				

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	2.63E15	2.42E15	2.05E14	1.41E14	2.42E11	4.35E9	kW kg <sup>-1</sup>	9.51E-2	8.69E-2	1.30E-2	5.73E-3	9.57E-6	8.88E-9
Kr83m	50.96	53.47	0.01				Kr85m	59.67	64.45				
Kr85m	32.66	34.95					Kr83m	9.42	9.98				
Kr85	5.74	6.23	73.54	99.95	97.47		Kr85	6.43	7.03	47.02	99.94	99.87	
Kr81m	4.90						Rb86	4.86	5.32	31.09			
Rb86	1.44	1.56	16.13				Kr81m	4.13					
Kr79	1.19	1.29	2.70				Rb84	2.58	2.83	17.55	0.02		
Br80	0.69	0.64					Br80	2.45	2.30				
Rb84	0.57	0.61	6.73	0.01			Br84m	1.72	1.02				
Rb84m	0.26	0.24					Kr79	1.49	1.63	1.93			
Br80m	0.17	0.18					Br82	1.37	1.50	1.80			
Br83	0.16	0.17					Br84	1.23	1.20				
Br82	0.11	0.12	0.26				Br86	1.06					
Br77	0.09	0.09	0.38				Kr87	0.90	0.94				
Kr81					2.50	99.99	Kr81					0.13	99.96
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	2.72E4	2.29E4	4.87E3	7.90E1	1.27E-1	5.96E-4	Sv kg <sup>-1</sup>	7.59E5	7.56E5	5.59E5	3.96E5	6.62E2	6.10E-1
Kr85m	38.71	45.26					Kr85	55.64	55.84	75.47	99.98	99.87	
Rb84	12.43	14.73	64.31	2.23			Kr85m	19.23	19.03				
Br84m	8.21	5.30					Rb86	13.97	14.02	16.55			
Br82	7.50	8.88	7.50				Rb84	5.49	5.51	6.91	0.01		
Kr79	5.69	6.73	5.60				Kr79	3.72	3.73	0.89			
Br84	5.32	5.63					Kr83m	1.27	1.23				
Br86	4.56	0.10					Br82	0.21	0.21	0.05			
Rb86	3.93	4.65	19.13				Kr87	0.09	0.08				
Kr81m	2.94						Se75	0.06	0.06	0.08	0.01		
Kr87	2.16	2.44					Sr85	0.02	0.02	0.03			
Rb86m	1.95	0.06					Kr81					0.13	99.81
Rb84m	1.48	1.47											
Br78	1.17	0.79											
Br80	1.17	1.19											
Kr85	0.30	0.35*	1.66*	95.74*	99.35*								
Se75			0.14	1.08									
Kr81					0.65	100.0							

Inh	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>	Clear	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>
Sv kg <sup>-1</sup>	3.95E7	3.95E7	3.92E7	3.68E7	6.14E4	6.09E1		2.54E11	2.21E11	2.54E10	3.84E9	6.42E6	3.34E4
Kr85	99.18	99.19	99.87	100.00	99.86		Kr85m	61.35	69.65				
Kr85m	0.54	0.54					Kr81m	6.93					
Kr79	0.10	0.10	0.02				Rb84	5.32	6.12	49.45	0.18		
Rb86	0.09	0.09	0.08				Kr83m	3.29	3.66				
Kr81				0.14	100.00		Kr79	3.24	3.73	5.75			
							Br84m	3.11	1.95				
							Br82	3.02	3.47	5.43			
							Rb86	2.44	2.81	21.37			
							Br84	1.90	1.95				
							Br86	1.66					
							Kr85	1.60	1.84	16.07	99.51	99.28	
							Br80	1.06	1.05				
							Rb84m	1.04	1.00				
							Rb86m	1.02					
							Br77	0.29	0.33	1.00			
							Kr81					0.72	99.99

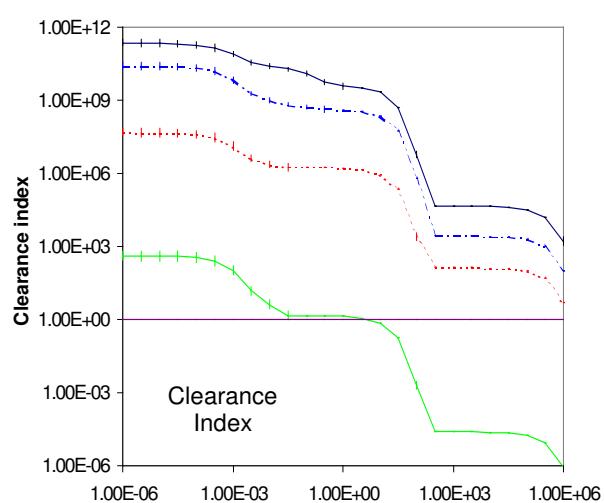
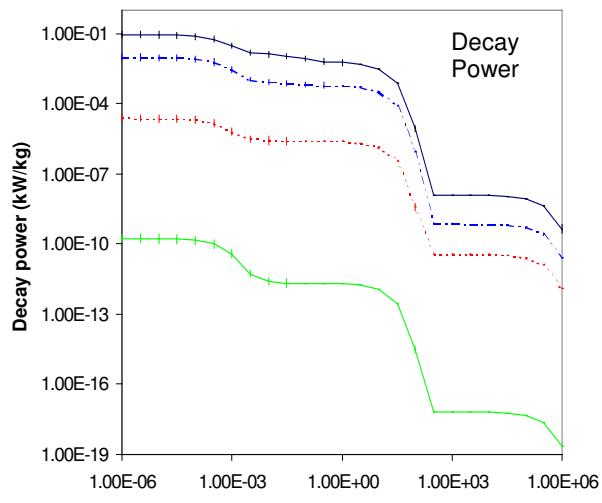
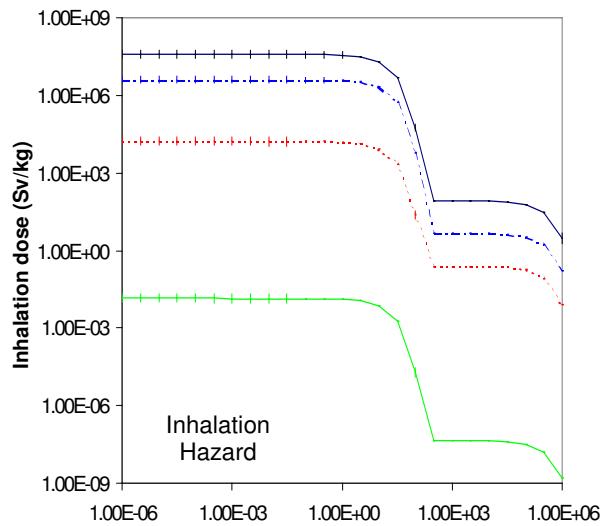
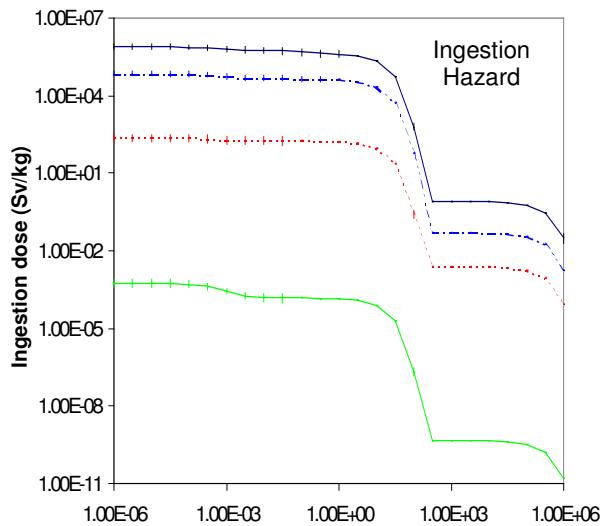
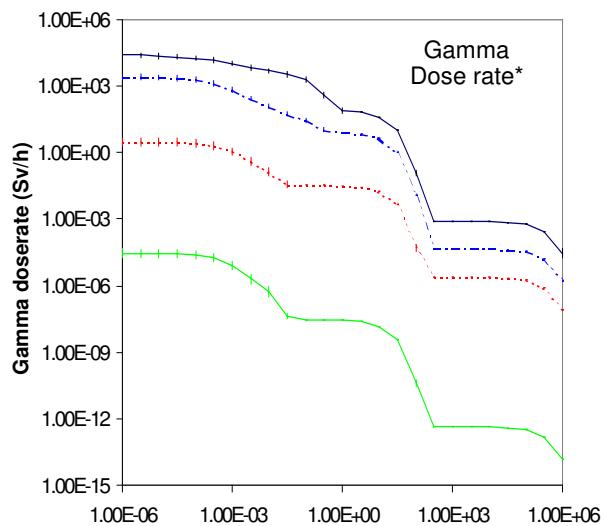
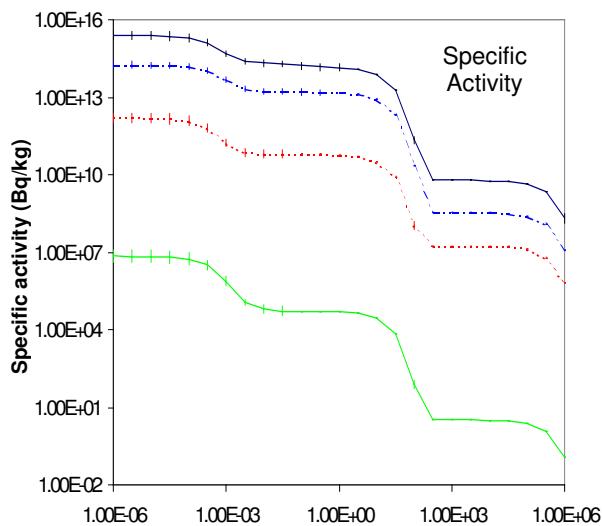
# Krypton

## Pathway analysis

Nuclide	T <sub>½</sub>	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Br78	6.46 m	Kr78(n,p)Br78 <b>&amp;Kr80(n,2n)Kr79(β<sup>+</sup>)Br79(n,2n)Br78</b> <b>&amp;Kr80(n,d)Br79(n,2n)Br78</b> <b>&amp;Kr82(n,2n)Kr81(n,2n)Kr80(n,2n)Kr79(β<sup>+</sup>)Br79(n,2n)Br78</b>	100.0	100.0	100.0	19.8 67.0 10.3 2.1
Kr87	1.272 h	Kr86(n,γ)Kr87	100.0	100.0	100.0	99.6
Kr83m	1.83 h	Kr82(n,γ)Kr83m <b>&amp;Kr80(n,γ)Kr81(n,γ)Kr82(n,γ)Kr83m</b> Kr84(n,2n)Kr83m Kr83(n,n')Kr83m Kr84(n,d)Br83(β <sup>-</sup> )Kr83m Kr84(n,2n)Kr83(n,n')Kr83m Kr83(n,p)Br83(β <sup>-</sup> )Kr83m	87.1 12.9	99.4 0.6	100.0	91.8 1.7 1.6 1.4 1.0
Kr85m	4.48 h	Kr84(n,γ)Kr85m Kr83(n,γ)Kr84(n,γ)Kr85m <b>&amp;Kr82(n,γ)Kr83(n,γ)Kr84(n,γ)Kr85m</b> Kr86(n,2n)Kr85m Kr86(n,2n)Kr85(n,n')Kr85m	73.7 14.9 11.2	99.9	99.1 0.9	0.2 96.7 1.8
Kr79	1.46 d	Kr78(n,γ)Kr79 Kr78(n,γ)Kr79m(IT)Kr79 <b>&amp;Kr80(n,2n)Kr79</b> <b>&amp;Kr82(n,2n)Kr81(n,2n)Kr80(n,2n)Kr79</b>	97.2 2.8	97.2 2.8	97.1 2.9	90.2 8.6
Br82	1.472 d	<b>&amp;Kr78(n,γ)Kr79(β<sup>+</sup>)Br79(n,γ)Br80(β<sup>+</sup>)Se80(n,γ)</b> <i>Se81(β<sup>-</sup>)Br81(n,γ)Br82</i> <b>&amp;Kr80(n,γ)Kr81m(β<sup>+</sup>)Br81(n,γ)Br82</b> <b>&amp;Kr80(n,γ)Kr81(β<sup>+</sup>)Br81(n,γ)Br82</b> <b>&amp;Kr82(n,p)Br82</b> <b>&amp;Kr84(n,2n)Kr83(n,d)Br82</b> <b>&amp;Kr83(n,d)Br82</b> <b>&amp;Kr83(n,2n)Kr82(n,p)Br82</b> <b>&amp;Kr84(n,2n)Kr83(n,2n)Kr82(n,p)Br82</b> <b>&amp;Kr84(n,t)Br82</b>	68.5 19.4 12.1	7.0 53.5 46.1	45.7 18.9 17.4 10.0 5.4 0.9	
Rb86	18.63 d	<b>&amp;Kr84(n,γ)Kr85m(β<sup>-</sup>)Rb85(n,γ)Rb86</b> <b>&amp;Kr83(n,γ)Kr84(n,γ)Kr85m(β<sup>-</sup>)Rb85(n,γ)Rb86</b> <b>&amp;Kr82(n,γ)Kr83(n,γ)Kr84(n,γ)Kr85m(β<sup>-</sup>)Rb85(n,γ)Rb86</b> <b>&amp;Kr84(n,γ)Kr85(β<sup>-</sup>)Rb85(n,γ)Rb86</b> <b>&amp;Kr86(n,γ)Kr87(β<sup>-</sup>)Rb87(n,2n)Rb86</b> <b>&amp;Kr86(n,2n)Kr85m(β<sup>-</sup>)Rb85(n,γ)Rb86</b> <b>&amp;Kr86(n,2n)Kr85(β<sup>-</sup>)Rb85(n,γ)Rb86</b>	74.1 13.7 5.8 5.6	93.6 0.2 6.4 6.6	77.8 12.1 9.4	
Rb84	33.5 d	<b>&amp;Kr86(n,2n)Kr85m(β<sup>-</sup>)Rb85(n,2n)Rb84</b> <b>&amp;Kr86(n,2n)Kr85(β<sup>-</sup>)Rb85(n,2n)Rb84</b> <b>&amp;Kr86(n,2n)Kr85(n,n')Kr85m(β<sup>-</sup>)Rb85(n,2n)Rb84</b>				56.0 42.7 0.5
Se75	119.64 d	Kr78(n,α)Se75 Kr80(n,nα)Se76(n,2n)Se75 <b>&amp;Kr78(n,d)Br77(β<sup>+</sup>)Se77(n,2n)Se76(n,2n)Se75</b> Kr78(n,2n)Kr77(β <sup>+</sup> )Br77(β <sup>+</sup> )Se77(n,2n)Se76(n,2n)Se75 <b>&amp;Kr80(n,2n)Kr79(β<sup>+</sup>)Br79(n,α)As76(β<sup>-</sup>)Se76(n,2n)Se75</b>	99.2	99.9	99.8	73.6 8.9 8.8 6.2 1.0
Kr85	10.73 y	Kr84(n,γ)Kr85 Kr84(n,γ)Kr85m(IT)Kr85 <b>&amp;Kr83(n,γ)Kr84(n,γ)Kr85</b> <b>&amp;Kr82(n,γ)Kr83(n,γ)Kr84(n,γ)Kr85</b> <b>&amp;Kr86(n,2n)Kr85</b>	40.0 38.0 14.8 7.2	51.3 48.7 48.3 0.5	51.2 48.3 0.5	0.2 99.7

Kr81	$2.1 \cdot 10^5$ y	$\text{Kr80}(n,\gamma)\text{Kr81}$ $\text{Kr80}(n,\gamma)\text{Kr81m(IT)}\text{Kr81}$ <b>&amp;Kr82(n,2n)Kr81</b> <b>&amp;Kr83(n,2n)Kr82(n,2n)Kr81</b> <b>&amp;Kr84(n,2n)Kr83(n,2n)Kr82(n,2n)Kr81</b>	59.8 39.3	60.3 39.7	60.4 39.6	86.7 9.6 3.4
Se79	$6.0 \cdot 10^5$ y	<b>&amp;Kr82(n,<math>\alpha</math>)Se79</b> <b>&amp;Kr80(n,<math>\gamma</math>)Kr81(n,<math>\gamma</math>)Kr82(n,<math>\alpha</math>)Se79</b> <b>&amp;Kr83(n,<math>\alpha</math>)Se80(n,2n)Se79</b> <b>&amp;Kr80(n,2n)Kr79(<math>\beta^+</math>)Br79(n,p)Se79</b> <b>&amp;Kr84(n,2n)Kr83(n,<math>\alpha</math>)Se80(n,2n)Se79</b> <b>&amp;Kr83(n,2n)Kr82(n,<math>\alpha</math>)Se79</b> <b>&amp;Kr80(n,d)Br79(n,p)Se79</b> <b>&amp;Kr84(n,2n)Kr83(n,2n)Kr82(n,<math>\alpha</math>)Se79</b> <b>&amp;Kr80(n,p)Br80(<math>\beta^+</math>)Se80(n,2n)Se79</b>	95.2 3.6	99.7	99.9	38.9  24.3 15.3 8.7 4.3 2.4 1.5 1.1

# Krypton activation characteristics

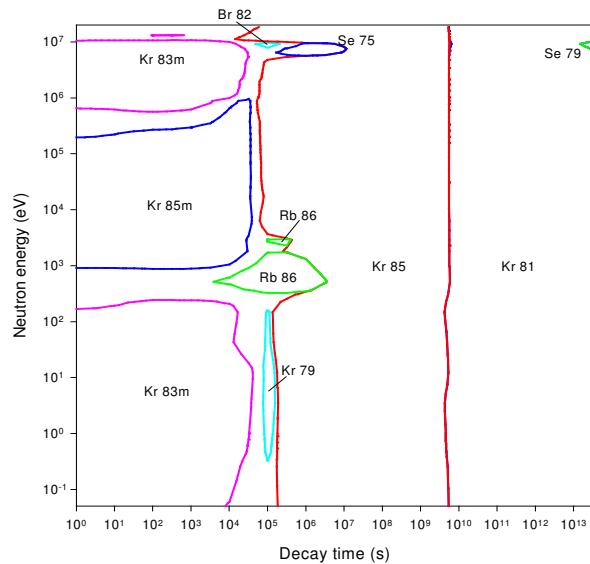


Decay time (years)

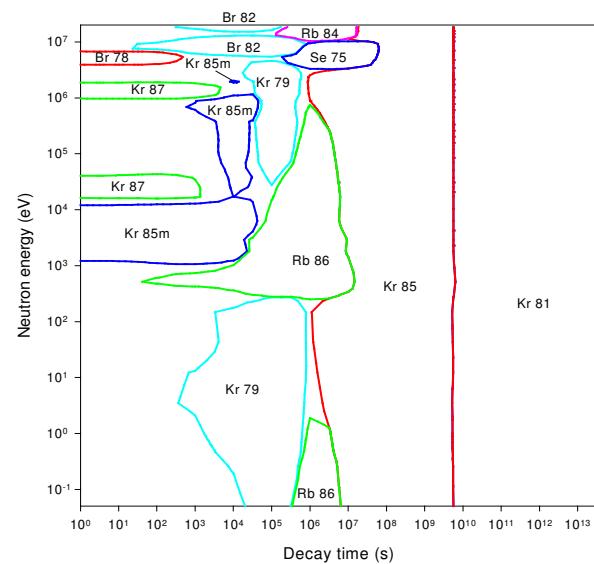
Decay time (years)

# Krypton importance diagrams & transmutation

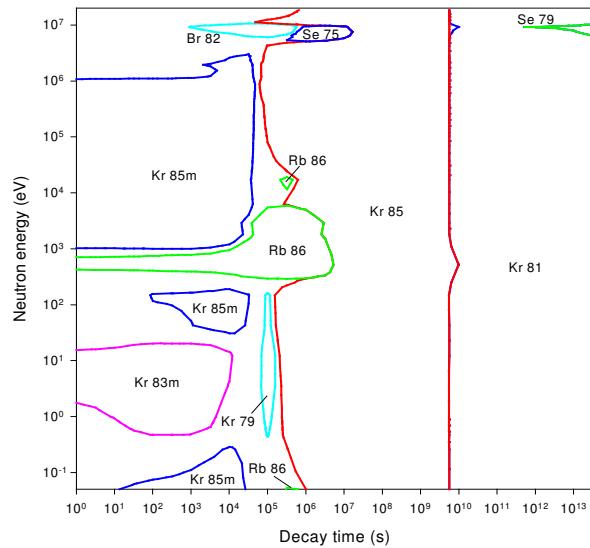
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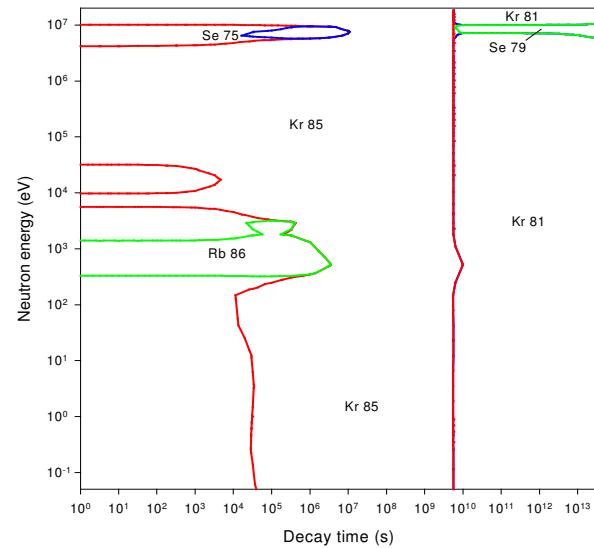
## Dose rate



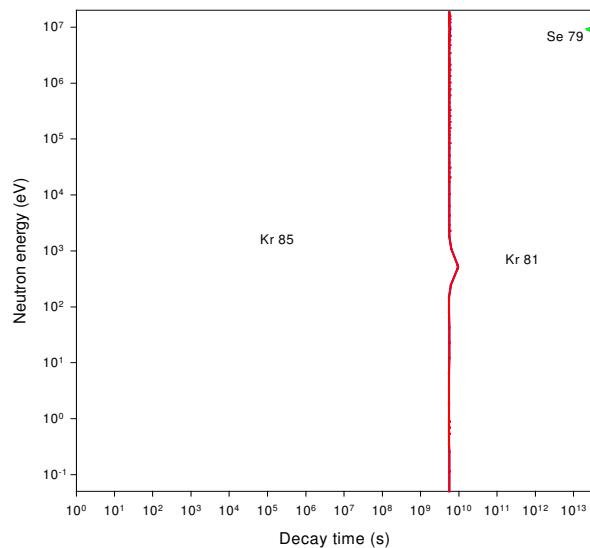
## Heat output



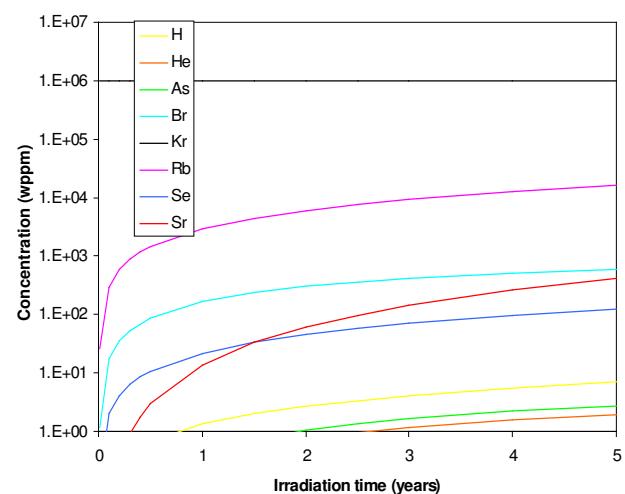
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Rubidium

## General properties

Atomic number	37	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	90	Rb85	72.17
Melting point / K	312.5	Rb87	27.83 ( $T_{1/2} = 4.7966 \cdot 10^{10}$ y)
Boiling point / K	961		
Density / kgm <sup>-3</sup>	1532		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	58.2		
Electrical resistivity / Ωm	$1.25 \cdot 10^{-7}$		
Coefficient of thermal expansion / K <sup>-1</sup>	$9.0 \cdot 10^{-5}$		
Crystal structure	BCC		
Number of stable isotopes	1(2)		
Mean atomic weight	85.4678		

## Activation properties

Act	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Heat	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y
Bq kg <sup>-1</sup>	3.51E15	3.11E15	2.31E15	6.83E12	9.65E9	1.37E6	kW kg <sup>-1</sup>	4.80E-1	4.34E-1	3.06E-1	3.48E-4	3.82E-7	1.19E-11
Rb86	54.73	61.83	72.55	0.04			Rb86	48.87	54.11	66.90	0.08		
Rb84	18.19	20.55	25.61	4.88			Rb84	21.97	24.32	31.95	15.81		
Rb86m	9.37	0.29					Rb88	15.98	14.42				
Rb84m	8.18	7.73					Rb86m	6.10	0.19				
Rb88	5.06	4.66					Rb84m	4.44	4.11				
Sr87m	1.64	1.81					Sr87m	0.74	0.80				
Sr85	1.02	1.15	1.49	10.55			Sr85	0.63	0.70	0.95	17.47		
Kr85m	0.85	0.94					Kr85m	0.41	0.45				
Kr85	0.17	0.19	0.26	82.68	97.64		Kr85	0.05	0.06	0.08	65.64	99.94	
H3				0.86	2.34		Rb83	0.01	0.01	0.02	0.89		
Rb87					0.01	62.86	Rb87						91.27
Kr81						37.13	Kr81						8.72
Dose	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Ing	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y
Sv h <sup>-1</sup>	2.97E5	2.52E5	1.84E5	1.57E2	4.95E-3	1.79E-7	Sv kg <sup>-1</sup>	7.24E6	7.23E6	6.39E6	1.72E4	2.64E1	1.36E-3
Rb84	48.25	56.90	72.34	47.71			Rb86	74.33	74.37	73.47	0.04		
Rb86	18.01	21.24	25.42	0.04			Rb84	24.70	24.72	25.94	5.42		
Rb86m	12.31	0.40					Sr85	0.28	0.28	0.30	2.34		
Rb88	12.11	11.63					Kr85	0.23	0.23	0.26	91.75	99.95	
Rb84m	5.51	5.44					Rb88	0.22	0.18				
Sr85	1.25	1.48	1.95	47.88			Rb84m	0.08	0.06				
Sr87m	0.96	1.11					Br82	0.03	0.03	0.01			
Br82	0.87	1.03	0.25				Rb83	0.02	0.02	0.02	0.42		
Rb83	0.02	0.03	0.04	2.44			Rb87					0.01	94.74
Kr85				1.89*	99.99*		Kr81						5.22
Kr81						100.00							
Inh	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Clear	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y
Sv kg <sup>-1</sup>	4.04E6	4.04E6	3.75E6	1.47E6	2.45E3	7.56E-3		1.40E12	1.17E12	8.33E11	8.55E8	2.55E5	1.05E1
Rb86	44.24	44.25	41.63				Rb84	41.54	49.48	64.57	35.46		
Kr85	38.78	38.80	41.78	99.93	100.00		Rb86	22.54	26.85	32.98	0.05		
Rb84	15.81	15.82	15.80	0.02			Rb86m	13.08	0.43				
Sr85	0.72	0.72	0.74	0.04			Rb88	10.59	10.28				
Kr85m	0.18	0.18					Rb84m	7.90	7.87				
Rb88	0.07	0.06					Sr85	1.35	1.60	2.17	44.35		
Br82	0.06	0.06	0.01				Sr87m	1.33	1.55				
Kr81						94.29	Br82	0.71	0.84	0.21			
Rb87						5.70	Rb83	0.03	0.03	0.04	2.23		
							Kr85	0.01	0.01	0.02	17.85	99.95	
							Rb87						62.86
							Kr81						37.13

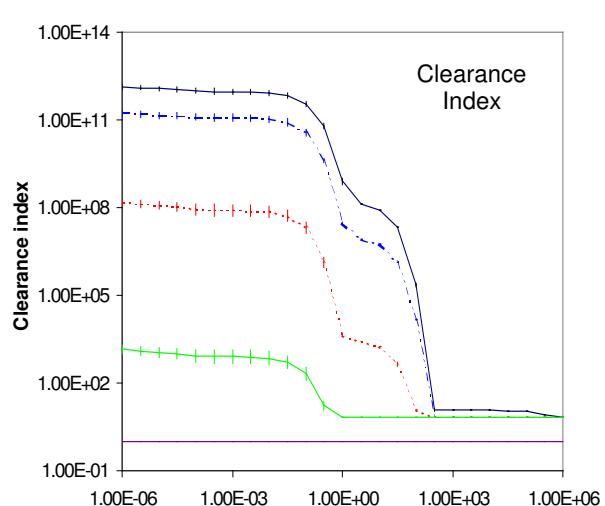
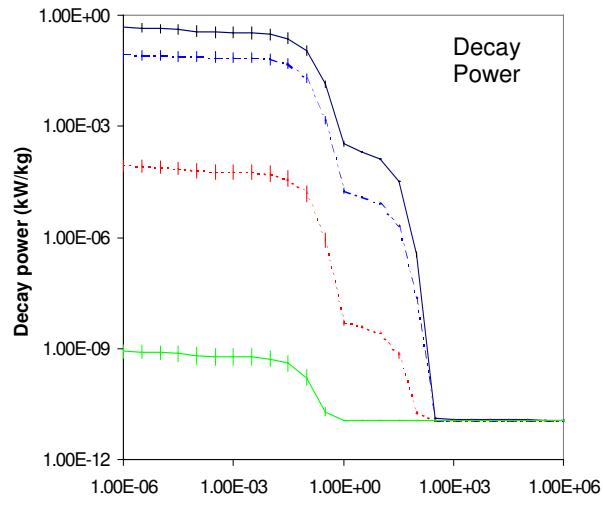
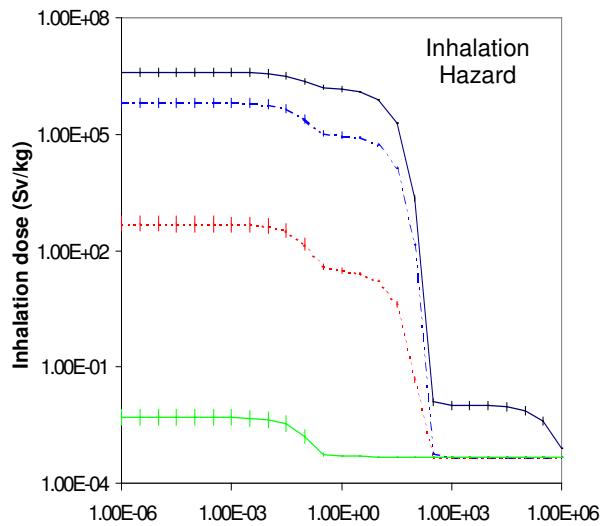
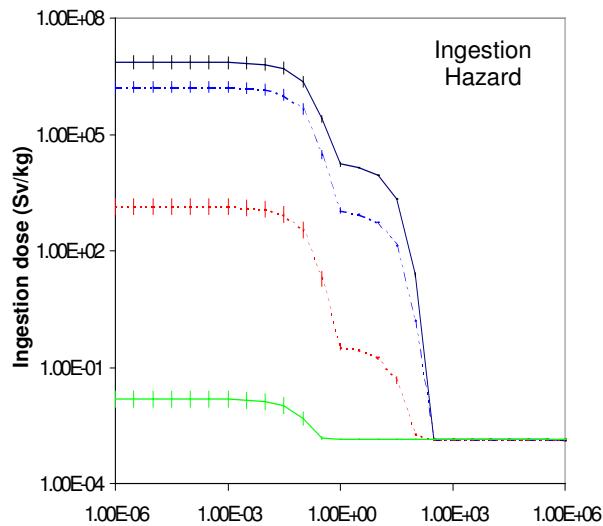
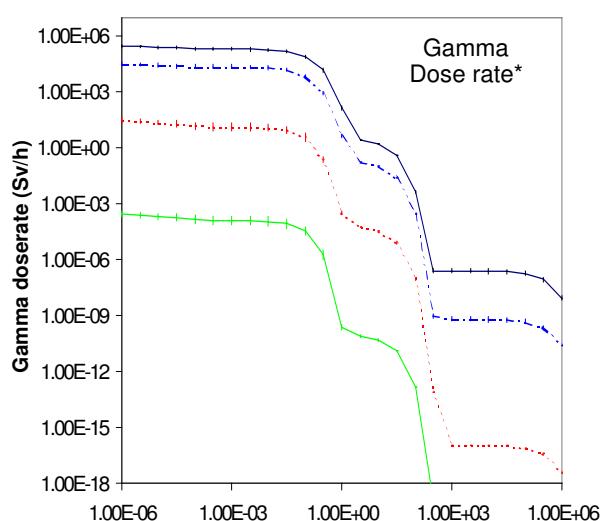
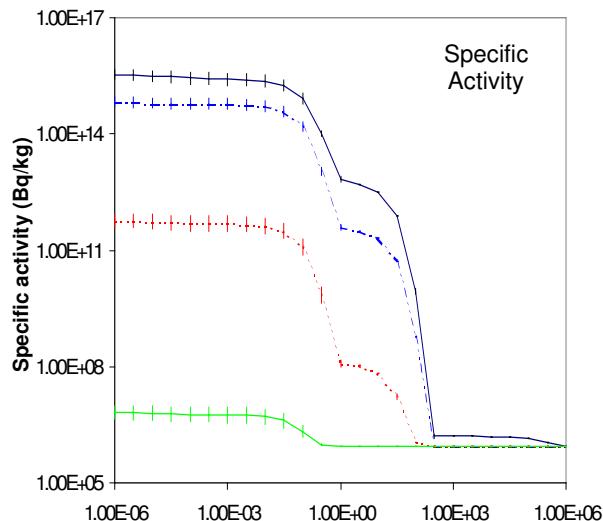
# Rubidium

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV	
Br82	1.472 d	&Rb85(n, $\alpha$ )Br82 &Rb85(n,2n)Rb84( $\beta^+$ )Kr84(n,2n)Kr83(n,d)Br82 &Rb85(n,d)Kr84(n,2n)Kr83(n,d)Br82 &Rb87(n,2n)Rb86( $\beta^-$ )Sr86(n,2n)Sr85( $\beta^+$ )Rb85(n, $\alpha$ )Br82	100.0	100.0	100.0	94.5 2.2 1.1 0.5	
Y90	2.671 d	Rb87(n, $\gamma$ )Rb88( $\beta^-$ )Sr88(n, $\gamma$ )Sr89( $\beta^-$ )Y89(n, $\gamma$ )Y90 Rb87(n, $\gamma$ )Rb88( $\beta^-$ )Sr88(n, $\gamma$ )Sr89( $\beta^-$ )Y89(n, $\gamma$ )Y90m(IT)Y90 &Rb85(n, $\gamma$ )Rb86( $\beta^-$ )Sr86(n, $\gamma$ )Sr87(n, $\gamma$ )Sr88(n, $\gamma$ ) Sr89( $\beta^-$ )Y89(n, $\gamma$ )Y90	95.2 4.8	100.0	98.0 1.6	67.3 32.2	
Rb86	18.63 d	Rb85(n, $\gamma$ )Rb86 Rb85(n, $\gamma$ )Rb86m(IT)Rb86 &Rb87(n,2n)Rb86	88.0 12.0	88.0 12.0	87.9 12.0	0.1 0.1 98.7	
Rb84	33.5 d	&Rb85(n,2n)Rb84 &Rb87(n,2n)Rb86( $\beta^-$ )Sr86(n,2n)Sr85( $\beta^+$ )Rb85(n,2n)Rb84				98.7 0.4	
Sr89	50.52 d	Rb87(n, $\gamma$ )Rb88( $\beta^-$ )Sr88(n, $\gamma$ )Sr89 &Rb85(n, $\gamma$ )Rb86( $\beta^-$ )Sr86(n, $\gamma$ )Sr87(n, $\gamma$ )Sr88(n, $\gamma$ )Sr89	91.0 8.9	100.0	99.9	99.7	
Sr85	64.849 d	&Rb87(n,2n)Rb86( $\beta^-$ )Sr86(n,2n)Sr85				99.7	
Kr85	10.73 y	Rb85(n,p)Kr85 Rb85(n,p)Kr85m(IT)Kr85 Rb87(n,d)Kr86(n,2n)Kr85 Rb87(n,t)Kr85	100.0	100.0	100.0	91.7 6.1 0.8 0.5	
H3	12.33 y	Rb85(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Rb85(n,X)H3 Rb87(n,X)H3 &Rb85(n,2n)Rb84( $\beta^+$ )Kr84(n,X)H3	93.3	95.2	100.0	75.9 20.0 1.7	
Nb93m	16.126 y	&Rb87(n, $\gamma$ )Rb88( $\beta^-$ )Sr88(n, $\gamma$ )Sr89( $\beta^-$ )Y89(n, $\gamma$ ) Y90(n, $\gamma$ )Y91( $\beta^-$ )Zr91(n, $\gamma$ )Zr92(n, $\gamma$ )Zr93( $\beta^-$ )Nb93m &Rb87(n, $\gamma$ )Rb88( $\beta^-$ )Sr88(n, $\gamma$ )Sr89( $\beta^-$ )Y89(n, $\gamma$ ) Y90(n, $\gamma$ )Y91(n, $\gamma$ )Y92( $\beta^-$ )Zr92(n, $\gamma$ )Zr93( $\beta^-$ )Nb93m &Rb87(n, $\gamma$ )Rb88( $\beta^-$ )Sr88(n, $\gamma$ )Sr89( $\beta^-$ )Y89(n, $\gamma$ ) Y90( $\beta^-$ )Zr90(n, $\gamma$ )Zr91(n, $\gamma$ )Zr92(n, $\gamma$ )Zr93( $\beta^-$ )Nb93m *Plus other similar pathways involving (n, $\gamma$ ) and ( $\beta^-$ )	65.5 23.6 8.9 2.0*				
Sr90	28.868 y	Rb87(n, $\gamma$ )Rb88( $\beta^-$ )Sr88(n, $\gamma$ )Sr89(n, $\gamma$ )Sr90 &Rb85(n, $\gamma$ )Rb86( $\beta^-$ )Sr86(n, $\gamma$ )Sr87(n, $\gamma$ )Sr88(n, $\gamma$ ) Sr89(n, $\gamma$ )Sr90	95.0 4.9	100.0	100.0	99.8	
Kr81	$2.1 \cdot 10^5$ y	&Rb85(n, $\alpha$ )Br82( $\beta^-$ )Kr82(n,2n)Kr81 &Rb85(n,2n)Rb84( $\beta^+$ )Kr84(n,2n)Kr83(n,2n)Kr82(n,2n)Kr81 &Rb85(n,d)Kr84(n,2n)Kr83(n,2n)Kr82(n,2n)Kr81 &Rb85(n,2n)Rb84( $\beta^-$ )Sr84(n, $\alpha$ )Kr81 &Rb85(n,2n)Rb84(n,2n)Rb83( $\beta^+$ )Kr83(n,2n)Kr82(n,2n)Kr81				48.7 28.0 13.9 4.4 2.4	
Se79	$6.0 \cdot 10^5$ y	&Rb85(n, $\alpha$ )Br82( $\beta^-$ )Kr82(n, $\alpha$ )Se79 &Rb85(n, $\alpha$ )Br82m( $\beta^-$ )Kr82(n, $\alpha$ )Se79 &Rb85(n,2n)Rb84( $\beta^+$ )Kr84(n,2n)Kr83(n, $\alpha$ )Se80(n,2n)Se79 &Rb85(n,n $\alpha$ )Br81(n,2n)Br80( $\beta^+$ )Se80(n,2n)Se79 &Rb85(n,d)Kr84(n,2n)Kr83(n, $\alpha$ )Se80(n,2n)Se79 &Rb85(n,n $\alpha$ )Br81(n,d)Se80(n,2n)Se79 &Rb85(n,2n)Rb84( $\beta^+$ )Kr84(n,2n)Kr83(n,2n)Kr82(n, $\alpha$ )Se79 &Rb85(n,2n)Rb84( $\beta^+$ )Kr84(n,n $\alpha$ )Se80(n,2n)Se79 &Rb85(n,d)Kr84(n,2n)Kr83(n,2n)Kr82(n, $\alpha$ )Se79 &Rb85(n,2n)Rb84(n,2n)Rb83( $\beta^+$ )Kr83(n, $\alpha$ )Se80(n,2n)Se79 &Rb85(n,d)Kr84(n,n $\alpha$ )Se80(n,2n)Se79 &Rb85(n,2n)Rb84( $\beta^+$ )Kr84(n,2n)Kr83(n,n $\alpha$ )Se79 &Rb85(n,n $\alpha$ )Br81(n,t)Se79	98.8 1.2 98.8 1.2 98.9 1.1 25.7 23.5 12.7 9.0 4.5 3.4 2.3 2.2 1.6 1.5 1.2				7.9 0.1 23.5 12.7 9.0 4.5 3.4 2.3 2.2 1.6 1.5 1.2
Rb87	$4.8 \cdot 10^{10}$ y	&Rb85(n, $\gamma$ )Rb86(n, $\gamma$ )Rb87 *Nuclide present in starting material	0.2 99.8*	100.0*	100.0*	100.0*	

Se82	$1.4 \cdot 10^{20}$ y	Rb85(n,p)Kr85(n, $\alpha$ )Se82 <b>&amp;Rb85(n,<math>\alpha</math>)Br82(n,p)Se82</b> <b>&amp;Rb85(n,2n)Rb84(<math>\beta^+</math>)Kr84(n,h)Se82</b> Rb85(n,d)Kr84(n,h)Se82 Rb85(n,p)Kr85m(IT)Kr85(n, $\alpha$ )Se82	99.4 0.5	99.5 0.5	99.5 0.5	52.2 0.4 29.1 13.7 3.5
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# Rubidium activation characteristics

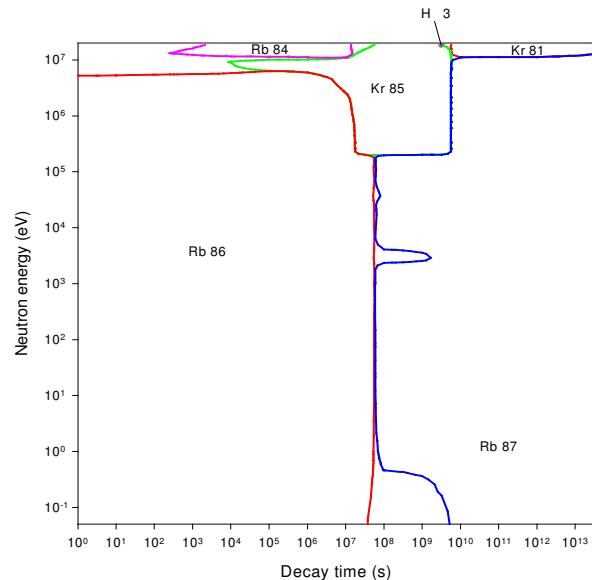


Decay time (years)

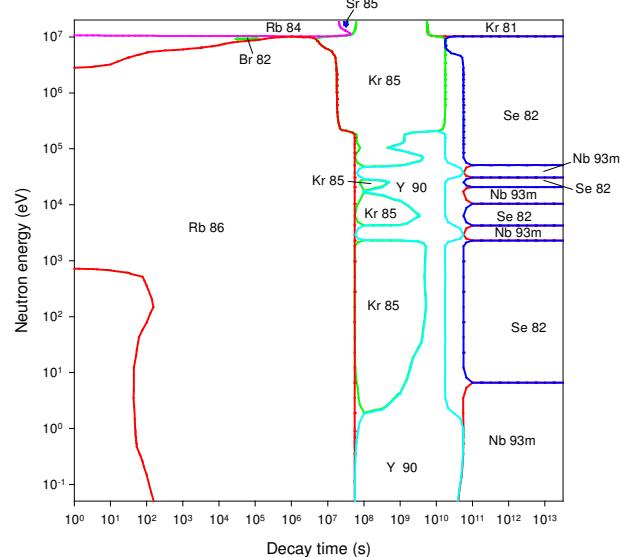
Decay time (years)

# Rubidium importance diagrams & transmutation

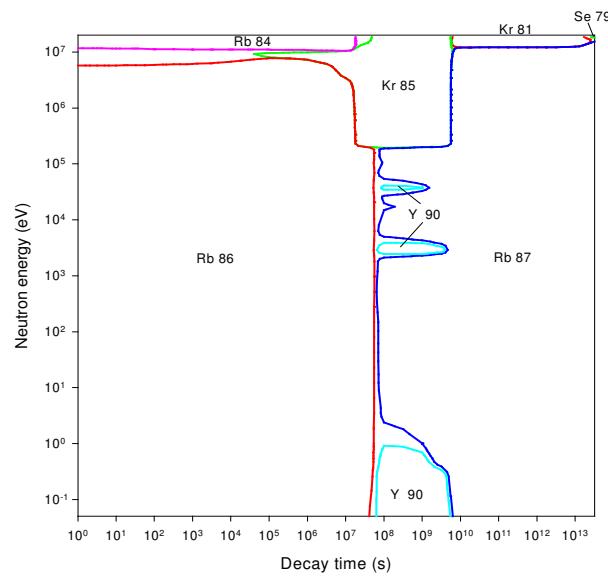
## Activity



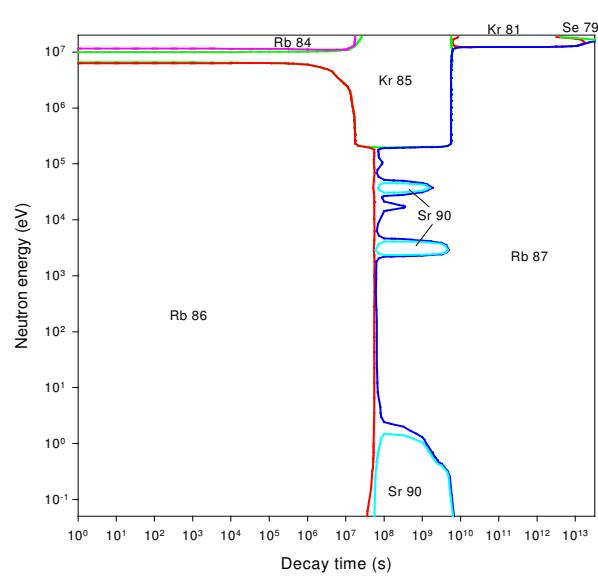
## Dose rate



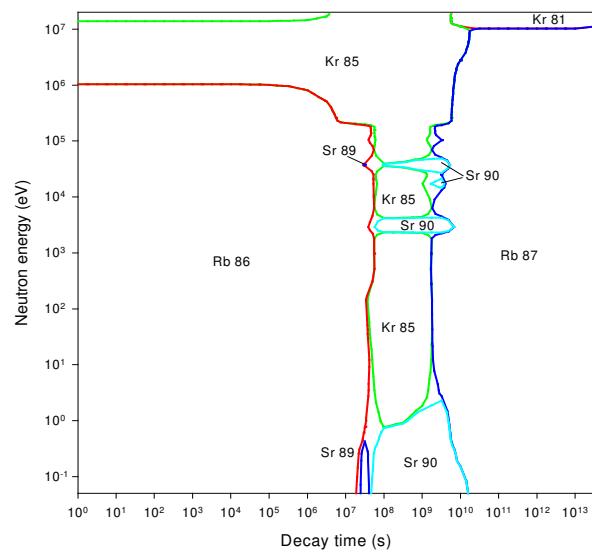
## Heat output



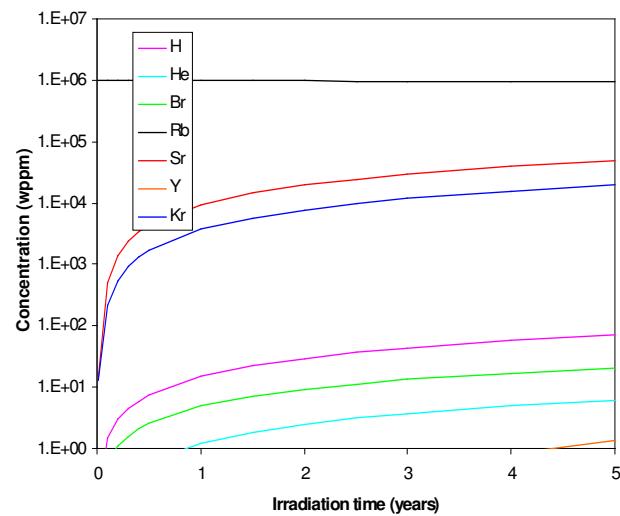
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Strontium

## General properties

		38	Isotopes	Isotopic abundances / %	
Atomic number				Sr84	0.56
Crustal abundance / wppm	370	Sr86	9.86		
Melting point / K	1050	Sr87	7.00		
Boiling point / K	1655	Sr88	82.58		
Density / kgm <sup>-3</sup>	2540				
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	35.3				
Electrical resistivity /Ωm	2.30 10 <sup>-7</sup>				
Coefficient of thermal expansion / K <sup>-1</sup>	2.25 10 <sup>-5</sup>				
Crystal structure	FCC				
Number of stable isotopes	4				
Mean atomic weight	87.62				

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	5.10E14	4.96E14	1.32E14	3.02E12	1.16E9	1.23E6	Kw kg <sup>-1</sup>	3.89E-2	3.73E-2	1.19E-2	2.32E-4	4.86E-8	2.52E-12
Sr87m	62.80	63.14					Sr87m	51.10	52.17				
Sr85	18.50	19.01	68.63	62.94			Sr85	20.50	21.39	64.53	69.40		
Sr85m	6.39	6.22					Rb88	11.60	9.86				
Sr89	4.78	4.91	17.53	5.37			Sr89	5.86	6.11	18.23	6.55		
Rb88	2.05	1.71					Rb86	3.22	3.36	9.20			
Rb86	2.01	2.07	6.77				Sr85m	3.07	3.04				
Rb83	0.59	0.61	2.24	5.36			Rb84	1.20	1.25	3.65	0.11		
Rb84	0.56	0.57	1.98	0.05			Sr83	1.05	1.10	0.53			
Kr83m	0.50	0.51	1.68	4.03			Rb83	0.63	0.65	2.02	5.66		
Kr85	0.13	0.13	0.50	20.58	89.63		Rb86m	0.49	0.01				
Y88	0.08	0.08	0.30	1.24			Y88	0.45	0.47	1.44	7.03		
Y90	0.02	0.02	0.03	0.01	3.08		Kr85	0.07	0.07	0.23	10.88	86.61	
H3			0.01	0.41	4.07		Y90	0.04	0.04	0.05	0.03	10.99	
Sr90				0.01	3.08		Sr90				0.01	2.30	
Kr81					0.15	99.98	Kr81					0.01	99.82
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	3.07E4	2.96E4	1.09E4	2.45E2	5.82E-4	4.03E-7	Sv kg <sup>-1</sup>	1.74E5	1.73E5	1.52E5	3.60E3	4.01E0	1.73E-4
Sr87m	50.94	51.76					Sr89	36.50	36.59	39.69	11.72		
Sr85	31.75	32.96	85.80	80.16			Sr85	30.43	30.51	33.47	29.56		
Rb88	6.85	5.80					Rb86	16.54	16.58	16.51			
Sr85m	2.26	2.22					Sr87m	5.53	5.43				
Rb84	2.06	2.14	5.36	0.13			Rb84	4.56	4.57	4.84	0.12		
Sr83	1.59	1.65	0.69				Rb83	3.30	3.31	3.71	8.55		
Y88	1.11	1.16	3.05	12.97			Kr85	1.07	1.07	1.22	48.33	72.59	
Rb83	0.97	1.01	2.69	6.56			Sr83	0.78	0.78	0.14			
Rb86	0.93	0.96	2.27				Y88	0.30	0.30	0.34	1.36		
Kr85				0.13*	92.23*		Y90	0.17	0.17	0.08	0.03	2.41	
Y90					7.48*		Sr90	0.01	0.01	0.01	0.30	24.95	
Kr81						0.10	100.00	Kr81				0.01	99.68
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	4.66E5	4.66E5	4.44E5	1.65E5	2.76E2	1.72E-2		1.80E11	1.74E11	5.46E10	1.20E9	4.01E4	9.46E0
Sr89	41.30	41.31	41.24	0.78			Sr87m	57.31	58.00				
Kr85	37.00	37.02	38.83	98.08	97.90		Sr85	27.55	28.49	87.47	83.20		
Sr85	16.39	16.40	16.55	0.93			Rb88	4.82	4.07				
Rb86	2.05	2.05	1.88				Sr85m	3.93	3.85				
Sr87m	1.44	1.41					Rb84	1.43	1.48	4.37	0.11		
Rb84	0.61	0.61	0.59				Sr83	1.18	1.22	0.60			
Rb83	0.45	0.45	0.46	0.07			Rb86	0.93	0.96	2.69			
Y88	0.38	0.38	0.39	0.10			Rb83	0.84	0.86	2.71	6.73		
Sr83	0.20	0.20	0.03				Y88	0.61	0.63	1.95	8.44		
Kr85m	0.06	0.06					Kr85	0.01	0.01	0.03	1.40	69.97	
Sr90	0.01	0.01	0.01	0.04	2.07		Sr90				0.01	29.66	
Kr81						0.01	Kr 81				0.03	99.97	

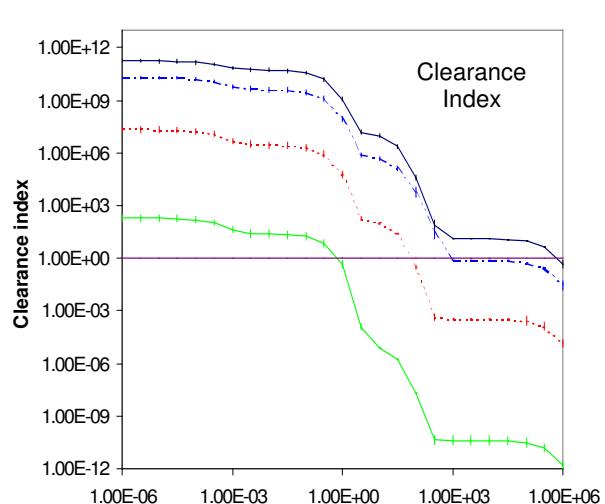
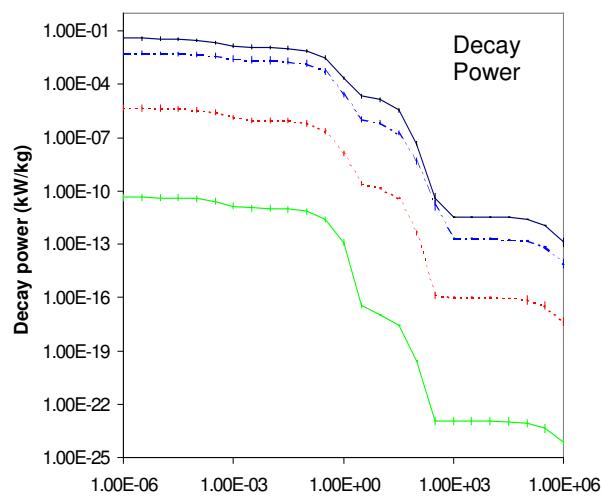
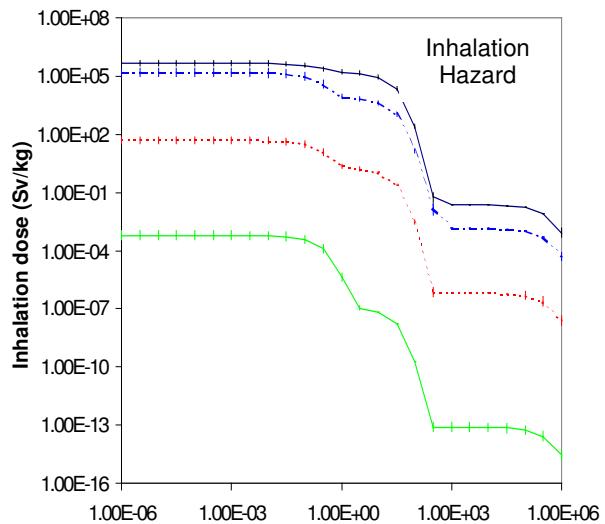
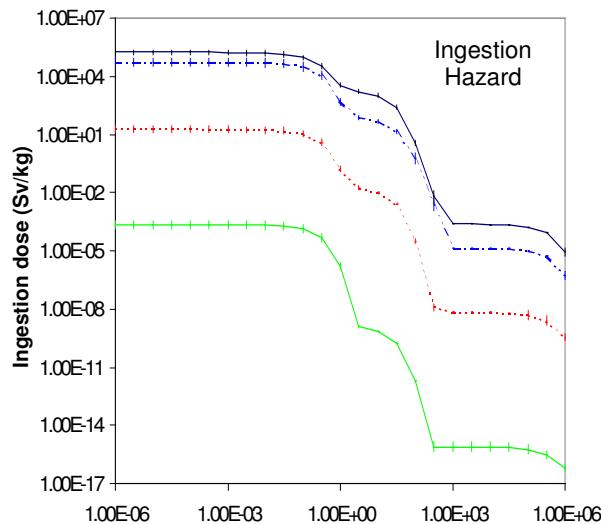
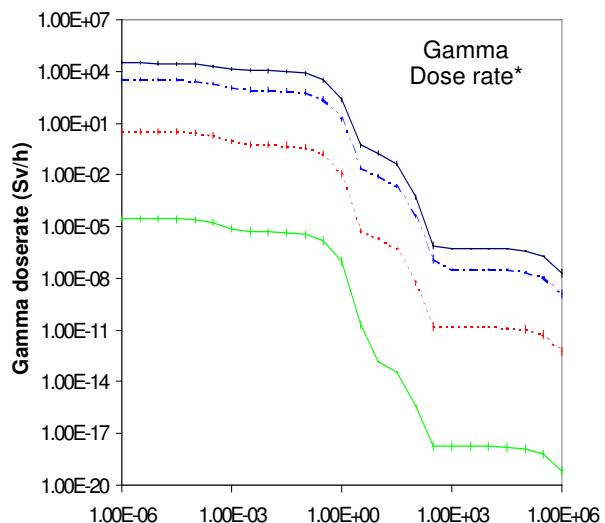
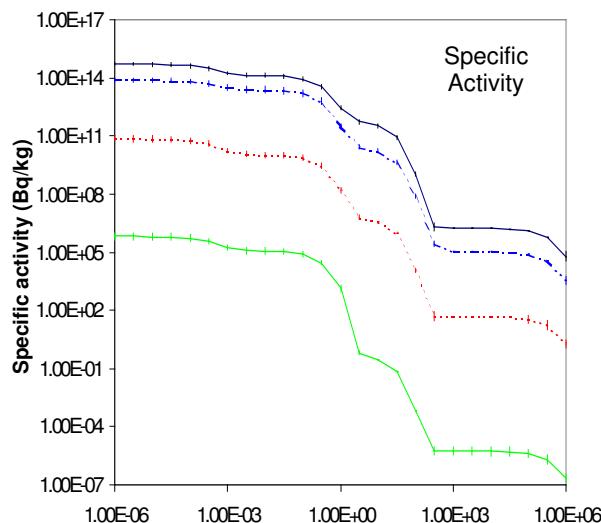
# Strontium

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Sr87m	2.808 h	Sr86(n, $\gamma$ )Sr87m Sr88(n,2n)Sr87m Sr88(n,2n)Sr87(n,n')Sr87m Sr87(n,n')Sr87m	100.0	100.0	100.0	92.5 3.5 2.5
Y90	2.671 d	Sr88(n, $\gamma$ )Sr89( $\beta^-$ )Y89(n, $\gamma$ )Y90 Sr87(n, $\gamma$ )Sr88(n, $\gamma$ )Sr89( $\beta^-$ )Y89(n, $\gamma$ )Y90 Sr88(n, $\gamma$ )Sr89(n, $\gamma$ )Sr90( $\beta^-$ )Y90 Sr88(n, $\gamma$ )Sr89( $\beta^-$ )Y89(n, $\gamma$ )Y90m(IT)Y90	96.5 3.3 0.1	99.9 0.1	97.8 0.7 1.6	67.0 0.7 32.1
Rb86	18.63 d	&Sr84(n, $\gamma$ )Sr85( $\beta^+$ )Rb85(n, $\gamma$ )Rb86 &Sr84(n, $\gamma$ )Sr85m( $\beta^+$ )Rb85(n, $\gamma$ )Rb86 &Sr86(n,p)Rb86 &Sr88(n,2n)Sr87(n,d)Rb86 &Sr87(n,d)Rb86 &Sr88(n,d)Rb87(n,2n)Rb86 &Sr87(n,2n)Sr86(n,p)Rb86 &Sr88(n,2n)Sr87(n,2n)Sr86(n,p)Rb86 &Sr87(n,p)Rb87(n,2n)Rb86 &Sr88(n,2n)Sr87(n,p)Rb87(n,2n)Rb86 &Sr88(n,2n)Sr87m( $\beta^+$ )Rb87(n,2n)Rb86	88.7 11.3	88.6 11.4	89.4 10.6	46.3 18.0 9.7 6.6 5.9 5.4 2.9 2.6 1.3
Rb84	33.5 d	&Sr86(n,2n)Sr85( $\beta^+$ )Rb85(n,2n)Rb84 &Sr87(n,2n)Sr86(n,2n)Sr85( $\beta^+$ )Rb85(n,2n)Rb84 &Sr84(n,p)Rb84 &Sr88(n,2n)Sr87(n,2n)Sr86(n,2n)Sr85( $\beta^+$ )Rb85(n,2n)Rb84 &Sr86(n,2n)Sr85m( $\beta^+$ )Rb85(n,2n)Rb84 &Sr86(n,d)Rb85(n,2n)Rb84				83.0 5.0 2.9 2.9 2.7 1.0
Sr89	50.52 d	Sr88(n, $\gamma$ )Sr89 Sr87(n, $\gamma$ )Sr88(n, $\gamma$ )Sr89 &Sr86(n, $\gamma$ )Sr87(n, $\gamma$ )Sr88(n, $\gamma$ )Sr89	94.3 5.4 0.3	99.9 0.1	99.9 0.1	99.4
Sr85	64.849 d	Sr84(n, $\gamma$ )Sr85m(IT)Sr85 Sr84(n, $\gamma$ )Sr85 &Sr86(n,2n)Sr85 &Sr87(n,2n)Sr86(n,2n)Sr85 &Sr88(n,2n)Sr87(n,2n)Sr86(n,2n)Sr85	72.2 27.8	72.2 27.8	72.1 27.9	80.4 9.9 8.8
Rb83	86.2 d	&Sr84(n,2n)Sr83( $\beta^+$ )Rb83 Sr84(n,d)Rb83 &Sr86(n,2n)Sr85(n,2n)Sr84(n,2n)Sr83( $\beta^+$ )Rb83 &Sr86(n,2n)Sr85( $\beta^+$ )Rb85(n,2n)Rb84(n,2n)Rb83				82.1 13.2 1.8 1.3
Kr85	10.73 y	&Sr86(n, $\alpha$ )Kr83(n, $\gamma$ )Kr84(n, $\gamma$ )Kr85 &Sr84(n, $\gamma$ )Sr85( $\beta^+$ )Rb85(n,p)Kr85 &Sr87(n, $\alpha$ )Kr84(n, $\gamma$ )Kr85 Sr84(n, $\gamma$ )Sr85m( $\beta^+$ )Rb85(n,p)Kr85 &Sr86(n, $\gamma$ )Sr87(n, $\alpha$ )Kr84(n, $\gamma$ )Kr85 &Sr88(n, $\alpha$ )Kr85 &Sr86(n,2n)Sr85( $\beta^+$ )Rb85(n,p)Kr85	48.1 32.9 13.8 4.3 0.5	60.5 48.8 31.3 8.0 6.0	2.0 48.8 43.0 6.0	95.4 3.9
H3	12.33 y	Sr87(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 &Sr86(n, $\gamma$ )Sr87(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Sr88(n,X)H3 Sr87(n,X)H3 &Sr88(n,2n)Sr87(n,X)H3 Sr86(n,X)H3 &Sr86(n,2n)Sr85( $\beta^+$ )Rb85(n,X)H3	90.5 2.5	95.1 0.1	99.1 0.3	46.9 22.5 21.4 5.2 2.2

Nb93m	16.126 y	<b>&amp;Sr88(n,<math>\gamma</math>)Sr89(<math>\beta^-</math>)Y89(n,<math>\gamma</math>)Y90(n,<math>\gamma</math>)Y91(<math>\beta^-</math>)</b> Zr91(n, $\gamma$ )Zr92(n, $\gamma$ )Zr93( $\beta^-$ )Nb93m <b>&amp;Sr88(n,<math>\gamma</math>)Sr89(<math>\beta^-</math>)Y89(n,<math>\gamma</math>)Y90(n,<math>\gamma</math>)Y91(n,<math>\gamma</math>)Y92(<math>\beta^-</math>)</b> Zr92(n, $\gamma$ )Zr93( $\beta^-$ )Nb93m Sr88(n, $\gamma$ )Sr89( $\beta^-$ )Y89(n, $\gamma$ )Y90( $\beta^-$ )Zr90(n, $\gamma$ )Zr91(n, $\gamma$ ) Zr92(n, $\gamma$ )Zr93( $\beta^-$ )Nb93m <b>&amp;Sr88(n,<math>\gamma</math>)Sr89(n,<math>\gamma</math>)Sr90(n,<math>\gamma</math>)Sr91(<math>\beta^-</math>)Y91(<math>\beta^-</math>)</b> Zr91(n, $\gamma$ )Zr92(n, $\gamma$ )Zr93( $\beta^-$ )Nb93m	67.2 20.2 10.3 0.6		8.9 1.5 79.5 8.0	
Sr90	28.868 y	Sr88(n, $\gamma$ )Sr89(n, $\gamma$ )Sr90 Sr87(n, $\gamma$ )Sr88(n, $\gamma$ )Sr89(n, $\gamma$ )Sr90	96.5 3.3	100.0	99.9	99.7
Kr81	$2.1 \cdot 10^5$ y	<b>&amp;Sr84(n,<math>\alpha</math>)Kr81</b> <b>&amp;Sr84(n,2n)Sr83(<math>\beta^+</math>)Rb83(<math>\beta^+</math>)Kr83(n,2n)Kr82(n,2n)Kr81</b> <b>&amp;Sr86(n,<math>\alpha</math>)Kr83(n,2n)Kr82(n,2n)Kr81</b> <b>&amp;Sr84(n,d)Rb83(<math>\beta^+</math>)Kr83(n,2n)Kr82(n,2n)Kr81</b> <b>&amp;Sr86(n,2n)Sr85(<math>\beta^+</math>)Rb85(n,<math>\alpha</math>)Br82(<math>\beta^-</math>)Kr82(n,2n)Kr81</b> <b>&amp;Sr84(n,2n)Sr83(<math>\beta^+</math>)Rb83(n,d)Kr82(n,2n)Kr81</b>	100.0   	100.0	100.0	71.3 13.3 4.2 2.1 1.5 1.0
Zr93	$1.5 \cdot 10^6$ y	<b>&amp;Sr88(n,<math>\gamma</math>)Sr89(<math>\beta^-</math>)Y89(n,<math>\gamma</math>)Y90(n,<math>\gamma</math>)Y91(<math>\beta^-</math>)</b> Zr91(n, $\gamma$ )Zr92(n, $\gamma$ )Zr93 <b>&amp;Sr88(n,<math>\gamma</math>)Sr89(<math>\beta^-</math>)Y89(n,<math>\gamma</math>)Y90(n,<math>\gamma</math>)Y91(n,<math>\gamma</math>)</b> Y92( $\beta^-$ )Zr92(n, $\gamma$ )Zr93 <b>&amp;Sr88(n,<math>\gamma</math>)Sr89(<math>\beta^-</math>)Y89(n,<math>\gamma</math>)Y90(<math>\beta^-</math>)Zr90(n,<math>\gamma</math>)</b> Zr91(n, $\gamma$ )Zr92(n, $\gamma$ )Zr93 <b>&amp;Sr87(n,<math>\gamma</math>)Sr88(n,<math>\gamma</math>)Sr89(<math>\beta^-</math>)Y89(n,<math>\gamma</math>)Y90(n,<math>\gamma</math>)</b> Y91( $\beta^-$ )Zr91(n, $\gamma$ )Zr92(n, $\gamma$ )Zr93 <b>&amp;Sr88(n,<math>\gamma</math>)Sr89(n,<math>\gamma</math>)Sr90(n,<math>\gamma</math>)Sr91(<math>\beta^-</math>)Y91(<math>\beta^-</math>)</b> Zr91(n, $\gamma$ )Zr92(n, $\gamma$ )Zr93 <b>&amp;Sr88(n,<math>\gamma</math>)Sr89(n,<math>\gamma</math>)Sr90(n,<math>\gamma</math>)Sr91(<math>\beta^-</math>)Y91(n,<math>\gamma</math>)</b> Y92( $\beta^-$ )Zr92(n, $\gamma$ )Zr93	68.7 16.7 12.0 1.1	80.7 3.6 14.7 1.0	7.9 1.1 82.0 7.2 1.0	1.6 0.3 71.6 19.8 5.8
Rb87	$4.8 \cdot 10^{10}$ y	Sr86(n, $\gamma$ )Sr87m( $\beta^+$ )Rb87 Sr88(n,d)Rb87 Sr87(n,p)Rb87 <b>&amp;Sr88(n,2n)Sr87(n,p)Rb87</b> Sr88(n,2n)Sr87m( $\beta^+$ )Rb87	99.5	100.0	100.0	49.0 21.2 19.8 9.3

# Strontium activation characteristics

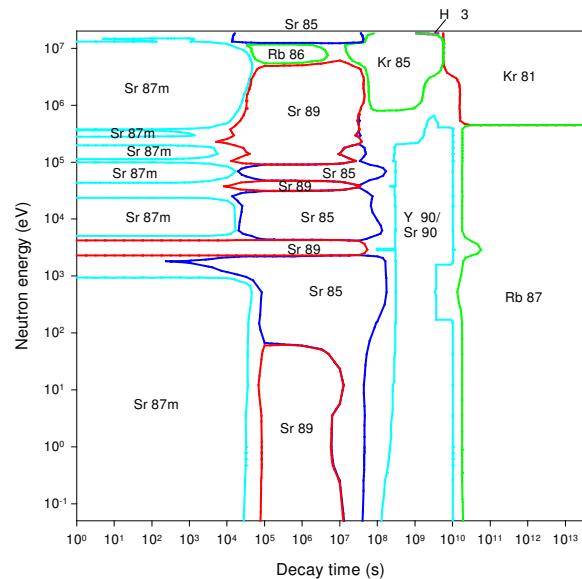


Decay time (years)

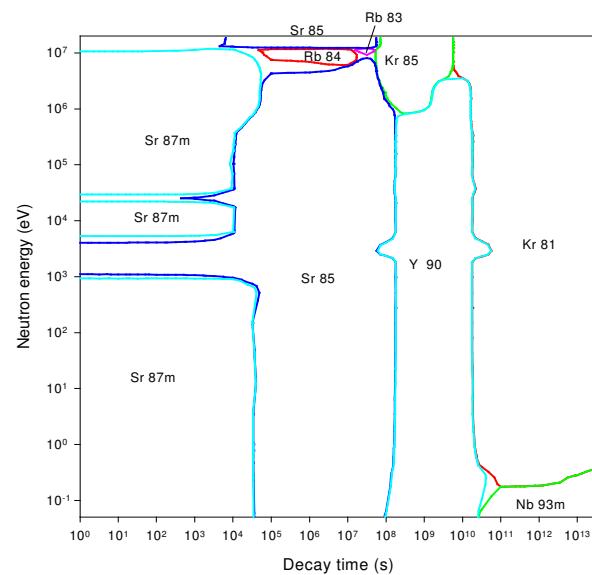
Decay time (years)

# Strontium importance diagrams & transmutation

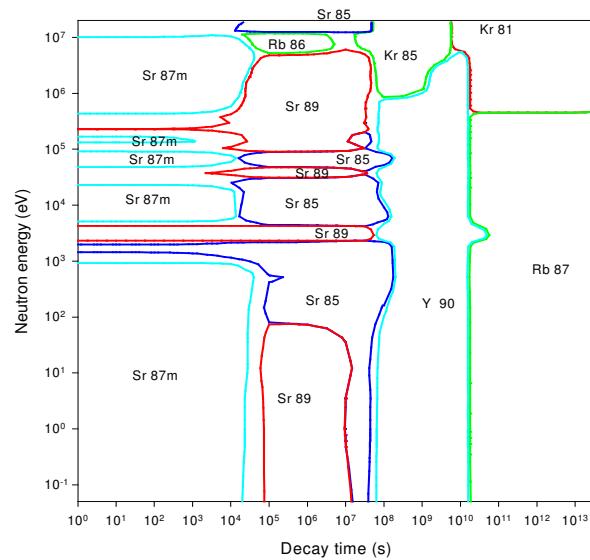
## Activity



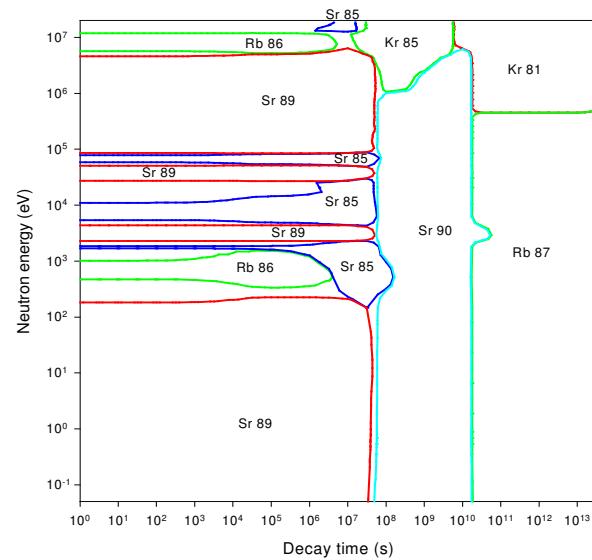
## Dose rate



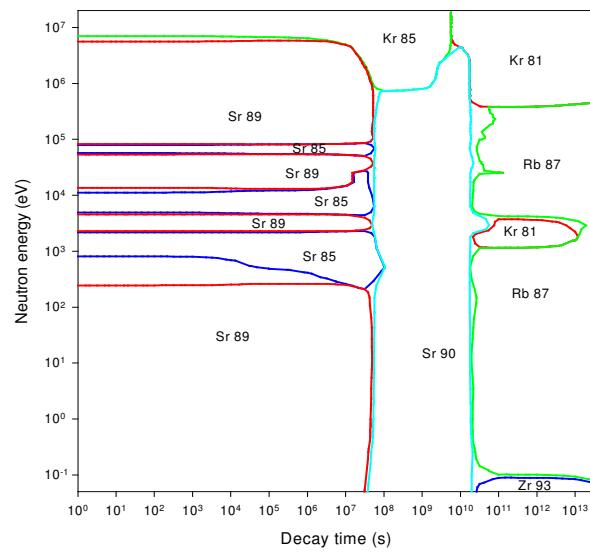
## Heat output



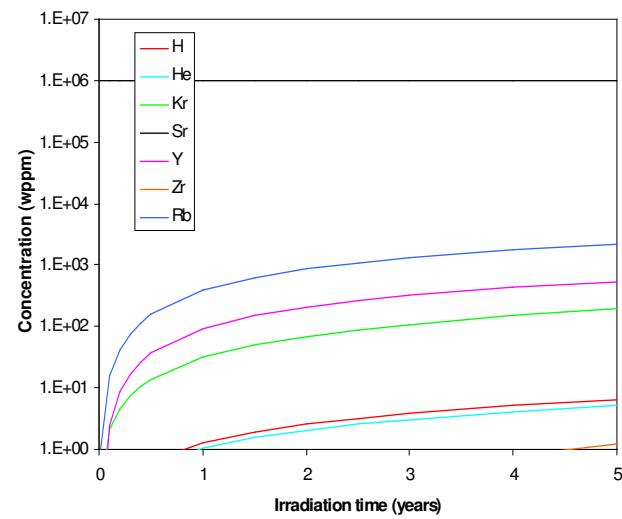
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Yttrium

## General properties

		39	Isotopes	Isotopic abundances / %	
				33	Y89
Atomic number		1799			
Crustal abundance / wppm		3609			
Melting point / K		4469			
Boiling point / K		17.2			
Density / kgm <sup>-3</sup>		5.70 10 <sup>-7</sup>			
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>		1.06 10 <sup>-5</sup>			
Electrical resistivity /Ωm		HCP			
Coefficient of thermal expansion / K <sup>-1</sup>		1			
Crystal structure		88.90585			
Number of stable isotopes					
Mean atomic weight					

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	
Bq kg <sup>-1</sup>	1.93E15	1.03E15	8.84E14	7.43E13	1.31E8	1.86E1	kW kg <sup>-1</sup>	5.09E-1	3.78E-1	3.51E-1	3.21E-2	7.06E-9	1.07E-16	
Y89m	46.07	0.25	0.13				Y88	67.79	91.20	95.92	99.95			
Y88	41.36	76.97	87.97	99.76			Y89m	25.40	0.10	0.05				
Y90	10.13	18.83	8.56		27.66		Y90	5.73	7.71	3.22		76.48		
Sr89	1.23	2.29	2.55	0.21			Sr89	0.44	0.59	0.60	0.05			
H3				0.02	35.50		Sr90					16.03		
Kr85				0.01	9.20		Kr85					6.89		
Sr90					27.65		H3					0.60		
Zr93						36.18	Rb87						48.21	
Nb93m						35.27	Nb93m						30.27	
Rb87						22.04	Zr93						19.21	
Kr81						6.51	Kr81						2.31	
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	
Sv h <sup>-1</sup>	8.83E5	6.67E5	6.50E5	6.19E4	4.89E-5	8.10E-13	Sv kg <sup>-1</sup>	1.64E6	1.64E6	1.29E6	9.68E4	1.14E0	1.45E-8	
Y88	75.27	99.73	99.90	100.0			Y88	63.01	63.05	78.45	99.54			
Y89m	24.21	0.09	0.04				Y90	32.05	32.04	15.85		8.52		
Zr90m	0.36						Sr89	3.75	3.75	4.54	0.42			
Y90	0.03*	0.03*	0.01*		85.46*		Rb86	0.94	0.94	1.04				
Sr87m	0.02	0.03					Kr85				0.02	2.94		
Y90m	0.02	0.03					Sr90				0.01	88.37		
Kr85					12.36*		Zr93						51.01	
Sr90					2.17*		Rb87						42.38	
Nb93m						54.73	Nb93m						5.43	
Kr81						45.25	Kr81						1.17	
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	
Sv kg <sup>-1</sup>	3.99E6	3.99E6	3.72E6	3.29E5	8.96E0	1.99E-7			2.98E12	2.16E12	2.11E12	2.00E11	1.25E4	8.50E-5
Y88	87.73	87.75	91.97	99.04			Y88	72.33	99.61	99.86	100.00			
Y90	7.33	7.32	3.05		0.60		Y89m	27.10	0.11	0.05				
Sr89	4.68	4.68	4.78	0.38			Y90	0.02	0.03	0.01		0.96		
Kr85	0.05	0.05	0.05	0.57	34.82		Sr90					96.31		
Sr90				0.02	64.44		Kr85					2.60		
Zr93						84.52	Rb87						37.08	
Kr81						8.52	Nb93m						36.74	
Nb93m						5.93	Zr93						15.22	
Rb87						1.03	Kr81						10.95	

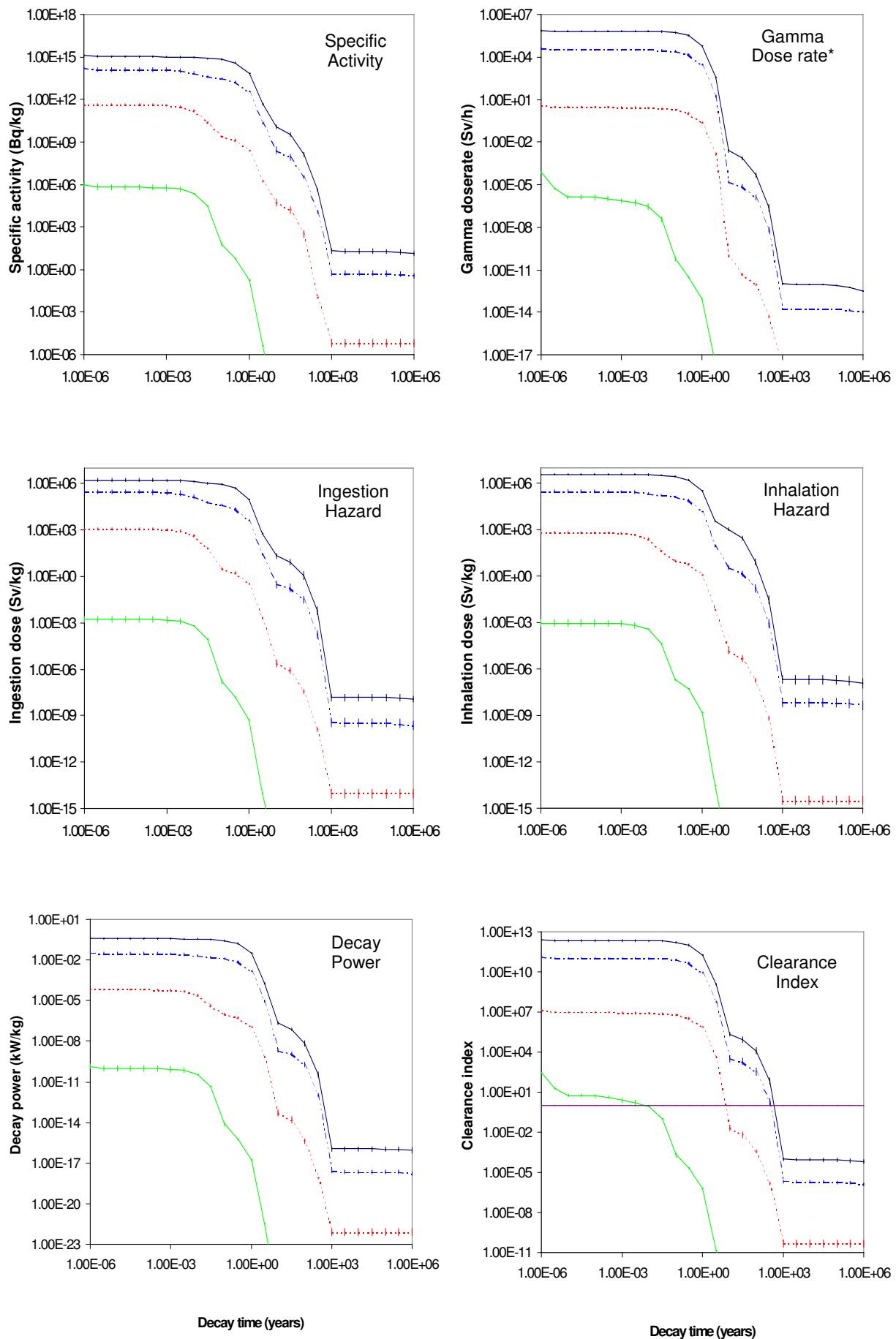
# Yttrium

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Y89m	16.05 s	Y89(n,n')Y89m				99.6
Y90m	3.19 h	Y89(n, $\gamma$ )Y90m Y89(n, $\gamma$ )Y90( $\beta^-$ )Zr90(n,p)Y90m	100.0	100.0	100.0	99.0 0.4
Y90	2.671 d	Y89(n, $\gamma$ )Y90 Y89(n, $\gamma$ )Y90m(IT)Y90	99.9 0.1	99.9 0.1	98.4 1.6	67.0 32.1
Rb86	18.63 d	&Y89(n, $\alpha$ )Rb86 &Y89(n,2n)Y88( $\beta^+$ )Sr88(n,2n)Sr87(n,d)Rb86 &Y89(n,2n)Y88( $\beta^+$ )Sr88(n,d)Rb87(n,2n)Rb86	99.9	100.0	100.0	94.3 1.9 0.7
Sr89	50.52 d	&Y89(n, $\gamma$ )Y90( $\beta^-$ )Zr90(n, $\alpha$ )Sr87(n, $\gamma$ )Sr88(n, $\gamma$ )Sr89 &Y89(n, $\alpha$ )Rb86( $\beta^-$ )Sr86(n, $\gamma$ )Sr87(n, $\gamma$ )Sr88(n, $\gamma$ )Sr89 &Y89(n, $\gamma$ )Y90(n, $\gamma$ )Y91( $\beta^-$ )Zr91(n, $\gamma$ )Zr92(n, $\alpha$ )Sr89 Y89(n, $\gamma$ )Y90( $\beta^-$ )Zr90(n, $\gamma$ )Zr91(n, $\gamma$ )Zr92(n, $\alpha$ )Sr89 &Y89(n, $\gamma$ )Y90(n, $\gamma$ )Y91(n, $\gamma$ )Y92( $\beta^-$ )Zr92(n, $\alpha$ )Sr89 &Y89(n, $\alpha$ )Rb86(n, $\gamma$ )Rb87(n, $\gamma$ )Rb88( $\beta^-$ )Sr88(n, $\gamma$ )Sr89 &Y89(n, $\gamma$ )Y90( $\beta^-$ )Zr90(n, $\gamma$ )Zr91(n, $\alpha$ )Sr88(n, $\gamma$ )Sr89 &Y89(n, $\gamma$ )Y90(n, $\gamma$ )Y91( $\beta^-$ )Zr91(n, $\alpha$ )Sr88(n, $\gamma$ )Sr89 Y89(n,p)Sr89 Y89(n,2n)Y88( $\beta^+$ )Sr88(n, $\gamma$ )Sr89	45.6 34.1 14.3 3.9 1.8 0.3	10.5 14.3 56.1 15.4 1.3 2.4	94.2 5.8	98.9 0.6
Y91	58.7 d	&Y89(n, $\gamma$ )Y90(n, $\gamma$ )Y91 &Y89(n, $\gamma$ )Y90( $\beta^-$ )Zr90(n, $\gamma$ )Zr91(n,p)Y91 &Y89(n,p)Sr89(n, $\gamma$ )Sr90(n, $\gamma$ )Sr91( $\beta^-$ )Y91	99.9	99.9	100.0	65.7 30.6 2.7
Y88	106.63 d	Y89(n,2n)Y88				99.7
Kr85	10.73 y	&Y89(n, $\alpha$ )Rb86( $\beta^-$ )Sr86(n, $\alpha$ )Kr83(n, $\gamma$ )Kr84(n, $\gamma$ )Kr85 &Y89(n,2n)Y88( $\beta^+$ )Sr88(n, $\alpha$ )Kr85 &Y89(n,d)Sr88(n, $\alpha$ )Kr85	100.0			90.1 9.2
H3	12.33 y	&Y89(n, $\gamma$ )Y90(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Y89(n,X)H3 Y89(n,2n)Y88( $\beta^+$ )Sr88(n,X)H3 &Y89(n,2n)Y88( $\beta^+$ )Sr88(n,2n)Sr87(n,X)H3	94.0			92.7 4.3 1.2
Nb93m	16.126 y	&Y89(n, $\gamma$ )Y90(n, $\gamma$ )Y91( $\beta^-$ )Zr91(n, $\gamma$ )Zr92(n, $\gamma$ ) Zr93( $\beta^-$ )Nb93m &Y89(n, $\gamma$ )Y90(n, $\gamma$ )Y91(n, $\gamma$ )Y92( $\beta^-$ )Zr92(n, $\gamma$ ) Zr93( $\beta^-$ )Nb93m &Y89(n, $\gamma$ )Y90( $\beta^-$ )Zr90(n, $\gamma$ )Zr91(n, $\gamma$ )Zr92(n, $\gamma$ ) Zr93( $\beta^-$ )Nb93m	71.0 16.2 12.8	81.3 3.3 15.4	8.2 0.8 91.0	2.1 0.6 97.1
Sr90	28.868 y	Y89(n, $\gamma$ )Y90(n,p)Sr90 Y89(n, $\gamma$ )Y90m(IT)Y90(n,p)Sr90 Y89(n,p)Sr89(n, $\gamma$ )Sr90	100.0	100.0	98.4 1.6	1.3 98.7

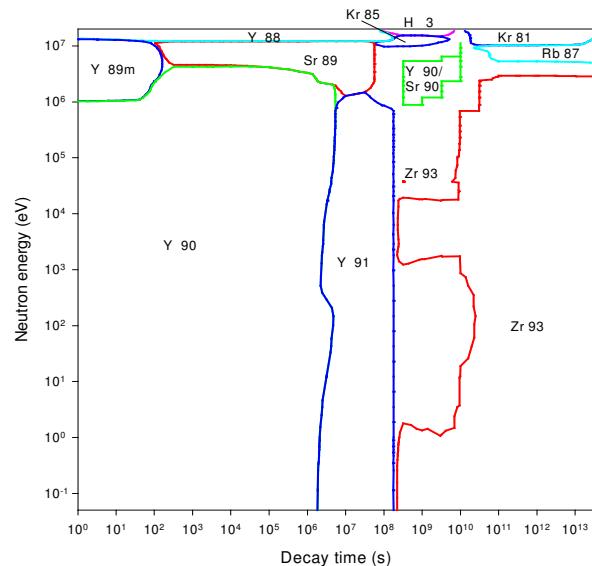
Kr81	$2.1 \cdot 10^5$ y	$\&Y89(n,\alpha)Rb86(\beta^-)Sr86(n,\alpha)Kr83(n,2n)Kr82(n,2n)Kr81$ $\&Y89(n,\alpha)Rb86(\beta^-)Sr86(n,2n)Sr85(\beta^+)Rb85(n,\alpha)$ $Br82(\beta^-)Kr82(n,2n)Kr81$ $\&Y89(n,\alpha)Rb86(\beta^-)Sr86(n,2n)Sr85(n,2n)Sr84(n,\alpha)Kr81$ $\&Y89(n,\alpha)Rb86(\beta^-)Sr86(n,2n)Sr85(n,\alpha)Kr82(n,2n)Kr81$ $\&Y89(n,2n)Y88(n,\alpha)Rb85(n,\alpha)Br82(\beta^-)Kr82(n,2n)Kr81$ $\&Y89(n,\alpha)Rb86(\beta^-)Sr86(n,n\alpha)Kr82(n,2n)Kr81$ $\&Y89(n,2n)Y88(\beta^+)Sr88(n,2n)Sr87(n,2n)Sr86(n,\alpha)$ $Kr83(n,2n)Kr82(n,2n)Kr81$ $\&Y89(n,\alpha)Rb86(\beta^-)Sr86(n,2n)Sr85(n,n\alpha)Kr81$ $\&Y89(n,2n)Y88(\beta^+)Sr88(n,2n)Sr87(n,\alpha)Kr84(n,2n)$ $Kr83(n,2n)Kr82(n,2n)Kr81$ $\&Y89(n,\alpha)Rb86(\beta^-)Sr86(n,2n)Sr85(\beta^+)Rb85(n,2n)$ $Rb84(\beta^+)Kr84(n,2n)Kr83(n,2n)Kr82(n,2n)Kr81$ $\&Y89(n,2n)Y88(\beta^+)Sr88(n,\alpha)Kr85m(\beta^-)Rb85(n,\alpha)$ $Br82(\beta^-)Kr82(n,2n)Kr81$ $\&Y89(n,2n)Y88(n,\alpha)Rb85(n,2n)Rb84(\beta^+)Kr84(n,2n)$ $Kr83(n,2n)Kr82(n,2n)Kr81$ $\&Y89(n,2n)Y88(\beta^+)Sr88(n,\alpha)Kr85(n,2n)Kr84(n,2n)$ $Kr83(n,2n)Kr82(n,2n)Kr81$ $\&Y89(n,2n)Y88(n,2n)Y87(\beta^+)Sr87(n,2n)Sr86(n,\alpha)$ $Kr83(n,2n)Kr82(n,2n)Kr81$ $\&Y89(n,2n)Y88(n,2n)Y87(\beta^+)Sr87(n,\alpha)Kr84(n,2n)$ $Kr83(n,2n)Kr82(n,2n)Kr81$ $\&Y89(n,2n)Y88(\beta^+)Sr88(n,2n)Sr87(n,2n)Sr86(n,2n)$ $Sr85(n,2n)Sr84(n,\alpha)Kr81$ $\&Y89(n,2n)Y88(\beta^+)Sr88(n,2n)Sr87(n,2n)Sr86(n,2n)$ $Sr85(n,\alpha)Kr82(n,2n)Kr81$ $Y89(n,\alpha)Rb86(\beta^-)Sr86(n,2n)Sr85(\beta^+)Rb85(n,d)$ $Kr84(n,2n)Kr83(n,2n)Kr82(n,2n)Kr81$ $*Plus other similar pathways involving (n,2n), (n,\alpha), (\beta^+), etc$				28.1 10.2  7.1 6.8 5.9 5.4 2.9  2.1 2.1  2.0  1.7  1.7  1.4  1.8  1.3  1.0  1.0  1.0  1.0  16.5*
Zr93	$1.5 \cdot 10^6$ y	$\&Y89(n,\gamma)Y90(n,\gamma)Y91(\beta^-)Zr91(n,\gamma)Zr92(n,\gamma)Zr93$ $\&Y89(n,\gamma)Y90(\beta^-)Zr90(n,\gamma)Zr91(n,\gamma)Zr92(n,\gamma)Zr93$ $\&Y89(n,\gamma)Y90(n,\gamma)Y91(n,\gamma)Y92(\beta^-)Zr92(n,\gamma)Zr93$	72.0 15.6 12.4	79.5 18.1 2.4	7.0 92.5 0.5	1.4 98.4 0.1
Rb87	$4.8 \cdot 10^{10}$ y	$\&Y89(n,\alpha)Rb86(n,\gamma)Rb87$ $Y89(n,\gamma)Y90(n,\alpha)Rb87$ $\&Y89(n,\alpha)Rb86(\beta^-)Sr86(n,\gamma)Sr87m(\beta^+)Rb87$ $Y89(n,2n)Y88(\beta^+)Sr88(n,d)Rb87$ $\&Y89(n,2n)Y88(\beta^+)Sr88(n,2n)Sr87(n,p)Rb87$ $Y89(n,2n)Y88(\beta^+)Sr88(n,2n)Sr87m(\beta^+)Rb87$ $Y89(n,d)Sr88(n,d)Rb87$ $\&Y89(n,2n)Y88(n,2n)Y87(\beta^+)Sr87(n,p)Rb87$ $\&Y89(n,d)Sr88(n,2n)Sr87(n,p)Rb87$ $Y89(n,h)Rb87$ $Y89(n,d)Sr88(n,2n)Sr87m(\beta^+)Rb87$	99.8 0.2	100.0	96.4 0.5 3.1	58.5 14.7 11.1 6.0 4.7 1.6 1.3 1.1

# Yttrium activation characteristics

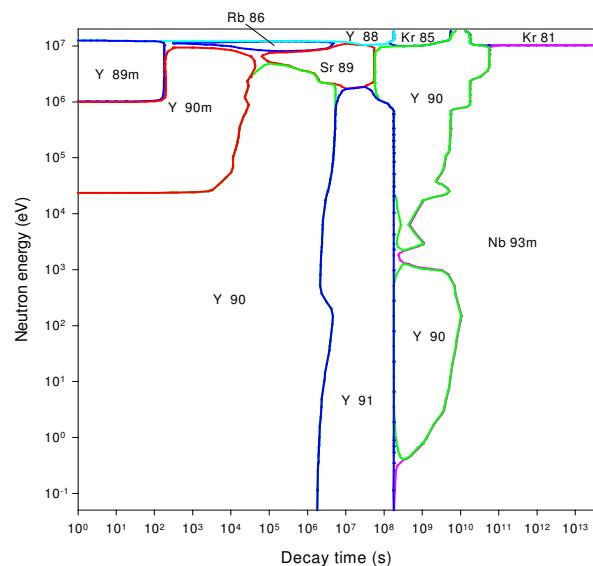


# Yttrium importance diagrams & transmutation

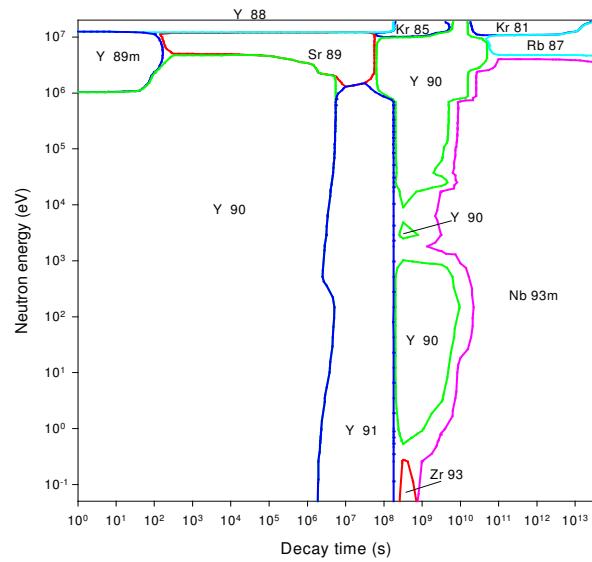
## Activity



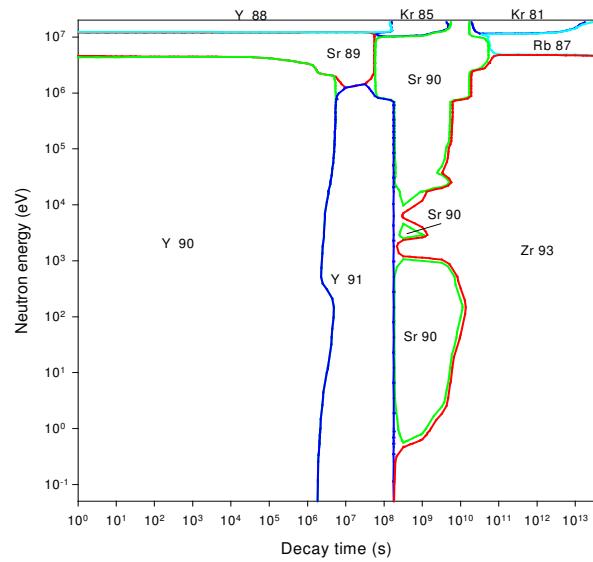
## Dose rate



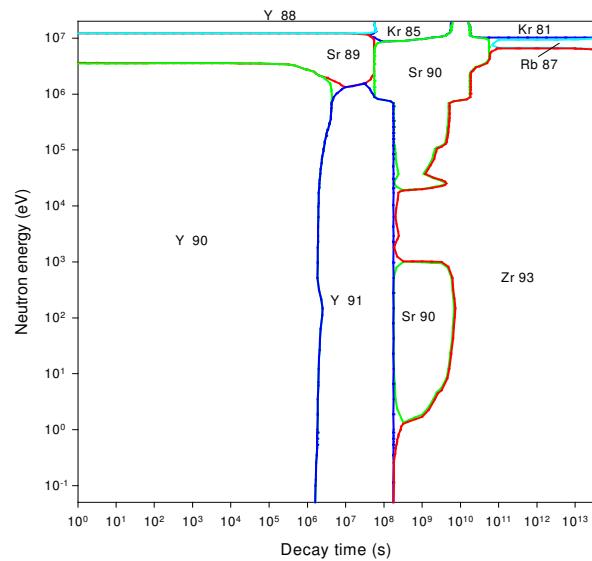
## Heat output



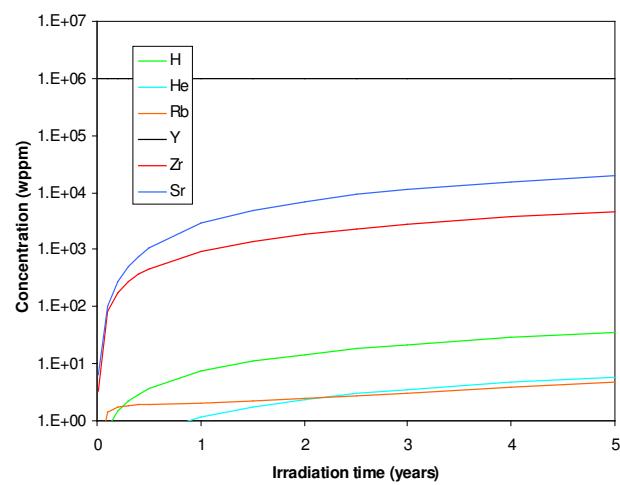
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Zirconium

## General properties

Atomic number	40	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	165	Zr90	51.45
Melting point / K	2128	Zr91	11.22
Boiling point / K	4682	Zr92	17.15
Density / kgm <sup>-3</sup>	6506	Zr94	17.38
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	22.7	Zr96	2.80
Electrical resistivity /Ωm	4.21 10 <sup>-7</sup>		
Coefficient of thermal expansion / K <sup>-1</sup>	5.70 10 <sup>-6</sup>		
Crystal structure	HCP		
Number of stable isotopes	5		
Mean atomic weight	91.224		

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.44E15	8.67E14	4.03E14	4.52E12	3.21E9	1.09E9	kW kg <sup>-1</sup>	3.04E-1	1.02E-1	4.68E-2	7.44E-4	1.89E-7	4.47E-9
Zr90m	36.86						Zr90m	64.85					
Y89m	20.39	31.94	31.67				Y89m	14.07	39.69	39.68			
Zr89	19.24	31.98	31.71				Zr89	5.06	15.16	15.15			
Zr95	4.44	7.38	15.25	27.15			Zr95	2.86	8.56	17.84	22.41		
Nb95	4.30	7.15	15.38	58.57			Nb95	2.64	7.90	17.15	46.07		
Zr89m	2.96	2.06					Nb97	2.38	7.15	0.43			
Nb97	2.77	4.61	0.27				Zr97	1.94	5.80	0.35			
Zr97	2.77	4.59	0.27				Zr89m	1.51	1.89				
Nb97m	2.62	4.35	0.26				Nb97m	1.48	4.42	0.26			
Y90	1.44	2.39	2.03	0.24	31.20		Y90	1.02	3.05	2.61	0.22	79.34	
Y88	0.39	0.64	1.35	11.49			Y88	0.79	2.37	5.02	30.20		
Y91	0.33	0.55	1.14	1.42			Y91	0.15	0.46	0.95	0.84		
H3				0.31	1.65		Sr90				0.05	16.63	
Sr90				0.24	31.20		Nb94					1.57	2.08
Zr93				0.01	18.03	50.60	Nb93m					1.47	59.81
Nb93m					17.46	49.33	Zr93					0.94	37.96
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	5.45E5	1.28E5	6.40E4	1.12E3	5.42E-3	1.67E-4	Sv kg <sup>-1</sup>	4.89E5	4.88E5	2.43E5	3.90E3	3.15E1	6.74E-1
Zr90m	75.16						Zr89	44.79	44.84	41.50			
Y89m	12.96	52.09	47.86				Zr97	17.15	17.12	0.95			
Zr89	2.59	11.04	10.15				Zr95	12.42	12.44	24.00	29.88		
Nb95	2.06	8.78	17.51	42.63			Y90	11.44	11.45	9.07	0.75	8.59	
Zr95	2.03	8.67	16.60	18.89			Nb95	7.34	7.36	14.78	39.35		
Nb97m	1.20	5.10	0.28				Y91	2.35	2.35	4.53	3.95		
Nb97	1.16	4.97	0.27				Y88	1.48	1.48	2.90	17.30		
Zr89m	1.07	1.91					Sr99	0.95	0.95	1.81	0.79		
Y88	0.85	3.62	7.05	38.46			Nb97	0.56	0.56	0.03			
Zr97	0.37	1.57	0.09				Nb96	0.47	0.47	0.07			
Y90		0.02*	0.01*		20.60*		Sr90	0.06	0.06	0.13	7.75	89.07	
Nb94					78.21	79.67	Zr93				0.02	2.02	90.28
Nb93m					0.65	20.30	Nb93m					0.21	9.60

Inh	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>	Clear	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>
Sv kg <sup>-1</sup>	7.98E5	7.98E5	6.38E5	1.67E4	1.78E2	1.48E1		1.80E12	5.28E11	2.62E11	4.39E9	3.77E5	4.75E3
Zr95	47.27	47.29	56.79	43.25			Zr90m	68.82					
Zr89	19.11	19.11	11.01				Y89m	14.89	47.67	44.30			
Nb95	13.97	13.97	17.47	28.46			Zr89	4.07	13.82	12.84			
Y91	5.33	5.34	6.39	3.41			Zr95	2.74	9.32	18.05	21.49		
Zr97	4.60	4.59	0.16				Nb95	2.65	9.03	18.21	46.35		
Y90	3.89	3.89	1.92	0.10	0.85		Nb97	1.59	5.41	0.30			
Y88	3.06	3.06	3.74	13.64			Nb97m	1.51	5.10	0.28			
Sr89	1.76	1.76	2.09	0.56			Zr89m	1.49	2.11				
Nb97	0.23	0.23	0.01				Y88	0.84	2.84	5.60	31.94		
Sr90	0.22	0.22	0.28	10.33	90.13		Zr97	0.59	1.98	0.11			
Nb96	0.17	0.17	0.02				Nb96	0.28	0.96	0.14			
Y90m	0.08	0.08					Y90m	0.23	0.75				
Nb95m	0.08	0.08	0.10	0.07			Sr90				0.08	88.66	
Zr93				0.09	8.14	93.31	Nb94					9.43	23.42
Nb94					0.29	0.11	Zr93					0.30	22.42
Nb93m					0.57	6.55	Nb93m					0.71	54.13

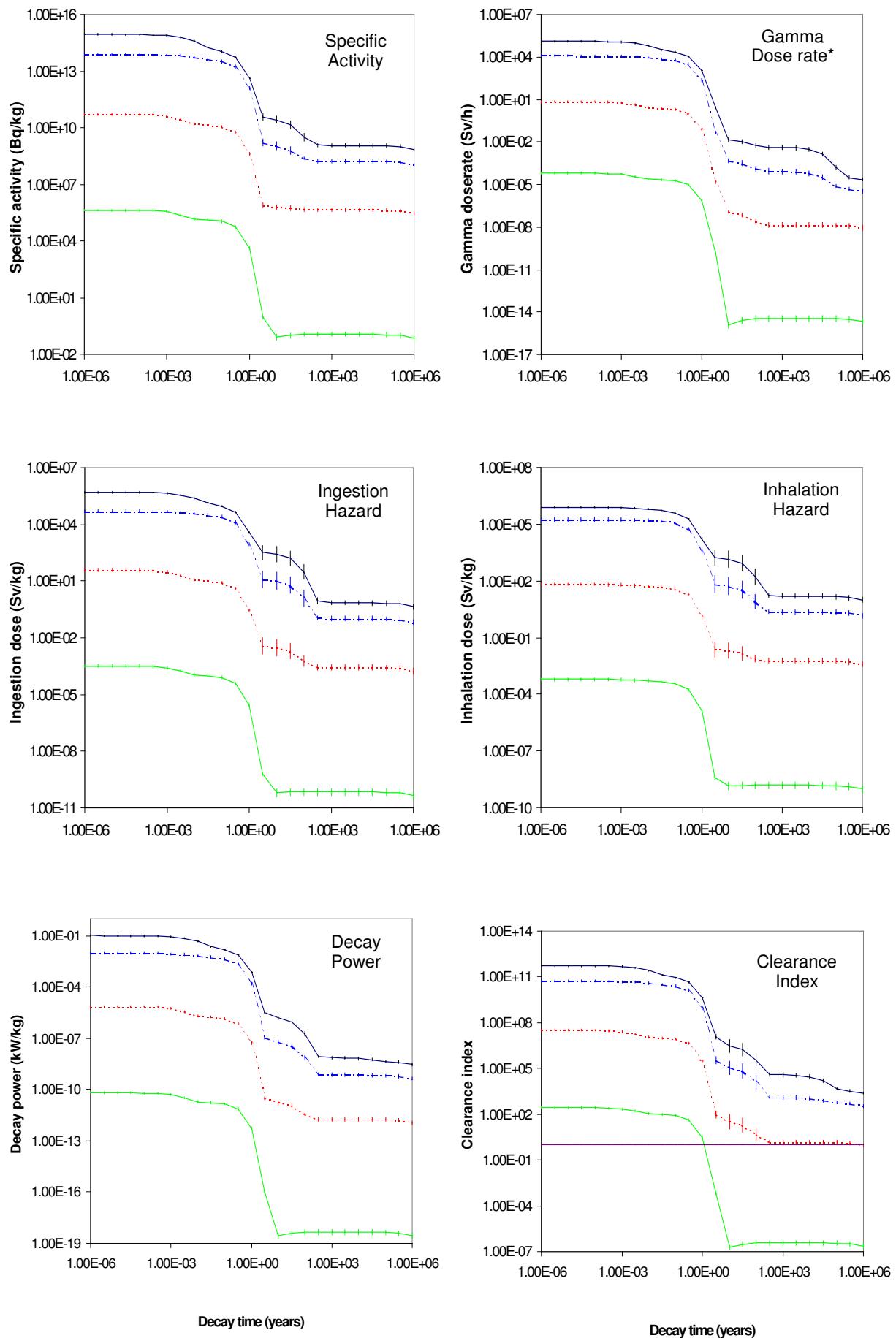
# Zirconium

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Zr90m	0.83 s	Zr90(n,n')Zr90m Zr91(n,2n)Zr90m Zr92(n,2n)Zr91(n,2n)Zr90m Zr91(n,2n)Zr90(n,n')Zr90m				69.1 20.1 6.6 1.4
Y89m	16.05 s	Zr92(n, $\alpha$ )Sr89( $\beta^-$ )Y89m Zr91(n, $\gamma$ )Zr92(n, $\alpha$ )Sr89( $\beta^-$ )Y89m Zr91(n, $\alpha$ )Sr88(n, $\gamma$ )Sr89( $\beta^-$ )Y89m <b>&amp;Zr90(n,2n)Zr89(<math>\beta^+</math>)Y89m</b> <b>&amp;Zr91(n,2n)Zr90(n,2n)Zr89(<math>\beta^+</math>)Y89m</b> Zr90(n,d)Y89m	95.1 4.8	99.2 0.8	99.4	85.9 3.9 3.3
Zr97	16.9 h	Zr96(n, $\gamma$ )Zr97	100.0	100.0	100.0	99.9
Y90	2.671 d	Zr92(n, $\alpha$ )Sr89( $\beta^-$ )Y89(n, $\gamma$ )Y90 Zr91(n, $\gamma$ )Zr92(n, $\alpha$ )Sr89( $\beta^-$ )Y89(n, $\gamma$ )Y90 Zr92(n, $\gamma$ )Zr93(n, $\alpha$ )Sr90( $\beta^-$ )Y90 <b>&amp;Zr91(n,<math>\alpha</math>)Sr88(n,<math>\gamma</math>)Sr89(<math>\beta^-</math>)Y89(n,<math>\gamma</math>)Y90</b> <b>&amp;Zr90(n,p)Y90</b> <b>&amp;Zr91(n,d)Y90</b> <b>&amp;Zr91(n,2n)Zr90(n,p)Y90</b> <b>&amp;Zr92(n,2n)Zr91(n,d)Y90</b>	96.4 2.5 1.0	99.2 0.4 0.4	0.1 99.1	83.1 8.4 3.7 2.7
Zr89	3.267 d	<b>&amp;Zr90(n,2n)Zr89</b> <b>&amp;Zr91(n,2n)Zr90(n,2n)Zr89</b> <b>&amp;Zr92(n,2n)Zr91(n,2n)Zr90(n,2n)Zr89</b>				94.4 4.3 0.6
Nb95	34.975 d	<b>&amp;Zr94(n,<math>\gamma</math>)Zr95(<math>\beta^-</math>)Nb95</b> <b>&amp;Zr96(n,2n)Zr95(<math>\beta^-</math>)Nb95</b>	99.9	100.0	100.0	0.4 98.8
Y91	58.7 d	<b>&amp;Zr94(n,<math>\alpha</math>)Sr91(<math>\beta^-</math>)Y91</b> <b>&amp;Zr91(n,p)Y91</b> <b>&amp;Zr92(n,2n)Zr91(n,p)Y91</b> <b>&amp;Zr92(n,d)Y91</b>	99.9	100.0	100.0	13.1 54.4 16.9 14.3
Zr95	64.03 d	Zr94(n, $\gamma$ )Zr95 Zr96(n,2n)Zr95	99.9	100.0	100.0	0.4 99.5
Y88	106.63 d	<b>&amp;Zr90(n,2n)Zr89(<math>\beta^+</math>)Y89(n,2n)Y88</b> <b>&amp;Zr90(n,d)Y89(n,2n)Y88</b> <b>&amp;Zr91(n,2n)Zr90(n,2n)Zr89(<math>\beta^+</math>)Y89(n,2n)Y88</b>				86.7 9.0 1.8
Kr85	10.73 y	<b>&amp;Zr90(n,2n)Zr89(<math>\beta^+</math>)Y89(n,2n)Y88(<math>\beta^+</math>)Sr88(n,<math>\alpha</math>)Kr85</b> <b>&amp;Zr90(n,2n)Zr89(<math>\beta^+</math>)Y89(n,d)Sr88(n,<math>\alpha</math>)Kr85</b> <b>&amp;Zr91(n,<math>\alpha</math>)Sr88(n,<math>\alpha</math>)Kr85</b> <b>&amp;Zr90(n,d)Y89(n,2n)Y88(<math>\beta^+</math>)Sr88(n,<math>\alpha</math>)Kr85</b> <b>&amp;Zr92(n,<math>\alpha</math>)Sr88(n,<math>\alpha</math>)Kr85</b>				70.8 7.8 7.7 7.4 1.1
H3	12.33 y	Zr91(n,X)H3 Zr90(n,X)H3 Zr92(n,2n)Zr91(n,X)H3 Zr94(n,2n)Zr93(n,X)H3 Zr92(n,X)H3 Zr94(n,X)H3 <b>&amp;Zr90(n,2n)Zr89(<math>\beta^+</math>)Y89(n,X)H3</b>				44.5 27.2 7.3 5.3 5.2 3.5 3.4
Nb93m	16.126 y	Zr92(n, $\gamma$ )Zr93( $\beta^-$ )Nb93m Zr91(n, $\gamma$ )Zr92(n, $\gamma$ )Zr93( $\beta^-$ )Nb93m <b>&amp;Zr96(n,2n)Zr95(<math>\beta^-</math>)Nb95(n,2n)Nb94(n,2n)Nb93m</b> <b>&amp;Zr96(n,2n)Zr95(<math>\beta^-</math>)Nb95(<math>\beta^-</math>)Mo95(n,2n)Mo94(n,d)Nb93m</b> Zr94(n,2n)Zr93( $\beta^-$ )Nb93m <b>&amp;Zr96(n,2n)Zr95(<math>\beta^-</math>)Nb95(<math>\beta^-</math>)Mo95(n,d)Nb94(n,2n)Nb93m</b> <b>&amp;Zr96(n,2n)Zr95(<math>\beta^-</math>)Nb95(<math>\beta^-</math>)Mo95(n,t)Nb93m</b> <b>&amp;Zr96(n,2n)Zr95(<math>\beta^-</math>)Nb95(n,2n)Nb94(n,2n)</b> Nb93(n,n')Nb93m	98.2 1.8	99.7 0.3	99.8 0.2	48.4 31.7 6.6 4.9 3.6 1.7

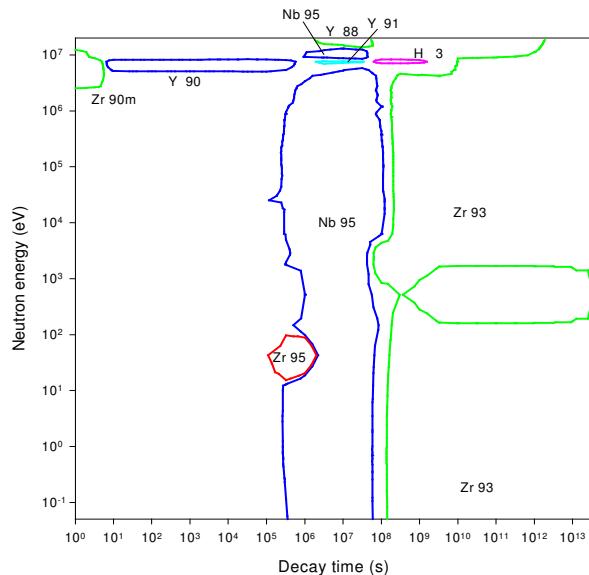
Sr90	28.868 y	Zr92(n, $\gamma$ )Zr93(n, $\alpha$ )Sr90 Zr92(n, $\alpha$ )Sr89(n, $\gamma$ )Sr90 Zr91(n, $\gamma$ )Zr92(n, $\gamma$ )Zr93(n, $\alpha$ )Sr90 Zr91(n, $\alpha$ )Sr88(n, $\gamma$ )Sr89(n, $\gamma$ )Sr90 Zr94(n,n $\alpha$ )Sr90 Zr94(n,2n)Zr93(n, $\alpha$ )Sr90	85.3 12.8 1.5	73.5 26.2 0.2	12.4 87.2	52.5 46.9
Mo93	3011.6 y	<b>&amp;Zr96(n,2n)Zr95(<math>\beta^-</math>)Nb95(<math>\beta^-</math>)Mo95(n,2n)Mo94(n,2n)Mo93</b>				99.3
Nb94	19986 y	<b>&amp;Zr92(n,<math>\gamma</math>)Zr93(<math>\beta^-</math>)Nb93m(n,<math>\gamma</math>)Nb94</b> <b>&amp;Zr92(n,<math>\gamma</math>)Zr93(<math>\beta^-</math>)Nb93(n,<math>\gamma</math>)Nb94</b> <b>&amp;Zr91(n,<math>\gamma</math>)Zr92(n,<math>\gamma</math>)Zr93(<math>\beta^-</math>)Nb93m(n,<math>\gamma</math>)Nb94</b> <b>&amp;Zr96(n,2n)Zr95(<math>\beta^-</math>)Nb95(n,2n)Nb94</b> <b>&amp;Zr96(n,2n)Zr95(<math>\beta^-</math>)Nb95(<math>\beta^-</math>)Mo95(n,d)Nb94</b> <b>&amp;Zr96(n,2n)Zr95(<math>\beta^-</math>)Nb95(<math>\beta^-</math>)Mo95(n,2n)Mo94(n,p)Nb94</b>	91.0 7.6 1.3	91.8 7.9 0.1	92.4 7.5	83.6 12.5 3.0
Tc99	$2.1 \cdot 10^5$ y	<b>&amp;Zr96(n,<math>\gamma</math>)Zr97(<math>\beta^-</math>)Nb97(<math>\beta^-</math>)Mo97(n,<math>\gamma</math>)Mo98(n,<math>\gamma</math>)Mo99(<math>\beta^-</math>)Tc99</b> <b>&amp;Zr94(n,<math>\gamma</math>)Zr95(<math>\beta^-</math>)Nb95(<math>\beta^-</math>)Mo95(n,<math>\gamma</math>)Mo96(n,<math>\gamma</math>)Mo97(n,<math>\gamma</math>)Mo98(n,<math>\gamma</math>)Mo99(<math>\beta^-</math>)Tc99</b>	98.6 1.4	93.1 6.9	100.0	100.0
Zr93	$1.5 \cdot 10^6$ y	Zr92(n, $\gamma$ )Zr93 Zr91(n, $\gamma$ )Zr92(n, $\gamma$ )Zr93 Zr94(n,2n)Zr93 <b>&amp;Zr94(n,d)Y93(<math>\beta^-</math>)Zr93</b>	97.4 2.6	99.6 0.4	99.7 0.3	0.1 99.6 0.2

# Zirconium activation characteristics

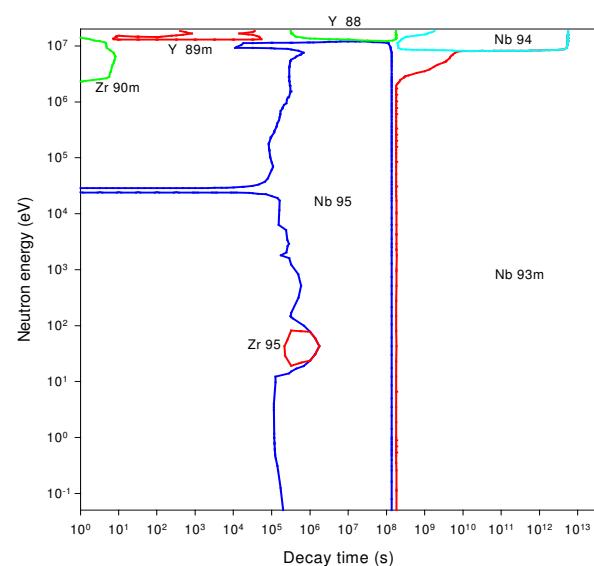


# Zirconium importance diagrams & transmutation

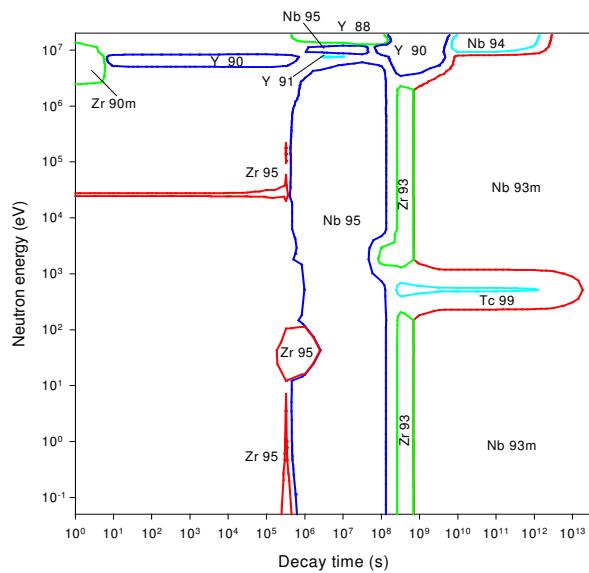
## Activity



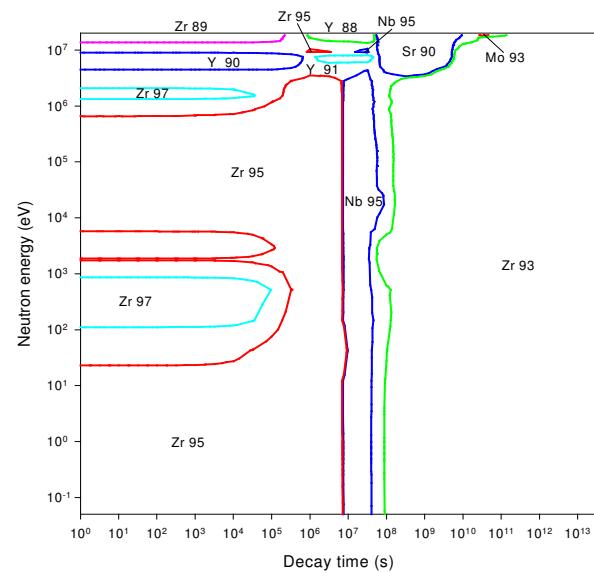
## Dose rate



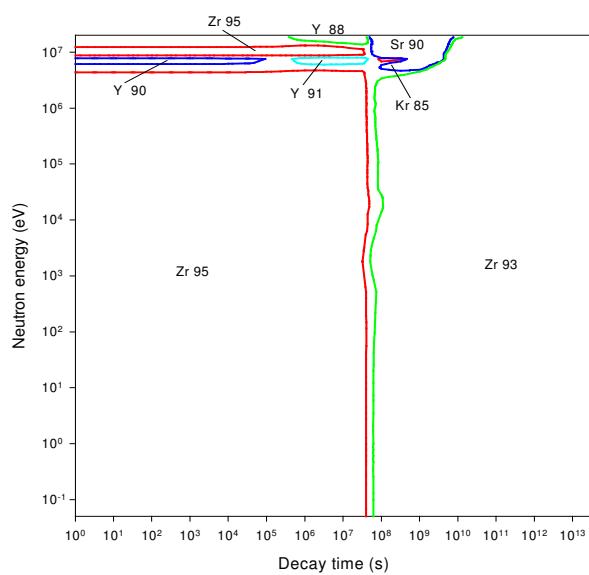
## Heat output



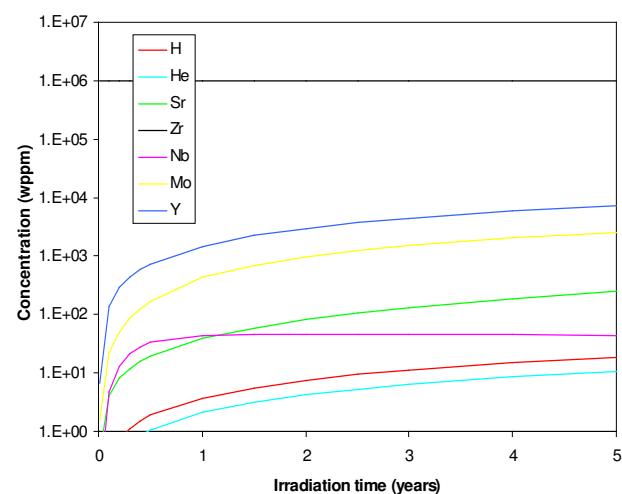
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Niobium

## General properties

Atomic number	41	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	20	Nb93	100.0
Melting point / K	2750		
Boiling point / K	5017		
Density / kgm <sup>-3</sup>	8570		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	53.7		
Electrical resistivity /Ωm	1.25 10 <sup>-7</sup>		
Coefficient of thermal expansion / K <sup>-1</sup>	7.3 10 <sup>-6</sup>		
Crystal structure	BCC		
Number of stable isotopes	1		
Mean atomic weight	92.90638		

## Activation properties

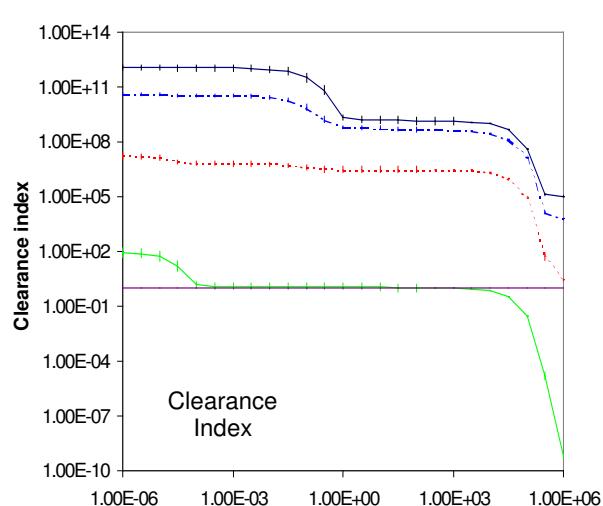
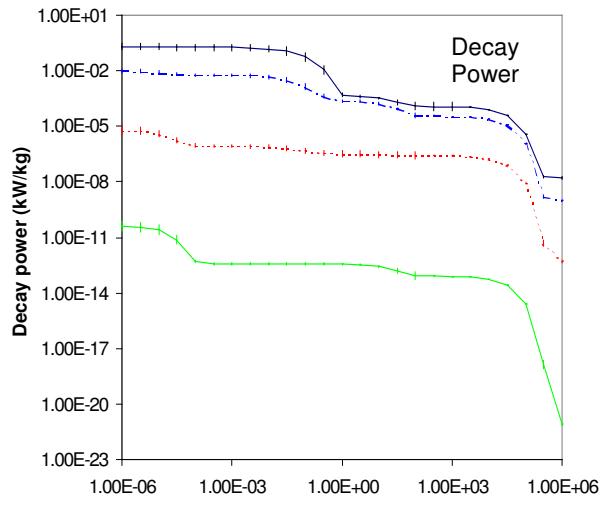
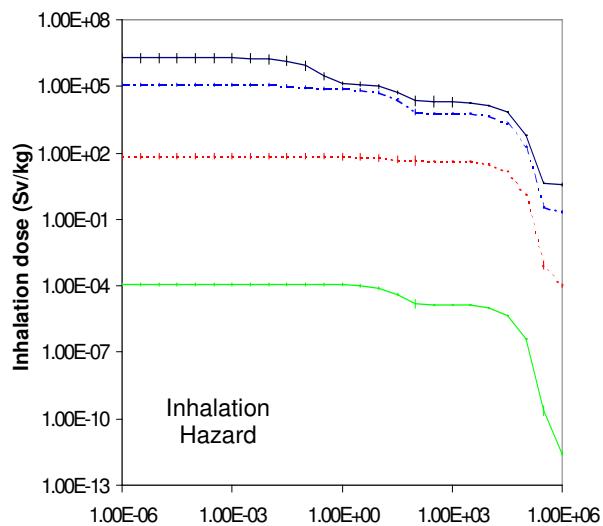
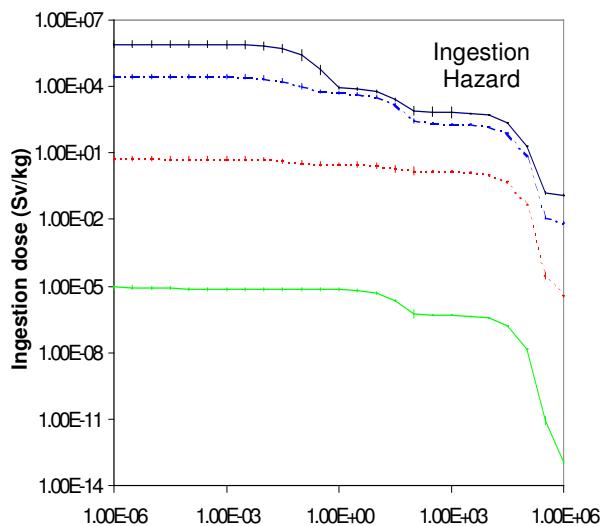
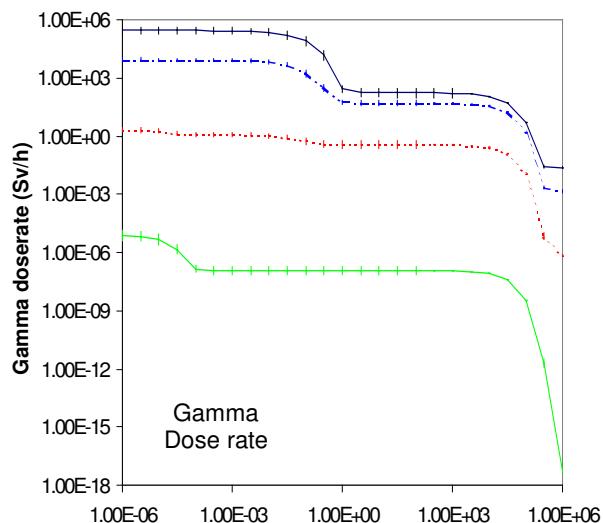
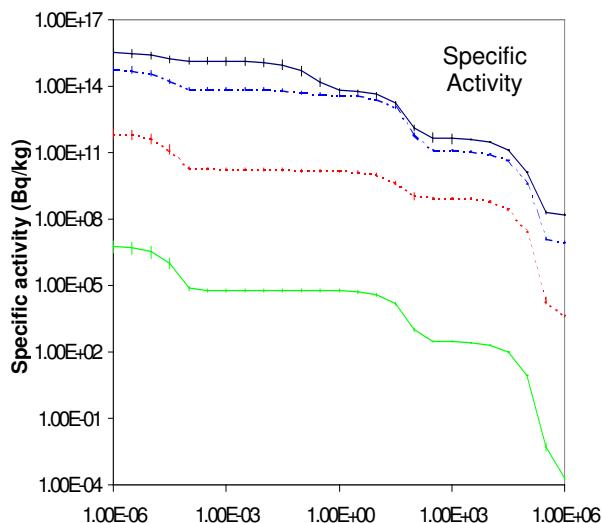
Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	3.35E15	2.48E15	1.18E15	6.48E13	1.37E12	1.33E10	kW kg <sup>-1</sup>	2.03E-1	1.96E-1	1.53E-1	5.12E-4	1.21E-4	3.66E-6
Nb94m	58.58	44.19					Nb95	51.81	53.69	64.25	14.85		
Nb95	24.26	32.75	64.14	0.91			Nb92m	32.73	33.91	33.94			
Nb92m	12.69	17.13	28.05				Nb94m	7.33	4.24				
Nb93m	1.98	2.68	5.63	98.21	66.09	0.48	Nb96	5.77	5.97	0.57			
Nb95m	1.00	1.35	1.41				Y90	0.85	0.88	0.45	0.01		
Nb96	0.82	1.10	0.17				Nb95m	0.65	0.67	0.43			
Nb94	0.01	0.02	0.04	0.65	30.60	98.51	Nb93m	0.16	0.17	0.22	61.57	3.69	0.01
Nb91				0.08	3.27		Nb94	0.06	0.06	0.08	22.85	96.18	99.53
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	2.74E5	2.72E5	2.21E5	2.78E2	1.65E2	5.17E0	Sv kg <sup>-1</sup>	8.18E5	8.18E5	6.72E5	8.74E3	8.23E2	2.24E1
Nb95	52.91	53.32	61.17	37.64			Nb95	57.54	57.57	65.29	3.89		
Nb92m	39.45	39.74	38.12				Nb92m	31.14	31.15	29.54			
Nb96	5.94	5.97	0.55				Y90	3.82	3.82	1.84	0.01	0.01	
Nb94m	0.98	0.55					Nb96	3.68	3.67	0.33			
Nb94	0.06	0.06	0.08	59.29	99.93	99.53	Nb95m	2.29	2.29	1.38			
Y88	0.02	0.02	0.02	1.65			Nb93m	0.97	0.97	1.19	87.39	13.17	0.03
Nb93m				1.32	0.03		Nb94	0.09	0.09	0.11	8.16	86.36	99.30
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	1.93E6	1.93E6	1.73E6	1.37E5	2.23E4	6.45E2		1.16E12	1.14E12	9.22E11	2.17E9	1.40E9	4.37E7
Nb95	75.88	75.89	78.82	0.77			Nb95	53.88	54.68	63.16	20.79		
Nb92m	13.01	13.01	11.30				Nb92m	36.65	37.19	35.91			
Nb93m	6.21	6.21	6.92	83.89	7.29	0.02	Nb96	5.76	5.83	0.54			
Nb95m	1.53	1.53	0.85				Nb94m	2.69	1.52				
Nb94	1.07	1.07	1.19	15.06	91.85	99.32	Nb95m	0.26	0.27	0.16			
Nb96	0.94	0.94	0.08				Nb94	0.12	0.12	0.15	64.44	99.64	99.76
Y90	0.90	0.90	0.40				Nb93m	0.03	0.03	0.03	13.96	0.31	

# Niobium

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Zr90m	0.83 s	Nb93(n,2n)Nb92m( $\beta^+$ )Zr92(n,2n)Zr91(n,2n)Zr90m <b>&amp;Nb93(n,2n)Nb92(n,2n)Nb91(n,d)Zr90m</b> <b>&amp;Nb93(n,<math>\alpha</math>)Y90(<math>\beta^-</math>)Zr90(n,n')Zr90m</b> Nb93(n,d)Zr92(n,2n)Zr91(n,2n)Zr90m <b>&amp;Nb93(n,2n)Nb92(n,2n)Nb91(n,2n)Nb90(<math>\beta^+</math>)Zr90(n,n')Zr90m</b> Nb93(n,2n)Nb92(n,d)Zr91(n,2n)Zr90m Nb93(n,2n)Nb92m( $\beta^+$ )Zr92(n,2n)Zr91(n,2n)Zr90(n,n')Zr90m				58.6 15.6 11.5 2.8 2.1 1.9 1.3
Nb94m	6.26 m	Nb93(n, $\gamma$ )Nb94m Nb93(n,n')Nb93m(n, $\gamma$ )Nb94m Nb93(n, $\gamma$ )Nb94(n,n')Nb94m	100.0	100.0	100.0	97.9 0.7 0.4
Y90m	3.19 h	Nb93(n, $\alpha$ )Y90m Nb93(n,2n)Nb92m( $\beta^+$ )Zr92(n,2n)Zr91(n,d)Y90m Nb93(n,n')Nb93m(n, $\alpha$ )Y90m Nb93(n, $\alpha$ )Y90( $\beta^-$ )Zr90(n,p)Y90m	100.0	100.0	100.0	98.0 0.6 0.4 0.3
Nb96	23.35 h	<b>&amp;Nb93(n,<math>\gamma</math>)Nb94(n,<math>\gamma</math>)Nb95(n,<math>\gamma</math>)Nb96</b> <b>&amp;Nb93(n,<math>\gamma</math>)Nb94(n,<math>\gamma</math>)Nb95m(n,<math>\gamma</math>)Nb96</b>	99.9	99.9	99.6	95.9 2.4
Y90	64.11 h	Nb93(n, $\alpha$ )Y90 Nb93(n, $\alpha$ )Y90m(IT)Y90 <b>&amp;Nb93(n,2n)Nb92m(<math>\beta^+</math>)Zr92(n,2n)Zr91(n,d)Y90</b>	50.0 50.0	50.0 50.0	50.0 50.0	54.1 43.3 0.9
Nb92m	10.15 d	Nb93(n,2n)Nb92m Nb93(n,2n)Nb92(n,n')Nb92m Nb93(n,n')Nb93m(n,2n)Nb92m				96.4 2.3 1.0
Nb95	34.975 d	<b>&amp;Nb93(n,<math>\gamma</math>)Nb94(n,<math>\gamma</math>)Nb95</b> Nb93(n,p)Zr93(n, $\gamma$ )Zr94(n, $\gamma$ )Zr95( $\beta^-$ )Nb95 Nb93(n,n')Nb93m(n, $\gamma$ )Nb94m(IT)Nb94(n, $\gamma$ )Nb95	100.0	100.0	100.0	99.1 0.2 0.2
Y88	106.63 d	<b>&amp;Nb93(n,n<math>\alpha</math>)Y89(n,2n)Y88</b> <b>&amp;Nb93(n,2n)Nb92(n,2n)Nb91(n,<math>\alpha</math>)Y88</b> <b>&amp;Nb93(n,2n)Nb92(n,<math>\alpha</math>)Y89(n,2n)Y88</b> <b>&amp;Nb93(n,<math>\alpha</math>)Y90(<math>\beta^-</math>)Zr90(n,2n)Zr89(<math>\beta^+</math>)Y89(n,2n)Y88</b> Nb93(n,2n)Nb92(n, $\alpha$ )Y88 Nb93(n,2n)Nb92m( $\beta^+$ )Zr92(n, $\alpha$ )Sr89( $\beta^-$ )Y89(n,2n)Y88 <b>&amp;Nb93(n,<math>\alpha</math>)Y90(<math>\beta^-</math>)Zr90(n,d)Y89(n,2n)Y88</b>				54.8 12.7 10.6 9.3 4.0 3.8 1.0
Nb93m	16.126 y	<b>&amp;Nb93(n,<math>\gamma</math>)Nb94(n,<math>\gamma</math>)Nb95(<math>\beta^-</math>)Mo95(n,<math>\alpha</math>)Zr92(n,<math>\gamma</math>)</b> Zr93( $\beta^-$ )Nb93m Nb93(n,p)Zr93( $\beta^-$ )Nb93m Nb93(n,n')Nb93m	98.4  1.4	100.0	100.0	100.0
Nb91	680.0 y	<b>&amp;Nb93(n,2n)Nb92(n,2n)Nb91</b> <b>&amp;Nb93(n,2n)Nb92m(n,2n)Nb91</b>				98.4 1.0
Nb94	19986 y	Nb93(n, $\gamma$ )Nb94m(IT)Nb94 Nb93(n, $\gamma$ )Nb94 <b>&amp;Nb93(n,n')Nb93m(n,<math>\gamma</math>)Nb94</b>	68.9 31.1	68.9 31.1	68.9 31.1	66.7 32.9 0.4
Tc99	$2.1 \cdot 10^5$ y	<b>&amp;Nb93(n,<math>\gamma</math>)Nb94(n,<math>\gamma</math>)Nb95(<math>\beta^-</math>)Mo95(n,<math>\gamma</math>)Mo96(n,<math>\gamma</math>)</b> Mo97(n, $\gamma$ )Mo98(n, $\gamma$ )Mo99( $\beta^-$ )Tc99 <b>&amp;Nb93(n,<math>\gamma</math>)Nb94(n,<math>\gamma</math>)Nb95(n,<math>\gamma</math>)Nb96(<math>\beta^-</math>)Mo96(n,<math>\gamma</math>)</b> Mo97(n, $\gamma$ )Mo98(n, $\gamma$ )Mo99( $\beta^-$ )Tc99	90.4  8.3	98.3 1.4	85.0 14.5	
Zr93	$1.5 \cdot 10^6$ y	Nb93(n, $\gamma$ )Nb94(n, $\gamma$ )Nb95( $\beta^-$ )Mo95(n, $\gamma$ )Mo96(n, $\alpha$ )Zr93 Nb93(n,p)Zr93 Nb93(n,n')Nb93m(n,p)Zr93	99.2 0.6	100.0	100.0	99.6 0.3
Nb92	$3.5 \cdot 10^7$ y	Nb93(n,2n)Nb92 Nb93(n,n')Nb93m(n,2n)Nb92				99.7 0.3

# Niobium activation characteristics

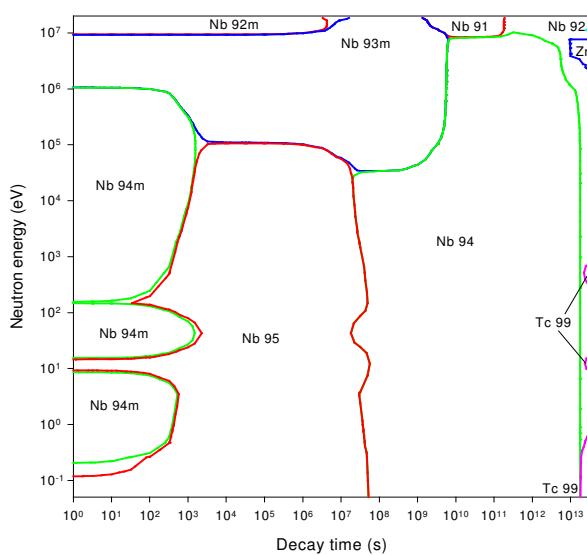


Decay time (years)

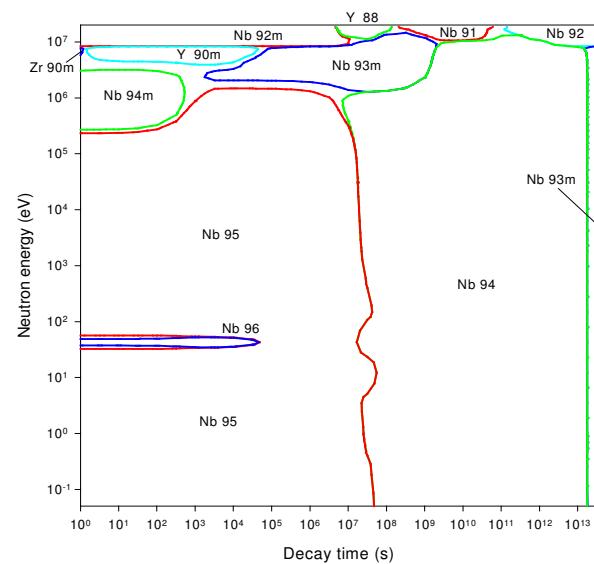
Decay time (years)

# Niobium importance diagrams & transmutation

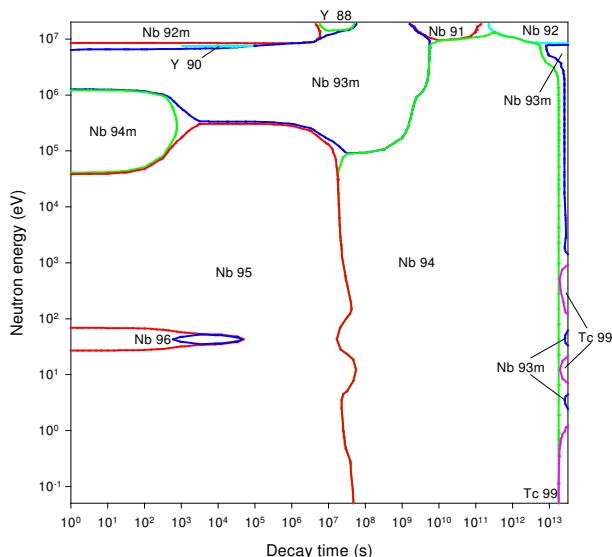
## Activity



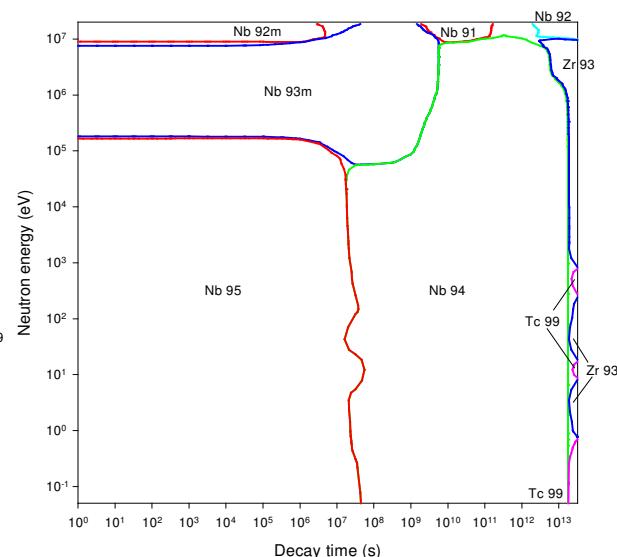
## Dose rate



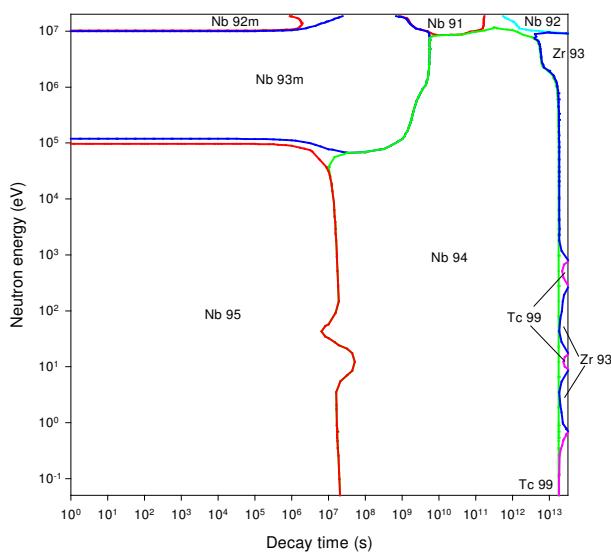
## Heat output



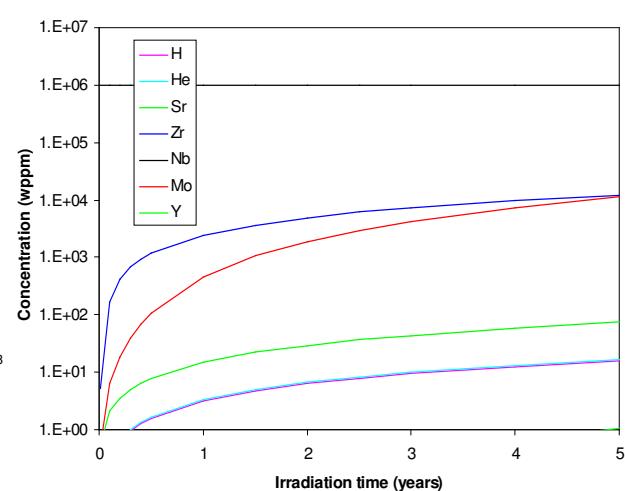
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Molybdenum

## General properties

Atomic number	42	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	1.2	Mo92	14.84
Melting point / K	2896	Mo94	9.25
Boiling point / K	4912	Mo95	15.92
Density / kgm <sup>-3</sup>	10220	Mo96	16.68
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	138	Mo97	9.55
Electrical resistivity /Ωm	5.2 10 <sup>-8</sup>	Mo98	24.13
Coefficient of thermal expansion / K <sup>-1</sup>	4.8 10 <sup>-6</sup>	Mo100	9.63
Crystal structure	BCC		
Number of stable isotopes	7		
Mean atomic weight	95.94		

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.64E15	1.35E15	4.90E14	1.37E12	7.85E11	5.05E9	kW kg <sup>-1</sup>	1.87E-1	1.17E-1	2.89E-2	2.65E-5	2.81E-6	8.99E-8
Mo99	34.20	41.73	45.59				Tc100	31.14					
Tc99m	30.57	37.33	44.19				Mo99	26.02	41.30	66.79			
Tc100	15.78						Mo101	19.19	23.75				
Tc101	6.81	8.09					Tc101	7.81	12.07				
Mo101	6.80	6.47					Tc99m	6.15	9.78	17.13			
Nb92m	1.22	1.49	3.19				Mo91	3.83	4.83				
Nb91m	1.20	1.47	3.86	22.50			Nb92m	1.68	2.67	8.46			
Mo91	1.12	1.08					Nb96	1.08	1.71	0.51			
Nb95	0.51	0.62	1.62	4.47			Nb95	0.58	0.92	3.55	29.99		
Nb96	0.29	0.35	0.07				Nb91m	0.22	0.35	1.38	24.52		
Y89m	0.21	0.25	0.31				Zr95	0.10	0.16	0.61	13.36		
Zr95	0.08	0.10	0.27	1.90			Y88		0.04	0.15	17.55		
Nb91		0.05	0.13	46.71	73.83		Nb91			0.01	7.14	60.98	
Nb93m			0.04	14.16	11.70	0.07	Nb93m				3.63	16.19	0.02
Mo93				0.02	7.88	13.47	Mo93				1.08	10.01	
Y88				0.02	0.78		Nb94				0.93	8.77	8.57
Tc99					0.51	0.89	Tc99				0.42	4.01	90.20
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	9.24E4	7.58E4	1.43E4	2.82E1	7.76E-1	1.24E-2	Sv kg <sup>-1</sup>	3.98E5	3.97E5	1.69E5	6.79E2	3.82E2	3.27E0
Mo101	48.06	45.67					Mo99	84.62	84.93	79.36			
Mo99	18.36	22.38	47.21				Nb91m	3.12	3.13	7.05	28.65		
Tc101	6.08	7.22					Nb92m	3.02	3.03	5.54			
Nb92m	5.55	6.77	27.94				Tc99m	2.77	2.79	2.82			
Tc100	4.83						Nb96	1.29	1.30	0.23			
Mo91	3.79	3.66					Nb95	1.22	1.22	2.72	5.24		
Nb96	3.03	3.68	1.45				Mo101	1.15	0.90				
Tc99m	2.33	2.85	6.51				Zr89	0.66	0.66	0.71			
Nb90	1.66	2.02	0.17				Tc101	0.53	0.52				
Nb95	1.62	1.98	9.93	38.97			Nb90	0.37	0.37	0.01			
Y89m	0.88	1.04	2.55				Zr95	0.32	0.33	0.73	3.65		
Zr95	0.25	0.31	1.56	15.82			Ru103	0.11	0.11	0.25	0.11		
Nb91m	0.18	0.22	1.13	9.34			Zr97	0.11	0.11	0.01			
Y88		0.11	0.57	31.60			Mo93	0.08	0.09	0.20	49.39	85.83	
Nb91				1.53	50.16		Y88	0.03	0.03	0.08	2.06		
Nb94				1.24	44.98	88.07	Nb91			0.02	6.04	9.71	
Mo93				0.11	4.03		Nb93m			0.01	3.44	2.89	0.01
Tc98					0.16	9.58	Tc99				0.66	1.17	98.18
Nb92					0.04	2.35	Nb94				0.22	0.39	1.44

Inh	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>	Clear	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>
Sv kg <sup>-1</sup>	6.65E5	6.63E5	3.08E5	4.41E3	2.92E3	6.68E1		4.70E11	3.66E11	7.56E10	1.26E8	1.23E7	1.15E5
Mo99	83.66	83.78	71.92				Mo101	36.06	36.06				
Nb91m	6.82	6.84	14.14	16.11			Mo99	22.16	28.41	54.76			
Nb95	2.26	2.27	4.64	2.51			Tc100	11.75					
Nb92m	1.78	1.78	2.99				Tc101	9.16	11.43				
Tc99m	1.51	1.51	1.41				Mo91	4.39	4.47				
Zr95	1.21	1.21	2.50	3.49			Nb92m	4.27	5.48	20.66			
Nb96	0.47	0.47	0.07				Tc99m	3.57	4.58	9.55			
Mo101	0.44	0.34					Nb96	2.43	3.11	1.12			
Nb91	0.39	0.39	0.85	59.61	81.40		Nb95	1.37	1.76	8.06	37.34		
Ru103	0.28	0.28	0.57	0.07			Nb90	1.10	1.41	0.11			
Zr89	0.27	0.28	0.27				Y89m	0.66	0.82	1.83			
Tc101	0.20	0.20					Zr95	0.22	0.29	1.33	15.86		
Nb95m	0.16	0.16	0.18	0.01			Nb91m	0.20	0.26	1.19	11.63		
Nb90	0.12	0.12					Y88		0.07	0.35	22.97		
Mo91	0.12	0.09					Nb91			0.01	6.67	62.23	
Y88	0.07	0.07	0.14	1.07			Nb94				2.34	24.04	79.95
Nb93m	0.05	0.05	0.12	7.94	5.66	0.01	Mo93				0.98	9.92	
Mo93	0.04	0.04	0.08	5.64	8.33		Nb93m				0.73	3.57	0.02
Tc99			0.03	2.05	3.10	97.54	Tc99				0.02	0.19	14.50
Nb94			0.01	0.99	1.48	2.03	Tc98					0.04	4.45
Tc98					0.01	0.24	Nb92					0.01	1.08

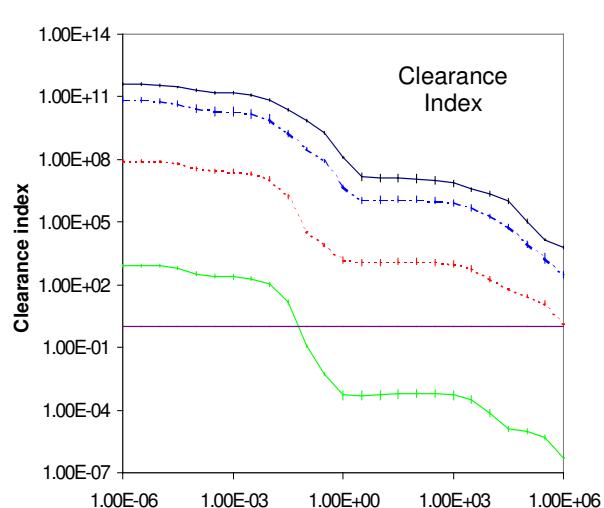
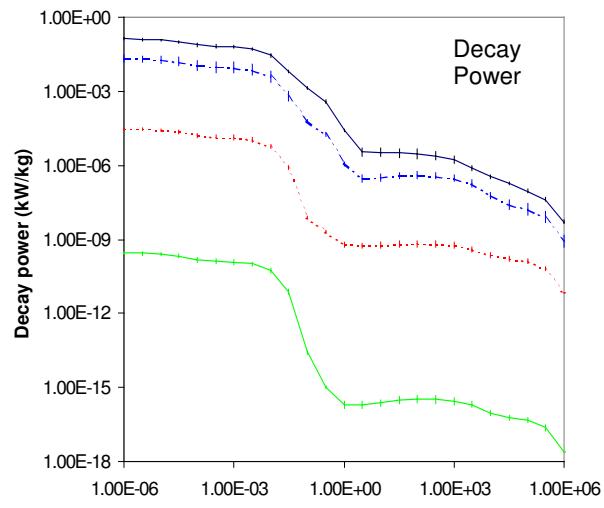
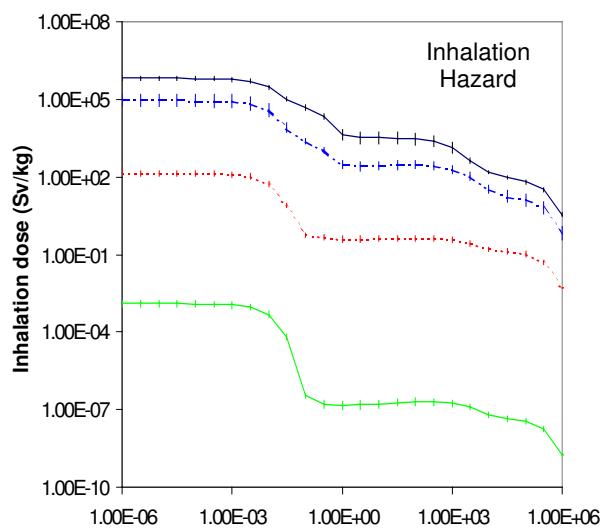
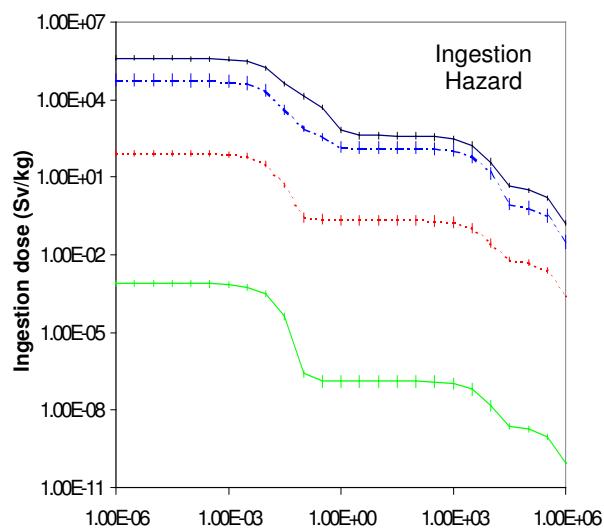
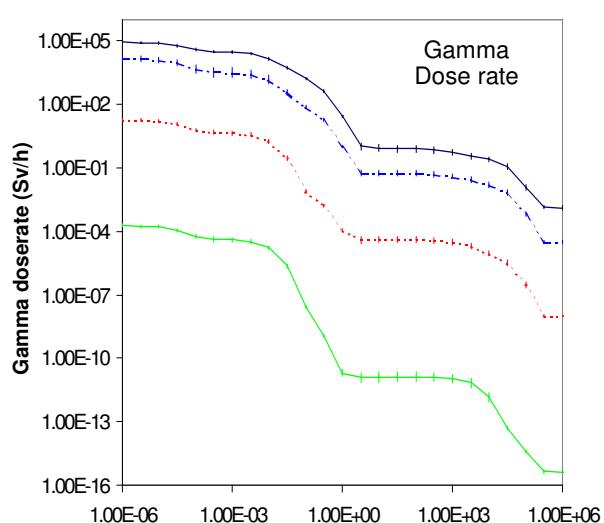
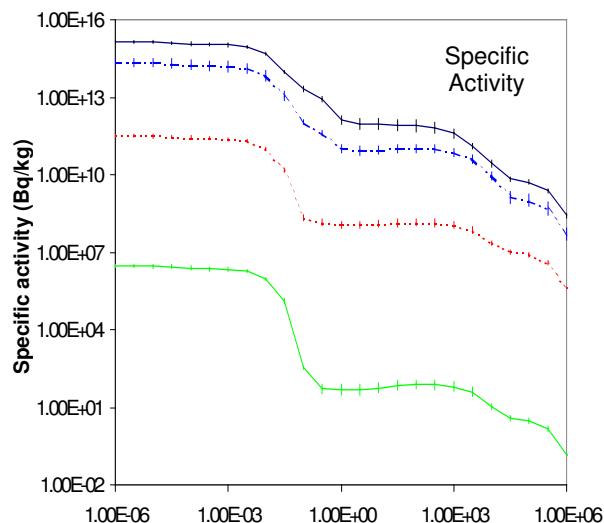
# Molybdenum

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Mo101	14.6 m	Mo100(n, $\gamma$ )Mo101	100.0	100.0	100.0	100.0
Nb90	14.6 h	&Mo92(n,d)Nb91(n,2n)Nb90 &Mo92(n,2n)Mo91( $\beta^+$ )Nb91(n,2n)Nb90 &Mo92(n,2n)Mo91m( $\beta^+$ )Nb91(n,2n)Nb90 &Mo92(n,d)Nb91m(n,2n)Nb90				75.6 17.6 1.0 0.6
Mo99	2.748 d	Mo98(n, $\gamma$ )Mo99 Mo97(n, $\gamma$ )Mo98(n, $\gamma$ )Mo99 Mo96(n, $\gamma$ )Mo97(n, $\gamma$ )Mo98(n, $\gamma$ )Mo99 Mo95(n, $\gamma$ )Mo96(n, $\gamma$ )Mo97(n, $\gamma$ )Mo98(n, $\gamma$ )Mo99 Mo100(n,2n)Mo99	94.6 5.2 0.2	91.3 2.9 4.6 1.2	98.1 1.8	0.3  99.3
Nb92m	10.15 d	Mo92(n,p)Nb92m Mo94(n,2n)Mo93(n,d)Nb92m Mo94(n,d)Nb93(n,2n)Nb92m Mo95(n,2n)Mo94(n,2n)Mo93(n,d)Nb92m Mo92(n,p)Nb92(n,n')Nb92m	100.0	100.0	100.0	84.6 8.0 1.9 1.4 0.9
Nb95	34.975 d	&Mo92(n, $\gamma$ )Mo93( $\beta^+$ )Nb93m(n, $\gamma$ )Nb94(n, $\gamma$ )Nb95 &Mo92(n, $\gamma$ )Mo93( $\beta^+$ )Nb93(n, $\gamma$ )Nb94(n, $\gamma$ )Nb95 &Mo98(n, $\alpha$ )Zr95( $\beta^-$ )Nb95 &Mo96(n, $\gamma$ )Mo97(n, $\gamma$ )Mo98(n, $\alpha$ )Zr95( $\beta^-$ )Nb95 &Mo97(n, $\gamma$ )Mo98(n, $\alpha$ )Zr95( $\beta^-$ )Nb95 &Mo97(n, $\alpha$ )Zr94(n, $\gamma$ ) Zr95( $\beta^-$ )Nb95 &Mo95(n,p)Nb95 &Mo96(n,d)Nb95 &Mo96(n,2n)Mo95(n,p)Nb95 &Mo97(n,2n)Mo96(n,d)Nb95	79.5 19.3 0.2	50.4 12.3 33.8 1.6 1.0	78.0 18.6 0.9 1.9	12.9  54.1 16.6 11.8 2.1
Ru103	39.26 d	Mo100(n, $\gamma$ )Mo101( $\beta^-$ )Tc101( $\beta^-$ )Ru101(n, $\gamma$ ) Ru102(n, $\gamma$ )Ru103 &Mo98(n, $\gamma$ )Mo99( $\beta^-$ )Tc99(n, $\gamma$ )Tc100( $\beta^-$ ) Ru100(n, $\gamma$ )Ru101(n, $\gamma$ )Ru102(n, $\gamma$ )Ru103	94.6 5.3	99.7 0.3	99.9	99.8
Nb91m	60.9 d	Mo92(n,d)Nb91m Mo92(n,d)Nb91(n,n')Nb91m Mo92(n,2n)Mo91( $\beta^+$ )Nb91(n,n')Nb91m				89.9 6.1 1.7
Zr95	64.03 d	Mo97(n, $\alpha$ )Zr94(n, $\gamma$ )Zr95 Mo98(n, $\alpha$ )Zr95 Mo95(n, $\alpha$ )Zr92(n, $\gamma$ )Zr93(n, $\gamma$ )Zr94(n, $\gamma$ )Zr95 Mo96(n, $\gamma$ )Mo97(n, $\alpha$ )Zr94(n, $\gamma$ )Zr95 Mo97(n, $\gamma$ )Mo98(n, $\alpha$ )Zr95 Mo96(n, $\gamma$ )Mo97(n, $\gamma$ )Mo98(n, $\alpha$ )Zr95 Mo95(n, $\gamma$ )Mo96(n, $\gamma$ )Mo97(n, $\gamma$ )Mo98(n, $\alpha$ )Zr95	64.4 29.6 2.0 1.9 1.5 4.4 1.1	0.1 91.3 0.2 0.8 2.8 0.6	66.4 32.1	99.4
Y88	106.63 d	&Mo92(n, $\alpha$ )Zr89( $\beta^+$ )Y89(n,2n)Y88 &Mo92(n,d)Nb91(n, $\alpha$ )Y88 &Mo92(n,2n)Mo91( $\beta^+$ )Nb91(n, $\alpha$ )Y88 &Mo92(n,d)Nb91(n,2n)Nb90( $\beta^+$ )Zr90(n,2n)Zr89( $\beta^+$ ) Y89(n,2n)Y88 Mo92(n,n $\alpha$ )Zr88( $\beta^+$ )Y88 &Mo92(n,d)Nb91(n,d)Zr90(n,2n)Zr89( $\beta^+$ )Y89(n,2n)Y88				55.2 26.7 6.5 2.3  2.2 1.2
Nb93m	16.126 y	&Mo92(n, $\gamma$ )Mo93( $\beta^+$ )Nb93m Mo94(n,d)Nb93m Mo95(n,2n)Mo94(n,d)Nb93m &Mo94(n,p)Nb94(n,2n)Nb93m Mo94(n,2n)Mo93( $\beta^+$ )Nb93m Mo94(n,2n)Mo93(n,p)Nb93m &Mo95(n,d)Nb94(n,2n)Nb93m Mo94(n,d)Nb93(n,n')Nb93m Mo96(n,2n)Mo95(n,2n)Mo94(n,d)Nb93m	100.0	100.0	100.0	69.8 13.2 4.3 2.9 2.3 2.0 1.1 1.0

Nb91	680.0 y	<b>&amp;Mo92(n,d)Nb91</b> <b>&amp;Mo92(n,2n)Mo91(<math>\beta^+</math>)Nb91</b> <b>Mo92(n,2n)Mo91m(<math>\beta^+</math>)Nb91</b>				78.8 19.0 1.0
Mo93	3011.6 y	Mo92( $n,\gamma$ )Mo93 Mo92( $n,\gamma$ )Mo93m(IT)Mo93 <b>&amp;Mo94(n,2n)Mo93</b> <b>&amp;Mo95(n,2n)Mo94(n,2n)Mo93</b> Mo96( $n,2n$ )Mo95( $n,2n$ )Mo94( $n,2n$ )Mo93	99.9 0.1	99.9 0.1	99.8 0.2	0.6 83.0 15.2 1.1
Nb94	19986 y	<b>&amp;Mo92(<math>n,\gamma</math>)Mo93(<math>\beta^+</math>)Nb93m(<math>n,\gamma</math>)Nb94</b> <b>&amp;Mo92(<math>n,\gamma</math>)Mo93(<math>\beta^+</math>)Nb93(<math>n,\gamma</math>)Nb94</b> <b>&amp;Mo92(<math>n,\gamma</math>)Mo93m(<math>\beta^+</math>)Nb93(<math>n,\gamma</math>)Nb94</b> <b>&amp;Mo94(<math>n,p</math>)Nb94</b> <b>&amp;Mo95(<math>n,d</math>)Nb94</b> <b>&amp;Mo95(<math>n,2n</math>)Mo94(<math>n,p</math>)Nb94</b> <b>&amp;Mo96(<math>n,2n</math>)Mo95(<math>n,d</math>)Nb94</b>	79.8 19.5 0.5	79.6 19.6 0.5	80.1 19.2 0.5	57.8 26.6 10.5 3.0
Tc99	$2.1 \cdot 10^5$ y	<b>&amp;Mo98(<math>n,\gamma</math>)Mo99(<math>\beta^-</math>)Tc99</b> <b>&amp;Mo97(<math>n,\gamma</math>)Mo98(<math>n,\gamma</math>)Mo99(<math>\beta^-</math>)Tc99</b> <b>&amp;Mo96(<math>n,\gamma</math>)Mo97(<math>n,\gamma</math>)Mo98(<math>n,\gamma</math>)Mo99(<math>\beta^-</math>)Tc99</b> <b>&amp;Mo100(<math>n,2n</math>)Mo99(<math>\beta^-</math>)Tc99</b>	96.7 3.3	94.6 2.0 3.0	99.1 0.9	0.3 99.7
Tc98	$4.2 \cdot 10^6$ y	<b>&amp;Mo100(<math>n,2n</math>)Mo99(<math>\beta^-</math>)Tc99(<math>n,2n</math>)Tc98</b>				99.9
Nb92	$3.5 \cdot 10^7$ y	Mo92( $n,p$ )Nb92 Mo94( $n,2n$ )Mo93( $n,d$ )Nb92 Mo94( $n,d$ )Nb93( $n,2n$ )Nb92	100.0	100.0	100.0	87.9 7.1 2.2

# Molybdenum activation characteristics

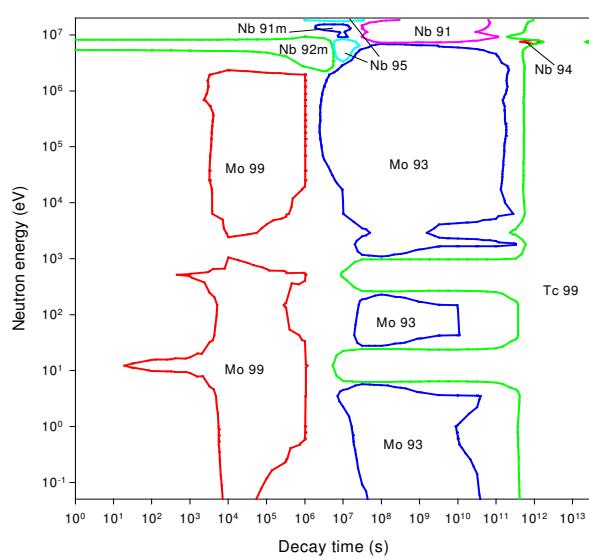


Decay time (years)

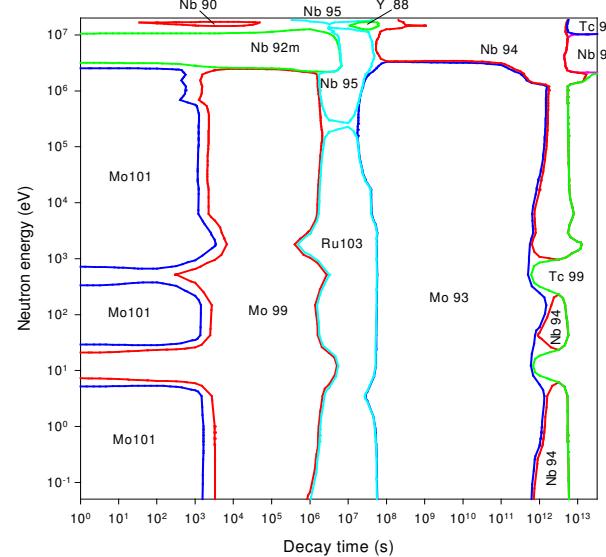
Decay time (years)

# Molybdenum importance diagrams & transmutation

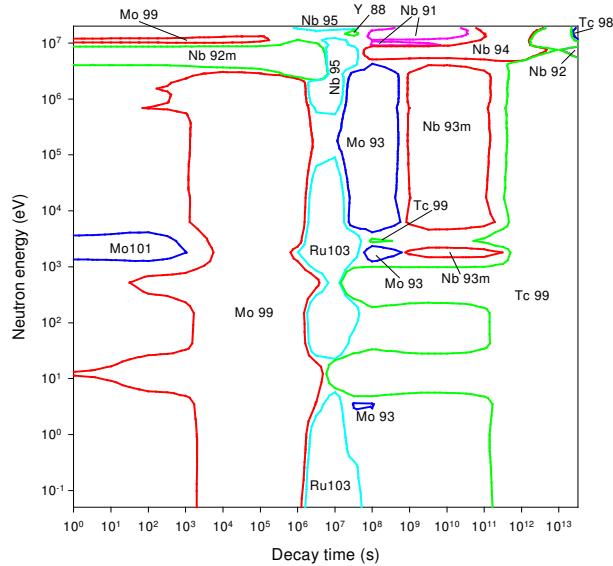
## Activity



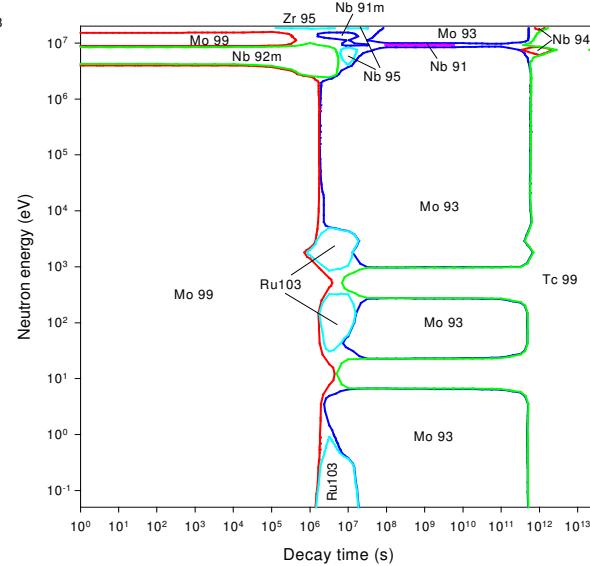
## Dose rate



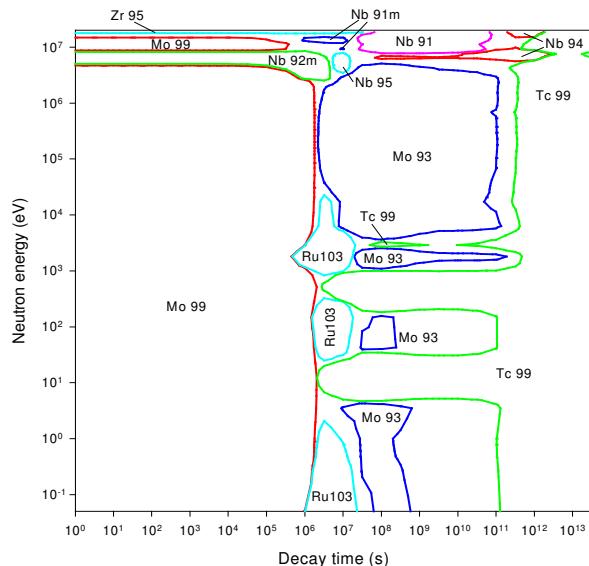
## Heat output



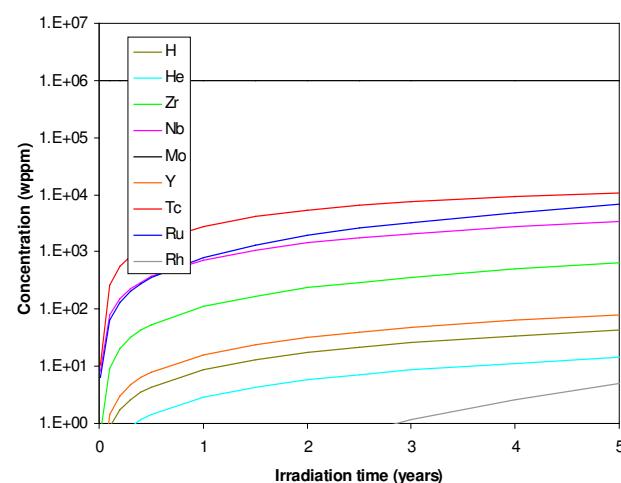
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Ruthenium

## General properties

	44	Isotopes	Isotopic abundances / %
Atomic number	1.0 10 <sup>-3</sup>	Ru96	5.54
Crustal abundance / wppm	2607	Ru98	1.87
Melting point / K	4423	Ru99	12.76
Boiling point / K	12410	Ru100	12.60
Density / kgm <sup>-3</sup>	117	Ru101	17.06
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	7.6 10 <sup>-8</sup>	Ru102	31.55
Electrical resistivity /Ωm	6.4 10 <sup>-6</sup>	Ru104	18.62
Coefficient of thermal expansion / K <sup>-1</sup>	HCP		
Crystal structure	7		
Number of stable isotopes	101.07		
Mean atomic weight			

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	2.50E15	2.24E15	1.28E15	4.62E12	3.93E9	5.47E8	kW kg <sup>-1</sup>	1.96E-1	1.54E-1	6.39E-2	7.59E-4	2.98E-8	1.47E-8
Rh103m	24.21	26.92	43.14	19.97			Ru105	28.66	35.88				
Ru103	23.57	26.26	43.26	20.18			Ru103	27.17	34.48	78.21	11.11		
Ru105	12.18	13.39					Rh104	18.04	1.02				
Rh105	12.13	13.52	4.88				Rh105	5.73	7.27	3.62			
Rh104	8.87	0.44					Ru97	4.42	5.60	5.66			
Ru97	8.45	9.41	6.91				Tc95	2.61	3.31	0.42	0.02		
Rh105m	3.41	3.76					Tc96	2.57	3.26	4.39			
Tc95	1.59	1.77	0.16	0.03			Ru95	2.50	3.06				
Tc99m	1.32	1.45	0.06				Tc100	2.31					
Ru95	0.93	1.00					Rh103m	1.97	2.50	5.52	0.78		
Tc96	0.50	0.56	0.55				Rh105m	0.91	1.14				
Rh102m	0.14	0.16	0.27	22.22			Tc102m	0.52	0.29				
Rh102	0.08	0.09	0.16	35.06			Rh102	0.35	0.45	1.09	72.98		
Tc97m		0.04	0.06	1.11			Tc104	0.29	0.30				
H3				0.59	2.65		Rh102m	0.19	0.24	0.57	14.45		
Mo93				0.04	42.57		Tc98					31.18	62.12
Tc99				0.01	10.87	56.19	Nb93m					23.49	
Nb93m				0.01	36.00		Tc99					23.16	33.80
Tc97					5.28	36.89	Mo93					14.91	
Nb91					1.53		Nb94					4.20	0.27
Tc98					0.96	6.81	Tc97					1.93	3.81
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	1.41E5	1.38E5	6.20E4	1.01E3	1.49E-2	1.24E-2	Sv kg <sup>-1</sup>	6.93E5	6.91E5	4.62E5	6.19E3	5.73E0	2.85E-1
Ru103	40.13	40.96	85.32	8.86			Ru103	62.12	62.26	87.31	10.99		
Ru105	34.67	34.90					Rh105	16.20	16.24	4.99			
Tc96	5.67	5.78	7.15				Ru105	11.43	11.30				
Tc95	5.24	5.34	0.62	0.02			Ru97	4.58	4.58	2.87			
Ru95	4.88	4.80					Tc96	1.99	2.00	1.66			
Ru97	3.33	3.40	3.16				Tc95	1.03	1.04	0.08			
Rh105	2.30	2.35	1.07				Rh102	0.76	0.76	1.14	68.01		
Tc102m	0.97	0.43					Rh102m	0.60	0.60	0.89	19.90		
Rh102	0.72	0.74	1.64	80.53			Mo93				0.09	90.42	
Rh102m	0.25	0.25	0.55	10.12			Tc99					4.77	68.98
Tc98					83.60	99.10	Nb93m					2.96	
Nb94					11.86	0.45	Tc98					1.32	26.12
Mo93					2.89		Tc97					0.25	4.81

<b>Inh</b>	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>	<b>Clear</b>	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>
Sv kg <sup>-1</sup>	2.04E6	2.04E6	1.76E6	3.80E4	1.45E1	6.04E0		7.57E11	7.18E11	3.33E11	4.46E9	1.00E5	5.72E4
Ru103	86.69	86.73	94.02	7.36			Ru103	38.95	41.02	82.92	10.46		
Rh105	5.21	5.21	1.24				Ru105	30.96	32.17				
Ru105	2.69	2.65					Ru97	6.81	7.17	6.46			
Rh102	1.69	1.69	1.95	72.45			Tc96	4.14	4.36	5.23			
Rh102m	1.21	1.21	1.38	19.18			Tc95	4.04	4.26	0.48	0.02		
Ru97	1.14	1.14	0.55				Ru95	3.83	3.89				
Tc96	0.43	0.43	0.28				Rh105	3.64	3.84	1.70			
Tc95	0.22	0.21	0.01				Rh104	3.33	0.16				
Tc97m	0.17	0.17	0.19	0.55			Rh102	0.57	0.60	1.29	77.32		
Tc95m	0.11	0.11	0.12	0.10			Rh103m	0.44	0.47	0.92	0.12		
Tc99				0.02	38.21	66.13	Rh102m	0.23	0.24	0.51	11.52		
Mo93				0.01	26.49		Tc98					54.00	93.08
Nb93m					17.53		Mo93					19.18	
Tc98					11.74	27.74	Nb94					14.95	0.82
Tc97					2.57	6.01	Nb93m					6.72	
Nb91					1.70		Tc97					2.52	4.31
Nb94					1.52	0.11	Tc99					1.42	1.79

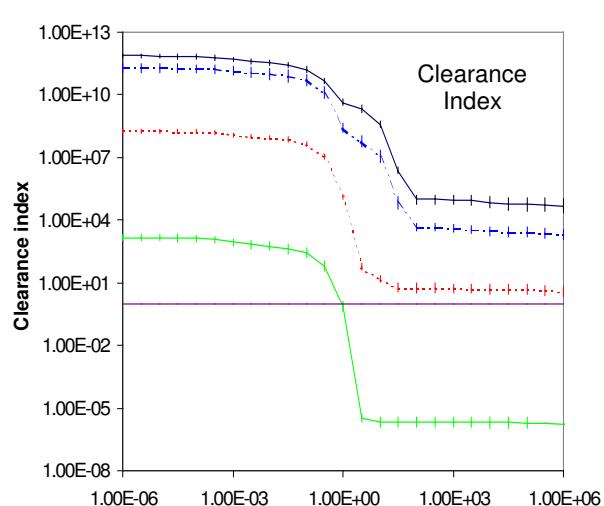
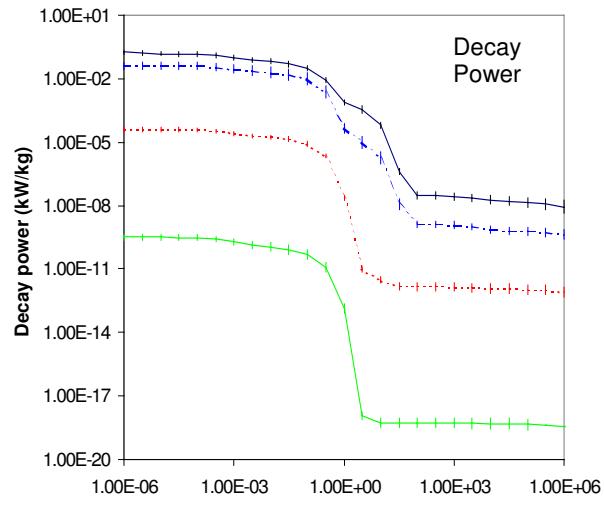
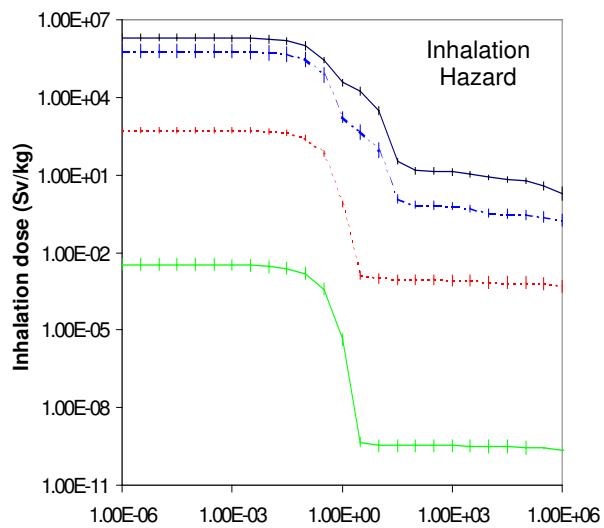
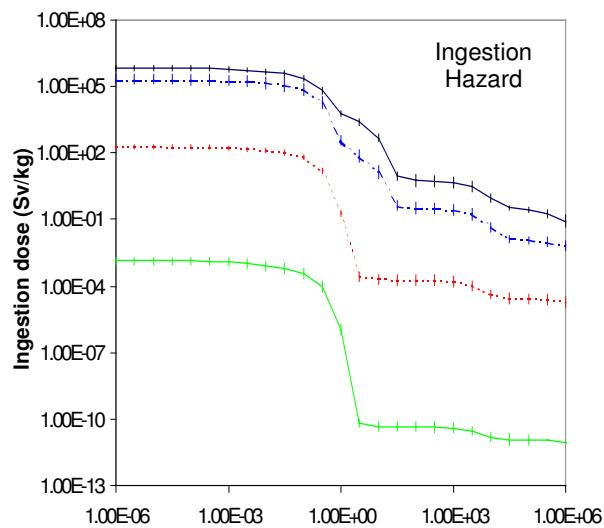
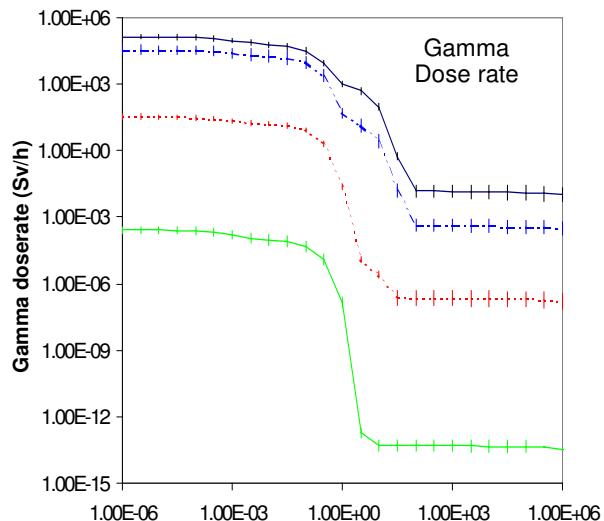
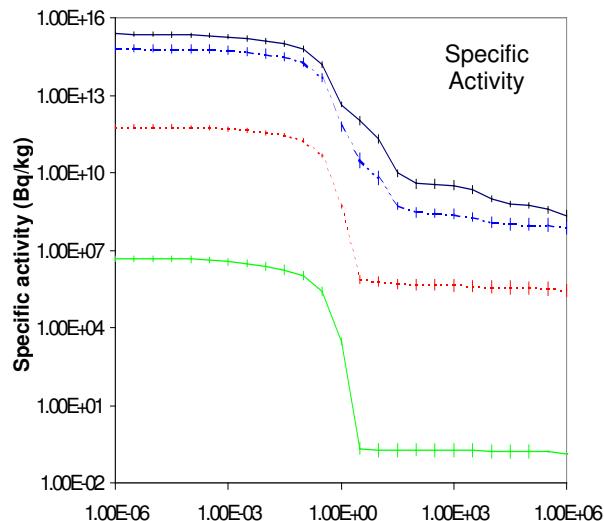
# Ruthenium

## Pathway analysis

Nuclide	T <sub>½</sub>	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Rh106	30.1 s	&Ru104(n,γ)Ru105(β⁻)Rh105(n,γ)Rh106 &Ru102(n,γ)Ru103(n,γ)Ru104(n,γ)Ru105(β⁻) Rh105(n,γ)Rh106 Ru104(n,γ)Ru105(n,γ)Ru106(β⁻)Rh106 &Ru104(n,γ)Ru105(β⁻)Rh105(β⁻)Pd105(n,γ)Pd106(n,p)Rh106	99.3 0.6	95.9 0.2	91.1	49.0
Rh104	42.3 s	&Ru102(n,γ)Ru103(β⁻)Rh103(n,γ)Rh104 &Ru101(n,γ)Ru102(n,γ)Ru103(β⁻)Rh103(n,γ)Rh104 &Ru100(n,γ)Ru101(n,γ)Ru102(n,γ)Ru103(β⁻) Rh103m(IT)Rh103(n,γ)Rh104 &Ru104(n,2n)Ru103(β⁻)Rh103(n,γ)Rh104	88.8 9.7 1.2	81.4 18.4	96.4 3.4	98.0
Ru97	2.9 d	Ru96(n,γ)Ru97 Ru99(n,2n)Ru98(n,2n)Ru97 Ru98(n,2n)Ru97 Ru100(n,2n)Ru99(n,2n)Ru98(n,2n)Ru97 Ru101(n,2n)Ru100(n,2n)Ru99(n,2n)Ru98(n,2n)Ru97	100.0	99.9	100.0	0.1 56.5 36.8 5.9 0.7
Tc96	4.28 d	&Ru96(n,p)Tc96 &Ru98(n,2n)Ru97(β⁺)Tc97(n,2n)Tc96 &Ru99(n,2n)Ru98(n,2n)Ru97(β⁺)Tc97(n,2n)Tc96 &Ru98(n,d)Tc97(n,2n)Tc96 &Ru99(n,2n)Ru98(n,d)Tc97(n,2n)Tc96	100.0	99.8	100.0	52.9 23.8 18.5 1.4 1.0
Ru103	39.26 d	Ru102(n,γ)Ru103 Ru101(n,γ)Ru102(n,γ)Ru103 Ru100(n,γ)Ru101(n,γ)Ru102(n,γ)Ru103 Ru104(n,2n)Ru103	87.9 10.4 1.4	77.8 22.0 0.1	93.6 6.4	0.2 99.2
Tc97m	90.2 d	Ru96(n,γ)Ru97(β⁺)Tc97m Ru99(n,2n)Ru98(n,d)Tc97m Ru98(n,d)Tc97m Ru99(n,d)Tc98(n,2n)Tc97m Ru98(n,2n)Ru97(β⁺)Tc97(n,n')Tc97m Ru98(n,p)Tc98(n,2n)Tc97m Ru99(n,2n)Ru98(n,2n)Ru97(β⁺)Tc97(n,n')Tc97m Ru100(n,2n)Ru99(n,2n)Ru98(n,d)Tc97m Ru99(n,2n)Ru98(n,p)Tc98(n,2n)Tc97m &Ru99(n,p)Tc99(n,2n)Tc98(n,2n)Tc97m Ru99(n,t)Tc97m Ru100(n,2n)Ru99(n,d)Tc98(n,2n)Tc97m Ru99(n,2n)Ru98(n,2n)Ru97(β⁺)Tc97m	100.0	99.9	100.0	34.0 23.8 12.5 5.1 4.4 3.7 3.3 3.2 1.9 1.3 1.2 1.0
Ag110m	249.79 d	&Ru104(n,γ)Ru105(β⁻)Rh105(n,γ)Rh106(β⁻)Pd106(n,γ) Pd107(n,γ)Pd108(n,γ)Pd109(β⁻)Ag109(n,γ)Ag110m &Ru104(n,γ)Ru105(β⁻)Rh105(β⁻)Pd105(n,γ)Pd106(n,γ) Pd107(n,γ)Pd108(n,γ)Pd109(β⁻)Ag109(n,γ)Ag110m &Ru104(n,γ)Ru105(β⁻)Rh105(n,γ)Rh106m(β⁻)Pd106 (n,γ)Pd107(n,γ)Pd108(n,γ)Pd109(β⁻)Ag109(n,γ)Ag110m &Ru102(n,γ)Ru103(β⁻)Rh103(n,γ)Rh104(β⁻) Pd104(n,γ)Pd105(n,γ)Pd106(n,γ)Pd107(n,γ) Pd108(n,γ)Pd109(β⁻)Ag109(n,γ)Ag110m	54.7 38.7 5.8	0.2 85.8 13.5	0.4 99.6	
Ru106	1.008 y	Ru104(n,γ)Ru105(n,γ)Ru106 Ru102(n,γ)Ru103(n,γ)Ru104(n,γ)Ru105(n,γ)Ru106	99.5 0.5	99.7 0.2	100.0	99.9
Rh102	2.9021 y	&Ru104(n,2n)Ru103(β⁻)Rh103(n,2n)Rh102				99.3
H3  more on next page	12.33 y	Ru99(n,X)H1(n,γ)H2(n,γ)H3 Ru96(n,X)H1(n,γ)H2(n,γ)H3 Ru98(n,γ)Ru99(n,X)H1(n,γ)H2(n,γ)H3 Ru96(n,γ)Ru97(β⁺)Tc97(n,X)H1(n,γ)H2(n,γ)H3 Ru101(n,X)H3	61.3 30.0 1.2	53.7 36.7 1.0 1.8	68.2 29.9 0.2	48.4

H3 continued	12.33 y	Ru99(n,X)H3 Ru102(n,2n)Ru101(n,X)H3 Ru104(n,2n)Ru103( $\beta^-$ )Rh103m(IT)Rh103(n,X)H3 Ru102(n,X)H3 Ru100(n,2n)Ru99(n,X)H3 Ru100(n,X)H3 Ru96(n,X)H3 Ru104(n,X)H3				21.5 10.2 5.4 3.4 2.3 2.0 2.0 1.4
Nb93m	16.126 y	&Ru96(n, $\alpha$ )Mo93( $\beta^+$ )Nb93m Ru96(n,2n)Ru95( $\beta^+$ )Tc95( $\beta^+$ )Mo95(n,2n)Mo94(n,d)Nb93m   &Ru96(n,d)Tc95( $\beta^+$ )Mo95(n,2n)Mo94(n,d)Nb93m &Ru98(n,2n)Ru97( $\beta^+$ )Tc97(n,n $\alpha$ )Nb93m &Ru96(n, $\alpha$ )Mo93(n,p)Nb93m &Ru99(n,2n)Ru98(n,2n)Ru97( $\beta^+$ )Tc97(n,n $\alpha$ )Nb93m &Ru96(n,2n)Ru95( $\beta^+$ )Tc95( $\beta^+$ )Mo95(n,d)Nb94(n,2n)Nb93m   &Ru96(n,d)Tc95( $\beta^+$ )Mo95(n,d)Nb94(n,2n)Nb93m Ru96(n,2n)Ru95( $\beta^+$ )Tc95( $\beta^+$ )Mo95(n,t)Nb93m &Ru96(n,d)Tc95( $\beta^+$ )Mo95(n,t)Nb93m Ru98(n,n $\alpha$ )Mo94(n,d)Nb93m &Ru98(n,2n)Ru97( $\beta^+$ )Tc97(n, $\alpha$ )Nb94(n,2n)Nb93m *Plus other long pathways from high mass Ru isotopes	100.0	100.0	100.0	12.5 18.8 14.8 13.9 9.7 7.4 2.9 2.3 2.0 1.6 1.4 1.3 11.4*
Mo93	3011.6 y	&Ru96(n, $\alpha$ )Mo93 Ru96(n,2n)Ru95( $\beta^+$ )Tc95( $\beta^+$ )Mo95(n,2n)Mo94(n,2n)Mo93	100.0	100.0	100.0	88.6 5.4 4.3
Nb94	19986 y	&Ru96(n, $\gamma$ )Ru97( $\beta^+$ )Tc97(n, $\alpha$ )Nb94 &Ru96(n, $\alpha$ )Mo93m( $\beta^+$ )Nb93(n, $\gamma$ )Nb94 &Ru96(n,2n)Ru95( $\beta^+$ )Tc95( $\beta^+$ )Mo95(n,d)Nb94 &Ru96(n,d)Tc95( $\beta^+$ )Mo95(n,d)Nb94 &Ru98(n,2n)Ru97( $\beta^+$ )Tc97(n, $\alpha$ )Nb94 &Ru96(n,2n)Ru95( $\beta^+$ )Tc95( $\beta^+$ )Mo95(n,2n)Mo94(n,p)Nb94   &Ru99(n,2n)Ru98(n,2n)Ru97( $\beta^+$ )Tc97(n, $\alpha$ )Nb94 &Ru96(n,d)Tc95( $\beta^+$ )Mo95(n,2n)Mo94(n,p)Nb94 &Ru96(n,d)Tc95m( $\beta^+$ )Mo95(n,d)Nb94 &Ru99(n,d)Tc98(n,n $\alpha$ )Nb94 &Ru99(n,n $\alpha$ )Mo95(n,d)Nb94 *Plus other long pathways from high mass Ru isotopes	99.6 0.4	100.0	100.0	30.0 23.5 13.0 7.8 6.8 6.1 2.5 2.1 1.0 8.0*
Tc99	$2.1 \cdot 10^5$ y	&Ru96(n, $\gamma$ )Ru97( $\beta^+$ )Tc97(n, $\gamma$ )Tc98(n, $\gamma$ )Tc99 &Ru99(n,p)Tc99 &Ru102(n, $\alpha$ )Mo99( $\beta^-$ )Tc99 &Ru100(n,d)Tc99 &Ru100(n,2n)Ru99(n,p)Tc99 &Ru104(n,2n)Ru103( $\beta^-$ )Rh103(n,n $\alpha$ )Tc99 &Ru101(n,2n)Ru100(n,d)Tc99 &Ru101(n,t)Tc99	100.0	100.0	100.0	55.5 18.7 11.8 5.8 3.2 2.2 1.2
Tc97	$2.6 \cdot 10^6$ y	Ru96(n, $\gamma$ )Ru97( $\beta^+$ )Tc97 Ru98(n,2n)Ru97( $\beta^+$ )Tc97 Ru99(n,2n)Ru98(n,2n)Ru97( $\beta^+$ )Tc97 &Ru98(n,d)Tc97 Ru100(n,2n)Ru99(n,2n)Ru98(n,2n)Ru97( $\beta^+$ )Tc97 &Ru99(n,2n)Ru98(n,d)Tc97	100.0	99.9	100.0	0.2 50.5 39.2 3.0 2.7 2.3
Tc98	$4.2 \cdot 10^6$ y	Ru96(n, $\gamma$ )Ru97( $\beta^+$ )Tc97(n, $\gamma$ )Tc98 Ru99(n,d)Tc98 Ru98(n,p)Tc98 Ru99(n,2n)Ru98(n,p)Tc98 &Ru99(n,p)Tc99(n,2n)Tc98 Ru100(n,2n)Ru99(n,d)Tc98 &Ru102(n, $\alpha$ )Mo99( $\beta^-$ )Tc99(n,2n)Tc98 &Ru100(n,d)Tc99(n,2n)Tc98	100.0	99.9	100.0	48.8 17.3 13.4 7.7 5.1 2.6 1.6

# Ruthenium activation characteristics

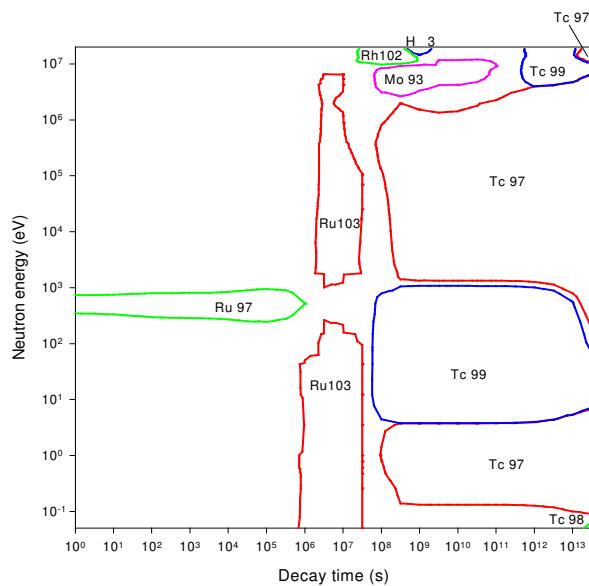


Decay time (years)

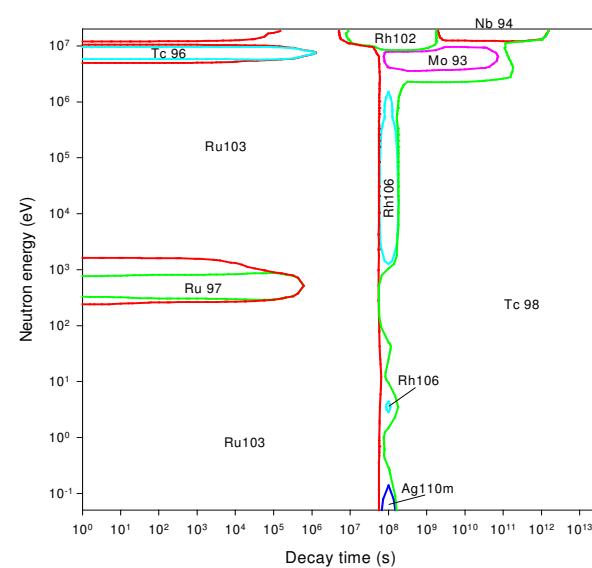
Decay time (years)

# Ruthenium importance diagrams & transmutation

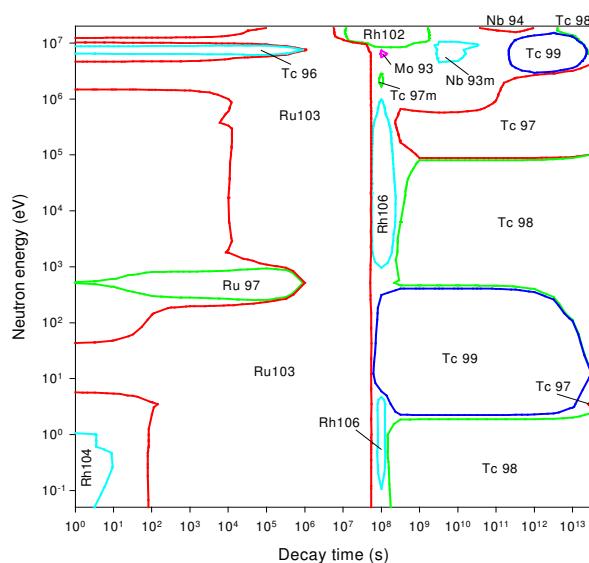
## Activity



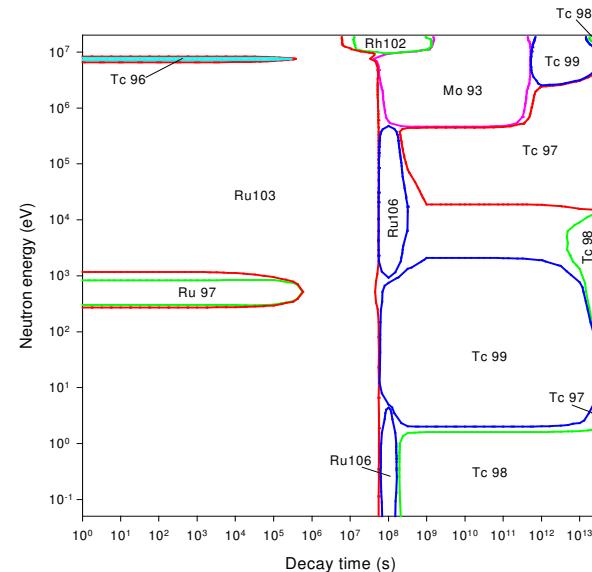
## Dose rate



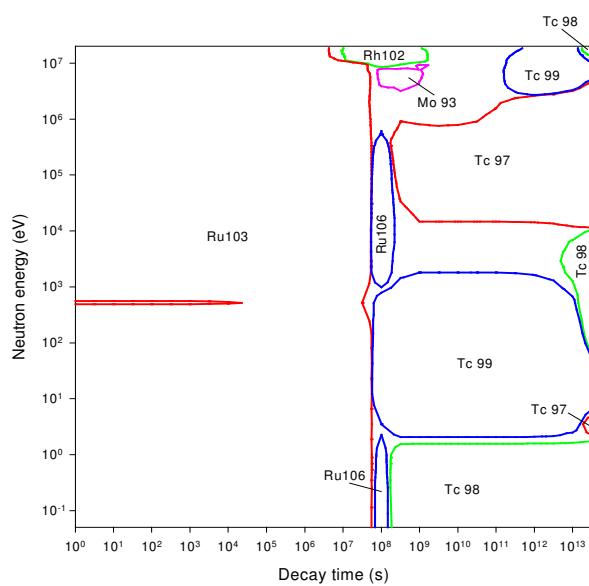
## Heat output



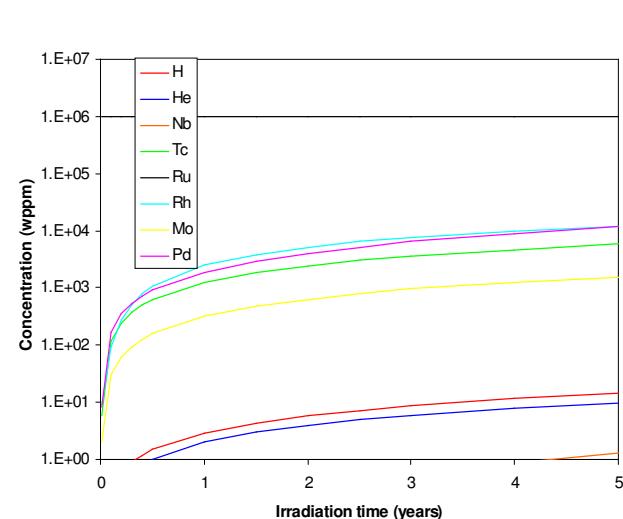
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Rhodium

## General properties

		45 1.0 10 <sup>-3</sup> 2237 3968 12410 150 4.51 10 <sup>-8</sup> 8.20 10 <sup>-6</sup> FCC 1 102.9055	Isotopes Rh103	Isotopic abundances / %	
Atomic number	Crustal abundance / wppm			100.0	
Melting point / K					
Boiling point / K					
Density / kgm <sup>-3</sup>					
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>					
Electrical resistivity /Ωm					
Coefficient of thermal expansion / K <sup>-1</sup>					
Crystal structure					
Number of stable isotopes					
Mean atomic weight					

## Activation properties

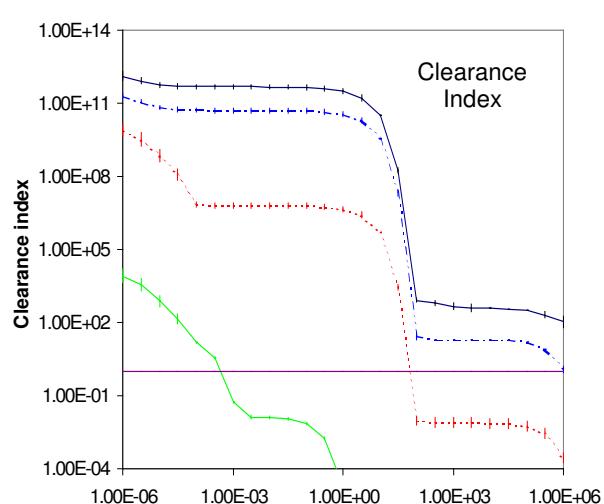
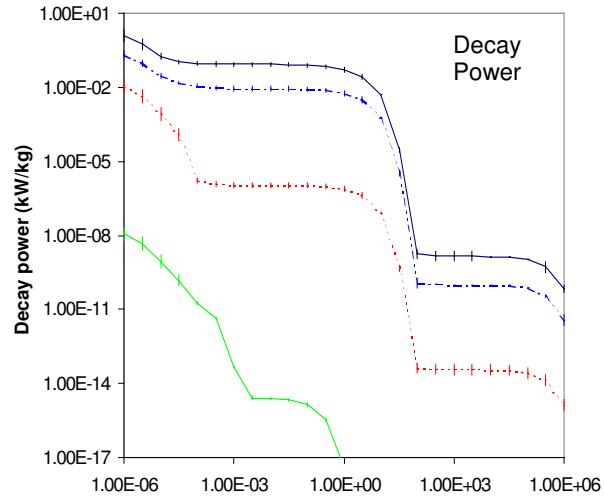
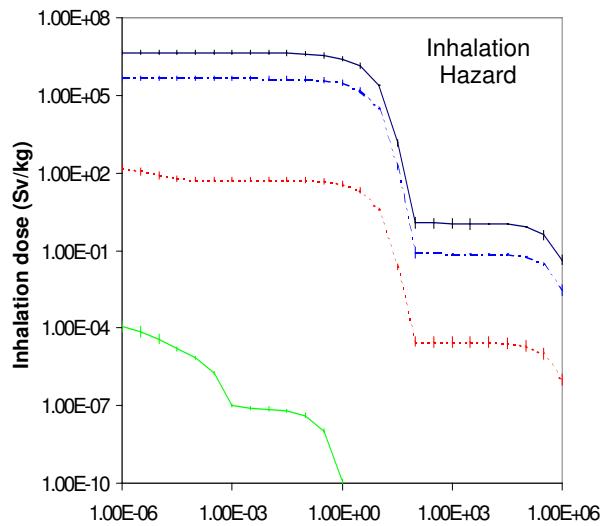
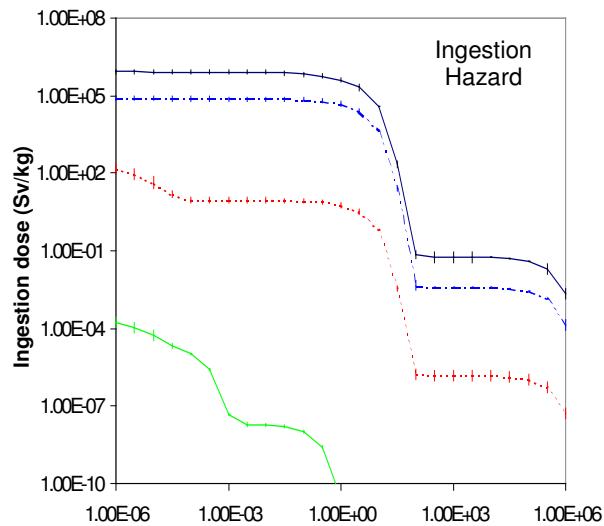
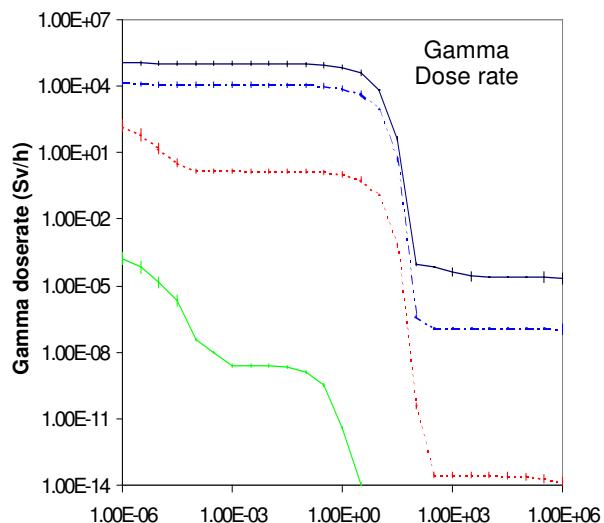
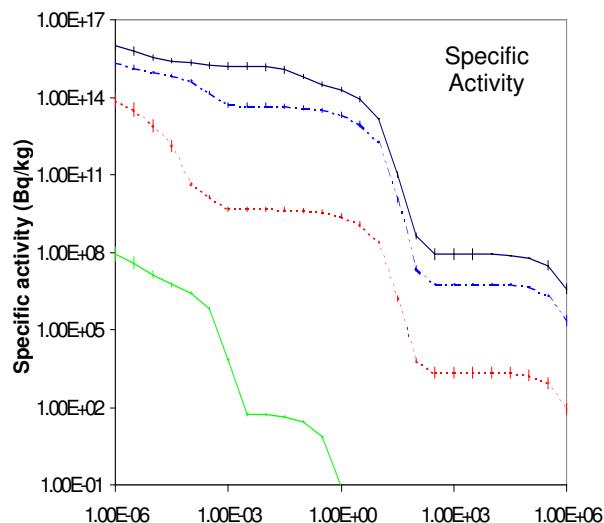
Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.46E16	3.38E15	1.45E15	1.92E14	4.45E8	6.30E7	kW kg <sup>-1</sup>	1.90E0	1.80E-1	8.50E-2	5.08E-2	1.80E-9	1.03E-9
Rh104	76.52	14.78					Rh104	94.03	44.19				
Rh103m	10.66	44.40	37.16	0.02			Rh102	2.92	30.79	65.16	86.83		
Rh104m	5.87	10.96					Rh102m	1.19	12.49	26.17	13.11		
Pd103	4.09	17.71	35.53				Rh104m	0.95	4.34				
Rh102m	1.44	6.24	14.35	32.48			Rh103m	0.53	5.32	4.06			
Rh102	1.11	4.81	11.16	67.19			Ru103	0.12	1.22	2.43	0.01		
Ru103	0.17	0.72	1.57	0.02			Pd103	0.10	1.09	2.00			
Rh101		0.02	0.04	0.25			Tc99					77.85	98.05
H3			0.01	0.05	80.35		H3					18.18	
Tc99					19.44	98.82	Ag108m					2.73	
Pd107					0.15	1.05	Tc98					1.08	1.86
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	1.31E5	1.06E5	1.03E5	7.01E4	9.20E-5	2.54E-5	Sv kg <sup>-1</sup>	8.36E5	8.19E5	7.89E5	4.11E5	7.09E-2	4.00E-2
Rh102	61.46	76.15	77.98	91.27			Rh102	50.47	51.52	53.39	81.70		
Rh104	19.72	1.09					Rh102m	30.24	30.88	31.68	18.23		
Rh102m	15.77	19.53	19.80	8.72			Pd103	13.60	13.88	12.42			
Ru103	1.76	2.18	2.09	0.01			Ru103	2.13	2.17	2.11	0.01		
Rh104m	0.54	0.29					Rh104	1.61	0.07				
Ru105	0.36	0.44					Rh103m	0.71	0.70	0.26			
Ag108m					71.58		Tc99					77.99	99.55
Tc98					28.06	99.97	H3					21.15	
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	4.62E6	4.61E6	4.54E6	2.64E6	1.23E0	8.14E-1		1.81E12	5.62E11	4.72E11	3.06E11	8.30E2	3.20E2
Rh102	59.69	59.85	60.68	83.12			Rh104	70.40	10.10				
Rh102m	32.37	32.45	32.58	16.78			Rh102	19.11	61.45	73.04	89.75		
Pd103	5.83	5.84	5.11				Rh102m	5.83	18.75	22.07	10.19		
Ru103	1.58	1.59	1.51				Rh104m	2.64	3.66				
Rh104	0.21	0.01					Ru103	0.67	2.17	2.42	0.01		
Rh103m	0.09	0.09	0.03				Pd103	0.50	1.61	1.66			
Rh101	0.07	0.07	0.07	0.10			Rh103m	0.48	1.48	0.64			
Tc99					91.54	99.52	Ag108m					36.76	
H3					7.57		Tc99					34.73	64.93
Ag108m					0.56		H3					14.35	
Tc98					0.29	0.43	Tc98					13.66	34.85

# Rhodium

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Rh106	30.1 s	&Rh103(n, $\gamma$ )Rh104( $\beta^+$ )Ru104(n, $\gamma$ )Ru105( $\beta^-$ ) Rh105(n, $\gamma$ )Rh106 &Rh103(n, $\gamma$ )Rh104( $\beta^+$ )Ru104(n, $\gamma$ )Ru105(n, $\gamma$ )Ru106( $\beta^-$ )Rh106 &Rh103(n, $\gamma$ )Rh104( $\beta^-$ )Pd104(n, $\gamma$ )Pd105(n, $\gamma$ )Pd106(n,p)Rh106 &Rh103(n, $\gamma$ )Rh104( $\beta^+$ )Ru104(n, $\gamma$ )Ru105( $\beta^-$ )Rh105(n, $\gamma$ )Rh106	100.0	96.5 3.5	93.2 6.8	96.1 1.2
Rh104	42.3 s	Rh103(n, $\gamma$ )Rh104 Rh103(n, $\gamma$ )Rh104m(IT)Rh104	91.6 8.4	91.9 8.1	92.3 7.7	46.8 53.2
Rh104m	4.34 m	Rh103(n, $\gamma$ )Rh104m	100.0	100.0	100.0	99.1
Rh103m	56.115 m	&Rh103(n, $\gamma$ )Rh104( $\beta^-$ )Pd104(n, $\gamma$ )Pd105(n, $\alpha$ ) Ru102(n, $\gamma$ )Ru103( $\beta^-$ )Rh103m &Rh103(n, $\gamma$ )Rh104( $\beta^-$ )Pd104(n, $\gamma$ )Pd105(n, $\gamma$ ) Pd106(n, $\alpha$ )Ru103( $\beta^-$ )Rh103m &Rh103(n, $\gamma$ )Rh104( $\beta^-$ )Pd104(n, $\alpha$ )Ru101(n, $\gamma$ ) Ru102(n, $\gamma$ )Ru103( $\beta^-$ )Rh103m Rh103(n, $n'$ )Rh103m Rh103(n,p)Ru103( $\beta^-$ )Rh103m	99.1 0.3 0.3	95.3 1.1 1.1	100.0	90.8 8.3
Ru105	4.439 h	&Rh103(n, $\gamma$ )Rh104( $\beta^+$ )Ru104(n, $\gamma$ )Ru105 Rh103(n,p)Ru103(n, $\gamma$ )Ru104(n, $\gamma$ )Ru105	100.0	100.0	100.0	96.0 1.6
Rh105	1.474 d	&Rh103(n, $\gamma$ )Rh104( $\beta^+$ )Ru104(n, $\gamma$ )Ru105( $\beta^-$ )Rh105 &Rh103(n, $\gamma$ )Rh104( $\beta^-$ )Pd104(n, $\gamma$ )Pd105(n,p)Rh105 &Rh103(n,p)Ru103(n, $\gamma$ )Ru104(n, $\gamma$ )Ru105( $\beta^-$ )Rh105	100.0	100.0	100.0	57.4 39.6 1.0
Ru103	39.26 d	&Rh103(n, $\gamma$ )Rh104( $\beta^-$ )Pd104(n, $\gamma$ )Pd105(n, $\alpha$ ) Ru102(n, $\gamma$ )Ru103 &Rh103(n, $\gamma$ )Rh104( $\beta^-$ )Pd104(n, $\gamma$ )Pd105(n, $\gamma$ ) Pd106(n, $\alpha$ )Ru103 &Rh103(n, $\gamma$ )Rh104( $\beta^-$ )Pd104(n, $\alpha$ )Ru101(n, $\gamma$ ) Ru102(n, $\gamma$ )Ru103 Rh103(n,p)Ru103	99.1 0.3 0.3	95.3 1.1 1.1	27.0 72.6	98.1
Ag110m	249.79 d	&Rh103(n, $\gamma$ )Rh104( $\beta^-$ )Pd104(n, $\gamma$ )Pd105(n, $\gamma$ )Pd106(n, $\gamma$ ) Pd107(n, $\gamma$ )Pd108(n, $\gamma$ )Pd109( $\beta^-$ )Ag109(n, $\gamma$ )Ag110m	99.2	100.0	99.6	
Ru106	1.008 y	&Rh103(n, $\gamma$ )Rh104( $\beta^+$ )Ru104(n, $\gamma$ )Ru105(n, $\gamma$ )Ru106 Rh103(n,p)Ru103(n, $\gamma$ )Ru104(n, $\gamma$ )Ru105(n, $\gamma$ )Ru106	100.0	100.0	100.0	97.9 1.6
Rh102	2.902 y	&Rh103(n,2n)Rh102				99.6
H3	12.33 y	Rh103(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 &Rh103(n, $\gamma$ )Rh104( $\beta^-$ )Pd104(n, $\gamma$ )Pd105(n,X)H1(n, $\gamma$ ) H2(n, $\gamma$ )H3 Rh103(n,X)H3	89.1 2.9	93.8 0.6	99.4	98.3
Ag108m	418.0 y	&Rh103(n, $\gamma$ )Rh104( $\beta^-$ )Pd104(n, $\gamma$ )Pd105(n, $\gamma$ ) Pd106(n, $\gamma$ )Pd107( $\beta^-$ )Ag107(n, $\gamma$ )Ag108m	99.2	100.0	99.6	
Tc99	$2.1 \cdot 10^5$ y	&Rh103(n, $\gamma$ )Rh104( $\beta^-$ )Pd104(n, $\gamma$ )Pd105(n, $\alpha$ ) Ru102(n, $\alpha$ )Mo99( $\beta^-$ )Tc99 &Rh103(n, $\gamma$ )Rh104( $\beta^-$ )Pd104(n, $\alpha$ )Ru101(n, $\alpha$ ) Mo98(n, $\gamma$ )Mo99( $\beta^-$ )Tc99 &Rh103(n, $\gamma$ )Rh104( $\beta^-$ )Pd104(n, $\alpha$ )Ru101(n, $\gamma$ ) Ru102(n, $\alpha$ )Mo99( $\beta^-$ )Tc99 &Rh103(n,no)Tc99 &Rh103(n,2n)Rh102(n, $\alpha$ )Tc99 &Rh103(n,2n)Rh102m( $\beta^+$ )Ru102(n, $\alpha$ )Mo99( $\beta^-$ )Tc99	92.4 6.7	99.0 1.0	98.1 0.8	95.4 1.6 0.7
Tc98	$4.2 \cdot 10^6$ y	&Rh103(n,no)Tc99(n,2n)Tc98 &Rh103(n,2n)Rh102(n,no)Tc98 Rh103(n,2n)Rh102m(n,no)Tc98 Rh103(n,2n)Rh102(n, $\alpha$ )Tc99(n,2n)Tc98				54.7 33.1 9.9 0.6
Pd107	$6.5 \cdot 10^6$ y	&Rh103(n, $\gamma$ )Rh104( $\beta^-$ )Pd104(n, $\gamma$ )Pd105(n, $\gamma$ ) Pd106(n, $\gamma$ )Pd107	99.3	100.0	99.6	99.2

# Rhodium activation characteristics

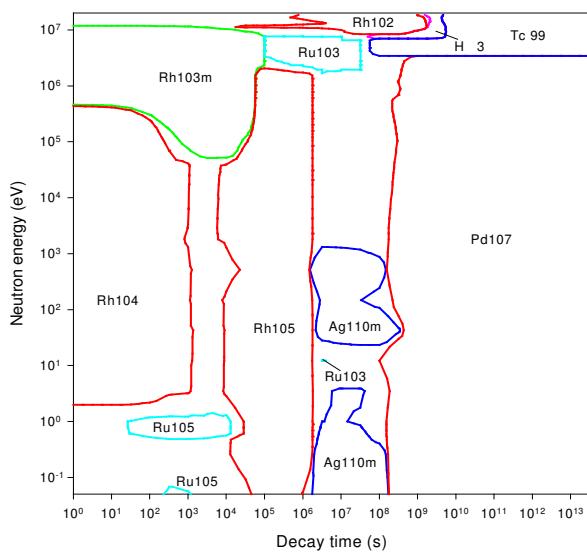


Decay time (years)

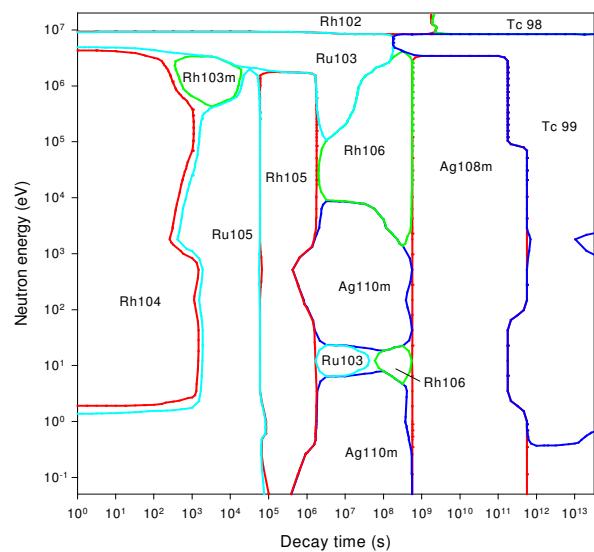
Decay time (years)

# Rhodium importance diagrams & transmutation

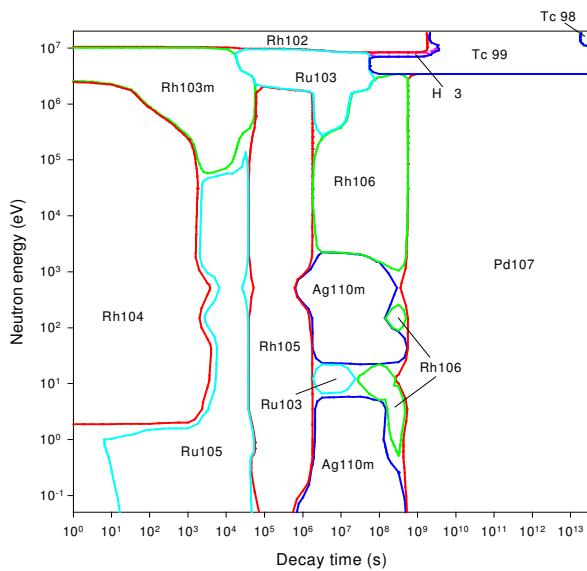
## Activity



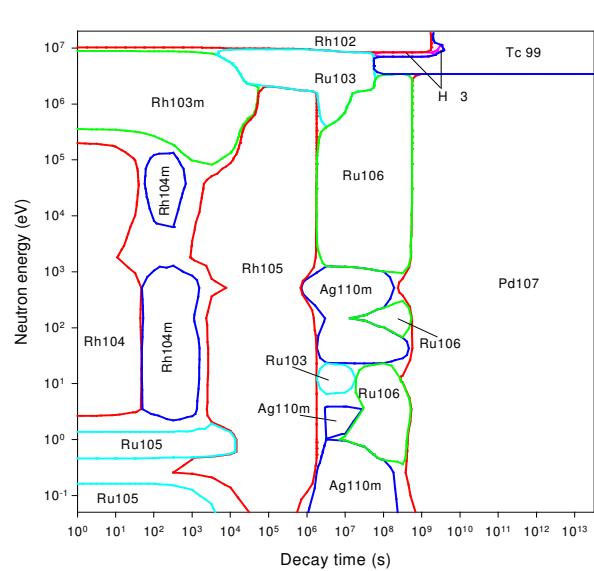
## Dose rate



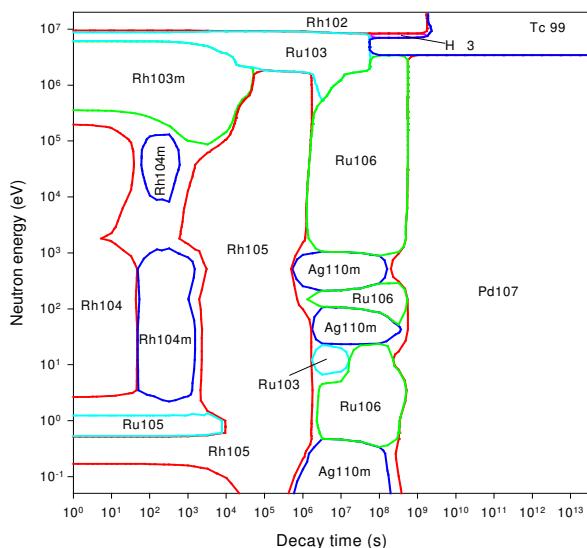
## Heat output



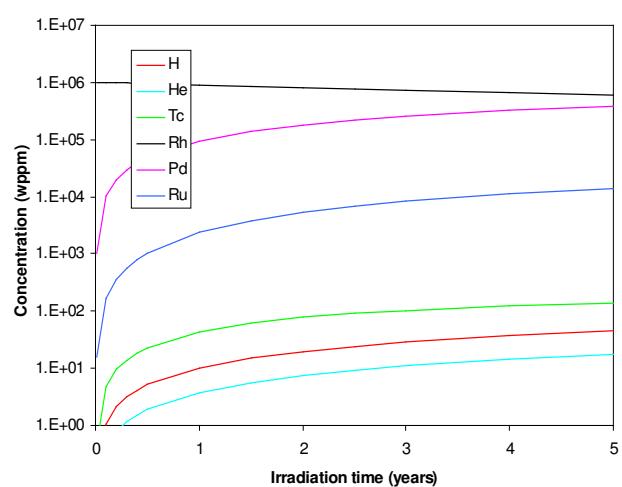
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Palladium

## General properties

Atomic number	46	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	1.5 10 <sup>-2</sup>	Pd102	1.02
Melting point / K	1828	Pd104	11.14
Boiling point / K	3236	Pd105	22.33
Density / kgm <sup>-3</sup>	12020	Pd106	27.33
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	71.8	Pd108	26.46
Electrical resistivity /Ωm	1.08 10 <sup>-7</sup>	Pd110	11.72
Coefficient of thermal expansion / K <sup>-1</sup>	1.18 10 <sup>-5</sup>		
Crystal structure	FCC		
Number of stable isotopes	6		
Mean atomic weight	106.42		

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.24E16	8.07E15	7.16E14	7.45E13	8.37E10	2.91E8	kW kg <sup>-1</sup>	1.10E0	3.22E-1	4.90E-2	1.35E-2	2.09E-5	4.42E-10
Ag110	31.37		0.13	0.47			Ag110	68.45	0.09	0.38	0.50		
Ag109m	29.48	44.21	10.45	28.09			Pd109	18.62	63.44	4.59			
Pd109	28.60	43.75	5.43				Ag109m	4.69	15.67	2.16	2.19		
Rh103m	1.66	2.54	23.84				Ag110m	3.12	10.68	69.49	92.33		
Ag111	1.59	2.43	19.60				Rh104	1.23	0.23				
Pd103	1.58	2.43	23.59				Ag111	1.09	3.71	17.43			
Ag111m	1.12	0.93					Pd111	1.01	3.00				
Pd109m	0.97	0.69					Pd109m	0.33	0.52				
Ag110m	0.61	0.94	10.48	36.96			Ag108	0.28	0.21		0.01	3.21	
Cd109	0.29	0.45	5.02	28.09			Rh103m	0.12	0.41	2.23			
Ag108	0.25	0.08		0.01	7.95		Pd103	0.06	0.20	1.14			
Rh102m		0.04	0.47	1.36			Rh102	0.04	0.13	0.84	2.45		
Rh101		0.04	0.45	3.54			Rh102m	0.03	0.11	0.74	0.80		
Rh102			0.17	1.30			Rh101			0.35	1.02		
Ag108m			0.01	0.12	91.40		Ag108m			0.05	0.18	96.76	
Pd107					0.35	99.92	Pd107						99.17
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	9.93E4	6.15E4	5.57E4	2.05E4	2.72E1	2.55E-7	Sv kg <sup>-1</sup>	2.56E6	2.55E6	5.30E5	1.25E5	1.80E2	1.09E-2
Ag110m	54.98	88.69	97.02	96.80			Pd109	76.19	76.23	4.03			
Ag110	35.81*		0.02*	0.02*			Ag111	9.98	10.03	34.43			
Rh106m	1.62	2.54					Ag110m	8.29	8.33	39.66	61.69		
Pd107m	1.00						Cd109	2.82	2.84	13.57	33.49		
Pd111	0.89	1.25					Pd103	1.46	1.46	6.06			
Pd111m	0.88	1.41					Rh102m	0.16	0.16	0.77	0.98		
Ag111	0.65	1.05	0.83				Rh102	0.12	0.12	0.59	2.02		
Rh102	0.60	0.97	1.07	2.36			Rh101	0.07	0.07	0.34	1.16		
Pd101	0.46	0.73					Cd113m	0.03	0.03	0.12	0.50	2.29	
Rh102m	0.34	0.55	0.60	0.49			Ag108m			0.04	0.17	97.70	
Ag108m		0.05	0.06	0.16	99.88		Pd107					0.01	98.72
Tc98						99.83	Tc99						1.27
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	3.03E6	3.02E6	1.59E6	5.44E5	2.85E3	1.74E-1		1.14E12	5.10E11	2.72E11	9.58E10	1.26E8	2.66E2
Pd109	43.29	43.23	0.90				Ag110	51.76		0.05	0.06		
Ag110m	30.01	30.10	56.49	60.72			Ag110m	22.19	49.57	92.03	95.79		
Ag111	11.02	11.05	14.96				Pd109	11.53	25.66	0.53			
Cd109	9.66	9.69	18.26	31.15			Ag109m	6.06	13.21	0.52	0.41		
Pd103	2.91	2.92	4.77				Pd109m	1.26	1.30				
Rh102m	0.80	0.81	1.51	1.33			Pd107m	1.16					
Rh102	0.67	0.68	1.28	3.03			Ag111	1.08	2.41	3.23			
Rh101	0.58	0.58	1.10	2.62			Pd111	0.89	1.73				
Ru103	0.16	0.16	0.28				Rh106m	0.57	1.23				
Ag108m	0.11	0.11	0.21	0.61	99.30		Pd111m	0.43	0.95				
Cd113m	0.10	0.10	0.20	0.54	0.69		Rh102	0.23	0.50	0.94	2.15		
Pd107					0.01	98.37	Ag108m			0.05	0.15	99.56	
Tc99						1.61	Pd107						99.31

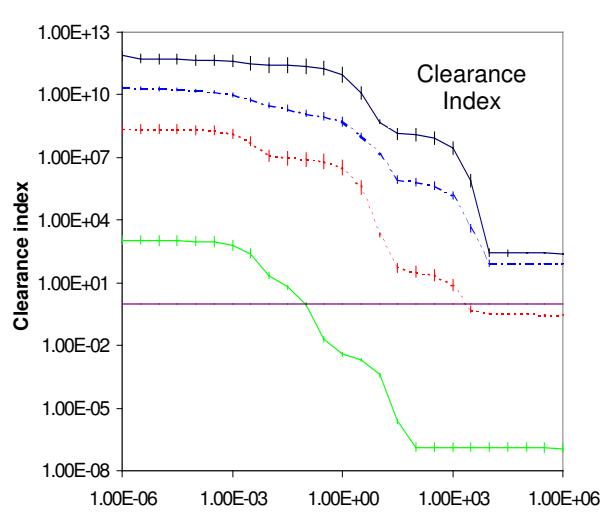
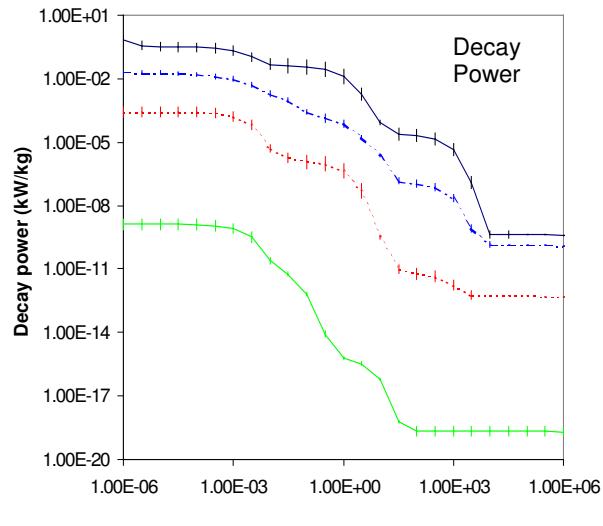
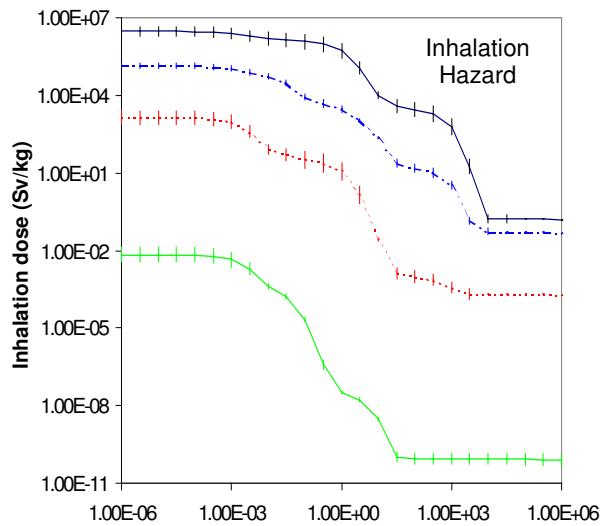
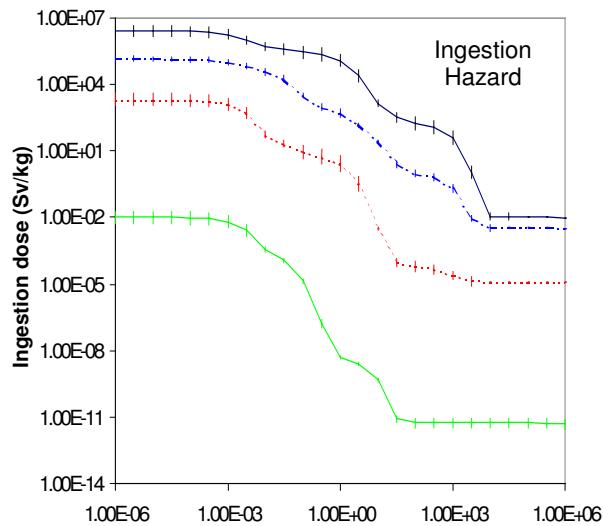
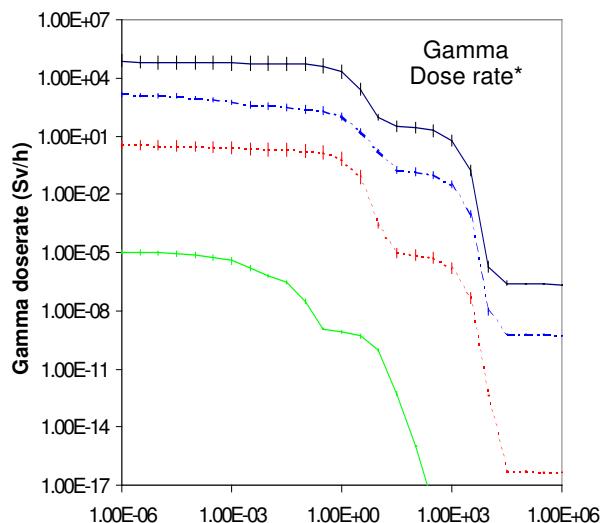
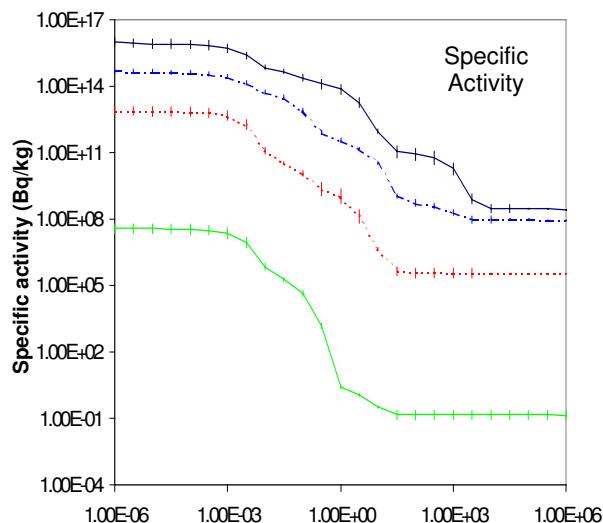
# Palladium

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Ag110	24.7 s	&Pd108(n, $\gamma$ )Pd109( $\beta^-$ )Ag109(n, $\gamma$ )Ag110 &Pd110(n,2n)Pd109( $\beta^-$ )Ag109(n, $\gamma$ )Ag110 &Pd110(n, $\gamma$ )Pd111( $\beta^-$ )Ag111(n,2n)Ag110	99.8	99.9	99.9	98.4 0.4
Rh106m	2.2 h	&Pd102(n, $\gamma$ )Pd103( $\beta^+$ )Rh103(n, $\gamma$ )Rh104( $\beta^+$ ) Ru104(n, $\gamma$ )Ru105( $\beta^-$ )Rh105(n, $\gamma$ )Rh106m &Pd108(n, $\gamma$ )Pd109( $\beta^-$ )Ag109(n, $\alpha$ )Rh106m &Pd108(n, $\alpha$ )Ru105( $\beta^-$ )Rh105(n, $\gamma$ )Rh106m Pd106(n,p)Rh106m &Pd108(n,2n)Pd107(n,2n)Pd106(n,p)Rh106m &Pd108(n,2n)Pd107(n,d)Rh106m &Pd110(n,2n)Pd109( $\beta^-$ )Ag109(n, $\alpha$ )Rh106m	100.0	71.6 27.5 0.9	17.5 82.4	90.3 3.1 3.1 3.0
Pd111m	5.5 h	Pd110(n, $\gamma$ )Pd111m	99.7	100.0	100.0	99.9
Pd109	13.46 h	Pd108(n, $\gamma$ )Pd109 Pd108(n, $\gamma$ )Pd109m(IT)Pd109 &Pd110(n,2n)Pd109	97.6 2.3	97.7 2.2	97.4 2.3	99.4
Ag111	7.45 d	&Pd108(n, $\gamma$ )Pd109( $\beta^-$ )Ag109(n, $\gamma$ )Ag110m(n, $\gamma$ )Ag111 &Pd110(n, $\gamma$ )Pd111( $\beta^-$ )Ag111 &Pd110(n, $\gamma$ )Pd111m( $\beta^-$ )Ag111	61.5 36.8 1.5	0.1 95.9 4.0	0.1 95.9 4.0	87.6 11.8
Pd103	16.98 d	Pd102(n, $\gamma$ )Pd103 Pd104(n,2n)Pd103 Pd105(n,2n)Pd104(n,2n)Pd103 Pd106(n,2n)Pd105(n,2n)Pd104(n,2n)Pd103	99.7	100.0	100.0	61.3 31.7 6.1
Ag110m	249.79 d	&Pd108(n, $\gamma$ )Pd109( $\beta^-$ )Ag109(n, $\gamma$ )Ag110m &Pd110(n,2n)Pd109( $\beta^-$ )Ag109(n, $\gamma$ )Ag110m &Pd110(n, $\gamma$ )Pd111( $\beta^-$ )Ag111(n,2n)Ag110m	99.9	99.9	100.0	98.3 0.7
Rh102	2.9021 y	&Pd104(n,2n)Pd103( $\beta^+$ )Rh103(n,2n)Rh102 &Pd105(n,2n)Pd104(n,2n)Pd103( $\beta^+$ )Rh103(n,2n)Rh102 &Pd102(n,p)Rh102 &Pd106(n,2n)Pd105(n,2n)Pd104(n,2n)Pd103( $\beta^+$ ) Rh103(n,2n)Rh102 &Pd104(n,d)Rh103(n,2n)Rh102				78.3 14.0 3.7 1.4 1.0
H3	12.33 y	Pd105(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Pd104(n, $\gamma$ )Pd105(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Pd105(n,X)H3 Pd106(n,2n)Pd105(n,X)H3 Pd104(n,2n)Pd103( $\beta^+$ )Rh103m(IT)Rh103(n,X)H3 Pd106(n,X)H3 Pd108(n,X)H3 Pd104(n,X)H3 &Pd110(n,2n)Pd109( $\beta^-$ )Ag109(n,X)H3 Pd110(n,X)H3 Pd105(n,2n)Pd104(n,2n)Pd103( $\beta^+$ )Rh103m(IT)Rh103(n,X)H3 Pd105(n,2n)Pd104(n,X)H3	92.6 0.3	94.2 0.3	99.1 0.3	51.8 10.0 8.0 8.0 7.1 3.8 3.0 2.6 1.3 1.0
Cd113m	13.7 y	&Pd108(n, $\gamma$ )Pd109( $\beta^-$ )Ag109(n, $\gamma$ )Ag110( $\beta^-$ ) Cd110(n, $\gamma$ )Cd111(n, $\gamma$ )Cd112(n, $\gamma$ )Cd113m &Pd108(n, $\gamma$ )Pd109( $\beta^-$ )Ag109(n, $\gamma$ )Ag110m(n, $\gamma$ ) Ag111( $\beta^-$ )Cd111(n, $\gamma$ )Cd112(n, $\gamma$ )Cd113m &Pd110(n, $\gamma$ )Pd111( $\beta^-$ )Ag111( $\beta^-$ )Cd111(n, $\gamma$ ) Cd112(n, $\gamma$ )Cd113m &Pd110(n, $\gamma$ )Pd111m( $\beta^-$ )Ag111( $\beta^-$ )Cd111(n, $\gamma$ ) Cd112(n, $\gamma$ )Cd113m &Pd110(n, $\gamma$ )Pd111( $\beta^-$ )Ag111(n, $\gamma$ )Ag112( $\beta^-$ ) Cd112(n, $\gamma$ )Cd113m &Pd108(n, $\gamma$ )Pd109( $\beta^-$ )Ag109(n, $\gamma$ )Ag110m( $\beta^-$ ) Cd110(n, $\gamma$ )Cd111(n, $\gamma$ )Cd112(n, $\gamma$ )Cd113m	80.2 10.8 7.2 0.4	26.3 66.0 4.0 2.8 3.3 4.0 0.7	0.1 94.5 83.0 11.2 0.9 3.7	

Ag108m	418.0 y	<b>&amp;Pd106(n,<math>\gamma</math>)Pd107(<math>\beta^-</math>)Ag107(n,<math>\gamma</math>)Ag108m</b> <b>&amp;Pd105(n,<math>\gamma</math>)Pd106(n,<math>\gamma</math>)Pd107(<math>\beta^-</math>)Ag107(n,<math>\gamma</math>)Ag108m</b> <b>&amp;Pd110(n,2n)Pd109(<math>\beta^-</math>)Ag109(n,2n)Ag108m</b>	78.2 21.7	66.0 33.9	96.6 3.4		
Tc99	$2.1 \cdot 10^5$ y	<b>&amp;Pd105(n,<math>\alpha</math>)Ru102(n,<math>\alpha</math>)Mo99(<math>\beta^-</math>)Tc99</b> <b>&amp;Pd104(n,2n)Pd103(<math>\beta^+</math>)Rh103(n,n<math>\alpha</math>)Tc99</b> <b>&amp;Pd105(n,2n)Pd104(n,2n)Pd103(<math>\beta^+</math>)Rh103(n,n<math>\alpha</math>)Tc99</b> <b>&amp;Pd106(n,2n)Pd105(n,2n)Pd104(n,2n)Pd103(<math>\beta^+</math>)</b> <b>Rh103(n,n<math>\alpha</math>)Tc99</b> <b>&amp;Pd104(n,d)Rh103(n,n<math>\alpha</math>)Tc99</b>	99.7	99.6	99.9	0.2 80.9 13.0 1.3 1.0	
Tc98	$4.2 \cdot 10^6$ y	<b>&amp;Pd104(n,2n)Pd103(<math>\beta^+</math>)Rh103(n,n<math>\alpha</math>)Tc99(n,2n)Tc98</b> <b>&amp;Pd104(n,2n)Pd103(<math>\beta^+</math>)Rh103(n,2n)Rh102(n,n<math>\alpha</math>)Tc98</b> Pd102(n,2n)Pd101( $\beta^+$ )Rh101(n, $\alpha$ )Tc98 <b>&amp;Pd104(n,2n)Pd103(<math>\beta^+</math>)Rh103(n,2n)Rh102m(n,n<math>\alpha</math>)Tc98</b> <b>&amp;Pd105(n,2n)Pd104(n,2n)Pd103(<math>\beta^+</math>)Rh103(n,n<math>\alpha</math>)</b> Tc99(n,2n)Tc98 <b>&amp;Pd105(n,2n)Pd104(n,2n)Pd103(<math>\beta^+</math>)Rh103(n,2n)</b> Rh102(n,n $\alpha$ )Tc98 <b>&amp;Pd102(n,p)Rh102(n,n<math>\alpha</math>)Tc98</b> Pd102(n,n $\alpha$ )Ru98(n,p)Tc98				34.9 23.2 15.9 8.3 4.3 3.0 1.8 1.0	
Pd107	$6.5 \cdot 10^6$ y	<b>&amp;Pd106(n,<math>\gamma</math>)Pd107</b> <b>&amp;Pd105(n,<math>\gamma</math>)Pd106(n,<math>\gamma</math>)Pd107</b> <b>&amp;Pd108(n,2n)Pd107</b>	72.0 27.9	57.5 42.3	93.4 6.6	99.5	
In115	$4.4 \cdot 10^{14}$ y	<b>&amp;Pd108(n,<math>\gamma</math>)Pd109(<math>\beta^-</math>)Ag109(n,<math>\gamma</math>)Ag110(<math>\beta^-</math>)</b> Cd110(n, $\gamma$ )Cd111(n, $\gamma$ )Cd112(n, $\gamma$ )Cd113(n, $\gamma$ ) Cd114(n, $\gamma$ )Cd115( $\beta^-$ )In115 <b>&amp;Pd108(n,<math>\gamma</math>)Pd109(<math>\beta^-</math>)Ag109(n,<math>\gamma</math>)Ag110m(n,<math>\gamma</math>)</b> Ag111( $\beta^-$ )Cd111(n, $\gamma$ )Cd112(n, $\gamma$ )Cd113(n, $\gamma$ ) Cd114(n, $\gamma$ )Cd115( $\beta^-$ )In115 <b>&amp;Pd108(n,<math>\gamma</math>)Pd109(<math>\beta^-</math>)Ag109(n,<math>\gamma</math>)Ag110(<math>\beta^-</math>)</b> Cd110(n, $\gamma$ )Cd111(n, $\gamma$ )Cd112(n, $\gamma$ )Cd113m(n, $\gamma$ ) Cd114(n, $\gamma$ )Cd115( $\beta^-$ )In115 <b>&amp;Pd110(n,<math>\gamma</math>)Pd111(<math>\beta^-</math>)Ag111(<math>\beta^-</math>)Cd111(n,<math>\gamma</math>)</b> Cd112(n, $\gamma$ )Cd113(n, $\gamma$ )Cd114(n, $\gamma$ )Cd115( $\beta^-$ )In115 <b>&amp;Pd108(n,<math>\gamma</math>)Pd109(<math>\beta^-</math>)Ag109(n,<math>\gamma</math>)Ag110(<math>\beta^-</math>)</b> Cd110(n, $\gamma$ )Cd111(n, $\gamma$ )Cd112(n, $\gamma$ )Cd113(n, $\gamma$ ) Cd114(n, $\gamma$ )Cd115m( $\beta^-$ )In115 <b>&amp;Pd108(n,<math>\gamma</math>)Pd109(<math>\beta^-</math>)Ag109(n,<math>\gamma</math>)Ag110m(n,<math>\gamma</math>)</b> Ag111( $\beta^-$ )Cd111(n, $\gamma$ )Cd112(n, $\gamma$ )Cd113(n, $\gamma$ ) Cd114(n, $\gamma$ )Cd115m( $\beta^-$ )In115 <b>&amp;Pd110(n,<math>\gamma</math>)Pd111(<math>\beta^-</math>)Ag111(<math>\beta^-</math>)Cd111(n,<math>\gamma</math>)</b> Cd112(n, $\gamma$ )Cd113m(n, $\gamma$ )Cd114(n, $\gamma$ )Cd115( $\beta^-$ )In115 <b>&amp;Pd110(n,<math>\gamma</math>)Pd111(<math>\beta^-</math>)Ag111(<math>\beta^-</math>)Cd111(n,<math>\gamma</math>)</b> Cd112(n, $\gamma$ )Cd113(n, $\gamma$ )Cd114(n, $\gamma$ )Cd115( $\beta^-$ )In115 <b>&amp;Pd110(n,<math>\gamma</math>)Pd111(<math>\beta^-</math>)Ag111(<math>\beta^-</math>)Cd111(n,<math>\gamma</math>)</b> Cd112(n, $\gamma$ )Cd113m(n, $\gamma$ )Cd114(n, $\gamma$ )Cd115m( $\beta^-$ )In115 <b>&amp;Pd110(n,<math>\gamma</math>)Pd111(<math>\beta^-</math>)Ag111(<math>\beta^-</math>)Ag112(<math>\beta^-</math>)</b> Cd112(n, $\gamma$ )Cd113(n, $\gamma$ )Cd114(n, $\gamma$ )Cd115( $\beta^-$ )In115 <b>&amp;Pd110(n,<math>\gamma</math>)Pd111(<math>\beta^-</math>)Ag111(<math>\beta^-</math>)Cd111(n,<math>\gamma</math>)</b> Cd112(n, $\gamma$ )Cd113(n, $\gamma$ )Cd114(n, $\gamma$ )Cd115m( $\beta^-$ )In115 <b>&amp;Pd110(n,<math>\gamma</math>)Pd111(<math>\beta^-</math>)Ag111(<math>\beta^-</math>)Cd111(n,<math>\gamma</math>)</b> Cd112(n, $\gamma$ )Cd113m(n, $\gamma$ )Cd114(n, $\gamma$ )Cd115m( $\beta^-$ )In115	58.4 10.2 8.7 8.2 6.7 1.2 1.2 1.0 0.3 0.1 0.1 4.0 0.3	12.1 1.8 60.0 77.2 1.2 8.6 5.5 6.0 9.3 2.5 3.2 0.4 0.9 0.7 1.3 0.4			15.2 32.3 10.6 2.1 4.4 22.5 1.1 1.4 3.0

# Palladium activation characteristics

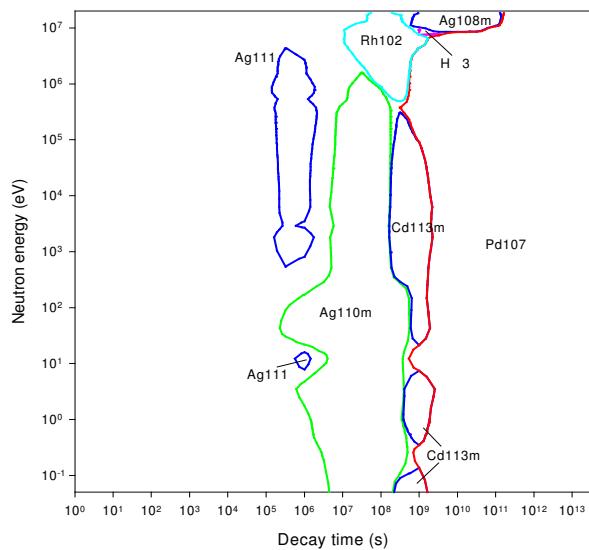


Decay time (years)

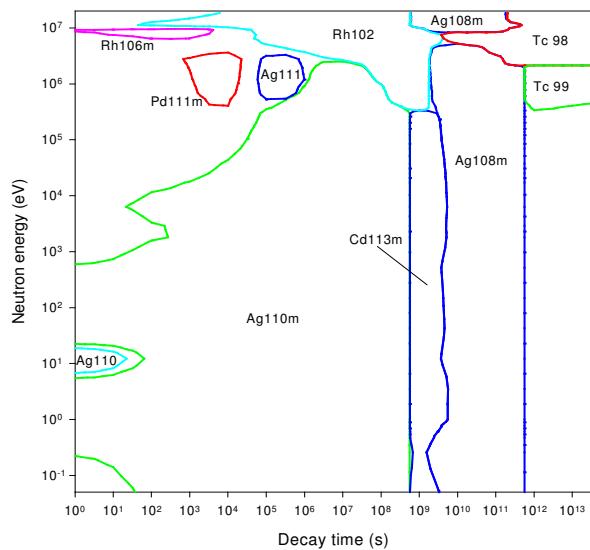
Decay time (years)

# Palladium importance diagrams & transmutation

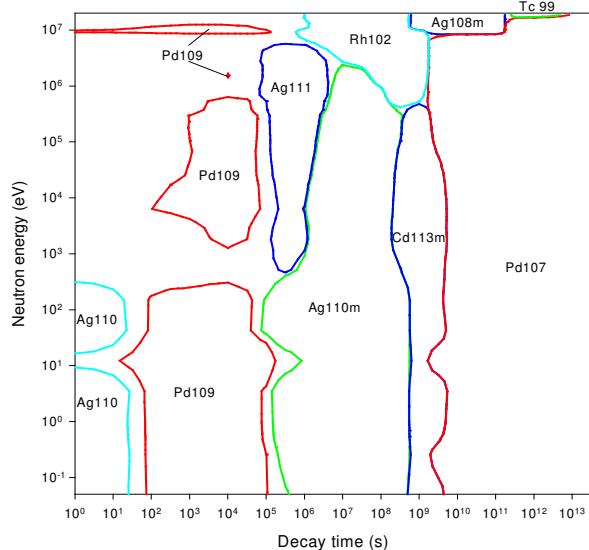
## Activity



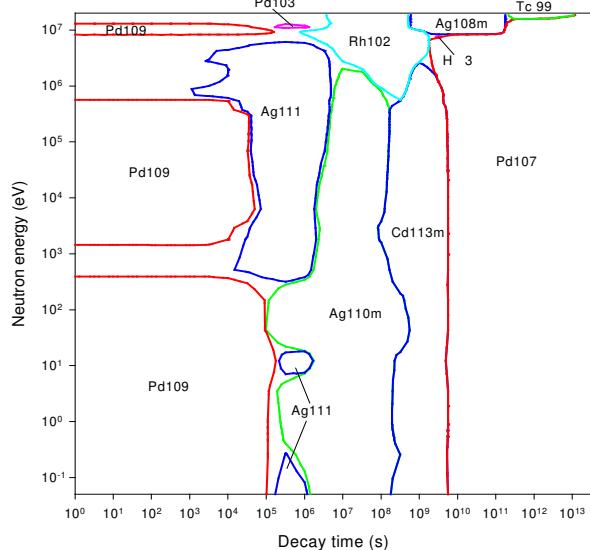
## Dose rate



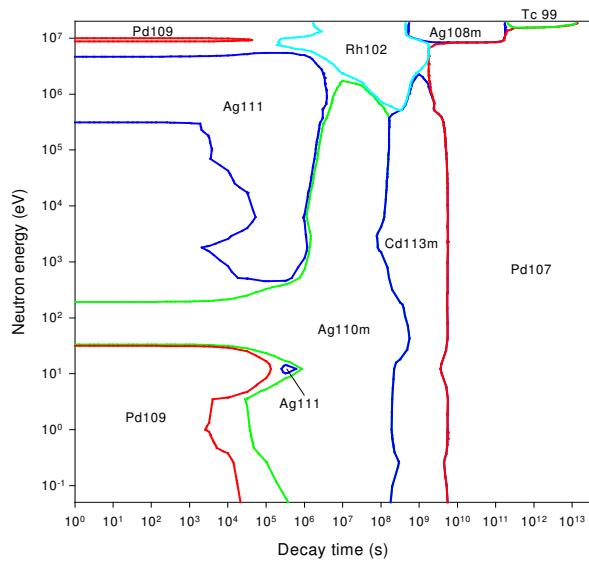
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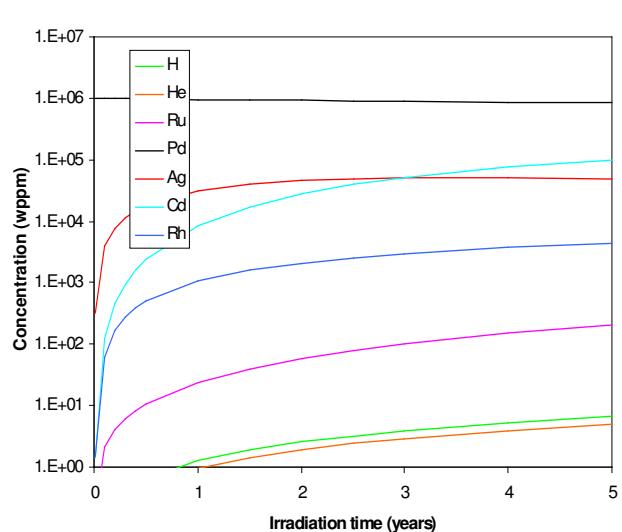
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Silver

## General properties

Atomic number	47	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	7.5 10 <sup>-2</sup>	Ag107	51.839
Melting point / K	1235	Ag109	48.161
Boiling point / K	2435		
Density / kgm <sup>-3</sup>	10500		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	429		
Electrical resistivity /Ωm	1.59 10 <sup>-5</sup>		
Coefficient of thermal expansion / K <sup>-1</sup>	1.89 10 <sup>-5</sup>		
Crystal structure	FCC		
Number of stable isotopes	2		
Mean atomic weight	107.8682		

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.18E16	3.31E15	1.41E15	6.77E14	4.47E11	1.11E7	kW kg <sup>-1</sup>	1.47E0	2.83E-1	1.06E-1	2.09E-2	1.12E-4	1.67E-11
Ag108	42.83	33.51		0.01	7.98		Ag110	52.69	0.12	0.21	0.39		
Ag110	33.75	0.05	0.08	0.06			Ag108	34.73	39.43		0.02	3.21	
Ag109m	6.62	19.92	39.23	47.46			Ag106m	4.49	23.30	46.06			
Cd109	4.70	16.78	39.15	47.46			Ag110m	2.83	14.65	38.66	72.08		
Ag107m	4.07	4.38					Ag106	2.54	11.32				
Ag106	1.63	5.00					Ag109m	0.75	3.29	7.36	21.73		
Ag106m	1.26	4.50	7.83				Ag111	0.58	3.03	5.75			
Cd107	1.21	4.30	0.00				Ag107m	0.49	0.76				
Ag111	1.19	4.26	7.12				Pd109	0.41	2.11	0.06			
Pd109	0.88	3.13	0.08				Cd111m	0.18	0.84				
Ag110m	0.77	2.77	6.42	4.91			Cd109	0.13	0.66	1.74	5.14		
Cd111m	0.34	1.14					Ag108m	0.01	0.05	0.12	0.61	96.75	
Ag108m		0.02	0.03	0.07	91.69		Pd107						99.89
Pd107					99.99		Tc99						0.11
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	2.52E5	1.94E5	1.39E5	2.38E4	1.43E2	3.34E-10	Sv kg <sup>-1</sup>	1.87E6	1.86E6	1.66E6	7.41E5	9.73E2	4.11E-4
Ag106m	39.74	51.76	53.39				Cd109	59.40	59.79	66.49	86.68		
Ag110m	25.76	33.56	46.21	99.14			Ag110m	13.70	13.79	15.27	12.54		
Ag110	14.18*	0.01	0.01	0.02			Ag106m	11.94	12.02	9.97			
Ag106	9.77	10.94					Ag111	9.80	9.86	7.86			
Ag108	9.72*	2.77*			0.12		Pd109	3.06	3.06	0.04			
Cd111m	0.31	0.38					Cd113m	0.26	0.26	0.29	0.63	3.18	
Ag108m	0.07	0.09	0.12	0.71	99.89		Ag108m	0.06	0.06	0.07	0.15	96.81	
Tc98					99.98		Pd107						99.83
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	6.11E6	6.10E6	5.89E6	3.04E6	1.53E4	6.55E-3		1.95E12	9.85E11	6.28E11	1.19E11	6.74E8	1.01E1
Cd109	73.62	73.72	75.89	85.57			Ag110	30.98	0.03	0.03	0.05		
Ag110m	17.97	18.00	18.44	13.11			Ag108	21.62	9.38		0.44		
Ag111	3.92	3.93	2.90				Ag106m	21.17	41.97	48.81			
Ag106m	2.68	2.68	2.06				Ag110m	15.62	30.96	48.07	93.26		
Pd109	0.63	0.63	0.01				Ag106	7.58	12.92				
Cd113m	0.38	0.38	0.40	0.73	0.97		Ag109m	0.76	1.26	1.66	5.11		
Ag108m	0.29	0.29	0.30	0.59	99.03		Cd111m	0.63	1.16				
Cd107	0.20	0.19					Ag107m	0.50	0.30				
Ag108	0.11	0.02					Ag111	0.45	0.89	1.00			
Cd111m	0.10	0.09					Cd109	0.10	0.19	0.29	0.90		
Pd107					99.78		Ag108m	0.04	0.08	0.13	0.67	99.56	
Tc99					0.22	Pd107							99.95

# Silver

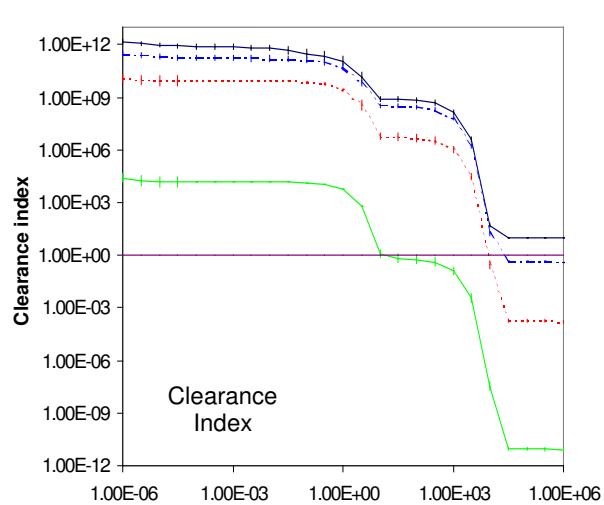
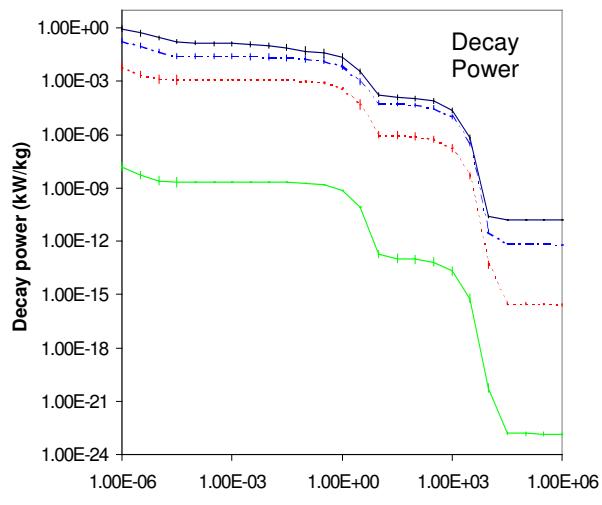
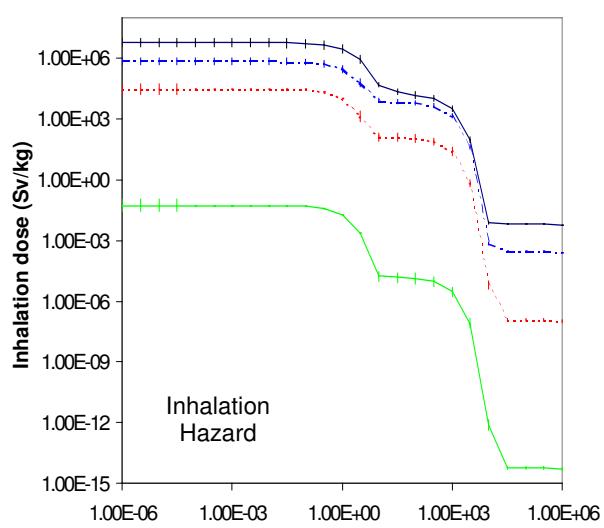
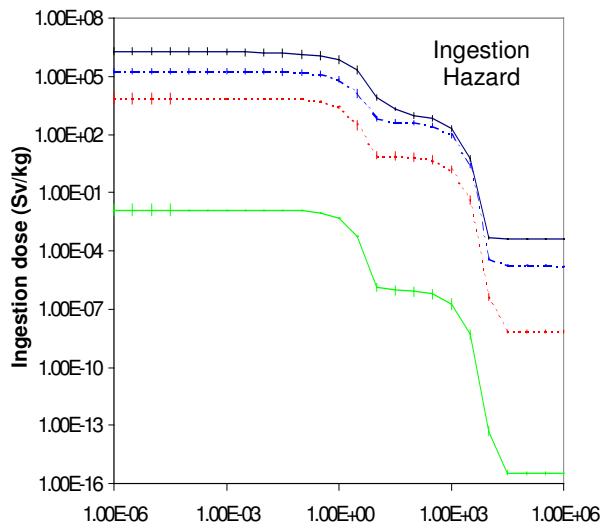
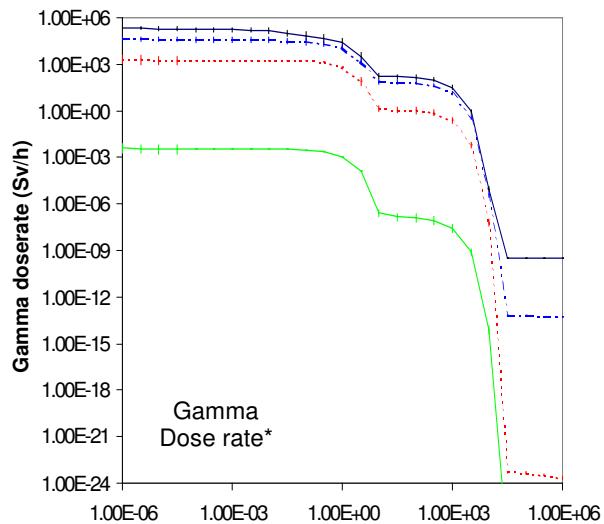
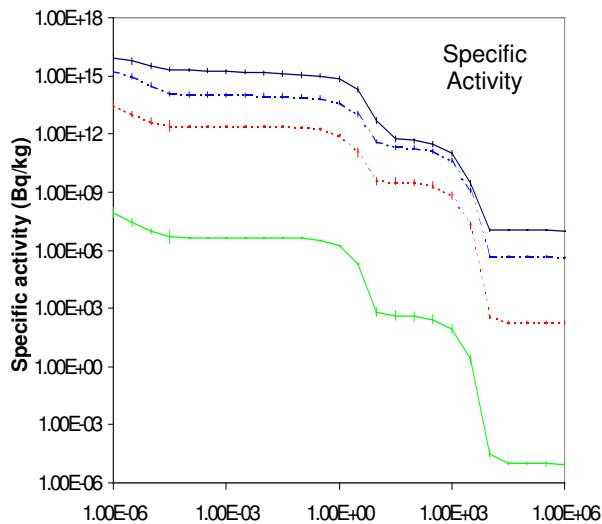
## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Ag110	24.7 s	&Ag107(n, $\gamma$ )Ag108( $\beta^-$ )Cd108(n, $\gamma$ )Cd109( $\beta^+$ ) Ag109(n, $\gamma$ )Ag110 &Ag107(n, $\gamma$ )Ag108( $\beta^+$ )Pd108(n, $\gamma$ )Pd109( $\beta^-$ ) Ag109(n, $\gamma$ )Ag110 &Ag109(n, $\gamma$ )Ag110 &Ag107(n, $\gamma$ )Ag108m(n, $\gamma$ )Ag109(n, $\gamma$ )Ag110	30.1 28.6 23.3 18.0	5.0 0.7 79.3 15.0	0.2 99.7 99.2	
Ag109m	39.8 s	Ag107(n, $\gamma$ )Ag108( $\beta^-$ )Cd108(n, $\gamma$ )Cd109( $\beta^+$ )Ag109m &Ag107(n, $\gamma$ )Ag108( $\beta^+$ )Pd108(n, $\gamma$ )Pd109( $\beta^-$ )Ag109m Ag107(n, $\gamma$ )Ag108m(n, $\gamma$ )Ag109m Ag109(n,n')Ag109m &Ag109(n,p)Pd109( $\beta^-$ )Ag109m	47.6 42.6 9.8	44.5 6.2 49.3	95.5 2.0 2.5	94.5 4.8
Ag107m	44.1 s	Ag107(n,n')Ag107m Ag109(n,2n)Ag108m(n,2n)Ag107m Ag109(n,2n)Ag108( $\beta^-$ )Cd108(n,2n)Cd107( $\beta^+$ )Ag107m Ag109(n,2n)Ag108( $\beta^-$ )Cd108(n,d)Ag107m				55.5 21.5 20.7 0.8
Ag108	2.4 m	Ag107(n, $\gamma$ )Ag108 &Ag109(n,2n)Ag108 Ag109(n,2n)Ag108m(n,n')Ag108	100.0	100.0	100.0	98.6 0.8
In116m	54.6 m	&Ag109(n, $\gamma$ )Ag110( $\beta^-$ )Cd110(n, $\gamma$ )Cd111(n, $\gamma$ )Cd112 (n, $\gamma$ )Cd113(n, $\gamma$ )Cd114(n, $\gamma$ )Cd115( $\beta^-$ )In115(n, $\gamma$ )In116m &Ag109(n, $\gamma$ )Ag110m(n, $\gamma$ )Ag111( $\beta^-$ )Cd111(n, $\gamma$ )Cd112 (n, $\gamma$ )Cd113(n, $\gamma$ )Cd114(n, $\gamma$ )Cd115( $\beta^-$ )In115(n, $\gamma$ )In116m &Ag109(n, $\gamma$ )Ag110( $\beta^-$ )Cd110(n, $\gamma$ )Cd111(n, $\gamma$ )Cd112 (n, $\gamma$ )Cd113m(n, $\gamma$ )Cd114(n, $\gamma$ )Cd115( $\beta^-$ )In115(n, $\gamma$ )In116m &Ag109(n, $\gamma$ )Ag110( $\beta^-$ )Cd110(n, $\gamma$ )Cd111(n, $\gamma$ )Cd112 (n, $\gamma$ )Cd113(n, $\gamma$ )Cd114(n, $\gamma$ )Cd115m( $\beta^-$ )In115(n, $\gamma$ )In116m &Ag109(n, $\gamma$ )Ag110m(n, $\gamma$ )Ag111( $\beta^-$ )Cd111(n, $\gamma$ )Cd112 (n, $\gamma$ )Cd113m(n, $\gamma$ )Cd114(n, $\gamma$ )Cd115( $\beta^-$ )In115(n, $\gamma$ )In116m &Ag109(n, $\gamma$ )Ag110( $\beta^-$ )Cd110(n, $\gamma$ )Cd111(n, $\gamma$ )Cd112(n, $\gamma$ ) Cd113m(n, $\gamma$ )Cd114(n, $\gamma$ )Cd115m( $\beta^-$ )In115(n, $\gamma$ )In116m &Ag109(n, $\gamma$ )Ag110m( $\beta^-$ )Cd110(n, $\gamma$ )Cd111(n, $\gamma$ )Cd112 (n, $\gamma$ )Cd113(n, $\gamma$ )Cd114(n, $\gamma$ )Cd115( $\beta^-$ )In115(n, $\gamma$ )In116m &Ag109(n, $\gamma$ )Ag110( $\beta^-$ )Cd110(n, $\gamma$ )Cd111(n, $\gamma$ )Cd112 (n, $\gamma$ )Cd113m( $\beta^-$ )In113(n, $\gamma$ )In114m(n, $\gamma$ )In115(n, $\gamma$ )In116m *Plus other similar pathways involving (n, $\gamma$ ) and $\beta^-$	63.5 9.5 9.5 7.7 1.4 1.2 1.2 0.8 5.2*	72.0 0.1 10.4 7.2 0.7 1.1 1.0 1.8 7.5* 9.8*	64.2 9.3 4.6 7.5 0.7 1.1 0.5 1.3 1.0 9.8*	
Pd109	13.46 h	&Ag107(n, $\gamma$ )Ag108( $\beta^+$ )Pd108(n, $\gamma$ )Pd109 Ag107(n, $\gamma$ )Ag108m( $\beta^+$ )Pd108(n, $\gamma$ )Pd109 &Ag109(n,p)Pd109	99.9 0.1	100.0	99.9 0.1	99.7
Ag111	7.45 d	&Ag109(n, $\gamma$ )Ag110m(n, $\gamma$ )Ag111 &Ag107(n, $\gamma$ )Ag108( $\beta^-$ )Cd108(n, $\gamma$ )Cd109( $\beta^+$ ) Ag109(n, $\gamma$ )Ag110m(n, $\gamma$ )Ag111 &Ag107(n, $\gamma$ )Ag108( $\beta^+$ )Pd108(n, $\gamma$ )Pd109( $\beta^-$ ) Ag109(n, $\gamma$ )Ag110m(n, $\gamma$ )Ag111 &Ag107(n, $\gamma$ )Ag108m(n, $\gamma$ )Ag109(n, $\gamma$ )Ag110m(n, $\gamma$ ) Ag111 &Ag109(n, $\gamma$ )Ag110( $\beta^+$ )Pd110(n, $\gamma$ )Pd111( $\beta^-$ )Ag111 &Ag109(n, $\gamma$ )Ag110( $\beta^+$ )Pd110(n, $\gamma$ )Pd111m( $\beta^-$ )Ag111 &Ag109(n, $\gamma$ )Ag110( $\beta^-$ )Cd110(n, $\gamma$ )Cd111(n,p)Ag111	32.8 24.0 23.2 16.5 3.0 3.0	61.6 0.4 0.1 1.9 34.4 1.4	96.6 0.1 3.0 0.1 3.0 1.6	93.9 2.3 1.6
Ag106m	8.46 d	Ag107(n,2n)Ag106m &Ag109(n,2n)Ag108m(n,2n)Ag107(n,2n)Ag106m &Ag109(n,2n)Ag108( $\beta^-$ )Cd108(n,2n)Cd107( $\beta^+$ ) Ag107(n,2n)Ag106m				97.7 1.1 1.0

Ag110m	249.79 d	Ag109(n, $\gamma$ )Ag110m <b>&amp;Ag107(n,<math>\gamma</math>)Ag108(<math>\beta^-</math>)Cd108(n,<math>\gamma</math>)Cd109(<math>\beta^+</math>)</b> Ag109(n, $\gamma$ )Ag110m <b>&amp;Ag107(n,<math>\gamma</math>)Ag108(<math>\beta^+</math>)Pd108(n,<math>\gamma</math>)Pd109(<math>\beta^-</math>)</b> Ag109(n, $\gamma$ )Ag110m <b>&amp;Ag107(n,<math>\gamma</math>)Ag108m(n,<math>\gamma</math>)Ag109(n,<math>\gamma</math>)Ag110m</b>	33.0 25.2 24.6 17.1	96.2 0.7 0.1 3.0	99.8 0.1	99.5
Cd109	1.267 y	Ag107(n, $\gamma$ )Ag108( $\beta^-$ )Cd108(n, $\gamma$ )Cd109 <b>&amp;Ag109(n,2n)Ag108(<math>\beta^-</math>)Cd108(n,<math>\gamma</math>)Cd109</b> <b>&amp;Ag109(n,<math>\gamma</math>)Ag110(<math>\beta^-</math>)Cd110(n,2n)Cd109</b> Ag109(n, $\gamma$ )Ag110m( $\beta^-$ )Cd110(n,2n)Cd109 Ag109(n,2n)Ag108m(n,n')Ag108( $\beta^-$ )Cd108(n, $\gamma$ )Cd109	100.0	100.0	100.0	61.6 26.2 11.8 0.2
Cd113m	13.7 y	<b>&amp;Ag109(n,<math>\gamma</math>)Ag110(<math>\beta^-</math>)Cd110(n,<math>\gamma</math>)Cd111(n,<math>\gamma</math>)</b> Cd112(n, $\gamma$ )Cd113m <b>&amp;Ag109(n,<math>\gamma</math>)Ag110m(n,<math>\gamma</math>)Ag111(<math>\beta^-</math>)Cd111(n,<math>\gamma</math>)</b> Cd112(n, $\gamma$ )Cd113m <b>&amp;Ag107(n,<math>\gamma</math>)Ag108(<math>\beta^-</math>)Cd108(n,<math>\gamma</math>)Cd109(n,<math>\gamma</math>)Cd110(n,<math>\gamma</math>)Cd111(n,<math>\gamma</math>)Cd112(n,<math>\gamma</math>)Cd113m</b> <b>&amp;Ag109(n,<math>\gamma</math>)Ag110m(<math>\beta^-</math>)Cd110(n,<math>\gamma</math>)Cd111(n,<math>\gamma</math>)</b> Cd112(n, $\gamma$ )Cd113m <b>&amp;Ag109(n,<math>\gamma</math>)Ag110m(n,<math>\gamma</math>)Ag111(n,<math>\gamma</math>)Ag112(<math>\beta^-</math>)</b> Cd112(n, $\gamma$ )Cd113m	88.4 8.6 1.2 1.1	96.9 0.1 9.8 2.9	87.7 19.1 2.2 0.1	59.4 19.3 1.0
Ag108m	418.0 y	Ag107(n, $\gamma$ )Ag108m Ag109(n,2n)Ag108m	100.0	100.0	100.0	99.7
Tc99	$2.1 \cdot 10^5$ y	<b>&amp;Ag107(n,n\alpha)Rh103(n,n\alpha)Tc99</b> <b>&amp;Ag107(n,\alpha)Rh104(<math>\beta^-</math>)Pd104(n,2n)Pd103(<math>\beta^+</math>)</b> Rh103(n,n\alpha)Tc99 <b>&amp;Ag107(n,2n)Ag106(<math>\beta^+</math>)Pd106(n,2n)Pd105(n,2n)</b> Pd104(n,2n)Pd103( $\beta^+$ )Rh103(n,n\alpha)Tc99 <b>&amp;Ag107(n,2n)Ag106m(<math>\beta^+</math>)Pd106(n,2n)Pd105(n,2n)</b> Pd104(n,2n)Pd103( $\beta^+$ )Rh103(n,n\alpha)Tc99 <b>&amp;Ag107(n,2n)Ag106(<math>\beta^+</math>)Pd106(n,\alpha)Ru103(<math>\beta^-</math>)</b> Rh103(n,n\alpha)Tc99 <b>&amp;Ag107(n,2n)Ag106m(<math>\beta^+</math>)Pd106(n,\alpha)Ru103(<math>\beta^-</math>)</b> Rh103(n,n\alpha)Tc99				71.3 10.3 4.0 3.4 2.9 2.5
Tc98	$4.2 \cdot 10^6$ y	<b>&amp;Ag107(n,n\alpha)Rh103(n,n\alpha)Tc99(n,2n)Tc98</b> <b>&amp;Ag107(n,n\alpha)Rh103(n,2n)Rh102(n,n\alpha)Tc98</b> <b>&amp;Ag107(n,n\alpha)Rh103(n,2n)Rh102m(n,n\alpha)Tc98</b> <b>&amp;Ag107(n,\alpha)Rh104(<math>\beta^-</math>)Pd104(n,2n)Pd103(<math>\beta^+</math>)</b> Rh103(n,n\alpha)Tc99(n,2n)Tc98 <b>&amp;Ag107(n,\alpha)Rh104(<math>\beta^-</math>)Pd104(n,2n)Pd103(<math>\beta^+</math>)</b> Rh103(n,2n)Rh102(n,n\alpha)Tc98 <b>&amp;Ag107(n,\alpha)Rh104(<math>\beta^-</math>)Pd104(n,2n)Pd103(<math>\beta^+</math>)</b> Rh103(n,2n)Rh102m(n,n\alpha)Tc98 <b>&amp;Ag107(n,2n)Ag106(<math>\beta^+</math>)Pd106(n,\alpha)Ru103(<math>\beta^-</math>)</b> Rh103(n,n\alpha)Tc99(n,2n)Tc98 <b>&amp;Ag107(n,2n)Ag106(<math>\beta^+</math>)Pd106(n,2n)Pd105(n,2n)</b> Pd104(n,2n)Pd103( $\beta^+$ )Rh103(n,n\alpha)Tc99(n,2n)Tc98 <b>&amp;Ag107(n,2n)Ag106m(<math>\beta^+</math>)Pd106(n,\alpha)Ru103(<math>\beta^-</math>)</b> Rh103(n,n\alpha)Tc99(n,2n)Tc98 <b>&amp;Ag107(n,2n)Ag106m(<math>\beta^+</math>)Pd106(n,2n)Pd105(n,2n)</b> Pd104(n,2n)Pd103( $\beta^+$ )Rh103(n,n\alpha)Tc99(n,2n)Tc98				41.4 27.4 9.8 4.4 3.1 1.3 1.2 1.2 1.1 1.0
Pd107	$6.5 \cdot 10^6$ y	<b>&amp;Ag107(n,<math>\gamma</math>)Ag108(<math>\beta^-</math>)Cd108(n,<math>\gamma</math>)Cd109(n,\alpha)Pd106(n,<math>\gamma</math>)Pd107</b> <b>&amp;Ag109(n,<math>\gamma</math>)Ag110(<math>\beta^-</math>)Cd110(n,\alpha)Pd107</b> Ag107(n,p)Pd107m(IT)Pd107 <b>&amp;Ag109(n,<math>\gamma</math>)Ag110m(<math>\beta^-</math>)Cd110(n,\alpha)Pd107</b> Ag107(n,p)Pd107 <b>&amp;Ag109(n,d)Pd108(n,2n)Pd107</b> <b>&amp;Ag109(n,2n)Ag108(<math>\beta^+</math>)Pd108(n,2n)Pd107</b> <b>&amp;Ag109(n,2n)Ag108m(n,d)Pd107</b>	100.0	29.7 49.1 18.7 2.1	70.0 3.1 26.0 0.1	23.8 58.1 9.0 5.2 1.4

In115	$4.4 \cdot 10^{14}$ y	<b>&amp;Ag109(n,<math>\gamma</math>)Ag110(<math>\beta^-</math>)Cd110(n,<math>\gamma</math>)Cd111(n,<math>\gamma</math>)</b> <b>Cd112(n,<math>\gamma</math>)Cd113(n,<math>\gamma</math>)Cd114(n,<math>\gamma</math>)Cd115(<math>\beta^-</math>)In115</b> <b>&amp;Ag109(n,<math>\gamma</math>)Ag110m(n,<math>\gamma</math>)Ag111(<math>\beta^-</math>)Cd111(n,<math>\gamma</math>)</b> <b>Cd112(n,<math>\gamma</math>)Cd113(n,<math>\gamma</math>)Cd114(n,<math>\gamma</math>)Cd115(<math>\beta^-</math>)In115</b> <b>&amp;Ag109(n,<math>\gamma</math>)Ag110(<math>\beta^-</math>)Cd110(n,<math>\gamma</math>)Cd111(n,<math>\gamma</math>)</b> <b>Cd112(n,<math>\gamma</math>)Cd113m(n,<math>\gamma</math>)Cd114(n,<math>\gamma</math>)Cd115(<math>\beta^-</math>)In115</b> <b>&amp;Ag109(n,<math>\gamma</math>)Ag110(<math>\beta^-</math>)Cd110(n,<math>\gamma</math>)Cd111(n,<math>\gamma</math>)</b> <b>Cd112(n,<math>\gamma</math>)Cd113(n,<math>\gamma</math>)Cd114(n,<math>\gamma</math>)Cd115m(<math>\beta^-</math>)In115</b> <b>&amp;Ag109(n,<math>\gamma</math>)Ag110m(<math>\beta^-</math>)Cd110(n,<math>\gamma</math>)Cd111(n,<math>\gamma</math>)</b> <b>Cd112(n,<math>\gamma</math>)Cd113(n,<math>\gamma</math>)Cd114(n,<math>\gamma</math>)Cd115(<math>\beta^-</math>)In115</b> <b>&amp;Ag109(n,<math>\gamma</math>)Ag110(<math>\beta^-</math>)Cd110(n,<math>\gamma</math>)Cd111(n,<math>\gamma</math>)</b> <b>Cd112(n,<math>\gamma</math>)Cd113m(<math>\beta^-</math>)In113(n,<math>\gamma</math>)In114m(n,<math>\gamma</math>)In115</b>	66.8	77.9	71.7	
			9.6	0.1	9.5	
			10.0	11.2	5.2	
			7.9	7.7	8.3	
			1.4		0.7	
			1.2		1.1	
			1.2	1.1	0.6	
			0.8	1.8	1.5	
				0.2	1.1	

# Silver activation characteristics

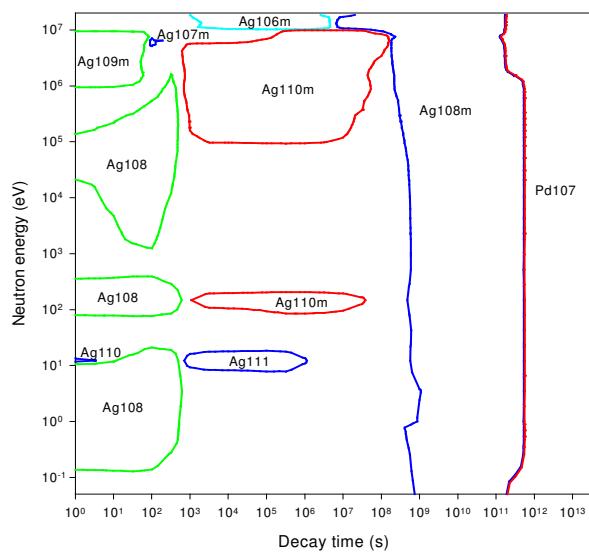


Decay time (years)

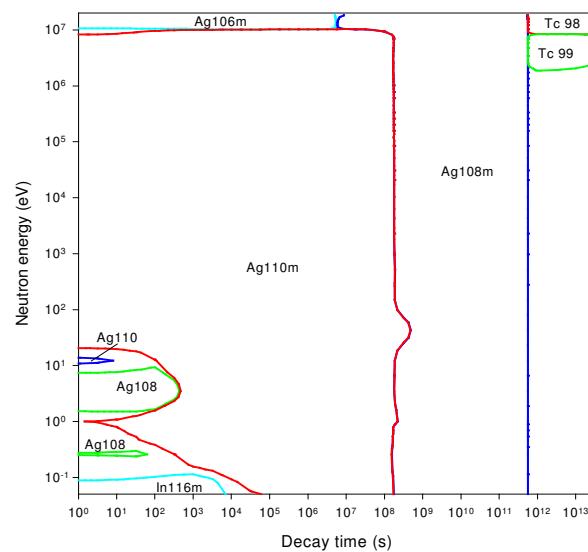
Decay time (years)

# Silver importance diagrams & transmutation

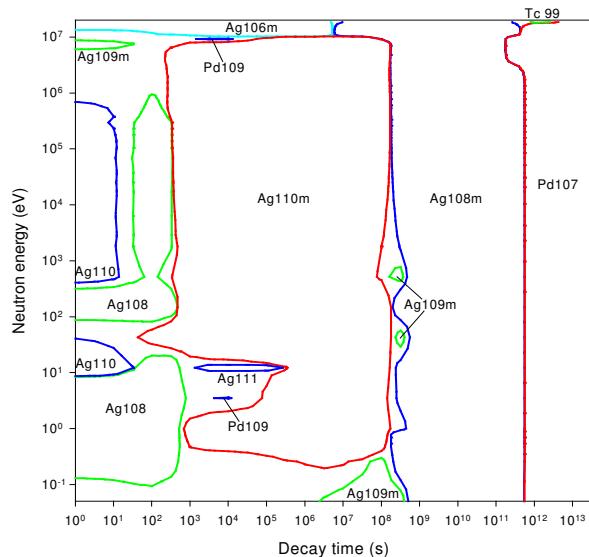
## Activity



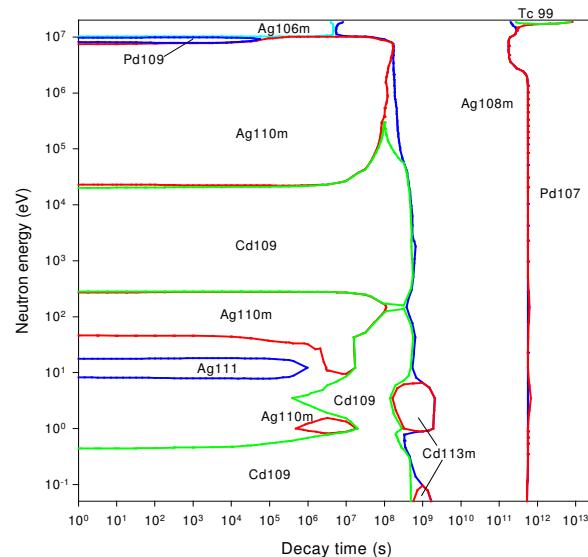
## Dose rate



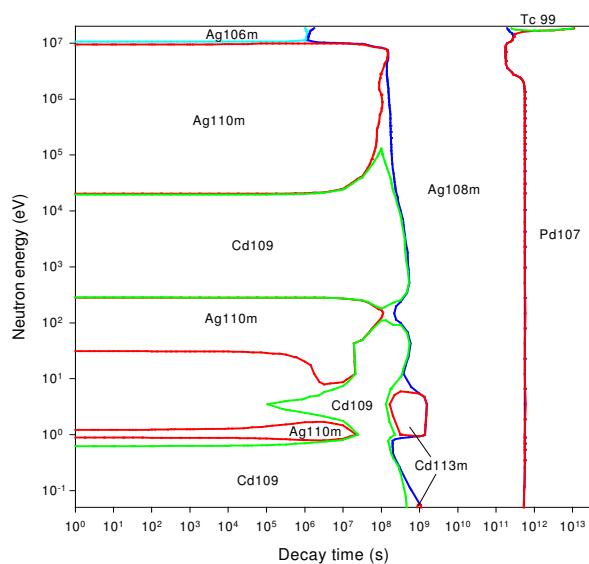
## Heat output



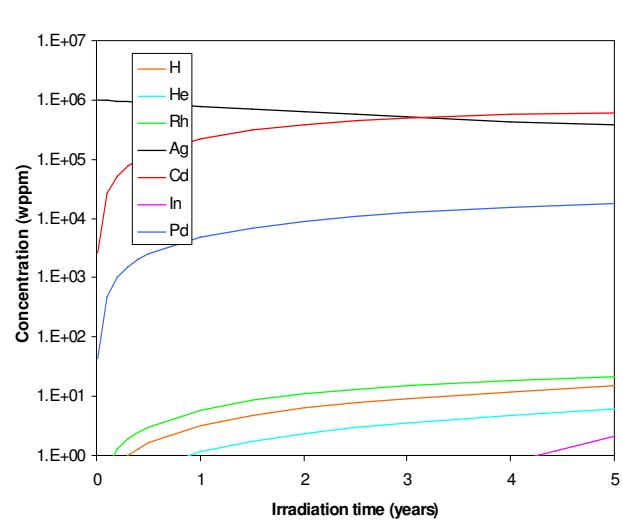
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Cadmium

## General properties

Atomic number	48	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	0.15	Cd106	1.25
Melting point / K	594.2	Cd108	0.89
Boiling point / K	1040	Cd110	12.49
Density / kgm <sup>-3</sup>	8650	Cd111	12.80
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	96.8	Cd112	24.13
Electrical resistivity /Ωm	6.83 10 <sup>-8</sup>	Cd113	12.22 ( $T_{1/2} = 9.3 \cdot 10^{15}$ y)
Coefficient of thermal expansion / K <sup>-1</sup>	3.08 10 <sup>-5</sup>	Cd114	28.73
Crystal structure	HCP	Cd116	7.49
Number of stable isotopes	7 (8)		
Mean atomic weight	112.411		

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	4.52E15	3.77E15	1.18E15	1.17E14	2.40E11	2.48E5	kW kg <sup>-1</sup>	6.08E-1	5.18E-1	7.73E-2	2.07E-3	7.45E-6	3.79E-13
In115m	25.71	30.82	34.23				In116m	53.21	58.52				
Cd115	25.56	30.60	31.36				Cd115	15.54	18.24	39.22			
In116m	15.93	17.87					In115m	10.21	12.00	27.97			
In116n	8.71						In116	7.07					
In116	4.36						Cd115m	3.10	3.64	23.03	3.12		
Cd115m	4.09	4.90	14.77	0.54			Ag110	1.98			0.06		
Cd111m	3.42	3.80					In116n	1.68					
Ag109m	1.59	1.86	5.81	34.11			Cd111m	1.61	1.76				
Cd109	1.53	1.83	5.81	34.11			Cd117	1.13	1.30				
Ag110	1.37			0.01			Cd117m	0.84	0.97				
Ag107m	1.14	1.32					In114	0.61	0.51	3.21	0.80		
Cd107	1.11	1.31					Cd113m	0.18	0.21	1.42	50.56	93.83	
Cd113m	0.83	0.99	3.17	30.46	99.22		Ag109m	0.17	0.19	1.26	27.25		
In114	0.66	0.57	1.69	0.11			Ag110m		0.12	0.82	11.27		
In117	0.63	0.76					Cd109			0.30	6.45		
Cd117	0.63	0.73					Ag108m				0.03	5.97	
In114m	0.48	0.58	1.76	0.12			Pd107					98.71	
Pd107					99.88		Tc99						1.22
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	6.28E5	5.92E5	2.50E4	3.87E2	6.02E-1	1.07E-10	Sv kg <sup>-1</sup>	3.52E6	3.52E6	2.23E6	9.03E5	5.48E3	9.55E-6
In116m	84.96	84.41					Cd115	45.94	45.98	23.27			
Cd115	6.37	6.75	51.41				Cd113m	24.47	24.52	38.66	90.71	99.93	
In115m	3.68	3.90	32.20*				Cd115m	17.31	17.34	25.85	0.23		
Cd117m	1.38	1.44					Cd109	3.92	3.92	6.16	8.83		
Cd117	1.32	1.36					In115m	2.84	2.85	1.56			
Cd115m	0.28*	0.29*	6.56*	1.53*			In114m	2.54	2.54	3.82	0.06		
Ag110m	0.16	0.17	4.05	95.88			In116m	1.31	1.23				
Ag106m	0.12	0.12	2.20				Cd111m	0.48	0.45				
Ag105	0.10	0.11	2.48	0.37			Pd107					96.12	
Ag108m				0.18	99.07		Tc99						1.91
Tc98					99.83	In115							1.77

Inh	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>	Clear	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>
Sv kg <sup>-1</sup>	7.76E6	7.76E6	6.68E6	4.25E6	2.62E4	1.52E-4		2.52E12	2.33E12	1.90E11	3.37E9	7.18E6	2.27E-1
Cd113m	53.11	53.15	61.68	92.11	99.76		In116m	71.42	72.35				
Cd115m	18.33	18.34	20.12	0.12			Cd115	10.41	11.26	44.35			
Cd115	16.38	16.38	6.10				In115m	8.23	8.91	38.05			
Cd109	7.20	7.20	8.32	7.60			Cd111m	1.86	1.86				
In114m	2.61	2.62	2.89	0.03			Cd117	1.27	1.35				
In115m	0.88	0.89	0.36				In116n	1.20					
In116m	0.42	0.39					Cd117m	1.15	1.22				
Cd111m	0.30	0.28					In116	1.10					
Ag110m	0.22	0.22	0.25	0.15			Cd115m	0.67	0.72	8.36	1.71		
Ag111	0.12	0.12	0.10				Ag110m	0.19	0.20	2.46	50.86		
Ag105	0.08	0.08	0.09				Ag105	0.17	0.18	2.07	0.27		
Sn117m	0.07	0.07	0.07				Ag106m	0.12	0.13	1.17			
Ag108m					0.24		In114m	0.09	0.10	1.13	0.42		
Pd107						96.15	Ag109m		0.06	0.68	22.34		
Tc99						2.43	Cd113m			0.37	19.58	61.34	
In115						1.35	Cd109			0.12	3.95		
							Ag108m				0.10	38.48	
							Pd107						99.33

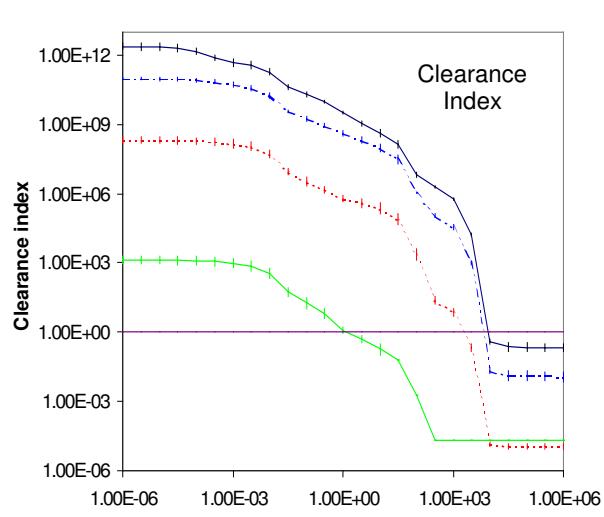
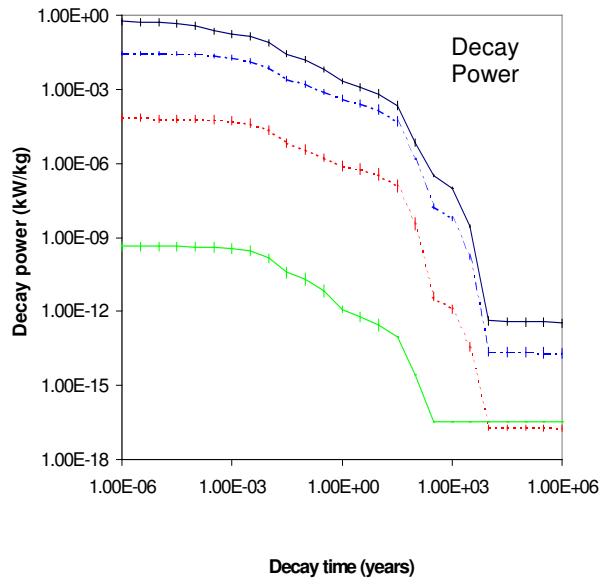
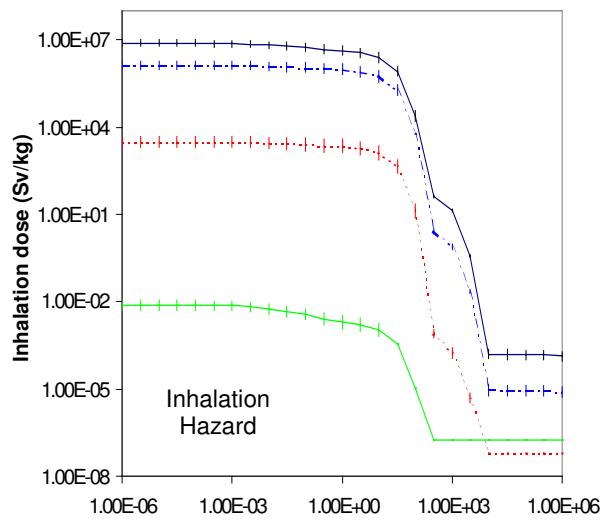
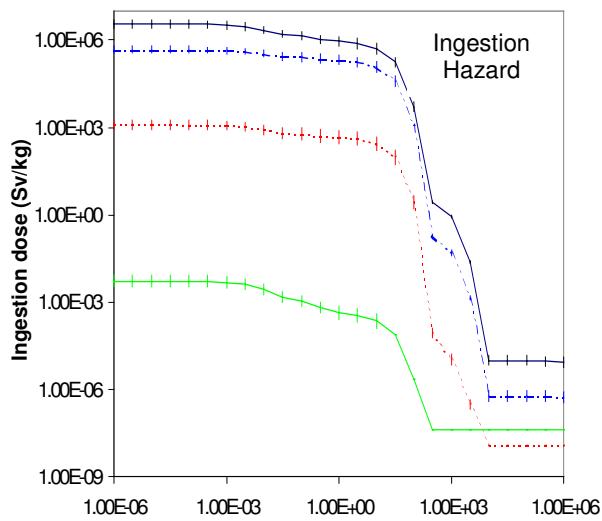
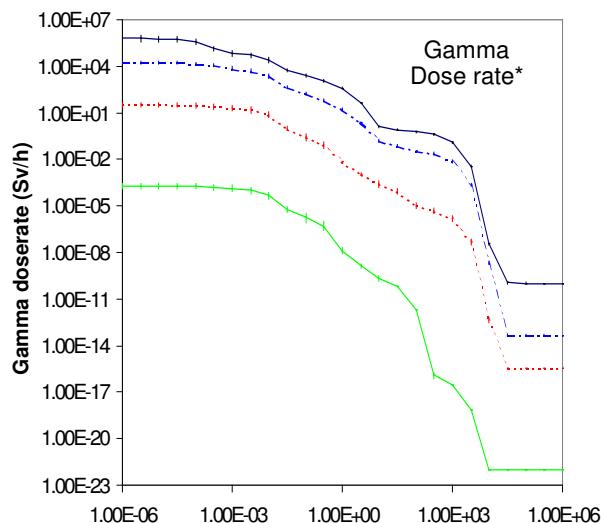
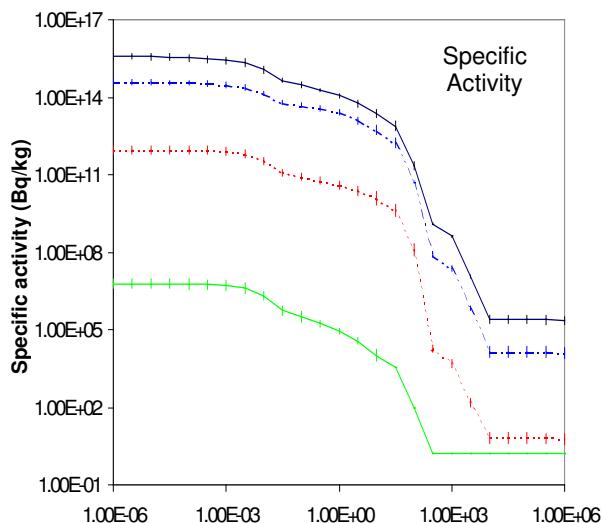
# Cadmium

## Pathway analysis

Nuclide	T <sub>½</sub>	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Ag109m	39.8 s	Cd108(n, $\gamma$ )Cd109( $\beta^+$ )Ag109m <b>&amp;Cd106(n,<math>\gamma</math>)Cd107(<math>\beta^+</math>)Ag107(n,<math>\gamma</math>)Ag108(<math>\beta^-</math>)</b> Cd108(n, $\gamma$ )Cd109( $\beta^+$ )Ag109m <b>&amp;Cd106(n,<math>\gamma</math>)Cd107(<math>\beta^+</math>)Ag107(n,<math>\gamma</math>)Ag108(<math>\beta^+</math>)</b> Pd108(n, $\gamma$ )Pd109( $\beta^-$ )Ag109m <b>&amp;Cd106(n,<math>\gamma</math>)Cd107(<math>\beta^+</math>)Ag107(n,<math>\gamma</math>)Ag108m(n,<math>\gamma</math>)Ag109m            Cd110(n,2n)Cd109(<math>\beta^+</math>)Ag109m            Cd111(n,2n)Cd110(n,2n)Cd109(<math>\beta^+</math>)Ag109m  <b>&amp;Cd112(n,2n)Cd111(n,2n)Cd110(n,2n)Cd109(<math>\beta^+</math>)Ag109m</b> </b>	85.5 5.4 5.4 3.1	99.8	99.6	77.1 15.7 2.6
Cd111m	48.54 m	Cd110(n, $\gamma$ )Cd111m Cd112(n,2n)Cd111m Cd113(n,2n)Cd112(n,2n)Cd111m Cd111(n,n')Cd111m Cd112(n,2n)Cd111(n,n')Cd111m Cd114(n,2n)Cd113(n,2n)Cd112(n,2n)Cd111m Cd114(n,2n)Cd113m(n,2n)Cd112(n,2n)Cd111m	99.2	100.0	100.0	75.8 10.1 7.5 1.8 1.6 1.0
In116m	54.6 m	<b>&amp;Cd114(n,<math>\gamma</math>)Cd115(<math>\beta^-</math>)In115(n,<math>\gamma</math>)In116m</b> <b>&amp;Cd113(n,<math>\gamma</math>)Cd114(n,<math>\gamma</math>)Cd115(<math>\beta^-</math>)In115(n,<math>\gamma</math>)In116m</b> <b>&amp;Cd114(n,<math>\gamma</math>)Cd115m(<math>\beta^-</math>)In115(n,<math>\gamma</math>)In116m</b> <b>&amp;Cd112(n,<math>\gamma</math>)Cd113(n,<math>\gamma</math>)Cd114(n,<math>\gamma</math>)Cd115(<math>\beta^-</math>)</b> <i>In115(n,<math>\gamma</math>)In116m</i> <b>&amp;Cd113(n,<math>\gamma</math>)Cd114(n,<math>\gamma</math>)Cd115m(<math>\beta^-</math>)In115(n,<math>\gamma</math>)In116m</b> <b>&amp;Cd116(n,2n)Cd115m(<math>\beta^-</math>)In115(n,<math>\gamma</math>)In116m</b> <b>&amp;Cd116(n,2n)Cd115(<math>\beta^-</math>)In115(n,<math>\gamma</math>)In116m</b>	75.3 12.9 9.3 2.4 0.1	77.0 12.2 8.5 1.3	83.4 1.8 11.6 0.2	0.1 0.1 49.5 49.0
Cd115	2.225 d	Cd114(n, $\gamma$ )Cd115 Cd113(n, $\gamma$ )Cd114(n, $\gamma$ )Cd115 Cd116(n,2n)Cd115	85.0 15.4	80.6 19.3	95.7 4.2	0.3 99.3
Ag106m	8.46 d	Cd106(n,p)Ag106m <b>&amp;Cd108(n,2n)Cd107(<math>\beta^+</math>)Ag107(n,2n)Ag106m</b> <b>&amp;Cd110(n,2n)Cd109(n,2n)Cd108(n,2n)Cd107(<math>\beta^+</math>)</b> Ag107(n,2n)Ag106m <b>&amp;Cd108(n,d)Ag107(n,2n)Ag106m</b> <b>&amp;Cd110(n,2n)Cd109(<math>\beta^+</math>)Ag109(n,2n)Ag108m(n,2n)</b> Ag107(n,2n)Ag106m	100.0	100.0	100.0	35.4 53.5 4.0 2.5 1.7
Cd115m	44.6 d	Cd114(n, $\gamma$ )Cd115m Cd112(n, $\gamma$ )Cd113(n, $\gamma$ )Cd114(n, $\gamma$ )Cd115m Cd111(n, $\gamma$ )Cd112(n, $\gamma$ )Cd113(n, $\gamma$ )Cd114(n, $\gamma$ )Cd115m Cd112(n, $\gamma$ )Cd113m(n, $\gamma$ )Cd114(n, $\gamma$ )Cd115m Cd110(n, $\gamma$ )Cd111(n, $\gamma$ )Cd112(n, $\gamma$ )Cd113(n, $\gamma$ ) Cd114(n, $\gamma$ )Cd115m Cd113(n, $\gamma$ )Cd114(n, $\gamma$ )Cd115m Cd116(n,2n)Cd115m	85.3 8.8 2.3 1.3 0.5	80.9	95.7	0.2 99.5
Ag110m	249.79 d	Cd108(n, $\gamma$ )Cd109( $\beta^+$ )Ag109m(IT)Ag109(n, $\gamma$ )Ag110m <b>&amp;Cd106(n,<math>\gamma</math>)Cd107(<math>\beta^+</math>)Ag107(n,<math>\gamma</math>)Ag108m(n,<math>\gamma</math>)</b> Ag109(n, $\gamma$ )Ag110m <b>&amp;Cd106(n,<math>\gamma</math>)Cd107(<math>\beta^+</math>)Ag107(n,<math>\gamma</math>)Ag108(<math>\beta^+</math>)</b> Pd108(n, $\gamma$ )Pd109( $\beta^-$ )Ag109(n, $\gamma$ )Ag110m <b>&amp;Cd106(n,<math>\gamma</math>)Cd107(<math>\beta^+</math>)Ag107(n,<math>\gamma</math>)Ag108(<math>\beta^-</math>)</b> Cd108(n, $\gamma$ )Cd109( $\beta^+$ )Ag109m(IT)Ag109(n, $\gamma$ )Ag110m Cd110(n,p)Ag110m Cd111(n,2n)Cd110(n,p)Ag110m Cd111(n,d)Ag110m <b>&amp;Cd112(n,2n)Cd111(n,d)Ag110m</b> <b>&amp;Cd112(n,2n)Cd111(n,2n)Cd110(n,p)Ag110m</b>	86.4 5.3 4.5 3.8	99.8	99.9	65.7 15.4 10.8 3.7 2.7

Cd109	1.267 y	Cd108(n, $\gamma$ )Cd109 <b>&amp;Cd106(n,<math>\gamma</math>)Cd107(<math>\beta^+</math>)Ag107(n,<math>\gamma</math>)Ag108(<math>\beta^-</math>)</b> Cd108(n, $\gamma$ )Cd109 Cd110(n,2n)Cd109 Cd111(n,2n)Cd110(n,2n)Cd109 <b>&amp;Cd112(n,2n)Cd111(n,2n)Cd110(n,2n)Cd109</b>	94.0 6.0	100.0	99.6	
Cd113m	13.7 y	Cd112(n, $\gamma$ )Cd113m Cd111(n, $\gamma$ )Cd112(n, $\gamma$ )Cd113m <b>&amp;Cd110(n,<math>\gamma</math>)Cd111(n,<math>\gamma</math>)Cd112(n,<math>\gamma</math>)Cd113m</b> Cd114(n,2n)Cd113m Cd113(n,n')Cd113m Cd114(n,2n)Cd113(n,n')Cd113m	61.7 27.7 10.6	69.4 30.2	95.9 4.0	0.1  92.3 6.3 1.1
Ag108m	418.0 y	<b>&amp;Cd106(n,<math>\gamma</math>)Cd107(<math>\beta^+</math>)Ag107(n,<math>\gamma</math>)Ag108m</b> <b>&amp;Cd110(n,2n)Cd109(<math>\beta^+</math>)Ag109(n,2n)Ag108m</b> <b>&amp;Cd111(n,2n)Cd110(n,2n)Cd109(<math>\beta^+</math>)Ag109(n,2n)Ag108m</b> Cd108(n,p)Ag108m <b>&amp;Cd110(n,d)Ag109(n,2n)Ag108m</b> <b>&amp;Cd112(n,<math>\alpha</math>)Pd109(<math>\beta^-</math>)Ag109(n,2n)Ag108m</b>	100.0	99.9	99.9	86.7 7.1 2.2 1.3 0.7
Tc99	$2.1 \cdot 10^5$ y	<b>&amp;Cd106(n,<math>\alpha</math>)Pd103(<math>\beta^+</math>)Rh103(n,n<math>\alpha</math>)Tc99</b> <b>&amp;Cd106(n,d)Ag105(<math>\beta^+</math>)Pd105(n,2n)Pd104(n,2n)</b> Pd103( $\beta^+$ )Rh103(n,n $\alpha$ )Tc99 <b>&amp;Cd106(n,2n)Cd105(<math>\beta^+</math>)Ag105(<math>\beta^+</math>)Pd105(n,2n)</b> Pd104(n,2n)Pd103( $\beta^+$ )Rh103(n,n $\alpha$ )Tc99 <b>&amp;Cd106(n,<math>\alpha</math>)Pd103(<math>\beta^+</math>)Rh103(n,2n)Rh102(n,<math>\alpha</math>)Tc99</b> <b>&amp;Cd108(n,n<math>\alpha</math>)Pd104(n,2n)Pd103(<math>\beta^+</math>)Rh103(n,n<math>\alpha</math>)Tc99</b>				76.4 8.6  8.2  0.9 0.9
Tc98	$4.2 \cdot 10^6$ y	<b>&amp;Cd106(n,<math>\alpha</math>)Pd103(<math>\beta^+</math>)Rh103(n,n<math>\alpha</math>)Tc99(n,2n)Tc98</b> <b>&amp;Cd106(n,<math>\alpha</math>)Pd103(<math>\beta^+</math>)Rh103(n,2n)Rh102(n,n<math>\alpha</math>)Tc98</b> Cd106(n,n $\alpha$ )Pd102(n,2n)Pd101( $\beta^+$ )Rh101(n, $\alpha$ )Tc98 <b>&amp;Cd106(n,<math>\alpha</math>)Pd103(<math>\beta^+</math>)Rh103(n,2n)Rh102m(n,n<math>\alpha</math>)Tc98</b> <b>&amp;Cd106(n,d)Ag105(<math>\beta^+</math>)Pd105(n,2n)Pd104(n,2n)</b> Pd103( $\beta^+$ )Rh103(n,n $\alpha$ )Tc99(n,2n)Tc98 <b>&amp;Cd106(n,2n)Cd105(<math>\beta^+</math>)Ag105(<math>\beta^+</math>)Pd105(n,2n)</b> Pd104(n,2n)Pd103( $\beta^+$ )Rh103(n,n $\alpha$ )Tc99(n,2n)Tc98 <b>&amp;Cd106(n,n<math>\alpha</math>)Pd102(n,p)Rh102(n,n<math>\alpha</math>)Tc98</b> *Plus other similar pathways				37.6 25.0 9.0 9.0 2.5  2.4  1.0 13.5*
Pd107	$6.5 \cdot 10^6$ y	<b>&amp;Cd108(n,<math>\gamma</math>)Cd109(n,<math>\alpha</math>)Pd106(n,<math>\gamma</math>)Pd107</b> <b>&amp;Cd106(n,<math>\gamma</math>)Cd107(<math>\beta^+</math>)Ag107(n,<math>\gamma</math>)Ag108(<math>\beta^-</math>)</b> Cd108(n, $\gamma$ )Cd109(n, $\alpha$ )Pd106(n, $\gamma$ )Pd107 <b>&amp;Cd110(n,<math>\alpha</math>)Pd107</b> <b>&amp;Cd111(n,2n)Cd110(n,<math>\alpha</math>)Pd107</b> <b>&amp;Cd111(n,<math>\alpha</math>)Pd108(n,2n)Pd107</b> <b>&amp;Cd108(n,2n)Cd107(<math>\beta^+</math>)Ag107(n,p)Pd107</b> <b>&amp;Cd110(n,2n)Cd109(<math>\beta^+</math>)Ag109(n,d)Pd108(n,2n)Pd107</b> <b>&amp;Cd112(n,2n)Cd111(n,2n)Cd110(n,<math>\alpha</math>)Pd107</b> <b>&amp;Cd111(n,n<math>\alpha</math>)Pd107</b>	98.5 1.3  0.2	17.8 82.2	71.7 28.2	
In115	$4.4 \cdot 10^{14}$ y	Cd114(n, $\gamma$ )Cd115( $\beta^-$ )In115m(IT)In115 Cd113(n, $\gamma$ )Cd114(n, $\gamma$ )Cd115( $\beta^-$ )In115m(IT)In115 Cd114(n, $\gamma$ )Cd115m( $\beta^-$ )In115 Cd112(n, $\gamma$ )Cd113(n, $\gamma$ )Cd114(n, $\gamma$ )Cd115m( $\beta^-$ )In115 Cd113(n, $\gamma$ )Cd114(n, $\gamma$ )Cd115m( $\beta^-$ )In115 Cd116(n,2n)Cd115m( $\beta^-$ )In115 Cd116(n,2n)Cd115( $\beta^-$ )In115m(IT)In115	75.9 13.7 9.9 1.0 0.1	77.6 12.5 8.6 1.3	86.2 1.9 11.7 0.2	0.1  0.1  49.9 49.7
Cd113	$9.3 \cdot 10^{15}$ y	Cd112(n, $\gamma$ )Cd113 Cd111(n, $\gamma$ )Cd112(n, $\gamma$ )Cd113 Cd110(n, $\gamma$ )Cd111(n, $\gamma$ )Cd112(n, $\gamma$ )Cd113 Cd114(n,2n)Cd113 *Nuclide also present in starting material	61.7 27.7 10.4  99.4*	0.4 0.2 0.3	6.5 24.8 75.2*	

# Cadmium activation characteristics

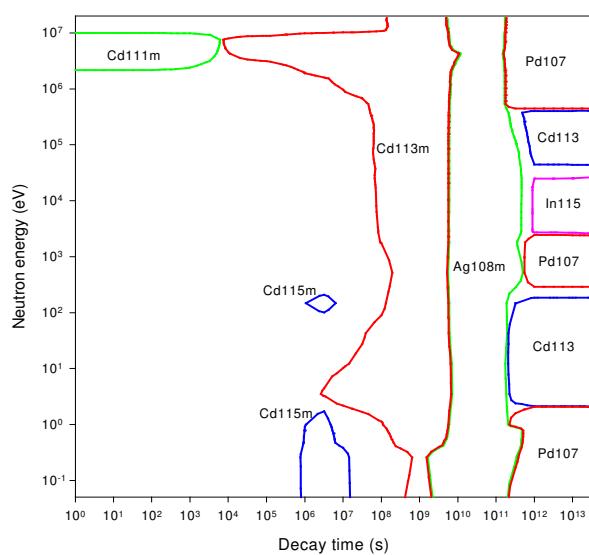


Decay time (years)

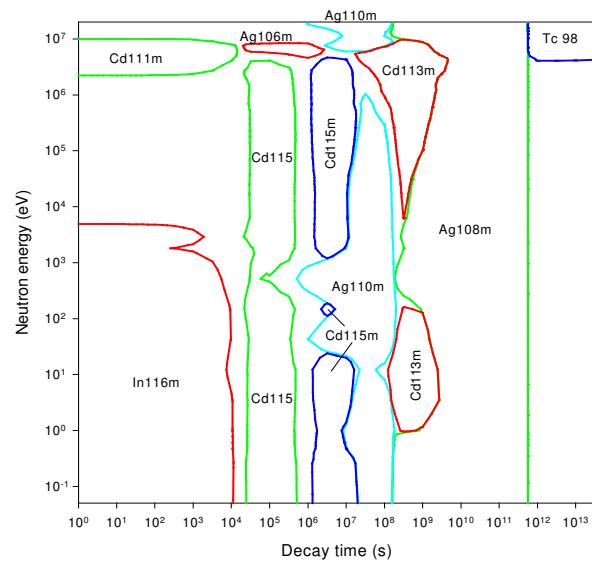
Decay time (years)

# Cadmium importance diagrams & transmutation

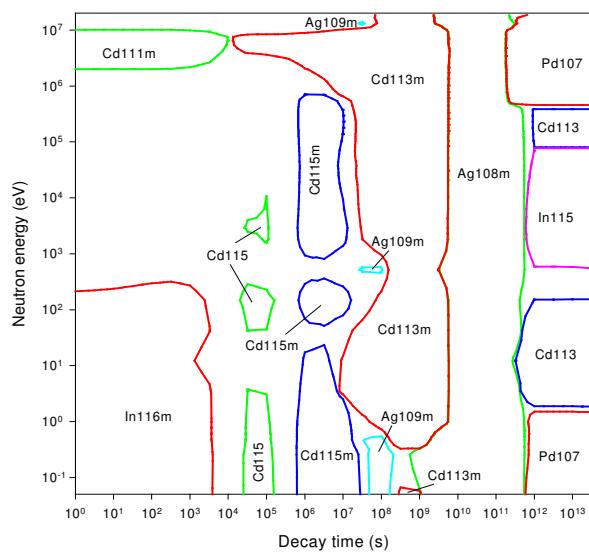
## Activity



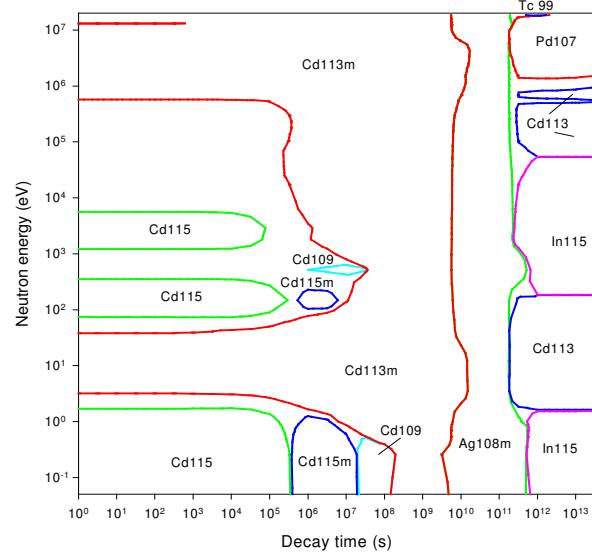
## Dose rate



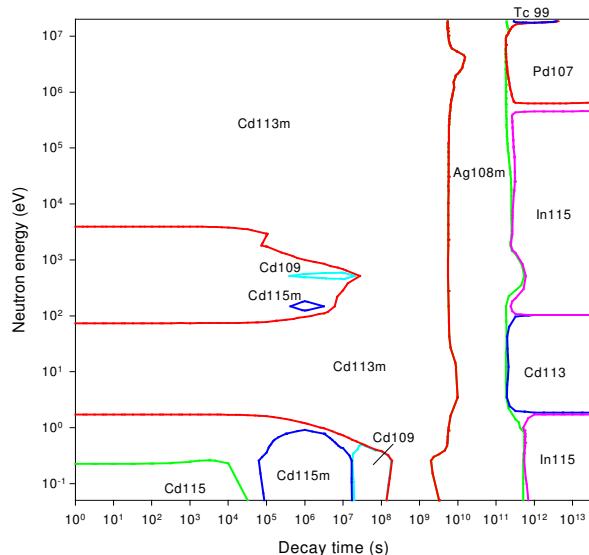
## Heat output



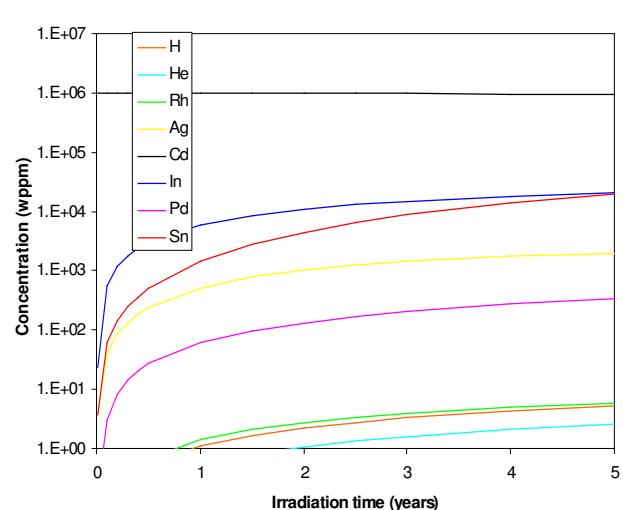
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Indium

## General properties

Atomic number Crustal abundance / wppm Melting point / K Boiling point / K Density / kgm <sup>-3</sup> Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup> Electrical resistivity /Ωm Coefficient of thermal expansion / K <sup>-1</sup> Crystal structure Number of stable isotopes Mean atomic weight	49	Isotopes In113 In115	Isotopic abundances / % 4.29 95.71 ( $T_{1/2} = 4.41 \cdot 10^{14}$ y)
	0.25		
	429.8		
	2345		
	7310		
	81.6		
	$8.37 \cdot 10^{-8}$		
	$3.21 \cdot 10^{-5}$		
	FCT		
	1(2)		
114.818			

## Activation properties

Act	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Heat	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y
Bq kg <sup>-1</sup>	1.68E16	9.08E15	9.53E14	1.19E13	1.13E9	6.47E1	kW kg <sup>-1</sup>	4.53E0	3.63E0	7.13E-2	6.53E-4	3.30E-8	2.04E-15
In116m	50.24	86.87					In116m	83.68	97.64				
In116n	27.44						In116	11.13					
In116	13.76						In116n	2.65					
In114	4.01	4.82	42.53	22.72			In114	1.84	1.50	70.41	51.15		
In114m	2.63	4.86	44.07	23.54			In114m	0.36	0.45	21.68	15.75		
In115m	0.63	1.14	0.15				In115m	0.12	0.15	0.11			
Sn117m	0.49	0.91	7.22				Sn117m	0.09	0.12	4.86			
In113m	0.19	0.35	2.86	26.05			In113m	0.05	0.06	2.40	29.70		
Sn113	0.17	0.31	2.86	26.04			Sn113			0.18	2.24		
Cd113m			0.02	1.42	99.61		Cd113m			0.01	0.76	99.92	
In115					94.21		In115						99.72
Pd107					5.79		Pd107						0.28
Dose	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Ing	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y
Sv h <sup>-1</sup>	6.25E6	5.84E6	5.97E3	1.35E2	5.27E-5	1.52E-12	Sv kg <sup>-1</sup>	2.46E6	2.42E6	1.80E6	1.77E4	2.58E1	1.95E-6
In116m	99.72	99.83					In114m	73.71	74.81	95.55	64.71		
In114m	0.07	0.08	72.26	21.27			In116m	21.97	20.87				
In113m	0.02	0.02	14.61	73.22			Sn117m	2.40	2.43	2.71			
In114	0.01*	0.01*	7.35*	2.16*			Sn113	0.83	0.84	1.11	12.74		
Sn117m			4.00				In115m	0.37	0.37	0.01			
Ag110m			0.14	2.35			Cd115m	0.17	0.18	0.23	0.08		
Ag108m					57.80		Cd113m	0.17	0.17	0.23	21.82	100.0	
Cd113m					42.13*		In113m	0.04	0.04	0.04	0.49		
In115					100.0*		In115						100.0
Inh	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Clear	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y
Sv kg <sup>-1</sup>	4.80E6	4.78E6	4.18E6	5.30E4	1.23E2	2.38E-5		2.19E13	1.99E13	9.77E10	1.44E9	2.09E4	1.27E-3
In114m	85.50	85.95	93.53	49.02			In116m	96.19	99.33				
In116m	7.90	7.43					In116n	1.62					
Sn117m	4.14	4.16	3.96	0.00			In116	1.48					
Sn113	1.57	1.58	1.76	15.74			In114	0.26	0.18	34.56	15.60		
Cd113m	0.40	0.41	0.47	34.86	100.00		In114m	0.21	0.23	44.31	20.00		
Cd115m	0.21	0.21	0.23	0.07			Sn117m	0.07	0.07	12.14			
In115m	0.13	0.13					In113m	0.04	0.04	7.55	58.01		
Cd115	0.09	0.09	0.03				Sn113			0.67	5.11		
In113m	0.01	0.01	0.01	0.12			Ag110m			0.04	1.02		
Cd109					0.06		Cd113m				0.22	99.31	
In115					99.99		In115						99.73

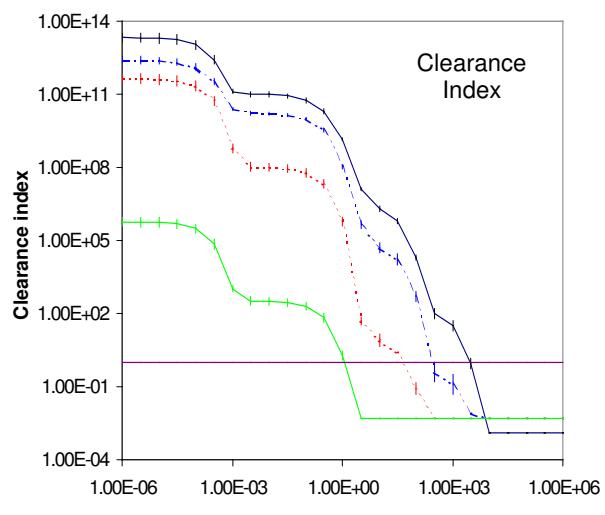
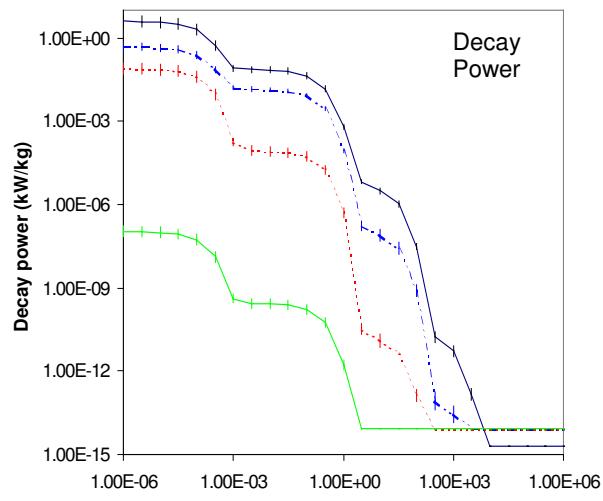
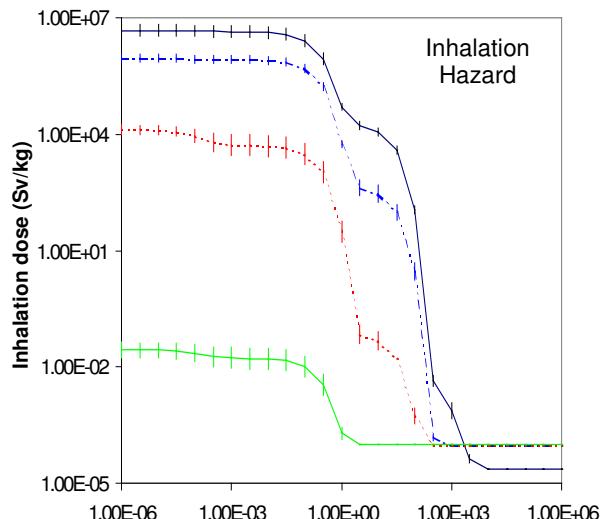
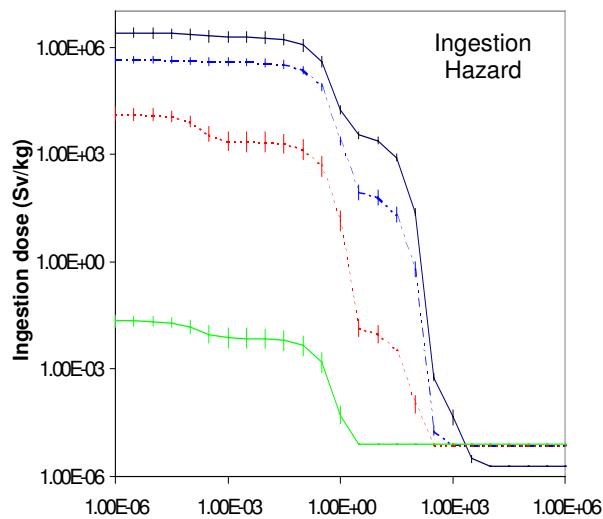
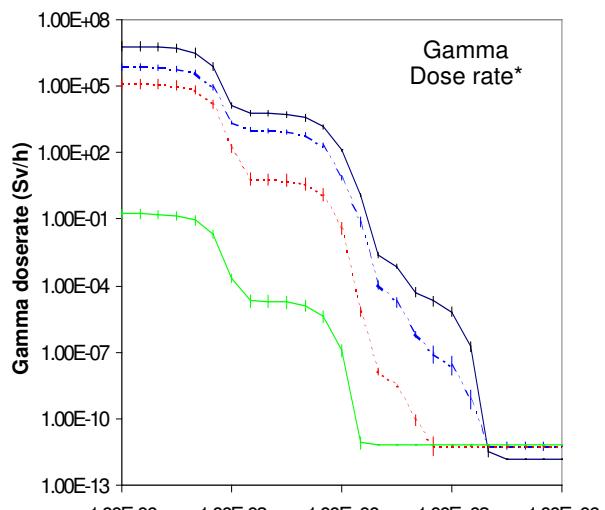
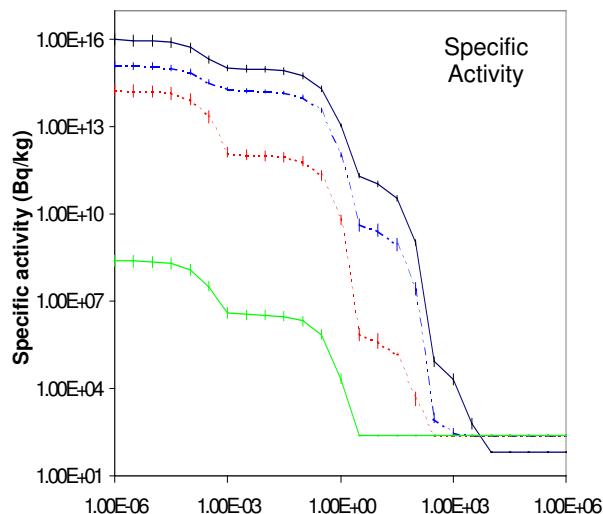
# Indium

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
In114	1.198 m	In113(n, $\gamma$ )In114m(IT)In114 In113(n, $\gamma$ )In114 <b>&amp;In115(n,2n)In114</b>	55.5 44.5	45.7 54.3	56.9 43.1	99.4
In116m	54.6 m	<b>&amp;In113(n,<math>\gamma</math>)In114m(n,<math>\gamma</math>)In115(n,<math>\gamma</math>)In116m</b> <b>&amp;In115(n,<math>\gamma</math>)In116m</b>	98.6	100.0	100.0	99.4
In113m	1.658 h	<b>&amp;In115(n,2n)In114(<math>\beta^-</math>)Sn114(n,2n)Sn113(<math>\beta^+</math>)In113m</b> In113(n,n')In113m In115(n,2n)In114m(n,2n)In113m				97.4 0.8 0.6
In115m	4.486 h	In113(n, $\gamma$ )In114m(n, $\gamma$ )In115m In113(n, $\gamma$ )In114m( $\beta^+$ )Cd114(n, $\gamma$ )Cd115( $\beta^-$ )In115m <b>&amp;In113(n,<math>\gamma</math>)In114(<math>\beta^+</math>)Cd114(n,<math>\gamma</math>)Cd115(<math>\beta^-</math>)In115m</b> In115(n,n')In115m In115(n,p)Cd115( $\beta^-$ )In115m	97.5 2.0 0.2	99.9	90.2 7.8 1.9	91.8 7.9
Sn117m	13.6 d	<b>&amp;In115(n,<math>\gamma</math>)In116m(<math>\beta^-</math>)Sn116(n,<math>\gamma</math>)Sn117m</b> In115(n, $\gamma$ )In116( $\beta^-$ )Sn116(n, $\gamma$ )Sn117m In115(n, $\gamma$ )In116m( $\beta^-$ )Sn116(n, $\gamma$ )Sn117(n,n')Sn117m In115(n, $\gamma$ )In116( $\beta^-$ )Sn116(n, $\gamma$ )Sn117(n,n')Sn117m	78.4 21.4	78.5 21.5	78.5 21.5	53.4 43.7 0.8 0.7
Sn121	1.121 d	<b>&amp;In115(n,<math>\gamma</math>)In116m(<math>\beta^-</math>)Sn116(n,<math>\gamma</math>)Sn117(n,<math>\gamma</math>)</b> Sn118(n, $\gamma$ )Sn119(n, $\gamma$ )Sn120(n, $\gamma$ )Sn121 <b>&amp;In115(n,<math>\gamma</math>)In116(<math>\beta^-</math>)Sn116(n,<math>\gamma</math>)Sn117(n,<math>\gamma</math>)</b> Sn118(n, $\gamma$ )Sn119(n, $\gamma$ )Sn120(n, $\gamma$ )Sn121	77.7 21.2	77.8 21.3	78.5 21.5	
In114m	50.0 d	In113(n, $\gamma$ )In114m In115(n,2n)In114m	100.0	100.0	100.0	99.5
Ag110m	249.79 d	In113(n, $\alpha$ )Ag110m <b>&amp;In115(n,2n)In114(<math>\beta^-</math>)Sn114(n,2n)Sn113(<math>\beta^+</math>)In113(n,<math>\alpha</math>)Ag110m</b> <b>&amp;In115(n,2n)In114m(n,2n)In113(n,<math>\alpha</math>)Ag110m</b> <b>&amp;In115(n,2n)In114(<math>\beta^-</math>)Sn114(n,2n)Sn113m(<math>\beta^+</math>)</b> In113(n, $\alpha$ )Ag110m	100.0	100.0	100.0	72.7 19.5 2.4 1.7
Sn119m	293.0 d	<b>&amp;In115(n,<math>\gamma</math>)In116m(<math>\beta^-</math>)Sn116(n,<math>\gamma</math>)Sn117(n,<math>\gamma</math>)</b> Sn118(n, $\gamma$ )Sn119m <b>&amp;In115(n,<math>\gamma</math>)In116(<math>\beta^-</math>)Sn116(n,<math>\gamma</math>)Sn117(n,<math>\gamma</math>)Sn118(n,<math>\gamma</math>)</b> Sn119m <b>&amp;In115(n,<math>\gamma</math>)In116m(<math>\beta^-</math>)Sn116(n,<math>\gamma</math>)Sn117m(n,<math>\gamma</math>)</b> Sn118(n, $\gamma$ )Sn119m In115(n, $\gamma$ )In116( $\beta^-$ )Sn116(n, $\gamma$ )Sn117m(n, $\gamma$ )Sn118(n, $\gamma$ )Sn119m	78.4 20.6	78.4 21.4	78.4 21.5	51.4 42.1 2.7 2.2
Cd113m	13.7 y	<b>&amp;In115(n,<math>\gamma</math>)In116m(<math>\beta^-</math>)Sn116(n,<math>\alpha</math>)Cd113m</b> In115(n, $\gamma$ )In116( $\beta^-$ )Sn116(n, $\alpha$ )Cd113m <b>&amp;In113(n,<math>\gamma</math>)In114(<math>\beta^-</math>)Sn114(n,<math>\gamma</math>)Sn115(n,<math>\alpha</math>)Cd112(n,<math>\gamma</math>)</b> Cd113m In113(n, $\gamma$ )In114m(n, $\gamma$ )In115m( $\beta^-$ )Sn115(n, $\alpha$ )Cd111(n, $\gamma$ ) Cd113m In113(n,p)Cd113m In115(n, $\alpha$ )Ag112( $\beta^-$ )Cd112(n, $\gamma$ )Cd113m In115(n,2n)In114m( $\beta^+$ )Cd114(n,2n)Cd113m In115(n,d)Cd114(n,2n)Cd113m <b>&amp;In115(n,2n)In114(<math>\beta^+</math>)Cd114(n,2n)Cd113m</b> <b>&amp;In115(n,2n)In114(<math>\beta^-</math>)Sn114(n,2n)Sn113(<math>\beta^+</math>)</b> In113(n,p)Cd113m	66.8 18.3 9.4 3.7 1.5	71.3 19.5	38.5 10.6 48.0 3.0	14.1 59.0 12.4 10.0 1.8
Sn121m	55.0 y	<b>&amp;In115(n,<math>\gamma</math>)In116m(<math>\beta^-</math>)Sn116(n,<math>\gamma</math>)Sn117(n,<math>\gamma</math>)</b> Sn118(n, $\gamma$ )Sn119(n, $\gamma$ )Sn120(n, $\gamma$ )Sn121m <b>&amp;In115(n,<math>\gamma</math>)In116(<math>\beta^-</math>)Sn116(n,<math>\gamma</math>)Sn117(n,<math>\gamma</math>)Sn118(n,<math>\gamma</math>)</b> Sn119(n, $\gamma$ )Sn120(n, $\gamma$ )Sn121m	75.5 21.2	75.3 21.0	76.1 21.4	

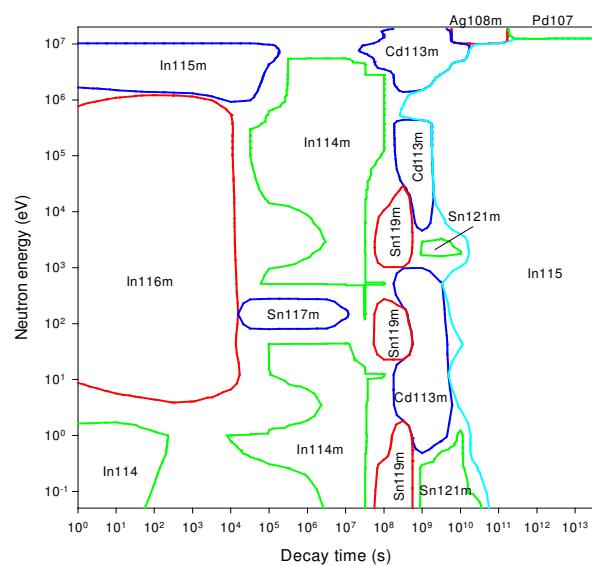


# Indium activation characteristics

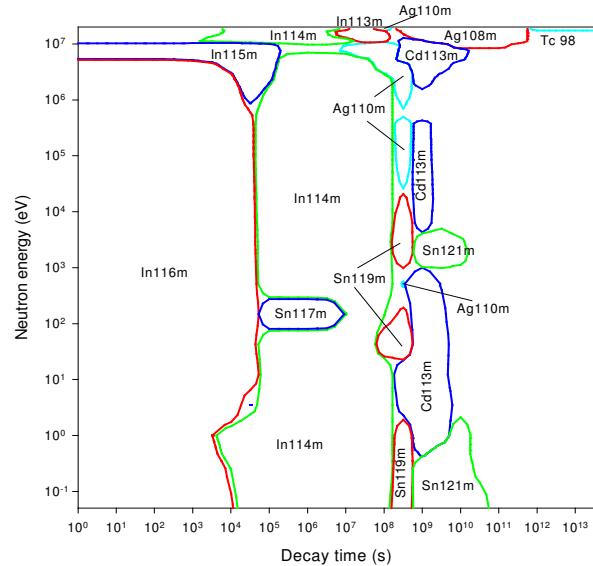


# Indium importance diagrams & transmutation

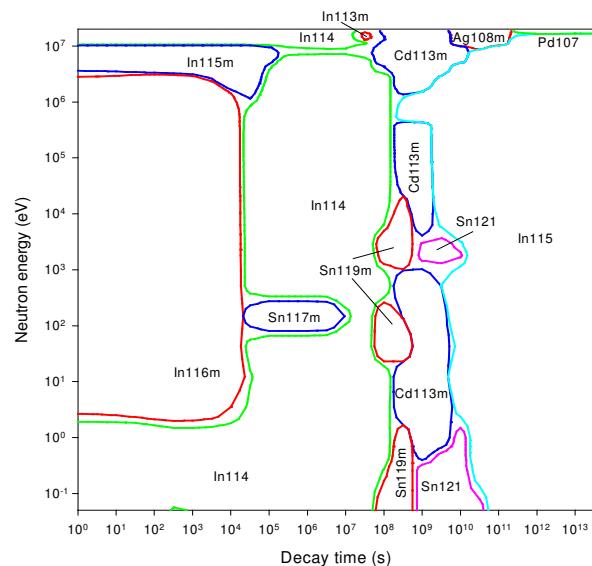
## Activity



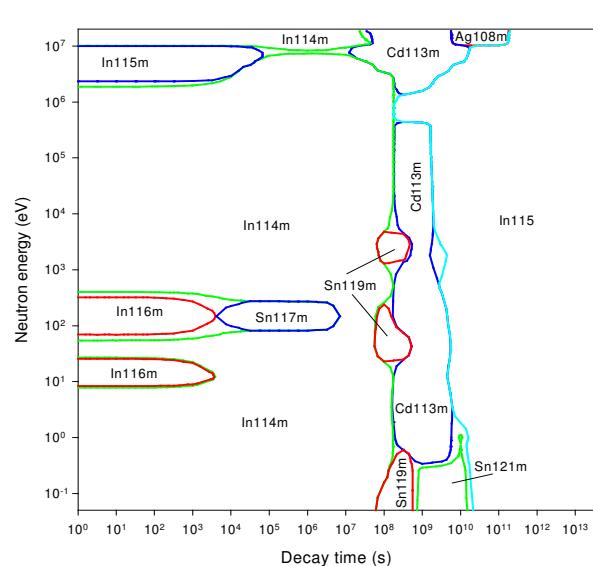
## Dose rate



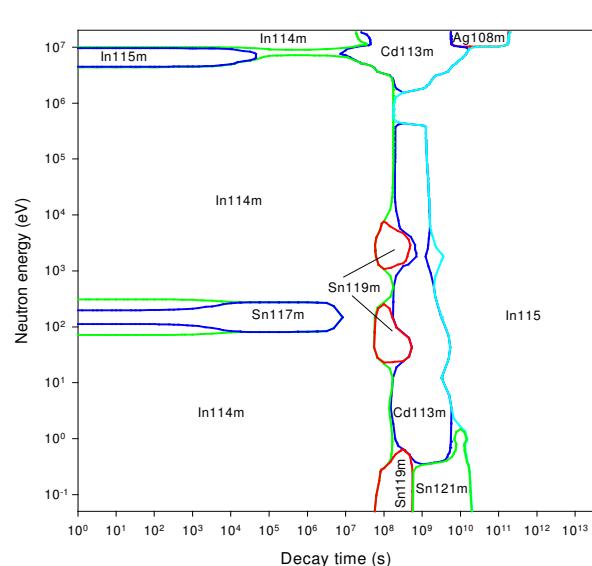
## Heat output



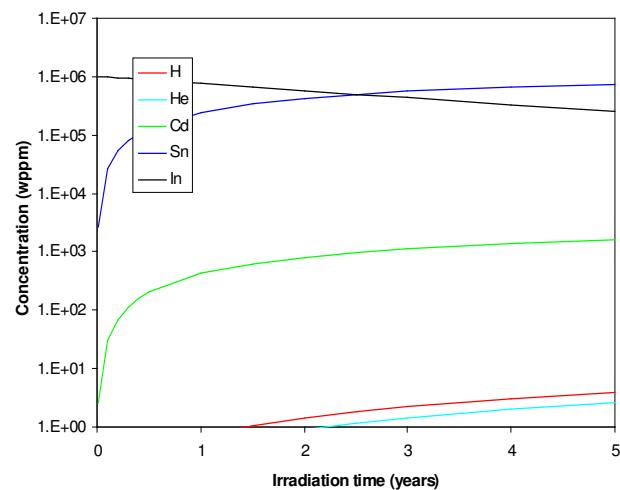
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Tin

## General properties

Atomic number	50	Isotopes	Isotopic abundances / %	
			Sn112	0.97
Crustal abundance / wppm	2.3	Sn114	0.66	
Melting point / K	505.1	Sn115	0.34	
Boiling point / K	2875	Sn116	14.54	
Density / kgm <sup>-3</sup>	5750	Sn117	7.68	
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	66.6	Sn118	24.22	
Electrical resistivity /Ωm	1.10 10 <sup>-7</sup>	Sn119	8.59	
Coefficient of thermal expansion / K <sup>-1</sup>	2.2 10 <sup>-5</sup>	Sn120	32.58	
Crystal structure	Cubic	Sn122	4.63	
Number of stable isotopes	10	Sn124	5.79	
Mean atomic weight	118.710			

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.02E15	9.70E14	6.65E14	1.65E14	8.52E11	7.50E4	kW kg <sup>-1</sup>	6.85E-2	6.11E-2	3.57E-2	5.77E-3	9.97E-6	1.20E-11
Sn119m	22.88	24.06	34.79	59.63			Sn125m	17.48	13.37				
Sn117m	17.67	18.57	22.49				Sb122	13.25	14.85	9.96			
Sn121	12.99	13.63	2.26	0.79	43.69		Sn117m	13.25	14.86	21.15			
Sn125m	6.41	4.60					Sb124	10.16	11.39	18.72	1.81		
Sb122	5.54	5.83	3.32				Sb125	5.90	6.62	11.32	54.58		
In113m	4.94	5.20	7.38	3.37			Sn119m	4.89	5.48	9.32	24.50		
Sn113	4.92	5.17	7.38	3.37			In113m	4.62	5.17	8.65	6.06		
Sb125	4.66	4.90	7.13	22.41			Sn123m	4.56	4.67				
Sn123	3.62	3.81	5.44	3.15			Sn123	4.56	5.11	8.59	7.63		
Sn123m	3.10	2.98					In114	3.91	2.39	3.73	0.15		
In114	2.12	1.21	1.61	0.04			Sn121	3.57	3.99	0.78	0.42	68.83	
Sb124	1.90	2.00	2.79	0.18			Sb126m	1.85	1.73				78.23
Sn113m	1.71	1.51					In116m	1.44	1.51				
Te125m	1.15	1.21	1.76	5.61			Sb126	1.41	1.59	2.22			15.35
In114m	1.15	1.21	1.67	0.05			Sn111	1.08	1.09				
Sb126m	0.35	0.31			35.60		Sn125	0.67	0.75	0.99			
Sb126n	0.32				23.78		In114m	0.63	0.71	1.15	0.05		
Sn121m			0.25	1.01	56.29		Te125m		0.45	0.76	3.72		
Sb126				0.24		4.99	Sn121m			0.03	0.19	31.12	
Sn126					35.60		Sn126						5.87
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	3.29E4	3.01E4	1.99E4	3.46E3	9.55E-3	1.17E-5	Sv kg <sup>-1</sup>	6.35E5	6.34E5	5.12E5	1.01E5	2.71E2	1.36E-4
Sb124	31.66	34.55	50.25	4.51			Sn117m	20.16	20.18	20.75			
Sb122	14.24	15.52	9.21				Sb122	15.15	15.15	7.34			
Sb125	12.09	13.19	19.96	89.52			Sn119m	12.50	12.52	15.37	33.24		
Sn125m	9.30	6.92					Sn123	12.22	12.23	14.85	10.86		
In116m	4.97	5.08					Sb125	8.23	8.24	10.18	40.41		
In113m	4.86	5.30	7.83	5.10			Sb124	7.62	7.63	9.06	0.72		
Sb126m	3.81	3.46			0.13	80.01	In114m	7.56	7.57	8.91	0.30		
Sb126	3.70	4.04	5.00		0.03	19.93	Sn113	5.77	5.78	7.00	4.04		
In118m	2.42	1.17					Sn121	4.80	4.80	0.68	0.30	31.52	
Sb120m	2.26	2.46	2.41				Te125m	1.61	1.61	1.99	8.00		
Sn111	2.19	2.16					Sn125	1.25	1.25	1.19			
Sn117m	1.84	2.00	2.52				Sb126	0.74	0.74	0.75			6.62
In120m	1.54						Sn121m	0.10	0.10	0.13	0.63	67.11	
Sn121m					93.86		Cd113m			0.11	0.55	1.37	
Ag108m					5.94		Sn126						92.54

Inh	0	$10^{-5}$ y	$10^2$ y	1 y	100 y	$10^5$ y	Clear	0	$10^{-5}$ y	$10^2$ y	1 y	100 y	$10^5$ y
Sv kg <sup>-1</sup>	2.42E6	2.42E6	2.24E6	7.73E5	2.26E3	7.60E-4		2.43E11	2.25E11	1.52E11	2.15E10	8.28E6	5.60E1
Sb125	23.57	23.58	25.34	57.43			Sb124	26.53	28.64	40.68	4.49		
Sn119m	21.23	21.24	22.68	28.01			Sn117m	12.78	13.79	16.96			
Sn117m	17.88	17.89	16.00				Sn125m	11.69	8.60				
Sn123	12.36	12.37	13.07	5.46			Sb122	11.63	12.54	7.27			
Sb124	6.88	6.89	7.11	0.32			Sb125	8.49	9.17	13.55	74.86		
Sn113	5.60	5.60	5.91	1.94			In113m	5.60	6.05	8.73	7.00		
In114m	4.50	4.50	4.61	0.09			Sn123m	2.45	2.42				
Sb122	2.57	2.57	1.08				Sb126m	2.42	2.18				78.19
Te125m	2.04	2.04	2.19	5.03			In116m	2.26	2.28				
Sn121	1.26	1.26	0.15	0.04	3.79		Sb126	2.24	2.42	2.92			18.55
Te123m	0.59	0.59	0.62	0.22			Sn119m	1.85	1.99	2.93	8.81		
Sn125	0.33	0.33	0.27				Sn111	1.42	1.38				
Sn121m	0.31	0.32	0.34	0.97	95.43		Sb120m	1.16	1.26	1.20			
Sb126	0.26	0.26	0.23			1.57	In118m	1.16	0.56				
Cd113m	0.12	0.12	0.12	0.34	0.78		In111	0.97	1.04	0.63			
Sn125m	0.11	0.07					Sn123	0.89	0.96	1.40	1.43		
Te121m	0.09	0.09	0.09	0.05			Sn121	0.63	0.67	0.11	0.07	51.66	
In111	0.07	0.07	0.03				Te125m			0.37	2.05		
Sn126						98.35	Sn121m				0.07	48.27	
Sb126m						0.07	Sn126						3.18

# Tin

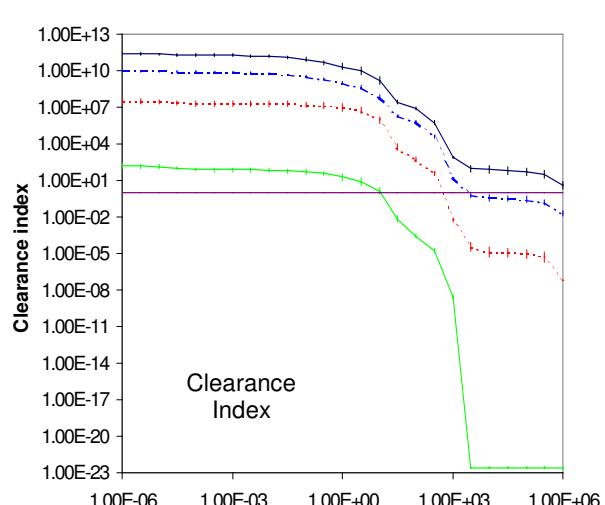
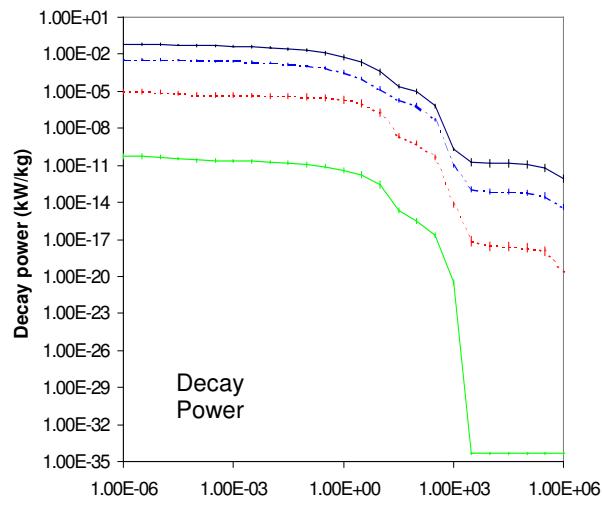
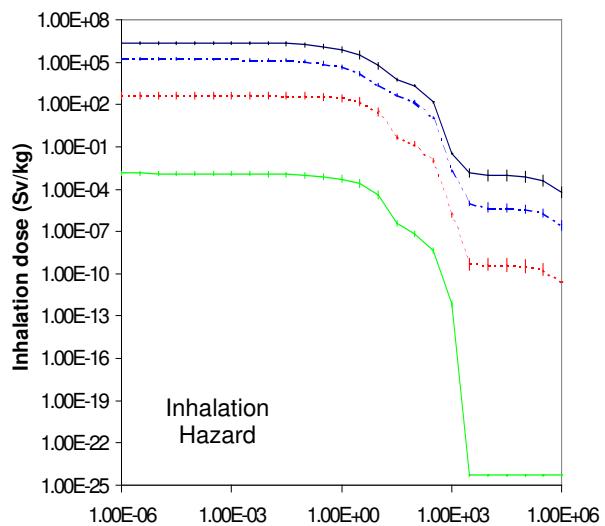
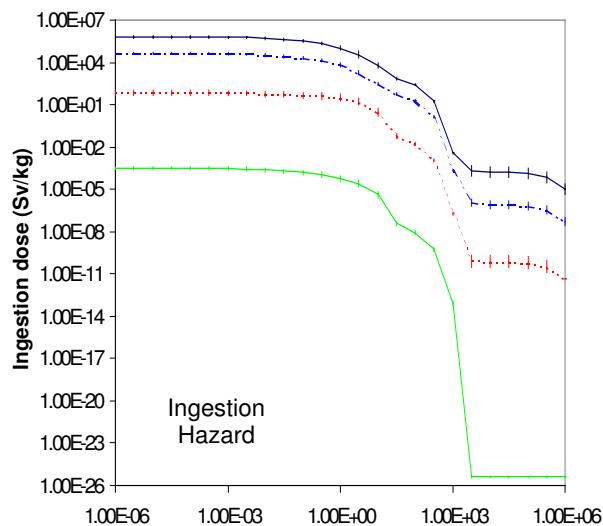
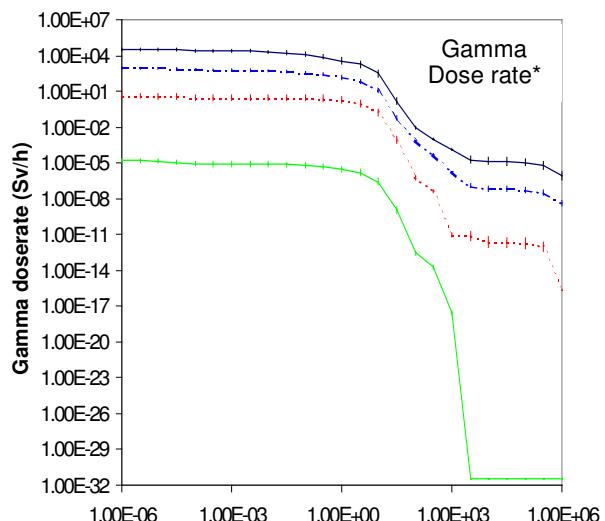
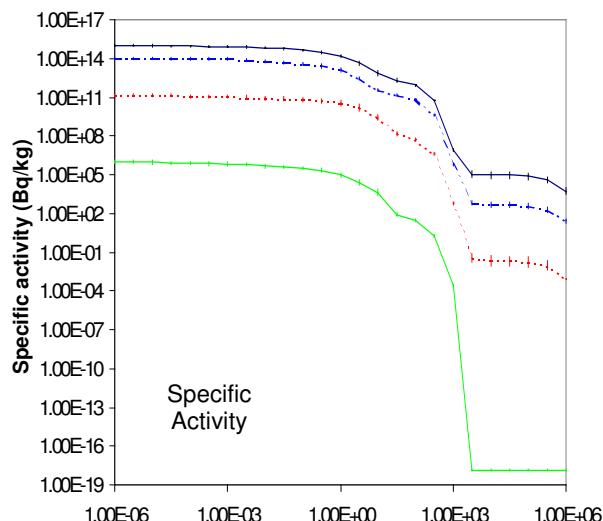
## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Sb126m	19.1 m	<b>&amp;Sn124(n,<math>\gamma</math>)Sn125m(<math>\beta^-</math>)Sb125(n,<math>\gamma</math>)Sb126m</b> <b>&amp;Sn124(n,<math>\gamma</math>)Sn125(<math>\beta^-</math>)Sb125(n,<math>\gamma</math>)Sb126m</b>	95.4 3.7	96.3 3.7	96.2 3.8	39.6 60.2
In113m	1.658 h	<b>&amp;Sn112(n,<math>\gamma</math>)Sn113(<math>\beta^+</math>)In113m</b> <b>&amp;Sn114(n,2n)Sn113(<math>\beta^+</math>)In113m</b> <b>&amp;Sn116(n,2n)Sn115(n,2n)Sn114(n,2n)Sn113(<math>\beta^+</math>)In113m</b> <b>&amp;Sn115(n,2n)Sn114(n,2n)Sn113(<math>\beta^+</math>)In113m</b>	100.0	100.0	100.0	61.7 29.1 6.6
Sn121	1.121 d	Sn120(n, $\gamma$ )Sn121 Sn119(n, $\gamma$ )Sn120(n, $\gamma$ )Sn121 <b>&amp;Sn122(n,2n)Sn121</b> Sn122(n,2n)Sn121m(n,n')Sn121	96.1 3.8	93.5 6.5	99.1 0.8	1.1 97.6 0.5
Sb122	2.696 d	<b>&amp;Sn120(n,<math>\gamma</math>)Sn121(<math>\beta^-</math>)Sb121(n,<math>\gamma</math>)Sb122</b> <b>&amp;Sn119(n,<math>\gamma</math>)Sn120(n,<math>\gamma</math>)Sn121(<math>\beta^-</math>)Sb121(n,<math>\gamma</math>)Sb122</b> <b>&amp;Sn124(n,2n)Sn123(<math>\beta^-</math>)Sb123(n,2n)Sb122</b> <b>&amp;Sn124(n,2n)Sn123m(<math>\beta^-</math>)Sb123(n,2n)Sb122</b>	98.0 2.0	95.1 4.9	99.8 0.4	60.2 39.6
Sn117m	13.6 d	Sn116(n, $\gamma$ )Sn117m Sn115(n, $\gamma$ )Sn116(n, $\gamma$ )Sn117m Sn118(n,2n)Sn117m Sn119(n,2n)Sn118(n,2n)Sn117m Sn117(n,n')Sn117m <b>&amp;Sn120(n,2n)Sn119(n,2n)Sn118(n,2n)Sn117m</b> Sn118(n,2n)Sn117(n,n')Sn117m	97.7 2.2	99.3 0.3	99.8 0.1	80.6 7.0 4.9 2.5 1.7
Sb124	60.24 d	<b>&amp;Sn122(n,<math>\gamma</math>)Sn123m(<math>\beta^-</math>)Sb123(n,<math>\gamma</math>)Sb124</b> Sn122(n, $\gamma$ )Sn123( $\beta^-$ )Sb123(n, $\gamma$ )Sb124 <b>&amp;Sn120(n,<math>\gamma</math>)Sn121(<math>\beta^-</math>)Sb121(n,<math>\gamma</math>)Sb122(n,<math>\gamma</math>)</b> Sb123(n, $\gamma$ )Sb124 Sn119(n, $\gamma$ )Sn120(n, $\gamma$ )Sn121( $\beta^-$ )Sb121(n, $\gamma$ )Sb122(n, $\gamma$ ) Sb123(n, $\gamma$ )Sb124 <b>&amp;Sn124(n,2n)Sn123(<math>\beta^-</math>)Sb123(n,<math>\gamma</math>)Sb124</b> <b>&amp;Sn124(n,2n)Sn123m(<math>\beta^-</math>)Sb123(n,<math>\gamma</math>)Sb124</b> <b>&amp;Sn124(n,<math>\gamma</math>)Sn125(<math>\beta^-</math>)Sb125(n,2n)Sb124</b> <b>&amp;Sn124(n,<math>\gamma</math>)Sn125m(<math>\beta^-</math>)Sb125(n,2n)Sb124</b>	98.9 0.6 0.5	61.4 0.4 37.2	99.3 0.7	53.2 35.2 6.8 4.5
Sn113	115.09 d	Sn112(n, $\gamma$ )Sn113 Sn112(n, $\gamma$ )Sn113m(IT)Sn113 <b>&amp;Sn114(n,2n)Sn113</b> <b>&amp;Sn116(n,2n)Sn115(n,2n)Sn114(n,2n)Sn113</b> <b>&amp;Sn115(n,2n)Sn114(n,2n)Sn113</b> <b>&amp;Sn117(n,2n)Sn116(n,2n)Sn115(n,2n)Sn114(n,2n)Sn113</b>	74.5 25.5	74.5 25.5	74.4 25.6	62.1 29.3 6.6 1.2
Sn123	129.2 d	Sn122(n, $\gamma$ )Sn123 Sn124(n,2n)Sn123	99.9	99.9	100.0	0.1 99.8
Sn119m	293.0 d	Sn118(n, $\gamma$ )Sn119m Sn117(n, $\gamma$ )Sn118(n, $\gamma$ )Sn119m Sn116(n, $\gamma$ )Sn117(n, $\gamma$ )Sn118(n, $\gamma$ )Sn119m Sn120(n,2n)Sn119m Sn119(n,n')Sn119m Sn120(n,2n)Sn119(n,n')Sn119m	96.5 3.5	99.1 0.7 0.2	98.8 1.2	93.2 4.0 1.3
Sb125	2.759 y	Sn124(n, $\gamma$ )Sn125m( $\beta^-$ )Sb125 Sn124(n, $\gamma$ )Sn125( $\beta^-$ )Sb125 Sn122(n, $\gamma$ )Sn123m( $\beta^-$ )Sb123(n, $\gamma$ )Sb124(n, $\gamma$ )Sb125	95.4 3.7 1.0	96.3 3.7 3.8	96.2	39.7 60.4

Cd113m	13.7 y	Sn115(n, $\alpha$ )Cd112(n, $\gamma$ )Cd113m Sn116(n, $\alpha$ )Cd113m Sn114(n, $\gamma$ )Sn115(n, $\alpha$ )Cd112(n, $\gamma$ )Cd113m Sn117(n,2n)Sn116(n, $\alpha$ )Cd113m Sn117(n, $\alpha$ )Cd114(n,2n)Cd113m Sn117(n,n $\alpha$ )Cd113m <b>&amp;Sn114(n,2n)Sn113(<math>\beta^+</math>)In113(n,p)Cd113m</b> <b>&amp;Sn118(n,2n)Sn117(n,2n)Sn116(n,<math>\alpha</math>)Cd113m</b> <b>&amp;Sn118(n,2n)Sn117(n,n<math>\alpha</math>)Cd113m</b>	95.6 3.1 1.3	2.3 97.5	2.9 96.8	80.8 5.4 3.3 3.0 1.8 1.4 1.2
Sn121m	55.0 y	Sn120(n, $\gamma$ )Sn121m Sn119(n, $\gamma$ )Sn120(n, $\gamma$ )Sn121m Sn122(n,2n)Sn121m	97.6 2.4	95.7 4.2	99.6 0.4	0.7 99.0
Ag108m	418.0 y	Sn112(n, $\alpha$ )Cd109( $\beta^+$ )Ag109m(IT)Ag109(n,2n)Ag108m Sn112(n,2n)Sn111( $\beta^+$ )In111( $\beta^+$ )Cd111(n,2n)Cd110 (n,2n)Cd109( $\beta^+$ )Ag109m(IT)Ag109(n,2n)Ag108m Sn112(n,n $\alpha$ )Cd108(n,p)Ag108m <b>&amp;Sn112(n,d)In111(<math>\beta^+</math>)Cd111(n,2n)Cd110(n,2n)</b> <b>Cd109(<math>\beta^+</math>)Ag109(n,2n)Ag108m</b>				84.7 9.5 2.3 1.2
Sn126	$2.1 \cdot 10^5$ y	Sn124(n, $\gamma$ )Sn125(n, $\gamma$ )Sn126	100.0	100.0	100.0	100.0
Tc98	$4.2 \cdot 10^6$ y	<b>&amp;Sn112(n,n<math>\alpha</math>)Cd108(n,n<math>\alpha</math>)Pd104(n,2n)Pd103(<math>\beta^+</math>)</b> <b>Rh103(n,n<math>\alpha</math>)Tc99(n,2n)Tc98</b> <b>&amp;Sn112(n,n<math>\alpha</math>)Cd108(n,n<math>\alpha</math>)Pd104(n,2n)Pd103(<math>\beta^+</math>)</b> <b>Rh103(n,2n)Rh102(n,n<math>\alpha</math>)Tc98</b> Sn112(n,n $\alpha$ )Cd108(n,2n)Cd107( $\beta^+$ )Ag107m(IT) Ag107(n,n $\alpha$ )Rh103m(IT)Rh103(n,n $\alpha$ )Tc99(n,2n)Tc98 Sn112(n,n $\alpha$ )Cd108(n,2n)Cd107( $\beta^+$ )Ag107m(IT) Ag107(n,n $\alpha$ )Rh103m(IT)Rh103(n,2n)Rh102(n,n $\alpha$ )Tc98 <b>&amp;Sn112(n,n<math>\alpha</math>)Cd108(n,n<math>\alpha</math>)Pd104(n,2n)Pd103(<math>\beta^+</math>)</b> <b>Rh103(n,2n)Rh102m(n,n<math>\alpha</math>)Tc98</b> Sn112(n,n $\alpha$ )Cd108(n,2n)Cd107( $\beta^+$ )Ag107m(IT)Ag107 (n,n $\alpha$ )Rh103m(IT)Rh103(n,2n)Rh102m(n,n $\alpha$ )Tc98 Sn112(n,n $\alpha$ )Cd108(n,2n)Cd107( $\beta^+$ )Ag107m(IT) Ag107(n,n $\alpha$ )Rh103(n,n $\alpha$ )Tc99(n,2n)Tc98 Sn112(n,n $\alpha$ )Cd108(n,2n)Cd107( $\beta^+$ )Ag107m(IT) Ag107(n,n $\alpha$ )Rh103(n,2n)Rh102(n,n $\alpha$ )Tc98 Sn112(n,n $\alpha$ )Cd108(n, $\alpha$ )Pd105(n,2n)Pd104(n,2n) Pd103( $\beta^+$ )Rh103m(IT)Rh103(n,n $\alpha$ )Tc99(n,2n)Tc98 Sn112(n, $\alpha$ )Cd109(n,2n)Cd108(n,n $\alpha$ )Pd104(n,2n) Pd103( $\beta^+$ )Rh103m(IT)Rh103(n,n $\alpha$ )Tc99(n,2n)Tc98 *Plus many other similar pathways				24.2 17.5 13.4 9.6 7.7 4.3 2.3 1.6 1.2 1.1 17.1*
Pd107	$6.5 \cdot 10^6$ y	<b>&amp;Sn112(n,<math>\alpha</math>)Cd109(n,<math>\alpha</math>)Pd106(n,<math>\gamma</math>)Pd107</b> <b>&amp;Sn112(n,2n)Sn111(<math>\beta^+</math>)In111(<math>\beta^+</math>)Cd111(n,2n)</b> Cd110(n, $\alpha$ )Pd107 <b>&amp;Sn112(n,2n)Sn111(<math>\beta^+</math>)In111(<math>\beta^+</math>)Cd111(n,<math>\alpha</math>)</b> Pd108(n,2n)Pd107 <b>&amp;Sn112(n,2n)Sn111(<math>\beta^+</math>)In111(<math>\beta^+</math>)Cd111(n,n<math>\alpha</math>)Pd107</b> <b>&amp;Sn112(n,d)In111(<math>\beta^+</math>)Cd111(n,2n)Cd110(n,<math>\alpha</math>)Pd107</b> <b>&amp;Sn112(n,n<math>\alpha</math>)Cd108(n,2n)Cd107(<math>\beta^+</math>)Ag107(n,p)Pd107</b> <b>&amp;Sn112(n,<math>\alpha</math>)Cd109(<math>\beta^+</math>)Ag109(n,d)Pd108(n,2n)Pd107</b> <b>&amp;Sn112(n,d)In111(<math>\beta^+</math>)Cd111(n,<math>\alpha</math>)Pd108(n,2n)Pd107</b> <b>&amp;Sn112(n,<math>\alpha</math>)Cd109(<math>\beta^+</math>)Ag109(n,2n)Ag108(<math>\beta^+</math>)</b> Pd108(n,2n)Pd107 <b>&amp;Sn112(n,d)In111(<math>\beta^+</math>)Cd111(n,n<math>\alpha</math>)Pd107</b> <b>&amp;Sn114(n,n<math>\alpha</math>)Cd110(n,<math>\alpha</math>)Pd107</b>	100.0	99.8	100.0	45.8 22.4 9.3 5.6 3.5 3.0 2.8 1.8 1.2 1.0



# Tin activation characteristics

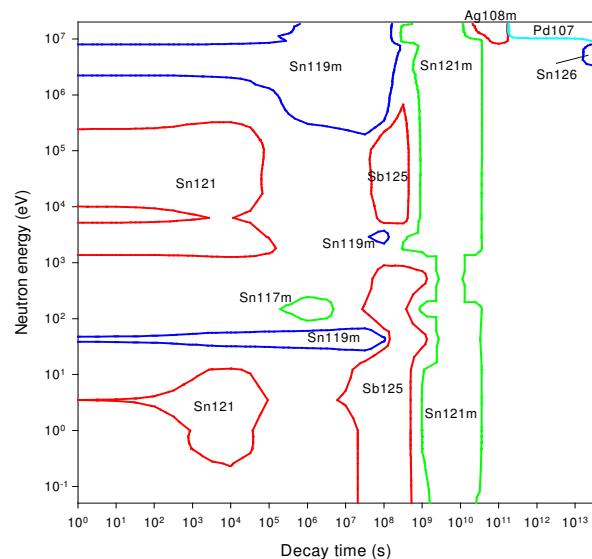


Decay time (years)

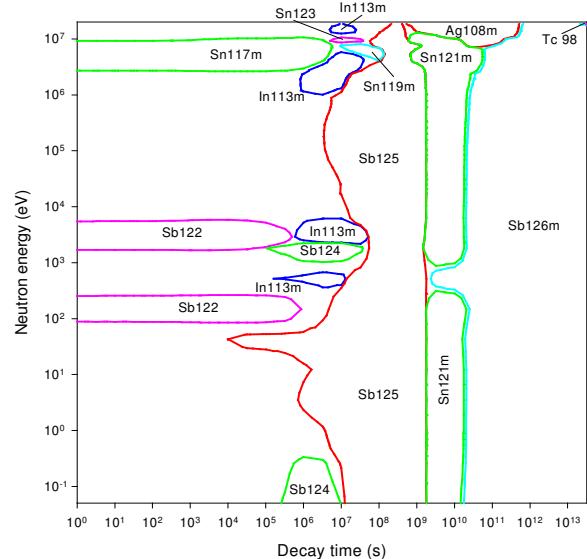
Decay time (years)

# Tin importance diagrams & transmutation

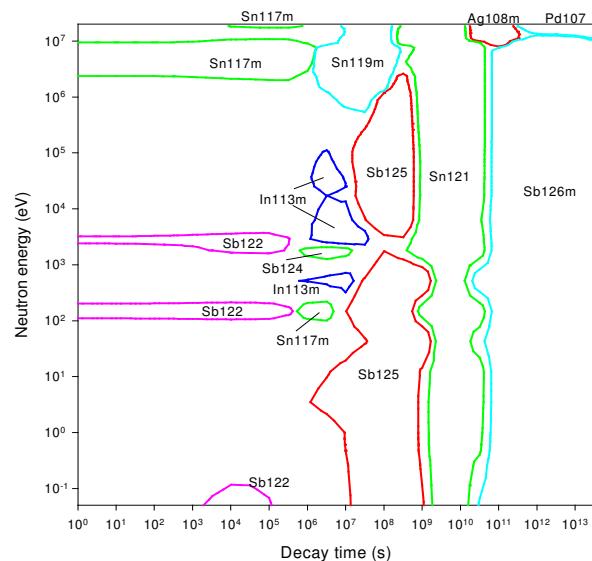
## Activity



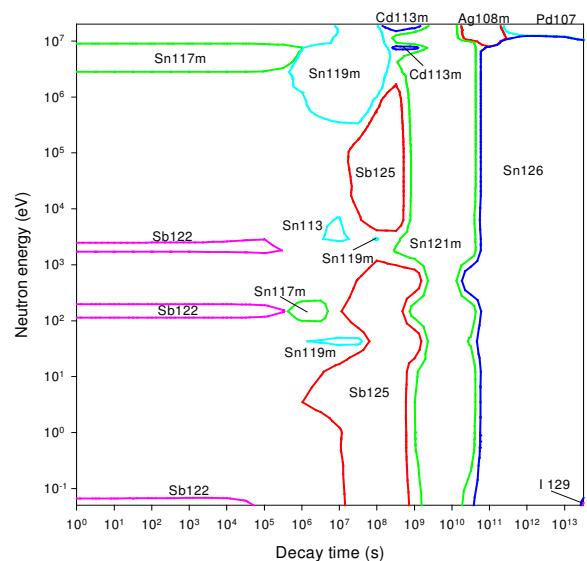
## Dose rate



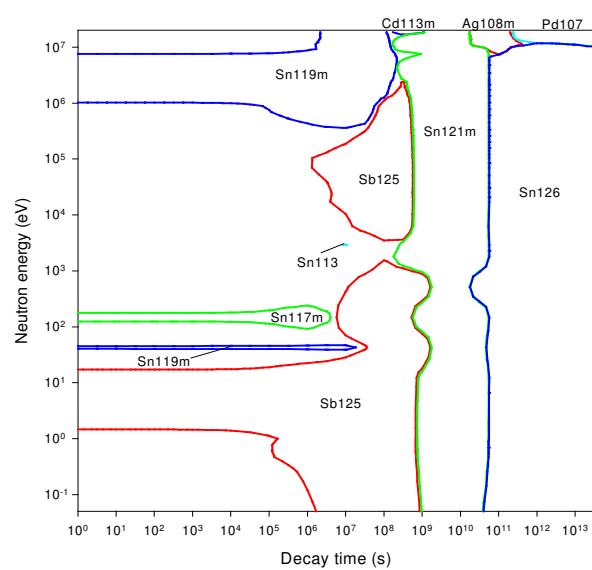
## Heat output



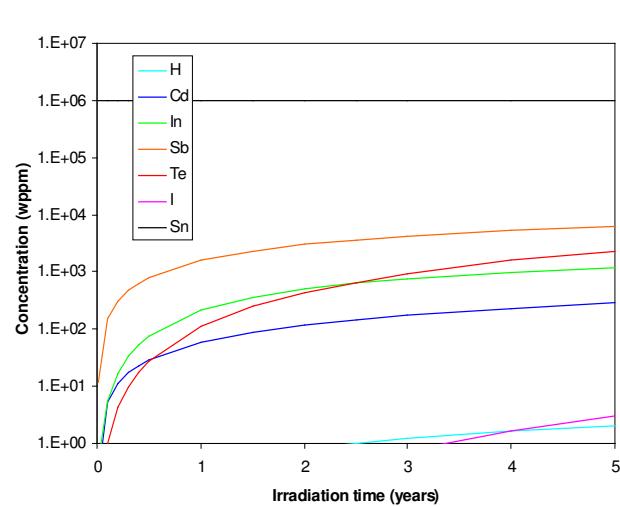
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Antimony

## General properties

Atomic number	51	Isotopes	Isotopic abundances / %	
Crustal abundance / wppm	0.2	Sb121	57.21	
Melting point / K	903.8	Sb123	42.79	
Boiling point / K	1860			
Density / kgm <sup>-3</sup>	6691			
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	24.3			
Electrical resistivity /Ωm	3.90 10 <sup>-7</sup>			
Coefficient of thermal expansion / K <sup>-1</sup>	1.1 10 <sup>-5</sup>			
Crystal structure	Rhombohedral			
Number of stable isotopes	2			
Mean atomic weight	121.76			

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.11E16	1.07E16	6.53E15	2.66E14	1.09E11	2.90E2	kW kg <sup>-1</sup>	2.25E0	2.23E0	1.57E0	3.01E-2	1.27E-6	1.32E-14
Sb122	52.24	54.01	34.60				Sb124	51.77	52.20	71.27	57.91		
Sb124	29.30	30.32	47.60	18.25			Sb122	41.21	41.52	23.14			
Te123m	6.49	6.71	10.76	32.58			Sb120m	2.07	2.09	1.91			
Sb122m	4.11	1.78					Sb120	1.39	1.12				
Sb120	2.31	1.90					Te123m	1.27	1.28	1.79	11.46		
Te121	1.54	1.59	2.44	6.89			Te121	0.71	0.72	0.96	5.72		
Sb120m	1.05	1.08	1.14				Sb122m	0.53	0.22				
Te121m	0.85	0.87	1.41	6.80			Sb125	0.35	0.35	0.50	20.45		
Sb125	0.84	0.87	1.42	27.22			Sb124m	0.23	0.08				
Te125m	0.25	0.26	0.42	6.84			Te121m	0.20	0.20	0.28	2.85		
Sn121	0.08	0.09	0.02	0.06	43.67		Sb126m	0.11	0.09				77.52
Sn119m	0.07	0.07	0.12	1.25			Sb126	0.08	0.09	0.10			15.21
Sb126m	0.06	0.06			10.04		Te125m	0.03	0.03	0.04	1.40		
Sb126n	0.06				6.71		Sn121	0.01	0.01	0.00	0.01	68.86	
Sb126	0.04	0.04	0.05		1.41		Sn121m				0.01	31.14	
Sn121m			0.08	56.27			Sn126						5.82
Te123				70.52			Te123						0.56
Sn126				10.04			Sb126n						0.54
I129				1.28			I129						0.35
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	2.36E6	2.35E6	1.94E6	3.46E4	1.12E-3	1.27E-8	Sv kg <sup>-1</sup>	1.95E7	1.95E7	1.31E7	3.89E5	3.42E1	1.46E-6
Sb124	74.08	74.38	86.40	75.43			Sb122	50.36	50.34	29.32			
Sb122	20.17	20.23	9.59				Sb124	41.54	41.56	59.31	31.19		
Sb120m	3.15	3.17	2.47				Te123m	5.15	5.15	7.51	31.18		
Sb120	0.91	0.72					Te121m	1.10	1.10	1.61	10.69		
Te121	0.73	0.73	0.83	5.31			Sb125	0.52	0.53	0.78	20.47		
Sb125	0.33	0.33	0.40	17.41			Te121	0.38	0.38	0.52	2.02		
Sb124m	0.23	0.08					Te125m	0.12	0.12	0.18	4.07		
Sb126m	0.10	0.09			79.99		Sn121	0.01	0.01		0.01	31.96	
Sb126	0.10	0.10	0.10		19.94		Sn121m				0.02	68.04	
Te123m	0.09	0.09	0.11	0.76			Te123						61.75
Te121m	0.08	0.08	0.10	1.08			I129						28.11
Sn121m				100.00			Sn126						9.39
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	3.99E7	3.99E7	3.47E7	1.92E6	2.87E2	1.76E-6		1.45E13	1.44E13	1.20E13	2.23E11	1.06E6	6.13E-2
Sb124	69.87	69.89	76.96	21.69			Sb124	74.68	75.05	86.70	72.60		
Sb122	15.93	15.92	7.16				Sb122	19.97	20.05	9.45			
Te123m	9.17	9.17	10.32	22.97			Sb120m	1.96	1.96	1.53			
Sb125	2.80	2.80	3.20	45.15			Te123m	0.79	0.79	0.93	6.17		
Te121m	1.34	1.34	1.51	5.36			Te121	0.69	0.70	0.79	4.84		
Te125m	0.29	0.29	0.33	3.97			Sb125	0.28	0.28	0.34	14.13		
Te121	0.18	0.18	0.19	0.39			Te121m	0.15	0.15	0.18	1.84		
Sn121	0.01	0.01			3.82		Sb126m	0.08	0.07				77.91
Sn121m				0.05	96.18		Sb126	0.07	0.07	0.07			18.48
Sn126					46.32		Sn121						51.70
Te123					45.30		Sn121m						48.30
I129					7.61		Sn126						3.17

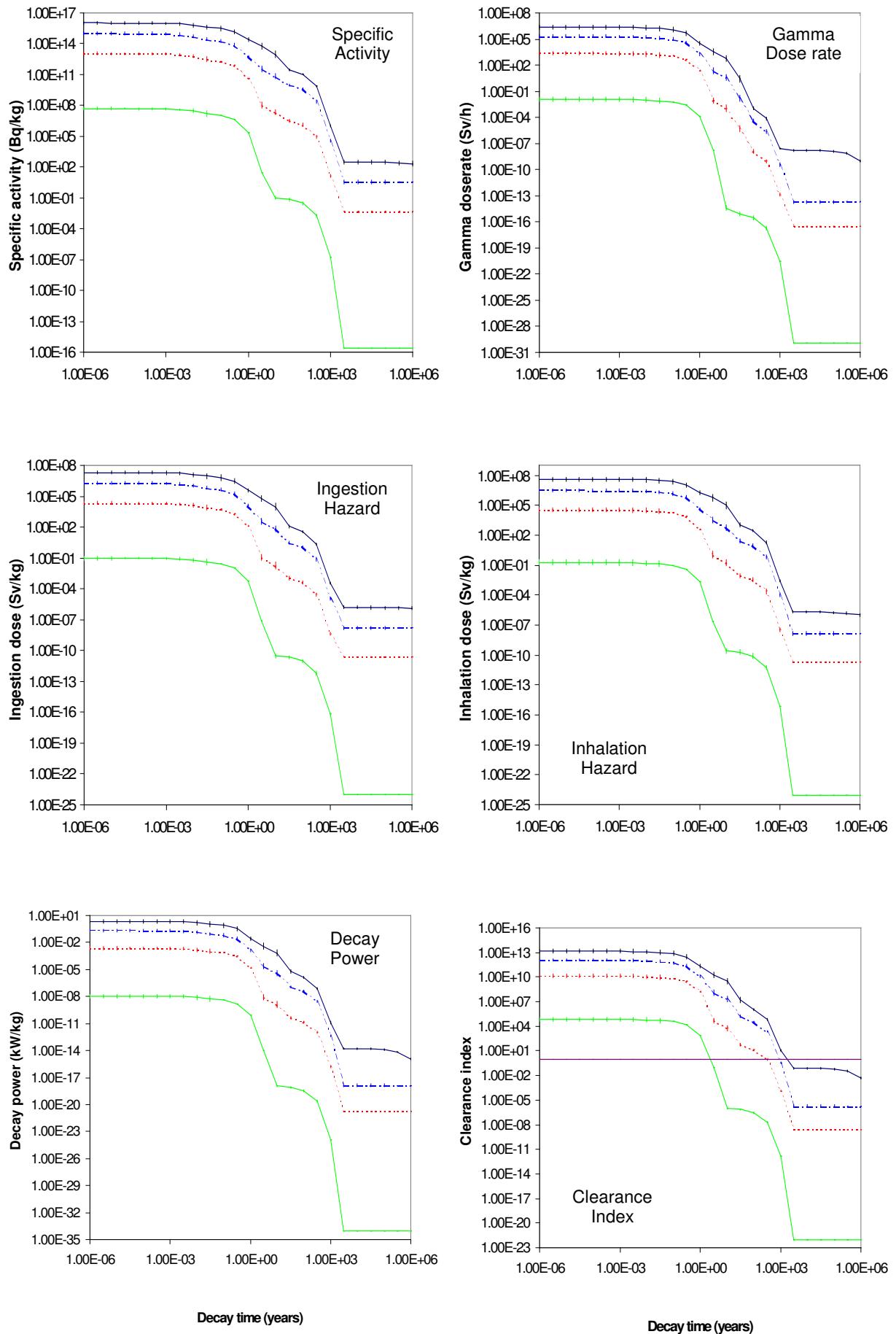
## Antimony

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Sn121	1.121 d	&Sb121(n, $\gamma$ )Sb122( $\beta^-$ )Te122(n, $\gamma$ )Te123(n, $\alpha$ ) Sn120(n, $\gamma$ )Sn121 &Sb121(n,p)Sn121 &Sb123(n, $\gamma$ )Sb124( $\beta^-$ )Te124(n, $\alpha$ )Sn121 &Sb121(n, $\gamma$ )Sb122( $\beta^-$ )Te122(n, $\gamma$ )Te123(n, $\gamma$ )Te124(n, $\alpha$ )Sn121 Sb123(n, $\alpha$ )In120m( $\beta^-$ )Sn120(n, $\gamma$ )Sn121 Sb123(n, $\alpha$ )In120( $\beta^-$ )Sn120(n, $\gamma$ )Sn121 Sb123(n, $\alpha$ )In120n( $\beta^-$ )Sn120(n, $\gamma$ )Sn121 Sb123(n, $\gamma$ )Sb124(n, $\alpha$ )In121( $\beta^-$ )Sn121 Sb123(n, $\gamma$ )Sb124(n, $\alpha$ )In121m( $\beta^-$ )Sn121 &Sb123(n,2n)Sb122( $\beta^+$ )Sn122(n,2n)Sn121 &Sb123(n,d)Sn122(n,2n)Sn121 Sb121(n,2n)Sb120( $\beta^+$ )Sn120(n, $\gamma$ )Sn121 Sb121(n,2n)Sb120m( $\beta^+$ )Sn120(n, $\gamma$ )Sn121	66.1  27.1  5.8  1.8  1.5  1.3  0.2  11.7  4.2	58.2  33.9  2.0  1.2  19.4  17.9  2.2  4.2		43.0  43.0
Sb122	2.696 d	&Sb121(n, $\gamma$ )Sb122 &Sb123(n,2n)Sb122	99.9	99.4	100.0	0.2 99.5
Sb120m	5.67 d	Sb121(n,2n)Sb120m Sb123(n,2n)Sb122( $\beta^-$ )Te122(n,2n)Te121( $\beta^+$ ) Sb121(n,2n)Sb120m				98.0 0.6
Te121	16.782 d	&Sb123(n,2n)Sb122( $\beta^-$ )Te122(n,2n)Te121				99.8
Sb124	60.24 d	&Sb123(n, $\gamma$ )Sb124	99.7	98.7	100.0	99.8
Te123m	119.7 d	&Sb121(n, $\gamma$ )Sb122( $\beta^-$ )Te122(n, $\gamma$ )Te123m &Sb123(n,2n)Sb122( $\beta^-$ )Te122(n, $\gamma$ )Te123m &Sb123(n, $\gamma$ )Sb124( $\beta^-$ )Te124(n,2n)Te123m &Sb123(n, $\gamma$ )Sb124m( $\beta^-$ )Te124(n,2n)Te123m	100.0	100.0	100.0	0.1 48.0 42.8 7.1
Sn123	129.2 d	&Sb121(n, $\gamma$ )Sb122( $\beta^+$ )Sn122(n, $\gamma$ )Sn123 Sb123(n,p)Sn123 Sb123(n,2n)Sb122( $\beta^+$ )Sn122(n, $\gamma$ )Sn123	100.0	100.0	100.0	99.8 0.1
Te121m	153.94 d	&Sb123(n,2n)Sb122( $\beta^-$ )Te122(n,2n)Te121m				99.9
Sn119m	293.0 d	&Sb121(n, $\gamma$ )Sb122( $\beta^-$ )Te122(n, $\alpha$ )Sn119m &Sb121(n, $\alpha$ )In118m( $\beta^-$ )Sn118(n, $\gamma$ )Sn119m Sb121(n, $\alpha$ )In118( $\beta^-$ )Sn118(n, $\gamma$ )Sn119m Sb121(n,2n)Sb120( $\beta^+$ )Sn120(n,2n)Sn119m Sb121(n,2n)Sb120m( $\beta^+$ )Sn120(n,2n)Sn119m	100.0	100.0	59.4 22.2 18.4	66.1 31.3
Sb125	2.759 y	&Sb123(n, $\gamma$ )Sb124(n, $\gamma$ )Sb125	99.8	98.9	100.0	99.6
Sn121m	55.0 y	Sb121(n,p)Sn121m Sb123(n, $\gamma$ )Sb124( $\beta^-$ )Te124(n, $\alpha$ )Sn121m Sb123(n, $\gamma$ )Sb124(n, $\alpha$ )In121( $\beta^-$ )Sn121m &Sb123(n,2n)Sb122( $\beta^+$ )Sn122(n,2n)Sn121m Sb123(n,d)Sn122(n,2n)Sn121m	87.6  10.2	98.2  0.8	94.9  1.3  3.4	73.1  22.8  1.7
Ag108m	418.0 y	Sb121(n,n $\alpha$ )In117( $\beta^-$ )Sn117(n,2n)Sn116(n,n $\alpha$ ) Cd112(n, $\alpha$ )Pd109( $\beta^-$ )Ag109m(IT)Ag109(n,2n)Ag108m *Many other very long pathways involving (n,n $\alpha$ ), (n,2n), (n, $\alpha$ ), and ( $\beta^-$ )				2.6  97.4*

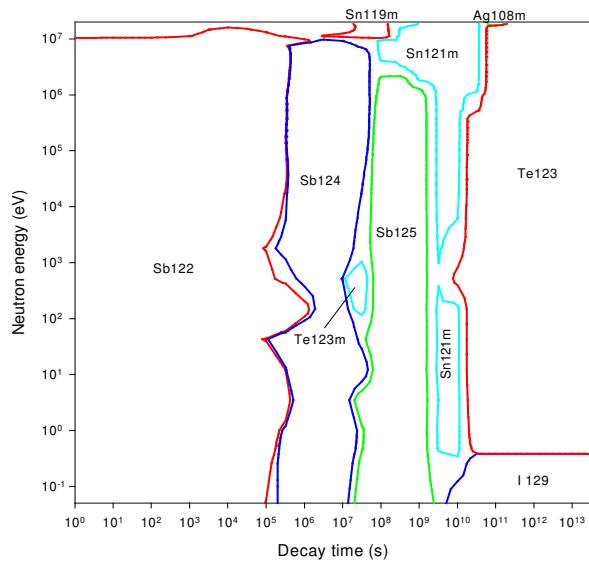


# Antimony activation characteristics

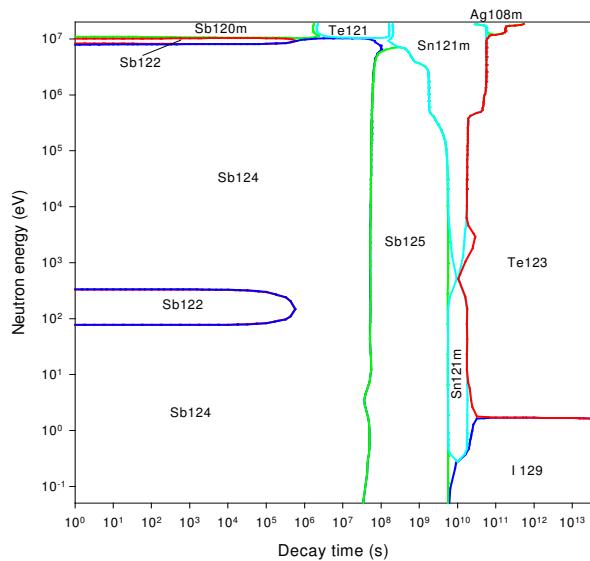


# Antimony importance diagrams & transmutation

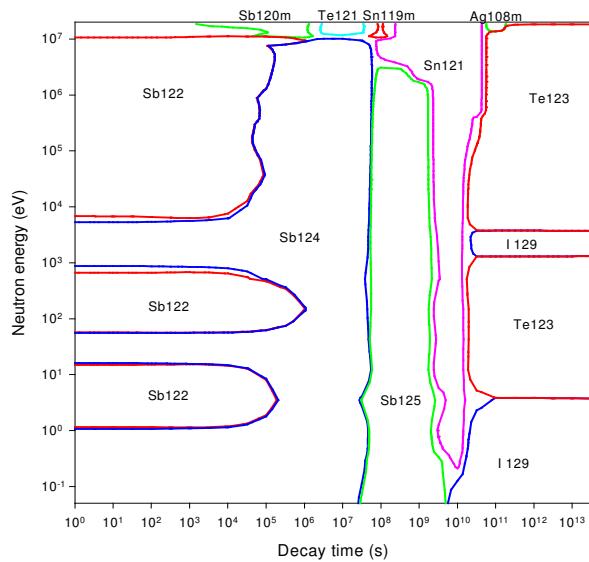
## Activity



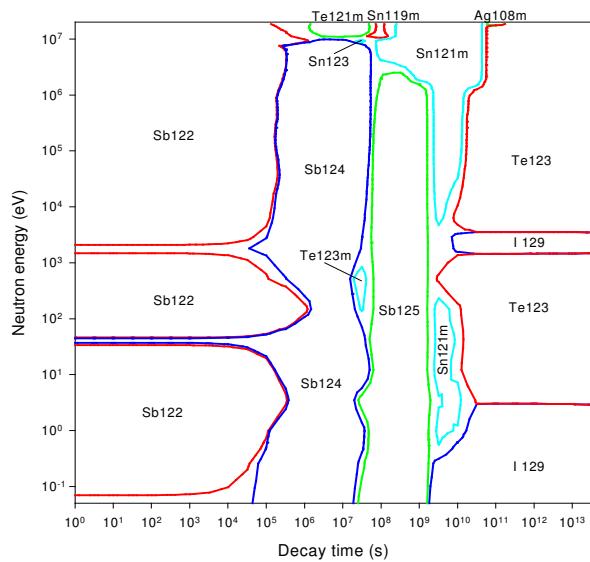
## Dose rate



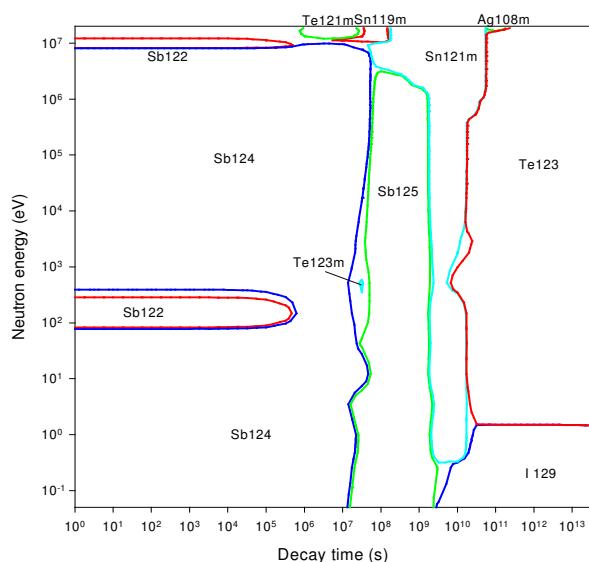
## Heat output



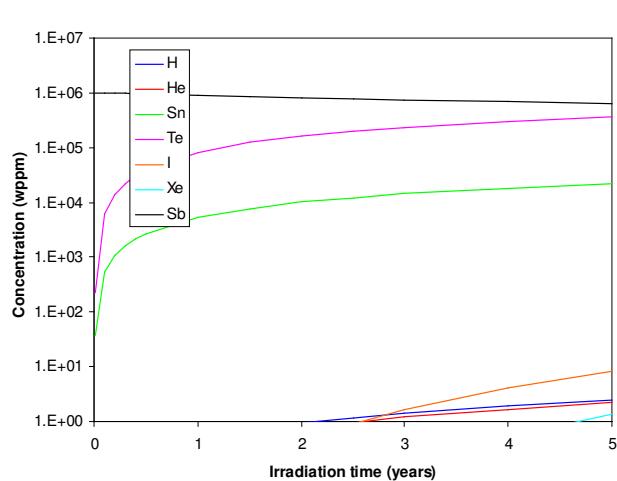
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Tellurium

## General properties

	52	Isotopes	Isotopic abundances / %
Atomic number	1.0 10 <sup>-3</sup>	Te120	0.09
Crustal abundance / wppm	722.7	Te122	2.55
Melting point / K	1261	Te123	0.89 ( $T_{1/2} = 9.9932 \cdot 10^{12}$ y)
Boiling point / K	6240	Te124	4.74
Density / kgm <sup>-3</sup>	2.35	Te125	7.07
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	4.36 10 <sup>-3</sup>	Te126	18.84
Electrical resistivity /Ωm	16.75 10 <sup>-6</sup>	Te128	31.74
Coefficient of thermal expansion / K <sup>-1</sup>	Hexagonal	Te130	34.08
Crystal structure	7(8)		
Number of stable isotopes	127.60		
Mean atomic weight			

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	2.50E15	2.41E15	1.19E15	6.04E13	1.83E9	1.10E8	kW kg <sup>-1</sup>	1.83E-1	1.74E-1	5.27E-2	1.89E-3	2.13E-8	1.38E-9
Te127	26.99	27.84	17.91	35.35			I128	25.96	23.66				
Te129	18.25	18.33	14.12	0.17			Te129	24.02	24.56	30.92	0.52		
I128	14.33	12.83					I130	15.00	15.77	0.39			
Te129m	10.53	10.91	20.45	0.24			Te127	13.49	14.17	14.90	41.54		
Te127m	8.91	9.23	18.21	36.09			Te129m	6.41	6.76	20.71	0.35		
Te125m	8.03	8.32	16.08	4.35			Te125m	2.54	2.67	8.45	3.23		
Te123m	3.51	3.63	7.19	17.49			Te131	2.22	2.03				
I130	2.83	2.93	0.04				Te123m	1.90	2.01	6.49	22.31		
I130m	1.85	1.28					Te127m	1.82	1.92	6.19	17.34		
I131	1.01	1.05	1.58				I131	1.26	1.33	3.29			
Te131	0.89	0.81					I130m	1.24	0.88				
I126	0.66	0.68	1.14				I126	0.84	0.88	2.39			
Te121	0.64	0.66	1.24	2.84			Te121	0.81	0.86	2.65	8.55		
Te121m	0.35	0.36	0.72	2.80			Sb122	0.70	0.74	0.96			
Xe127	0.31	0.32	0.61	0.01			Te121m	0.23	0.24	0.78	4.27		
H3				0.01	0.99		Sb125			0.07	1.45		
Sn121m				0.01	52.34		Sn121				64.30		
Sn121					40.62		Sn121m				29.08		
I129					6.05	99.97	I129				6.50	99.64	
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	5.78E4	5.60E4	9.13E3	2.99E2	3.10E-5	1.16E-5	Sv kg <sup>-1</sup>	3.03E6	3.02E6	2.44E6	7.66E4	1.27E1	1.21E1
I130	58.20	59.83	2.72				Te129m	26.03	26.10	29.99	0.58		
I128	9.74	8.68					I131	18.34	18.39	17.03			
Te129	8.48	8.47	19.82	0.36			Te127m	16.88	16.93	20.48	65.42		
Te129m	3.16	3.26	18.56	0.34			I126	15.79	15.83	16.13			
Te131	2.98	2.67					Te125m	5.76	5.77	6.84	2.98		
Te121	2.79	2.88	16.52	58.34			I130	4.67	4.67	0.04			
I126	2.37	2.44	12.33				Te123m	4.05	4.06	4.92	19.30		
Te131m	2.34	2.40	1.95				Te127	3.78	3.78	1.49	4.74		
I131	2.29	2.36	10.82				Te129	0.95	0.92	0.44	0.01		
I130m	1.79	1.23					Xe127	0.82	0.82	0.95	0.03		
Sb122	1.16	1.19	2.86				Te121m	0.67	0.67	0.81	5.08		
Te127	1.00*	1.02*	2.00*	6.10*			I128	0.54	0.47				
Te123m	0.45	0.47	2.81	10.57			Sb122	0.45	0.45	0.22			
Sb124	0.42	0.43	2.55	1.21			I130m	0.38	0.25				
Te121m	0.31	0.32	1.96	11.74			Te131m	0.24	0.24	0.04			
Sb126m	0.29	0.25			16.72	33.63	Te121	0.23	0.23	0.26	0.96		
Xe127	0.25	0.26	1.49	0.05			Xe129m	0.15	0.15	0.14			
Sb126			0.84		4.17	8.38	Sb125			0.02	0.46		
Sb125			0.38	9.11			Cs134			0.02	0.33		
Cs134				1.63			I129			0.02	95.79	100.00	
Sn121m					55.34		Sn121m				2.86		
I129					21.74	57.96	Sn121				1.34		
Ba133					1.53								

Inh	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>	Clear	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>
Sv kg <sup>-1</sup>	6.44E6	6.44E6	5.95E6	2.98E5	8.47E0	3.97E0		3.90E11	3.76E11	9.89E10	4.43E9	2.03E4	3.70E3
Te127m	33.82	33.83	35.75	71.75			I130	39.40	40.80	1.15			
Te129m	32.23	32.24	32.35	0.39			I128	14.78	13.26				
Te125m	13.07	13.07	13.53	3.71			Te129	13.42	13.51	19.58	0.26		
Te123m	6.93	6.93	7.34	18.10			Te127	4.67	4.82	5.84	13.02		
Xe127	4.33	4.33	4.37	0.09			Te129m	4.21	4.37	15.41	0.21		
I131	2.90	2.90	2.35				Te123m	3.56	3.70	13.76	37.84		
I126	2.51	2.51	2.23				Te131	2.86	2.58				
Te127	1.46	1.46	0.50	1.00			Te125m	2.45	2.54	9.24	2.83		
Te121m	0.78	0.78	0.83	3.24			Te121	2.39	2.48	8.82	22.77		
I130	0.74	0.73					I131	2.16	2.24	6.36			
Te129	0.28	0.27	0.11				I126	1.92	1.99	6.24			
Xe129m	0.23	0.23	0.19				I130m	1.64	1.14				
Sb122	0.14	0.14	0.06				Te131m	1.41	1.46	0.73			
I128	0.11	0.10					Te127m	1.12	1.16	4.31	9.65		
Te121	0.10	0.10	0.10	0.24			Sb122	1.03	1.06	1.58			
Xe131m	0.10	0.10	0.09				Xe127	0.57	0.59	2.09	0.05		
Sb125	0.08	0.08	0.08	1.30			Te121m	0.51	0.53	1.98	8.68		
Sb124	0.06	0.06	0.06	0.02			Sb124	0.38	0.39	1.42	0.50		
Sn121m				0.01	50.87		Sb125			0.18	3.16		
I129					47.05	99.99	Cs134				1.01		
Sn121					2.02		Sn121					42.16	
							Sn121m					39.39	
							I129					18.22	99.38

# Tellurium

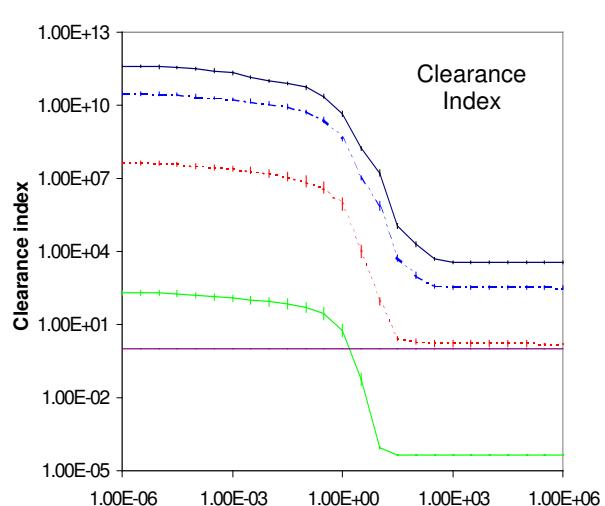
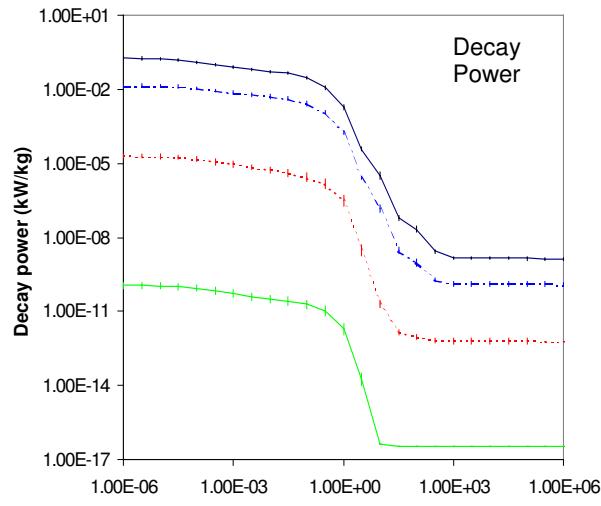
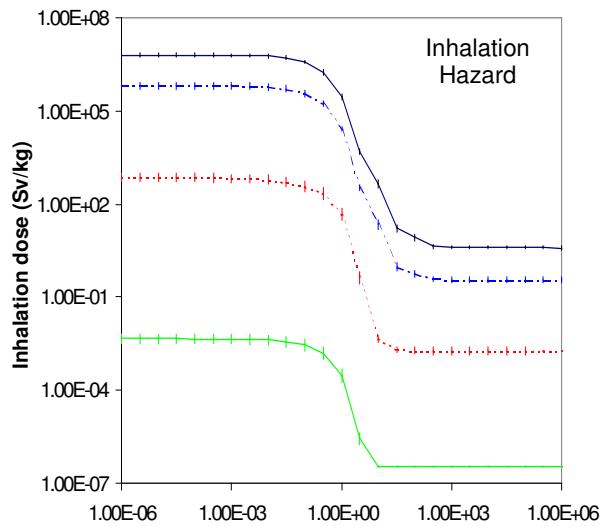
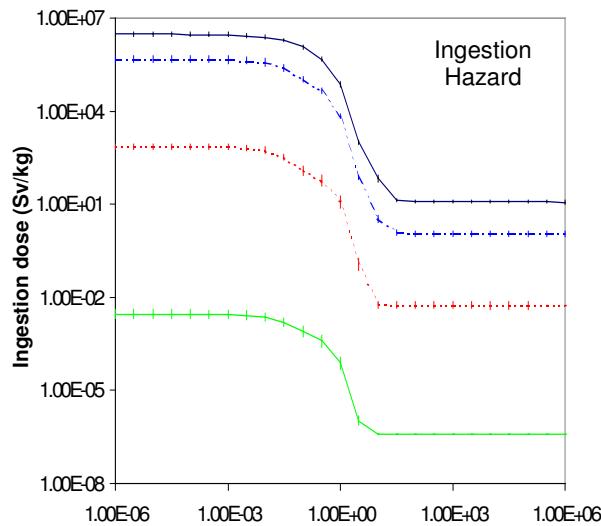
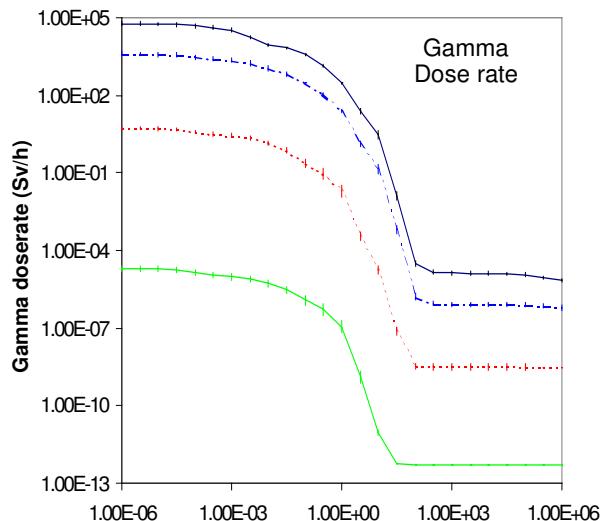
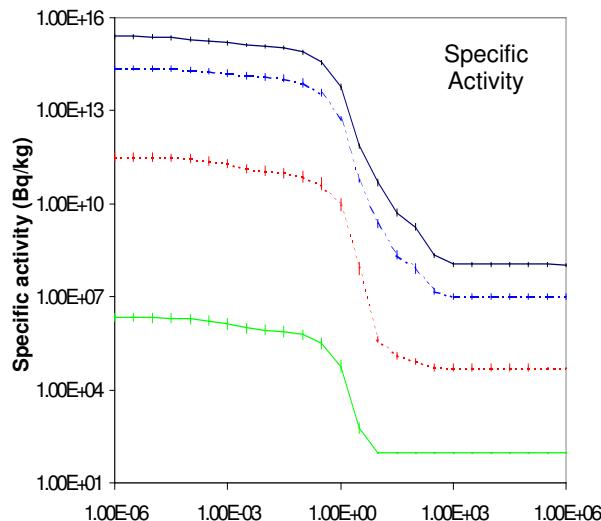
## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Ba137m	2.553 m	<b>&amp;Te130(n,<math>\gamma</math>)Te131(<math>\beta^-</math>)I131(<math>\beta^-</math>)Xe131(n,<math>\gamma</math>)Xe132(n,<math>\gamma</math>)Xe133(<math>\beta^-</math>)Cs133(n,<math>\gamma</math>)Cs134(n,<math>\gamma</math>)Cs135(n,<math>\gamma</math>)Cs136(<math>\beta^-</math>)Ba136(n,<math>\gamma</math>)Ba137m</b> <b>&amp;Te130(n,<math>\gamma</math>)Te131(<math>\beta^-</math>)I131(<math>\beta^-</math>)Xe131(n,<math>\gamma</math>)Xe132(n,<math>\gamma</math>)Xe133(<math>\beta^-</math>)Cs133(n,<math>\gamma</math>)Cs134(n,<math>\gamma</math>)Cs135(n,<math>\gamma</math>)Cs136(n,<math>\gamma</math>)Cs137(<math>\beta^-</math>)Ba137m</b> <b>&amp;Te130(n,<math>\gamma</math>)Te131m(<math>\beta^-</math>)I131(<math>\beta^-</math>)Xe131(n,<math>\gamma</math>)Xe132(n,<math>\gamma</math>)Xe133(<math>\beta^-</math>)Cs133(n,<math>\gamma</math>)Cs134(n,<math>\gamma</math>)Cs135(n,<math>\gamma</math>)Cs136(<math>\beta^-</math>)Ba136(n,<math>\gamma</math>)Ba137m</b> <b>&amp;Te130(n,<math>\gamma</math>)Te131m(<math>\beta^-</math>)I131(<math>\beta^-</math>)Xe131(n,<math>\gamma</math>)Xe132(n,<math>\gamma</math>)Xe133(<math>\beta^-</math>)Cs133(n,<math>\gamma</math>)Cs134(n,<math>\gamma</math>)Cs135(n,<math>\gamma</math>)Cs136(<math>\beta^-</math>)Ba137m</b> <b>&amp;Te130(n,<math>\gamma</math>)Te131m(<math>\beta^-</math>)I131(<math>\beta^-</math>)Xe131(n,<math>\gamma</math>)Xe132(n,<math>\gamma</math>)Xe133(<math>\beta^-</math>)Cs133(n,<math>\gamma</math>)Cs134(n,<math>\gamma</math>)Cs135(n,<math>\gamma</math>)Cs136(<math>\beta^-</math>)Ba136(n,<math>\gamma</math>)Ba137m</b> <b>&amp;Te130(n,<math>\gamma</math>)Te131m(<math>\beta^-</math>)I131(<math>\beta^-</math>)Xe131(n,<math>\gamma</math>)Xe132(n,<math>\gamma</math>)Xe133(<math>\beta^-</math>)Cs133(n,<math>\gamma</math>)Cs134(n,<math>\gamma</math>)Cs135(n,<math>\gamma</math>)Cs136(<math>\beta^-</math>)Ba136(n,<math>\gamma</math>)Ba137m</b> <b>&amp;Te130(n,<math>\gamma</math>)Te131m(<math>\beta^-</math>)I131(<math>\beta^-</math>)Xe131(n,<math>\gamma</math>)Xe132(n,<math>\gamma</math>)Xe133(<math>\beta^-</math>)Cs133(n,<math>\gamma</math>)Cs134(n,<math>\gamma</math>)Cs135(n,<math>\gamma</math>)Cs136(<math>\beta^-</math>)Ba136(n,<math>\gamma</math>)Ba137m</b>	74.5 11.7 9.3 1.5 0.2	0.3 83.7 7.6 10.5 10.1	60.5	
Sb126m	19.1 m	<b>&amp;Te120(n,<math>\gamma</math>)Te121(<math>\beta^+</math>)Sb121(n,<math>\gamma</math>)Sb122(n,<math>\gamma</math>)Sb123(n,<math>\gamma</math>)Sb124(n,<math>\gamma</math>)Sb125(n,<math>\gamma</math>)Sb126n(IT)Sb126m</b> <b>&amp;Te120(n,<math>\gamma</math>)Te121(<math>\beta^+</math>)Sb121(n,<math>\gamma</math>)Sb122(n,<math>\gamma</math>)Sb123(n,<math>\gamma</math>)Sb124(n,<math>\gamma</math>)Sb125(n,<math>\gamma</math>)Sb126m</b> <b>&amp;Te128(n,<math>\alpha</math>)Sn125m(<math>\beta^-</math>)Sb125(n,<math>\gamma</math>)Sb126m</b> <b>&amp;Te128(n,<math>\alpha</math>)Sn125(<math>\beta^-</math>)Sb125(n,<math>\gamma</math>)Sb126m</b> <b>&amp;Te125(n,p)Sb125(n,<math>\gamma</math>)Sb126m</b> <b>&amp;Te126(n,p)Sb126m</b> <b>&amp;Te130(n,2n)Te129(<math>\beta^-</math>)I129(n,<math>\alpha</math>)Sb126m</b> <b>&amp;Te130(n,2n)Te129m(<math>\beta^-</math>)I129(n,<math>\alpha</math>)Sb126m</b>	81.1 8.7 0.1	28.0 3.0 32.1 29.2 5.3		
I128	24.99 m	<b>&amp;Te126(n,<math>\gamma</math>)Te127(<math>\beta^-</math>)I127(n,<math>\gamma</math>)I128</b> <b>&amp;Te125(n,<math>\gamma</math>)Te126(n,<math>\gamma</math>)Te127(<math>\beta^-</math>)I127(n,<math>\gamma</math>)I128</b> <b>&amp;Te130(n,2n)Te129(<math>\beta^-</math>)I129(n,2n)I128</b> <b>Te130(n,2n)Te129m(<math>\beta^-</math>)I129(n,2n)I128</b>	97.6 2.1	82.0 17.7	98.6 1.1	87.0 8.8 2.2
Te129	1.16 h	<b>&amp;Te128(n,<math>\gamma</math>)Te129</b> <b>&amp;Te130(n,2n)Te129</b>	99.2	100.0	100.0	99.2
Te127	9.35 h	<b>&amp;Te126(n,<math>\gamma</math>)Te127</b> <b>&amp;Te125(n,<math>\gamma</math>)Te126(n,<math>\gamma</math>)Te127</b> <b>&amp;Te128(n,2n)Te127</b>	95.5 3.8	77.9 21.9	97.8 2.2	80.3 19.2
I130	12.36 h	<b>&amp;Te128(n,<math>\gamma</math>)Te129(<math>\beta^-</math>)I129(n,<math>\gamma</math>)I130</b> <b>&amp;Te128(n,<math>\gamma</math>)Te129m(<math>\beta^-</math>)I129(n,<math>\gamma</math>)I130</b> <b>&amp;Te130(n,2n)Te129(<math>\beta^-</math>)I129(n,<math>\gamma</math>)I130</b> <b>&amp;Te130(n,2n)Te129m(<math>\beta^-</math>)I129(n,<math>\gamma</math>)I130</b>	96.8 2.2	97.7 2.3	97.7 2.3	78.0 18.9
Sn121	1.121 d	Te123(n, $\alpha$ )Sn120(n, $\gamma$ )Sn121 <b>&amp;Te122(n,<math>\gamma</math>)Te123(n,<math>\alpha</math>)Sn120(n,<math>\gamma</math>)Sn121</b> <b>&amp;Te124(n,<math>\alpha</math>)Sn121</b> <b>&amp;Te123(n,<math>\gamma</math>)Te124(n,<math>\alpha</math>)Sn121</b> <b>&amp;Te125(n,2n)Te124(n,<math>\alpha</math>)Sn121</b> <b>&amp;Te125(n,<math>\alpha</math>)Sn122(n,2n)Sn121</b> <b>&amp;Te122(n,2n)Te121(<math>\beta^+</math>)Sb121(n,p)Sn121</b> <b>&amp;Te126(n,2n)Te125(n,2n)Te124(n,<math>\alpha</math>)Sn121</b> <b>&amp;Te126(n,2n)Te125(n,<math>\alpha</math>)Sn122(n,2n)Sn121</b>	69.8 25.7 3.4 0.6	81.5 1.1 14.6 2.7	42.0 2.9 54.2 1.1	50.1
I131	8.04 d	<b>&amp;Te130(n,<math>\gamma</math>)Te131(<math>\beta^-</math>)I131</b> <b>Te130(n,<math>\gamma</math>)Te131m(<math>\beta^-</math>)I131</b>	88.9 11.1	88.9 11.1	88.9 11.1	65.9 33.8

I126	12.98 d	<b>&amp;Te128(n,2n)Te127(<math>\beta^-</math>)I127(n,2n)I126 Te128(n,2n)Te127m(<math>\beta^-</math>)I127(n,2n)I126</b>				97.4 1.4
Te121	16.782 d	<b>&amp;Te120(n,<math>\gamma</math>)Te121 &amp;Te122(n,2n)Te121 &amp;Te123(n,2n)Te122(n,2n)Te121 &amp;Te124(n,2n)Te123(n,2n)Te122(n,2n)Te121</b>	99.8	100.0	99.9	86.9 7.4 3.9
Te129m	33.8 d	Te128(n, $\gamma$ )Te129m Te130(n,2n)Te129m	99.2	100.0	100.0	99.1
Te125m	58.0 d	Te124(n, $\gamma$ )Te125m Te123(n, $\gamma$ )Te124(n, $\gamma$ )Te125m <b>&amp;Te122(n,<math>\gamma</math>)Te123(n,<math>\gamma</math>)Te124(n,<math>\gamma</math>)Te125m Te122(n,<math>\gamma</math>)Te123m(n,<math>\gamma</math>)Te124(n,<math>\gamma</math>)Te125m Te126(n,2n)Te125m Te125(n,n')Te125m <b>&amp;Te128(n,2n)Te127(<math>\beta^-</math>)I127(n,2n)I126(<math>\beta^+</math>)Te126(n,2n)Te125m</b></b>	76.7 14.6 6.4 2.3	83.9 15.8 0.2	98.3 1.5 0.1	89.7 4.5 2.1
Te127m	109.0 d	Te126(n, $\gamma$ )Te127m Te125(n, $\gamma$ )Te126(n, $\gamma$ )Te127m Te128(n,2n)Te127m	95.5 3.9	78.4 21.4	98.0 2.0	99.3
Te123m	119.7 d	Te122(n, $\gamma$ )Te123m Te124(n,2n)Te123m Te125(n,2n)Te124(n,2n)Te123m <b>&amp;Te126(n,2n)Te125(n,2n)Te124(n,2n)Te123m Te123(n,n')Te123m</b>	99.4	100.0	100.0	63.9 23.5 6.7 2.1
Cs134	2.065 y	<b>&amp;Te130(n,<math>\gamma</math>)Te131(<math>\beta^-</math>)I131(<math>\beta^-</math>)Xe131(n,<math>\gamma</math>)Xe132(n,<math>\gamma</math>) Xe133(<math>\beta^-</math>)Cs133(n,<math>\gamma</math>)Cs134 &amp;Te130(n,<math>\gamma</math>)Te131m(<math>\beta^-</math>)I131(<math>\beta^-</math>)Xe131(n,<math>\gamma</math>) Xe132(n,<math>\gamma</math>)Xe133(<math>\beta^-</math>)Cs133(n,<math>\gamma</math>)Cs134 &amp;Te128(n,<math>\gamma</math>)Te129(<math>\beta^-</math>)I129(n,<math>\gamma</math>)I130(<math>\beta^-</math>)Xe130(n,<math>\gamma</math>) Xe131(n,<math>\gamma</math>)Xe132(n,<math>\gamma</math>)Xe133(<math>\beta^-</math>)Cs133(n,<math>\gamma</math>)Cs134 &amp;Te130(n,<math>\gamma</math>)Te131(<math>\beta^-</math>)I131(n,<math>\gamma</math>)I132(<math>\beta^-</math>)Xe132(n,<math>\gamma</math>) Xe133(<math>\beta^-</math>)Cs133(n,<math>\gamma</math>)Cs134 &amp;Te130(n,<math>\gamma</math>)Te131m(<math>\beta^-</math>)I131(n,<math>\gamma</math>)I132(<math>\beta^-</math>)Xe132(n,<math>\gamma</math>) Xe133(<math>\beta^-</math>)Cs133(n,<math>\gamma</math>)Cs134</b>	85.9 10.6 2.2	85.9 10.7	88.1 11.0	62.0 31.9 3.2 1.5
Sb125	2.759 y	<b>&amp;Te120(n,<math>\gamma</math>)Te121(<math>\beta^+</math>)Sb121(n,<math>\gamma</math>)Sb122(n,<math>\gamma</math>) Sb123(n,<math>\gamma</math>)Sb124(n,<math>\gamma</math>)Sb125 Te120(n,<math>\gamma</math>)Te121(<math>\beta^+</math>)Sb121(n,<math>\gamma</math>)Sb122(<math>\beta^+</math>)Sn122(n,<math>\gamma</math>) Sn123m(<math>\beta^-</math>)Sb123(n,<math>\gamma</math>)Sb124(n,<math>\gamma</math>)Sb125 Te125(n,p)Sb125 Te128(n,<math>\alpha</math>)Sn125m(<math>\beta^-</math>)Sb125 Te128(n,<math>\alpha</math>)Sn125(<math>\beta^-</math>)Sb125 Te126(n,d)Sb125 <b>&amp;Te126(n,2n)Te125(n,p)Sb125 Te126(n,2n)Te125m(n,p)Sb125</b></b>	97.8 1.3 0.1 5.3 32.1 29.3 52.4 47.7 32.2 15.8 14.3 22.5 12.1 1.1	33.0		
H3	12.33 y	Te125(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Te124(n, $\gamma$ )Te125(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Te126(n, $\gamma$ )Te127( $\beta^-$ )I127(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Te123(n, $\gamma$ )Te124(n, $\gamma$ )Te125(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Te123(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 <b>&amp;Te130(n,2n)Te129(<math>\beta^-</math>)I129(n,X)H3 Te130(n,X)H3 Te125(n,X)H3 Te130(n,2n)Te129m(<math>\beta^-</math>)I129(n,X)H3 Te128(n,X)H3 Te126(n,X)H3 <b>&amp;Te126(n,2n)Te125(n,X)H3 Te123(n,X)H3 <b>&amp;Te128(n,2n)Te127(<math>\beta^-</math>)I127(n,X)H3 Te124(n,X)H3 <b>&amp;Te124(n,2n)Te123(n,X)H3 Te122(n,X)H3</b></b></b></b>	82.0 6.1 3.1 1.0 3.7 0.2 0.5 54.5 27.7 0.1 15.6 7.1 6.8 5.3 4.9 2.6 2.0 1.8 1.5 1.3	90.2 0.2 0.5 54.5 27.7 0.1 15.6 7.1 6.8 5.3 4.9 2.6 2.0 1.8 1.5 1.3		

Cs137	30.171 y	$\text{&Te130(n,\gamma)Te131(\beta^-)I131(\beta^-)Xe131(n,\gamma)Xe132(n,\gamma)}$	83.8 10.3 3.0  1.2	84.4 10.5   98.8	87.6 10.9   58.4	
		$Xe133(\beta^-)\text{Cs133(n,\gamma)Cs134(n,\gamma)Cs135(n,\gamma)Cs136(n,\gamma)}$				
		$\text{Cs137}$				
		$\text{&Te130(n,\gamma)Te131m(\beta^-)I131(\beta^-)Xe131(n,\gamma)}$				
		$Xe132(n,\gamma)Xe133(\beta^-)\text{Cs133(n,\gamma)Cs134(n,\gamma)Cs135(n,\gamma)}$				
Sn121m	55.0 y	$\text{Cs136(n,\gamma)Cs137}$				
		$\text{&Te130(n,\gamma)Te131(\beta^-)I131(\beta^-)Xe131(n,\gamma)Xe132(n,\gamma)}$				
		$Xe133(n,\gamma)Xe134(n,\gamma)Xe135(n,\gamma)Xe136(n,\gamma)$				
		$\text{Xe137}(\beta^-)\text{Cs137}$				
		$\text{&Te130(n,\gamma)Te131(\beta^-)I131(n,\gamma)I132(\beta^-)Xe132(n,\gamma)}$				
		$Xe133(\beta^-)\text{Cs133(n,\gamma)Cs134(n,\gamma)Cs135(n,\gamma)Cs136(n,\gamma)Cs137}$				
		$\text{Te124(n,\alpha)Sn121m}$	70.7	81.8	98.8	58.4
		$\text{Te123(n,\gamma)Te124(n,\alpha)Sn121m}$	13.2	14.6	0.8	
		$\text{Te123(n,\alpha)Sn120(n,\gamma)Sn121m}$	9.4	3.4	0.3	
		$\text{&Te122(n,\gamma)Te123(n,\gamma)Te124(n,\alpha)Sn121m}$	3.3			
I129	$1.6 \cdot 10^7$ y	$\text{&Te122(n,\gamma)Te123(n,\alpha)Sn120(n,\gamma)Sn121m}$	2.1			
		$\text{Te122(n,\gamma)Te123m(n,\gamma)Te124(n,\alpha)Sn121m}$	1.2			
		$\text{Te125(n,2n)Te124(n,\alpha)Sn121m}$				12.2
		$\text{&Te122(n,2n)Te121(\beta^+)Sb121(n,p)Sn121m}$				11.1
		$\text{Te125(n,\alpha)Sn122(n,2n)Sn121m}$				9.6
		$\text{&Te126(n,2n)Te125(n,2n)Te124(n,\alpha)Sn121m}$				2.5
		$\text{&Te126(n,2n)Te125(n,\alpha)Sn122(n,2n)Sn121m}$				2.0
		$\text{&Te128(n,\gamma)Te129(\beta^-)I129}$	97.2	97.7	97.7	
		$\text{Te128(n,\gamma)Te129m(\beta^-)I129}$	2.3	2.3	2.3	
		$\text{&Te130(n,2n)Te129(\beta^-)I129}$				80.6
		$\text{Te130(n,2n)Te129m(\beta^-)I129}$				19.2

# Tellurium activation characteristics

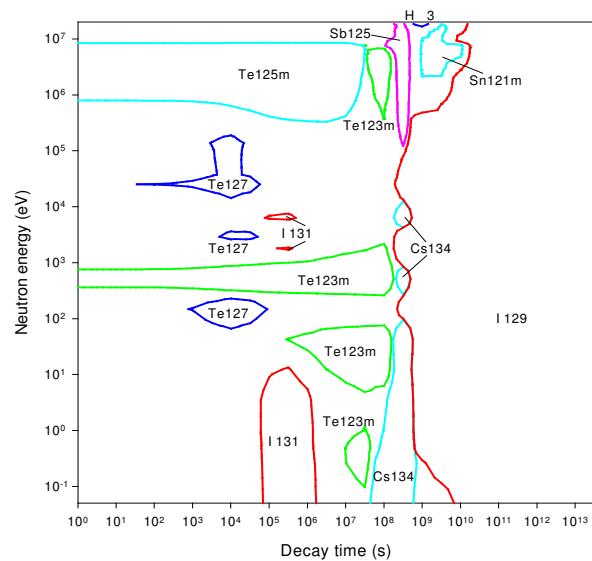


Decay time (years)

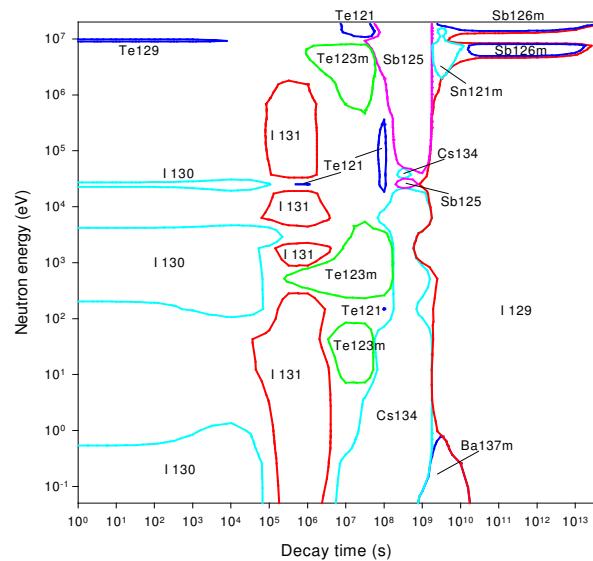
Decay time (years)

# Tellurium importance diagrams & transmutation

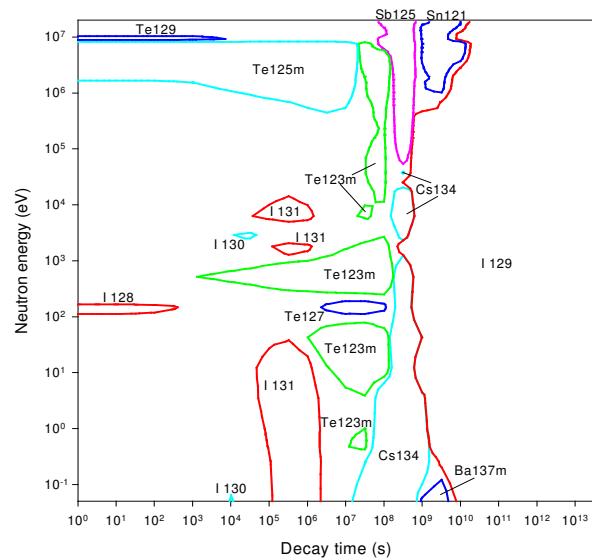
## Activity



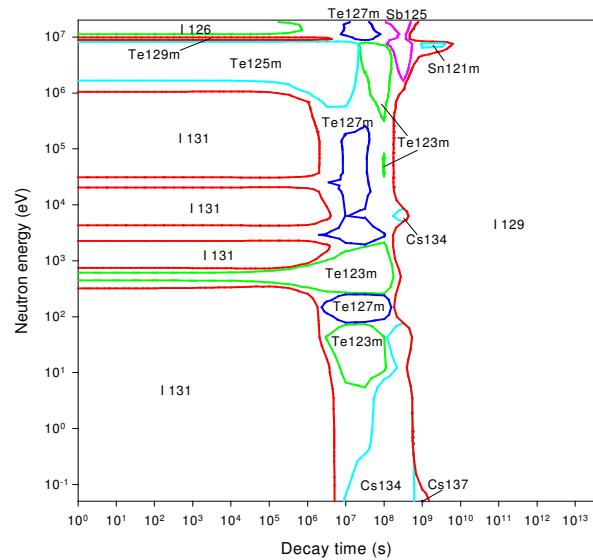
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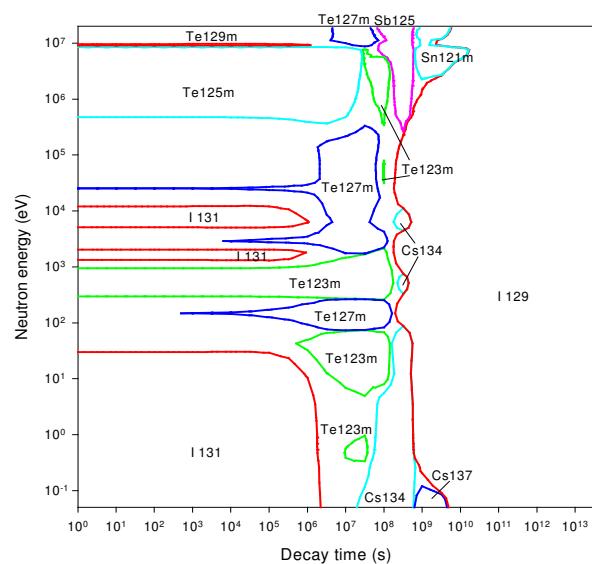
## Heat output



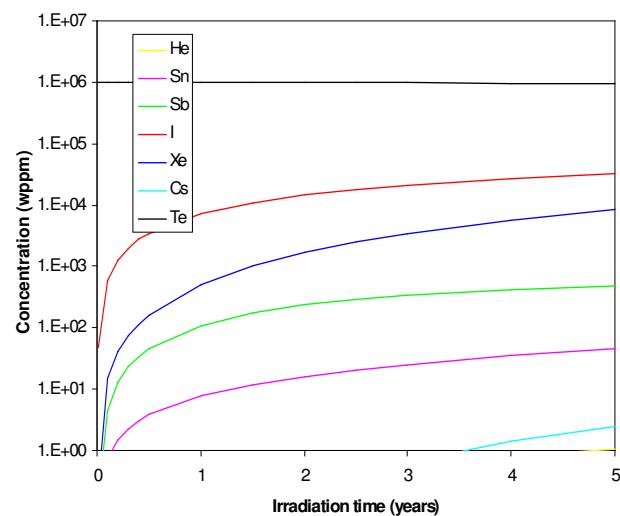
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Iodine

## General properties

		53	Isotopes	Isotopic abundances / %	
				100.0	
Atomic number					
Crustal abundance / wppm	0.45				
Melting point / K	386.9				
Boiling point / K	457.6				
Density / kgm <sup>-3</sup>	4930				
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	0.449				
Electrical resistivity /Ωm	1.37 10 <sup>7</sup>				
Coefficient of thermal expansion / K <sup>-1</sup>	9.3 10 <sup>-5</sup>				
Crystal structure	Orthorhombic				
Number of stable isotopes	1				
Mean atomic weight	126.90447				

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.18E16	1.03E16	1.13E15	5.16E12	2.00E7	1.42E6	kW kg <sup>-1</sup>	1.47E0	1.28E0	7.21E-2	1.50E-4	4.22E-11	1.80E-11
I128	87.63	86.86					I128	93.73	93.18				
Xe127	5.10	5.85	49.83	11.22			I126	3.21	3.69	53.81			
I126	4.30	4.93	37.02				Xe127	2.06	2.37	39.15	19.33		
Xe129m	1.00	1.15	7.90				Xe129m	0.31	0.35	4.68			
Xe127m	0.93	0.05					Te127	0.15	0.17	1.10	52.62		
Te127	0.51	0.58	1.91	41.73			Te127m	0.02	0.03	0.46	21.97		
Te127m	0.19	0.22	1.94	42.61			Te125m	0.02	0.02	0.32	2.16		
Te125m	0.09	0.10	0.89	2.71			Sb124	0.01	0.02	0.27	1.98		
I125	0.03	0.03	0.28	0.90			Sb125				1.44		
H3				0.09	89.57		I129					42.41	99.00
I129					7.14	99.92	H3					38.83	
Sn121m					1.84		Sn121					12.52	
Sn121					1.43		Sn121m					5.66	
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	2.10E5	1.88E5	4.38E4	1.88E1	3.19E-7	2.54E-7	Sv kg <sup>-1</sup>	1.75E7	1.74E7	1.42E7	8.16E3	1.58E-1	1.57E-1
I128	74.76	72.05					I126	84.15	84.46	85.27			
I126	19.37	21.60	76.31				Xe127	11.02	11.07	12.67	22.73		
Xe127	5.12	5.71	22.87	54.92			I128	2.72	2.36				
Sb124	0.14	0.16	0.65	23.56			Xe129m	1.36	1.36	1.26			
Te127	0.02	0.03	0.04	9.45*			Te127m	0.30	0.30	0.36	62.03		
Sb126m	0.01	0.01			57.24	54.03	I125	0.27	0.27	0.33	8.54		
Sb126			0.01		14.28	13.48	Te127	0.06	0.06	0.03	4.49		
Sb125			0.01	11.02			Te125m	0.05	0.05	0.06	1.49		
I129					25.94	32.45	I129					99.39	99.99
Sn121m					2.04		H3					0.48	
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	2.80E7	2.80E7	2.52E7	4.40E4	5.79E-2	5.12E-2		2.11E12	1.87E12	3.61E11	3.15E8	6.11E1	4.83E1
Xe127	77.57	77.65	80.28	47.46			I128	79.05	77.34				
I126	17.79	17.80	16.24				I126	10.92	12.36	52.66			
Xe129m	2.80	2.80	2.33				Xe127	8.15	9.23	44.56	52.62		
Te127m	0.79	0.79	0.85	49.05			Xe129m	0.40	0.45	1.77			
I128	0.74	0.64					Sb124	0.09	0.10	0.49	8.79		
Te125m	0.16	0.16	0.17	1.34			Te127	0.08	0.09	0.16	18.51		
I125	0.06	0.06	0.06	0.54			Te125m	0.02	0.03	0.13	2.12		
Te127	0.03	0.03	0.01	0.69			Te127m	0.02	0.02	0.12	13.71		
Te129m	0.03	0.03	0.03	0.01			Sb125				3.51		
Sb124	0.02	0.02	0.02	0.16			I129					77.95	98.26
Sb125				0.69			H3					9.77	
I129					88.94	99.98	Sn121					5.38	
H3					8.05		Sn121m					5.03	
Sn121m					2.87		Sb126m					1.43	1.36

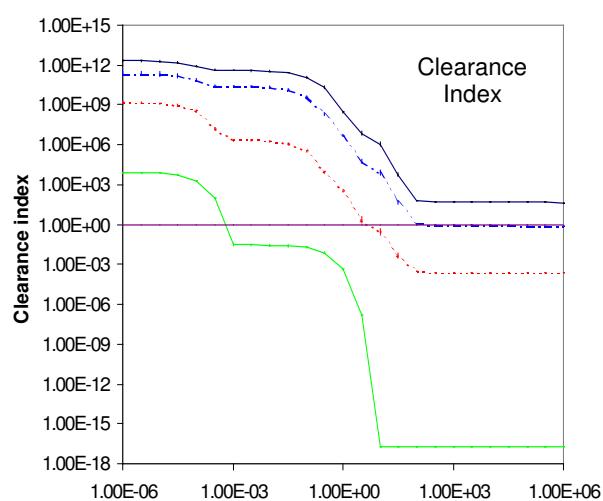
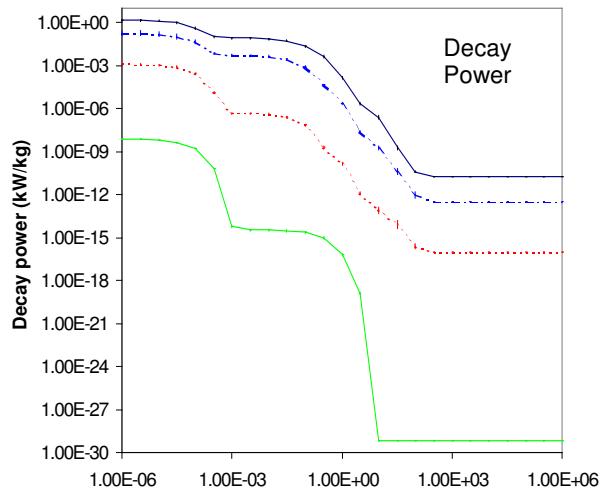
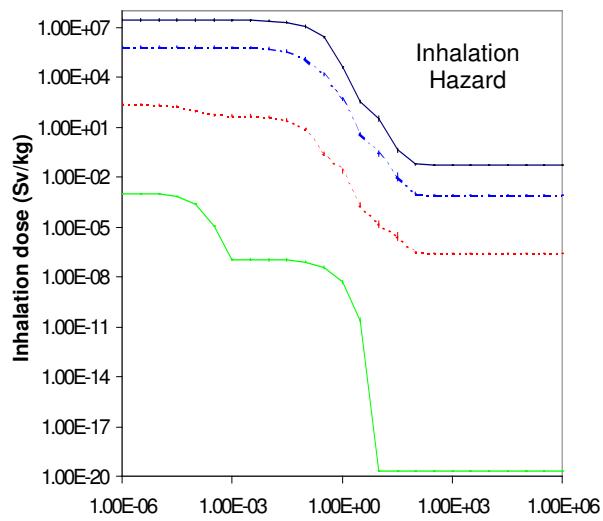
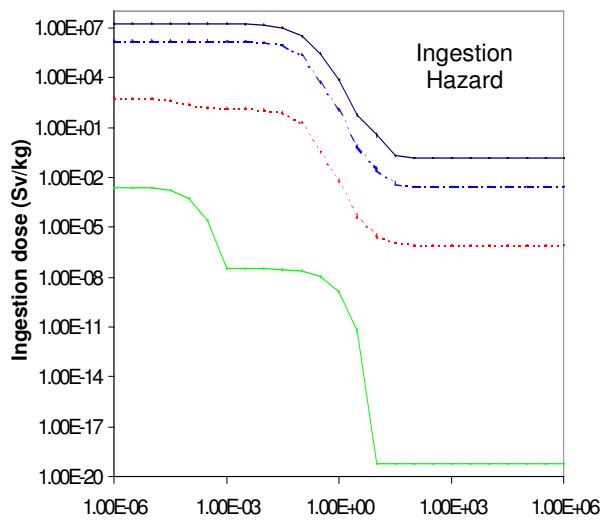
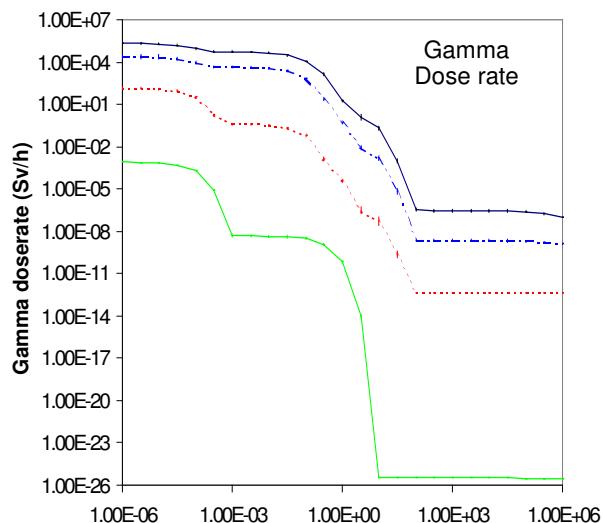
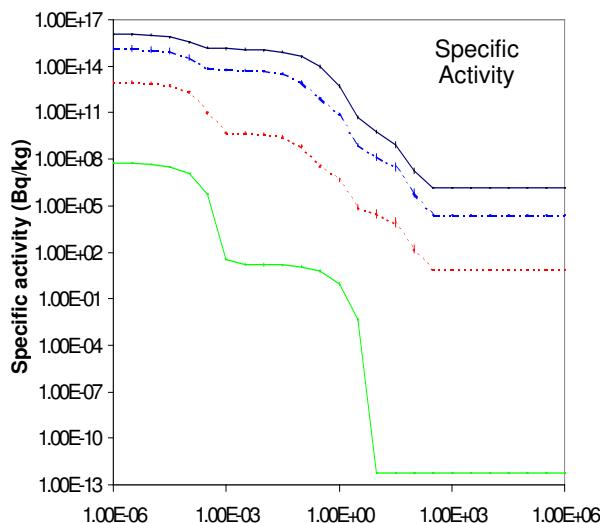
# Iodine

# Pathway analysis

Te129m	33.8 d	I127(n, $\gamma$ )I128( $\beta^+$ )Te128(n, $\gamma$ )Te129m	100.0	100.0	100.0	99.4
I125	59.43 d	&I127(n,2n)I126( $\beta^-$ )Xe126(n,2n)Xe125( $\beta^+$ )I125 I127(n,2n)I126(n,2n)I125				97.0 2.7
Sb124	60.24 d	I127(n, $\alpha$ )Sb124 I127(n, $\alpha$ )Sb124m(IT)Sb124 I127(n, $\alpha$ )Sb124n(IT)Sb124m(IT)Sb124 &I127(n,2n)I126( $\beta^+$ )Te126(n,2n)Te125(n,d)Sb124	40.0 30.0 30.0	40.0 30.0 30.0	40.0 30.0 30.0	50.4 41.0 4.7 1.1
Te127m	109 d	&I127(n, $\gamma$ )I128( $\beta^-$ )Xe128(n, $\gamma$ )Xe129(n, $\gamma$ )Xe130(n, $\alpha$ ) Te127m &I127(n, $\gamma$ )I128( $\beta^-$ )Xe128(n, $\alpha$ )Te125(n, $\gamma$ )Te126(n, $\gamma$ ) Te127m I127(n, $\gamma$ )I128( $\beta^-$ )Xe128(n, $\alpha$ )Te125m(n, $\gamma$ )Te126(n, $\gamma$ )Te127m I127(n,p)Te127m I127(n,2n)I126( $\beta^+$ )Te126(n, $\gamma$ )Te127m	96.7 0.6 2.6	60.4 30.8 100.0		98.3 1.4
Cs134	2.065 y	&I127(n, $\gamma$ )I128( $\beta^-$ )Xe128(n, $\gamma$ )Xe129(n, $\gamma$ )Xe130(n, $\gamma$ ) Xe131(n, $\gamma$ )Xe132(n, $\gamma$ )Xe133( $\beta^-$ )Cs133(n, $\gamma$ )Cs134	98.3	97.8	98.1	
Sb125	2.759 y	&I127(n, $\alpha$ )Sb124(n, $\gamma$ )Sb125 I127(n, $\gamma$ )I128( $\beta^+$ )Te128(n, $\alpha$ )Sn125m( $\beta^-$ )Sb125 I127(n, $\gamma$ )I128( $\beta^+$ )Te128(n, $\alpha$ )Sn125( $\beta^-$ )Sb125 I127(n,2n)I126( $\beta^+$ )Te126(n,d)Sb125 &I127(n,2n)I126( $\beta^+$ )Te126(n,2n)Te125(n,p)Sb125 &I127(n,2n)I126( $\beta^-$ )Xe126(n,2n)Xe125( $\beta^+$ )I125( $\beta^+$ ) Te125(n,p)Sb125 I127(n,2n)I126( $\beta^+$ )Te126(n,2n)Te125m(n,p)Sb125 I127(n,d)Te126(n,d)Sb125 I127(n,h)Sb125 I127(n,2n)I126(n,2n)I125( $\beta^+$ )Te125(n,p)Sb125	100.0 38.8 35.1	26.1 51.6 46.4		58.8 18.6 13.2 2.7 2.2 2.2 1.0
H3	12.33 y	I127(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 &I127(n, $\gamma$ )I128( $\beta^-$ )Xe128(n, $\gamma$ )Xe129(n,X)H1(n, $\gamma$ ) H2(n, $\gamma$ )H3 I127(n,X)H3 I127(n,2n)I126( $\beta^-$ )Xe126(n,X)H3 I127(n,2n)I126( $\beta^+$ )Te126(n,X)H3 &I127(n,2n)I126( $\beta^+$ )Te126(n,2n)Te125(n,X)H3 I127(n,2n)I126( $\beta^-$ )Xe126(n,2n)Xe125( $\beta^+$ )I125(n,X)H3	92.7 0.6	94.7	99.3	85.6 5.8 3.1 1.8 0.9
Cs137	30.171 y	&I127(n, $\gamma$ )I128( $\beta^-$ )Xe128(n, $\gamma$ )Xe129(n, $\gamma$ )Xe130(n, $\gamma$ ) Xe131(n, $\gamma$ )Xe132(n, $\gamma$ )Xe133( $\beta^-$ )Cs133(n, $\gamma$ )Cs134(n, $\gamma$ ) Cs135(n, $\gamma$ )Cs136(n, $\gamma$ )Cs137 &I127(n, $\gamma$ )I128( $\beta^-$ )Xe128(n, $\gamma$ )Xe129(n, $\gamma$ )Xe130(n, $\gamma$ ) Xe131(n, $\gamma$ )Xe132(n, $\gamma$ )Xe133(n, $\gamma$ )Xe134(n, $\gamma$ ) Xe135(n, $\gamma$ )Xe136(n, $\gamma$ )Xe137( $\beta^-$ )Cs137	93.9 3.8	97.4	97.7	
Sn121m	55.0 y	&I127(n, $\alpha$ )Sb124( $\beta^-$ )Te124(n, $\alpha$ )Sn121m &I127(n, $\alpha$ )Sb124m( $\beta^-$ )Te124(n, $\alpha$ )Sn121m &I127(n, $\alpha$ )Sb124(n, $\alpha$ )In121( $\beta^-$ )Sn121m &I127(n,2n)I126( $\beta^+$ )Te126(n,2n)Te125(n,2n)Te124(n, $\alpha$ )Sn121m &I127(n,2n)I126( $\beta^+$ )Te126(n,2n)Te125(n, $\alpha$ )Sn122(n,2n)Sn121m &I127(n,2n)I126( $\beta^-$ )Xe126(n,2n)Xe125( $\beta^+$ )I125( $\beta^+$ ) Te125(n,2n)Te124(n, $\alpha$ )Sn121m &I127(n,2n)I126( $\beta^-$ )Xe126(n,2n)Xe125( $\beta^+$ )I125( $\beta^+$ ) Te125(n, $\alpha$ )Sn122(n,2n)Sn121m I127(n,2n)I126( $\beta^+$ )Te126(n, $\alpha$ )Sn123(n,2n)Sn122(n,2n)Sn121m I127(n,2n)I126( $\beta^+$ )Te126(n,2n)Te125m(n,2n)Te124(n, $\alpha$ )Sn121m &I127(n,2n)I126( $\beta^+$ )Te126(n,2n)Te125(n, $\alpha$ )Sn121m I127(n,2n)I126( $\beta^+$ )Te126(n,2n)Te125m(n, $\alpha$ )Sn122(n,2n)Sn121m &I127(n,2n)I126( $\beta^-$ )Xe126(n,2n)Xe125( $\beta^+$ )I125(n,2n) I124( $\beta^+$ )Te124(n, $\alpha$ )Sn121m I127(n,2n)I126( $\beta^+$ )Te126(n, $\alpha$ )Sn122(n,2n)Sn121m &I127(n,2n)I126( $\beta^-$ )Xe126(n,2n)Xe125( $\beta^+$ )I125( $\beta^+$ ) Te125(n, $\alpha$ )Sn121m I127(n,2n)I126(n,2n)I125( $\beta^+$ )Te125(n,2n)Te124(n, $\alpha$ )Sn121m I127(n,2n)I126(n,2n)I125( $\beta^+$ )Te125(n, $\alpha$ )Sn122(n,2n)Sn121m	81.6 18.4 0.5 21.4 17.0 14.9 11.8 3.4 2.9 2.5 2.4 2.4 2.3 1.7 1.6 1.3	81.7 17.6 0.5 69.1 5.6 25.3 8.1 17.6 0.5 69.1 21.4 17.0 14.9 11.8 3.4 2.9 2.5 2.4 2.4 2.3 1.7 1.6 1.3		

Sn126	$2.4 \cdot 10^5$ y	I127(n, $\gamma$ )I128( $\beta^+$ )Te128(n, $\gamma$ )Te129m(n, $\alpha$ )Sn126 <b>&amp;I127(n,<math>\gamma</math>)I128(<math>\beta^+</math>)Te128(n,<math>\gamma</math>)Te129(n,<math>\alpha</math>)Sn126</b> I127(n, $\gamma$ )I128( $\beta^+$ )Te128(n, $\alpha$ )Sn125(n, $\gamma$ )Sn126 <b>&amp;I127(n,2n)I126(<math>\beta^+</math>)Te126(n,p)Sb126(n,p)Sn126</b> I127(n, $\gamma$ )I128( $\beta^+$ )Te128(n,h)Sn126 <b>&amp;I127(n,d)Te126(n,p)Sb126(n,p)Sn126</b>	98.0 1.9	17.0 0.3 82.7	0.1 99.9	88.1 8.5 3.2
Cs135	$2.4 \cdot 10^6$ y	<b>&amp;I127(n,<math>\gamma</math>)I128(<math>\beta^-</math>)Xe128(n,<math>\gamma</math>)Xe129(n,<math>\gamma</math>)Xe130(n,<math>\gamma</math>)</b> Xe131(n, $\gamma$ )Xe132(n, $\gamma$ )Xe133( $\beta^-$ )Cs133(n, $\gamma$ )Cs134(n, $\gamma$ ) Cs135	98.1	97.7	97.9	
I129	$1.6 \cdot 10^7$ y	<b>&amp;I127(n,<math>\gamma</math>)I128(<math>\beta^+</math>)Te128(n,<math>\gamma</math>)Te129(<math>\beta^-</math>)I129</b> I127(n, $\gamma$ )I128(n, $\gamma$ )I129 I127(n, $\gamma$ )I128( $\beta^+$ )Te128(n, $\gamma$ )Te129m( $\beta^-$ )I129	94.9 2.9 2.2	97.1 0.7 2.2	96.6 1.2 2.2	86.1 13.1
Te123	$1.0 \cdot 10^{13}$ y	<b>&amp;I127(n,<math>\alpha</math>)Sb124(n,<math>\alpha</math>)In121(<math>\beta^-</math>)Sn121(<math>\beta^-</math>)Sb121(n,<math>\gamma</math>)</b> Sb122( $\beta^-$ )Te122(n, $\gamma$ )Te123 <b>&amp;I127(n,<math>\alpha</math>)Sb124(n,<math>\alpha</math>)In121m(<math>\beta^-</math>)Sn121(<math>\beta^-</math>)</b> Sb121(n, $\gamma$ )Sb122( $\beta^-$ )Te122(n, $\gamma$ )Te123 <b>&amp;I127(n,<math>\alpha</math>)Sb124(<math>\beta^-</math>)Te124(n,<math>\alpha</math>)Sn121(<math>\beta^-</math>)Sb121(n,<math>\gamma</math>)</b> Sb122( $\beta^-$ )Te122(n, $\gamma$ )Te123 <b>&amp;I127(n,2n)I126(<math>\beta^+</math>)Te126(n,2n)Te125(n,2n)</b> Te124(n,2n)Te123 <b>&amp;I127(n,2n)I126(<math>\beta^-</math>)Xe126(n,2n)Xe125(<math>\beta^+</math>)I125(<math>\beta^+</math>)</b> Te125(n,2n)Te124(n,2n)Te123 <b>&amp;I127(n,<math>\alpha</math>)Sb124(<math>\beta^-</math>)Te124(n,2n)Te123</b> I127(n,2n)I126( $\beta^+$ )Te126(n,2n)Te125m(n,2n) Te124(n,2n)Te123 <b>&amp;I127(n,2n)I126(<math>\beta^-</math>)Xe126(n,<math>\alpha</math>)Te123</b> <b>&amp;I127(n,2n)I126(n,2n)I125(<math>\beta^+</math>)Te125(n,2n)Te124(n,2n)Te123</b>   <b>&amp;I127(n,<math>\alpha</math>)Sb124m(<math>\beta^-</math>)Te124(n,2n)Te123</b>   <b>&amp;I127(n,d)Te126(n,2n)Te125(n,2n)Te124(n,2n)Te123</b>			74.4 25.5 1.1 36.6 25.4 15.3 5.1 4.4 2.9 2.7 1.4	

# Iodine activation characteristics

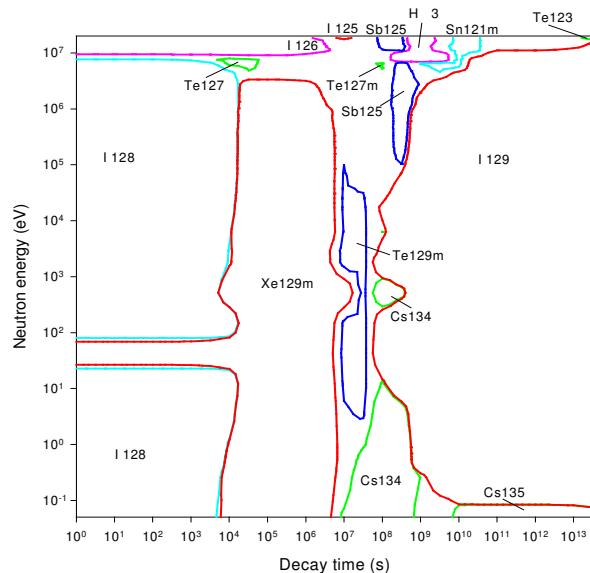


Decay time (years)

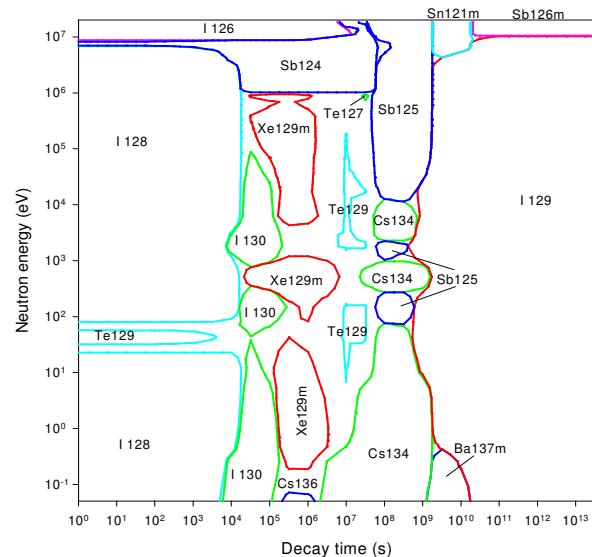
Decay time (years)

# Iodine importance diagrams & transmutation

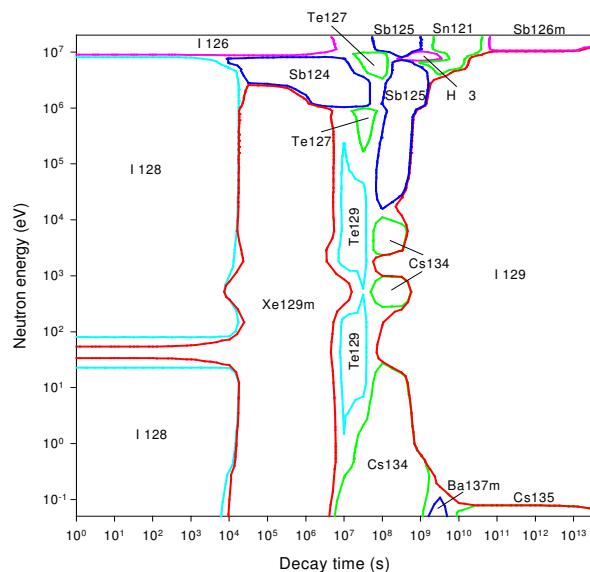
## Activity



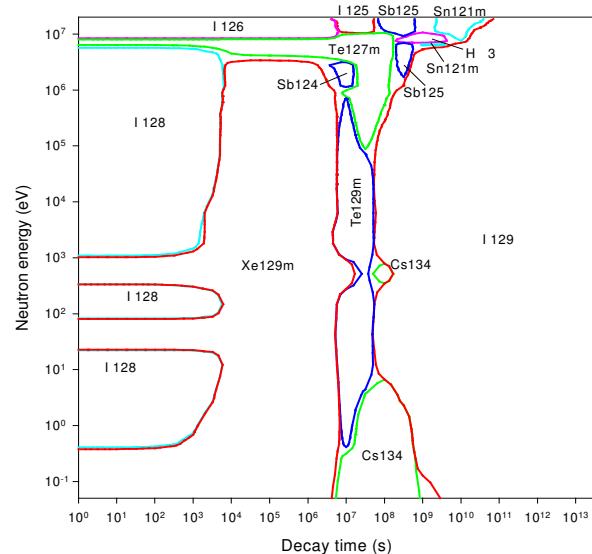
## Dose rate



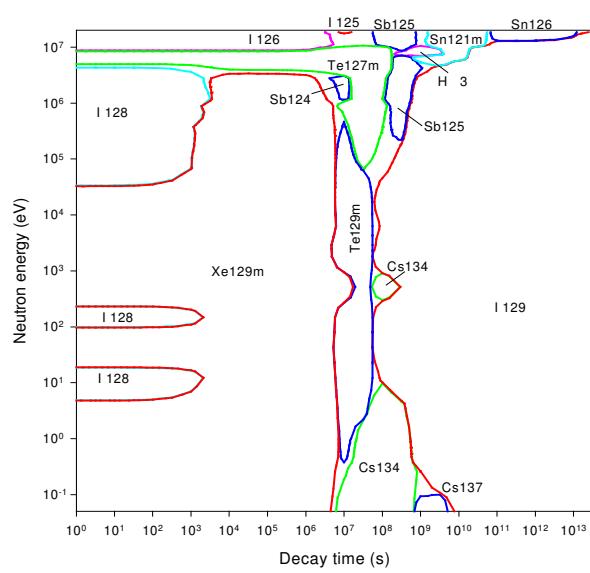
## Heat output



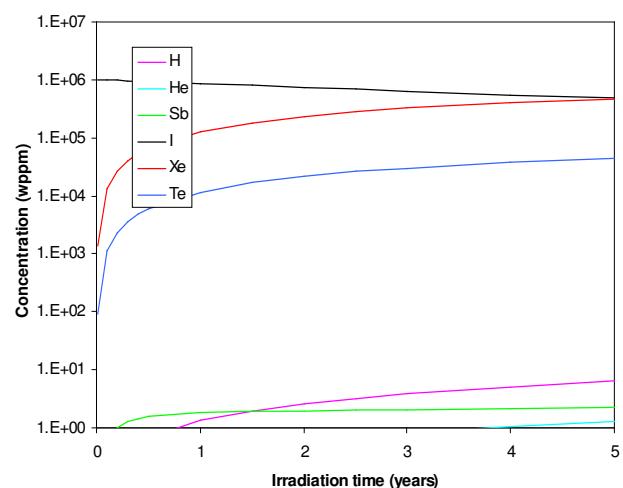
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Xenon

## General properties

	54	Isotopes	Isotopic abundances / %
Atomic number	3.0 10 <sup>-5</sup>	Xe124	0.095
Crustal abundance / wppm	161.4	Xe126	0.089
Melting point / K	165	Xe128	1.910
Boiling point / K	5.887	Xe129	26.400
Density / kgm <sup>-3</sup>	5.69 10 <sup>-3</sup>	Xe130	4.071
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	-	Xe131	21.232
Electrical resistivity /Ωm	-	Xe132	26.909
Coefficient of thermal expansion / K <sup>-1</sup>	FCC	Xe134	10.436
Crystal structure	9	Xe135	8.857
Number of stable isotopes	131.293		
Mean atomic weight			

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.22E15	1.17E15	7.37E14	5.91E13	2.48E10	1.36E8	kW kg <sup>-1</sup>	9.04E-2	7.82E-2	5.19E-2	1.62E-2	1.65E-6	1.46E-9
Xe131m	28.69	30.01	38.41				Cs134	25.00	28.88	43.40	99.85		
Xe133	22.78	23.83	25.27				Cs136	12.99	15.00	18.63			
Xe129m	10.49	10.97	13.06				Xe134m	11.35					
Xe135	8.89	9.26	0.02				Xe135	10.88	12.51	0.02			
Cs134	6.72	7.03	11.10	99.32			Xe131m	10.18	11.75	14.32			
Xe133m	5.47	5.72	2.85				Xe133	8.97	10.36	10.46			
Xe135m	3.76	3.12					Xe129m	5.36	6.19	7.01			
Xe127	3.02	3.16	4.67	0.06			Xe135m	4.29	3.93				
Xe134m	2.67						I128	2.78	2.78				
Cs136	2.62	2.74	3.58				Xe133m	2.76	3.19	1.52			
I128	1.55	1.40					Xe127	2.05	2.36	3.33	0.01		
Cs134m	1.33	1.36					Cs132	0.74	0.85	0.87			
Cs137			0.02	0.21	50.76		Ba137m			0.02	0.08	76.54	
Ba137m			0.02	0.20	48.02		Cs137			0.01	0.02	22.82	
Cs135					0.56	99.92	Cs135					0.09	99.90
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	7.14E4	5.52E4	4.53E4	2.09E4	1.62E0	6.88E-9	Sv kg <sup>-1</sup>	3.15E6	3.15E6	2.70E6	1.12E6	1.64E2	2.84E-1
Cs134	40.83	52.78	64.06	99.91			Cs134	49.45	49.47	57.58	99.82		
Cs136	25.15	32.51	32.60				Xe131m	16.66	16.67	15.73			
Xe134m	21.39						Xe133	11.47	11.47	8.97			
Xe135m	4.84	4.95					Xe129m	8.12	8.12	7.13			
Xe135	2.94	3.79	0.01				Xe127	3.74	3.74	4.08	0.01		
Cs132	1.26	1.63	1.35				Xe133m	3.18	3.18	1.17			
Xe127	0.91	1.17	1.33				Cs136	3.05	3.05	2.93			
I132	0.64	0.81					I126	1.85	1.85	1.78			
I130	0.48	0.62	0.01				Xe135	1.69	1.68	0.00			
Ba137m		0.03	0.04	0.08	99.71		Cs137	0.05	0.05	0.06	0.14	99.69	
I129						98.14	Cs135					0.17	95.58
Sb126m						1.49	I129					0.01	4.42
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	7.18E6	7.18E6	5.96E6	1.18E6	4.94E2	1.17E0		5.24E11	4.56E11	3.73E11	1.96E11	4.90E7	9.09E2
Xe131m	29.76	29.76	28.97				Cs134	52.23	60.05	73.06	99.74		
Cs134	22.86	22.86	27.45	99.40			Cs136	13.29	15.27	15.36			
Xe127	18.47	18.47	20.76	0.11			Xe134m	11.73					
Xe129m	11.77	11.77	10.66				Xe135	5.76	6.59	0.01			
Xe133	11.62	11.62	9.37				Xe135m	3.81	3.47				
Xe133m	2.70	2.70	1.02				Xe133	3.12	3.59	2.93			
Cs136	1.25	1.25	1.24				Xe131m	2.39	2.75	2.71			
Xe135	1.01	1.01	0.00				Xe127	2.01	2.31	2.63	0.01		
I126	0.27	0.27	0.27				Xe129m	1.75	2.01	1.84			
Cs137	0.07	0.07	0.08	0.40	99.50		Cs132	0.78	0.89	0.74			
Ba133	0.01	0.01	0.02	0.07	0.25		Cs137		0.09	0.11	0.21	85.60	
Cs135					0.24	99.65	Ba137m			0.02	0.04	14.29	
I129						0.35	Cs135					99.58	

# Xenon

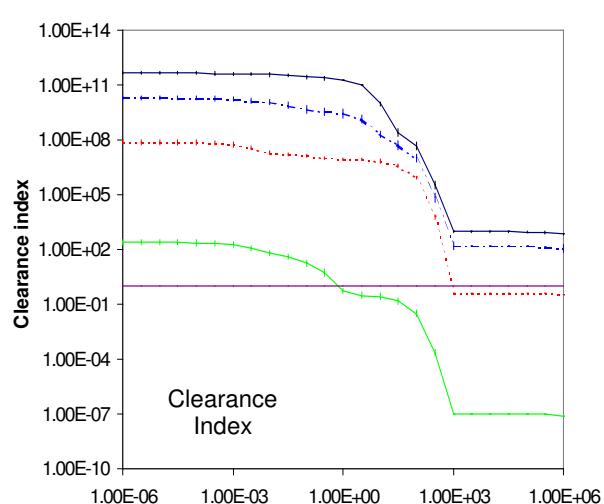
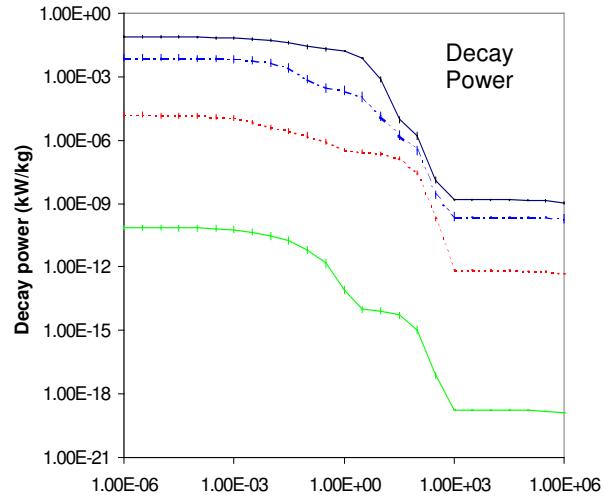
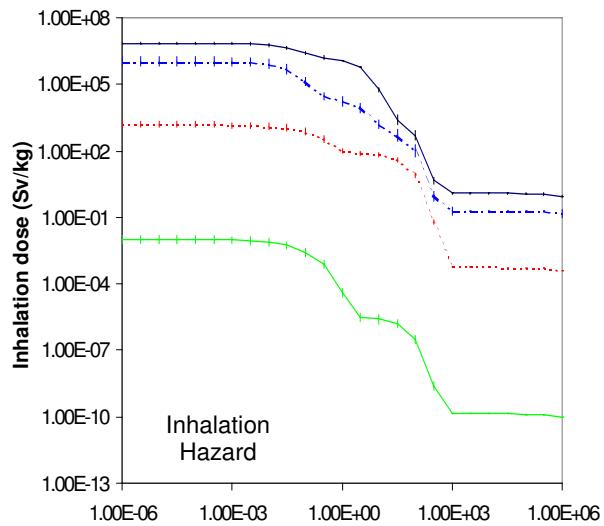
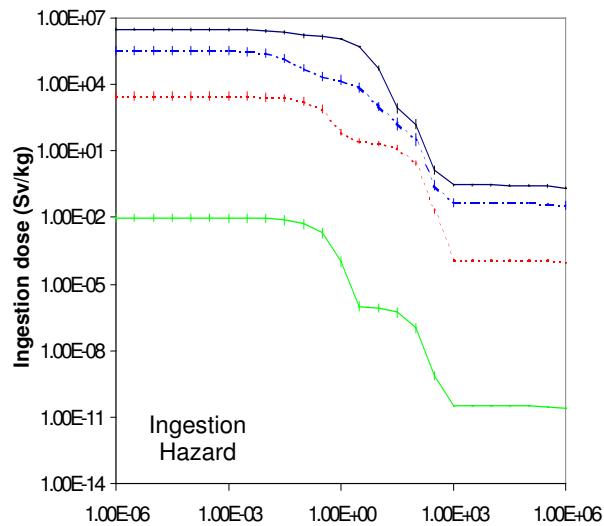
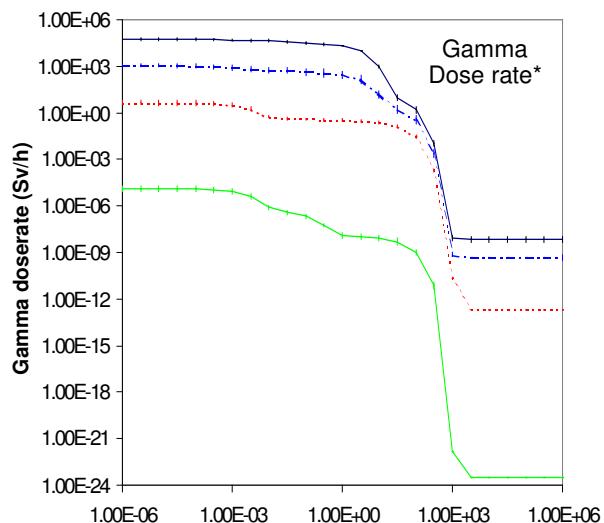
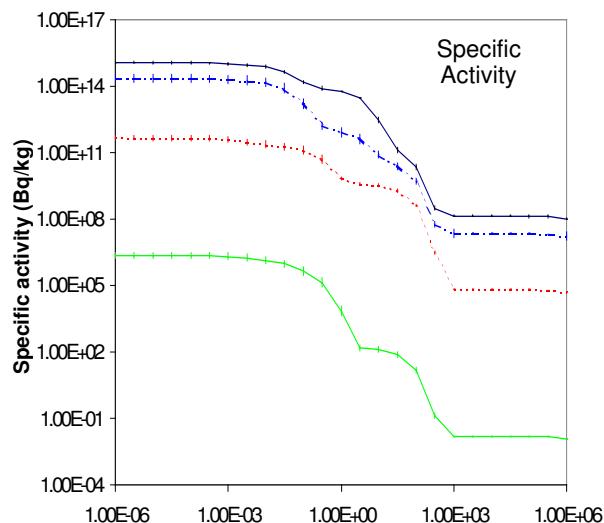
## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Xe134m	0.29 s	<b>&amp;Xe132(n,<math>\gamma</math>)Xe133(n,<math>\gamma</math>)Xe134m</b> <b>&amp;Xe131(n,<math>\gamma</math>)Xe132(n,<math>\gamma</math>)Xe133(n,<math>\gamma</math>)Xe134m</b> <b>&amp;Xe129(n,<math>\gamma</math>)Xe130(n,<math>\gamma</math>)Xe131(n,<math>\gamma</math>)Xe132(n,<math>\gamma</math>)Xe133(n,<math>\gamma</math>)Xe134m</b> <b>Xe132(n,<math>\gamma</math>)Xe134m</b> <b>Xe132(n,<math>\gamma</math>)Xe133m(n,<math>\gamma</math>)Xe134m</b> <b>&amp;Xe130(n,<math>\gamma</math>)Xe131(n,<math>\gamma</math>)Xe132(n,<math>\gamma</math>)Xe133(n,<math>\gamma</math>)Xe134m</b> <b>Xe131(n,<math>\gamma</math>)Xe132(n,<math>\gamma</math>)Xe133m(n,<math>\gamma</math>)Xe134m</b> <b>Xe134(n,n')Xe134m</b>	48.7 38.5 6.0  2.3 2.2 1.8	17.3 0.2  81.5  0.9	92.6 2.9  4.3  0.1	99.8
Ba137m	2.553 m	<b>Xe136(n,<math>\gamma</math>)Xe137(<math>\beta^-</math>)Cs137(<math>\beta^-</math>)Ba137m</b> <b>Xe134(n,<math>\gamma</math>)Xe135(n,<math>\gamma</math>)Xe136(n,<math>\gamma</math>)Xe137(<math>\beta^-</math>)Cs137(<math>\beta^-</math>)Ba137m</b> <b>Xe132(n,<math>\gamma</math>)Xe133(<math>\beta^-</math>)Cs133(n,<math>\gamma</math>)Cs134(n,<math>\gamma</math>)Cs135(n,<math>\gamma</math>)Cs136(<math>\beta^-</math>)Ba136(n,<math>\gamma</math>)Ba137m</b>	98.5 1.0  0.2	99.1 0.6	100.0	98.7
Sb126m	19.1 m	<b>&amp;Xe124(n,<math>\gamma</math>)Xe125(<math>\beta^+</math>)I125(<math>\beta^+</math>)Te125(n,p)Sb125(n,<math>\gamma</math>)Sb126m</b> <b>&amp;Xe124(n,<math>\gamma</math>)Xe125(<math>\beta^+</math>)I125(n,<math>\gamma</math>)I126(n,<math>\gamma</math>)I127(n,<math>\alpha</math>)Sb124(n,<math>\gamma</math>)Sb125(n,<math>\gamma</math>)Sb126m</b> <b>&amp;Xe126(n,<math>\gamma</math>)Xe127(<math>\beta^+</math>)I127(n,<math>\alpha</math>)Sb124(n,<math>\gamma</math>)Sb125(n,<math>\gamma</math>)Sb126m</b> <b>&amp;Xe126(n,<math>\gamma</math>)Xe127(<math>\beta^+</math>)I127(n,<math>\gamma</math>)I128(<math>\beta^+</math>)Te128(n,<math>\alpha</math>)Sn125m(<math>\beta^-</math>)Sb125(n,<math>\gamma</math>)Sb126m</b> <b>&amp;Xe126(n,<math>\gamma</math>)Xe127(<math>\beta^+</math>)I127(n,<math>\gamma</math>)I128(<math>\beta^+</math>)Te128(n,<math>\alpha</math>)Sn125(<math>\beta^-</math>)Sb125(n,<math>\gamma</math>)Sb126m</b> <b>&amp;Xe126(n,<math>\gamma</math>)Xe127(<math>\beta^+</math>)I127(n,2n)I126(<math>\beta^+</math>)Te126(n,p)Sb126m</b> <b>&amp;Xe129(n,2n)Xe128(n,2n)Xe127(<math>\beta^+</math>)I127(n,2n)I126(<math>\beta^+</math>)Te126(n,p)Sb126m</b> <b>&amp;Xe129(n,<math>\alpha</math>)Te126(n,p)Sb126m</b> <b>&amp;Xe129(n,p)I129(n,<math>\alpha</math>)Sb126m</b> <b>&amp;Xe129(n,2n)Xe128(n,2n)Xe127(<math>\beta^+</math>)I127(n,d)Te126(n,p)Sb126m</b> <b>&amp;Xe128(n,2n)Xe127(<math>\beta^+</math>)I127(n,d)Te126(n,p)Sb126m</b>	74.8 21.8 2.7  18.5 16.6	32.7 32.0 0.8  11.8 11.3	70.6  44.3  33.7 10.8 4.0 1.6  1.2	
Xe135	9.09 h	<b>&amp;Xe134(n,<math>\gamma</math>)Xe135</b> <b>&amp;Xe136(n,2n)Xe135</b>	99.2	100.0	100.0	100.0
Xe133	5.243 d	<b>&amp;Xe132(n,<math>\gamma</math>)Xe133</b> <b>&amp;Xe131(n,<math>\gamma</math>)Xe132(n,<math>\gamma</math>)Xe133</b> <b>&amp;Xe129(n,<math>\gamma</math>)Xe130(n,<math>\gamma</math>)Xe131(n,<math>\gamma</math>)Xe132(n,<math>\gamma</math>)Xe133</b> <b>&amp;Xe130(n,<math>\gamma</math>)Xe131(n,<math>\gamma</math>)Xe132(n,<math>\gamma</math>)Xe133</b> <b>&amp;Xe134(n,2n)Xe133</b>	51.0 40.3 6.2 2.3	98.9 1.1 3.1	96.9  99.5	0.2
Xe129m	8.87 d	<b>Xe128(n,<math>\gamma</math>)Xe129m</b> <b>&amp;Xe124(n,<math>\gamma</math>)Xe125(<math>\beta^+</math>)I125(n,<math>\gamma</math>)I126(n,<math>\gamma</math>)I127(n,<math>\gamma</math>)I128(<math>\beta^-</math>)Xe128(n,<math>\gamma</math>)Xe129m</b> <b>Xe131(n,2n)Xe130(n,2n)Xe129m</b> <b>Xe130(n,2n)Xe129m</b> <b>Xe129(n,n')Xe129m</b> <b>&amp;Xe132(n,2n)Xe131(n,2n)Xe130(n,2n)Xe129m</b>	98.4 1.1	100.0	100.0	39.6 25.8 25.6 6.5
Cs136	13.03 d	<b>&amp;Xe132(n,<math>\gamma</math>)Xe133(<math>\beta^-</math>)Cs133(n,<math>\gamma</math>)Cs134(n,<math>\gamma</math>)Cs135(n,<math>\gamma</math>)Cs136</b> <b>&amp;Xe131(n,<math>\gamma</math>)Xe132(n,<math>\gamma</math>)Xe133(<math>\beta^-</math>)Cs133(n,<math>\gamma</math>)Cs134(n,<math>\gamma</math>)Cs135(n,<math>\gamma</math>)Cs136</b> <b>&amp;Xe129(n,<math>\gamma</math>)Xe130(n,<math>\gamma</math>)Xe131(n,<math>\gamma</math>)Xe132(n,<math>\gamma</math>)Xe133(<math>\beta^-</math>)Cs133(n,<math>\gamma</math>)Cs134(n,<math>\gamma</math>)Cs135(n,<math>\gamma</math>)Cs136</b> <b>&amp;Xe134(n,<math>\gamma</math>)Xe135(<math>\beta^-</math>)Cs135(n,<math>\gamma</math>)Cs136</b> <b>&amp;Xe136(n,<math>\gamma</math>)Xe137(<math>\beta^-</math>)Cs137(n,2n)Cs136</b> <b>&amp;Xe136(n,2n)Xe135(<math>\beta^-</math>)Cs135(n,<math>\gamma</math>)Cs136</b>	60.6 36.7 1.3	90.3 0.4  9.0		100.0 53.3 46.7



I129	$1.6 \cdot 10^7$ y	<b>&amp;Xe124(n,<math>\gamma</math>)Xe125(<math>\beta^+</math>)I125(n,<math>\gamma</math>)I126(n,<math>\gamma</math>)I127(n,<math>\gamma</math>)I128(<math>\beta^+</math>)Te128(n,<math>\gamma</math>)Te129(<math>\beta^-</math>)I129</b> <b>&amp;Xe126(n,<math>\gamma</math>)Xe127(<math>\beta^+</math>)I127(n,<math>\gamma</math>)I128(<math>\beta^+</math>)Te128(n,<math>\gamma</math>)Te129(<math>\beta^-</math>)I129</b> <b>&amp;Xe124(n,<math>\gamma</math>)Xe125(<math>\beta^+</math>)I125(n,<math>\gamma</math>)I126(<math>\beta^+</math>)Te126(n,<math>\gamma</math>)Te127m(n,<math>\gamma</math>)Te128(n,<math>\gamma</math>)Te129(<math>\beta^-</math>)I129</b> <b>&amp;Xe124(n,<math>\gamma</math>)Xe125(<math>\beta^+</math>)I125(n,<math>\gamma</math>)I126(n,<math>\gamma</math>)I127(n,<math>\gamma</math>)I128(n,<math>\gamma</math>)I129</b> <b>&amp;Xe124(n,<math>\gamma</math>)Xe125(<math>\beta^+</math>)I125(n,<math>\gamma</math>)I126(n,<math>\gamma</math>)I127(n,<math>\gamma</math>)I128(<math>\beta^+</math>)Te128(n,<math>\gamma</math>)Te129m(<math>\beta^-</math>)I129</b> <b>&amp;Xe124(n,<math>\gamma</math>)Xe125(<math>\beta^+</math>)I125(n,<math>\gamma</math>)I126(<math>\beta^+</math>)Te126(n,<math>\gamma</math>)Te127(n,<math>\gamma</math>)Te128(n,<math>\gamma</math>)Te129(<math>\beta^-</math>)I129</b> <b>&amp;Xe126(n,<math>\gamma</math>)Xe127(<math>\beta^+</math>)I127(n,<math>\gamma</math>)I128(<math>\beta^+</math>)Te128(n,<math>\gamma</math>)Te129m(<math>\beta^-</math>)I129</b> <b>&amp;Xe132(n,<math>\alpha</math>)Te129(<math>\beta^-</math>)I129</b> <b>&amp;Xe126(n,<math>\gamma</math>)Xe127(<math>\beta^+</math>)I127(n,<math>\gamma</math>)I128(n,<math>\gamma</math>)I129</b> Xe132(n, $\alpha$ )Te129m( $\beta^-$ )I129 Xe129(n,p)I129 Xe130(n,d)I129 Xe131(n,2n)Xe130(n,d)I129 Xe131(n,t)I129 <b>&amp;Xe130(n,2n)Xe129(n,p)I129</b> <b>&amp;Xe134(n,2n)Xe133(<math>\beta^-</math>)Cs133(n,n<math>\alpha</math>)I129</b> <b>&amp;Xe131(n,2n)Xe130(n,2n)Xe129(n,p)I129</b>	81.0	7.4	84.1	88.5	
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# Xenon activation characteristics

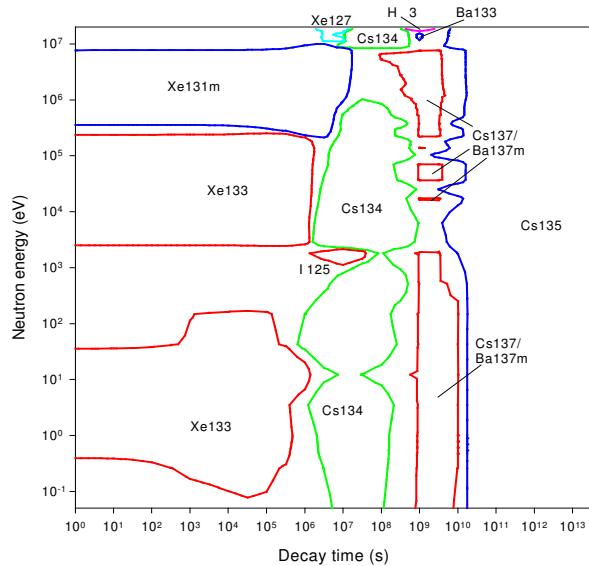


Decay time (years)

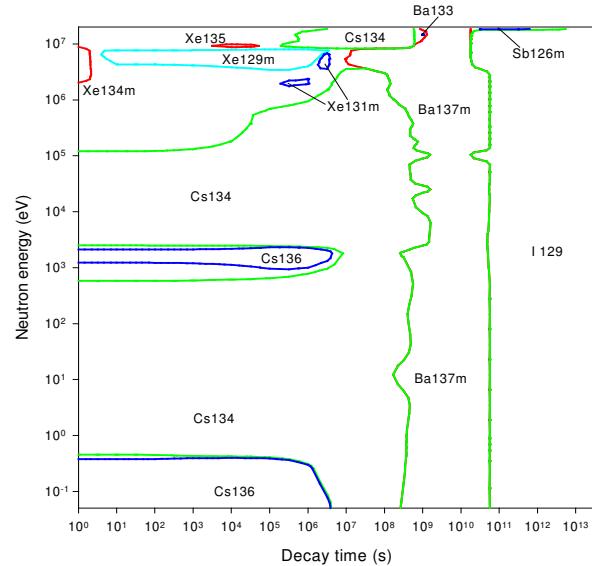
Decay time (years)

# Xenon importance diagrams & transmutation

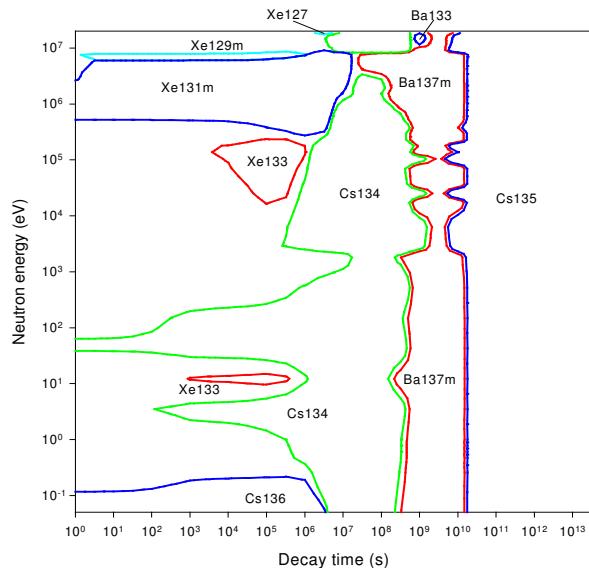
## Activity



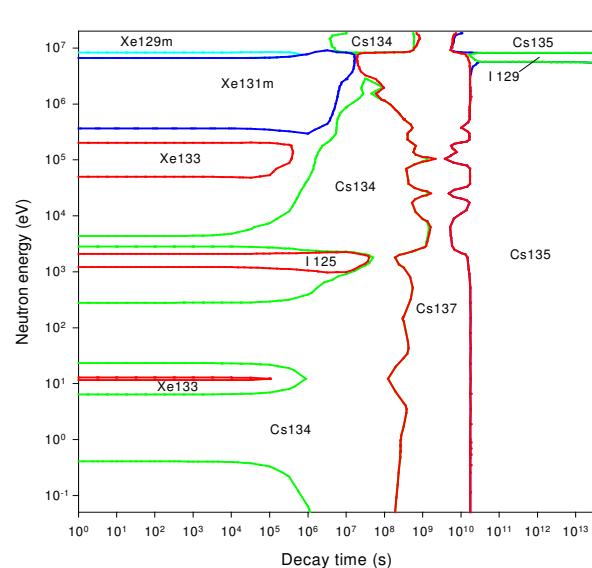
## Dose rate



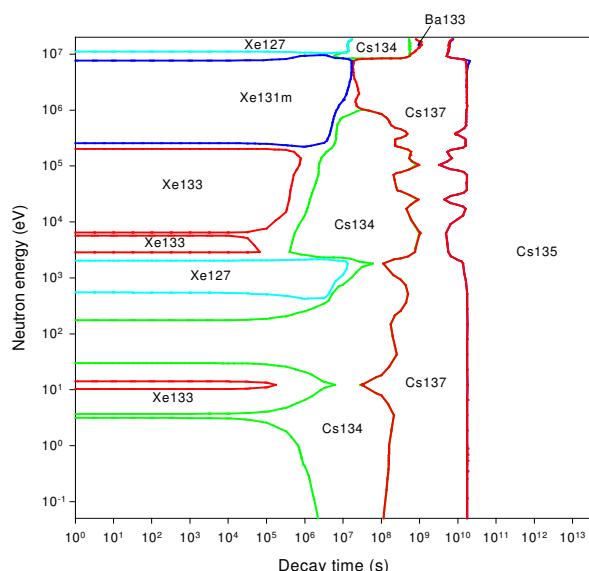
## Heat output



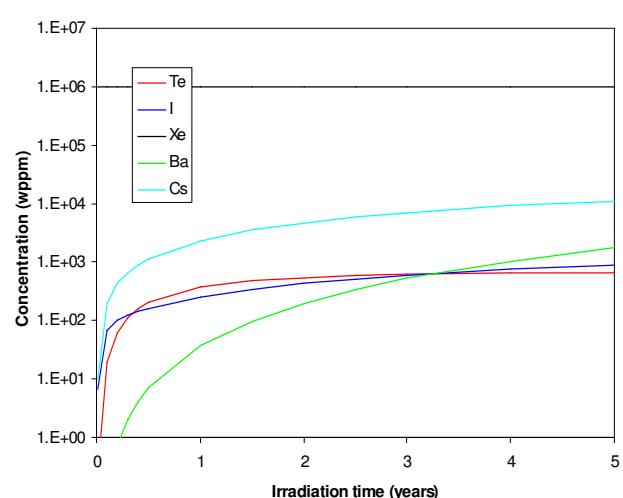
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Caesium

## General properties

		55	Isotopes	Isotopic abundances / %	
				Cs133	100.0
Atomic number					
Crustal abundance / wppm	3.0				
Melting point / K	301.6				
Boiling point / K	944				
Density / kgm <sup>-3</sup>	1873				
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	35.9				
Electrical resistivity /Ωm	2.0 10 <sup>-7</sup>				
Coefficient of thermal expansion / K <sup>-1</sup>	9.7 10 <sup>-5</sup>				
Crystal structure	BCC				
Number of stable isotopes	1				
Mean atomic weight	132.90543				

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.29E16	1.29E16	1.14E16	7.70E15	5.94E10	1.74E9	kW kg <sup>-1</sup>	3.19E0	3.19E0	3.10E0	2.11E0	4.17E-6	1.87E-8
Cs134	83.17	83.39	93.92	99.59			Cs134	92.56	92.64	94.88	99.89		
Cs134m	8.08	7.94					Cs136	4.72	4.72	4.00			
Cs136	3.18	3.19	2.97				Cs132	1.38	1.38	0.96			
Cs132	2.92	2.93	2.25				Cs134m	0.73	0.71				
Ba133m	1.17	1.17	0.27				Ba133m	0.22	0.22	0.05			
Ba135m	0.83	0.83	0.11				Ba135m	0.14	0.14	0.02			
Ba133	0.26	0.26	0.30	0.41	80.49		Ba133	0.08	0.08	0.08	0.11	83.85	
Cs137					8.46		Ba137m					12.09	
Ba137m					8.00		Cs137					3.60	
Cs135					3.02	99.99	Cs135					0.46	100.00
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	4.04E6	4.04E6	3.96E6	2.68E6	2.39E0	1.86E-8	Sv kg <sup>-1</sup>	2.06E8	2.06E8	2.04E8	1.46E8	1.41E2	3.50E0
Cs134	92.73	92.77	94.24	99.96			Cs134	99.19	99.19	99.39	99.97		
Cs136	5.62	5.62	4.72				Cs136	0.60	0.60	0.50			
Cs132	1.45	1.45	1.01				Ba133	0.02	0.02	0.03	0.03	50.99	
Ba133	0.03	0.03	0.03	0.04	73.43		Cs137					46.44	
Ba137m					26.56		Cs135					2.55	99.79
I129					100.00		I129					0.01	0.21
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	2.17E8	2.17E8	2.15E8	1.54E8	6.89E2	1.50E1		3.70E13	3.70E13	3.66E13	2.56E13	3.87E7	1.16E4
Cs134	99.12	99.12	99.31	99.79			Cs134	96.58	96.61	97.44	99.95		
Cs136	0.53	0.53	0.44				Cs136	2.41	2.41	2.01			
Ba133	0.16	0.16	0.16	0.21	69.34		Ba133	0.04	0.04	0.04	0.05	49.44	
Cs132	0.05	0.05	0.04				Cs137					43.30	
Cs137					28.42		Ba137m					7.23	
Cs135					2.24	99.99	Cs135					0.03	99.98

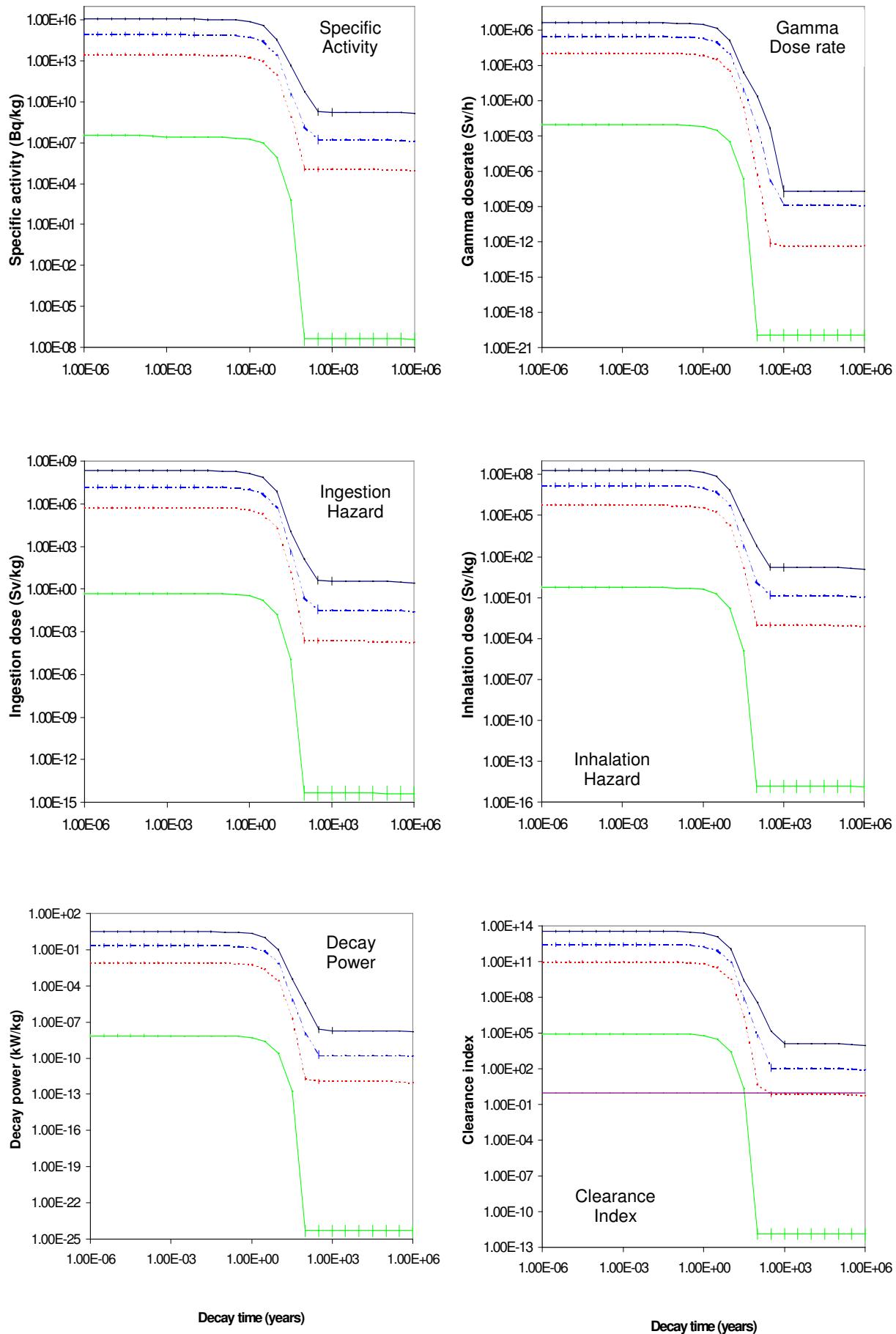
# Caesium

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Ba137m	2.553 m	&Cs133(n, $\gamma$ )Cs134(n, $\gamma$ )Cs135(n, $\gamma$ )Cs136( $\beta^-$ ) Ba136(n, $\gamma$ )Ba137m &Cs133(n, $\gamma$ )Cs134(n, $\gamma$ )Cs135(n, $\gamma$ )Cs136(n, $\gamma$ ) Cs137( $\beta^-$ )Ba137m &Cs133(n, $\gamma$ )Cs134(n, $\gamma$ )Cs135(n, $\gamma$ )Cs136m( $\beta^-$ ) Ba136(n, $\gamma$ )Ba137m &Cs133(n, $\gamma$ )Cs134( $\beta^-$ )Ba134(n, $\gamma$ )Ba135(n, $\gamma$ ) Ba136(n, $\gamma$ )Ba137m	85.5  13.2  0.7  0.6	0.3  99.6  0.5  19.1	63.5  16.9  3.8  31.5	62.7  0.2  3.8  31.5
Cs132	6.53 d	Cs133(n,2n)Cs132				99.7
Xe131m	11.87 d	&Cs133(n, $\alpha$ )I130( $\beta^-$ )Xe130(n, $\gamma$ )Xe131m Cs133(n, $\alpha$ )I130m( $\beta^-$ )Xe130(n, $\gamma$ )Xe131m &Cs133(n, $\gamma$ )Cs134(n, $\alpha$ )I131( $\beta^-$ )Xe131m &Cs133(n, $\gamma$ )Cs134( $\beta^-$ )Ba134(n, $\alpha$ )Xe131m Cs133(n,2n)Cs132( $\beta^+$ )Xe132(n,2n)Xe131m Cs133(n,d)Xe132(n,2n)Xe131m	90.4  8.2  1.4  99.7		100.0	96.9  1.2
Cs136	13.03 d	&Cs133(n, $\gamma$ )Cs134(n, $\gamma$ )Cs135(n, $\gamma$ )Cs136	99.9	99.9	99.9	99.3
Cs134	2.065 y	&Cs133(n, $\gamma$ )Cs134	100.0	100.0	100.0	99.9
Ba133	10.574 y	&Cs133(n, $\gamma$ )Cs134( $\beta^-$ )Ba134(n,2n)Ba133 &Cs133(n,2n)Cs132( $\beta^-$ )Ba132(n, $\gamma$ )Ba133				94.5  5.5
H3	12.33 y	Cs133(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 &Cs133(n, $\gamma$ )Cs134(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Cs133(n,X)H3 Cs133(n,2n)Cs132( $\beta^+$ )Xe132(n,X)H3 &Cs133(n,2n)Cs132( $\beta^+$ )Xe132(n,2n)Xe131(n,X)H3	80.8  12.0	72.0  23.0	98.0  1.4	78.9  17.0  2.8
Cs137	30.171 y	&Cs133(n, $\gamma$ )Cs134(n, $\gamma$ )Cs135(n, $\gamma$ )Cs136(n, $\gamma$ )Cs137	99.9	99.9	99.9	98.6
Ho166m	1200 y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ ) with reaction cross sections only high enough for production below 0.26eV				
Cs135	$2.4 \cdot 10^6$ y	&Cs133(n, $\gamma$ )Cs134(n, $\gamma$ )Cs135	100.0	100.0	100.0	99.9
I129	$1.6 \cdot 10^7$ y	&Cs133(n, $\gamma$ )Cs134(n, $\gamma$ )Cs135(n, $\alpha$ )I132( $\beta^-$ ) Xe132(n, $\alpha$ )Te129( $\beta^-$ )I129 &Cs133(n, $\alpha$ )I130( $\beta^-$ )Xe130(n, $\gamma$ )Xe131(n, $\gamma$ ) Xe132(n, $\alpha$ )Te129( $\beta^-$ )I129 &Cs133(n, $\gamma$ )Cs134(n, $\gamma$ )Cs135(n, $\alpha$ )I132( $\beta^-$ ) Xe132(n, $\alpha$ )Te129m( $\beta^-$ )I129 &Cs133(n, $\gamma$ )Cs134(n, $\alpha$ )I131( $\beta^-$ )Xe131(n, $\gamma$ ) Xe132(n, $\alpha$ )Te129( $\beta^-$ )I129 &Cs133(n, $\gamma$ )Cs134(n, $\gamma$ )Cs135(n, $\alpha$ )I132m( $\beta^-$ ) Xe132(n, $\alpha$ )Te129( $\beta^-$ )I129 &Cs133(n, $\alpha$ )I130( $\beta^-$ )Xe130(n, $\gamma$ )Xe131(n, $\gamma$ ) Xe132(n, $\alpha$ )Te129m( $\beta^-$ )I129 &Cs133(n, $\gamma$ )Cs134(n, $\alpha$ )I131( $\beta^-$ )Xe131(n, $\gamma$ ) Xe132(n, $\alpha$ )Te129m( $\beta^-$ )I129 &Cs133(n, $\alpha$ )I130m( $\beta^-$ )Xe130(n, $\gamma$ )Xe131(n, $\gamma$ ) Xe132(n, $\alpha$ )Te129( $\beta^-$ )I129 &Cs133(n, $\gamma$ )Cs134( $\beta^-$ )Ba134(n, $\alpha$ )Xe131(n, $\gamma$ ) Xe132(n, $\alpha$ )Te129( $\beta^-$ )I129 &Cs133(n, $\gamma$ )Cs134(n, $\gamma$ )Cs135(n, $\alpha$ )I132m( $\beta^-$ ) Xe132(n, $\alpha$ )Te129m( $\beta^-$ )I129 &Cs133(n, $\gamma$ )Cs134( $\beta^-$ )Ba134(n, $\alpha$ )Xe131(n, $\gamma$ ) Xe132(n, $\alpha$ )Te129m( $\beta^-$ )I129 &Cs133(n, $\gamma$ )Cs134( $\beta^-$ )Ba134(n, $\alpha$ )Xe131m(n, $\gamma$ ) Xe132(n, $\alpha$ )Te129( $\beta^-$ )I129 &Cs133(n, $\gamma$ )Cs134( $\beta^-$ )Ba134(n, $\alpha$ )Xe131(n, $\alpha$ )Te128(n, $\gamma$ )Te129( $\beta^-$ )I129   Cs133(n, $\alpha$ )I129	57.8  12.3  10.4  7.4  4.4  2.2  1.3  1.1  0.8  1.0  0.1  5.3	70.6  12.7  2.6  5.4  0.5  5.5  1.0  1.0  0.1  77.2  13.4  1.5  5.3	0.7  0.1  0.2  0.1  77.2  13.4  1.5  5.3	98.7

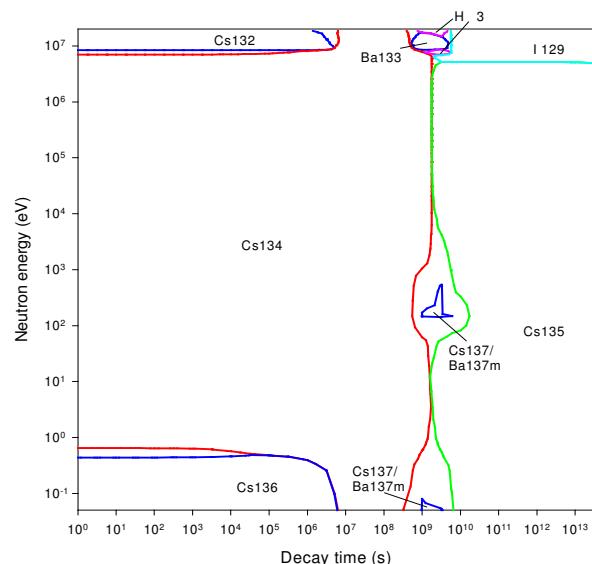
La138	$1.1 \cdot 10^{11}$ y	<b>&amp;Cs133(n,<math>\gamma</math>)Cs134(n,<math>\gamma</math>)Cs135(n,<math>\gamma</math>)Cs136(<math>\beta^-</math>)</b> Ba136(n, $\gamma$ )Ba137(n, $\gamma$ )Ba138(n, $\gamma$ )Ba139( $\beta^-$ )La139(n, $\gamma$ ) La140( $\beta^-$ )Ce140(n, $\gamma$ )Ce141( $\beta^-$ )Pr141(n, $\alpha$ )La138 <b>&amp;Cs133(n,<math>\gamma</math>)Cs134(n,<math>\gamma</math>)Cs135(n,<math>\gamma</math>)Cs136(<math>\beta^-</math>)</b> Ba136(n, $\gamma$ )Ba137(n, $\gamma$ )Ba138(n, $\gamma$ )Ba139( $\beta^-$ )La139(n, $\gamma$ ) La140(n, $\gamma$ )La141( $\beta^-$ )Ce141( $\beta^-$ )Pr141(n, $\alpha$ )La138	93.3			
			4.6			

# Caesium activation characteristics

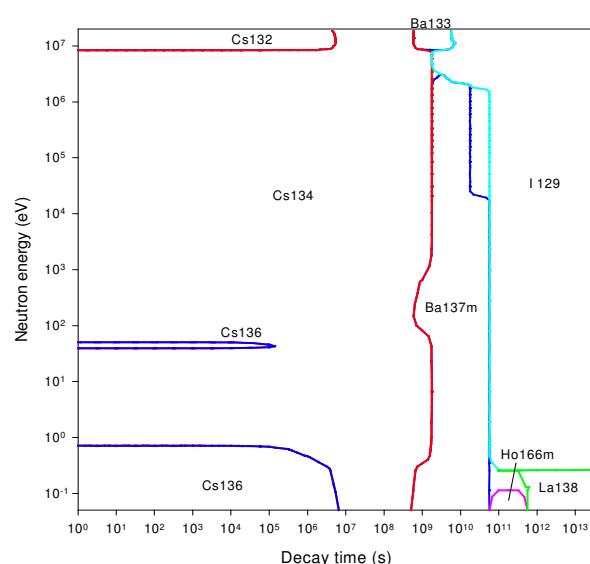


# Caesium importance diagrams & transmutation

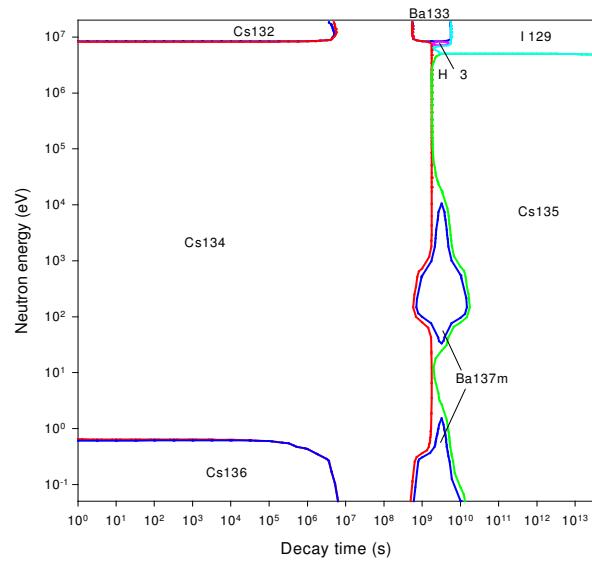
## Activity



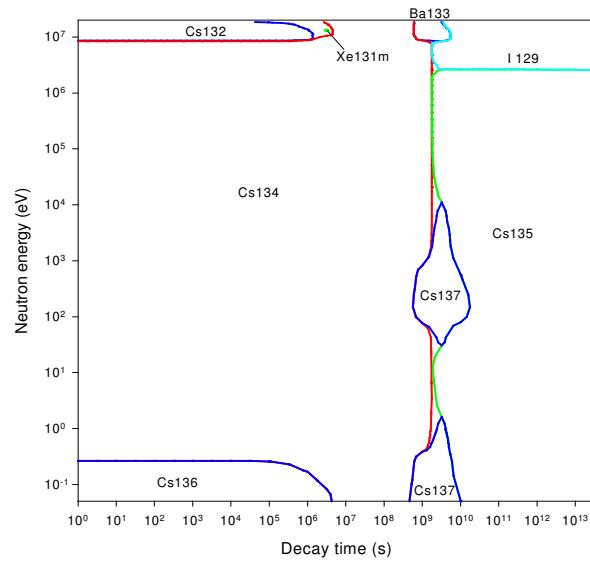
## Dose rate



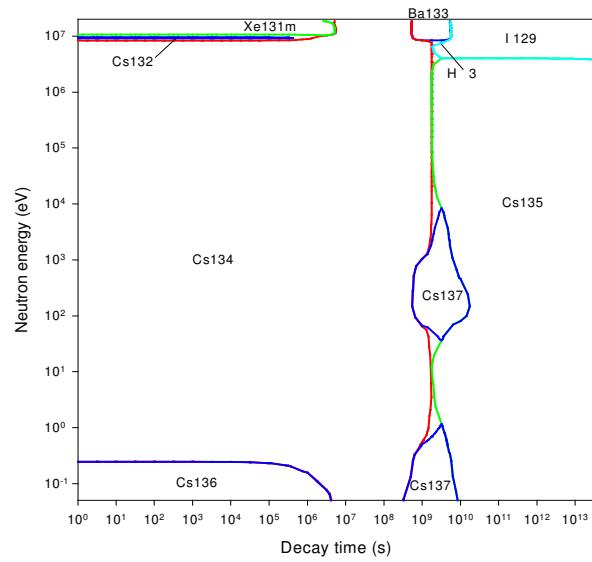
## Heat output



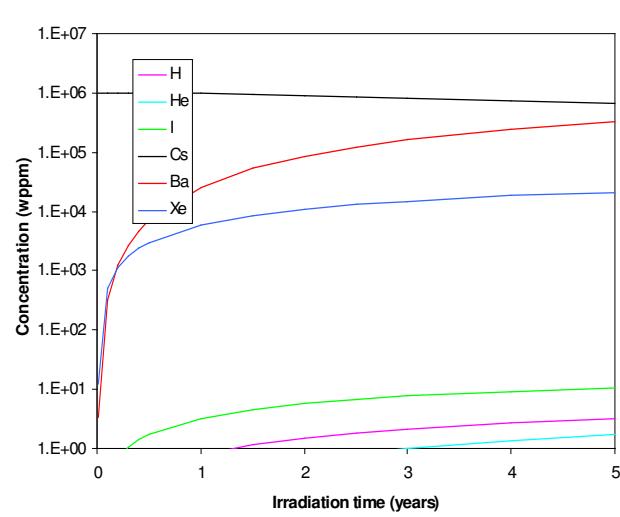
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Barium

## General properties

	56	Isotopes	Isotopic abundances / %	
Atomic number	56	Ba130	0.106	
Crustal abundance / wppm	425	Ba132	0.101	
Melting point / K	1000	Ba134	2.417	
Boiling point / K	2170	Ba135	6.592	
Density / kgm <sup>-3</sup>	3500	Ba136	7.854	
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	18.4	Ba137	11.232	
Electrical resistivity /Ωm	5.0 10 <sup>-7</sup>	Ba138	71.698	
Coefficient of thermal expansion / K <sup>-1</sup>	2.06 10 <sup>-5</sup>			
Crystal structure	BCC			
Number of stable isotopes	7			
Mean atomic weight	137.327			

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	6.81E14	2.66E14	4.32E13	6.75E12	2.26E10	1.56E6	kW kg <sup>-1</sup>	8.01E-2	2.08E-2	2.50E-3	6.62E-4	1.56E-6	1.64E-11
Ba137m	66.32	40.70	0.15	0.97	29.71		Ba137m	59.74	55.11	0.28	1.04	45.48	
Ba135m	14.67	37.44	27.82				Ba136m	28.31					
Ba136m	10.24						Ba135m	5.32	20.42	20.52			
Ba133m	1.70	4.35	5.47				Ba139	2.00	7.36				
Ba131	1.64	4.20	20.79				Ba131	1.13	4.35	29.10			
Cs131	1.63	4.16	25.05				Ba133m	0.67	2.57	4.37			
Ba139	1.56	3.81					Cs138	0.67	2.34				
Ba133	0.90	2.31	14.25	85.46	38.80		Ba133	0.56	2.16	17.99	63.66	40.96	
Ba131m	0.24	0.48					Cs134	0.41	1.56	12.92	34.98		
Cs134	0.17	0.44	2.72	12.47			Cs136	0.35	1.33	9.10			
Cs136	0.11	0.28	1.44				La140	0.30	1.15	2.13			
Xe131m	0.07	0.18	0.88				Cs131	0.07	0.25	2.04			
Cs137			0.16	1.02	31.41		Cs137			0.08	0.31	13.56	
Cs135					0.01	96.80	Cs135						98.43
La137						3.20	La137						1.57
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	1.00E5	1.78E4	1.69E3	5.15E2	1.22E0	1.82E-8	Sv kg <sup>-1</sup>	9.52E4	9.41E4	4.66E4	2.55E4	1.05E2	3.02E-3
Ba137m	60.52	82.00	0.53	1.70	73.81		Ba135m	45.11	45.53	11.08			
Ba136m	36.18						Cs134	23.51	23.78	47.82	62.62		
Ba131	0.68	3.86	32.57				Ba133	9.70	9.81	19.79	33.87	12.47	
Cs138	0.64	3.32					Ba133m	6.58	6.65	2.74			
Cs136	0.42	2.37	20.50				Ba131	5.29	5.35	8.67			
Cs134	0.41	2.33	24.38	57.41			Cs136	2.38	2.41	4.00			
La140	0.36	2.00	4.66				Ba139	1.34	1.29				
Ba135m	0.28	1.57	1.99				Ba137m	1.23	0.30		0.02		
Ba133	0.22	1.26	13.29	40.88	26.15		La140	1.11	1.12	0.50			
Ba133m	0.04	0.21	0.45				Cs137	0.96	0.98	1.97	3.51	87.51	
Cs132	0.03	0.19	1.33				Xe131m	0.74	0.75	1.23			
La137					85.92		Cs131	0.67	0.68	1.35			
La138					14.06	Cs135							99.81
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	1.48E5	1.48E5	1.07E5	7.72E4	3.64E2	1.34E-2		4.29E11	9.19E10	1.39E10	5.38E9	3.11E7	1.14E1
Ba133	41.50	41.66	57.74	74.70	24.05		Ba137m	61.98	69.30	0.28	0.71	12.69	
Ba135m	24.24	24.28	4.06				Ba136m	31.28					
Cs134	15.88	15.95	22.03	21.81			Ba135m	1.79	8.34	6.65			
Ba131	6.56	6.58	7.33				Ba131	1.19	5.53	29.36			
Ba133m	3.60	3.61	1.02				Cs134	0.92	4.27	28.14	52.15		
Xe131m	1.94	1.95	2.18				Ba133	0.57	2.68	17.70	42.87	11.27	
Cs137	1.86	1.86	2.58	3.48	75.94		Cs138	0.54	2.28				
Cs136	1.43	1.43	1.63				Cs136	0.38	1.78	9.71			
Xe133	0.56	0.56	0.52				Ba139	0.33	1.49				
Xe135	0.43	0.43					La140	0.29	1.37	2.00			
Ba139	0.42	0.41					Ba133m	0.25	1.15	1.55			
La140	0.39	0.39	0.12				Cs131	0.06	0.29	1.85			
Cs131	0.35	0.35	0.48				Cs137	0.06	0.26	1.69	4.27	76.04	
Cs135					96.76	Cs135							88.38
La137					3.24	La137							11.54

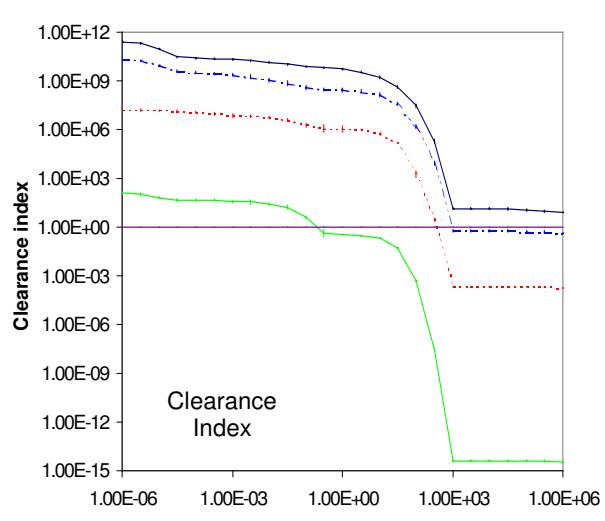
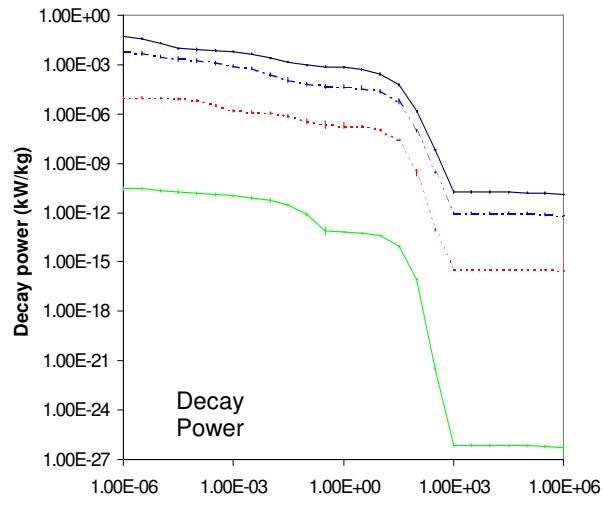
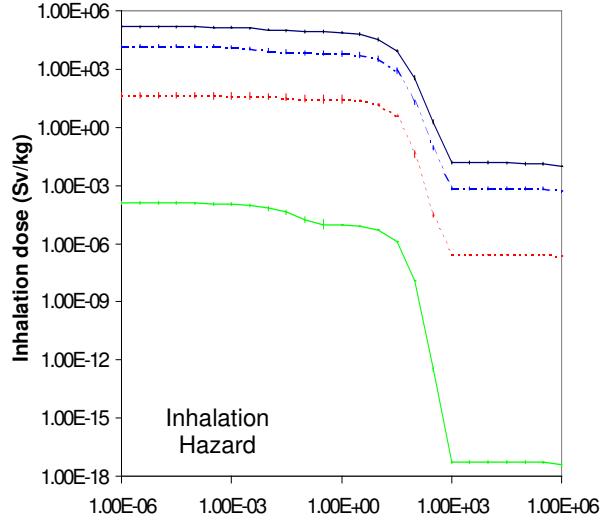
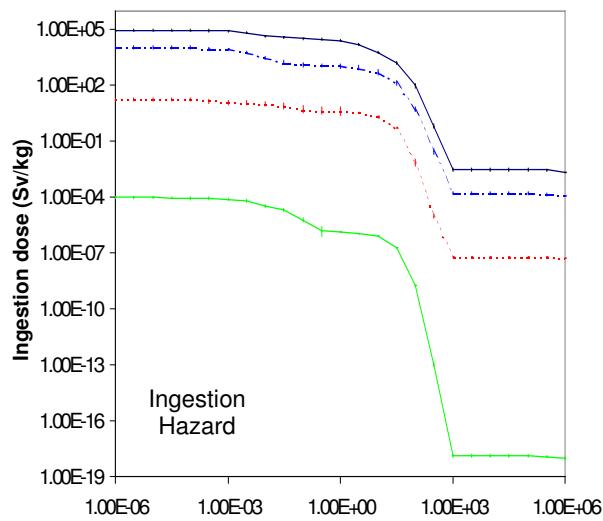
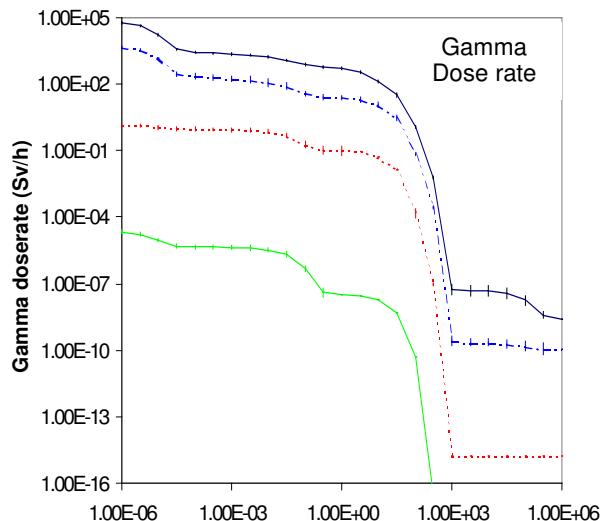
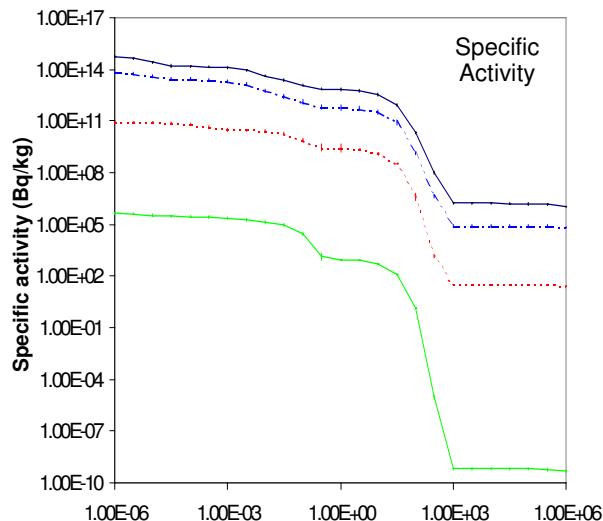
# Barium

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Ba137m	2.553 m	Ba136(n, $\gamma$ )Ba137m Ba135(n, $\gamma$ )Ba136(n, $\gamma$ )Ba137m Ba134(n, $\gamma$ )Ba135(n, $\gamma$ )Ba136(n, $\gamma$ )Ba137m <b>&amp;Ba132(n,<math>\gamma</math>)Ba133(<math>\beta^+</math>)Cs133(n,<math>\gamma</math>)Cs134(n,<math>\gamma</math>)</b> Cs135(n, $\gamma$ )Cs136(n, $\gamma$ )Cs137( $\beta^-$ )Ba137m Ba138(n,2n)Ba137m Ba137(n,n')Ba137m Ba138(n,2n)Ba137(n,n')Ba137m	77.2 22.1 0.6	97.2 1.3 1.4	96.2 3.7	
Ba139	1.384 h	Ba138(n, $\gamma$ )Ba139 Ba137(n, $\gamma$ )Ba138(n, $\gamma$ )Ba139	95.4 4.6	99.8 0.2	99.9 0.1	99.9
Ba135m	1.196 d	Ba134(n, $\gamma$ )Ba135m Ba136(n,2n)Ba135m <b>&amp;Ba137(n,2n)Ba136(n,2n)Ba135m</b> <b>&amp;Ba138(n,2n)Ba137(n,2n)Ba136(n,2n)Ba135m</b> Ba135(n,n')Ba135m	99.7	99.9	100.0	52.4 21.0 16.1 7.3
La140	1.679 d	Ba138(n, $\gamma$ )Ba139( $\beta^-$ )La139(n, $\gamma$ )La140 Ba137(n, $\gamma$ )Ba138(n, $\gamma$ )Ba139( $\beta^-$ )La139(n, $\gamma$ )La140	97.3 2.7	100.0	100.0	100.0
Cs131	9.69 d	<b>&amp;Ba130(n,<math>\gamma</math>)Ba131(<math>\beta^+</math>)Cs131</b> <b>&amp;Ba132(n,2n)Ba131(<math>\beta^+</math>)Cs131</b> <b>&amp;Ba134(n,2n)Ba133(n,2n)Ba132(n,2n)Ba131(<math>\beta^+</math>)Cs131</b> <b>&amp;Ba135(n,2n)Ba134(n,2n)Ba133(n,2n)Ba132(n,2n)</b> Ba131( $\beta^+$ )Cs131	100.0 	100.0	100.0	51.8 37.0 9.5
Ba131	11.55 d	<b>&amp;Ba130(n,<math>\gamma</math>)Ba131</b> <b>&amp;Ba132(n,2n)Ba131</b> <b>&amp;Ba134(n,2n)Ba133(n,2n)Ba132(n,2n)Ba131</b> <b>&amp;Ba135(n,2n)Ba134(n,2n)Ba133(n,2n)Ba132(n,2n)Ba131</b>	99.3 	100.0	99.9	51.5 37.4 9.7
Cs136	13.03 d	<b>&amp;Ba132(n,<math>\gamma</math>)Ba133(<math>\beta^+</math>)Cs133(n,<math>\gamma</math>)Cs134(n,<math>\gamma</math>)</b> Cs135(n, $\gamma$ )Cs136 <b>&amp;Ba130(n,<math>\gamma</math>)Ba131(<math>\beta^+</math>)Cs131(<math>\beta^+</math>)Xe131(n,<math>\gamma</math>)Xe132(n,<math>\gamma</math>)Xe133(<math>\beta^-</math>)Cs133(n,<math>\gamma</math>)Cs134(n,<math>\gamma</math>)Cs135(n,<math>\gamma</math>)Cs136</b> <b>&amp;Ba130(n,<math>\gamma</math>)Ba131(n,<math>\gamma</math>)Ba132(n,<math>\gamma</math>)Ba133(<math>\beta^+</math>)Cs133(n,<math>\gamma</math>)Cs134(n,<math>\gamma</math>)Cs135(n,<math>\gamma</math>)Cs136</b> <b>&amp;Ba138(n,<math>\alpha</math>)Xe135(<math>\beta^-</math>)Cs135(n,<math>\gamma</math>)Cs136</b> <b>&amp;Ba136(n,p)Cs136</b> <b>&amp;Ba137(n,p)Cs137(n,2n)Cs136</b> <b>&amp;Ba138(n,2n)Ba137(n,d)Cs136</b> <b>&amp;Ba138(n,2n)Ba137(n,p)Cs137(n,2n)Cs136</b> <b>&amp;Ba137(n,2n)Ba136(n,p)Cs136</b> <b>&amp;Ba137(n,d)Cs136</b> <b>&amp;Ba138(n,2n)Ba137(n,2n)Ba136(n,p)Cs136</b> <b>&amp;Ba138(n,d)Cs137(n,2n)Cs136</b>	92.2 7.2 1.2 0.6	97.8	99.3	27.2 15.8 13.0 12.2 10.9 8.4 7.8 3.8
Ce141	32.5 d	Ba138(n, $\gamma$ )Ba139( $\beta^-$ )La139(n, $\gamma$ )La140( $\beta^-$ )Ce140(n, $\gamma$ )Ce141 Ba137(n, $\gamma$ )Ba138(n, $\gamma$ )Ba139( $\beta^-$ )La139(n, $\gamma$ )La140( $\beta^-$ )Ce140(n, $\gamma$ )Ce141 Ba138(n, $\gamma$ )Ba139( $\beta^-$ )La139(n, $\gamma$ )La140(n, $\gamma$ )La141( $\beta^-$ )Ce141	97.2 1.7 1.1	1.0 99.0	94.2 5.8	99.3

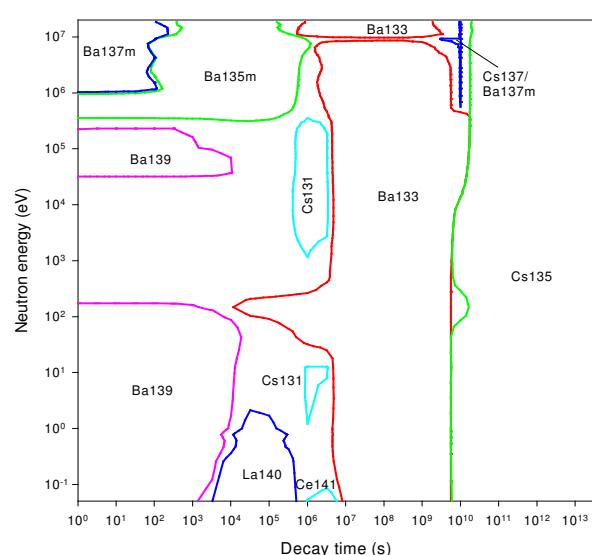


# Barium activation characteristics

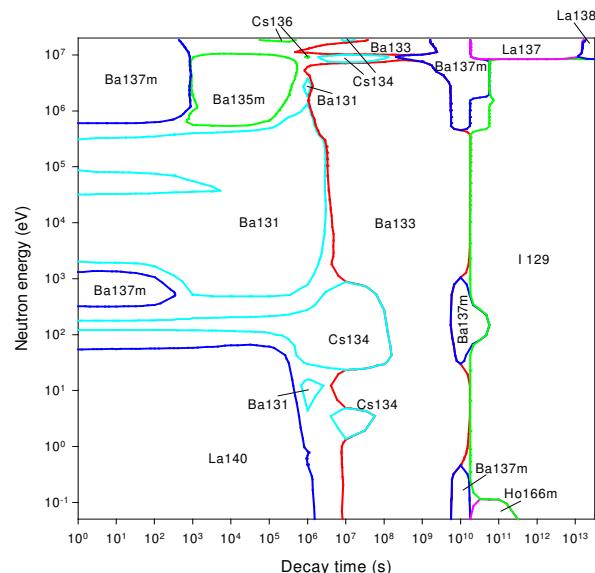


# Barium importance diagrams & transmutation

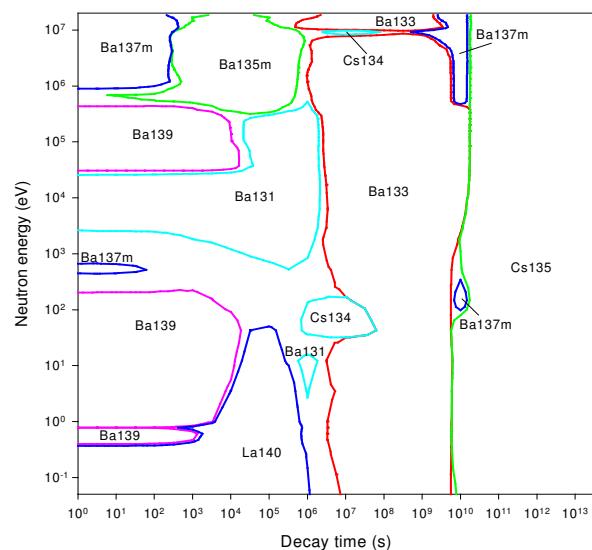
## Activity



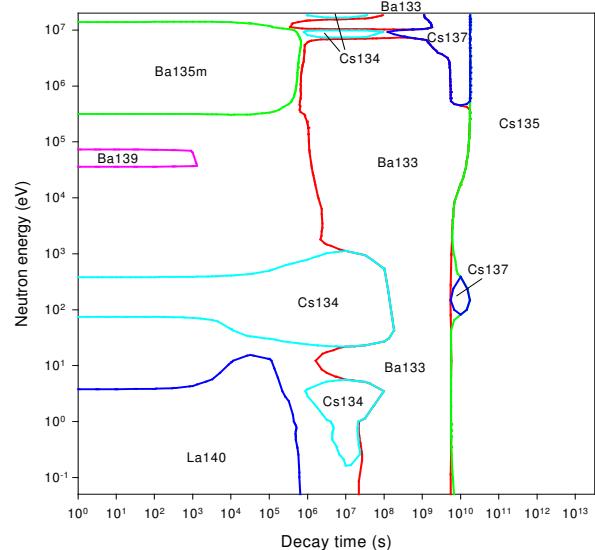
## Dose rate



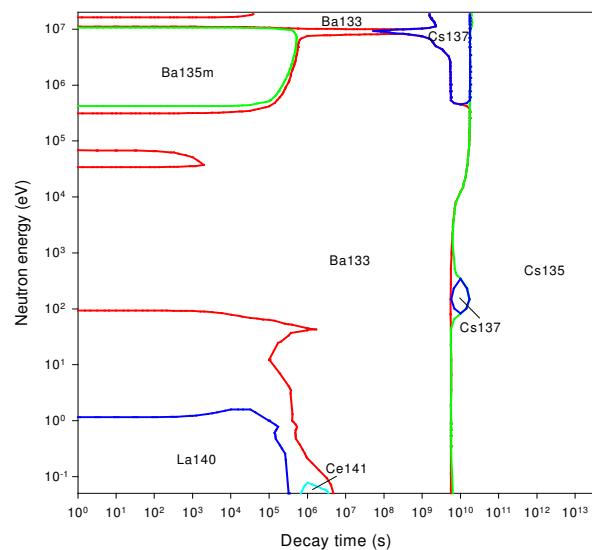
## Heat output



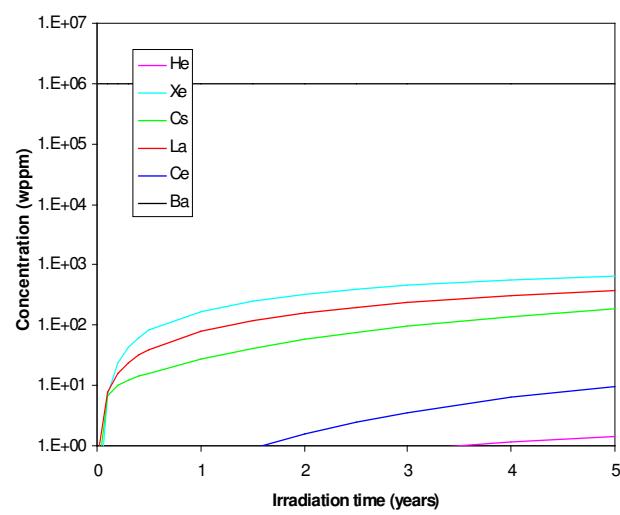
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Lanthanum

## General properties

Atomic number	57	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	39.0	La138	0.09 ( $T_{1/2} = 1.05 \cdot 10^{11}$ y)
Melting point / K	1193	La139	99.91
Boiling point / K	3728		
Density / kgm <sup>-3</sup>	6145		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	13.5		
Electrical resistivity /Ωm	$5.7 \cdot 10^{-7}$		
Coefficient of thermal expansion / K <sup>-1</sup>	$1.21 \cdot 10^{-5}$		
Crystal structure	Hexagonal		
Number of stable isotopes	1(2)		
Mean atomic weight	138.9055		

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.36E15	1.33E15	3.26E14	6.19E12	1.24E9	3.46E8	kW kg <sup>-1</sup>	5.94E-1	5.90E-1	1.32E-1	1.94E-4	1.14E-8	1.79E-9
La140	94.80	96.57	87.55				La140	99.12	99.62	98.85			
Ce139	2.85	2.91	11.69	99.70			Ce139m	0.50	0.01				
Ce139m	1.79	0.04					Ce139	0.21	0.21	0.91	99.79		
Ba137m	0.01			0.01	3.33		Ba137m				0.02	38.39	
H3			0.01	0.24	4.49		H3				0.01	0.45	
La137				0.02	88.65	99.98	Cs137				0.01	11.45	
Cs137				0.01	3.52		La137					49.65	99.60
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	8.63E5	8.58E5	1.91E5	1.68E1	5.79E-3	1.14E-4	Sv kg <sup>-1</sup>	2.59E6	2.59E6	5.84E5	1.63E3	6.58E-1	2.82E-2
La140	99.48	99.92	99.74				La140	99.43	99.43	97.72			
Ce139	0.01	0.01	0.05	97.44			Ce139	0.39	0.39	1.70	98.32		
Cs134				2.24			Cs136	0.10	0.10	0.37	0.00		
Ba137m				0.32	94.19		Cs134				0.01	1.27	
La137					5.60	89.61	Cs137				0.34	86.10	
La138					0.21	10.39	La137				0.01	13.51	99.59
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	1.50E6	1.50E6	3.95E5	1.18E4	1.13E1	3.02E0		3.10E12	3.08E12	6.88E11	1.02E9	1.99E5	9.15E3
La140	94.42	94.42	79.48				La140	99.13	99.69	98.84			
Ce139	4.91	4.92	18.33	99.54			Ce139m	0.56	0.01				
Ce141	0.48	0.48	1.67	0.03			Ce139	0.21	0.21	0.91	99.47		
Cs136	0.16	0.16	0.51				Cs137				0.14	73.20	
Cs137				0.14	15.09		Ba137m				0.02	12.22	
La137				0.08	84.74	99.82	La137					14.55	99.55

# Lanthanum

## Pathway analysis

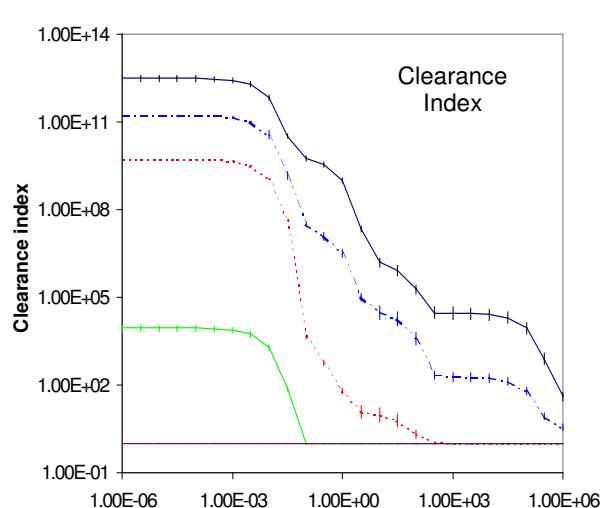
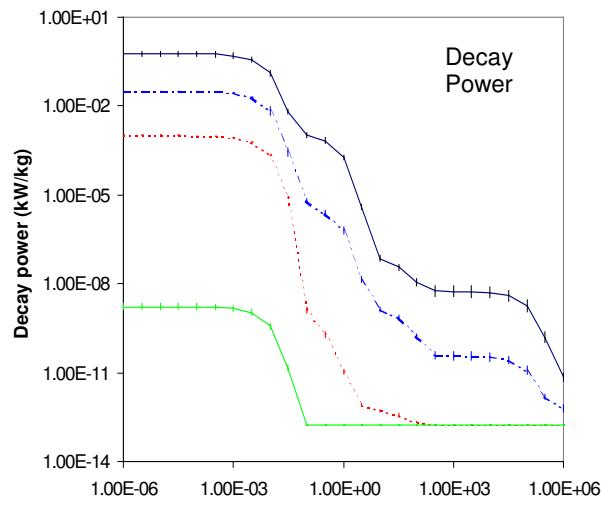
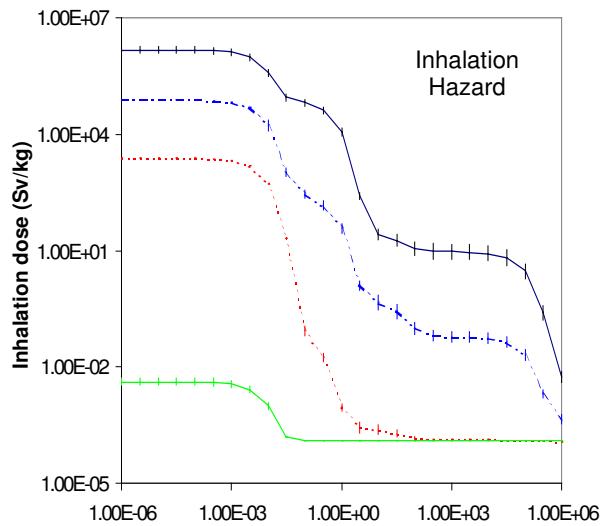
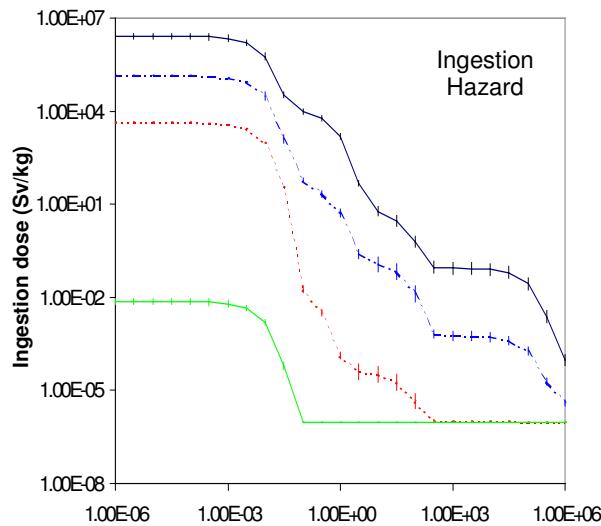
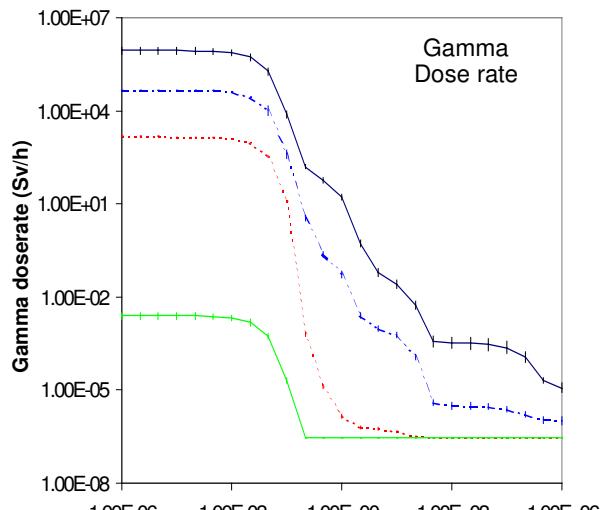
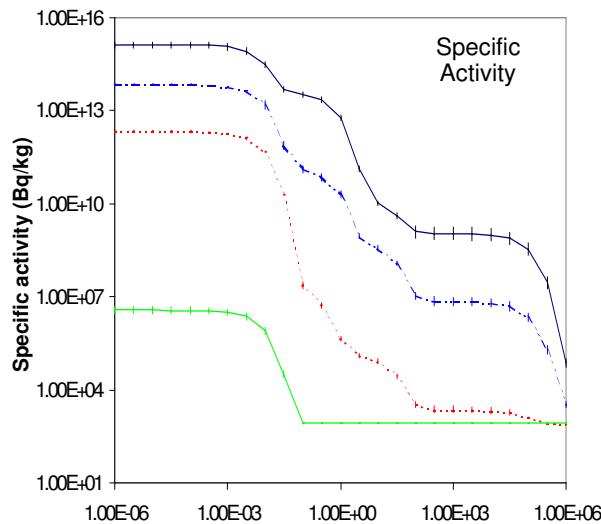
Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Ba137m	2.553 m	La139(n, $\gamma$ )La140( $\beta^-$ )Ce140(n, $\alpha$ )Ba137m <b>&amp;La139(n,<math>\alpha</math>)Cs136(<math>\beta^-</math>)Ba136(n,<math>\gamma</math>)Ba137m</b> <b>&amp;La139(n,<math>\alpha</math>)Cs136(n,<math>\gamma</math>)Cs137(<math>\beta^-</math>)Ba137m</b> La139(n, $\alpha$ )Cs136m( $\beta^-$ )Ba136(n, $\gamma$ )Ba137m La139(n,2n)La138(n,2n)La137(n,p)Ba137m La139(n,2n)La138(n,d)Ba137m La139(n,d)Ba138(n,2n)Ba137m La139(n,2n)La138(n,p)Ba138(n,2n)Ba137m La139(n,t)Ba137m	99.7 0.1	11.0 0.1 88.9	91.2 5.6 1.4 1.8	37.0 30.7 20.1 8.0 1.8
La136	9.87 m	<b>&amp;La139(n,2n)La138(n,2n)La137(n,2n)La136</b>				96.8
Pr144	17.28 m	<b>&amp;La139(n,<math>\gamma</math>)La140(<math>\beta^-</math>)Ce140(n,<math>\gamma</math>)Ce141(n,<math>\gamma</math>)Ce142(n,<math>\gamma</math>)Ce143(<math>\beta^-</math>)Pr143(n,<math>\gamma</math>)Pr144</b> <b>&amp;La139(n,<math>\gamma</math>)La140(<math>\beta^-</math>)Ce140(n,<math>\gamma</math>)Ce141(<math>\beta^-</math>)Pr141(n,<math>\gamma</math>)Pr142(n,<math>\gamma</math>)Pr143(n,<math>\gamma</math>)Pr144</b> <b>&amp;La139(n,<math>\gamma</math>)La140(n,<math>\gamma</math>)La141(<math>\beta^-</math>)Ce141(n,<math>\gamma</math>)Ce142(n,<math>\gamma</math>)Ce143(<math>\beta^-</math>)Pr143(n,<math>\gamma</math>)Pr144</b> <b>&amp;La139(n,<math>\gamma</math>)La140(n,<math>\gamma</math>)La141(n,<math>\gamma</math>)La142(<math>\beta^-</math>)Ce142(n,<math>\gamma</math>)Ce143(<math>\beta^-</math>)Pr143(n,<math>\gamma</math>)Pr144</b> <b>&amp;La139(n,<math>\gamma</math>)La140(n,<math>\gamma</math>)La141(<math>\beta^-</math>)Ce141(<math>\beta^-</math>)Pr141(n,<math>\gamma</math>)Pr142(n,<math>\gamma</math>)Pr143(n,<math>\gamma</math>)Pr144</b> <b>&amp;La139(n,<math>\gamma</math>)La140(<math>\beta^-</math>)Ce140(n,<math>\gamma</math>)Ce141(<math>\beta^-</math>)Pr141(n,<math>\gamma</math>)Pr142(n,<math>\gamma</math>)Pr143(n,<math>\gamma</math>)Pr144</b>	81.8 12.8 1.0	0.2 0.1 18.0	68.4 4.4	
Ba139	1.384 h	<b>&amp;La139(n,<math>\gamma</math>)La140(<math>\beta^-</math>)Ce140(n,<math>\alpha</math>)Ba137(n,<math>\gamma</math>)Ba138(n,<math>\gamma</math>)Ba139</b> <b>&amp;La139(n,<math>\alpha</math>)Cs136(<math>\beta^-</math>)Ba136(n,<math>\gamma</math>)Ba137(n,<math>\gamma</math>)Ba138(n,<math>\gamma</math>)Ba139</b> <b>&amp;La139(n,<math>\alpha</math>)Cs136m(<math>\beta^-</math>)Ba136(n,<math>\gamma</math>)Ba137(n,<math>\gamma</math>)Ba138(n,<math>\gamma</math>)Ba139</b> La138( $\beta^+$ )Ba138(n, $\gamma$ )Ba139 La138(n,p)Ba138(n, $\gamma$ )Ba139 <b>&amp;La139(n,<math>\alpha</math>)Cs136(n,<math>\gamma</math>)Cs137(<math>\beta^-</math>)Ba137(n,<math>\gamma</math>)Ba138(n,<math>\gamma</math>)Ba139</b> <b>&amp;La139(n,<math>\alpha</math>)Cs136(n,<math>\gamma</math>)Cs137(n,<math>\gamma</math>)Cs138(<math>\beta^-</math>)Ba138(n,<math>\gamma</math>)Ba139</b> La139(n, $\gamma$ )La140( $\beta^-$ )Ce140(n, $\gamma$ )Ce141(n, $\gamma$ )Ce142(n, $\alpha$ )Ba139 La139(n, $\gamma$ )La140(n, $\gamma$ )La141( $\beta^-$ )Ce141(n, $\gamma$ )Ce142(n, $\alpha$ )Ba139 La139(n,p)Ba139	93.3 4.1 1.4 0.5 0.3 2.4 1.9 16.4 1.0		0.6 0.2 54.9 39.1 2.4 1.9 1.0	100.0
Ba135m	1.196 d	<b>&amp;La139(n,2n)La138(n,2n)La137(n,2n)La136(<math>\beta^+</math>)Ba136(n,2n)Ba135m</b> <b>&amp;La139(n,<math>\alpha</math>)Cs136(<math>\beta^-</math>)Ba136(n,2n)Ba135m</b> La139(n, $\alpha$ )Cs136m( $\beta^-$ )Ba136(n,2n)Ba135m				89.4 6.4 1.1
La140	1.679 d	La139(n, $\gamma$ )La140 La138(n, $\gamma$ )La139(n, $\gamma$ )La140	99.8 0.1	99.9	100.0	99.8
Cs136	13.03 d	<b>&amp;La139(n,<math>\alpha</math>)Cs136</b>	99.3	99.9	100.0	98.3
Ce141	32.5 d	La139(n, $\gamma$ )La140( $\beta^-$ )Ce140(n, $\gamma$ )Ce141 La139(n, $\gamma$ )La140(n, $\gamma$ )La141( $\beta^-$ )Ce141	99.5 0.5	2.0 97.9	97.0 3.0	99.6 0.4
Ce144	284.9 d	La139(n, $\gamma$ )La140( $\beta^-$ )Ce140(n, $\gamma$ )Ce141(n, $\gamma$ )Ce142(n, $\gamma$ )Ce143(n, $\gamma$ )Ce144 La139(n, $\gamma$ )La140(n, $\gamma$ )La141( $\beta^-$ )Ce141(n, $\gamma$ )Ce142(n, $\gamma$ )Ce143(n, $\gamma$ )Ce144 La139(n, $\gamma$ )La140(n, $\gamma$ )La141(n, $\gamma$ )La142( $\beta^-$ )Ce142(n, $\gamma$ )Ce143(n, $\gamma$ )Ce144	98.8 1.2	0.2 22.8 77.0	93.2 6.8	

Cs134	2.065 y	&La139(n, $\alpha$ )Cs136( $\beta^-$ )Ba136(n, $\alpha$ )Xe133( $\beta^-$ ) Cs133(n, $\gamma$ )Cs134 &La139(n, $\alpha$ )Cs136m( $\beta^-$ )Ba136(n, $\alpha$ )Xe133( $\beta^-$ ) Cs133(n, $\gamma$ )Cs134 &La139(n, $\alpha$ )Cs136(n, $\alpha$ )I133( $\beta^-$ )Xe133( $\beta^-$ )Cs133(n, $\gamma$ )Cs134   &La139(n,2n)La138(n,2n)La137(n, $\alpha$ )Cs134 &La139(n,2n)La138(n, $\alpha$ )Cs135(n,2n)Cs134 &La139(n,2n)La138(n,n $\alpha$ )Cs134 &La139(n,n $\alpha$ )Cs135(n,2n)Cs134	74.7 25.3 2.3 87.9	71.7 25.8 3.1 46.1 38.2 11.7 1.9	9.0		
Pm147	2.622 y	&La139(n, $\gamma$ )La140( $\beta^-$ )Ce140(n, $\gamma$ )Ce141( $\beta^-$ ) Pr141(n, $\gamma$ )Pr142( $\beta^-$ )Nd142(n, $\gamma$ )Nd143(n, $\gamma$ ) Nd144(n, $\gamma$ )Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147 &La139(n, $\gamma$ )La140(n, $\gamma$ )La141( $\beta^-$ )Ce141( $\beta^-$ ) Pr141(n, $\gamma$ )Pr142( $\beta^-$ )Nd142(n, $\gamma$ )Nd143(n, $\gamma$ ) Nd144(n, $\gamma$ )Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147 La139(n, $\gamma$ )La140( $\beta^-$ )Ce140(n, $\gamma$ )Ce141(n, $\gamma$ )Ce142(n, $\gamma$ ) Ce143( $\beta^-$ )Pr143( $\beta^-$ )Nd143(n, $\gamma$ )Nd144(n, $\gamma$ )Nd145(n, $\gamma$ ) Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147 &La139(n, $\gamma$ )La140( $\beta^-$ )Ce140(n, $\gamma$ )Ce141( $\beta^-$ ) Pr141(n, $\gamma$ )Pr142(n, $\gamma$ )Pr143( $\beta^-$ )Nd143(n, $\gamma$ )Nd144(n, $\gamma$ ) Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147 La139(n, $\gamma$ )La140(n, $\gamma$ )La141( $\beta^-$ )Ce141(n, $\gamma$ )Ce142(n, $\gamma$ ) Ce143( $\beta^-$ )Pr143( $\beta^-$ )Nd143(n, $\gamma$ )Nd144(n, $\gamma$ )Nd145(n, $\gamma$ ) Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147 La139(n, $\gamma$ )La140(n, $\gamma$ )La141(n, $\gamma$ )La142( $\beta^-$ )Ce142(n, $\gamma$ ) Ce143( $\beta^-$ )Pr143( $\beta^-$ )Nd143(n, $\gamma$ )Nd144(n, $\gamma$ )Nd145(n, $\gamma$ ) Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147 &La139(n, $\gamma$ )La140(n, $\gamma$ )La141( $\beta^-$ )Ce141( $\beta^-$ ) Pr141(n, $\gamma$ )Pr142(n, $\gamma$ )Pr143( $\beta^-$ )Nd143(n, $\gamma$ )Nd144(n, $\gamma$ ) Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147	93.4 3.5 2.4 0.4 0.1 8.8	0.2 49.7 10.9 3.2 8.3 30.4 0.7	65.3		
Eu154	8.593 y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0	100.0			
Ba133	10.574 y	&La139(n,2n)La138(n,2n)La137(n,2n)La136( $\beta^+$ ) Ba136(n,2n)Ba135(n,2n)Ba134(n,2n)Ba133 &La139(n, $\alpha$ )Cs136( $\beta^-$ )Ba136(n,2n)Ba135(n,2n) Ba134(n,2n)Ba133 &La139(n,2n)La138(n,2n)La137(n, $\alpha$ )Cs134( $\beta^-$ ) Ba134(n,2n)Ba133 &La139(n,2n)La138(n, $\alpha$ )Cs135(n,2n)Cs134( $\beta^-$ ) Ba134(n,2n)Ba133 &La139(n,2n)La138(n,n $\alpha$ )Cs134( $\beta^-$ )Ba134(n,2n)Ba133   &La139(n, $\alpha$ )Cs136m( $\beta^-$ )Ba136(n,2n)Ba135(n,2n) Ba134(n,2n)Ba133			53.4 18.1 9.4 7.8 4.3 3.2		
H3	12.33 y	La139(n, $\gamma$ )La140( $\beta^-$ )Ce140(n, $\gamma$ )Ce141( $\beta^-$ )Pr141(n,X) H1(n, $\gamma$ )H2(n, $\gamma$ )H3 La138(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 La139(n, $\gamma$ )La140(n, $\gamma$ )La141( $\beta^-$ )Ce141( $\beta^-$ )Pr141(n,X) H1(n, $\gamma$ )H2(n, $\gamma$ )H3 La139(n,X)H3 La139(n,2n)La138(n,2n)La137(n,X)H3 La139(n,2n)La138(n,X)H3	63.2 29.7 1.9	94.3 0.3		89.0 8.3 2.5	
Cs137	30.171 y	&La139(n, $\alpha$ )Cs136(n, $\gamma$ )Cs137 La139(n, $\gamma$ )La140(n, $\alpha$ )Cs137 La139(n,h)Cs137 &La139(n,2n)La138(n,d)Ba137(n,p)Cs137 &La139(n,d)Ba138(n,2n)Ba137(n,p)Cs137 &La139(n,t)Ba137(n,p)Cs137 &La139(n,2n)La138(n,2n)La137(n,p)Ba137(n,p)Cs137   La139(n,d)Ba138(n,d)Cs137	69.0 31.0	100.0 0.5	99.5 0.5	87.1 3.7 2.5 2.3 2.0 1.2	

Sm151	30.171 y	<b>&amp;La139(n,<math>\gamma</math>)La140(<math>\beta^-</math>)Ce140(n,<math>\gamma</math>)Ce141(<math>\beta^-</math>)Pr141(n,<math>\gamma</math>)</b> <i>Pr142(<math>\beta^-</math>)Nd142(n,<math>\gamma</math>)Nd143(n,<math>\gamma</math>)Nd144(n,<math>\gamma</math>)</i> Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ ) Pm148(n, $\gamma$ )Pm149( $\beta^-$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151 <b>&amp;La139(n,<math>\gamma</math>)La140(<math>\beta^-</math>)Ce140(n,<math>\gamma</math>)Ce141(<math>\beta^-</math>)Pr141(n,<math>\gamma</math>)</b> <i>Pr142(<math>\beta^-</math>)Nd142(n,<math>\gamma</math>)Nd143(n,<math>\gamma</math>)Nd144(n,<math>\gamma</math>)</i> Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ ) Pm148( $\beta^-$ )Sm148(n, $\gamma$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151 <b>&amp;La139(n,<math>\gamma</math>)La140(<math>\beta^-</math>)Ce140(n,<math>\gamma</math>)Ce141(<math>\beta^-</math>)Pr141(n,<math>\gamma</math>)</b> <i>Pr142(<math>\beta^-</math>)Nd142(n,<math>\gamma</math>)Nd143(n,<math>\gamma</math>)Nd144(n,<math>\gamma</math>)</i> Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ ) Nd149( $\beta^-$ )Pm149( $\beta^-$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151 <b>&amp;La139(n,<math>\gamma</math>)La140(n,<math>\gamma</math>)La141(<math>\beta^-</math>)Ce141(<math>\beta^-</math>)Pr141(n,<math>\gamma</math>)</b> <i>Pr142(<math>\beta^-</math>)Nd142(n,<math>\gamma</math>)Nd143(n,<math>\gamma</math>)Nd144(n,<math>\gamma</math>)Nd145(n,<math>\gamma</math>)</i> Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ )Pm148(n, $\gamma$ ) Pm149( $\beta^-$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151 *Plus other similar pathways of (n, $\gamma$ ), ( $\beta^-$ )	15.3	1.4			
Ho166m	1200 y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0				
La137	$6.0 \cdot 10^4$ y	La139(n,2n)La138(n,2n)La137					99.4
Cs135	$2.4 \cdot 10^6$ y	<b>&amp;La138(n,<math>\alpha</math>)Cs135</b> <b>&amp;La139(n,2n)La138(n,<math>\alpha</math>)Cs135</b> <b>&amp;La139(n,<math>\alpha</math>)Cs136(n,2n)Cs135</b>	100.0	100.0	100.0	3.8 93.5 1.3	
Sm147	$1.1 \cdot 10^{11}$ y	<b>&amp;La139(n,<math>\gamma</math>)La140(<math>\beta^-</math>)Ce140(n,<math>\gamma</math>)Ce141(<math>\beta^-</math>)</b> <i>Pr141(n,<math>\gamma</math>)Pr142(<math>\beta^-</math>)Nd142(n,<math>\gamma</math>)Nd143(n,<math>\gamma</math>)Nd144(n,<math>\gamma</math>)</i> Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147( $\beta^-$ )Sm147 <b>&amp;La139(n,<math>\gamma</math>)La140(n,<math>\gamma</math>)La141(<math>\beta^-</math>)Ce141(<math>\beta^-</math>)</b> <i>Pr141(n,<math>\gamma</math>)Pr142(<math>\beta^-</math>)Nd142(n,<math>\gamma</math>)Nd143(n,<math>\gamma</math>)Nd144(n,<math>\gamma</math>)</i> Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147( $\beta^-$ )Sm147 La139(n, $\gamma$ )La140( $\beta^-$ )Ce140(n, $\gamma$ )Ce141(n, $\gamma$ )Ce142(n, $\gamma$ ) Ce143( $\beta^-$ )Pr143( $\beta^-$ )Nd143(n, $\gamma$ )Nd144(n, $\gamma$ )Nd145(n, $\gamma$ ) Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147( $\beta^-$ )Sm147 <b>&amp;La139(n,<math>\gamma</math>)La140(<math>\beta^-</math>)Ce140(n,<math>\gamma</math>)Ce141(<math>\beta^-</math>)</b> <i>Pr141(n,<math>\gamma</math>)Pr142(n,<math>\gamma</math>)Pr143(<math>\beta^-</math>)Nd143(n,<math>\gamma</math>)Nd144(n,<math>\gamma</math>)</i> Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147( $\beta^-$ )Sm147 La139(n, $\gamma$ )La140(n, $\gamma$ )La141( $\beta^-$ )Ce141(n, $\gamma$ )Ce142(n, $\gamma$ ) Ce143( $\beta^-$ )Pr143( $\beta^-$ )Nd143(n, $\gamma$ )Nd144(n, $\gamma$ )Nd145(n, $\gamma$ ) Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147( $\beta^-$ )Sm147 La139(n, $\gamma$ )La140(n, $\gamma$ )La141(n, $\gamma$ )La142( $\beta^-$ )Ce142(n, $\gamma$ ) Ce143( $\beta^-$ )Pr143( $\beta^-$ )Nd143(n, $\gamma$ )Nd144(n, $\gamma$ )Nd145(n, $\gamma$ ) Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147( $\beta^-$ )Sm147 <b>&amp;La139(n,<math>\gamma</math>)La140(n,<math>\gamma</math>)La141(<math>\beta^-</math>)Ce141(<math>\beta^-</math>)</b> <i>Pr141(n,<math>\gamma</math>)Pr142(n,<math>\gamma</math>)Pr143(<math>\beta^-</math>)Nd143(n,<math>\gamma</math>)Nd144(n,<math>\gamma</math>)</i> Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147( $\beta^-$ )Sm147	92.7	0.1	62.3		
La138	$1.1 \cdot 10^{11}$ y	*Nuclide present in starting material La139(n,2n)La138	100.0*	100.0*	100.0*	99.7	

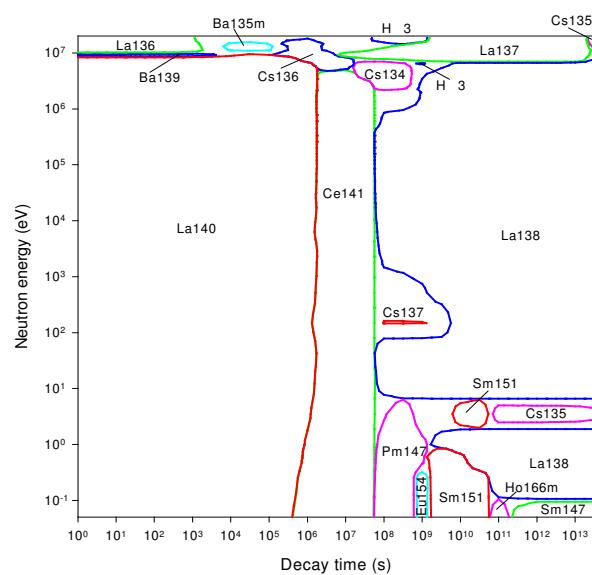
Nd144	$2.1 \cdot 10^{15}$ y	$\text{&La139(n,\gamma)La140(\beta^-)Ce140(n,\gamma)Ce141(\beta^-)}$ $\text{Pr141(n,\gamma)Pr142(\beta^-)Nd142(n,\gamma)Nd143(n,\gamma)Nd144}$ $\text{&La139(n,\gamma)La140(n,\gamma)La141(\beta^-)Ce141(\beta^-)}$ $\text{Pr141(n,\gamma)Pr142(\beta^-)Nd142(n,\gamma)Nd143(n,\gamma)Nd144}$ $\text{La139(n,\gamma)La140(\beta^-)Ce140(n,\gamma)Ce141(n,\gamma)Ce142(n,\gamma)}$ $\text{Ce143(\beta^-)Pr143(\beta^-)Nd143(n,\gamma)Nd144}$ $\text{&La139(n,\gamma)La140(\beta^-)Ce140(n,\gamma)Ce141(\beta^-)}$ $\text{Pr141(n,\gamma)Pr142(n,\gamma)Pr143(\beta^-)Nd143(n,\gamma)Nd144}$ $\text{La139(n,\gamma)La140(n,\gamma)La141(n,\gamma)La142(\beta^-)Ce142(n,\gamma)}$ $\text{Ce143(\beta^-)Pr143(\beta^-)Nd143(n,\gamma)Nd144}$ $\text{&La139(n,\gamma)La140(n,\gamma)La141(\beta^-)Ce141(\beta^-)}$ $\text{Pr141(n,\gamma)Pr142(n,\gamma)Pr143(\beta^-)Nd143(n,\gamma)Nd144}$ $\text{La139(n,\gamma)La140(n,\gamma)La141(\beta^-)Ce141(n,\gamma)Ce142(n,\gamma)}$ $\text{Ce143(\beta^-)Pr143(\beta^-)Nd143(n,\gamma)Nd144}$ $\text{&La139(n,\gamma)La140(n,\gamma)La141(n,\gamma)La142(\beta^-)}$ $\text{Ce142(n,\gamma)Ce143(\beta^-)Pr143(n,\gamma)Pr144(\beta^-)Nd144}$	95.8	0.3	75.7	95.2
			2.2	63.1	11.8	1.9
			1.8		8.2	2.5
			0.2		2.4	0.3
				22.1		
					6.8	0.3
					6.4	1.0
					1.0	

# Lanthanum activation characteristics

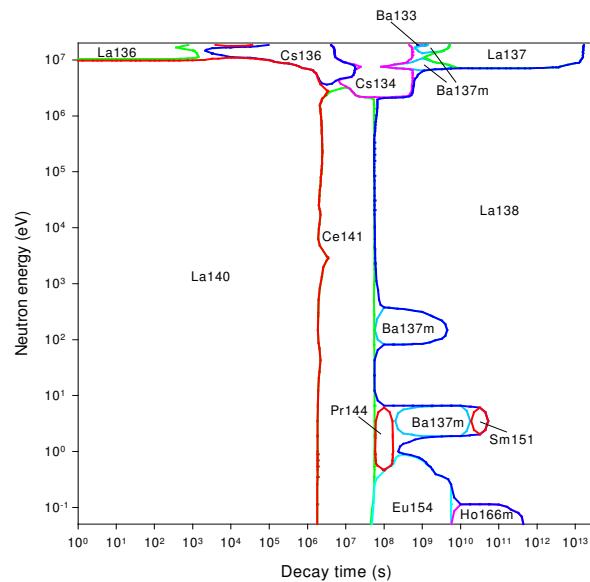


# Lanthanum importance diagrams & transmutation

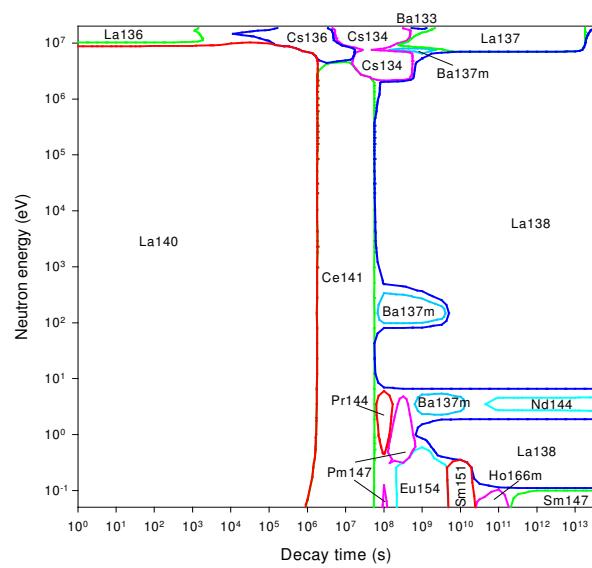
## Activity



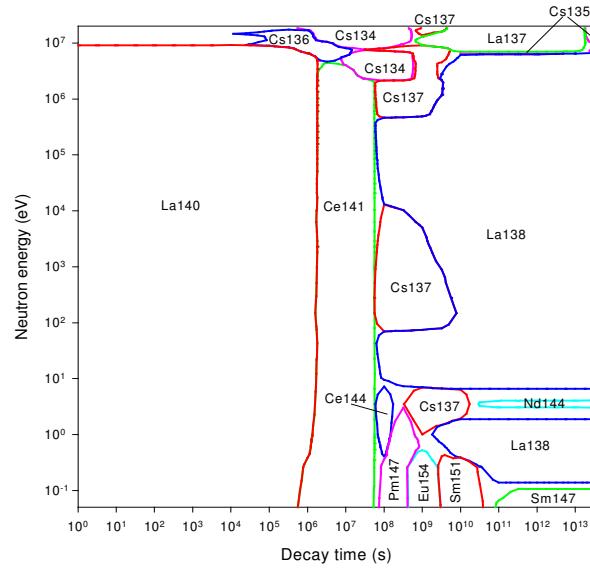
## Dose rate



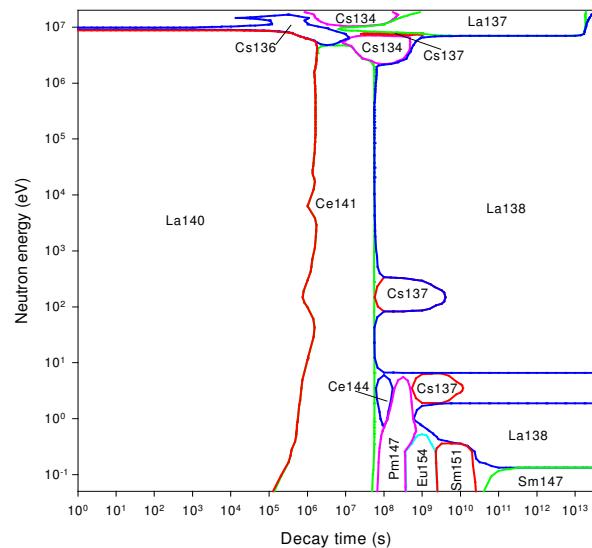
## Heat output



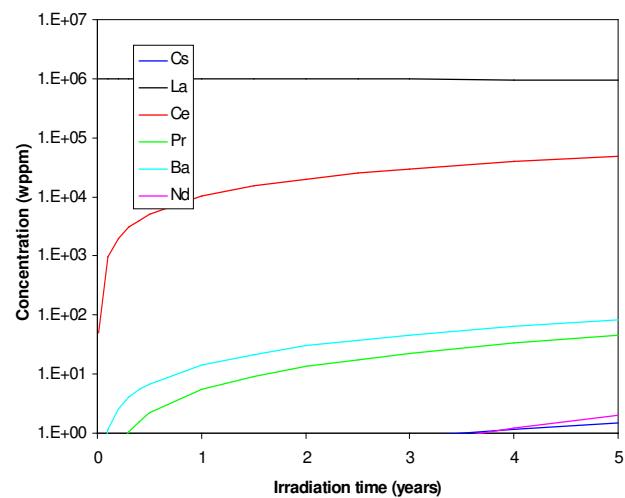
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Cerium

## General properties

Atomic number	58	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	66.5	Ce136	0.185
Melting point / K	1072	Ce138	0.251
Boiling point / K	3697	Ce140	88.450
Density / kgm <sup>-3</sup>	6770	Ce142	11.114 ( $T_{1/2} = 5.0 \cdot 10^{16}$ y)
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	11.4		
Electrical resistivity /Ωm	$7.3 \cdot 10^{-7}$		
Coefficient of thermal expansion / K <sup>-1</sup>	$5.2 \cdot 10^{-6}$		
Crystal structure	FCC		
Number of stable isotopes	3(4)		
Mean atomic weight	140.115		

## Activation properties

Act	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Heat	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y
Bq kg <sup>-1</sup>	1.46E15	1.03E15	9.09E14	1.19E14	7.55E8	2.32E8	kW kg <sup>-1</sup>	1.05E-1	5.37E-2	3.38E-2	3.73E-3	4.28E-9	1.19E-9
Ce139	51.38	72.74	80.86	99.94			Ce139m	49.22	1.96				
Ce139m	29.48	0.85					Ce139	22.24	43.65	68.16	99.93		
Ce141	10.92	15.46	16.19	0.06			La140	16.33	32.01	11.28			
La140	2.59	3.66	0.92				Ce141	5.98	11.74	17.27	0.07		
Pr142	1.08	1.53	0.07				Pr142	2.08	4.07	0.27			
Ce137	1.07	1.51	0.08				Ce143	1.66	3.26	0.82			
Ce143	1.06	1.50	0.27				Pr143	0.73	1.44	2.07			
Pr143	1.05	1.49	1.53				Ba137m	0.14	0.07			6.07	
Pr142m	0.38	0.42					La137					88.58	99.99
La137					97.38	100.00	Ba133					3.26	
H3						1.70	Cs137						1.81
Dose	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Ing	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y
Sv h <sup>-1</sup>	9.38E4	2.95E4	7.61E3	2.99E2	5.87E-4	6.47E-5	Sv kg <sup>-1</sup>	4.42E5	4.42E5	3.33E5	3.10E4	9.66E-2	1.88E-2
Ce139m	69.37	4.47					Ce139	43.98	44.04	57.40	99.81		
La140	26.41	83.83	72.01				Ce141	25.52	25.55	31.39	0.15		
Ce139	2.00	6.36	24.21	99.90			La140	17.06	17.06	5.02			
Ce143	0.51	1.60	0.99				Pr142	4.63	4.63	0.26			
Pr142	0.31	0.98	0.16				Pr143	4.15	4.16	5.00			
Ce141	0.21	0.66	2.38	0.03			Ce143	3.83	3.83	0.81			
Ba137m	0.19	0.15			54.05		Ba133				0.01	2.96	
Ba133					0.01	11.04	La137					61.65	99.99
La137						34.85	Cs137						34.82
Inh	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Clear	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y
Sv kg <sup>-1</sup>	2.13E6	2.13E6	2.00E6	2.26E5	6.52E0	2.02E0		5.48E11	2.44E11	1.55E11	1.95E10	3.02E4	6.10E3
Ce139	66.79	66.82	69.79	99.88			Ce139m	55.94	2.54				
Ce141	28.39	28.39	27.95	0.11			Ce139	22.37	50.17	77.64	99.96		
La140	1.95	1.95	0.46				La140	16.39	36.69	12.82			
Pr143	1.73	1.73	1.66				Ce141	2.64	5.91	8.62	0.03		
Ce143	0.60	0.60	0.10				Ce143	0.88	1.97	0.49			
Pr142	0.41	0.41	0.02				Pr142	0.40	0.89	0.06			
Ce137m	0.07	0.07	0.01				Ba137m	0.15	0.08			4.77	
Ba133					0.01	0.29	La137					64.11	99.99
La137						98.11	100.00	Cs137					28.58
Cs137						1.55	Ba133						2.53

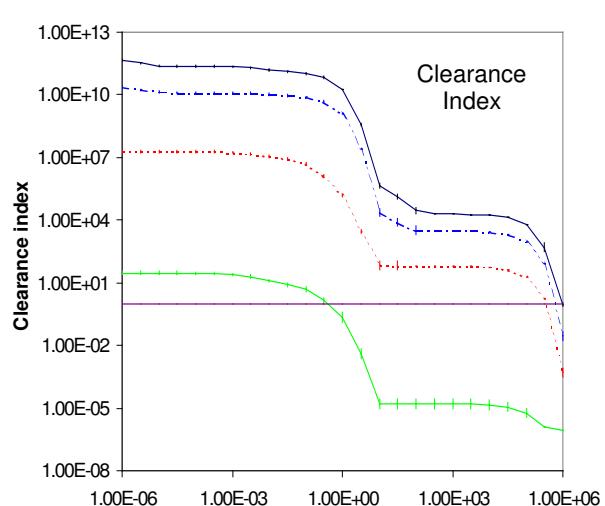
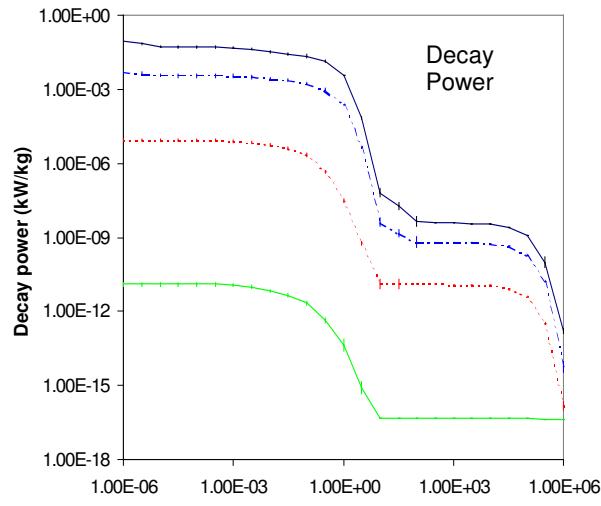
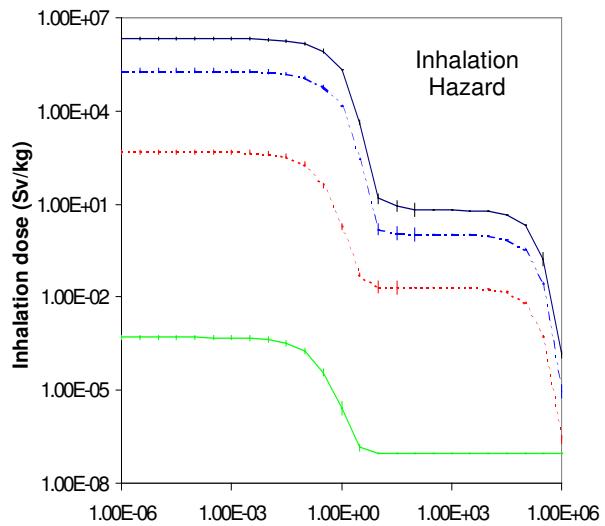
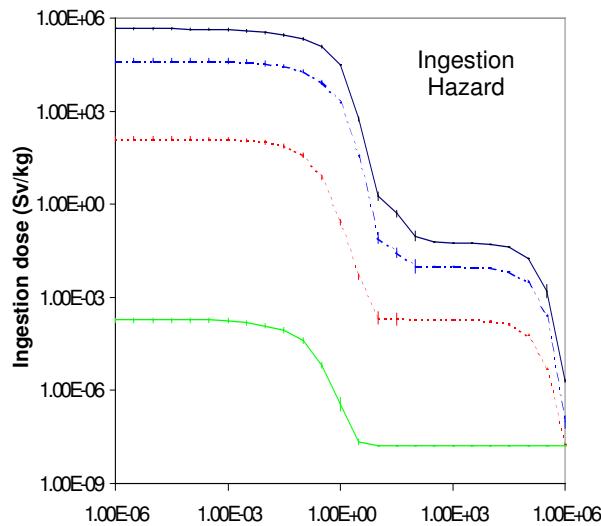
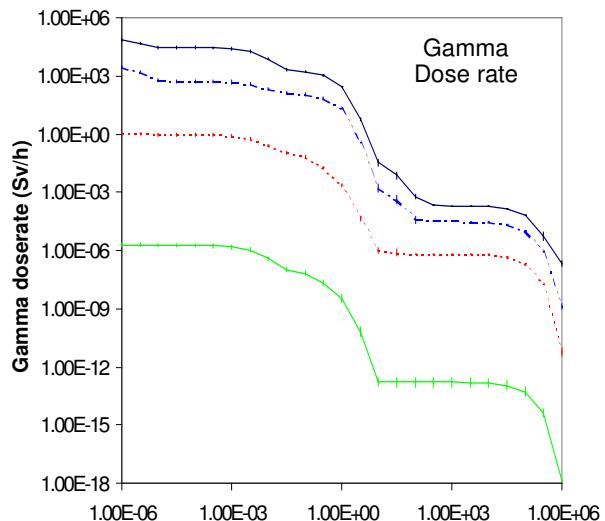
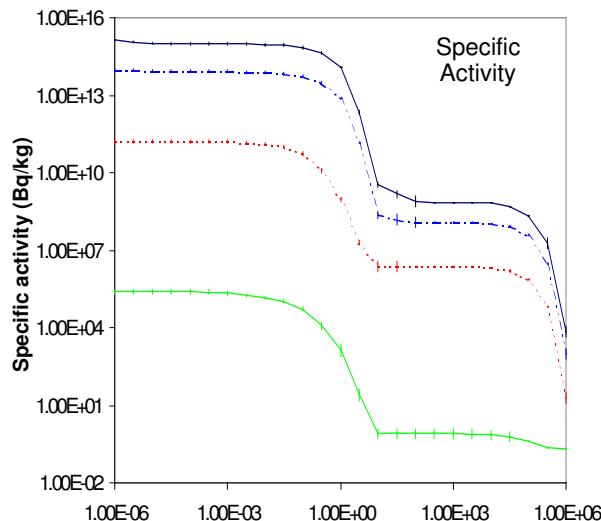
# Cerium

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Ce139m	56.1 s	Ce138(n, $\gamma$ )Ce139m Ce140(n,2n)Ce139m Ce142(n,3n)Ce140(n,2n)Ce139m	100.0	100.0	100.0	97.6 1.2
Ba137m	2.553 m	Ce140(n, $\alpha$ )Ba137m Ce142(n,n $\alpha$ )Ba138(n,2n)Ba137m <b>&amp;Ce140(n,2n)Ce139(<math>\beta^+</math>)La139(n,2n)La138(n,d)Ba137m</b> Ce140(n, $\alpha$ )Ba137(n,n')Ba137m <b>&amp;Ce140(n,2n)Ce139(<math>\beta^+</math>)La139(n,2n)La138(n,2n)</b> La137(n,p)Ba137m Ce142(n,3n)Ce140(n, $\alpha$ )Ba137m <b>&amp;Ce140(n,2n)Ce139(<math>\beta^+</math>)La139(n,d)Ba138(n,2n)Ba137m</b>	100.0	100.0	100.0	88.5 1.8 1.5 1.2 1.1 1.1 1.0
Pr144	17.28 m	<b>&amp;Ce142(n,<math>\gamma</math>)Ce143(<math>\beta^-</math>)Pr143(n,<math>\gamma</math>)Pr144</b> <b>&amp;Ce140(n,<math>\gamma</math>)Ce141(n,<math>\gamma</math>)Ce142(n,<math>\gamma</math>)Ce143(<math>\beta^-</math>)</b> Pr143(n, $\gamma$ )Pr144 Ce142(n, $\gamma$ )Ce143(n, $\gamma$ )Ce144( $\beta^-$ )Pr144 <b>&amp;Ce142(n,<math>\gamma</math>)Ce143(<math>\beta^-</math>)Pr143(<math>\beta^-</math>)Nd143(n,<math>\gamma</math>)Nd144(n,p)Pr144</b>	97.6 1.5 0.7	99.9	97.0	88.2 9.1 3.0
Ce137	9.0 h	Ce136(n, $\gamma$ )Ce137 Ce136(n, $\gamma$ )Ce137m(IT)Ce137 <b>&amp;Ce140(n,2n)Ce139(n,2n)Ce138(n,2n)Ce137</b> <b>&amp;Ce138(n,2n)Ce137</b>	86.8 13.2	86.7 13.3	86.7 13.3	72.5 27.0
Pr142	19.13 h	<b>&amp;Ce140(n,<math>\gamma</math>)Ce141(<math>\beta^-</math>)Pr141(n,<math>\gamma</math>)Pr142</b> <b>&amp;Ce142(n,2n)Ce141(<math>\beta^-</math>)Pr141(n,<math>\gamma</math>)Pr142</b>	99.4	99.1	99.1	0.4 98.2
Ce143	1.375 d	Ce142(n, $\gamma$ )Ce143 Ce140(n, $\gamma$ )Ce141(n, $\gamma$ )Ce142(n, $\gamma$ )Ce143	98.4 1.5	100.0	100.0	99.9
La140	1.679 d	<b>&amp;Ce136(n,<math>\gamma</math>)Ce137(<math>\beta^+</math>)La137(n,<math>\gamma</math>)La138(n,<math>\gamma</math>)</b> La139(n, $\gamma$ )La140 <b>&amp;Ce138(n,<math>\gamma</math>)Ce139(<math>\beta^+</math>)La139(n,<math>\gamma</math>)La140</b> Ce140(n,p)La140 <b>&amp;Ce140(n,2n)Ce139(<math>\beta^+</math>)La139(n,<math>\gamma</math>)La140</b> Ce142(n,3n)Ce140(n,p)La140	87.5 12.7	94.5 5.5	100.0	96.1 2.1 1.2
Pr143	13.56 d	Ce142(n, $\gamma$ )Ce143( $\beta^-$ )Pr143 Ce140(n, $\gamma$ )Ce141(n, $\gamma$ )Ce142(n, $\gamma$ )Ce143( $\beta^-$ )Pr143	98.3 1.5	100.0	100.0	99.7
Ce141	32.5 d	Ce140(n, $\gamma$ )Ce141 Ce142(n,2n)Ce141	99.9	100.0	100.0	0.4 99.3
Ce139	137.65 d	<b>&amp;Ce138(n,<math>\gamma</math>)Ce139</b> <b>&amp;Ce140(n,2n)Ce139</b> <b>&amp;Ce142(n,3n)Ce140(n,2n)Ce139</b>	99.8	100.0	100.0	98.4 1.1
Ce144	284.9 d	Ce142(n, $\gamma$ )Ce143(n, $\gamma$ )Ce144 Ce140(n, $\gamma$ )Ce141(n, $\gamma$ )Ce142(n, $\gamma$ )Ce143(n, $\gamma$ )Ce144	98.8 1.2	100.0	100.0	99.9
Pm147	2.622 y	Ce142(n, $\gamma$ )Ce143( $\beta^-$ )Pr143( $\beta^-$ )Nd143(n, $\gamma$ )Nd144(n, $\gamma$ ) Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147 <b>&amp;Ce140(n,<math>\gamma</math>)Ce141(<math>\beta^-</math>)Pr141(n,<math>\gamma</math>)Pr142(<math>\beta^-</math>)</b> Nd142(n, $\gamma$ )Nd143(n, $\gamma$ )Nd144(n, $\gamma$ )Nd145(n, $\gamma$ ) Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147 <b>&amp;Ce142(n,<math>\gamma</math>)Ce143(<math>\beta^-</math>)Pr143(n,<math>\gamma</math>)Pr144(<math>\beta^-</math>)</b> Nd144(n, $\gamma$ )Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147	80.7 12.9 6.1	95.4 4.6	93.9 6.1	87.9 11.1
Eu154	8.593 y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0	100.0	100.0	
Ba133	10.574 y	Ce136(n, $\alpha$ )Ba133 Ce136(n, $\alpha$ )Ba133m(IT)Ba133 <b>&amp;Ce136(n,2n)Ce135(<math>\beta^+</math>)La135(<math>\beta^+</math>)Ba135(n,2n)</b> Ba134(n,2n)Ba133	50.1 49.9	50.1 49.9	50.0 50.0	12.0 14.8 68.3

H3	12.33 y	Ce140(n, $\gamma$ )Ce141( $\beta^-$ )Pr141(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Ce136(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 <b>&amp;Ce136(n,<math>\gamma</math>)Ce137(<math>\beta^+</math>)La137(n,X)H1(n,<math>\gamma</math>)H2(n,<math>\gamma</math>)H3</b> <b>&amp;Ce136(n,<math>\gamma</math>)Ce137(<math>\beta^+</math>)La137(n,<math>\gamma</math>)La138(n,X)H1(n,<math>\gamma</math>)H2(n,<math>\gamma</math>)H3</b> Ce140(n,X)H3 <b>&amp;Ce140(n,2n)Ce139(<math>\beta^+</math>)La139(n,X)H3</b> Ce142(n,2n)Ce141( $\beta^-$ )Pr141(n,X)H3 <b>&amp;Ce140(n,2n)Ce139(n,X)H3</b> Ce142(n,X)H3	61.0 30.2 2.7 0.2	0.8 31.7 47.5 15.0			37.2 26.6 14.5 14.3 3.1
Cs137	30.171 y	<b>&amp;Ce136(n,<math>\gamma</math>)Ce137(<math>\beta^+</math>)La137(n,<math>\gamma</math>)La138(n,<math>\gamma</math>)</b> La139(n, $\alpha$ )Cs136(n, $\gamma$ )Cs137 <b>&amp;Ce136(n,<math>\gamma</math>)Ce137(<math>\beta^+</math>)La137(n,<math>\alpha</math>)Cs134(n,<math>\gamma</math>)</b> Cs135(n, $\gamma$ )Cs136(n, $\gamma$ )Cs137 <b>&amp;Ce136(n,<math>\gamma</math>)Ce137(<math>\beta^+</math>)La137(n,<math>\gamma</math>)La138(n,<math>\gamma</math>)</b> La139(n, $\gamma$ )La140(n, $\alpha$ )Cs137 <b>&amp;Ce138(n,<math>\gamma</math>)Ce139(<math>\beta^+</math>)La139(n,<math>\alpha</math>)Cs136(n,<math>\gamma</math>)Cs137</b> <b>&amp;Ce136(n,<math>\alpha</math>)Ba133(<math>\beta^+</math>)Cs133(n,<math>\gamma</math>)Cs134(n,<math>\gamma</math>)</b> Cs135(n, $\gamma$ )Cs136(n, $\gamma$ )Cs137 <b>&amp;Ce136(n,<math>\gamma</math>)Ce137(<math>\beta^+</math>)La137(n,<math>\gamma</math>)La138(n,<math>\alpha</math>)</b> Cs135(n, $\gamma$ )Cs136(n, $\gamma$ )Cs137 <b>&amp;Ce138(n,<math>\gamma</math>)Ce139(<math>\beta^+</math>)La139(n,<math>\gamma</math>)La140(n,<math>\alpha</math>)Cs137</b> <b>&amp;Ce140(n,<math>\alpha</math>)Ba137(n,p)Cs137</b> <b>&amp;Ce140(n,2n)Ce139(<math>\beta^+</math>)La139(n,h)Cs137</b>	36.9 20.8 17.2 8.7 6.6 5.8 4.0	52.6 5.7 98.9 38.5 0.1 3.0 0.8	0.1		85.7 11.8
La137	$6.0 \cdot 10^4$ y	<b>&amp;Ce136(n,<math>\gamma</math>)Ce137(<math>\beta^+</math>)La137</b> Ce136(n, $\gamma$ )Ce137m( $\beta^+$ )La137 <b>&amp;Ce140(n,2n)Ce139(<math>\beta^+</math>)La139(n,2n)La138(n,2n)La137</b> <b>&amp;Ce140(n,2n)Ce139(n,2n)Ce138(n,2n)Ce137(<math>\beta^+</math>)La137</b> <b>&amp;Ce138(n,2n)Ce137(<math>\beta^+</math>)La137</b>	99.9 0.1	99.9 0.1	99.9 0.1		64.3 19.2 15.8
Cs135	$2.4 \cdot 10^6$ y	<b>&amp;Ce136(n,<math>\gamma</math>)Ce137(<math>\beta^+</math>)La137(n,<math>\alpha</math>)Cs134(n,<math>\gamma</math>)Cs135</b> <b>&amp;Ce136(n,<math>\alpha</math>)Ba133(<math>\beta^+</math>)Cs133(n,<math>\gamma</math>)Cs134(n,<math>\gamma</math>)Cs135</b> <b>&amp;Ce136(n,<math>\gamma</math>)Ce137(<math>\beta^+</math>)La137(n,<math>\gamma</math>)La138(n,<math>\alpha</math>)Cs135</b> <b>&amp;Ce140(n,2n)Ce139(<math>\beta^+</math>)La139(n,2n)La138(n,<math>\alpha</math>)Cs135</b> <b>&amp;Ce140(n,2n)Ce139(<math>\beta^+</math>)La139(n,<math>\alpha</math>)Cs135</b> <b>&amp;Ce136(n,2n)Ce135(<math>\beta^+</math>)La135(<math>\beta^+</math>)Ba135(n,p)Cs135</b> <b>&amp;Ce140(n,2n)Ce139(<math>\beta^+</math>)La139(n,<math>\alpha</math>)Cs136(n,2n)Cs135</b>	57.5 24.8 17.7	13.2 0.8 85.9	45.9 4.0 50.0		84.8 5.6 4.9 2.0
La138	$1.1 \cdot 10^{11}$ y	<b>&amp;Ce136(n,<math>\gamma</math>)Ce137(<math>\beta^+</math>)La137(n,<math>\gamma</math>)La138</b> Ce136(n, $\gamma$ )Ce137m( $\beta^+$ )La137(n, $\gamma$ )La138 <b>&amp;Ce140(n,2n)Ce139(<math>\beta^+</math>)La139(n,2n)La138</b>	99.9 0.1	99.9 0.1	99.9 0.1		99.2
Sm147	$1.1 \cdot 10^{11}$ y	Ce142(n, $\gamma$ )Ce143( $\beta^-$ )Pr143( $\beta^-$ )Nd143(n, $\gamma$ )Nd144(n, $\gamma$ ) Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147( $\beta^-$ )Sm147 <b>&amp;Ce140(n,<math>\gamma</math>)Ce141(<math>\beta^-</math>)Pr141(n,<math>\gamma</math>)Pr142(<math>\beta^-</math>)</b> Nd142(n, $\gamma$ )Nd143(n, $\gamma$ )Nd144(n, $\gamma$ )Nd145(n, $\gamma$ ) Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147( $\beta^-$ )Sm147 <b>&amp;Ce142(n,<math>\gamma</math>)Ce143(<math>\beta^-</math>)Pr143(n,<math>\gamma</math>)Pr144(<math>\beta^-</math>)</b> Nd144(n, $\gamma$ )Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ ) Pm147( $\beta^-$ )Sm147	83.2 10.2 6.5	95.2 4.8 7.4	92.6 13.2		85.7
Ce142	$5.0 \cdot 10^{16}$ y	Ce140(n, $\gamma$ )Ce141(n, $\gamma$ )Ce142 *Nuclide present in starting material	1.6 98.4*	100.0*	100.0*		100.0*

# Cerium activation characteristics

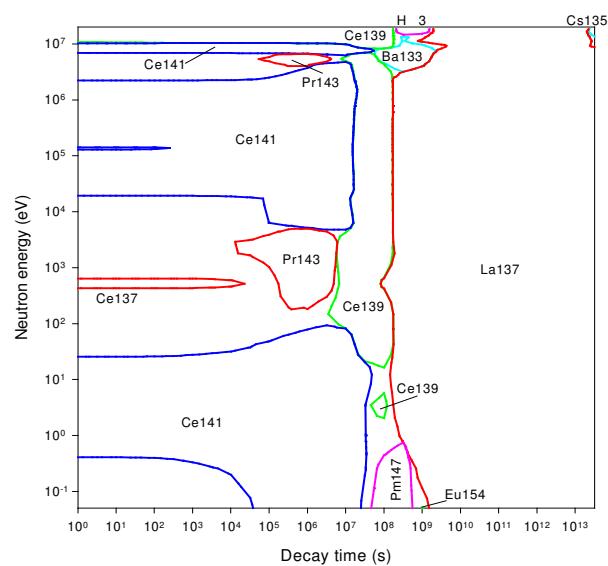


Decay time (years)

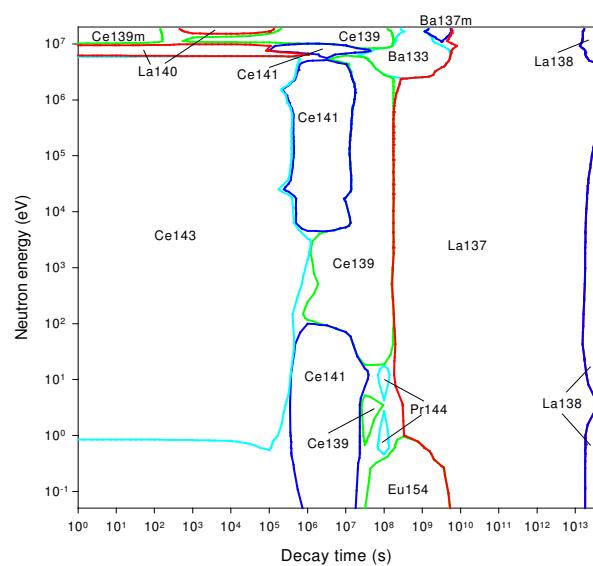
Decay time (years)

# Cerium importance diagrams & transmutation

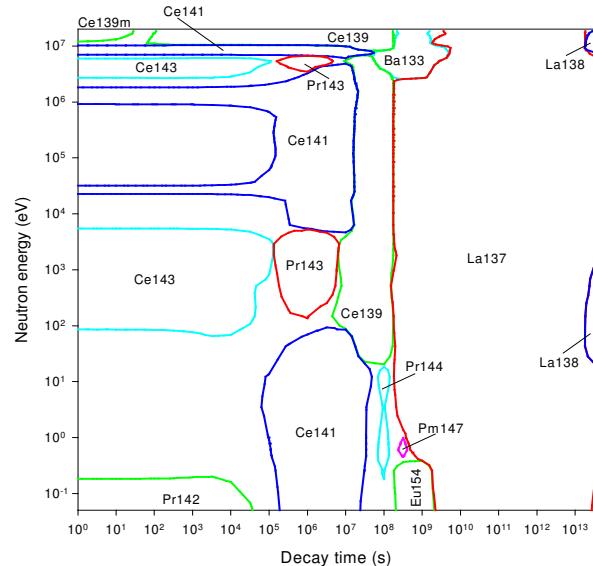
## Activity



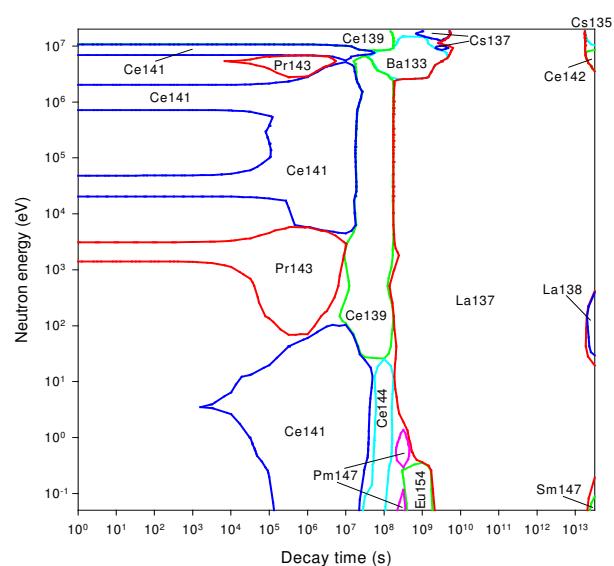
## Dose rate



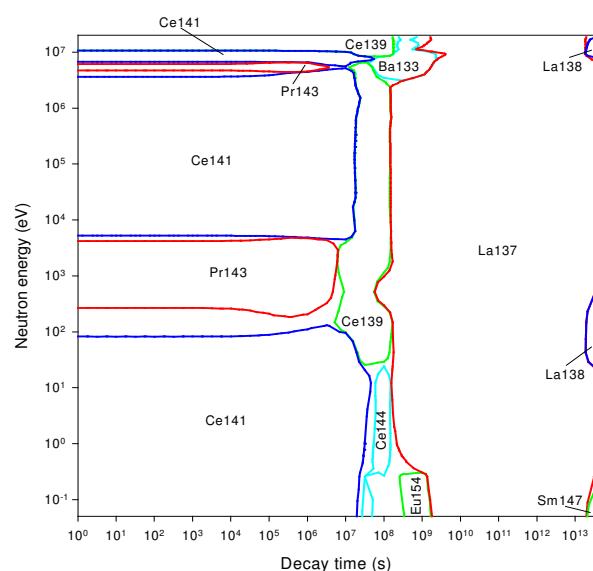
## Heat output



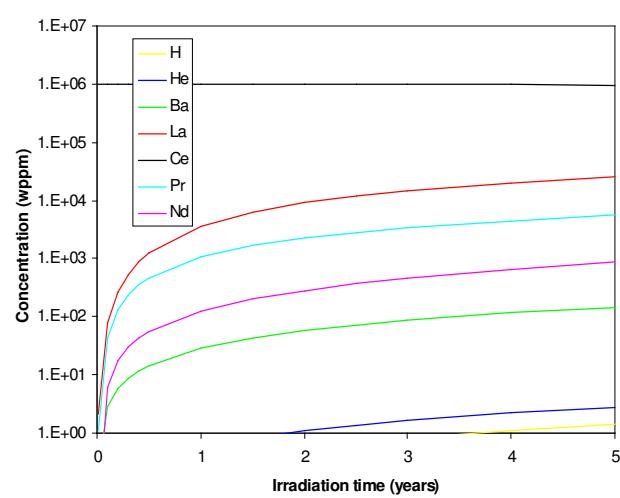
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Praseodymium

## General properties

Atomic number		59	Isotopes	Isotopic abundances / %	
		9.2		Pr141	100.0
Crustal abundance / wppm		1204			
Melting point / K		3783			
Boiling point / K		6773			
Density / kgm <sup>-3</sup>		12.5			
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>		6.8 10 <sup>-7</sup>			
Electrical resistivity /Ωm		6.7 10 <sup>-6</sup>			
Coefficient of thermal expansion / K <sup>-1</sup>		HCP			
Crystal structure		1			
Number of stable isotopes		140.90765			
Mean atomic weight					

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	4.39E15	3.58E15	1.36E14	4.29E12	1.96E8	1.48E6	kW kg <sup>-1</sup>	5.03E-1	3.99E-1	1.56E-2	1.33E-4	2.03E-10	7.65E-12
Pr142	56.84	69.44	76.71				Pr142	68.89	86.58	92.89			
Pr142m	19.79	18.87					Pr140	29.27	12.58				
Pr140	19.27	8.05					Nd141m	0.77	0.03				
Nd141	2.24	2.68					Nd141	0.28	0.34				
Nd141m	0.73	0.03					Ce139	0.17	0.21	5.25	99.89		
Ce139	0.61	0.74	19.21	98.78			Ce141	0.05	0.06	1.34	0.07		
Ce141	0.13	0.16	3.89	0.06			H3				0.03	85.90	
H3				1.16	97.57		La137					11.91	99.86
La137					2.40	99.99	Ba137m						1.69
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	1.27E5	7.19E4	2.08E3	1.01E1	5.36E-6	4.04E-7	Sv kg <sup>-1</sup>	3.28E6	3.26E6	1.47E5	1.11E3	8.85E-3	1.20E-4
Pr140	57.11	34.37					Pr142	98.99	99.19	92.53			
Pr142	35.74	62.91	91.33				Pr142m	0.45	0.35				
Nd141m	3.73	0.20					Ce139	0.21	0.21	4.63	99.65		
Ce139m	1.96	0.07					Pr140	0.15	0.05				
Nd141	0.80	1.38					Ce141	0.12	0.13	2.56	0.15		
La140	0.40	0.70	5.38				La140	0.05	0.05	0.24			
Ce139	0.05	0.09	2.99	99.97			H3				0.19	90.66	
Ba137m	0.01				76.75		Cs137					5.03	
La137					22.90	95.88	La137					4.30	99.88
La138					0.31	4.12	Cs135						0.07
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	1.46E6	1.45E6	1.28E5	8.08E3	9.20E-2	1.29E-2		8.96E11	5.33E11	1.97E10	6.95E8	3.21E2	3.91E1
Pr142	94.22	94.48	45.04				Pr140	55.49	31.84				
Ce139	3.48	3.50	38.96	99.73			Pr142	38.66	64.87	73.68			
Ce141	1.50	1.50	15.76	0.11			Nd141m	2.56	0.13				
Pr142m	0.42	0.33					Ce139m	1.34	0.05				
Pr140	0.28	0.10					Nd141	0.84	1.38				
La140	0.06	0.06	0.15				Ce139	0.49	0.82	21.78	99.97		
Nd141	0.03	0.03					La140	0.21	0.35	2.09			
Pr143	0.01	0.01	0.07				Ce141	0.06	0.10	2.44	0.03		
H3			0.01	0.16	54.04		La137					38.57	99.85
La137					44.50	99.95	Cs137					35.61	
Cs137					1.45		H3					19.85	
La138					0.01	0.06	Ba137m					5.95	

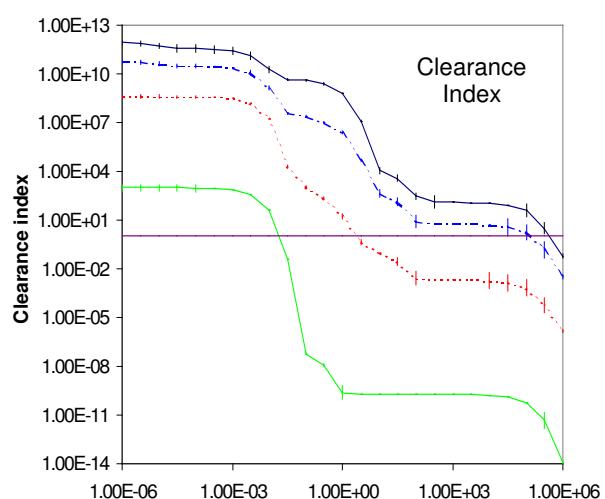
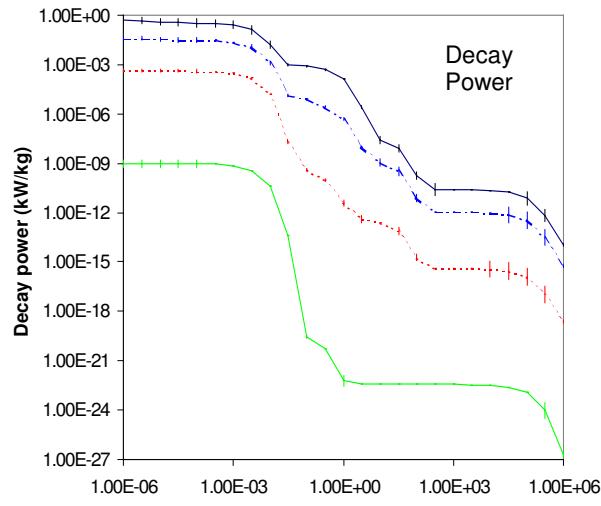
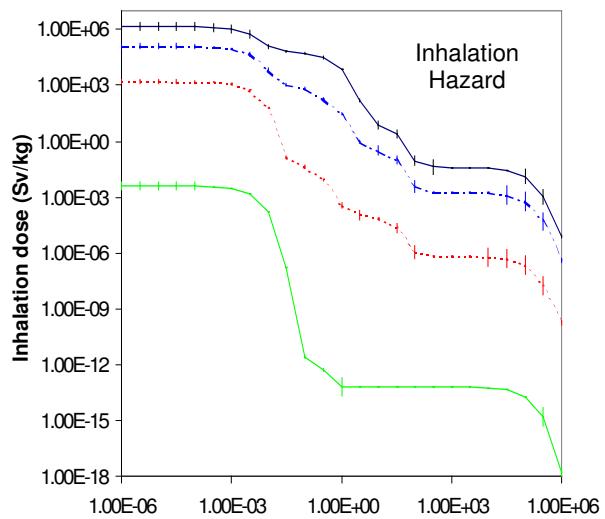
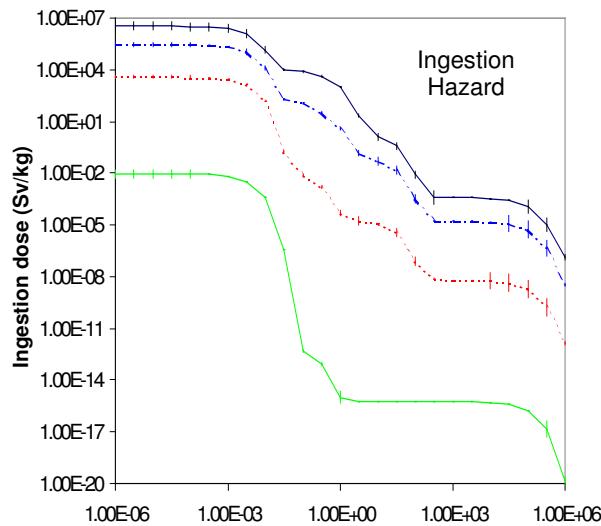
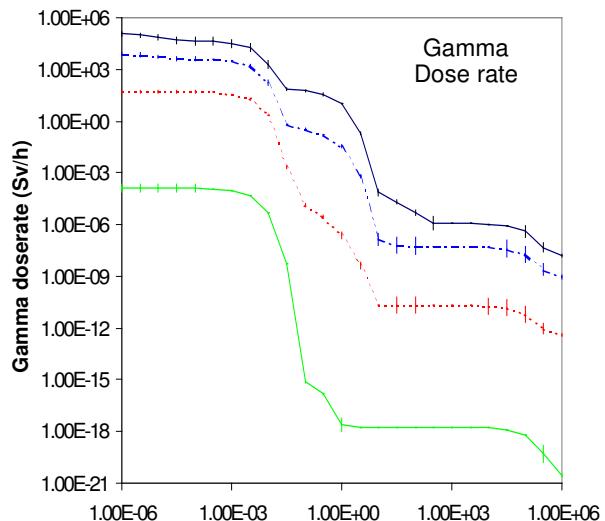
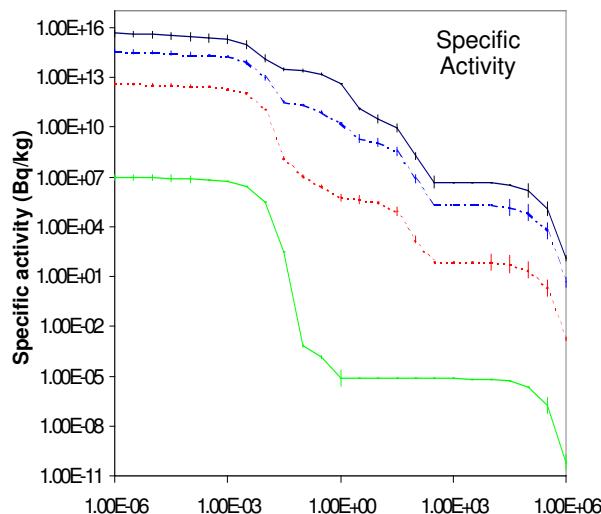
# Praseodymium

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Ba137m	2.553 m	&Pr141(n, $\gamma$ )Pr142( $\beta^-$ )Nd142(n, $\gamma$ )Nd143(n, $\alpha$ ) Ce140(n, $\alpha$ )Ba137m Pr141(n,2n)Pr140( $\beta^+$ )Ce140(n, $\alpha$ )Ba137m	99.8			95.9
Pr140	3.39 m	Pr141(n,2n)Pr140				99.8
Pr144	17.28 m	&Pr141(n, $\gamma$ )Pr142(n, $\gamma$ )Pr143(n, $\gamma$ )Pr144 &Pr141(n, $\gamma$ )Pr142( $\beta^+$ )Ce142(n, $\gamma$ )Ce143( $\beta^-$ ) Pr143(n, $\gamma$ )Pr144 &Pr141(n, $\gamma$ )Pr142( $\beta^-$ )Nd142(n, $\gamma$ )Nd143(n, $\gamma$ )Nd144(n,p)Pr144 &Pr141(n, $\gamma$ )Pr142( $\beta^-$ )Nd142(n, $\gamma$ )Nd143(n,p)Pr143(n, $\gamma$ )Pr144	98.7 1.3	98.3 1.7	98.9 1.1	5.3 0.5 86.6 7.3
Pr142	19.13 h	&Pr141(n, $\gamma$ )Pr142	99.9	100.0	100.0	99.6
La140	1.679 d	Pr141(n, $\alpha$ )La138(n, $\gamma$ )La139(n, $\gamma$ )La140 &Pr141(n, $\gamma$ )Pr142( $\beta^-$ )Nd142(n, $\alpha$ )Ce139( $\beta^+$ ) La139(n, $\gamma$ )La140 &Pr141(n, $\gamma$ )Pr142( $\beta^+$ )Ce142(n, $\alpha$ )Ba139( $\beta^-$ )La139(n, $\gamma$ )La140 Pr141(n,2n)Pr140( $\beta^+$ )Ce140(n,p)La140	86.5 13.1	98.7 1.3	62.5 36.4 1.1	
Nd147	11.02 d	&Pr141(n, $\gamma$ )Pr142( $\beta^-$ )Nd142(n, $\gamma$ )Nd143(n, $\gamma$ ) Nd144(n, $\gamma$ )Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147 &Pr141(n, $\gamma$ )Pr142(n, $\gamma$ )Pr143( $\beta^-$ )Nd143(n, $\gamma$ ) Nd144(n, $\gamma$ )Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147	99.9 0.1	88.2 11.4	97.0 3.0	
Pr143	13.56 d	&Pr141(n, $\gamma$ )Pr142(n, $\gamma$ )Pr143 &Pr141(n, $\gamma$ )Pr142( $\beta^+$ )Ce142(n, $\gamma$ )Ce143( $\beta^-$ )Pr143 &Pr141(n, $\gamma$ )Pr142( $\beta^-$ )Nd142(n, $\gamma$ )Nd143(n,p)Pr143	98.1 1.9	98.2 1.8	98.9 1.1	40.0 3.6 55.7
Eu156	15.2 d	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0	100.0		
Ce141	32.5 d	&Pr141(n, $\gamma$ )Pr142( $\beta^-$ )Nd142(n, $\gamma$ )Nd143(n, $\alpha$ ) Ce140(n, $\gamma$ )Ce141 Pr141(n,p)Ce141 Pr141(n,2n)Pr140( $\beta^+$ )Ce140(n, $\gamma$ )Ce141	99.9	99.9	1.5 98.4	97.5 1.9
Pm148m	41.05 d	&Pr141(n, $\gamma$ )Pr142( $\beta^-$ )Nd142(n, $\gamma$ )Nd143(n, $\gamma$ ) Nd144(n, $\gamma$ )Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ ) Pm147(n, $\gamma$ )Pm148m &Pr141(n, $\gamma$ )Pr142(n, $\gamma$ )Pr143( $\beta^-$ )Nd143(n, $\gamma$ ) Nd144(n, $\gamma$ )Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ ) Pm147(n, $\gamma$ )Pm148m	99.8 0.2	87.6 12.4	96.5 3.5	
Ta182	114.7 d	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ ) with reaction cross sections only high enough for production below 0.26eV				
Ce139	137.65 d	&Pr141(n, $\gamma$ )Pr142( $\beta^-$ )Nd142(n, $\alpha$ )Ce139 &Pr141(n, $\gamma$ )Pr142( $\beta^-$ )Nd142(n, $\gamma$ )Nd143(n,n $\alpha$ )Ce139 &Pr141(n,2n)Pr140( $\beta^+$ )Ce140(n,2n)Ce139	97.1 2.9	100.0	99.9	
Ce144	284.9 d	&Pr141(n, $\gamma$ )Pr142( $\beta^+$ )Ce142(n, $\gamma$ )Ce143(n, $\gamma$ )Ce144 Pr141(n,p)Ce141(n, $\gamma$ )Ce142(n, $\gamma$ )Ce143(n, $\gamma$ )Ce144	100.0	100.0	100.0	88.1 11.3
Cs134	2.065 y	&Pr141(n,2n)Pr140( $\beta^+$ )Ce140(n,2n)Ce139( $\beta^+$ ) La139(n,2n)La138(n,2n)La137(n, $\alpha$ )Cs134 &Pr141(n,2n)Pr140( $\beta^+$ )Ce140(n,2n)Ce139( $\beta^+$ ) La139(n,2n)La138(n, $\alpha$ )Cs135(n,2n)Cs134 &Pr141(n, $\alpha$ )La138(n,2n)La137(n, $\alpha$ )Cs134 &Pr141(n, $\alpha$ )La138(n, $\alpha$ )Cs135(n,2n)Cs134 &Pr141(n,2n)Pr140( $\beta^+$ )Ce140(n,2n)Ce139( $\beta^+$ ) La139(n,2n)La138(n,n $\alpha$ )Cs134 &Pr141(n,n $\alpha$ )La137(n, $\alpha$ )Cs134 &Pr141(n,2n)Pr140( $\beta^+$ )Ce140(n,2n)Ce139(n,2n) Ce138(n,2n)Ce137( $\beta^+$ )La137(n, $\alpha$ )Cs134 &Pr141(n, $\alpha$ )La138(n,n $\alpha$ )Cs134 &Pr141(n,2n)Pr140( $\beta^+$ )Ce140(n,2n)Ce139( $\beta^+$ ) La139(n,n $\alpha$ )Cs135(n,2n)Cs134				21.3 17.7 13.1 10.8 10.5 9.0 5.8 3.4 1.8

Pm147	2.622 y	&Pr141(n, $\gamma$ )Pr142( $\beta^-$ )Nd142(n, $\gamma$ )Nd143(n, $\gamma$ ) Nd144(n, $\gamma$ )Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147 &Pr141(n, $\gamma$ )Pr142(n, $\gamma$ )Pr143( $\beta^-$ )Nd143(n, $\gamma$ ) Nd144(n, $\gamma$ )Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147	99.8 0.2	87.3 12.3	96.6 3.4	
Eu154	8.593 y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0	100.0		
H3	12.33 y	Pr141(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Pr141(n,X)H3	93.1	95.2	100.0	98.8
Eu152	13.522 y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0	100.0		
Cs137	30.171 y	&Pr141(n, $\alpha$ )La138(n, $\gamma$ )La139(n, $\alpha$ )Cs136(n, $\gamma$ )Cs137 &Pr141(n, $\alpha$ )La138(n, $\alpha$ )Cs135(n, $\gamma$ )Cs136(n, $\gamma$ )Cs137 &Pr141(n,2n)Pr140( $\beta^+$ )Ce140(n, $\alpha$ )Ba137(n,p)Cs137 &Pr141(n,2n)Pr140( $\beta^+$ )Ce140(n,2n)Ce139( $\beta^+$ )La139(n,h)Cs137		56.3 43.7		87.5 11.1
Sm151	90.0 y	&Pr141(n, $\gamma$ )Pr142( $\beta^-$ )Nd142(n, $\gamma$ )Nd143(n, $\gamma$ )Nd144 (n, $\gamma$ )Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ ) Pm148(n, $\gamma$ )Pm149( $\beta^-$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151 &Pr141(n, $\gamma$ )Pr142( $\beta^-$ )Nd142(n, $\gamma$ )Nd143(n, $\gamma$ )Nd144 (n, $\gamma$ )Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147(n, $\gamma$ )Nd148(n, $\gamma$ ) Nd149( $\beta^-$ )Pm149( $\beta^-$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151 &Pr141(n, $\gamma$ )Pr142( $\beta^-$ )Nd142(n, $\gamma$ )Nd143(n, $\gamma$ )Nd144 (n, $\gamma$ )Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147( $\beta^-$ ) Sm147(n, $\gamma$ )Sm148(n, $\gamma$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151 &Pr141(n, $\gamma$ )Pr142(n, $\gamma$ )Pr143( $\beta^-$ )Nd143(n, $\gamma$ )Nd144(n, $\gamma$ ) Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147( $\beta^-$ )Sm147(n, $\gamma$ ) Sm148(n, $\gamma$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151 *Plus other similar pathways of (n, $\gamma$ ), ( $\beta^-$ )	16.4 1.7 0.2 81.7*	3.3 10.0 3.4 82.5*	9.1 0.8 4.5 0.3	
Ho166m	1200.0 y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0			
La137	6.0 $10^4$ y	&Pr141(n,2n)Pr140( $\beta^+$ )Ce140(n,2n)Ce139( $\beta^+$ ) La139(n,2n)La138(n,2n)La137 &Pr141(n,2n)Pr140( $\beta^+$ )Ce140(n,2n)Ce139(n,2n) Ce138(n,2n)Ce137( $\beta^+$ )La137 Pr141(n, $\alpha$ )La138(n,2n)La137 Pr141(n, $\alpha$ )La137				49.7 19.6 19.5 10.1
Cs135	2.4 $10^6$ y	&Pr141(n, $\alpha$ )La138(n, $\alpha$ )Cs135 &Pr141(n,2n)Pr140( $\beta^+$ )Ce140(n,2n)Ce139( $\beta^+$ ) La139(n,2n)La138(n, $\alpha$ )Cs135 &Pr141(n,2n)Pr140( $\beta^+$ )Ce140(n,2n)Ce139( $\beta^+$ )La139(n,n $\alpha$ )Cs135 &Pr141(n,2n)Pr140( $\beta^+$ )Ce140(n,2n)Ce139( $\beta^+$ ) La139(n, $\alpha$ )Cs136(n,2n)Cs135	99.9	100.0	100.0	25.3 64.7 5.7 2.0
La138	1.1 $10^{11}$ y	Pr141(n, $\alpha$ )La138 &Pr141(n,2n)Pr140( $\beta^+$ )Ce140(n,2n)Ce139( $\beta^+$ ) La139(n,2n)La138	100.0	100.0	100.0	15.2 83.7
Sm147	1.1 $10^{11}$ y	&Pr141(n, $\gamma$ )Pr142( $\beta^-$ )Nd142(n, $\gamma$ )Nd143(n, $\gamma$ )Nd144 (n, $\gamma$ )Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147( $\beta^-$ )Sm147 &Pr141(n, $\gamma$ )Pr142(n, $\gamma$ )Pr143( $\beta^-$ )Nd143(n, $\gamma$ )Nd144(n, $\gamma$ ) Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147( $\beta^-$ )Sm147	99.8 0.2	86.4 13.2	95.9 4.0	
Nd144	2.1 $10^{15}$ y	&Pr141(n, $\gamma$ )Pr142( $\beta^-$ )Nd142(n, $\gamma$ )Nd143(n, $\gamma$ )Nd144 &Pr141(n, $\gamma$ )Pr142(n, $\gamma$ )Pr143( $\beta^-$ )Nd143(n, $\gamma$ )Nd144	99.9 0.1	93.1 6.7	98.2 1.8	99.8 0.1
Ce142	5.0 $10^{16}$ y	&Pr141(n, $\gamma$ )Pr142( $\beta^+$ )Ce142 Pr141(n,p)Ce141(n, $\gamma$ )Ce142	100.0	100.0	100.0	87.9 11.4

# Praseodymium activation characteristics

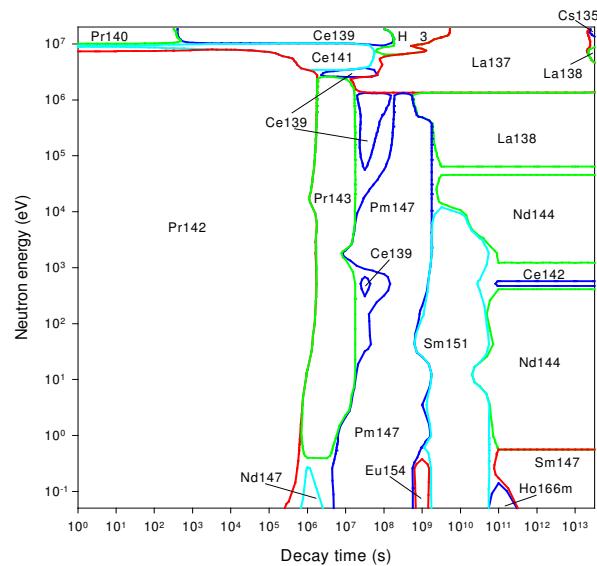


Decay time (years)

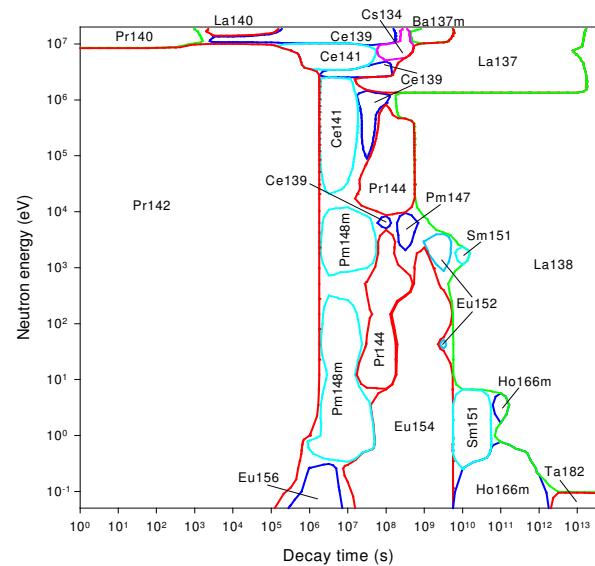
Decay time (years)

# Praseodymium importance diagrams & transmutation

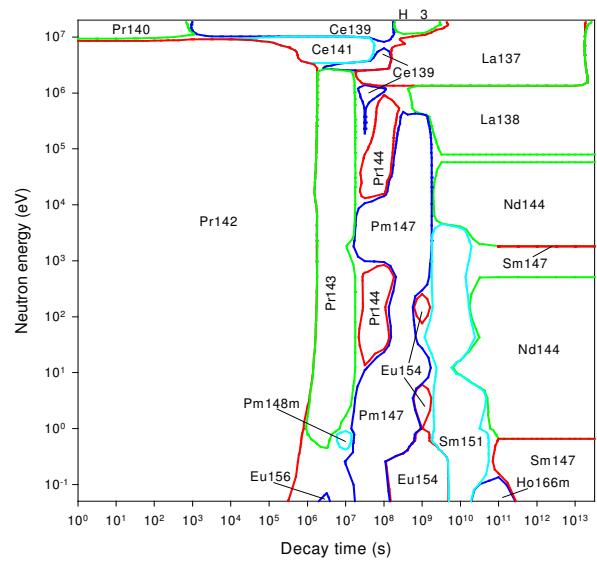
## Activity



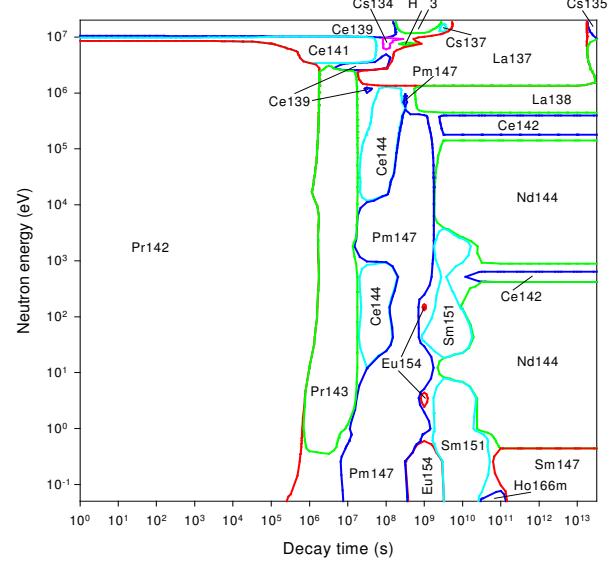
## Dose rate



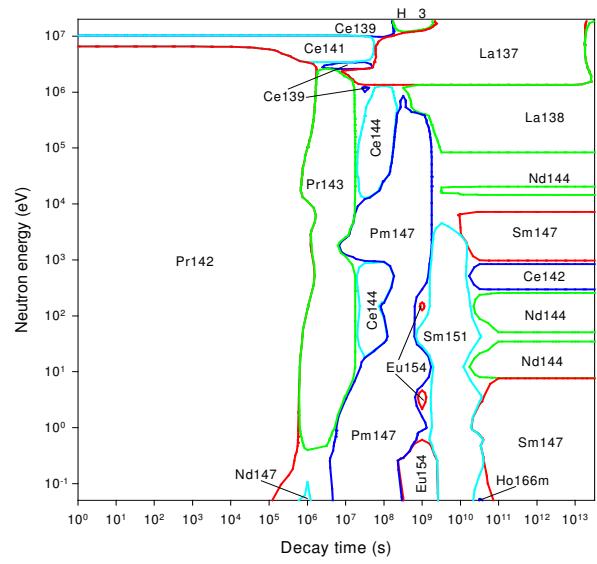
## Heat output



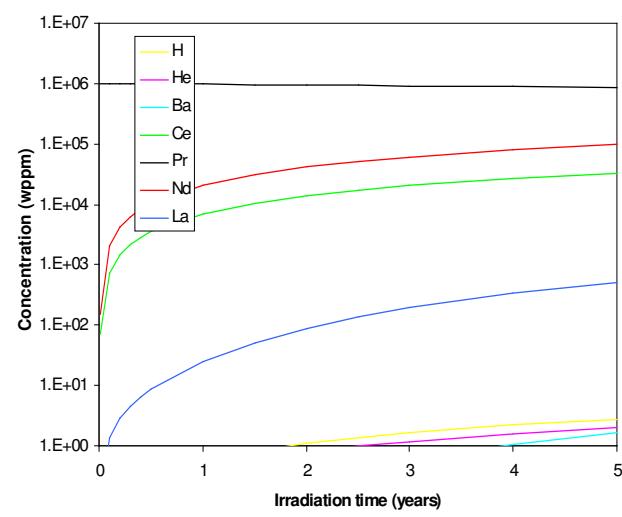
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Neodymium

## General properties

		60	Isotopes	Isotopic abundances / %
Atomic number		41.5	Nd142	27.2
Crustal abundance / wppm		1289	Nd143	12.2
Melting point / K		3339	Nd144	23.8 ( $T_{1/2} = 2.1 \cdot 10^{15}$ y)
Boiling point / K		7008	Nd145	8.3
Density / kgm <sup>-3</sup>		16.5	Nd146	17.2
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>		$6.4 \cdot 10^{-7}$	Nd148	5.7
Electrical resistivity /Ωm		$9.6 \cdot 10^{-6}$	Nd150	5.6
Coefficient of thermal expansion / K <sup>-1</sup>		Hexagonal		
Crystal structure		6(7)		
Number of stable isotopes		144.24		
Mean atomic weight				

## Activation properties

Act	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Heat	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	
Bq kg <sup>-1</sup>	1.71E15	1.57E15	4.73E14	5.46E13	8.80E11	3.03E4	kW kg <sup>-1</sup>	1.78E-1	1.58E-1	5.64E-2	2.98E-3	3.76E-6	6.81E-12	
Nd141	15.36	16.36					Nd149	17.33	18.88					
Pm149	13.27	14.45	15.80				Nd151	17.11	14.40					
Nd149	12.77	13.42					Pm148m	9.30	10.49	27.61	1.17			
Sm153	12.09	13.15	11.80				Pm148	7.88	8.89	15.86	0.04			
Nd147	9.68	10.54	27.89				Pm149	7.76	8.76	8.05				
Nd151	7.48	6.08					Pm151	7.23	8.16	2.65				
Pm151	7.48	8.14	3.14				Eu156	7.10	8.01	18.99				
Nd141m	5.03	0.17					Sm153	6.17	6.95	5.25				
Pm148	3.93	4.27	9.07	0.01			Nd147	6.10	6.88	15.31				
Pm148m	2.80	3.05	9.54	0.18			Nd141m	5.84	0.20					
Eu156	2.66	2.90	8.17				Pr142	2.22	2.50	0.29				
Pm147	2.36	2.57	8.61	59.55			Nd141	2.11	2.33					
Pr142	1.66	1.81	0.25				Eu154	1.44	1.63	4.55	79.46	21.41		
Eu155	0.67	0.73	2.43	18.28			Pm147	0.23	0.25	0.71	10.79			
Eu154	0.62	0.67	2.23	17.83	0.38		Eu155	0.14	0.15	0.43	7.01			
Pr142m	0.60	0.51					Eu152			0.05	0.84	4.18		
Sm151	0.11	0.12	0.40	3.44	99.53		Sm151			0.01	0.20	74.17		
La137						46.54	Sm146						68.11	
Sm146						37.13	Gd150						22.45	
Gd150						11.25	Sm147						8.32	
Sm147						5.04	La137						1.07	
Dose	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Ing	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	
Sv h <sup>-1</sup>	1.10E5	8.98E4	4.45E4	3.13E3	1.25E0	3.74E-9	Sv kg <sup>-1</sup>	1.13E6	1.13E6	5.88E5	3.17E4	9.36E1	8.63E-4	
Nd151	23.73	21.62					Pm149	19.96	20.00	12.57				
Pm148m	17.12	20.91	39.70	1.26			Nd147	16.17	16.21	24.67				
Eu156	15.33	18.72	32.00				Pm148	16.10	16.13	19.68	0.04			
Nd141m	11.53	0.42					Sm153	13.59	13.60	7.02				
Pm148	9.41*	11.49*	14.78*	0.02			Eu156	8.90	8.91	14.45				
Nd149	7.81	9.22					Pm151	8.29	8.31	1.84				
Pm151	4.55	5.56	1.30				Pm148m	7.23	7.24	13.04	0.54			
Eu154	3.01	3.67	7.41	97.15	82.60		Pr142	3.28	3.28	0.26				
Nd141	2.47	2.95					Nd149	2.33	2.25					
Nd147	2.20	2.69	4.31				Eu154	1.87	1.87	3.59	61.28	7.07		
Pm150	0.84	1.00					Pm147	0.93	0.93	1.80	26.61			
Pr140	0.69	0.29					Eu155	0.33	0.33	0.63	10.05			
Eu152	0.03	0.04	0.08	1.06	16.62		Sm151			0.03	0.58	91.74		
Eu150						0.73	Sm146						70.51	
La137						94.10	Gd150						20.57	
La138						5.90	Sm147						8.69	

Inh	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>	Clear	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>
Sv kg <sup>-1</sup>	2.23E6	2.23E6	1.76E6	7.62E5	3.71E3	4.22E-1		6.36E11	5.36E11	2.21E11	1.37E10	8.52E6	5.85E-1
Eu154	25.02	25.04	31.73	67.67	4.72		Nd151	20.13	17.83				
Nd147	17.82	17.83	17.98				Pm148m	15.07	17.89	40.79	1.47		
Pm148m	12.24	12.25	14.61	0.08			Nd149	14.31	16.40				
Pm147	9.05	9.05	11.56	21.33			Nd141m	9.68	0.35				
Pm149	7.43	7.44	3.10				Eu156	9.55	11.34	23.29			
Eu156	6.94	6.95	7.46				Pm151	7.19	8.53	2.40			
Pm148	6.63	6.63	5.36				Pm148	7.04	8.36	12.92	0.03		
Sm153	5.84	5.84	2.00				Nd147	4.27	5.07	9.77			
Eu155	3.56	3.56	4.51	9.03			Nd141	3.18	3.69				
Pm151	2.64	2.64	0.39				Sm153	2.96	3.51	2.29			
Nd149	0.87	0.84					Eu154	2.10	2.49	6.03	89.68	49.14	
Pr142	0.70	0.70	0.04				Pm149	1.79	2.12	1.69			
Sm151	0.34	0.34	0.43	0.99	94.35		Eu152	0.07	0.08	0.19	2.94	29.65	
Eu152	0.24	0.24	0.30	0.67	0.86		Sm151				0.03	20.56	
Ce141	0.19	0.19	0.22				Eu150					0.62	
Pr143	0.12	0.12	0.13				La137						63.57
Gd150					0.01	67.13	Gd150						24.33
Sm146						29.36	Sm146						10.71
Sm147						3.48	Sm147						1.25

# Neodymium

## Pathway analysis

Eu156 continued	15.2 d	Nd146(n, $\gamma$ )Nd147(n, $\gamma$ )Nd148(n, $\gamma$ )Nd149( $\beta^-$ )Pm149( $\beta^-$ ) Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151(n, $\gamma$ )Sm152(n, $\gamma$ ) Sm153( $\beta^-$ )Eu153(n, $\gamma$ )Eu154(n, $\gamma$ )Eu155(n, $\gamma$ )Eu156 Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ )Pm148(n, $\gamma$ )Pm149(n, $\gamma$ ) Pm150( $\beta^-$ )Sm150(n, $\gamma$ )Sm151(n, $\gamma$ )Sm152(n, $\gamma$ ) Sm153( $\beta^-$ )Eu153(n, $\gamma$ )Eu154(n, $\gamma$ )Eu155(n, $\gamma$ )Eu156 &Nd150(n, $\gamma$ )Nd151( $\beta^-$ )Pm151( $\beta^-$ )Sm151( $\beta^-$ )Eu151(n, $\gamma$ ) Eu152(n, $\gamma$ )Eu153(n, $\gamma$ )Eu154(n, $\gamma$ )Eu155(n, $\gamma$ )Eu156	1.2 1.0		4.9	
Pm148m	41.05 d	Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ )Pm148m Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ )Pm148m Nd144(n, $\gamma$ )Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ ) Pm147(n, $\gamma$ )Pm148m Nd143(n, $\gamma$ )Nd144(n, $\gamma$ )Nd145(n, $\gamma$ )Nd146(n, $\gamma$ ) Nd147( $\beta^-$ )Pm147(n, $\gamma$ )Pm148m Nd142(n, $\gamma$ )Nd143(n, $\gamma$ )Nd144(n, $\gamma$ )Nd145(n, $\gamma$ ) Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ )Pm148m Nd150(n,2n)Nd149( $\beta^-$ )Pm149(n,2n)Pm148m Nd150(n,2n)Nd149( $\beta^-$ )Pm149( $\beta^-$ )Sm149(n,2n)Sm148(n,p)Pm148m Nd150(n,2n)Nd149( $\beta^-$ )Pm149( $\beta^-$ )Sm149(n,d)Pm148m Nd148(n,2n)Nd147( $\beta^-$ )Pm147(n, $\gamma$ )Pm148m	54.4 25.1 11.1 5.3 4.1	72.3 27.2 0.3 0.1	98.4 1.6	
Ta182	114.7 d	Very long Pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0			
Ce139	137.65 d	&Nd142(n, $\alpha$ )Ce139 Nd142(n, $\gamma$ )Nd143(n,n $\alpha$ )Ce139 Nd143(n,n $\alpha$ )Ce139 &Nd142(n,2n)Nd141( $\beta^+$ )Pr141(n,2n)Pr140( $\beta^+$ )Ce140(n,2n)Ce139 &Nd143(n,2n)Nd142(n,2n)Nd141( $\beta^+$ )Pr141(n,2n) Pr140( $\beta^+$ )Ce140(n,2n)Ce139 &Nd143(n,2n)Nd142(n, $\alpha$ )Ce139 &Nd144(n,n $\alpha$ )Ce140(n,2n)Ce139	97.0 3.0 0.1	99.9 0.2 17.8	81.9 0.2 80.5	10.5 3.2 1.2
Pm147	2.622 y	Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147 Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147 Nd144(n, $\gamma$ )Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147 Nd143(n, $\gamma$ )Nd144(n, $\gamma$ )Nd145(n, $\gamma$ )Nd146(n, $\gamma$ ) Nd147( $\beta^-$ )Pm147 Nd142(n, $\gamma$ )Nd143(n, $\gamma$ )Nd144(n, $\gamma$ )Nd145(n, $\gamma$ ) Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147 Nd148(n,2n)Nd147( $\beta^-$ )Pm147 Nd150(n,3n)Nd148(n,2n)Nd147( $\beta^-$ )Pm147	54.4 25.1 11.1 5.3 4.1	72.1 27.3 0.3 0.1	98.3 1.6	
Eu155	4.846 y	&Nd148(n, $\gamma$ )Nd149( $\beta^-$ )Pm149( $\beta^-$ )Sm149(n, $\gamma$ ) Sm150(n, $\gamma$ )Sm151(n, $\gamma$ )Sm152(n, $\gamma$ )Sm153( $\beta^-$ ) Eu153(n, $\gamma$ )Eu154(n, $\gamma$ )Eu155 &Nd150(n, $\gamma$ )Nd151( $\beta^-$ )Pm151( $\beta^-$ )Sm151(n, $\gamma$ ) Sm152(n, $\gamma$ )Sm153( $\beta^-$ )Eu153(n, $\gamma$ )Eu154(n, $\gamma$ )Eu155 &Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ )Pm148m(n, $\gamma$ ) Pm149( $\beta^-$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151(n, $\gamma$ ) Sm152(n, $\gamma$ )Sm153( $\beta^-$ )Eu153(n, $\gamma$ )Eu154(n, $\gamma$ )Eu155 &Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ )Pm148m(n, $\gamma$ ) (n, $\gamma$ )Pm149( $\beta^-$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151(n, $\gamma$ ) Sm152(n, $\gamma$ )Sm153( $\beta^-$ )Eu153(n, $\gamma$ )Eu154(n, $\gamma$ )Eu155 &Nd148(n, $\gamma$ )Nd149( $\beta^-$ )Pm149(n, $\gamma$ )Pm150( $\beta^-$ ) Sm150(n, $\gamma$ )Sm151(n, $\gamma$ )Sm152(n, $\gamma$ )Sm153( $\beta^-$ ) Eu153(n, $\gamma$ )Eu154(n, $\gamma$ )Eu155 Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ )Pm148(n, $\gamma$ ) Pm149( $\beta^-$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151(n, $\gamma$ ) Sm152(n, $\gamma$ )Sm153( $\beta^-$ )Eu153(n, $\gamma$ )Eu154(n, $\gamma$ )Eu155 Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ )Pm148m(n, $\gamma$ ) Pm149(n, $\gamma$ )Pm150( $\beta^-$ )Sm150(n, $\gamma$ )Sm151(n, $\gamma$ ) Sm152(n, $\gamma$ )Sm153( $\beta^-$ )Eu153(n, $\gamma$ )Eu154(n, $\gamma$ )Eu155	28.1 16.7 16.6 6.6 6.2 4.5 3.7	94.7 0.3 95.2 4.8 4.8		98.6
More on next page						

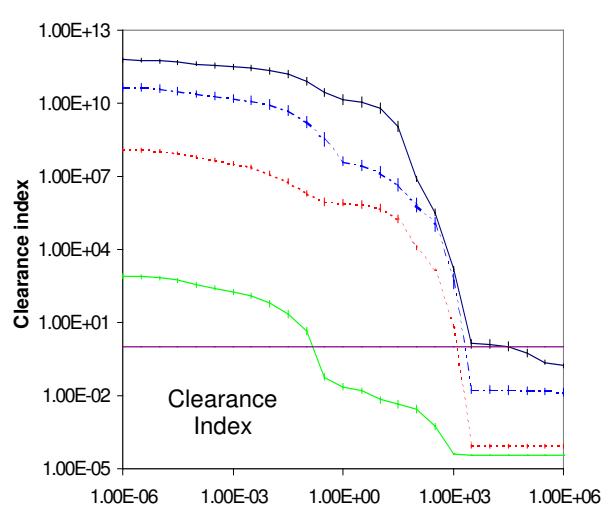
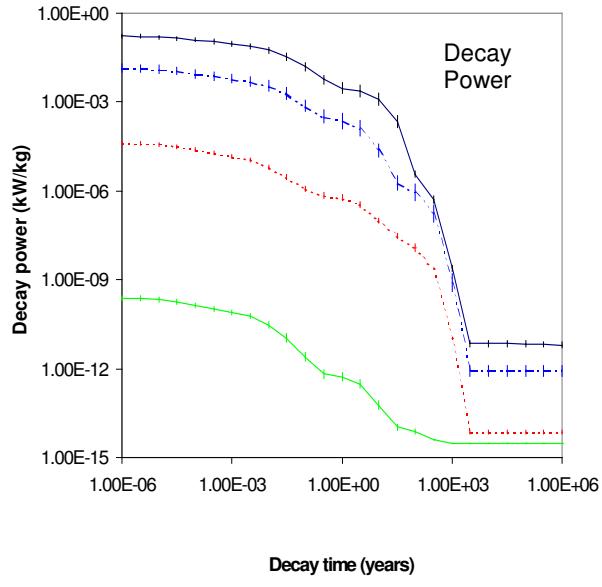
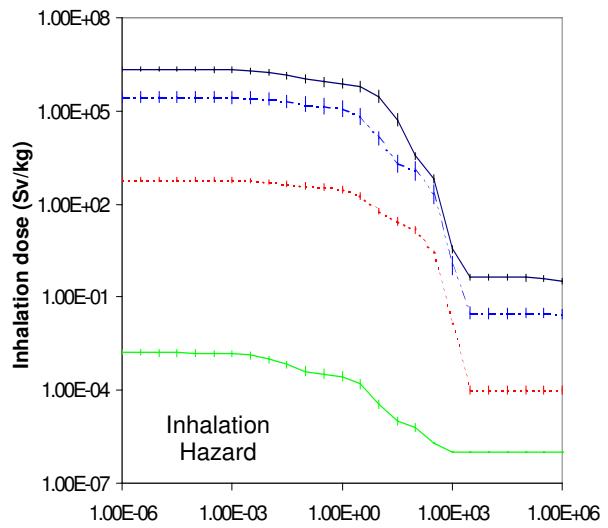
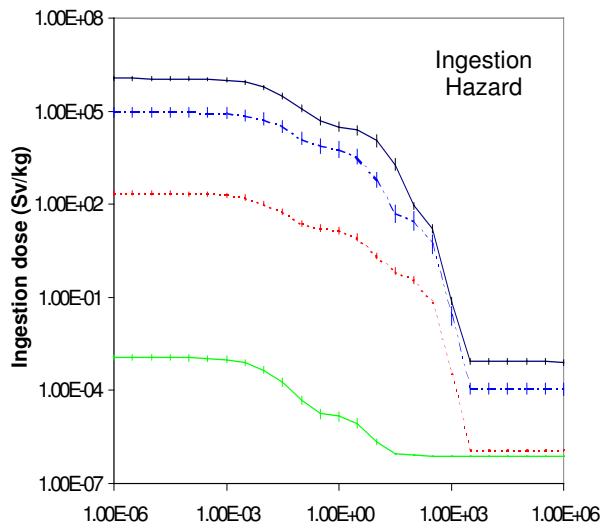
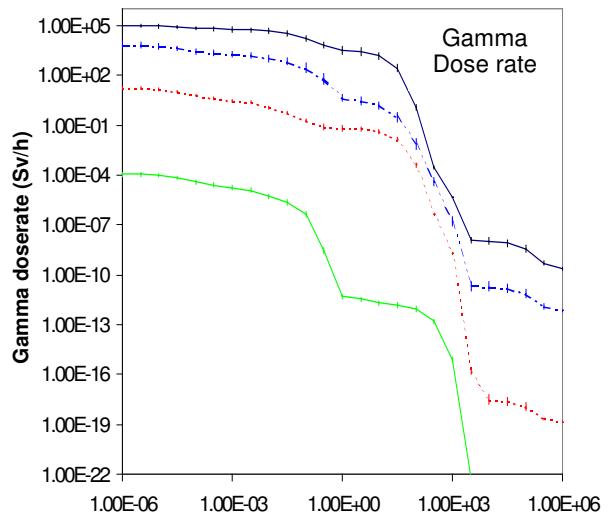
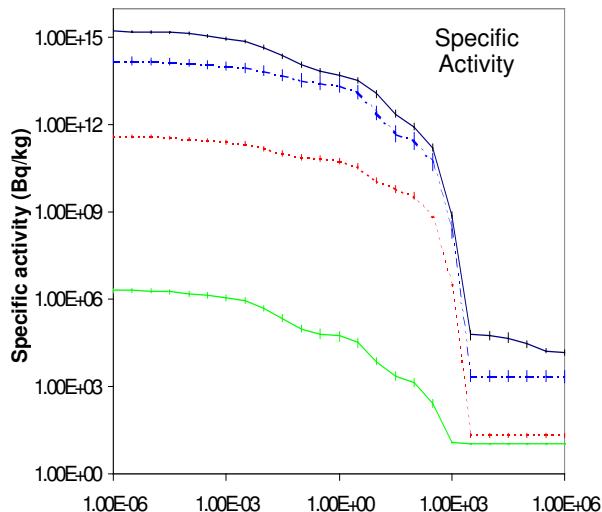


Eu152	13.522 y	Nd148(n, $\gamma$ )Nd149( $\beta^-$ )Pm149( $\beta^-$ )Sm149(n, $\gamma$ ) Sm150(n, $\gamma$ )Sm151( $\beta^-$ )Eu151(n, $\gamma$ )Eu152 Nd150(n, $\gamma$ )Nd151( $\beta^-$ )Pm151( $\beta^-$ )Sm151( $\beta^-$ ) Eu151(n, $\gamma$ )Eu152 Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ )Pm148m(n, $\gamma$ )Pm149 ( $\beta^-$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151( $\beta^-$ )Eu151(n, $\gamma$ )Eu152 Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ ) Pm148m(n, $\gamma$ )Pm149( $\beta^-$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ ) Sm151( $\beta^-$ )Eu151(n, $\gamma$ )Eu152 Nd148(n, $\gamma$ )Nd149( $\beta^-$ )Pm149(n, $\gamma$ )Pm150( $\beta^-$ ) Sm150(n, $\gamma$ )Sm151( $\beta^-$ )Eu151(n, $\gamma$ )Eu152 Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ )Pm148(n, $\gamma$ )Pm149( $\beta^-$ ) Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151( $\beta^-$ )Eu151(n, $\gamma$ )Eu152 Nd146(n, $\gamma$ )Nd147(n, $\gamma$ )Nd148(n, $\gamma$ )Nd149( $\beta^-$ )Pm149( $\beta^-$ ) Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151( $\beta^-$ )Eu151(n, $\gamma$ )Eu152 Nd143(n, $\gamma$ )Nd144(n, $\gamma$ )Nd145(n, $\gamma$ )Nd146(n, $\gamma$ ) Nd147( $\beta^-$ )Pm147(n, $\gamma$ )Pm148m(n, $\gamma$ )Pm149( $\beta^-$ ) Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151( $\beta^-$ )Eu151(n, $\gamma$ )Eu152 Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ )Pm148(n, $\gamma$ )Pm149(n, $\gamma$ ) Pm150( $\beta^-$ )Sm150(n, $\gamma$ )Sm151( $\beta^-$ )Eu151(n, $\gamma$ )Eu152 Nd150(n, $\gamma$ )Nd151( $\beta^-$ )Pm151( $\beta^-$ )Sm151( $\beta^-$ )Eu151(n, $\gamma$ )Eu152n(IT)Eu152	27.0 16.3 16.2 7.1 6.0 4.4 3.6 2.6 2.5 1.9 1.6 1.4 1.2 1.0 0.1	95.1 0.3 99.8 88.9		
Pm145	17.7 y	Nd148(n,2n)Nd147( $\beta^-$ )Pm147(n,2n)Pm146(n,2n)Pm145 Nd148(n,2n)Nd147( $\beta^-$ )Pm147( $\beta^-$ )Sm147(n,2n) Sm146(n,2n)Sm145( $\beta^+$ )Pm145 Nd148(n,2n)Nd147( $\beta^-$ )Pm147(n,3n)Pm145 Nd148(n,2n)Nd147( $\beta^-$ )Pm147(n,2n)Pm146( $\beta^-$ ) Sm146(n,2n)Sm145( $\beta^+$ )Pm145				78.1 9.3  9.1 2.0
Eu150	36.359 y	Nd150(n, $\gamma$ )Nd151( $\beta^-$ )Pm151( $\beta^-$ )Sm151( $\beta^-$ )Eu151(n,2n)Eu150				100.0

Sm151	90.0 y	Nd148(n, $\gamma$ )Nd149( $\beta^-$ )Pm149( $\beta^-$ )Sm149(n, $\gamma$ ) Sm150(n, $\gamma$ )Sm151 Nd150(n, $\gamma$ )Nd151( $\beta^-$ )Pm151( $\beta^-$ )Sm151 Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ )Pm148m(n, $\gamma$ ) Pm149( $\beta^-$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151 Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ ) Pm148m(n, $\gamma$ )Pm149( $\beta^-$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151 Nd148(n, $\gamma$ )Nd149( $\beta^-$ )Pm149(n, $\gamma$ )Pm150( $\beta^-$ ) Sm150(n, $\gamma$ )Sm151 Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ )Pm148(n, $\gamma$ ) Pm149( $\beta^-$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151 Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ )Pm148m(n, $\gamma$ ) Pm149(n, $\gamma$ )Pm150( $\beta^-$ )Sm150(n, $\gamma$ )Sm151 Nd144(n, $\gamma$ )Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ ) Pm148m(n, $\gamma$ )Pm149( $\beta^-$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151 Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ )Pm148( $\beta^-$ ) Sm148(n, $\gamma$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151 Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ ) Pm148(n, $\gamma$ )Pm149( $\beta^-$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151 Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ ) Pm148m(n, $\gamma$ )Pm149(n, $\gamma$ )Pm150( $\beta^-$ )Sm150(n, $\gamma$ )Sm151 Nd146(n, $\gamma$ )Nd147(n, $\gamma$ )Nd148(n, $\gamma$ )Nd149( $\beta^-$ ) Pm149( $\beta^-$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151 Nd143(n, $\gamma$ )Nd144(n, $\gamma$ )Nd145(n, $\gamma$ )Nd146(n, $\gamma$ ) Nd147( $\beta^-$ )Pm147(n, $\gamma$ )Pm148m(n, $\gamma$ )Pm149( $\beta^-$ ) Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151 Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147(n, $\gamma$ )Pm148(n, $\gamma$ ) Pm149(n, $\gamma$ )Pm150( $\beta^-$ )Sm150(n, $\gamma$ )Sm151	27.0 16.3 16.2 7.1 6.0 4.4 3.6 2.6 2.5 1.9 1.6 1.5 1.2 1.0	95.1 0.3 99.8 4.5	0.2	100.0
Ho166m	1200.0 y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0	100.0		
La137	$6.0 \cdot 10^4$ y	&Nd142(n, $\alpha$ )Ce139( $\beta^+$ )La139(n,2n)La138(n,2n)La137 &Nd142(n,2n)Nd141( $\beta^+$ )Pr141(n,2n)Pr140( $\beta^+$ ) Ce140(n,2n)Ce139( $\beta^+$ )La139(n,2n)La138(n,2n)La137 &Nd142(n,2n)Nd141( $\beta^+$ )Pr141(n, $\alpha$ )La138(n,2n)La137 &Nd142(n,2n)Nd141( $\beta^+$ )Pr141(n,n $\alpha$ )La137 &Nd142(n,2n)Nd141( $\beta^+$ )Pr141(n,2n)Pr140( $\beta^+$ ) Ce140(n,2n)Ce139(n,2n)Ce138(n,2n)Ce137( $\beta^+$ )La137 &Nd142(n, $\alpha$ )Ce139(n,2n)Ce138(n,2n)Ce137( $\beta^+$ )La137 &Nd142(n,n $\alpha$ )Ce138(n,2n)Ce137( $\beta^+$ )La137			25.1 20.5  14.5 11.2 10.0  7.5 4.8	
Hf182	$9.0 \cdot 10^6$ y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0			
Sm146	$1.0 \cdot 10^8$ y	Nd148(n,2n)Nd147( $\beta^-$ )Pm147( $\beta^-$ )Sm147(n,2n)Sm146 Nd148(n,2n)Nd147( $\beta^-$ )Pm147(n,2n)Pm146( $\beta^-$ )Sm146 Nd150(n,2n)Nd149( $\beta^-$ )Pm149( $\beta^-$ )Sm149(n,2n) Sm148(n,2n)Sm147(n,2n)Sm146			80.4 16.4 1.7	
Lu176	$3.6 \cdot 10^{10}$ y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0	100.0		
La138	$1.1 \cdot 10^{11}$ y	Nd143(n, $\alpha$ )Ce140(n, $\gamma$ )Ce141( $\beta^-$ )Pr141(n, $\alpha$ )La138 Nd142(n, $\gamma$ )Nd143(n, $\alpha$ )Ce140(n, $\gamma$ )Ce141( $\beta^-$ ) Pr141(n, $\alpha$ )La138 Nd144(n, $\alpha$ )Ce141( $\beta^-$ )Pr141(n, $\alpha$ )La138 &Nd142(n,2n)Nd141( $\beta^+$ )Pr141(n,2n)Pr140( $\beta^+$ ) Ce140(n,2n)Ce139( $\beta^+$ )La139(n,2n)La138 &Nd142(n, $\alpha$ )Ce139( $\beta^+$ )La139(n,2n)La138 &Nd142(n,2n)Nd141( $\beta^+$ )Pr141(n, $\alpha$ )La138 &Nd144(n,n $\alpha$ )Ce140(n,2n)Ce139( $\beta^+$ )La139(n,2n)La138 &Nd143(n,2n)Nd142(n, $\alpha$ )Ce139( $\beta^+$ )La139(n,2n)La138	53.2 46.7  0.7  0.7	98.9 0.3  0.6  0.6	98.9 0.3  43.5  32.3 17.1 1.3 1.3	

Sm147	$1.1 \cdot 10^{11}$ y	Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147( $\beta^-$ )Sm147 Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147( $\beta^-$ )Sm147 Nd144(n, $\gamma$ )Nd145(n, $\gamma$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ ) Pm147( $\beta^-$ )Sm147 Nd143(n, $\gamma$ )Nd144(n, $\gamma$ )Nd145(n, $\gamma$ )Nd146(n, $\gamma$ ) Nd147( $\beta^-$ )Pm147( $\beta^-$ )Sm147 Nd142(n, $\gamma$ )Nd143(n, $\gamma$ )Nd144(n, $\gamma$ )Nd145(n, $\gamma$ ) Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147( $\beta^-$ )Sm147 Nd148(n,2n)Nd147( $\beta^-$ )Pm147( $\beta^-$ )Sm147 Nd150(n,2n)Nd149( $\beta^-$ )Pm149( $\beta^-$ )Sm149(n,2n) Sm148(n,2n)Sm147 Nd150(n,3n)Nd148(n,2n)Nd147( $\beta^-$ )Pm147( $\beta^-$ )Sm147	60.2 24.9 8.4 3.9 2.6	73.4 26.2 0.3 0.1	99.0 1.0	
Nd144	$2.1 \cdot 10^{15}$ y	Nd142(n, $\gamma$ )Nd143(n, $\gamma$ )Nd144 Nd143(n, $\gamma$ )Nd144 Nd145(n,2n)Nd144 Nd146(n,2n)Nd145(n,2n)Nd144 Nd146(n,3n)Nd144 *Nuclide also present in starting material	37.4 21.4 41.2*	33.9 66.1*	1.9 98.1*	8.8 2.6 0.9 87.7*

# Neodymium activation characteristics

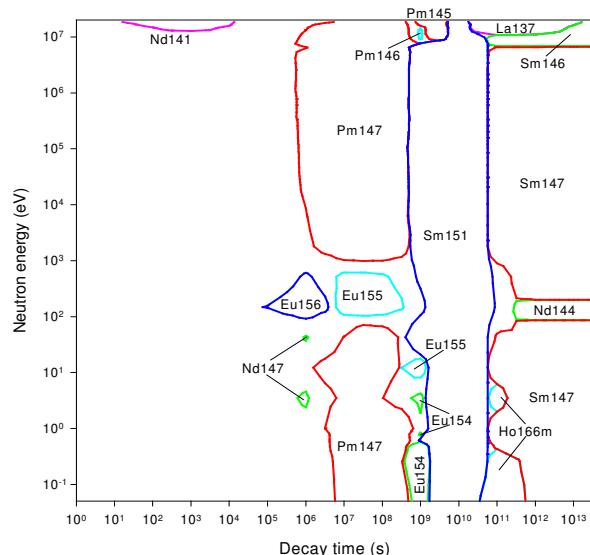


Decay time (years)

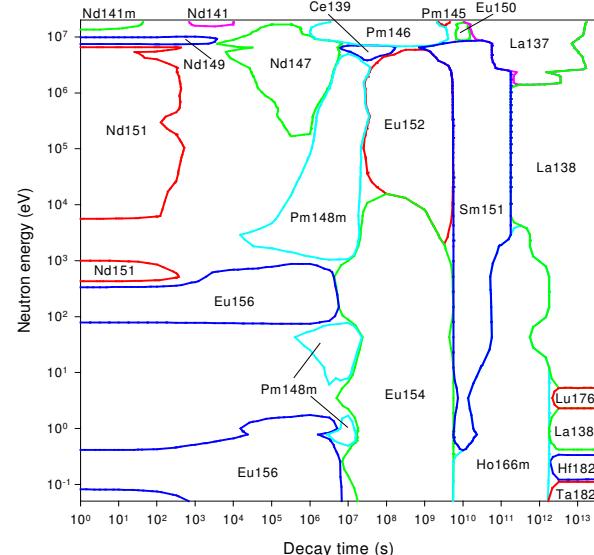
Decay time (years)

# Neodymium importance diagrams & transmutation

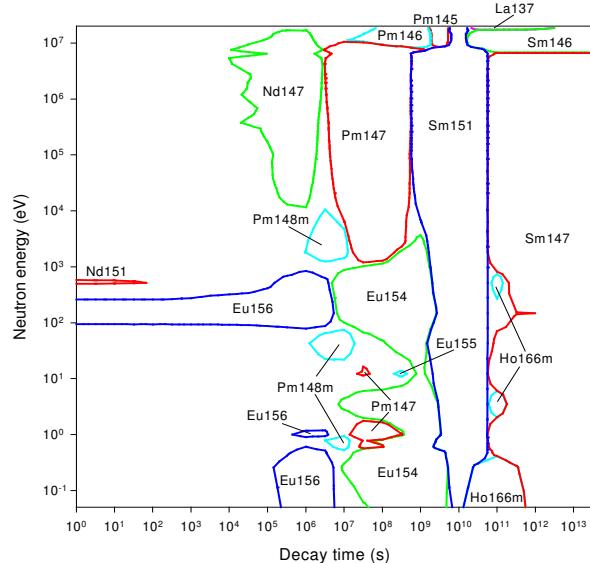
## Activity



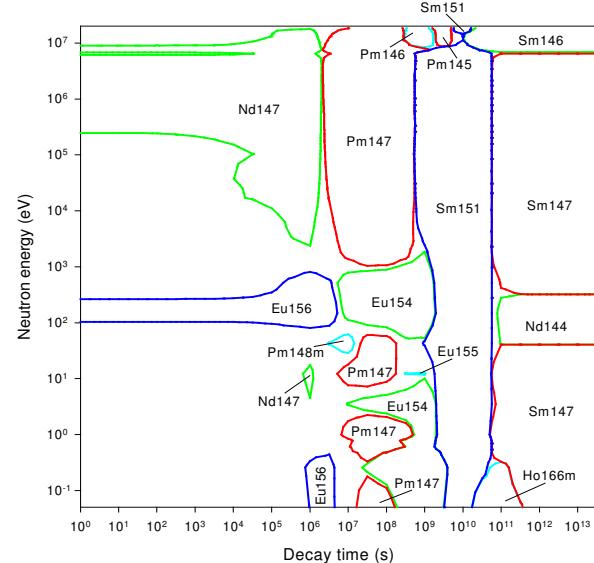
## Dose rate



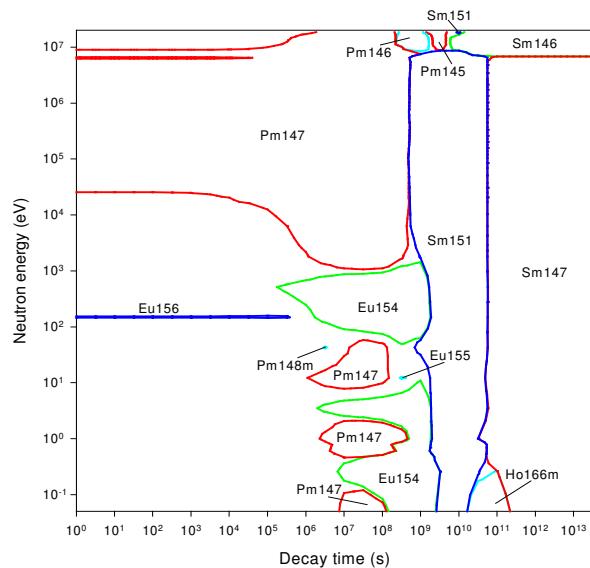
## Heat output



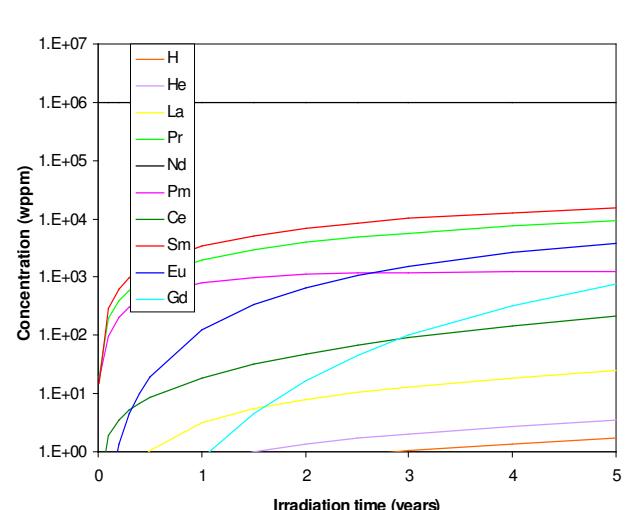
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Samarium

## General properties

Atomic number	62	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	7.05	Sm144	3.07
Melting point / K	1345	Sm147	14.99 ( $T_{1/2} = 1.06 \cdot 10^{11}$ y)
Boiling point / K	2063	Sm148	11.24 ( $T_{1/2} = 6.97 \cdot 10^{15}$ y)
Density / kgm <sup>-3</sup>	7520	Sm149	13.82 ( $T_{1/2} = 2.00 \cdot 10^{15}$ y)
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	13.3	Sm150	7.38
Electrical resistivity /Ωm	$9.4 \cdot 10^{-7}$	Sm152	26.75
Coefficient of thermal expansion / K <sup>-1</sup>	$1.27 \cdot 10^{-5}$	Sm154	22.75
Crystal structure	Rhombohedral		
Number of stable isotopes	4(7)		
Mean atomic weight	150.36		

## Activation properties

Act	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Heat	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y
Bq kg <sup>-1</sup>	1.20E16	1.18E16	7.46E15	1.73E15	1.10E13	1.79E6	kW kg <sup>-1</sup>	1.97E0	1.95E0	1.49E0	1.58E-1	8.62E-5	7.37E-10
Eu156	44.82	45.45	61.06				Eu156	75.73	76.43	84.83			
Sm153	28.12	28.48	12.18				Sm153	9.09	9.16	3.24			
Eu155	10.97	11.12	17.62	65.83	0.01		Eu154	7.30	7.37	9.66	83.73	52.39	
Sm155	7.52	6.47					Sm155	5.14	4.40				
Eu154	4.92	4.99	7.92	31.46	1.68		Eu155	1.40	1.41	1.85	15.07	0.02	
Eu157	0.99	1.00	0.03				Eu152	0.05	0.05	0.07	0.62	7.16	
Eu154m	0.95	0.89					Sm151			0.01	0.05	39.89	
Sm151	0.19	0.20	0.31	1.34	97.77		Sm146						95.43
Sm146						95.66	Gd150						3.91
Gd150						3.60	Sm147						0.66
Dose	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Ing	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y
Sv h <sup>-1</sup>	2.18E6	2.18E6	1.86E6	1.72E5	6.61E1	1.46E-12	Sv kg <sup>-1</sup>	1.61E7	1.61E7	1.23E7	1.47E6	1.47E3	9.62E-2
Eu156	90.55	90.65	89.72				Eu156	73.40	73.43	81.19			
Eu154	8.42	8.43	9.84	98.43	87.23		Sm153	15.49	15.48	5.45			
Eu157	0.21	0.20	0.00				Eu154	7.33	7.33	9.57	74.18	25.14	
Tb160	0.13	0.13	0.14	0.05			Eu155	2.61	2.61	3.41	24.84	0.02	
Eu152	0.06	0.06	0.07	0.75	12.28		Eu152	0.04	0.04	0.06	0.45	2.83	
Eu155	0.03	0.03	0.04	0.36			Sm151	0.01	0.01	0.02	0.15	71.68	
La137						92.87	Sm146					0.01	95.86
La138						7.13	Gd150						3.47
Inh	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Clear	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y
Sv kg <sup>-1</sup>	6.14E7	6.14E7	5.69E7	3.71E7	5.44E4	2.43E1		8.59E12	8.55E12	7.04E12	7.92E11	3.58E8	1.22E1
Eu154	51.03	51.03	54.99	77.86	18.05		Eu156	83.49	83.82	86.25			
Eu156	29.80	29.80	27.21				Eu154	8.71	8.74	10.62	87.10	65.54	
Eu155	14.80	14.80	15.94	21.21	0.01		Sm153	3.57	3.58	1.17			
Sm153	3.46	3.46	1.01				Sm155	1.72	1.47				
Eu152	0.34	0.34	0.37	0.54	2.30		Eu155	1.09	1.10	1.33	10.29	0.02	
Sm151	0.15	0.15	0.16	0.25	79.28		Eu152	0.19	0.20	0.24	2.00	27.70	
Sm146					0.04	77.48	Sm151				0.01	6.03	
Gd150					0.01	22.00	Sm146						77.58
Sm147						0.52	Gd150						21.90

# Samarium

## Pathway analysis

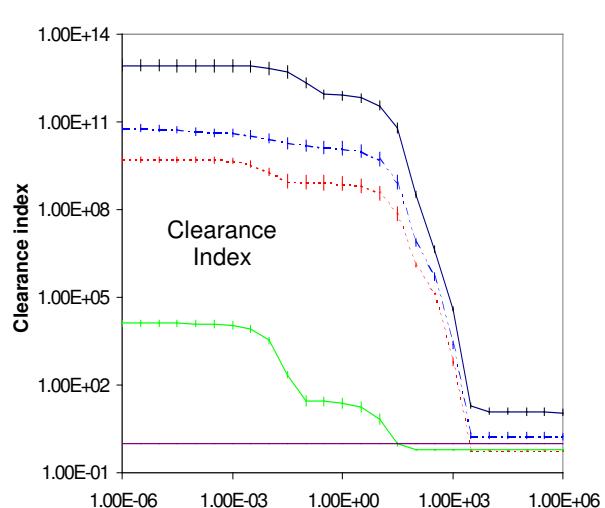
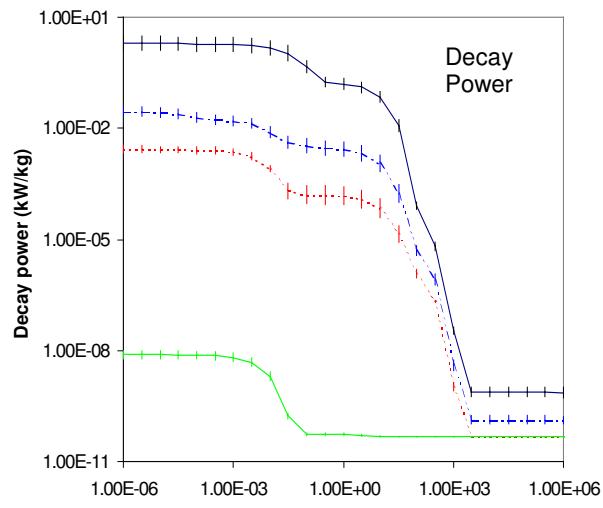
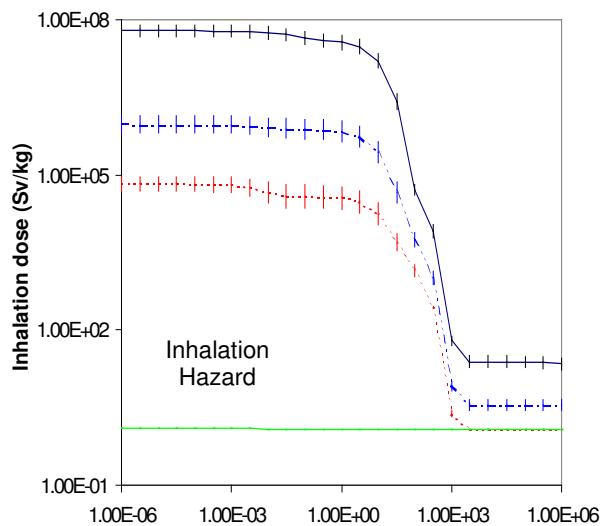
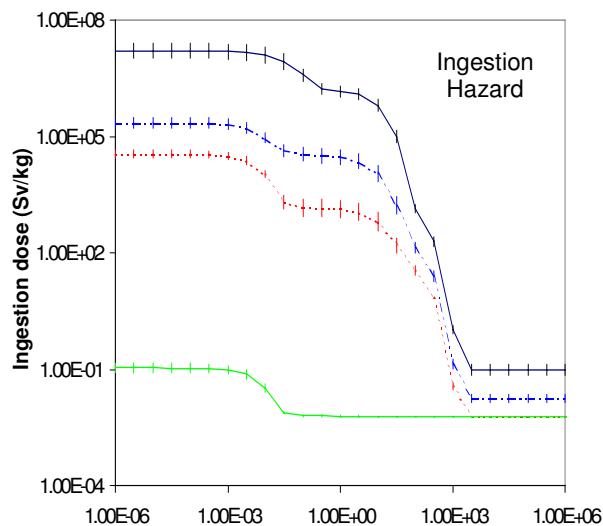
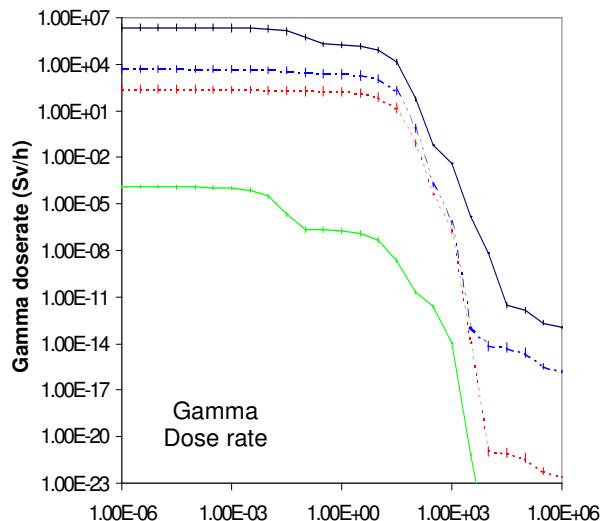
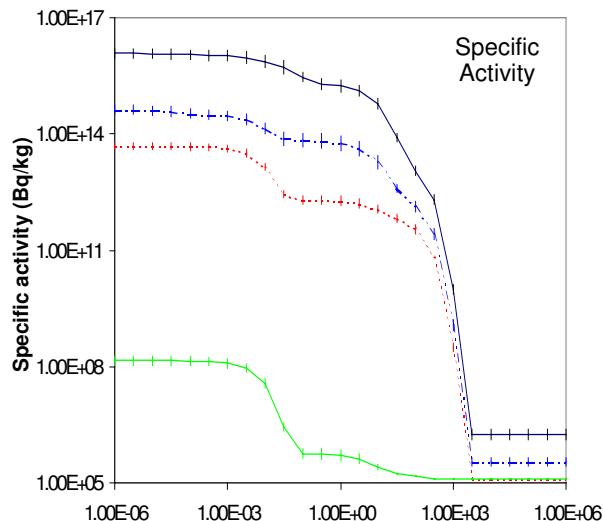
Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Sm155	22.1 m	Sm154(n, $\gamma$ )Sm155 Sm152(n, $\gamma$ )Sm153(n, $\gamma$ )Sm154(n, $\gamma$ )Sm155 Sm150(n, $\gamma$ )Sm151(n, $\gamma$ )Sm152(n, $\gamma$ )Sm153(n, $\gamma$ ) Sm154(n, $\gamma$ )Sm155 Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151(n, $\gamma$ )Sm152(n, $\gamma$ ) Sm153(n, $\gamma$ )Sm154(n, $\gamma$ )Sm155	92.1 5.0 1.5 0.9	97.2 1.9 0.2	100.0	99.9
Sm153	1.929 d	Sm147(n, $\gamma$ )Sm148(n, $\gamma$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ ) Sm151(n, $\gamma$ )Sm152(n, $\gamma$ )Sm153 Sm148(n, $\gamma$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151(n, $\gamma$ ) Sm152(n, $\gamma$ )Sm153 Sm150(n, $\gamma$ )Sm151(n, $\gamma$ )Sm152(n, $\gamma$ )Sm153 Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151(n, $\gamma$ )Sm152(n, $\gamma$ )Sm153 Sm152(n, $\gamma$ )Sm153 Sm154(n,2n)Sm153	55.0 41.8 1.8 1.1	27.4 21.8 16.5 32.2	0.3 99.7	99.7
Eu156	15.2 d	Sm154(n, $\gamma$ )Sm155( $\beta^-$ )Eu155(n, $\gamma$ )Eu156 <b>&amp;Sm147(n,<math>\gamma</math>)Sm148(n,<math>\gamma</math>)Sm149(n,<math>\gamma</math>)Sm150(n,<math>\gamma</math>)</b> Sm151(n, $\gamma$ )Sm152(n, $\gamma$ )Sm153( $\beta^-$ )Eu153(n, $\gamma$ ) <i>Eu154(n,<math>\gamma</math>)Eu155(n,<math>\gamma</math>)Eu156</i> <b>&amp;Sm148(n,<math>\gamma</math>)Sm149(n,<math>\gamma</math>)Sm150(n,<math>\gamma</math>)Sm151(n,<math>\gamma</math>)Sm152(n,<math>\gamma</math>)Sm153(<math>\beta^-</math>)Eu153(n,<math>\gamma</math>)<i>Eu154(n,<math>\gamma</math>)Eu155(n,<math>\gamma</math>)Eu156</i></b> Sm152(n, $\gamma$ )Sm153(n, $\gamma$ )Sm154(n, $\gamma$ )Sm155( $\beta^-$ ) <i>Eu155(n,<math>\gamma</math>)Eu156</i> <b>&amp;Sm150(n,<math>\gamma</math>)Sm151(n,<math>\gamma</math>)Sm152(n,<math>\gamma</math>)Sm153(<math>\beta^-</math>)</b> <i>Eu153(n,<math>\gamma</math>)Eu154(n,<math>\gamma</math>)Eu155(n,<math>\gamma</math>)Eu156</i> Sm150(n, $\gamma$ )Sm151(n, $\gamma$ )Sm152(n, $\gamma$ )Sm153(n, $\gamma$ ) Sm154(n, $\gamma$ )Sm155( $\beta^-$ )Eu155(n, $\gamma$ )Eu156 <b>&amp;Sm149(n,<math>\gamma</math>)Sm150(n,<math>\gamma</math>)Sm151(n,<math>\gamma</math>)Sm152(n,<math>\gamma</math>)</b> Sm153( $\beta^-$ )Eu153(n, $\gamma$ ) <i>Eu154(n,<math>\gamma</math>)Eu155(n,<math>\gamma</math>)Eu156</i> <b>&amp;Sm152(n,<math>\gamma</math>)Sm153(<math>\beta^-</math>)Eu153(n,<math>\gamma</math>)<i>Eu154(n,<math>\gamma</math>)Eu155(n,<math>\gamma</math>)Eu156</i></b>	60.2 18.0 14.2 3.3 1.6 1.0 1.0 20.8	0.6 16.5 15.6 16.4 31.0 5.6	94.3	99.9
Tb160	72.3 d	<b>&amp;Sm152(n,<math>\gamma</math>)Sm153(<math>\beta^-</math>)Eu153(n,<math>\gamma</math>)<i>Eu154(n,<math>\gamma</math>)</i></b> Eu155(n, $\gamma$ )Eu156(n, $\gamma$ )Eu157( $\beta^-$ )Gd157(n, $\gamma$ ) Gd158(n, $\gamma$ )Gd159( $\beta^-$ )Tb159(n, $\gamma$ )Tb160 <b>&amp;Sm149(n,<math>\gamma</math>)Sm150(n,<math>\gamma</math>)Sm151(n,<math>\gamma</math>)Sm152(n,<math>\gamma</math>)Sm153(<math>\beta^-</math>)Eu153(n,<math>\gamma</math>)<i>Eu154(n,<math>\gamma</math>)Eu155(n,<math>\gamma</math>)Eu156(n,<math>\gamma</math>)Eu157(<math>\beta^-</math>)</i></b> ( $\beta^-$ )Gd157(n, $\gamma$ )Gd158(n, $\gamma$ )Gd159( $\beta^-$ )Tb159(n, $\gamma$ )Tb160 Sm154(n, $\gamma$ )Sm155( $\beta^-$ )Eu155(n, $\gamma$ )Eu156(n, $\gamma$ )Eu157( $\beta^-$ ) Gd157(n, $\gamma$ )Gd158(n, $\gamma$ )Gd159( $\beta^-$ )Tb159(n, $\gamma$ )Tb160 <b>&amp;Sm150(n,<math>\gamma</math>)Sm151(n,<math>\gamma</math>)Sm152(n,<math>\gamma</math>)Sm153(<math>\beta^-</math>)Eu153(n,<math>\gamma</math>)<i>Eu154(n,<math>\gamma</math>)Eu155(n,<math>\gamma</math>)Eu156(n,<math>\gamma</math>)Eu157(<math>\beta^-</math>)</i></b> Gd157(n, $\gamma$ )Gd158(n, $\gamma$ )Gd159( $\beta^-$ )Tb159(n, $\gamma$ )Tb160 <b>&amp;Sm152(n,<math>\gamma</math>)Sm153(<math>\beta^-</math>)Eu153(n,<math>\gamma</math>)<i>Eu154(n,<math>\gamma</math>)</i></b> Eu155(n, $\gamma$ )Eu156( $\beta^-$ )Gd156(n, $\gamma$ )Gd157(n, $\gamma$ ) Gd158(n, $\gamma$ )Gd159( $\beta^-$ )Tb159(n, $\gamma$ )Tb160 Sm154(n, $\gamma$ )Sm155( $\beta^-$ )Eu155(n, $\gamma$ )Eu156( $\beta^-$ )Gd156(n, $\gamma$ ) Gd157(n, $\gamma$ )Gd158(n, $\gamma$ )Gd159( $\beta^-$ )Tb159(n, $\gamma$ )Tb160 Sm148(n, $\gamma$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151(n, $\gamma$ ) Sm152(n, $\gamma$ )Sm153( $\beta^-$ )Eu153(n, $\gamma$ )Eu154(n, $\gamma$ ) Eu155(n, $\gamma$ )Eu156(n, $\gamma$ )Eu157( $\beta^-$ )Gd157(n, $\gamma$ ) Gd158(n, $\gamma$ )Gd159( $\beta^-$ )Tb159(n, $\gamma$ )Tb160 <b>&amp;Sm152(n,<math>\gamma</math>)Sm153(<math>\beta^-</math>)Eu153(n,<math>\gamma</math>)<i>Eu154(n,<math>\gamma</math>)</i></b> Eu155( $\beta^-$ )Gd155(n, $\gamma$ )Gd156(n, $\gamma$ )Gd157(n, $\gamma$ ) Gd158(n, $\gamma$ )Gd159( $\beta^-$ )Tb159(n, $\gamma$ )Tb160	42.8 19.7 12.6 10.7 5.6 1.3 1.2	0.6 0.4 0.4 81.4 0.3 0.3 0.3		
More on next page					6.1	0.1

Tb160 continued	72.3 d	<b>&amp;Sm152(n,<math>\gamma</math>)Sm153(<math>\beta^-</math>)Eu153(n,<math>\gamma</math>)Eu154(<math>\beta^-</math>)</b> Gd154(n, $\gamma$ )Gd155(n, $\gamma$ )Gd156(n, $\gamma$ )Gd157(n, $\gamma$ ) Gd158(n, $\gamma$ )Gd159( $\beta^-$ )Tb159(n, $\gamma$ )Tb160 <b>&amp;Sm149(n,<math>\gamma</math>)Sm150(n,<math>\gamma</math>)Sm151(n,<math>\gamma</math>)Sm152(n,<math>\gamma</math>)Sm153(<math>\beta^-</math>)Eu153(n,<math>\gamma</math>)Eu154(n,<math>\gamma</math>)Eu155(n,<math>\gamma</math>)Eu156(<math>\beta^-</math>)Gd156(n,<math>\gamma</math>)Gd157(n,<math>\gamma</math>)Gd158(n,<math>\gamma</math>)Gd159(<math>\beta^-</math>)Tb159(n,<math>\gamma</math>)Tb160 <b>&amp;Sm150(n,<math>\gamma</math>)Sm151(n,<math>\gamma</math>)Sm152(n,<math>\gamma</math>)Sm153(<math>\beta^-</math>)Eu153(n,<math>\gamma</math>)Eu154(n,<math>\gamma</math>)Eu155(n,<math>\gamma</math>)Eu156(<math>\beta^-</math>)Gd156(n,<math>\gamma</math>)Gd157(n,<math>\gamma</math>)Gd158(n,<math>\gamma</math>)Gd159(<math>\beta^-</math>)Tb159(n,<math>\gamma</math>)Tb160 <b>Sm154(n,<math>\gamma</math>)Sm155(<math>\beta^-</math>)Eu155(<math>\beta^-</math>)Gd155(n,<math>\gamma</math>)Gd156(n,<math>\gamma</math>)Gd157(n,<math>\gamma</math>)Gd158(n,<math>\gamma</math>)Gd159(<math>\beta^-</math>)Tb159(n,<math>\gamma</math>)Tb160</b></b></b>	2.2 1.2	2.6 4.1 2.8 25.4		
Ta182	114.7 d	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0			
Sm145	340.0 d	Sm144(n, $\gamma$ )Sm145 Sm147(n,2n)Sm146(n,2n)Sm145 Sm148(n,2n)Sm147(n,2n)Sm146(n,2n)Sm145	100.0	100.0	100.0	91.2 7.5
Pm144	363.0 d	Sm144(n,p)Pm144 Sm147(n,2n)Sm146(n,2n)Sm145( $\beta^+$ )Pm145(n,2n)Pm144 Sm148(n,2n)Sm147(n,2n)Sm146(n,2n)Sm145( $\beta^+$ ) Pm145(n,2n)Pm144	100.0	100.0	100.0	17.6 76.4 3.8
Eu155	4.846 y	Sm154(n, $\gamma$ )Sm155( $\beta^-$ )Eu155 <b>&amp;Sm147(n,<math>\gamma</math>)Sm148(n,<math>\gamma</math>)Sm149(n,<math>\gamma</math>)Sm150(n,<math>\gamma</math>)Sm151(n,<math>\gamma</math>)Sm152(n,<math>\gamma</math>)Sm153(<math>\beta^-</math>)Eu153(n,<math>\gamma</math>)Eu154(n,<math>\gamma</math>)Eu155</b> <b>&amp;Sm148(n,<math>\gamma</math>)Sm149(n,<math>\gamma</math>)Sm150(n,<math>\gamma</math>)Sm151(n,<math>\gamma</math>)Sm152(n,<math>\gamma</math>)Sm153(<math>\beta^-</math>)Eu153(n,<math>\gamma</math>)Eu154(n,<math>\gamma</math>)Eu155</b> Sm152(n, $\gamma$ )Sm153(n, $\gamma$ )Sm154(n, $\gamma$ )Sm155( $\beta^-$ )Eu155 <b>&amp;Sm150(n,<math>\gamma</math>)Sm151(n,<math>\gamma</math>)Sm152(n,<math>\gamma</math>)Sm153(<math>\beta^-</math>)Eu153(n,<math>\gamma</math>)Eu154(n,<math>\gamma</math>)Eu155</b> Sm150(n, $\gamma$ )Sm151(n, $\gamma$ )Sm152(n, $\gamma$ )Sm153(n, $\gamma$ ) Sm154(n, $\gamma$ )Sm155( $\beta^-$ )Eu155 <b>&amp;Sm149(n,<math>\gamma</math>)Sm150(n,<math>\gamma</math>)Sm151(n,<math>\gamma</math>)Sm152(n,<math>\gamma</math>)Sm153(<math>\beta^-</math>)Eu153(n,<math>\gamma</math>)Eu154(n,<math>\gamma</math>)Eu155</b> <b>&amp;Sm152(n,<math>\gamma</math>)Sm153(<math>\beta^-</math>)Eu153(n,<math>\gamma</math>)Eu154(n,<math>\gamma</math>)Eu155</b>	60.1 18.1 14.2 3.3 1.5 1.0 0.9 19.6	17.0 14.9 16.5 31.2 5.8	94.2	99.9
Pm146	5.531 y	Sm144(n, $\gamma$ )Sm145( $\beta^+$ )Pm145(n, $\gamma$ )Pm146 Sm147(n,d)Pm146 Sm147(n,2n)Sm146(n,p)Pm146 Sm147(n,p)Pm147(n,2n)Pm146 Sm148(n,2n)Sm147(n,d)Pm146 Sm148(n,d)Pm147(n,2n)Pm146 Sm150(n, $\alpha$ )Nd147( $\beta^-$ )Pm147(n,2n)Pm146 Sm148(n,2n)Sm147(n,2n)Sm146(n,p)Pm146 Sm148(n,2n)Sm147(n,p)Pm147(n,2n)Pm146	100.0	100.0	100.0	32.5 28.8 23.2 3.6 2.8 2.7 2.0 1.8
Eu154	8.593 y	<b>&amp;Sm147(n,<math>\gamma</math>)Sm148(n,<math>\gamma</math>)Sm149(n,<math>\gamma</math>)Sm150(n,<math>\gamma</math>)Sm151(n,<math>\gamma</math>)Sm152(n,<math>\gamma</math>)Sm153(<math>\beta^-</math>)Eu153(n,<math>\gamma</math>)Eu154</b> <b>&amp;Sm148(n,<math>\gamma</math>)Sm149(n,<math>\gamma</math>)Sm150(n,<math>\gamma</math>)Sm151(n,<math>\gamma</math>)Sm152(n,<math>\gamma</math>)Sm153(<math>\beta^-</math>)Eu153(n,<math>\gamma</math>)Eu154</b> <b>&amp;Sm150(n,<math>\gamma</math>)Sm151(n,<math>\gamma</math>)Sm152(n,<math>\gamma</math>)Sm153(<math>\beta^-</math>)Eu153(n,<math>\gamma</math>)Eu154</b> <b>&amp;Sm149(n,<math>\gamma</math>)Sm150(n,<math>\gamma</math>)Sm151(n,<math>\gamma</math>)Sm152(n,<math>\gamma</math>)Sm153(<math>\beta^-</math>)Eu153(n,<math>\gamma</math>)Eu154</b> <b>&amp;Sm152(n,<math>\gamma</math>)Sm153(<math>\beta^-</math>)Eu153(n,<math>\gamma</math>)Eu154</b> <b>&amp;Sm154(n,<math>\gamma</math>)Sm155(<math>\beta^-</math>)Eu155(n,2n)Eu154</b> <b>&amp;Sm154(n,2n)Sm153(<math>\beta^-</math>)Eu153(n,<math>\gamma</math>)Eu154</b>	52.5 41.1 4.2 2.6 7.8 100.0	22.2 18.7 17.4 33.5 100.0		68.1 31.9
Eu152	13.522 y	Sm147(n, $\gamma$ )Sm148(n, $\gamma$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ ) Sm151( $\beta^-$ )Eu151(n, $\gamma$ )Eu152 Sm148(n, $\gamma$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151( $\beta^-$ ) Eu151(n, $\gamma$ )Eu152 Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151( $\beta^-$ )Eu151(n, $\gamma$ )Eu152 Sm150(n, $\gamma$ )Sm151( $\beta^-$ )Eu151(n, $\gamma$ )Eu152 <b>&amp;Sm154(n,2n)Sm153(<math>\beta^-</math>)Eu153(n,2n)Eu152</b>	56.0 41.9 1.1 1.0	29.0 22.8 31.8 16.3	12.2 87.6	100.0

Pm145	17.7 y	Sm144(n, $\gamma$ )Sm145( $\beta^+$ )Pm145 Sm147(n,2n)Sm146(n,2n)Sm145( $\beta^+$ )Pm145 Sm148(n,2n)Sm147(n,2n)Sm146(n,2n)Sm145( $\beta^+$ )Pm145	100.0	100.0	100.0	92.7 5.4
Eu150	36.359 y	Sm152(n,2n)Sm151( $\beta^-$ )Eu151(n,2n)Eu150 &Sm154(n,2n)Sm153( $\beta^-$ )Eu153(n,2n)Eu152(n,2n)Eu151(n,2n)Eu150 Sm154(n,2n)Sm153( $\beta^-$ )Eu153(n,2n)Eu152m( $\beta^-$ ) Gd152(n,2n)Gd151( $\beta^+$ )Eu151(n,2n)Eu150				65.3 31.2 2.7
Sm151	90.0 y	Sm147(n, $\gamma$ )Sm148(n, $\gamma$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151 Sm148(n, $\gamma$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151 Sm150(n, $\gamma$ )Sm151 Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151 Sm152(n,2n)Sm151	56.1 41.9 1.0 0.2	31.0 23.7 15.4 30.0	0.3 78.9 20.8	
Ho166m	1200 y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0	100.0	100.0	
La137	$6.0 \cdot 10^4$ y	&Sm144(n, $\alpha\alpha$ )Nd140( $\beta^+$ )Pr140( $\beta^+$ )Ce140(n,2n) Ce139( $\beta^+$ )La139(n,2n)La138(n,2n)La137 &Sm144(n, $\alpha\alpha$ )Nd140( $\beta^+$ )Pr140( $\beta^+$ )Ce140(n,2n) Ce139(n,2n)Ce138(n,2n)Ce137( $\beta^+$ )La137 &Sm144(n, $\alpha\alpha$ )Nd141( $\beta^+$ )Pr141(n,2n)Pr140( $\beta^+$ ) Ce140(n,2n)Ce139( $\beta^+$ )La139(n,2n)La138(n,2n)La137 &Sm144(n,2n)Sm143( $\beta^+$ )Pm143(n, $\alpha\alpha$ )Pr139( $\beta^+$ ) Ce139( $\beta^+$ )La139(n,2n)La138(n,2n)La137 &Sm144(n, $\alpha\alpha$ )Nd141( $\beta^+$ )Pr141(n, $\alpha\alpha$ )La138(n,2n)La137 &Sm144(n, $\alpha\alpha$ )Nd141( $\beta^+$ )Pr141(n, $\alpha\alpha$ )La137 &Sm144(n, $\alpha\alpha$ )Nd141( $\beta^+$ )Pr141(n,2n)Pr140( $\beta^+$ ) Ce140(n,2n)Ce139(n,2n)Ce138(n,2n)Ce137( $\beta^+$ )La137 &Sm144(n,2n)Sm143( $\beta^+$ )Pm143(n, $\alpha\alpha$ )Pr140( $\beta^+$ ) Ce140(n,2n)Ce139( $\beta^+$ )La139(n,2n)La138(n,2n)La137 &Sm144(n,2n)Sm143( $\beta^+$ )Pm143(n, $\alpha\alpha$ )Pr139( $\beta^+$ ) Ce139(n,2n)Ce138(n,2n)Ce137( $\beta^+$ )La137 &Sm144(n,2n)Sm143( $\beta^+$ )Pm143( $\beta^+$ )Nd143(n,2n) Nd142(n, $\alpha\alpha$ )Ce139( $\beta^+$ )La139(n,2n)La138(n,2n)La137 &Sm144(n,2n)Sm143( $\beta^+$ )Pm143( $\beta^+$ )Nd143(n,2n) Nd142(n,2n)Nd141( $\beta^+$ )Pr141(n, $\alpha\alpha$ )La137 &Sm144(n,2n)Sm143( $\beta^+$ )Pm143(n,2n)Pm142( $\beta^+$ ) Nd142(n,2n)Nd141( $\beta^+$ )Pr141(n, $\alpha\alpha$ )La137 &Sm144(n,2n)Sm143( $\beta^+$ )Pm143( $\beta^+$ )Nd143(n,2n) Nd142(n,2n)Nd141( $\beta^+$ )Pr141(n, $\alpha\alpha$ )La138(n,2n)La137 &Sm144(n,2n)Sm143( $\beta^+$ )Pm143(n,2n)Pm142( $\beta^+$ ) Nd142(n,2n)Nd141( $\beta^+$ )Pr141(n, $\alpha\alpha$ )La138(n,2n)La137 &Sm144(n,2n)Sm143( $\beta^+$ )Pm143( $\beta^+$ )Nd143(n, $\alpha\alpha$ ) Ce140(n,2n)Ce139( $\beta^+$ )La139(n,2n)La138(n,2n)La137 &Sm144(n,2n)Sm143( $\beta^+$ )Pm143(n,2n)Pm142( $\beta^+$ ) Nd142(n,2n)Nd141( $\beta^+$ )Pr141(n,2n)Pr140( $\beta^+$ ) Ce140(n,2n)Ce139( $\beta^+$ )La139(n,2n)La138(n,2n)La137 *Plus other similar pathways				28.4 11.2 8.6 6.4 6.1 4.8 4.2 3.0 2.2 2.1 2.1 1.6 1.5 1.4 1.3 1.0 12.0*
Sm146	$1.0 \cdot 10^8$ y	Sm144(n, $\gamma$ )Sm145(n, $\gamma$ )Sm146 Sm144(n, $\gamma$ )Sm145( $\beta^+$ )Pm145(n, $\gamma$ )Pm146( $\beta^-$ )Sm146 Sm147(n,2n)Sm146 Sm148(n,2n)Sm147(n,2n)Sm146 Sm149(n,2n)Sm148(n,2n)Sm147(n,2n)Sm146	100.0     	95.3 4.7	84.2 15.8	89.4 9.0 1.1
Lu176	$3.6 \cdot 10^{10}$ y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0	100.0		

Isotope	Half-life (y)	Decay Pathways and Nuclides Involved	Yield (%)	Yield (%)	Yield (%)	Yield (%)
La138	$1.1 \cdot 10^{11}$ y	$\text{Sm144}(\text{n},\alpha)\text{Nd141}(\beta^+)\text{Pr141}(\text{n},\alpha)\text{La138}$ $\text{Sm144}(\text{n},\gamma)\text{Sm145}(\beta^+)\text{Pm145}(\alpha)\text{Pr141}(\text{n},\alpha)\text{La138}$ $\text{Sm144}(\text{n},\text{n}\alpha)\text{Nd140}(\beta^+)\text{Pr140}(\beta^+)\text{Ce140}(\text{n},2\text{n})$ $\text{Ce139}(\beta^+)\text{La139}(\text{n},2\text{n})\text{La138}$ $\text{Sm144}(\text{n},\alpha)\text{Nd141}(\beta^+)\text{Pr141}(\text{n},2\text{n})\text{Pr140}(\beta^+)$ $\text{Ce140}(\text{n},2\text{n})\text{Ce139}(\beta^+)\text{La139}(\text{n},2\text{n})\text{La138}$ $\text{Sm144}(\text{n},2\text{n})\text{Sm143}(\beta^+)\text{Pm143}(\text{n},\text{n}\alpha)\text{Pr139}(\beta^+)$ $\text{Ce139}(\beta^+)\text{La139}(\text{n},2\text{n})\text{La138}$ $\text{Sm144}(\text{n},2\text{n})\text{Sm143}(\beta^+)\text{Pm143}(\text{n},\alpha)\text{Pr140}(\beta^+)$ $\text{Ce140}(\text{n},2\text{n})\text{Ce139}(\beta^+)\text{La139}(\text{n},2\text{n})\text{La138}$ $\text{Sm144}(\text{n},2\text{n})\text{Sm143}(\beta^+)\text{Pm143}(\beta^+)\text{Nd143}(\text{n},2\text{n})$ $\text{Nd142}(\text{n},\alpha)\text{Ce139}(\beta^+)\text{La139}(\text{n},2\text{n})\text{La138}$ $\text{Sm144}(\text{n},2\text{n})\text{Sm143}(\beta^+)\text{Pm143}(\text{n},2\text{n})\text{Pm142}(\beta^+)$ $\text{Nd142}(\text{n},\alpha)\text{Ce139}(\beta^+)\text{La139}(\text{n},2\text{n})\text{La138}$ $\text{Sm144}(\text{n},2\text{n})\text{Sm143}(\beta^+)\text{Pm143}(\beta^+)\text{Nd143}(\text{n},2\text{n})$ $\text{Nd142}(\text{n},2\text{n})\text{Nd141}(\beta^+)\text{Pr141}(\text{n},\alpha)\text{La138}$ $\text{Sm144}(\text{n},2\text{n})\text{Sm143}(\beta^+)\text{Pm143}(\beta^+)\text{Nd143}(\text{n},\alpha)$ $\text{Ce140}(\text{n},2\text{n})\text{Ce139}(\beta^+)\text{La139}(\text{n},2\text{n})\text{La138}$ $\text{Sm144}(\text{n},2\text{n})\text{Sm143}(\beta^+)\text{Pm143}(\text{n},2\text{n})\text{Pm142}(\beta^+)$ $\text{Nd142}(\text{n},2\text{n})\text{Nd141}(\beta^+)\text{Pr141}(\text{n},2\text{n})\text{Pr140}(\beta^+)$ $\text{Ce140}(\text{n},2\text{n})\text{Ce139}(\beta^+)\text{La139}(\text{n},2\text{n})\text{La138}$ $\text{Sm144}(\text{n},2\text{n})\text{Sm143}(\beta^+)\text{Pm143}(\text{n},2\text{n})\text{Pm142}(\beta^+)$ $\text{Nd142}(\text{n},2\text{n})\text{Nd141}(\beta^+)\text{Pr141}(\text{n},\alpha)\text{La138}$ *Plus other similar pathways	91.9	99.1	96.1	6.2
Sm147	$1.1 \cdot 10^{11}$ y	$\text{Sm144}(\text{n},\gamma)\text{Sm145}(\text{n},\gamma)\text{Sm146}(\text{n},\gamma)\text{Sm147}$ $\text{Sm144}(\text{n},\gamma)\text{Sm145}(\beta^+)\text{Pm145}(\text{n},\gamma)\text{Pm146}(\text{n},\gamma)$ $\text{Pm147}(\beta^-)\text{Sm147}$ $\text{Sm144}(\text{n},\gamma)\text{Sm145}(\beta^+)\text{Pm145}(\text{n},\gamma)\text{Pm146}(\beta^-)\text{Sm146}(\text{n},\gamma)\text{Sm147}$ $\text{Sm148}(\text{n},2\text{n})\text{Sm147}$ $\text{Sm149}(\text{n},2\text{n})\text{Sm148}(\text{n},2\text{n})\text{Sm147}$ $\text{Sm150}(\text{n},2\text{n})\text{Sm149}(\text{n},2\text{n})\text{Sm148}(\text{n},2\text{n})\text{Sm147}$ $\text{Sm149}(\text{n},3\text{n})\text{Sm147}$ *Nuclide also present in starting material	12.0	6.6		

# Samarium activation characteristics

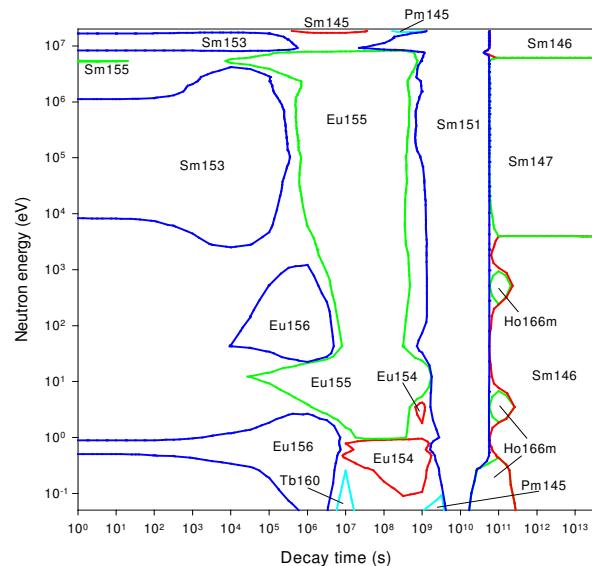


Decay time (years)

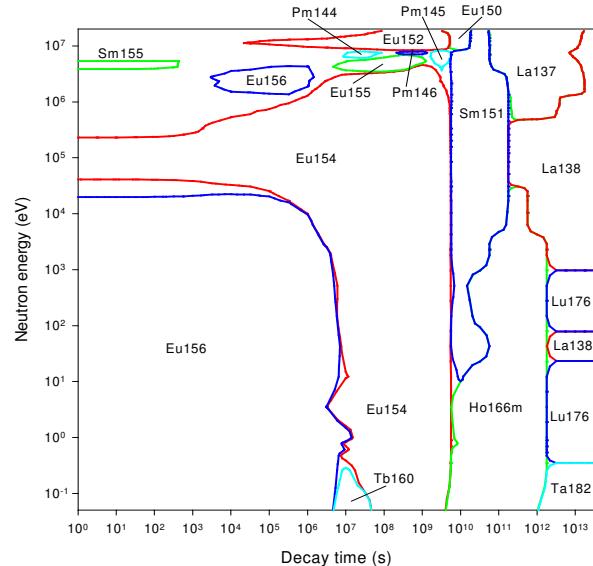
Decay time (years)

# Samarium importance diagrams & transmutation

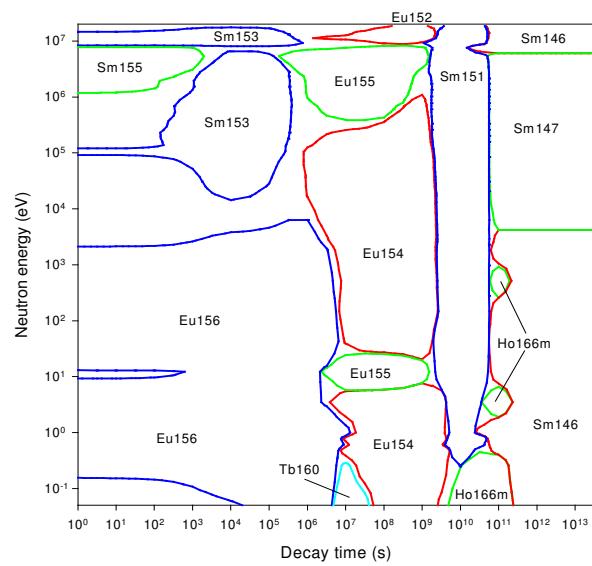
## Activity



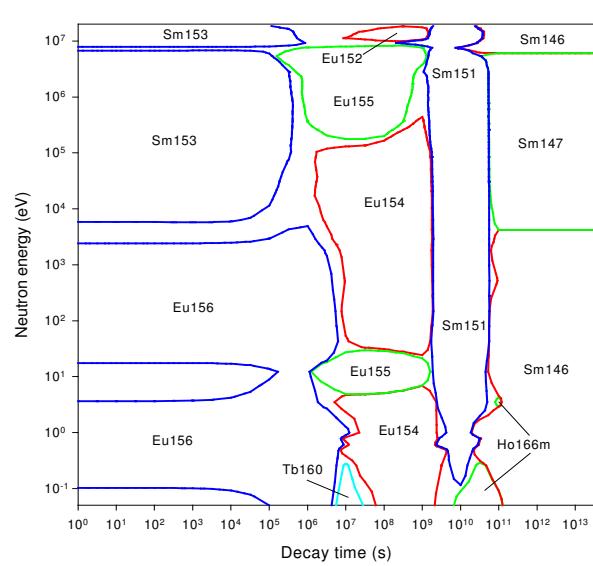
## Dose rate



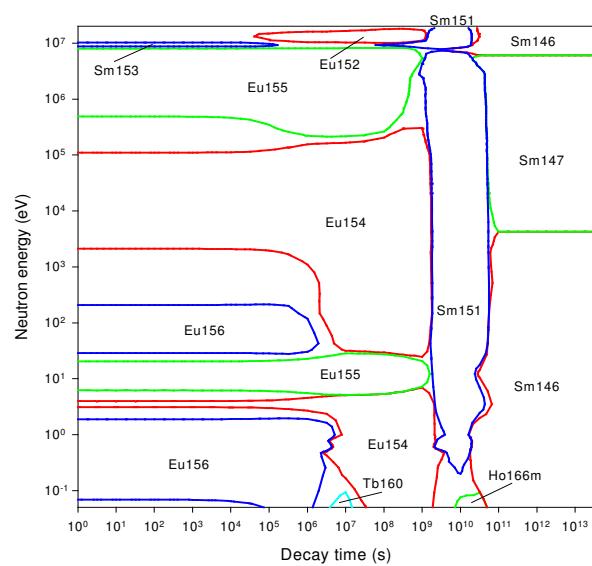
## Heat output



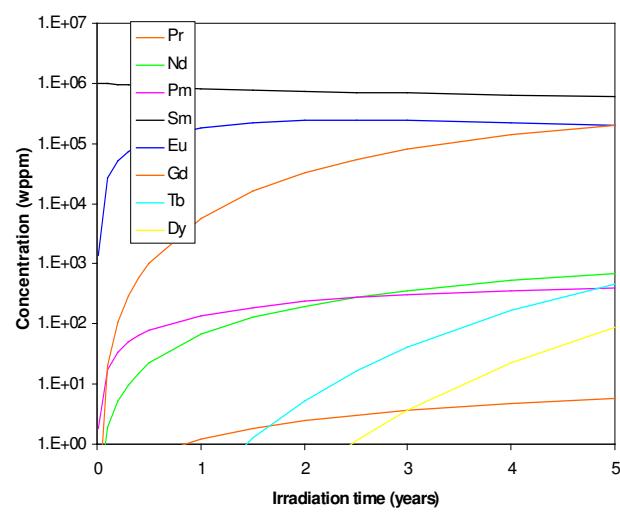
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Europium

## General properties

		63	Isotopes	Isotopic abundances / %	
Atomic number	2			Eu151	47.81
Crustal abundance / wppm	1095		Eu153	52.19	
Melting point / K	1869				
Boiling point / K	5244				
Density / kgm <sup>-3</sup>	13.9				
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	9.0 10 <sup>-7</sup>				
Electrical resistivity /Ωm	3.5 10 <sup>-5</sup>				
Coefficient of thermal expansion / K <sup>-1</sup>	BCC				
Crystal structure	2				
Number of stable isotopes	151.965				
Mean atomic weight					

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.70E16	1.69E16	1.41E16	3.73E15	1.20E12	3.81E7	kW kg <sup>-1</sup>	3.56E0	3.56E0	3.02E0	3.46E-1	2.60E-4	1.71E-8
Eu156	65.77	65.85	66.94				Eu156	86.80	86.82	86.80			
Eu155	16.00	16.02	19.20	62.93	0.14		Eu154	8.27	8.27	9.76	78.44	35.61	
Eu154	7.13	7.14	8.57	29.87	31.65		Eu155	1.59	1.60	1.88	14.22	0.01	
Gd153	2.73	2.73	3.24	4.32			Eu152m	0.81	0.81				
Sm153	2.21	2.21	0.72				Eu152	0.62	0.62	0.73	6.07	50.65	
Eu157	1.45	1.45	0.03				Sm153	0.56	0.56	0.18			
Eu152m	1.31	1.30					Eu157	0.34	0.34	0.01			
Eu154m	1.18	1.09					Gd153	0.31	0.31	0.37	1.12		
Gd159	1.08	1.08	0.05				Gd159	0.30	0.30	0.01			
Eu152	0.63	0.63	0.76	2.72	52.90		Tb160	0.20	0.20	0.23	0.06		
Eu150	0.01	0.01	0.01	0.03	11.75		Eu154m	0.14	0.13				
Sm151					3.34		Eu150	0.01	0.01	0.01	0.07	13.53	
Gd150					99.93	Gd150					0.01	99.94	
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	4.49E6	4.48E6	3.84E6	3.72E5	3.23E2	1.58E-20	Sv kg <sup>-1</sup>	2.88E7	2.88E7	2.45E7	3.17E6	1.84E3	1.98E0
Eu156	90.26	90.26	89.31				Eu156	85.22	85.23	84.89			
Eu154	8.28	8.28	9.67	92.16	36.04		Eu154	8.40	8.41	9.88	70.33	41.25	
Eu152	0.64	0.64	0.75	7.35	52.82		Eu155	3.02	3.02	3.54	23.71	0.03	
Eu152m	0.35	0.35					Sm153	0.96	0.96	0.31			
Tb160	0.19	0.19	0.22	0.07			Eu152	0.52	0.52	0.61	4.48	48.27	
Eu150	0.01	0.01	0.01	0.06	11.00		Gd153	0.43	0.43	0.51	1.37		
La137					93.51		Eu150			0.01	0.04	9.96	
La138					6.49	Gd150					0.11	99.93	
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	1.27E8	1.27E8	1.21E8	8.00E7	5.79E4	3.16E3		1.73E13	1.73E13	1.48E13	1.94E12	2.81E9	1.59E3
Eu154	50.51	50.51	53.09	73.90	34.73		Eu156	86.14	86.14	85.23			
Eu156	29.88	29.87	26.60				Eu154	8.87	8.87	10.36	72.83	17.07	
Eu155	14.75	14.75	15.49	20.27	0.02		Eu152	2.06	2.06	2.41	17.44	75.14	
Eu152	3.54	3.54	3.72	5.33	46.00		Eu155	1.12	1.12	1.31	8.66		
Gd153	0.76	0.77	0.80	0.42			Gd153	0.30	0.30	0.34	0.92		
Eu150	0.04	0.04	0.04	0.06	12.90		Eu150	0.01	0.01	0.01	0.07	7.71	
Gd150					5.67	99.99	Gd150						99.99

# Europium

## Pathway analysis

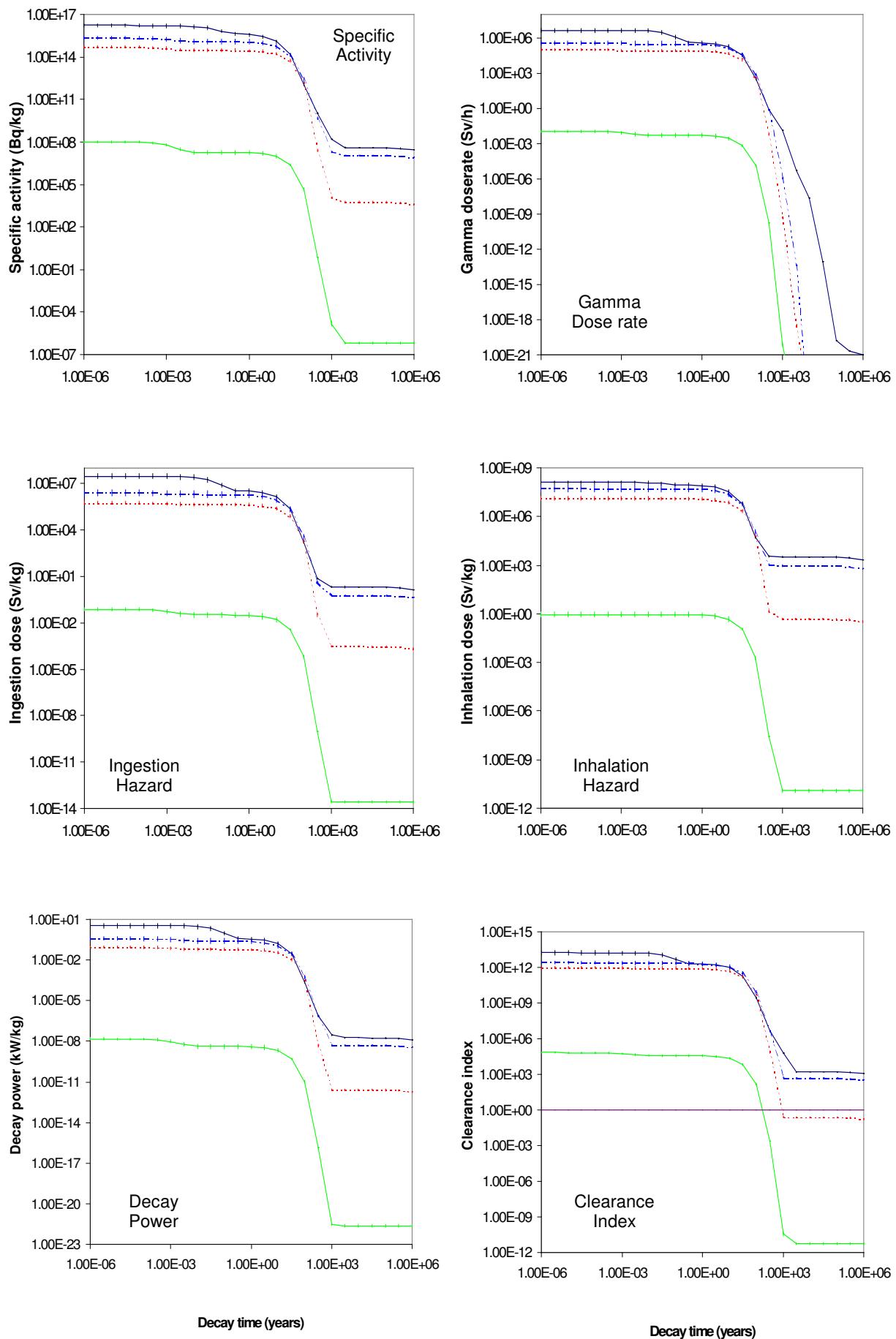
Nuclide	T <sub>½</sub>	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Tb161	6.89 d	<b>&amp;Eu153(n,γ)Eu154(n,γ)Eu155(n,γ)Eu156(n,γ)</b> Eu157(β⁻)Gd157(n,γ)Gd158(n,γ)Gd159(β⁻) Tb159(n,γ)Tb160(n,γ)Tb161 <b>&amp;Eu151(n,γ)Eu152(n,γ)Eu153(n,γ)Eu154(n,γ)</b> Eu155(n,γ)Eu156(n,γ)Eu157(β⁻)Gd157(n,γ) Gd158(n,γ)Gd159(β⁻)Tb159(n,γ)Tb160(n,γ)Tb161 <b>&amp;Eu153(n,γ)Eu154(n,γ)Eu155(n,γ)Eu156(β⁻)</b> Gd156(n,γ)Gd157(n,γ)Gd158(n,γ)Gd159(β⁻) Tb159(n,γ)Tb160(n,γ)Tb161 Eu151(n,γ)Eu152m(β⁻)Gd152(n,γ)Gd153(n,γ) Gd154(n,γ)Gd155(n,γ)Gd156(n,γ)Gd157(n,γ) Gd158(n,γ)Gd159(β⁻)Tb159(n,γ)Tb160(n,γ)Tb161 <b>&amp;Eu153(n,γ)Eu154(β⁻)Gd154(n,γ)Gd155(n,γ)</b> Gd156(n,γ)Gd157(n,γ)Gd158(n,γ)Gd159(β⁻) Tb159(n,γ)Tb160(n,γ)Tb161 <b>&amp;Eu151(n,γ)Eu152(n,γ)Eu153(n,γ)Eu154(n,γ)</b> Eu155(n,γ)Eu156(β⁻)Gd156(n,γ)Gd157(n,γ) Gd158(n,γ)Gd159(β⁻)Tb159(n,γ)Tb160(n,γ)Tb161 <b>&amp;Eu153(n,γ)Eu154(n,γ)Eu155(β⁻)Gd155(n,γ)Gd156(n,γ)</b> Gd157(n,γ)Gd158(n,γ)Gd159(β⁻)Tb159(n,γ)Tb160(n,γ)Tb161 <b>&amp;Eu151(n,γ)Eu152(n,γ)Eu153(n,γ)Eu154(n,γ)</b> Eu155(β⁻)Gd155(n,γ)Gd156(n,γ)Gd157(n,γ) Gd158(n,γ)Gd159(β⁻)Tb159(n,γ)Tb160(n,γ)Tb161 *Plus other similar pathways	48.9		0.5	
Eu156	15.2 d	Eu151(n,γ)Eu152m(β⁺)Sm152(n,γ)Sm153(n,γ) Sm154(n,γ)Sm155(β⁻)Eu155(n,γ)Eu156 <b>&amp;Eu151(n,γ)Eu152m(β⁻)Gd152(n,γ)Gd153(β⁺)</b> Eu153(n,γ)Eu154(n,γ)Eu155(n,γ)Eu156 <b>&amp;Eu151(n,γ)Eu152(n,γ)Eu153(n,γ)Eu154(n,γ)Eu155(n,γ)Eu156</b> <b>&amp;Eu151(n,γ)Eu152m(β⁺)Sm152(n,γ)Sm153(β⁻)</b> Eu153(n,γ)Eu154(n,γ)Eu155(n,γ)Eu156 <b>&amp;Eu153(n,γ)Eu154(n,γ)Eu155(n,γ)Eu156</b> <b>&amp;Eu151(n,γ)Eu152(β⁺)Sm152(n,γ)Sm153(β⁻)</b> Eu153(n,γ)Eu154(n,γ)Eu155(n,γ)Eu156	97.8			
Tb160	72.3 d	<b>&amp;Eu153(n,γ)Eu154(n,γ)Eu155(n,γ)Eu156(n,γ)Eu157</b> (β⁻)Gd157(n,γ)Gd158(n,γ)Gd159(β⁻)Tb159(n,γ)Tb160 <b>&amp;Eu151(n,γ)Eu152(n,γ)Eu153(n,γ)Eu154(n,γ)</b> Eu155(n,γ)Eu156(n,γ)Eu157(β⁻)Gd157(n,γ) Gd158(n,γ)Gd159(β⁻)Tb159(n,γ)Tb160 <b>&amp;Eu153(n,γ)Eu154(n,γ)Eu155(n,γ)Eu156(β⁻)Gd156</b> (n,γ)Gd157(n,γ)Gd158(n,γ)Gd159(β⁻)Tb159(n,γ)Tb160 Eu151(n,γ)Eu152m(β⁻)Gd152(n,γ)Gd153(n,γ) Gd154(n,γ)Gd155(n,γ)Gd156(n,γ)Gd157(n,γ) Gd158(n,γ)Gd159(β⁻)Tb159(n,γ)Tb160 <b>&amp;Eu153(n,γ)Eu154(β⁻)Gd154(n,γ)Gd155(n,γ)Gd156</b> (n,γ)Gd157(n,γ)Gd158(n,γ)Gd159(β⁻)Tb159(n,γ)Tb160 <b>&amp;Eu151(n,γ)Eu152(n,γ)Eu153(n,γ)Eu154(n,γ)</b> Eu155(n,γ)Eu156(β⁻)Gd156(n,γ)Gd157(n,γ) Gd158(n,γ)Gd159(β⁻)Tb159(n,γ)Tb160 <b>&amp;Eu153(n,γ)Eu154(n,γ)Eu155(β⁻)Gd155(n,γ)Gd156</b> (n,γ)Gd157(n,γ)Gd158(n,γ)Gd159(β⁻)Tb159(n,γ)Tb160 <b>&amp;Eu151(n,γ)Eu152(n,γ)Eu153(n,γ)Eu154(n,γ)Eu155(β⁻)Gd155(n,γ)</b> Gd156(n,γ)Gd157(n,γ)Gd158(n,γ)Gd159(β⁻)Tb159(n,γ)Tb160 *Plus other similar pathways	48.9	0.4	0.5	

Eu149	93.1 d	Eu151(n,2n)Eu150(n,2n)Eu149 Eu151(n,2n)Eu150m( $\beta^-$ )Gd150(n,2n)Gd149( $\beta^+$ )Eu149				70.4 27.5
Ta182	114.7 d	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0			
Gd153	240.5 d	Eu151(n, $\gamma$ )Eu152m( $\beta^-$ )Gd152(n, $\gamma$ )Gd153 Eu151(n, $\gamma$ )Eu152( $\beta^-$ )Gd152(n, $\gamma$ )Gd153 &Eu153(n, $\gamma$ )Eu154( $\beta^-$ )Gd154(n,2n)Gd153 Eu153(n,2n)Eu152m( $\beta^-$ )Gd152(n, $\gamma$ )Gd153 &Eu153(n,2n)Eu152( $\beta^-$ )Gd152(n, $\gamma$ )Gd153	93.0 7.0	98.0 1.8	93.6 6.4	52.8 39.2 7.8
Tm171	1.920 y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0	100.0		
Eu155	4.846 y	Eu151(n, $\gamma$ )Eu152m( $\beta^+$ )Sm152(n, $\gamma$ )Sm153(n, $\gamma$ ) Sm154(n, $\gamma$ )Sm155( $\beta^-$ )Eu155 &Eu151(n, $\gamma$ )Eu152m( $\beta^-$ )Gd152(n, $\gamma$ )Gd153( $\beta^+$ ) Eu153(n, $\gamma$ )Eu154(n, $\gamma$ )Eu155 &Eu151(n, $\gamma$ )Eu152(n, $\gamma$ )Eu153(n, $\gamma$ )Eu154(n, $\gamma$ )Eu155 &Eu151(n, $\gamma$ )Eu152m( $\beta^+$ )Sm152(n, $\gamma$ )Sm153( $\beta^-$ ) Eu153(n, $\gamma$ )Eu154(n, $\gamma$ )Eu155 &Eu153(n, $\gamma$ )Eu154(n, $\gamma$ )Eu155 &Eu151(n, $\gamma$ )Eu152( $\beta^+$ )Sm152(n, $\gamma$ )Sm153( $\beta^-$ ) Eu153(n, $\gamma$ )Eu154(n, $\gamma$ )Eu155	98.1	39.2 29.2 14.8 13.9 1.9	2.0	99.9
Eu154	8.593 y	Eu151(n, $\gamma$ )Eu152m( $\beta^+$ )Sm152(n, $\gamma$ )Sm153( $\beta^-$ ) Eu153(n, $\gamma$ )Eu154 &Eu153(n, $\gamma$ )Eu154 &Eu151(n, $\gamma$ )Eu152(n, $\gamma$ )Eu153(n, $\gamma$ )Eu154 Eu151(n, $\gamma$ )Eu152m(n, $\gamma$ )Eu153(n, $\gamma$ )Eu154 Eu151(n, $\gamma$ )Eu152m( $\beta^-$ )Gd152(n, $\gamma$ )Gd153( $\beta^+$ )Eu153(n, $\gamma$ )Eu154 Eu151(n, $\gamma$ )Eu152( $\beta^+$ )Sm152(n, $\gamma$ )Sm153( $\beta^-$ )Eu153(n, $\gamma$ )Eu154 Eu151(n, $\gamma$ )Eu152( $\beta^-$ )Gd152(n, $\gamma$ )Gd153( $\beta^+$ )Eu153(n, $\gamma$ )Eu154	40.1 32.8 21.9 3.2 64.3 2.4 1.2	17.5 2.5 10.6 3.7	95.9	99.9
Eu152	13.522 y	Eu151(n, $\gamma$ )Eu152 Eu151(n, $\gamma$ )Eu152n(IT)Eu152	99.9	99.8 99.9 0.1	94.6 5.2	
Eu150	36.359 y	Eu151(n,2n)Eu150 Eu153(n,2n)Eu152(n,2n)Eu151(n,2n)Eu150				98.3 1.4
Gd148	74.467 y	Eu151(n,2n)Eu150m( $\beta^-$ )Gd150(n,2n)Gd149(n,2n)Gd148				98.7
Sm151	90.0 y	Eu151(n, $\gamma$ )Eu152m( $\beta^-$ )Gd152(n, $\gamma$ )Gd153(n, $\gamma$ ) Gd154(n, $\alpha$ )Sm151 Eu151(n, $\gamma$ )Eu152m( $\beta^-$ )Gd152(n, $\alpha$ )Sm149(n, $\gamma$ ) Sm150(n, $\gamma$ )Sm151 &Eu153(n, $\gamma$ )Eu154( $\beta^-$ )Gd154(n, $\alpha$ )Sm151 Eu151(n, $\gamma$ )Eu152(n, $\gamma$ )Eu153(n, $\gamma$ )Eu154( $\beta^-$ ) Gd154(n, $\alpha$ )Sm151 Eu151(n, $\gamma$ )Eu152m( $\beta^-$ )Gd152(n, $\gamma$ )Gd153(n, $\alpha$ ) Sm150(n, $\gamma$ )Sm151 Eu151(n, $\gamma$ )Eu152( $\beta^-$ )Gd152(n, $\alpha$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151 Eu151(n,p)Sm151 &Eu153(n, $\gamma$ )Eu154(n, $\alpha$ )Pm151( $\beta^-$ )Sm151 &Eu153(n,2n)Eu152( $\beta^+$ )Sm152(n,2n)Sm151 Eu153(n,2n)Eu152m( $\beta^+$ )Sm152(n,2n)Sm151 Eu153(n,d)Sm152(n,2n)Sm151	59.1 21.3 8.8 5.4 3.1 1.2 42.2 33.5	93.8 6.0 16.7 4.9 4.9 1.2 24.7 37.0 35.0 1.9		

Ho166m	1200 y	$\text{&Eu153(n,\gamma)Eu154(n,\gamma)Eu155(n,\gamma)Eu156(n,\gamma)Eu157(\beta^-)Gd157(n,\gamma)Gd158(n,\gamma)Gd159(\beta^-)Tb159(n,\gamma)}$ $\text{Tb160(n,\gamma)Tb161(\beta^-)Dy161(n,\gamma)Dy162(n,\gamma)}$ $\text{Dy163(n,\gamma)Dy164(n,\gamma)Dy165(\beta^-)Ho165(n,\gamma)Ho166m}$ $\text{\&Eu153(n,\gamma)Eu154(n,\gamma)Eu155(n,\gamma)Eu156(n,\gamma)Eu157(\beta^-)Gd157(n,\gamma)Gd158(n,\gamma)Gd159(\beta^-)Tb159(n,\gamma)}$ $\text{Tb160(\beta^-)Dy160(n,\gamma)Dy161(n,\gamma)Dy162(n,\gamma)}$ $\text{Dy163(n,\gamma)Dy164(n,\gamma)Dy165(\beta^-)Ho165(n,\gamma)Ho166m}$ $\text{\&Eu153(n,\gamma)Eu154(n,\gamma)Eu155(n,\gamma)Eu156(\beta^-)Gd156(n,\gamma)Gd157(n,\gamma)Gd158(n,\gamma)Gd159(\beta^-)Tb159(n,\gamma)}$ $\text{Tb160(n,\gamma)Tb161(n,\gamma)Tb162(\beta^-)Dy162(n,\gamma)}$ $\text{Dy163(n,\gamma)Dy164(n,\gamma)Dy165(\beta^-)Ho165(n,\gamma)Ho166m}$ $\text{\&Eu153(n,\gamma)Eu154(n,\gamma)Eu155(n,\gamma)Eu156(\beta^-)Gd156(n,\gamma)Gd157(n,\gamma)Gd158(n,\gamma)Gd159(\beta^-)Tb159(n,\gamma)}$ $\text{Gd157(n,\gamma)Gd158(n,\gamma)Gd159(\beta^-)Tb160(\beta^-)}$ $\text{Dy160(n,\gamma)Dy161(n,\gamma)Dy162(n,\gamma)Dy163(n,\gamma)Dy164(n,\gamma)}$ $\text{Dy165(\beta^-)Ho165(n,\gamma)Ho166m}$ $\text{\&Eu153(n,\gamma)Eu154(n,\gamma)Eu155(\beta^-)Gd155(n,\gamma)Gd156(n,\gamma)}$ $\text{Gd157(n,\gamma)Gd158(n,\gamma)Gd159(\beta^-)Tb159(n,\gamma)Tb160(n,\gamma)}$ $\text{Tb161(\beta^-)Dy161(n,\gamma)Dy162(n,\gamma)Dy163(n,\gamma)Dy164(n,\gamma)}$ $\text{Dy165(\beta^-)Ho165(n,\gamma)Ho166m}$ $\text{\&Eu153(n,\gamma)Eu154(\beta^-)Gd154(n,\gamma)Gd155(n,\gamma)Gd156(n,\gamma)}$ $\text{Gd157(n,\gamma)Gd158(n,\gamma)Gd159(\beta^-)Tb159(n,\gamma)Tb160(n,\gamma)}$ $\text{Tb161(\beta^-)Dy161(n,\gamma)Dy162(n,\gamma)Dy163(n,\gamma)Dy164(n,\gamma)}$ $\text{Dy165(\beta^-)Ho165(n,\gamma)Ho166m}$ *Plus other similar pathways	37.5 12.5 3.2 0.9 0.1  45.8*	0.4 0.5 29.7 34.0 1.4  29.6*	0.7 0.4 50.7 27.2 2.5  4.5 1.7 8.9 0.8 1.4  3.7*
La137	$6.0 \cdot 10^4$ y	$\text{Eu151(n,2n)Eu150(n,2n)Eu149(n,no)Pm145(n,n\alpha)Pr141(n,n\alpha)La137}$ $\text{Eu151(n,2n)Eu150(n,n\alpha)Pm146(n,2n)Pm145(n,n\alpha)Pr141(n,n\alpha)La137}$ *Plus many other similar long pathways of (n,2n), (n, $\alpha$ ), (n, $\alpha$ ), etc			1.6 0.8 97.6*
Gd150	$1.8 \cdot 10^6$ y	$\text{Eu151(n,2n)Eu150m(\beta^-)Gd150}$ $\text{Eu153(n,2n)Eu152(n,2n)Eu151(n,2n)Eu150m(\beta^-)Gd150}$			97.6 1.3
Hf182	$9.0 \cdot 10^6$ y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0		
Sm146	$1.0 \cdot 10^8$ y	$\text{Eu151(n,2n)Eu150m(\beta^-)Gd150(n,no)Sm146}$ $\text{Eu151(n,2n)Eu150(n,2n)Eu149(\beta^+)Sm149(n,2n)}$ $\text{Sm148(n,2n)Sm147(n,2n)Sm146}$ $\text{Eu151(n,2n)Eu150m(\beta^-)Gd150(n,\alpha)Sm147(n,2n)Sm146}$ $\text{Eu151(n,\alpha)Pm148m(\beta^-)Sm148(n,2n)Sm147(n,2n)Sm146}$ $\text{\&Eu151(n,\alpha)Pm148(\beta^-)Sm148(n,2n)Sm147(n,2n)Sm146}$ $\text{Eu151(n,2n)Eu150m(\beta^-)Gd150(n,2n)Gd149(\beta^+)$ $\text{Eu149(\beta^+)Sm149(n,2n)Sm148(n,2n)Sm147(n,2n)Sm146}$ $\text{Eu151(n,2n)Eu150(n,2n)Eu149(n,2n)Eu148(\beta^+)$ $\text{Sm148(n,2n)Sm147(n,2n)Sm146}$ $\text{Eu151(n,2n)Eu150(n,no)Pm146(\beta^-)Sm146}$ $\text{Eu151(n,2n)Eu150(n,\alpha)Pm147(\beta^-)Sm147(n,2n)Sm146}$ $\text{Eu151(n,2n)Eu150m(\beta^-)Gd150(n,2n)Gd149(\beta^+)$ $\text{Eu149(n,2n)Eu148(\beta^+)Sm148(n,2n)Sm147(n,2n)Sm146}$ $\text{Eu151(n,2n)Eu150(n,2n)Eu149(\beta^+)Sm149(n,3n)}$ $\text{Sm147(n,2n)Sm146}$			57.2 9.2  4.7 4.6 4.5 3.5  2.7  2.2 1.5 1.0  1.0
Lu176	$3.6 \cdot 10^{10}$ y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0	100.0	
La138	$1.1 \cdot 10^{11}$ y	$\text{Eu151(n,2n)Eu150(n,2n)Eu149(n,no)Pm145(n,n\alpha)Pr141(n,n\alpha)La138}$ $\text{Eu151(n,2n)Eu150(n,n\alpha)Pm146(n,2n)Pm145(n,n\alpha)Pr141(n,n\alpha)La138}$ *Plus many other similar long pathways of (n,2n), (n, $\alpha$ ), (n, $\alpha$ ), etc			1.9 0.9 97.2*

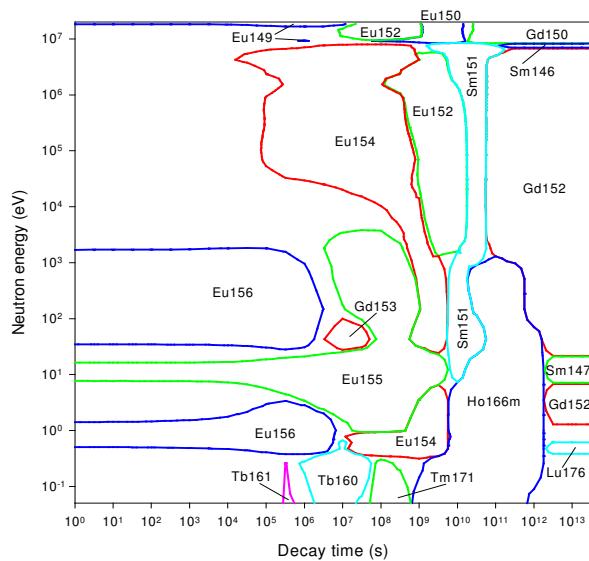
Sm147	$1.1 \cdot 10^{11}$ y	Eu151(n, $\alpha$ )Pm147( $\beta^-$ )Sm147 Eu151(n, $\gamma$ )Eu152m( $\beta^-$ )Gd152(n, $\alpha$ )Sm149(n, $\alpha$ ) Nd146(n, $\gamma$ )Nd147( $\beta^-$ )Pm147( $\beta^-$ )Sm147 Eu151(n,2n)Eu150(n,2n)Eu149( $\beta^+$ )Sm149(n,2n) Sm148(n,2n)Sm147 Eu151(n,2n)Eu150m( $\beta^-$ )Gd150(n,2n)Gd149( $\beta^+$ ) Eu149( $\beta^+$ )Sm149(n,2n)Sm148(n,2n)Sm147 Eu151(n, $\alpha$ )Pm148m( $\beta^-$ )Sm148(n,2n)Sm147 Eu151(n,2n)Eu150m( $\beta^-$ )Gd150(n, $\alpha$ )Sm147 <b>&amp;Eu151(n,<math>\alpha</math>)Pm148(<math>\beta^-</math>)Sm148(n,2n)Sm147</b> Eu151(n,2n)Eu150(n,2n)Eu149(n,2n)Eu148( $\beta^+$ ) Sm148(n,2n)Sm147 Eu151(n,2n)Eu150(n, $\alpha$ )Pm147( $\beta^-$ )Sm147 Eu151(n,2n)Eu150m( $\beta^-$ )Gd150(n,2n)Gd149( $\beta^+$ ) Eu149(n,2n)Eu148( $\beta^+$ )Sm148(n,2n)Sm147 Eu151(n,2n)Eu150(n,2n)Eu149( $\beta^+$ )Sm149(n,3n)Sm147 Eu151(n,2n)Eu150m( $\beta^+$ )Sm150(n,2n)Sm149(n,2n) Sm148(n,2n)Sm147 Eu151(n,2n)Eu150m( $\beta^-$ )Gd150(n,2n)Gd149( $\beta^+$ ) Eu149( $\beta^+$ )Sm149(n,3n)Sm147 Eu151(n,2n)Eu150(n,2n)Eu149(n,2n)Eu148(n,2n) Eu147( $\beta^+$ )Sm147	100.0	58.1 38.5	100.0	31.2 11.9 9.3 9.2 8.7 7.6 3.6 2.9 2.7 2.1 1.0 1.0
Gd152	$1.1 \cdot 10^{14}$ y	Eu151(n, $\gamma$ )Eu152m( $\beta^-$ )Gd152 Eu151(n, $\gamma$ )Eu152( $\beta^-$ )Gd152 Eu153(n,2n)Eu152m( $\beta^-$ )Gd152 <b>&amp;Eu153(n,2n)Eu152(<math>\beta^-</math>)Gd152</b>	91.7 8.0	98.0 1.8	92.8 7.2	80.9 18.7

# Europium activation characteristics

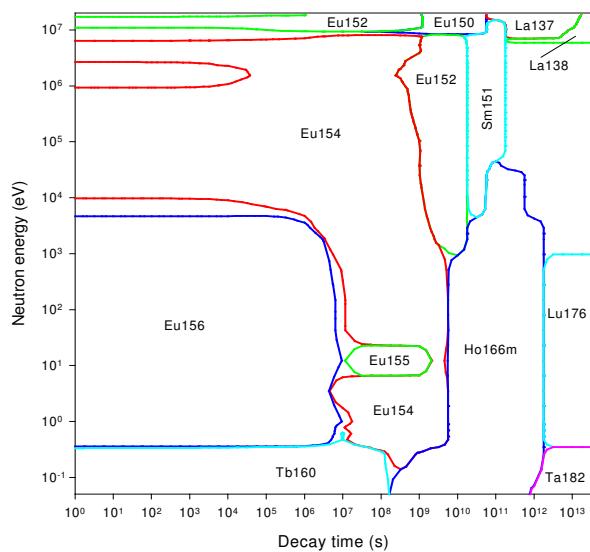


# Europium importance diagrams & transmutation

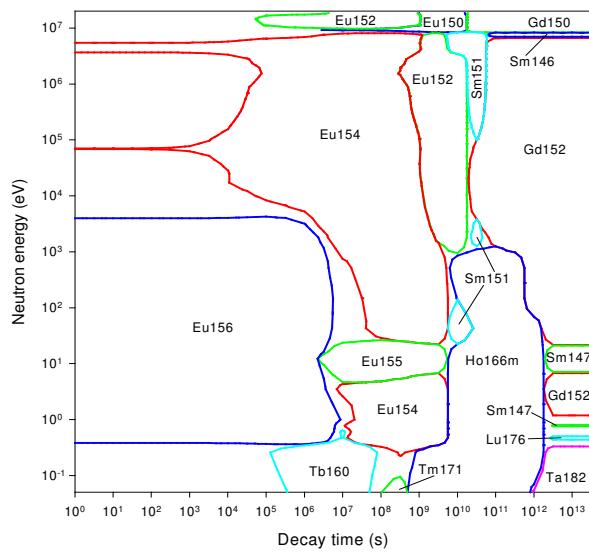
## Activity



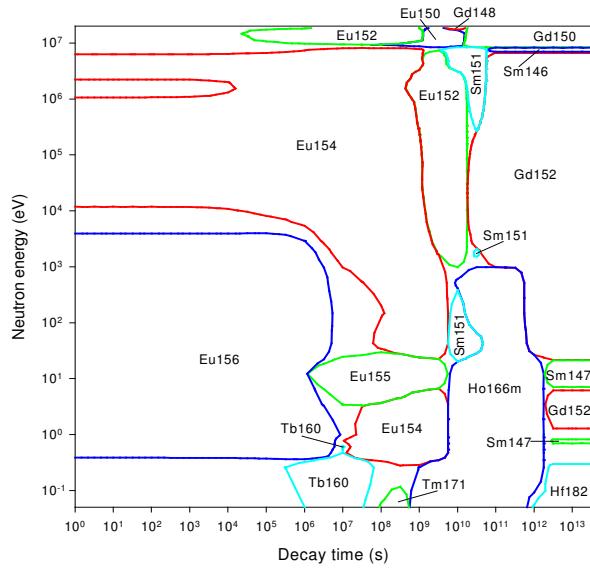
## Dose rate



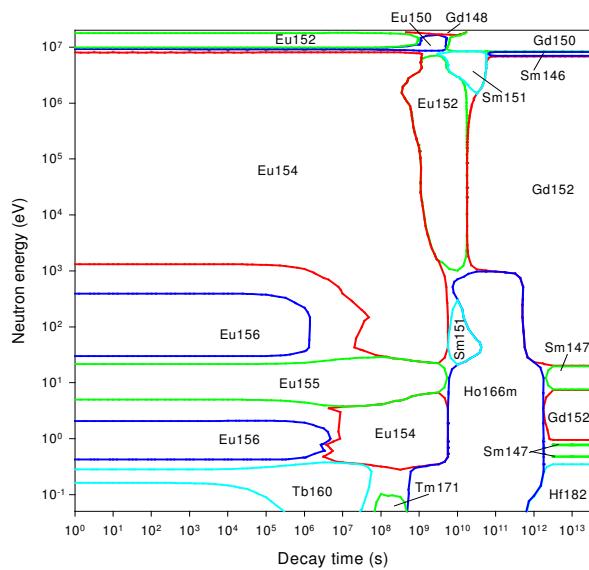
## Heat output



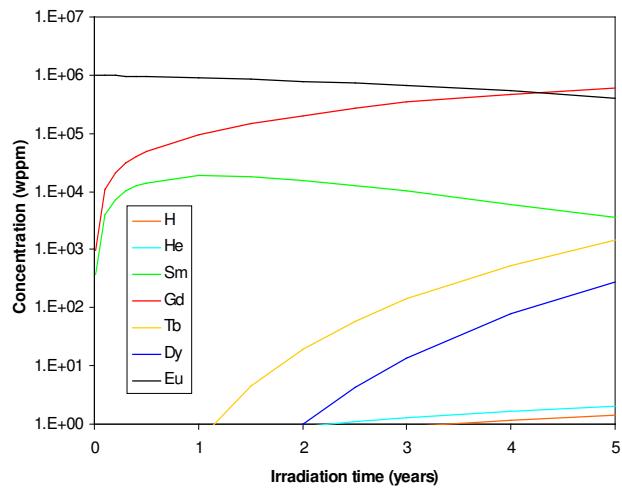
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Gadolinium

## General properties

Atomic number	64	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	6.2	Gd152	0.20 ( $T_{1/2}=1.0793 \cdot 10^{14}$ y)
Melting point / K	1587	Gd154	2.18
Boiling point / K	3537	Gd155	14.80
Density / kgm <sup>-3</sup>	7901	Gd156	20.47
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	10.6	Gd157	15.65
Electrical resistivity /Ωm	1.34 10 <sup>-6</sup>	Gd158	24.84
Coefficient of thermal expansion / K <sup>-1</sup>	9.0 10 <sup>-6</sup>	Gd160	21.86
Crystal structure	HCP		
Number of stable isotopes	6(7)		
Mean atomic weight	157.25		

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	4.66E15	4.42E15	1.79E15	4.81E13	1.90E11	6.49E3	kW kg <sup>-1</sup>	5.13E-1	4.81E-1	3.10E-1	9.48E-3	2.72E-5	2.91E-12
Gd159	50.50	53.05	4.97				Tb160	58.09	61.96	92.70	94.76		
Tb160	28.96	30.52	72.66	84.49			Gd159	26.72	28.40	1.67			
Tb161	11.56	12.18	20.81				Gd161	9.34	3.69				
Gd161	6.60	2.57					Tb161	3.94	4.21	4.51			
Gd153	0.15	0.16	0.39	5.10			Eu156	0.61	0.65	0.85			
Dy159	0.12	0.13	0.32	2.08			Dy165	0.42	0.44				
Eu155	0.06	0.06	0.15	4.78			Tb162	0.31	0.20				
Eu154	0.03	0.03	0.08	2.85	0.25		Eu154	0.07	0.08	0.12	3.53	0.42	
Tb158		0.01	0.02	0.57	97.96		Gd153	0.03	0.04	0.05	0.62		
Tb157				0.01	1.56		Tb158	0.01	0.01	0.01	0.42	99.25	
Gd150					99.93		Gd150						99.94
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	3.83E5	3.76E5	3.50E5	1.13E4	3.39E1	7.55E-21	Sv kg <sup>-1</sup>	3.75E6	3.74E6	2.43E6	6.97E4	2.06E2	3.38E-4
Tb160	93.39	95.07	98.72	95.68			Tb160	57.57	57.64	85.93	93.41		
Gd161	2.54	0.96					Gd159	30.74	30.69	1.80			
Gd159	2.34	2.38	0.10				Tb161	10.34	10.35	11.07			
Eu156	1.08	1.10	1.00				Eu154	0.08	0.08	0.12	3.94	0.45	
Eu154	0.12	0.12	0.13	3.78	0.43		Eu155	0.02	0.02	0.04	1.06		
Tb158	0.01	0.01	0.01	0.44	99.28		Tb158	0.01	0.01	0.01	0.43	99.23	
Lu176					99.66		Gd150						99.92
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	1.10E7	1.10E7	9.79E6	3.93E5	8.61E3	5.39E-1		1.95E12	1.85E12	1.54E12	4.93E10	1.56E8	2.70E-1
Tb160	86.19	86.23	93.16	72.51			Tb160	79.69	83.68	97.19	94.83		
Tb161	6.39	6.39	4.95				Gd159	10.08	10.55	0.48			
Gd159	5.80	5.78	0.25				Gd161	7.18	2.79				
Eu154	0.72	0.72	0.81	18.53	0.29		Tb161	1.46	1.53	1.27			
Eu155	0.17	0.17	0.19	4.04			Eu156	0.77	0.81	0.82			
Gd153	0.14	0.14	0.15	1.31			Eu154	0.10	0.10	0.12	3.53	0.38	
Tb158	0.12	0.12	0.13	3.19	99.37		Tb158	0.01	0.01	0.02	0.46	99.05	
Gd150					0.01	99.99	Gd150						99.99

# Gadolinium

## Pathway analysis

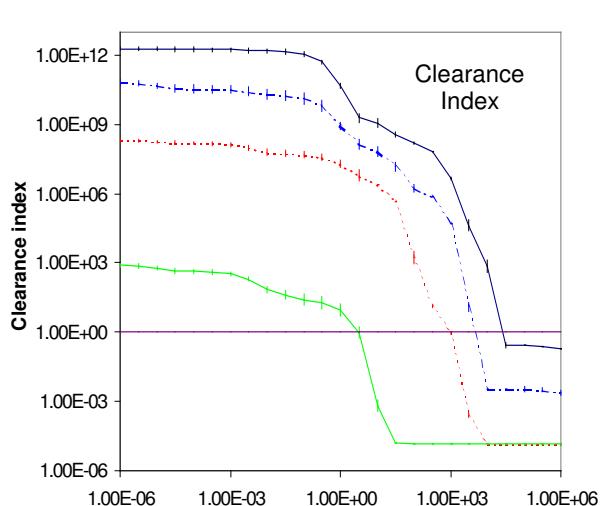
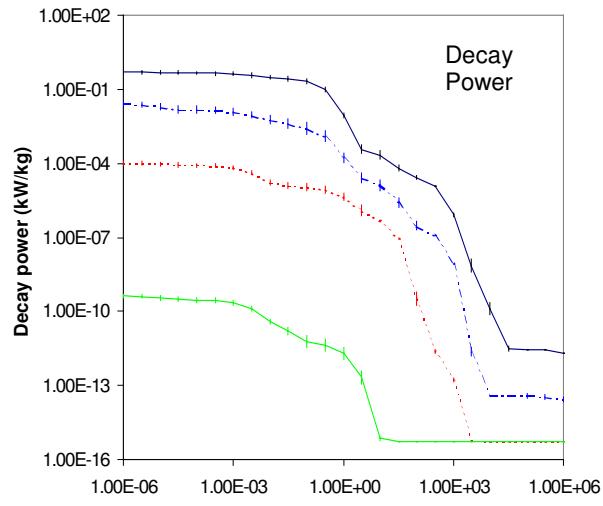
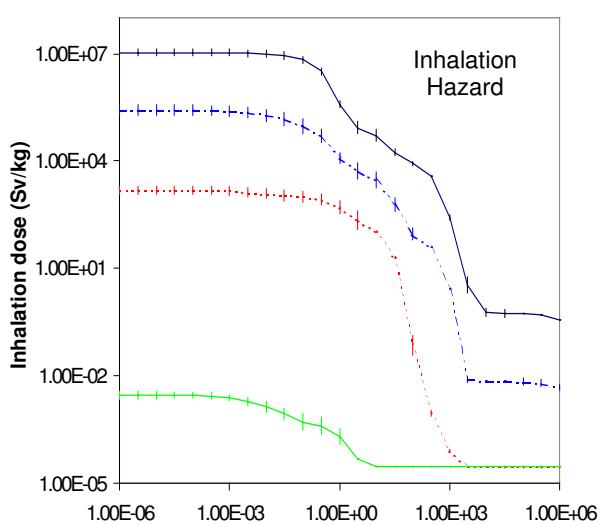
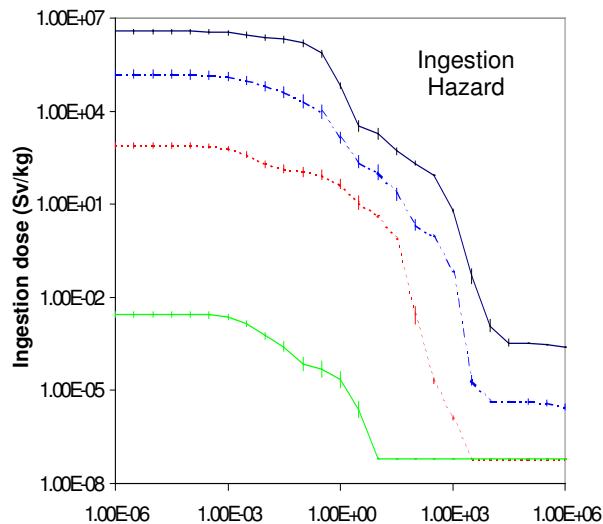
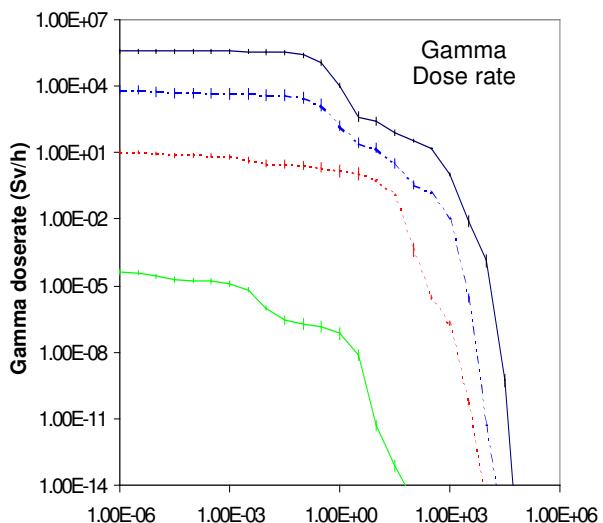
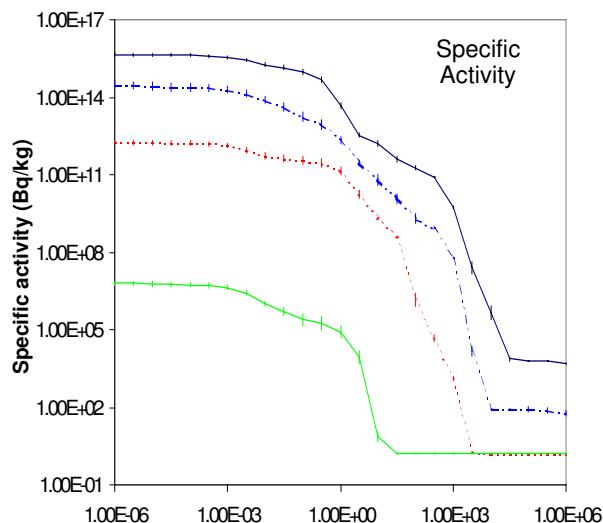
Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Gd161	3.667 m	Gd160(n, $\gamma$ )Gd161	99.9	100.0	100.0	100.0
Gd159	18.56 h	Gd158(n, $\gamma$ )Gd159	86.4	33.0	87.7	0.2
		Gd156(n, $\gamma$ )Gd157(n, $\gamma$ )Gd158(n, $\gamma$ )Gd159	8.0	25.5	0.7	
		Gd155(n, $\gamma$ )Gd156(n, $\gamma$ )Gd157(n, $\gamma$ )Gd158(n, $\gamma$ )Gd159	4.7	17.9		
		Gd157(n, $\gamma$ )Gd158(n, $\gamma$ )Gd159	0.2	20.8	11.5	
		Gd154(n, $\gamma$ )Gd155(n, $\gamma$ )Gd156(n, $\gamma$ )Gd157(n, $\gamma$ )Gd158(n, $\gamma$ )Gd159		2.6		
		Gd160(n,2n)Gd159				99.6
Tb161	6.89 d	Gd158(n, $\gamma$ )Gd159( $\beta^-$ )Tb159(n, $\gamma$ )Tb160(n, $\gamma$ )Tb161	61.5	22.5	0.5	
		Gd160(n, $\gamma$ )Gd161( $\beta^-$ )Tb161	32.3	34.4	99.4	99.8
		Gd157(n, $\gamma$ )Gd158(n, $\gamma$ )Gd159( $\beta^-$ )Tb159(n, $\gamma$ )	6.2	14.2		
		Tb160(n, $\gamma$ )Tb161		16.3		
		Gd156(n, $\gamma$ )Gd157(n, $\gamma$ )Gd158(n, $\gamma$ )Gd159( $\beta^-$ )		11.1		
		Tb159(n, $\gamma$ )Tb160(n, $\gamma$ )Tb161		1.5		
		Gd155(n, $\gamma$ )Gd156(n, $\gamma$ )Gd157(n, $\gamma$ )Gd158(n, $\gamma$ )				
		Gd159( $\beta^-$ )Tb159(n, $\gamma$ )Tb160(n, $\gamma$ )Tb161				
		Gd154(n, $\gamma$ )Gd155(n, $\gamma$ )Gd156(n, $\gamma$ )Gd157(n, $\gamma$ )				
		Gd158(n, $\gamma$ )Gd159( $\beta^-$ )Tb159(n, $\gamma$ )Tb160(n, $\gamma$ )Tb161				
Eu156	15.2 d	&Gd154(n, $\alpha$ )Sm151(n, $\gamma$ )Sm152(n, $\gamma$ )Sm153( $\beta^-$ )	64.0			
		Eu153(n, $\gamma$ )Eu154(n, $\gamma$ )Eu155(n, $\gamma$ )Eu156				
		Gd154(n, $\alpha$ )Sm151(n, $\gamma$ )Sm152(n, $\gamma$ )Sm153(n, $\gamma$ )	20.8			
		Sm154(n, $\gamma$ )Sm155( $\beta^-$ )Eu155(n, $\gamma$ )Eu156				
		&Gd152(n, $\gamma$ )Gd153(n, $\gamma$ )Gd154(n, $\alpha$ )Sm151(n, $\gamma$ )Sm152(n, $\gamma$ )Sm153( $\beta^-$ )Eu153(n, $\gamma$ )Eu154(n, $\gamma$ )Eu155(n, $\gamma$ )Eu156	6.4			
		&Gd152(n, $\alpha$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151(n, $\gamma$ )Sm152(n, $\gamma$ )Sm153( $\beta^-$ )Eu153(n, $\gamma$ )Eu154(n, $\gamma$ )Eu155(n, $\gamma$ )Eu156	3.2			
		Gd152(n, $\gamma$ )Gd153(n, $\gamma$ )Gd154(n, $\alpha$ )Sm151(n, $\gamma$ )Sm152(n, $\gamma$ )Sm153(n, $\gamma$ )Sm154(n, $\gamma$ )Sm155( $\beta^-$ )Eu155(n, $\gamma$ )Eu156	1.9			
		Gd152(n, $\alpha$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151(n, $\gamma$ )Sm152(n, $\gamma$ )Sm153(n, $\gamma$ )Sm154(n, $\gamma$ )Sm155( $\beta^-$ )Eu155(n, $\gamma$ )Eu156	1.8			
		Gd152(n, $\gamma$ )Gd153( $\beta^+$ )Eu153(n, $\gamma$ )Eu154(n, $\gamma$ )Eu155(n, $\gamma$ )Eu156		98.4	98.3	
		Gd156(n,p)Eu156				55.5
		Gd157(n,d)Eu156				13.3
		Gd157(n,2n)Gd156(n,p)Eu156				11.7
		Gd160(n,2n)Gd159( $\beta^-$ )Tb159(n, $\alpha$ )Eu156				10.2
		Gd158(n,2n)Gd157(n,d)Eu156				5.9
		Gd158(n,2n)Gd157(n,2n)Gd156(n,p)Eu156				2.6
Tb160	72.3 d	Gd158(n, $\gamma$ )Gd159( $\beta^-$ )Tb159(n, $\gamma$ )Tb160	91.4	34.3	93.6	0.2
		Gd156(n, $\gamma$ )Gd157(n, $\gamma$ )Gd158(n, $\gamma$ )Gd159( $\beta^-$ )	5.1	24.5	0.2	
		Tb159(n, $\gamma$ )Tb160				
		Gd155(n, $\gamma$ )Gd156(n, $\gamma$ )Gd157(n, $\gamma$ )Gd158(n, $\gamma$ )	2.9	16.9		
		Gd159( $\beta^-$ )Tb159(n, $\gamma$ )Tb160				
		Gd157(n, $\gamma$ )Gd158(n, $\gamma$ )Gd159( $\beta^-$ )Tb159(n, $\gamma$ )Tb160	0.2	21.5	6.2	
		Gd154(n, $\gamma$ )Gd155(n, $\gamma$ )Gd156(n, $\gamma$ )Gd157(n, $\gamma$ )		2.4		
		Gd158(n, $\gamma$ )Gd159( $\beta^-$ )Tb159(n, $\gamma$ )Tb160				
		Gd160(n,2n)Gd159( $\beta^-$ )Tb159(n, $\gamma$ )Tb160				
Ta182	114.7 d	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0	100.0		
Tm170	128.6 d	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0	100.0	100.0	
Gd153	240.5 d	Gd152(n, $\gamma$ )Gd153 Gd155(n,2n)Gd154(n,2n)Gd153 Gd154(n,2n)Gd153 Gd156(n,2n)Gd155(n,2n)Gd154(n,2n)Gd153	100.0	100.0	100.0	
Tm171	1.920 y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0	100.0	100.0	

Eu155	4.846 y	&Gd154(n, $\alpha$ )Sm151(n, $\gamma$ )Sm152(n, $\gamma$ )Sm153( $\beta^-$ ) Eu153(n, $\gamma$ )Eu154(n, $\gamma$ )Eu155 Gd154(n, $\alpha$ )Sm151(n, $\gamma$ )Sm152(n, $\gamma$ )Sm153(n, $\gamma$ ) Sm154(n, $\gamma$ )Sm155( $\beta^-$ )Eu155 Gd152(n, $\gamma$ )Gd153(n, $\gamma$ )Gd154(n, $\alpha$ )Sm151(n, $\gamma$ ) Sm152(n, $\gamma$ )Sm153( $\beta^-$ )Eu153(n, $\gamma$ )Eu154(n, $\gamma$ )Eu155 Gd152(n, $\alpha$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151(n, $\gamma$ ) Sm152(n, $\gamma$ )Sm153( $\beta^-$ )Eu153(n, $\gamma$ )Eu154(n, $\gamma$ )Eu155 Gd152(n, $\gamma$ )Gd153(n, $\gamma$ )Gd154(n, $\alpha$ )Sm151(n, $\gamma$ ) Sm152(n, $\gamma$ )Sm153(n, $\gamma$ )Sm154(n, $\gamma$ )Sm155( $\beta^-$ )Eu155 Gd152(n, $\alpha$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151(n, $\gamma$ ) Sm152(n, $\gamma$ )Sm153(n, $\gamma$ )Sm154(n, $\gamma$ )Sm155( $\beta^-$ )Eu155 &Gd152(n, $\gamma$ )Gd153( $\beta^+$ )Eu153(n, $\gamma$ )Eu154(n, $\gamma$ )Eu155 Gd155(n,p)Eu155 Gd158(n, $\alpha$ )Sm155( $\beta^-$ )Eu155 Gd156(n,d)Eu155 Gd156(n,2n)Gd155(n,p)Eu155 Gd157(n,2n)Gd156(n,d)Eu155	62.7 21.4 6.2 3.0 2.0 1.8 100.0 100.0				46.3 25.6 13.5 9.9 1.6
Eu154	8.593 y	&Gd154(n, $\alpha$ )Sm151(n, $\gamma$ )Sm152(n, $\gamma$ )Sm153( $\beta^-$ ) Eu153(n, $\gamma$ )Eu154 &Gd152(n, $\gamma$ )Gd153(n, $\gamma$ )Gd154(n, $\alpha$ )Sm151(n, $\gamma$ ) Sm152(n, $\gamma$ )Sm153( $\beta^-$ )Eu153(n, $\gamma$ )Eu154 &Gd152(n, $\alpha$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151(n, $\gamma$ ) Sm152(n, $\gamma$ )Sm153( $\beta^-$ )Eu153(n, $\gamma$ )Eu154 &Gd152(n, $\gamma$ )Gd153( $\beta^+$ )Eu153(n, $\gamma$ )Eu154 &Gd155(n,2n)Gd154(n,p)Eu154 &Gd154(n,p)Eu154 &Gd155(n,d)Eu154 &Gd155(n,p)Eu155(n,2n)Eu154 &Gd158(n, $\alpha$ )Sm155( $\beta^-$ )Eu155(n,2n)Eu154 &Gd156(n,2n)Gd155(n,2n)Gd154(n,p)Eu154 &Gd156(n,2n)Gd155(n,d)Eu154 &Gd156(n,d)Eu155(n,2n)Eu154 &Gd156(n,2n)Gd155(n,p)Eu155(n,2n)Eu154	86.0 8.6 4.2 100.0 100.0				28.3 26.6 15.9 10.2 5.6 3.7 3.2 3.0 1.4
Eu152	13.522 y	Gd154(n, $\alpha$ )Sm151( $\beta^-$ )Eu151(n, $\gamma$ )Eu152 Gd152(n, $\gamma$ )Gd153(n, $\gamma$ )Gd154(n, $\alpha$ )Sm151( $\beta^-$ ) Eu151(n, $\gamma$ )Eu152 Gd152(n, $\alpha$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151( $\beta^-$ ) Eu151(n, $\gamma$ )Eu152 Gd152(n, $\gamma$ )Gd153(n, $\alpha$ )Sm150(n, $\gamma$ )Sm151( $\beta^-$ )Eu151(n, $\gamma$ )Eu152 &Gd154(n,2n)Gd153( $\beta^+$ )Eu153(n,2n)Eu152 &Gd155(n,2n)Gd154(n,2n)Gd153( $\beta^+$ )Eu153(n,2n)Eu152 &Gd156(n,2n)Gd155(n,2n)Gd154(n,2n)Gd153( $\beta^+$ ) Eu153(n,2n)Eu152 &Gd156(n, $\alpha$ )Sm153( $\beta^-$ )Eu153(n,2n)Eu152	87.6 8.7 3.2 4.9	95.0	99.0	59.3 35.0 3.0 1.5	
Gd148	74.467 y	Gd152(n,2n)Gd151(n,2n)Gd150(n,2n)Gd149(n,2n)Gd148 Gd152(n,2n)Gd151( $\beta^+$ )Eu151(n,2n)Eu150m( $\beta^-$ ) Gd150(n,2n)Gd149(n,2n)Gd148 Gd154(n,2n)Gd153(n,2n)Gd152(n,2n)Gd151(n,2n) Gd150(n,2n)Gd149(n,2n)Gd148 Gd154(n,2n)Gd153( $\beta^+$ )Eu153(n,2n)Eu152(n,2n) Eu151(n,2n)Eu150m( $\beta^-$ )Gd150(n,2n)Gd149(n,2n)Gd148				53.3 40.0 1.9 1.1	

Sm151	90 y	Gd154(n, $\alpha$ )Sm151 Gd152(n, $\gamma$ )Gd153(n, $\gamma$ )Gd154(n, $\alpha$ )Sm151 Gd152(n, $\alpha$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151 Gd152(n, $\gamma$ )Gd153(n, $\alpha$ )Sm150(n, $\gamma$ )Sm151 Gd155(n,2n)Gd154(n, $\alpha$ )Sm151 Gd155(n, $\alpha$ )Sm152(n,2n)Sm151 Gd154(n,2n)Gd153( $\beta^+$ )Eu153(n,2n)Eu152m( $\beta^+$ ) Sm152(n,2n)Sm151 <b>&amp;Gd154(n,2n)Gd153(<math>\beta^+</math>)Eu153(n,2n)Eu152(<math>\beta^+</math>)Sm152(n,2n)Sm151</b> Gd155(n,no $\alpha$ )Sm151 Gd156(n,2n)Gd155(n,2n)Gd154(n, $\alpha$ )Sm151 Gd155(n,2n)Gd154(n,2n)Gd153( $\beta^+$ )Eu153(n,2n) Eu152m( $\beta^+$ )Sm152(n,2n)Sm151 Gd156(n,2n)Gd155(n, $\alpha$ )Sm152(n,2n)Sm151 <b>&amp;Gd155(n,2n)Gd154(n,2n)Gd153(<math>\beta^+</math>)Eu153(n,2n)</b> <b>Eu152(<math>\beta^+</math>)Sm152(n,2n)Sm151</b>	87.7 8.7 3.1 5.0 	95.0 5.0 	97.3 0.1 2.4 	25.3 25.5 19.7 6.1 4.4 4.2 3.3 2.7 2.5 1.6
Tb158	180.62 y	<b>&amp;Gd160(n,2n)Gd159(<math>\beta^-</math>)Tb159(n,2n)Tb158</b>				99.8
Ho166m	1200 y	&Gd158(n, $\gamma$ )Gd159( $\beta^-$ )Tb159(n, $\gamma$ )Tb160(n, $\gamma$ ) Tb161( $\beta^-$ )Dy161(n, $\gamma$ )Dy162(n, $\gamma$ )Dy163(n, $\gamma$ ) Dy164(n, $\gamma$ )Dy165( $\beta^-$ )Ho165(n, $\gamma$ )Ho166m <b>&amp;Gd160(n,<math>\gamma</math>)Gd161(<math>\beta^-</math>)Tb161(<math>\beta^-</math>)Dy161(n,<math>\gamma</math>)</b> Dy162(n, $\gamma$ )Dy163(n, $\gamma$ )Dy164(n, $\gamma$ )Dy165( $\beta^-$ ) Ho165(n, $\gamma$ )Ho166m <b>&amp;Gd158(n,<math>\gamma</math>)Gd159(<math>\beta^-</math>)Tb159(n,<math>\gamma</math>)Tb160(<math>\beta^-</math>)</b> Dy160(n, $\gamma$ )Dy161(n, $\gamma$ )Dy162(n, $\gamma$ )Dy163(n, $\gamma$ ) Dy164(n, $\gamma$ )Dy165( $\beta^-$ )Ho165(n, $\gamma$ )Ho166m <b>&amp;Gd157(n,<math>\gamma</math>)Gd158(n,<math>\gamma</math>)Gd159(<math>\beta^-</math>)Tb159(n,<math>\gamma</math>)</b> Tb160( $\beta^-$ )Dy160(n, $\gamma$ )Dy161(n, $\gamma$ )Dy162(n, $\gamma$ ) Dy163(n, $\gamma$ )Dy164(n, $\gamma$ )Dy165( $\beta^-$ )Ho165(n, $\gamma$ )Ho166m <b>&amp;Gd157(n,<math>\gamma</math>)Gd158(n,<math>\gamma</math>)Gd159(<math>\beta^-</math>)Tb159</b> (n, $\gamma$ )Tb160(n, $\gamma$ )Tb161( $\beta^-$ )Dy161(n, $\gamma$ )Dy162(n, $\gamma$ ) Dy163(n, $\gamma$ )Dy164(n, $\gamma$ )Dy165( $\beta^-$ )Ho165(n, $\gamma$ )Ho166m <b>&amp;Gd155(n,<math>\gamma</math>)Gd156(n,<math>\gamma</math>)Gd157(n,<math>\gamma</math>)Gd158(n,<math>\gamma</math>)Gd159</b> ( $\beta^-$ )Tb159(n, $\gamma$ )Tb160(n, $\gamma$ )Tb161( $\beta^-$ )Dy161(n, $\gamma$ )Dy162 (n, $\gamma$ )Dy163(n, $\gamma$ )Dy164(n, $\gamma$ )Dy165( $\beta^-$ )Ho165(n, $\gamma$ )Ho166m <b>&amp;Gd160(n,<math>\gamma</math>)Gd161(<math>\beta^-</math>)Tb161(n,<math>\gamma</math>)Tb162(<math>\beta^-</math>)Dy162(n,<math>\gamma</math>)</b> Dy163(n, $\gamma$ )Dy164(n, $\gamma$ )Dy165( $\beta^-$ )Ho165(n, $\gamma$ )Ho166m <b>&amp;Gd156(n,<math>\gamma</math>)Gd157(n,<math>\gamma</math>)Gd158(n,<math>\gamma</math>)Gd159(<math>\beta^-</math>)Tb159</b> (n, $\gamma$ )Tb160( $\beta^-$ )Dy160(n, $\gamma$ )Dy161(n, $\gamma$ )Dy162(n, $\gamma$ ) Dy163(n, $\gamma$ )Dy164(n, $\gamma$ )Dy165( $\beta^-$ )Ho165(n, $\gamma$ )Ho166m <b>&amp;Gd155(n,<math>\gamma</math>)Gd156(n,<math>\gamma</math>)Gd157(n,<math>\gamma</math>)Gd158(n,<math>\gamma</math>)</b> Gd159( $\beta^-$ )Tb159(n, $\gamma$ )Tb160( $\beta^-$ )Dy160(n, $\gamma$ ) Dy161(n, $\gamma$ )Dy162(n, $\gamma$ )Dy163(n, $\gamma$ )Dy164(n, $\gamma$ ) <b>Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166m</b>	42.7 29.7 15.0 4.4 1.6 1.4 0.8 0.5 0.4 0.2	14.3 34.0 20.6 6.4 8.9 3.5 1.7 1.3 4.5 2.1	96.1 	
La137	$6.0 \cdot 10^4$ y	Gd152(n,no $\alpha$ )Sm148(n,no $\alpha$ )Nd144(n, $\alpha$ )Ce141( $\beta^-$ ) Pr141(n,no $\alpha$ )La137 <i>*Many other long pathways involving (n,<math>\alpha</math>), (n,no<math>\alpha</math>) and (<math>\beta^-</math>)</i>				1.4 98.6*
Gd150	$1.8 \cdot 10^6$ y	Gd152(n,2n)Gd151( $\beta^+$ )Eu151(n,2n)Eu150m( $\beta^-$ )Gd150 Gd152(n,2n)Gd151(n,2n)Gd150 Gd154(n,2n)Gd153(n,2n)Gd152(n,2n)Gd151(n,2n)Gd150 Gd154(n,2n)Gd153( $\beta^+$ )Eu153(n,2n)Eu152(n,2n) Eu151(n,2n)Eu150m( $\beta^-$ )Gd150 Gd154(n,2n)Gd153(n,2n)Gd152(n,2n)Gd151( $\beta^+$ ) Eu151(n,2n)Eu150m( $\beta^-$ )Gd150 Gd155(n,2n)Gd154(n,2n)Gd153(n,2n)Gd152(n,2n) Gd151(n,2n)Gd150				46.8 41.7 2.5 2.3 1.7 1.3
Hf182	$9.0 \cdot 10^6$ y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0			
Lu176	$3.6 \cdot 10^{10}$ y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0			

La138	$1.1 \cdot 10^{11}$ y	Gd152(n,n $\alpha$ )Sm148(n,n $\alpha$ )Nd144(n, $\alpha$ )Ce141( $\beta^-$ ) Pr141(n, $\alpha$ )La138 *Many other long pathways involving (n, $\alpha$ ), (n,n $\alpha$ ) and ( $\beta^-$ )				1.5 98.5*
Sm147	$1.1 \cdot 10^{11}$ y	Gd152(n, $\alpha$ )Sm149(n, $\alpha$ )Nd146(n, $\gamma$ )Nd147( $\beta^-$ ) Pm147( $\beta^-$ )Sm147 Gd152(n, $\alpha$ )Sm149(n, $\gamma$ )Sm150(n, $\alpha$ )Nd147( $\beta^-$ )Pm147( $\beta^-$ )Sm147 Gd152(n,n $\alpha$ )Sm148(n,2n)Sm147 Gd152(n,2n)Gd151(n,n $\alpha$ )Sm147 Gd152(n, $\alpha$ )Sm149(n,2n)Sm148(n,2n)Sm147 Gd154(n,2n)Gd153(n,2n)Gd152(n,n $\alpha$ )Sm148(n,2n)Sm147 Gd152(n,2n)Gd151( $\beta^+$ )Eu151(n,2n)Eu150(n,2n) Eu149( $\beta^+$ )Sm149(n,2n)Sm148(n,2n)Sm147 Gd155(n,2n)Gd154(n,2n)Gd153(n,2n)Gd152(n,n $\alpha$ ) Sm148(n,2n)Sm147 Gd152(n,2n)Gd151(n,2n)Gd150(n, $\alpha$ )Sm147 Gd152(n,2n)Gd151(n,2n)Gd150(n,2n)Gd149( $\beta^+$ ) Eu149( $\beta^+$ )Sm149(n,2n)Sm148(n,2n)Sm147	100.0 	93.1 6.5 	95.7 4.0 	71.7 7.0 2.9 2.8 1.3 1.2 1.1 1.1
Gd152	$1.1 \cdot 10^{14}$ y	*Nuclide present in starting material Gd154(n,2n)Gd153(n,2n)Gd152 Gd155(n,2n)Gd154(n,2n)Gd153(n,2n)Gd152 Gd154(n,2n)Gd153( $\beta^+$ )Eu153(n,2n)Eu152m( $\beta^-$ )Gd152 Gd155(n,2n)Gd154(n,2n)Gd153( $\beta^+$ )Eu153(n,2n) Eu152m( $\beta^-$ )Gd152 Gd156(n,2n)Gd155(n,2n)Gd154(n,2n)Gd153(n,2n)Gd152	100.0* 	100.0* 	100.0* 	73.1* 11.5 9.7 2.9 1.7 1.1

# Gadolinium activation characteristics

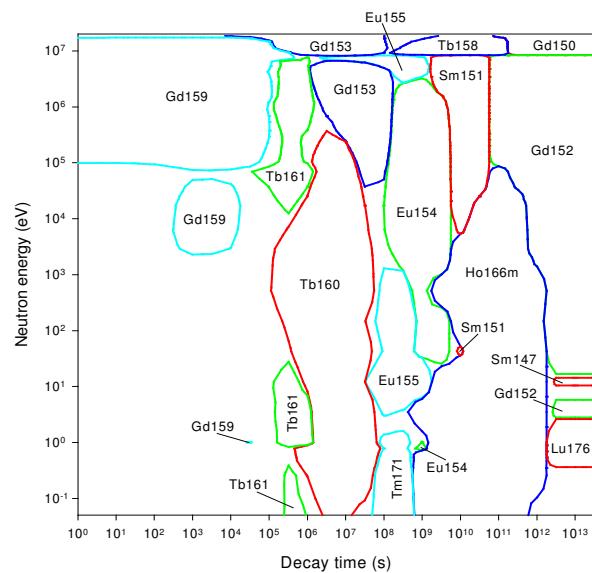


Decay time (years)

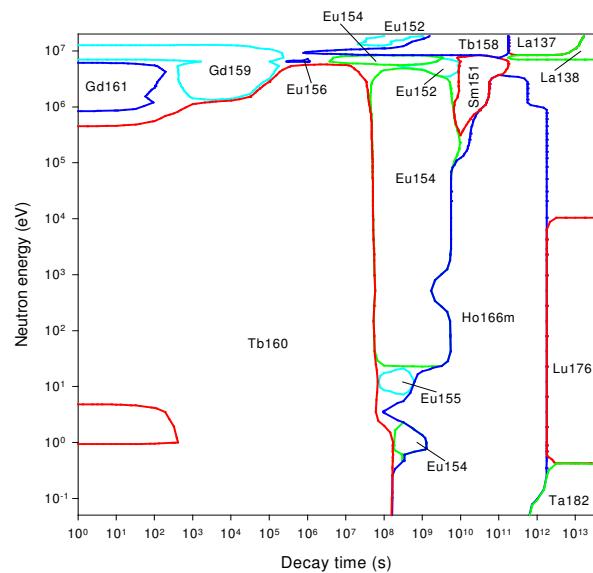
Decay time (years)

# Gadolinium importance diagrams & transmutation

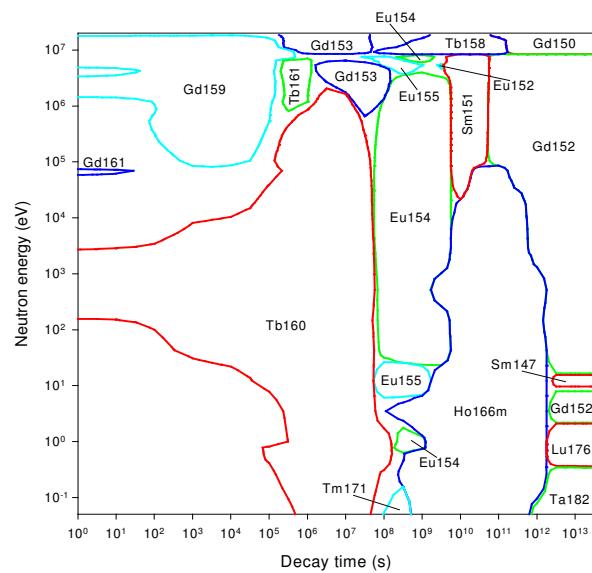
## Activity



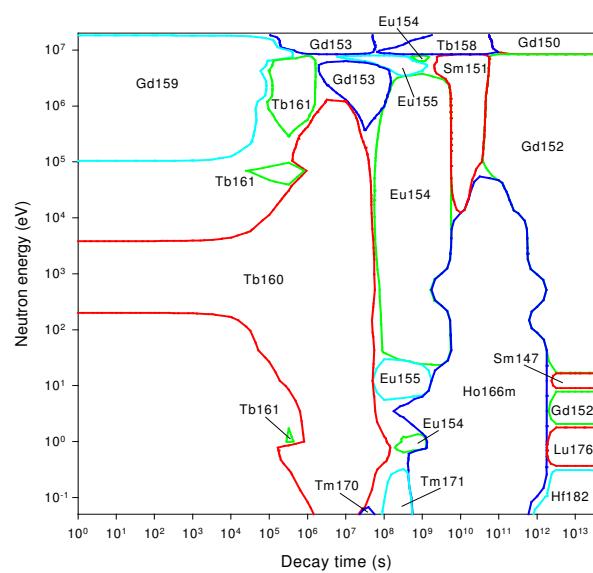
## Dose rate



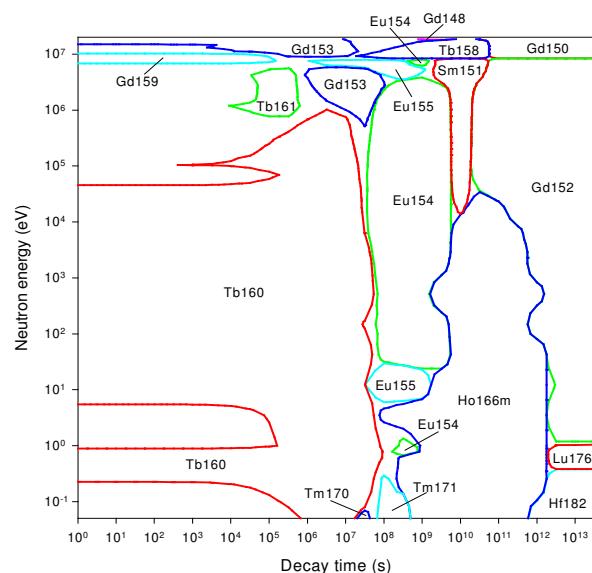
## Heat output



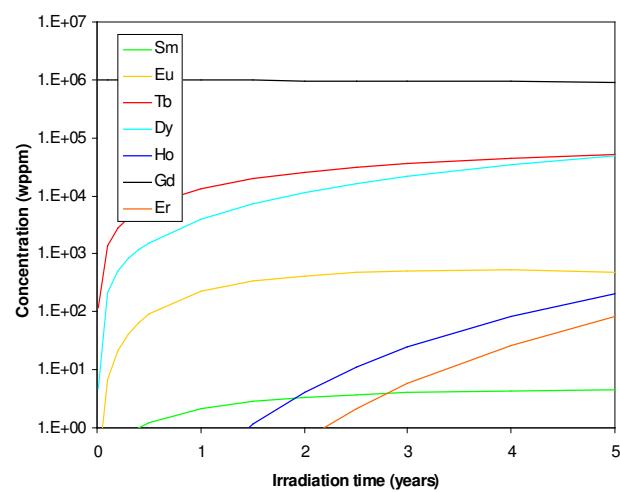
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Terbium

## General properties

		65	Isotopes	Isotopic abundances / %	
Atomic number	1.2	Tb159	100.0		
Crustal abundance / wppm	1632				
Melting point / K	3494				
Boiling point / K	8230				
Density / kgm <sup>-3</sup>	11.1				
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	1.14 10 <sup>-6</sup>				
Electrical resistivity /Ωm	1.03 10 <sup>-5</sup>				
Coefficient of thermal expansion / K <sup>-1</sup>	Rhombic				
Crystal structure	1				
Number of stable isotopes	158.92534				
Mean atomic weight					

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.03E16	9.78E15	8.22E15	2.40E14	2.10E12	5.35E-01	kW kg <sup>-1</sup>	1.79E0	1.78E0	1.63E0	5.04E-2	2.97E-4	2.35E-19
Tb160	72.60	76.45	87.89	93.87			Tb160	92.07	92.72	97.69	98.92		
Tb161	12.63	13.30	10.97				Dy165	2.81	2.77				
Dy165	6.46	6.66					Tb161	2.72	2.74	2.07			
Dy165m	4.13	0.24					Ho166	1.48	1.48	0.17			
Ho166	2.22	2.33	0.29				Dy165m	0.47	0.03				
Dy159	0.65	0.69	0.80	4.83			Tb162	0.22	0.14				
Tb158	0.03	0.03	0.04	1.24	97.14		Tb158	0.02	0.02	0.03	0.86	99.62	
Tb157				0.05	2.70		Ho163						96.64
Ho163					100.00	Gd150							3.35
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	1.97E6	1.96E6	1.89E6	5.96E4	3.66E2	1.14E-19	Sv kg <sup>-1</sup>	1.33E7	1.33E7	1.22E7	3.65E5	2.26E3	7.34E-12
Tb160	99.56	99.66	99.95	99.10			Tb160	89.90	89.92	94.34	98.78		
Tb162	0.16	0.10					Tb161	7.04	7.04	5.30			
Dy165	0.10	0.10					Ho166	2.41	2.40	0.28			
Tb158	0.03	0.03	0.03	0.90	99.71		Tb158	0.03	0.03	0.03	0.90	99.62	
Ho166m					0.29		Ho163						87.51
Lu176					99.95	Gd150							12.47
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	5.44E7	5.44E7	5.19E7	1.72E6	9.45E4	1.48E-9		8.78E12	8.76E12	8.36E12	2.62E11	1.71E9	1.42E-7
Tb160	96.24	96.24	97.40	91.73			Tb160	97.91	98.18	99.33	98.84		
Tb161	3.11	3.11	2.26				Tb161	0.78	0.78	0.57			
Ho166	0.27	0.27	0.03				Dy165	0.54	0.53				
Tb158	0.25	0.25	0.27	7.99	99.51		Ho166	0.26	0.26	0.03			
Gd150					99.00	Tb158	0.03	0.03	0.03	0.95	99.63		
Ho163					0.94	Ho163							99.49

# Terbium

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Tb158m	10.5 s	Tb159(n,2n)Tb158m				99.8
Ho166	1.117 d	<b>&amp;Tb159(n,<math>\gamma</math>)Tb160(n,<math>\gamma</math>)Tb161(<math>\beta^-</math>)Dy161(n,<math>\gamma</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166</b> <b>&amp;Tb159(n,<math>\gamma</math>)Tb160(<math>\beta^-</math>)Dy160(n,<math>\gamma</math>)Dy161(n,<math>\gamma</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166</b> <b>&amp;Tb159(n,<math>\gamma</math>)Tb160(n,<math>\gamma</math>)Tb161(n,<math>\gamma</math>)Tb162(<math>\beta^-</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166</b> <b>&amp;Tb159(n,<math>\gamma</math>)Tb160(n,<math>\gamma</math>)Tb161(<math>\beta^-</math>)Dy161(n,<math>\gamma</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho166</b>	62.0 33.7 1.1 1.0	35.5 61.8 1.2 1.0	46.1 51.4 1.0	
Tm172	2.65 d	<b>&amp;Tb159(n,<math>\gamma</math>)Tb160(n,<math>\gamma</math>)Tb161(<math>\beta^-</math>)Dy161(n,<math>\gamma</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166(<math>\beta^-</math>)Er166(n,<math>\gamma</math>)Er167(n,<math>\gamma</math>)Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(n,<math>\gamma</math>)Tm172</b> <b>&amp;Tb159(n,<math>\gamma</math>)Tb160(<math>\beta^-</math>)Dy160(n,<math>\gamma</math>)Dy161(n,<math>\gamma</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166(<math>\beta^-</math>)Er166(n,<math>\gamma</math>)Er167(n,<math>\gamma</math>)Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(n,<math>\gamma</math>)Tm172</b> <b>&amp;Tb159(n,<math>\gamma</math>)Tb160(n,<math>\gamma</math>)Tb161(<math>\beta^-</math>)Dy161(n,<math>\gamma</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166m(n,<math>\gamma</math>)Ho167(<math>\beta^-</math>)Er167(n,<math>\gamma</math>)Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(n,<math>\gamma</math>)Tm172</b> <b>&amp;Tb159(n,<math>\gamma</math>)Tb160(<math>\beta^-</math>)Dy160(n,<math>\gamma</math>)Dy161(n,<math>\gamma</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166m(n,<math>\gamma</math>)Ho167(<math>\beta^-</math>)Er167(n,<math>\gamma</math>)Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(n,<math>\gamma</math>)Tm172</b> <b>&amp;Tb159(n,<math>\gamma</math>)Tb160(n,<math>\gamma</math>)Tb161(n,<math>\gamma</math>)Tb162(<math>\beta^-</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166m(n,<math>\gamma</math>)Ho167(<math>\beta^-</math>)Er167(n,<math>\gamma</math>)Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(n,<math>\gamma</math>)Tm172</b> <b>&amp;Tb159(n,<math>\gamma</math>)Tb160(n,<math>\gamma</math>)Tb161(n,<math>\gamma</math>)Tb162(<math>\beta^-</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166m(n,<math>\gamma</math>)Ho167(<math>\beta^-</math>)Er167(n,<math>\gamma</math>)Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(n,<math>\gamma</math>)Tm172</b>	65.1 16.4 7.9 2.2 1.2	33.9 39.5 8.8 10.5 1.6	53.4 30.1 5.7 3.4 2.4	
Tb156	5.17 d	<b>&amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,2n)Tb156</b>				100.0
Tb161	6.89 d	Tb159(n, $\gamma$ )Tb160(n, $\gamma$ )Tb161 Tb159(n, $\gamma$ )Tb160( $\beta^-$ )Dy160(n, $\gamma$ )Dy161(n,p)Tb161	100.0	100.0	99.3	99.0 0.6
Tb160	72.3 d	Tb159(n, $\gamma$ )Tb160	100.0	100.0	100.0	99.8
Ta182	114.7 d	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0			
Tm170	128.6 d	<b>&amp;Tb159(n,<math>\gamma</math>)Tb160(n,<math>\gamma</math>)Tb161(<math>\beta^-</math>)Dy161(n,<math>\gamma</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166(<math>\beta^-</math>)Er166(n,<math>\gamma</math>)Er167(n,<math>\gamma</math>)Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)Tm169(n,<math>\gamma</math>)Tm170</b> <b>&amp;Tb159(n,<math>\gamma</math>)Tb160(<math>\beta^-</math>)Dy160(n,<math>\gamma</math>)Dy161(n,<math>\gamma</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166(<math>\beta^-</math>)Er166(n,<math>\gamma</math>)Er167(n,<math>\gamma</math>)Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)Tm169(n,<math>\gamma</math>)Tm170</b> <b>&amp;Tb159(n,<math>\gamma</math>)Tb160(n,<math>\gamma</math>)Tb161(<math>\beta^-</math>)Dy161(n,<math>\gamma</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166m(n,<math>\gamma</math>)Ho167(<math>\beta^-</math>)Er167(n,<math>\gamma</math>)Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)Tm169(n,<math>\gamma</math>)Tm170</b> <b>&amp;Tb159(n,<math>\gamma</math>)Tb160(n,<math>\gamma</math>)Tb161(<math>\beta^-</math>)Dy161(n,<math>\gamma</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166m(n,<math>\gamma</math>)Ho167(<math>\beta^-</math>)Er167(n,<math>\gamma</math>)Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)Tm169(n,<math>\gamma</math>)Tm170</b> <b>&amp;Tb159(n,<math>\gamma</math>)Tb160(n,<math>\gamma</math>)Tb161(<math>\beta^-</math>)Dy161(n,<math>\gamma</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166m(n,<math>\gamma</math>)Ho167(<math>\beta^-</math>)Er167(n,<math>\gamma</math>)Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)Tm169(n,<math>\gamma</math>)Tm170</b> <b>&amp;Tb159(n,<math>\gamma</math>)Tb160(n,<math>\gamma</math>)Tb161(n,<math>\gamma</math>)Tb162(<math>\beta^-</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166m(n,<math>\gamma</math>)Ho167(<math>\beta^-</math>)Er167(n,<math>\gamma</math>)Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)Tm169(n,<math>\gamma</math>)Tm170</b>	65.7 17.8 7.6 2.4 1.3	33.4 41.2 8.1 10.4 1.5	51.7 33.6 5.6 3.7 2.1	

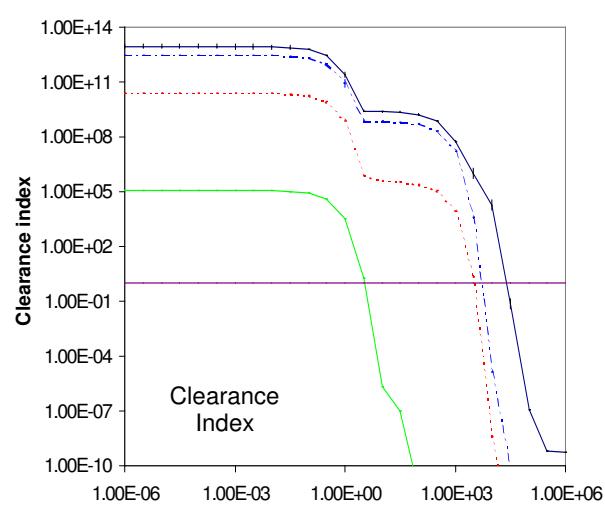
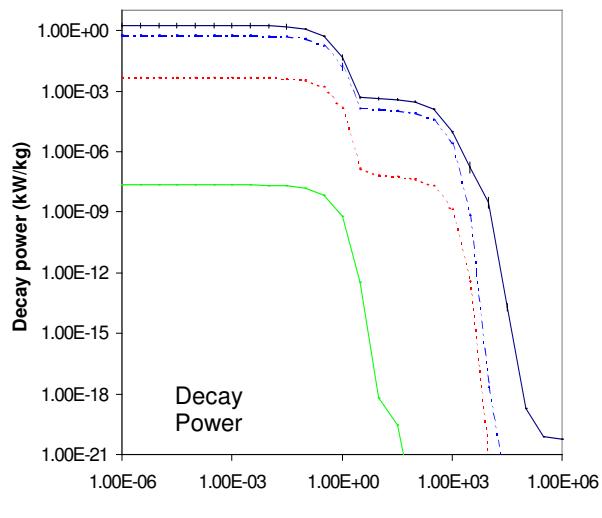
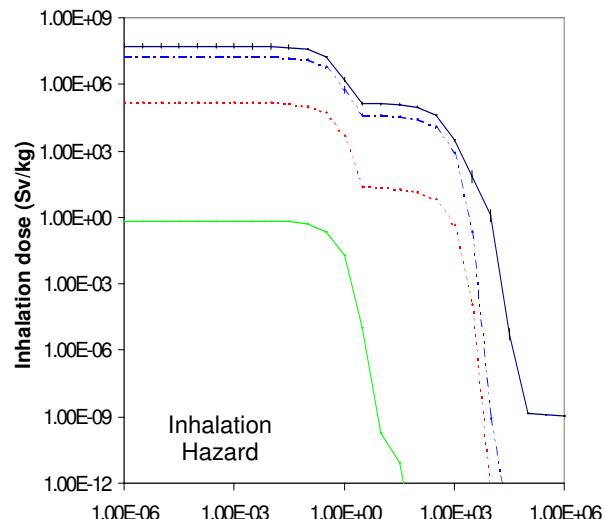
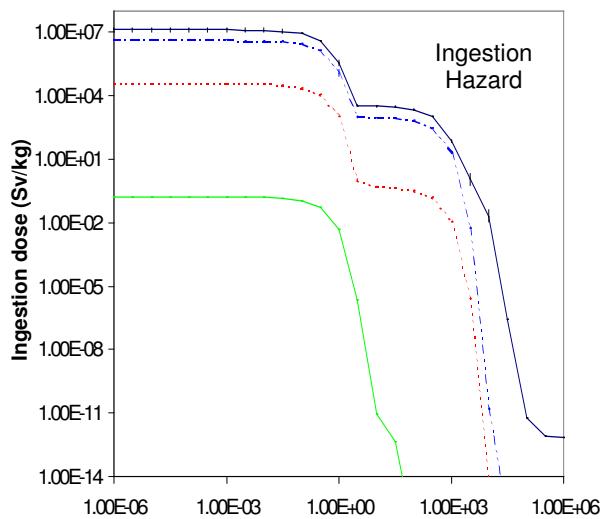
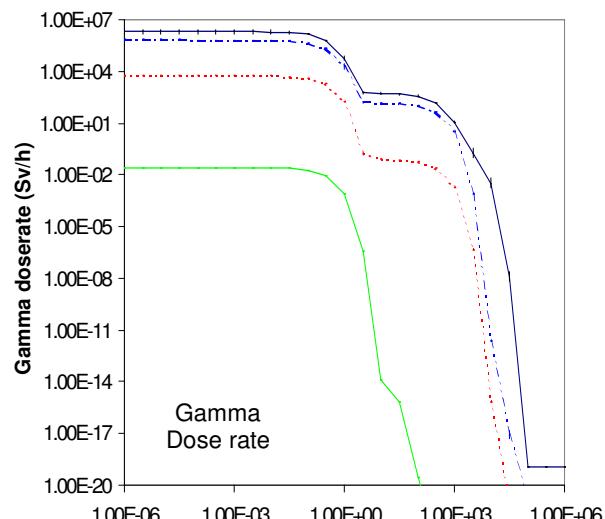
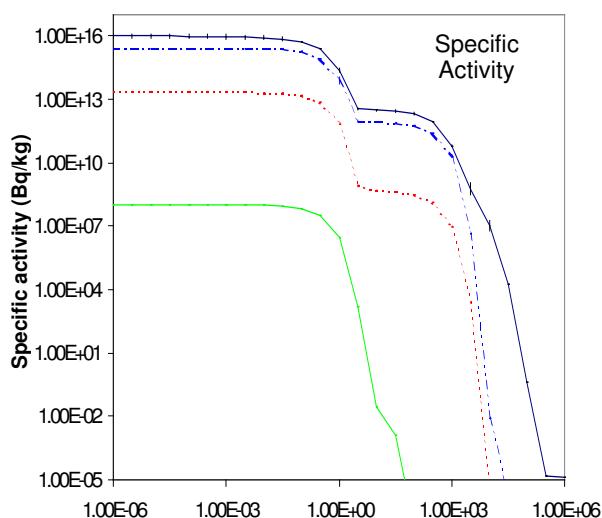
Tm171	1.920 y	<b>&amp;Tb159(n,<math>\gamma</math>)Tb160(n,<math>\gamma</math>)Tb161(<math>\beta^-</math>)Dy161(n,<math>\gamma</math>)</b> Dy162(n, $\gamma$ )Dy163(n, $\gamma$ )Dy164(n, $\gamma$ )Dy165( $\beta^-$ ) Ho165(n, $\gamma$ )Ho166( $\beta^-$ )Er166(n, $\gamma$ )Er167(n, $\gamma$ )Er168(n, $\gamma$ ) Er169( $\beta^-$ )Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171 <b>&amp;Tb159(n,<math>\gamma</math>)Tb160(<math>\beta^-</math>)Dy160(n,<math>\gamma</math>)Dy161(n,<math>\gamma</math>)</b> Dy162(n, $\gamma$ )Dy163(n, $\gamma$ )Dy164(n, $\gamma$ )Dy165( $\beta^-$ ) Ho165(n, $\gamma$ )Ho166m(n, $\gamma$ )Ho167( $\beta^-$ )Er167(n, $\gamma$ ) Er168(n, $\gamma$ )Er169( $\beta^-$ )Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171 <b>&amp;Tb159(n,<math>\gamma</math>)Tb160(<math>\beta^-</math>)Dy160(n,<math>\gamma</math>)Dy161(n,<math>\gamma</math>)</b> Dy162(n, $\gamma$ )Dy163(n, $\gamma$ )Dy164(n, $\gamma$ )Dy165( $\beta^-$ ) Ho165(n, $\gamma$ )Ho166m(n, $\gamma$ )Ho167( $\beta^-$ )Er167(n, $\gamma$ ) Er168(n, $\gamma$ )Er169( $\beta^-$ )Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171 <b>&amp;Tb159(n,<math>\gamma</math>)Tb160(n,<math>\gamma</math>)Tb161(n,<math>\gamma</math>)Tb162(<math>\beta^-</math>)</b> Dy162(n, $\gamma$ )Dy163(n, $\gamma$ )Dy164(n, $\gamma$ )Dy165( $\beta^-$ ) Ho165(n, $\gamma$ )Ho166( $\beta^-$ )Er166(n, $\gamma$ )Er167(n, $\gamma$ )Er168(n, $\gamma$ ) Er169( $\beta^-$ )Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171	65.3 16.7 8.1 2.4 1.3	33.6 39.9 8.5 10.5 1.5	52.7 31.7 5.7 3.5 2.3	
Eu155	4.846 y	Tb159(n, $\gamma$ )Tb160( $\beta^-$ )Dy160(n, $\alpha$ )Gd157(n, $\alpha$ ) Sm154(n, $\gamma$ )Sm155( $\beta^-$ )Eu155 Tb159(n, $\gamma$ )Tb160( $\beta^-$ )Dy160(n, $\alpha$ )Gd157(n, $\gamma$ ) Gd158(n, $\alpha$ )Sm155( $\beta^-$ )Eu155 Tb159(n, $\gamma$ )Tb160( $\beta^-$ )Dy160(n, $\gamma$ )Dy161(n, $\alpha$ ) Gd158(n, $\alpha$ )Sm155( $\beta^-$ )Eu155 Tb159(n, $\gamma$ )Tb160(n, $\gamma$ )Tb161( $\beta^-$ )Dy161(n, $\alpha$ ) Gd158(n, $\alpha$ )Sm155( $\beta^-$ )Eu155 <b>&amp;Tb159(n,2n)Tb158(n,<math>\alpha</math>)Eu155</b> Tb159(n, $\alpha$ )Eu155 Tb159(n, $\alpha$ )Eu156(n,2n)Eu155	100.0	35.1 59.3 3.6 1.9	1.6 90.2 5.1 3.0	71.1 26.0 1.9
H3	12.33 y	Tb159(n, $\gamma$ )Tb160(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Tb159(n, $\gamma$ )Tb160(n, $\gamma$ )Tb161( $\beta^-$ )Dy161(n,X)H1(n, $\gamma$ ) H2(n, $\gamma$ )H3 Tb159(n, $\gamma$ )Tb160( $\beta^-$ )Dy160(n, $\gamma$ )Dy161(n,X)H1(n, $\gamma$ ) H2(n, $\gamma$ )H3 Tb159(n,X)H3 <b>&amp;Tb159(n,2n)Tb158(n,X)H3</b> <b>&amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,X)H3</b>	43.5 37.8 10.9	42.9 20.5 31.3		94.4 2.7 2.6

Sm151	90.0 y	$\& Tb159(n,2n) Tb158(n,2n) Tb157(n,n\alpha) Eu153(n,2n)$ $Eu152m(\beta^+) Sm152(n,2n) Sm151$ $Tb159(n,\alpha) Eu156(\beta^-) Gd156(n,2n) Gd155(n,2n) Gd154(n,\alpha) Sm151$ $\& Tb159(n,2n) Tb158(n,2n) Tb157(n,2n) Tb156(\beta^+)$ $Gd156(n,2n) Gd155(n,2n) Gd154(n,\alpha) Sm151$ $Tb159(n,\alpha) Eu156(\beta^-) Gd156(n,2n) Gd155(n,\alpha) Sm152(n,2n) Sm151$ $\& Tb159(n,2n) Tb158(n,2n) Tb157(n,n\alpha) Eu153(n,2n)$ $Eu152(\beta^+) Sm152(n,2n) Sm151$ $\& Tb159(n,2n) Tb158(n,2n) Tb157(n,2n) Tb156(\beta^+)$ $Gd156(n,2n) Gd155(n,\alpha) Sm152(n,2n) Sm151$ $\& Tb159(n,2n) Tb158(n,2n) Tb157(n,\alpha) Eu154(n,\alpha)$ $Pm151(\beta^-) Sm151$ $\& Tb159(n,2n) Tb158(n,n\alpha) Eu154(n,\alpha) Pm151(\beta^-) Sm151$ $\& Tb159(n,2n) Tb158(n,2n) Tb157(n,2n) Tb156(\beta^+)$ $Gd156(n,2n) Gd155(n,n\alpha) Sm151$ $\& Tb159(n,n\alpha) Eu155(n,2n) Eu154(n,\alpha) Pm151(\beta^-) Sm151$ $Tb159(n,\alpha) Eu156(\beta^-) Gd156(n,2n) Gd155(n,n\alpha) Sm151$ $Tb159(n,\alpha) Eu156(\beta^-) Gd156(n,n\alpha) Sm152(n,2n) Sm151$ $\& Tb159(n,2n) Tb158(n,\alpha) Eu155(n,\alpha) Pm152m(\beta^-)$ $Sm152(n,2n) Sm151$ $Tb159(n,n\alpha) Eu155(n,\alpha) Pm152m(\beta^-) Sm152(n,2n) Sm151$ $\& Tb159(n,2n) Tb158(n,n\alpha) Eu154(n,2n) Eu153(n,2n)$ $Eu152m(\beta^+) Sm152(n,2n) Sm151$ $\& Tb159(n,2n) Tb158(n,\alpha) Eu155(n,\alpha) Pm152(\beta^-)$ $Sm152(n,2n) Sm151$ $Tb159(n,n\alpha) Eu155(\beta^-) Gd155(n,2n) Gd154(n,\alpha) Sm151$ $\& Tb159(n,2n) Tb158(n,\alpha) Eu155(\beta^-) Gd155(n,2n)$ $Gd154(n,\alpha) Sm151$				19.1*
Tb157	99 y	$\& Tb159(n,2n) Tb158(n,2n) Tb157$				100.0
Tb158	180.62 y	$\& Tb159(n,2n) Tb158$				100.0
Ho166m	1200 y	$\& Tb159(n,\gamma) Tb160(n,\gamma) Tb161(\beta^-) Dy161(n,\gamma)$ $Dy162(n,\gamma) Dy163(n,\gamma) Dy164(n,\gamma) Dy165(\beta^-)$ $Ho165(n,\gamma) Ho166m$ $\& Tb159(n,\gamma) Tb160(\beta^-) Dy160(n,\gamma) Dy161(n,\gamma)$ $Dy162(n,\gamma) Dy163(n,\gamma) Dy164(n,\gamma) Dy165(\beta^-)$ $Ho165(n,\gamma) Ho166m$ $\& Tb159(n,\gamma) Tb160(n,\gamma) Tb161(n,\gamma) Tb162(\beta^-) Dy162(n,\gamma)$ $Dy163(n,\gamma) Dy164(n,\gamma) Dy165(\beta^-) Ho165(n,\gamma) Ho166m$	63.1	36.7	49.6	
			34.3	60.5	47.7	
			1.1	1.3	1.3	
La137	$6.0 \cdot 10^4$ y	Very long pathways involving (n, $\alpha$ ), (n,n $\alpha$ ), (n,2n), ( $\beta^+$ ), etc.				100.0
Gd150	$1.8 \cdot 10^6$ y	$\& Tb159(n,2n) Tb158(n,2n) Tb157(n,n\alpha) Eu153(n,2n)$ $Eu152(n,2n) Eu151(n,2n) Eu150m(\beta^-) Gd150$ $\& Tb159(n,2n) Tb158(n,2n) Tb157(n,n\alpha) Eu153(n,2n)$ $Eu152m(\beta^-) Gd152(n,2n) Gd151(n,2n) Gd150$ $\& Tb159(n,2n) Tb158(n,n\alpha) Eu154(n,2n) Eu153(n,2n)$ $Eu152(n,2n) Eu151(n,2n) Eu150m(\beta^-) Gd150$ $\& Tb159(n,n\alpha) Eu155(n,2n) Eu154(n,2n) Eu153(n,2n)$ $Eu152(n,2n) Eu151(n,2n) Eu150m(\beta^-) Gd150$ $\& Tb159(n,2n) Tb158(n,2n) Tb157(n,\alpha) Eu154(n,2n) Eu153$ $(n,2n) Eu152(n,2n) Eu151(n,2n) Eu150m(\beta^-) Gd150$ $Tb159(n,\alpha) Eu156(\beta^-) Gd156(n,2n) Gd155(n,2n)$ $Gd154(n,2n) Gd153(n,2n) Gd152(n,2n) Gd151(n,2n) Gd150$ $\& Tb159(n,2n) Tb158(n,\alpha) Eu155(n,2n) Eu154(n,2n)$ $Eu153(n,2n) Eu152(n,2n) Eu151(n,2n) Eu150m(\beta^-) Gd150$ $Tb159(n,\alpha) Eu156(\beta^-) Gd156(n,\alpha) Sm153(\beta^-) Eu153(n,2n)$ $Eu152(n,2n) Eu151(n,2n) Eu150m(\beta^-) Gd150$				47.6
						9.2
						4.7
						4.0
						3.3
						2.6
						2.6
						2.2
		*Plus many other similar pathways				23.4*

Hf182	$9.0 \cdot 10^6$ y	Very long pathways of $(n,\gamma)$ , $(\beta^-)$	100.0			
Sm146	$1.0 \cdot 10^8$ y	<b>&amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,n<math>\alpha</math>)Eu153(n,2n)</b> Eu152(n,2n)Eu151(n,2n)Eu150m( $\beta^-$ )Gd150(n,n $\alpha$ )Sm146 <b>&amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,n<math>\alpha</math>)Eu153(n,n<math>\alpha</math>)</b> Pm149( $\beta^-$ )Sm149(n,2n)Sm148(n,2n)Sm147(n,2n)Sm146 <b>&amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,n<math>\alpha</math>)Eu153(n,2n)</b> Eu152m( $\beta^-$ )Gd152(n,n $\alpha$ )Sm148(n,2n)Sm147(n,2n)Sm146 <b>&amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,n<math>\alpha</math>)Eu153(n,2n)</b> Eu152m( $\beta^-$ )Gd152(n,2n)Gd151(n,2n)Gd150(n,n $\alpha$ )Sm146 <b>&amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,n<math>\alpha</math>)Eu153(n,2n)</b> Eu152m( $\beta^-$ )Gd152(n,2n)Gd151(n,n $\alpha$ )Sm147(n,2n)Sm146 <b>Tb159(n,<math>\alpha</math>)Eu156(<math>\beta^-</math>)Gd156(n,2n)Gd155(n,2n)Gd154(n,2n)</b> Gd153(n,2n)Gd152(n,n $\alpha$ )Sm148(n,2n)Sm147(n,2n)Sm146 <b>&amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,n<math>\alpha</math>)Eu153(n,2n)</b> Eu152m( $\beta^-$ )Gd152(n,2n)Gd151(n,n $\alpha$ )Sm147(n,2n)Sm146 <b>&amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,n<math>\alpha</math>)Eu153(n,n<math>\alpha</math>)</b> Pm149( $\beta^-$ )Sm149(n,3n)Sm147(n,2n)Sm146			16.0	
		*Plus many other similar pathways				13.4
						11.0
						3.5
						3.2
						2.7
						2.6
						1.9
						44.7*
Lu176	$3.6 \cdot 10^{10}$ y	Very long pathways of $(n,\gamma)$ , $(\beta^-)$	100.0	100.0		
La138	$1.1 \cdot 10^{11}$ y	Very long pathways involving $(n,\alpha)$ , $(n,n\alpha)$ , $(n,2n)$ , $(\beta^+)$ , etc.			100.0	
Sm147	$1.1 \cdot 10^{11}$ y	<b>&amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,n<math>\alpha</math>)Eu153(n,n<math>\alpha</math>)</b> Pm149( $\beta^-$ )Sm149(n,2n)Sm148(n,2n)Sm147 <b>&amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,n<math>\alpha</math>)Eu153(n,2n)</b> Eu152m( $\beta^-$ )Gd152(n,n $\alpha$ )Sm148(n,2n)Sm147 <b>&amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,n<math>\alpha</math>)Eu153(n,2n)</b> Eu152m( $\beta^-$ )Gd152(n,2n)Gd151(n,n $\alpha$ )Sm147 <b>Tb159(n,<math>\alpha</math>)Eu156(<math>\beta^-</math>)Gd156(n,2n)Gd155(n,2n)</b> Gd154(n,2n)Gd153(n,2n)Gd152(n,n $\alpha$ )Sm148(n,2n)Sm147 <b>&amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,n<math>\alpha</math>)Eu153(n,n<math>\alpha</math>)</b> Pm149( $\beta^-$ )Sm149(n,3n)Sm147 <b>&amp;Tb159(n,2n)Tb158(n,n<math>\alpha</math>)Eu154(n,2n)Eu153(n,n<math>\alpha</math>)</b> Pm149( $\beta^-$ )Sm149(n,2n)Sm148(n,2n)Sm147 <b>Tb159(n,n<math>\alpha</math>)Eu155(n,2n)Eu154(n,2n)Eu153(n,n<math>\alpha</math>)</b> Pm149( $\beta^-$ )Sm149(n,2n)Sm148(n,2n)Sm147 <b>&amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,2n)Tb156(<math>\beta^+</math>)</b> Gd156(n,2n)Gd155(n,2n)Gd154(n,2n)Gd153(n,2n) Gd152(n,n $\alpha$ )Sm148(n,2n)Sm147 <b>Tb159(n,n<math>\alpha</math>)Eu155(n,2n)Eu154(n,2n)Eu153(n,2n)</b> Eu152m( $\beta^-$ )Gd152(n,n $\alpha$ )Sm148(n,2n)Sm147 <b>Tb159(n,<math>\alpha</math>)Eu156(<math>\beta^-</math>)Gd156(n,<math>\alpha</math>)Sm153(<math>\beta^-</math>)</b> Eu153(n,n $\alpha$ )Pm149( $\beta^-$ )Sm149(n,2n)Sm148(n,2n)Sm147 <b>&amp;Tb159(n,2n)Tb158(n,n<math>\alpha</math>)Eu154(n,2n)Eu153(n,2n)</b> Eu152m( $\beta^-$ )Gd152(n,n $\alpha$ )Sm148(n,2n)Sm147			21.3	
		*Plus many other similar pathways				17.5
						3.7
						4.7
						2.6
						2.3
						1.3
						1.3
						1.1
						1.1
						1.0
						1.0
						41.1*

Gd152	$1.1 \cdot 10^{14}$ y	<p>&amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,n<math>\alpha</math>)Eu153(n,2n)      Eu152m(<math>\beta^-</math>)Gd152      Tb159(n,<math>\alpha</math>)Eu156(<math>\beta^-</math>)Gd156(n,2n)Gd155(n,2n)      Gd154(n,2n)Gd153(n,2n)Gd152      &amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,2n)Tb156(<math>\beta^+</math>)      Gd156(n,2n)Gd155(n,2n)Gd154(n,2n)Gd153(n,2n)Gd152      &amp;Tb159(n,2n)Tb158(n,n<math>\alpha</math>)Eu154(n,2n)Eu153(n,2n)      Eu152m(<math>\beta^-</math>)Gd152      &amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,<math>\alpha</math>)Eu154(n,2n)      Eu153(n,2n)Eu152m(<math>\beta^-</math>)Gd152      &amp;Tb159(n,2n)Tb158(n,n<math>\alpha</math>)Eu153(n,2n)      Eu152(<math>\beta^-</math>)Gd152      &amp;Tb159(n,2n)Tb158(n,<math>\alpha</math>)Eu155(n,2n)Eu154(n,2n)      Eu153(n,2n)Eu152m(<math>\beta^-</math>)Gd152      &amp;Tb159(n,n<math>\alpha</math>)Eu155(n,2n)Eu154(n,2n)Eu153(n,2n)      Eu152m(<math>\beta^-</math>)Gd152      Tb159(n,n<math>\alpha</math>)Eu155(<math>\beta^-</math>)Gd155(n,2n)Gd154(n,2n)      Gd153(n,2n)Gd152      &amp;Tb159(n,2n)Tb158(n,<math>\alpha</math>)Eu155(<math>\beta^-</math>)Gd155(n,2n)      Gd154(n,2n)Gd153(n,2n)Gd152      Tb159(n,<math>\alpha</math>)Eu156(<math>\beta^-</math>)Gd156(n,2n)Gd155(n,2n)      Gd154(n,2n)Gd153(<math>\beta^+</math>)Eu153(n,2n)Eu152m(<math>\beta^-</math>)Gd152      &amp;Tb159(n,2n)Tb158(n,n<math>\alpha</math>)Eu154(<math>\beta^-</math>)Gd154(n,2n)      Gd153(n,2n)Gd152      Tb159(n,<math>\alpha</math>)Eu156(<math>\beta^-</math>)Gd156(n,<math>\alpha</math>)Sm153(<math>\beta^-</math>)      Eu153(n,2n)Eu152m(<math>\beta^-</math>)Gd152      &amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,<math>\alpha</math>)Eu154(<math>\beta^-</math>)      Gd154(n,2n)Gd153(n,2n)Gd152      &amp;Tb159(n,n<math>\alpha</math>)Eu155(n,2n)Eu154(<math>\beta^-</math>)Gd154(n,2n)      Gd153(n,2n)Gd152      *Plus many other similar pathways   </p>				39.7
					13.2	
					8.8	
					4.2	
					4.1	
					3.8	
					3.2	
					3.1	
					1.6	
					1.5	
					1.4	
					1.4	
					1.3	
					1.2	
					1.0	
					10.5*	
Sm149	$2.0 \cdot 10^{15}$ y	<p>&amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,n<math>\alpha</math>)Eu153(n,n<math>\alpha</math>)      Pm149(<math>\beta^-</math>)Sm149      &amp;Tb159(n,2n)Tb158(n,n<math>\alpha</math>)Eu154(n,2n)Eu153(n,n<math>\alpha</math>)      Pm149(<math>\beta^-</math>)Sm149      &amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,<math>\alpha</math>)Eu154(n,2n)      Eu153(n,n<math>\alpha</math>)Pm149(<math>\beta^-</math>)Sm149      &amp;Tb159(n,2n)Tb158(n,<math>\alpha</math>)Eu155(n,2n)Eu154(n,2n)      Eu153(n,n<math>\alpha</math>)Pm149(<math>\beta^-</math>)Sm149      &amp;Tb159(n,n<math>\alpha</math>)Eu155(n,2n)Eu154(n,2n)Eu153(n,n<math>\alpha</math>)      Pm149(<math>\beta^-</math>)Sm149      &amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,n<math>\alpha</math>)Eu153(n,2n)      Eu152(n,<math>\alpha</math>)Pm149(<math>\beta^-</math>)Sm149      &amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,n<math>\alpha</math>)Eu153(n,<math>\alpha</math>)      Pm150(<math>\beta^-</math>)Sm150(n,2n)Sm149      &amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,n<math>\alpha</math>)Eu153(n,2n)      Eu152(n,2n)Eu151(n,2n)Eu150(n,2n)Eu149(<math>\beta^+</math>)Sm149      Tb159(n,<math>\alpha</math>)Eu156(<math>\beta^-</math>)Gd156(n,2n)Gd155(n,2n)      Gd154(n,n<math>\alpha</math>)Sm150(n,2n)Sm149      &amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,2n)Tb156(<math>\beta^+</math>)      Gd156(n,<math>\alpha</math>)Sm153(<math>\beta^-</math>)Eu153(n,n<math>\alpha</math>)Pm149(<math>\beta^-</math>)Sm149      Tb159(n,<math>\alpha</math>)Eu156(<math>\beta^-</math>)Gd156(n,2n)Gd155(n,2n)      Gd154(n,2n)Gd153(<math>\beta^+</math>)Eu153(n,n<math>\alpha</math>)Pm149(<math>\beta^-</math>)Sm149      Tb159(n,<math>\alpha</math>)Eu156(<math>\beta^-</math>)Gd156(n,<math>\alpha</math>)Sm153(<math>\beta^-</math>)      Eu153(n,n<math>\alpha</math>)Pm149(<math>\beta^-</math>)Sm149      &amp;Tb159(n,2n)Tb158(n,2n)Tb157(n,2n)Tb156(<math>\beta^+</math>)      Gd156(n,2n)Gd155(n,2n)Gd154(n,n<math>\alpha</math>)Sm150(n,2n)Sm149      *Plus many other similar pathways   </p>				45.0
					4.8	
					4.6	
					3.6	
					3.5	
					3.1	
					2.6	
					2.3	
					2.2	
					2.0	
					1.6	
					1.5	
					1.4	
					21.8*	

# Terbium activation characteristics

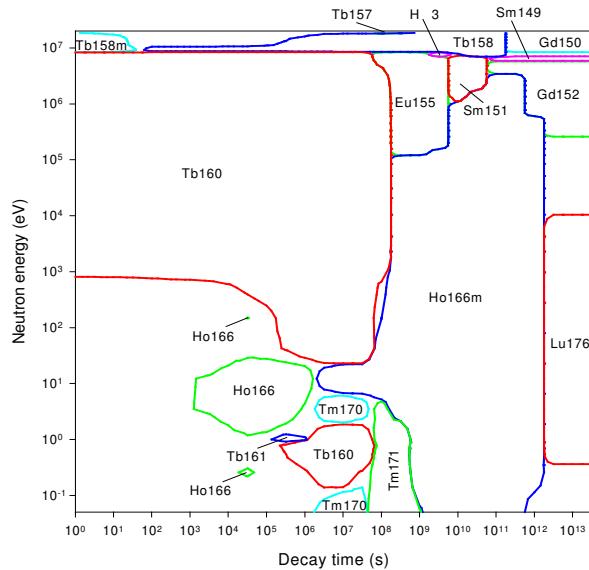


Decay time (years)

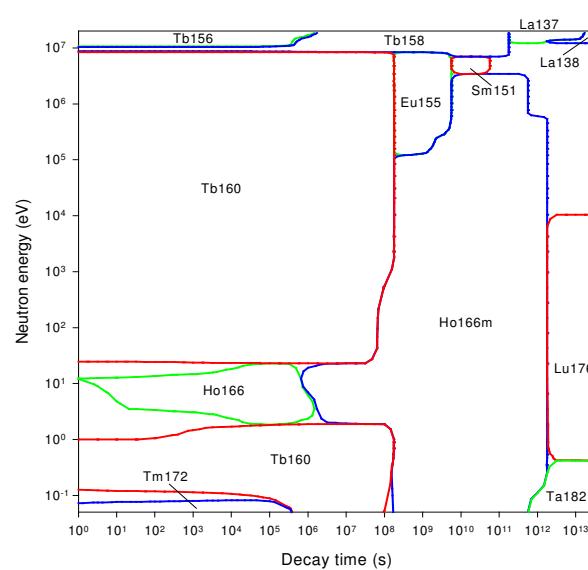
Decay time (years)

# Terbium importance diagrams & transmutation

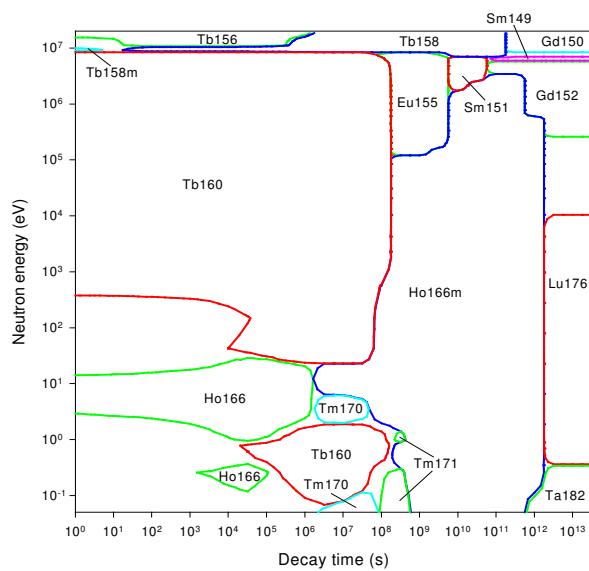
# Activity



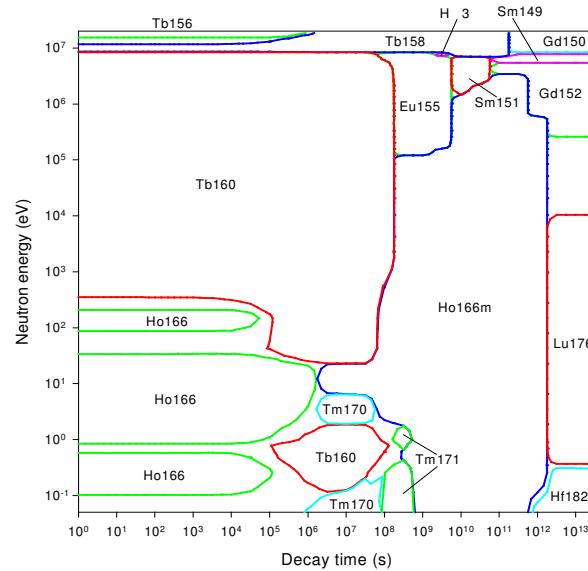
## Dose rate



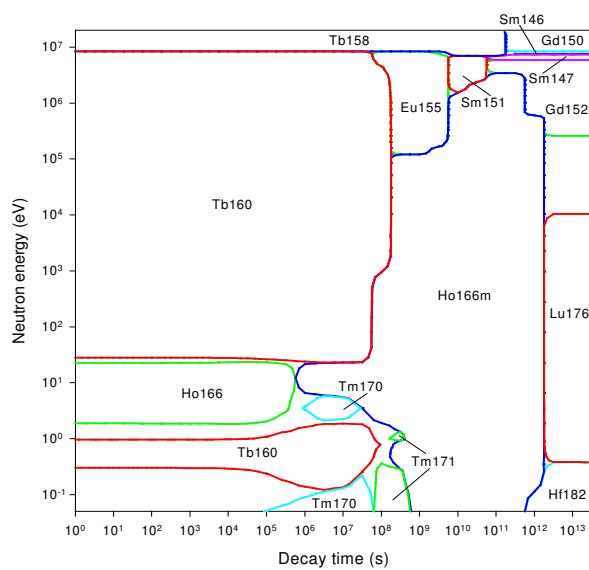
## Heat output



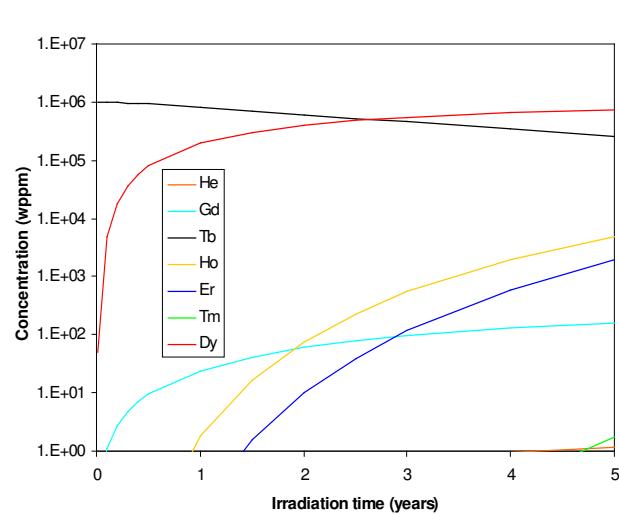
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Dysprosium

## General properties

	66	Isotopes	Isotopic abundances / %
Atomic number	66		
Crustal abundance / wppm	5.2	Dy156	0.06
Melting point / K	1684	Dy158	0.10
Boiling point / K	2834	Dy160	2.34
Density / kgm <sup>-3</sup>	8551	Dy161	18.91
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	10.7	Dy162	25.51
Electrical resistivity /Ωm	5.7 10 <sup>-7</sup>	Dy163	24.90
Coefficient of thermal expansion / K <sup>-1</sup>	9.9 10 <sup>-6</sup>	Dy164	28.18
Crystal structure	Rhombic		
Number of stable isotopes	7		
Mean atomic weight	162.5		

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.05E16	7.38E15	3.62E14	2.80E12	1.66E11	2.99E10	kW kg <sup>-1</sup>	7.33E-1	6.59E-1	3.87E-2	1.72E-4	2.62E-5	9.49E-16
Dy165	38.48	53.38					Ho166	46.18	51.27	91.36			
Ho166	27.95	39.51	84.31				Dy165	41.55	45.28				
Dy165m	24.61	1.92					Dy165m	7.01	0.43				
Er167m	5.30	0.21					Er167m	2.52	0.08				
Ho167	1.31	1.82					Ho167	1.69	1.85				
Er169	0.37	0.53	8.23				Tb160	0.30	0.34	5.53	38.68		
Tb160	0.10	0.14	2.68	10.79			Er169	0.09	0.10	1.27			
Tm170	0.08	0.12	2.31	42.52			Tm170	0.06	0.07	1.16	36.96		
Dy159	0.04	0.06	1.22	27.72			Tm168	0.01	0.01	0.12	1.75		
Tm171		0.01	0.10	9.29			Dy159	0.01	0.01	0.11	4.20		
Tb157			0.03	3.78	31.88		Ho166m			0.05	11.80	73.36	
Ho166m				0.02	2.48	39.54	Tb158			0.03	5.80	26.12	
Tb158				0.02	2.47	28.48	Dy154						93.37
Ho163					0.06	93.33	Gd150						5.39
Dy154						6.29	Ho163						1.25
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	4.17E4	3.57E4	4.37E3	1.17E2	2.91E1	2.83E-16	Sv kg <sup>-1</sup>	4.60E6	4.58E6	4.69E5	2.37E3	1.85E2	1.15E-7
Ho166	39.59	46.11	39.42				Ho166	88.91	89.13	90.94			
Dy165	29.02	33.18					Dy165	9.62	9.46				
Ho167	9.90	11.33					Tb160	0.35	0.35	3.30	20.40		
Dy165m	8.42	0.54					Er169	0.31	0.32	2.35			
Tb160	6.28	7.33	57.86	67.50			Ho167	0.25	0.24				
Er167m	4.98	0.16					Tm170	0.24	0.24	2.31	65.30		
Tb164	0.83	0.29					Dy159	0.01	0.01	0.09	3.28		
Tm168	0.12	0.14	1.08	2.73			Ho166m			0.03	5.86	70.93	
Ho166m	0.05	0.06	0.50	18.77	71.10		Tb158			0.02	3.21	28.10	
Tb158	0.03	0.04	0.28	10.53	28.88		Tm171			0.01	1.21		
Tm170			0.05*	0.24*			Dy154						94.56
Lu176						99.81	Gd150						5.15
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	2.35E6	2.34E6	3.74E5	2.28E4	1.01E4	5.27E-5		8.05E11	6.54E11	4.32E10	6.26E8	1.53E8	3.37E-5
Ho166	80.90	81.11	52.95				Ho166	36.30	44.60	70.54			
Dy165	10.28	10.12					Dy165	35.69	43.04				
Tb160	2.99	3.00	18.10	9.28			Dy165m	9.69	0.66				
Tm170	2.54	2.55	15.63	36.57			Er167m	8.72	0.30				
Er169	1.67	1.67	7.96				Ho167	6.53	7.88				
Ho167	0.41	0.41					Tb160	1.43	1.76	25.73	55.43		
Ho166m	0.36	0.36	2.23	36.57	77.87		Tm170	0.04	0.05	0.74	7.31		
Dy166	0.31	0.31	0.93				Tm168	0.03	0.04	0.59	2.74		
Tb158	0.14	0.14	0.85	13.94	21.50		Dy159	0.03	0.03	0.49	5.90		
Dy159	0.07	0.07	0.44	1.26			Ho166m		0.02	0.28	19.11	73.89	
Tm171	0.02	0.02	0.14	1.60			Tb158			0.13	9.18	25.72	
Tb157	0.01	0.01	0.03	0.56	0.63		Dy154						64.09
Dy154						82.01	Ho163						21.77
Gd150						17.99	Gd150						14.12

# Dysprosium

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Er167m	2.28 s	<b>&amp;Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)</b> Ho165(n, $\gamma$ )Ho166( $\beta^-$ )Er166(n, $\gamma$ )Er167m <b>&amp;Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)</b> Ho166( $\beta^-$ )Er166(n, $\gamma$ )Er167m <b>&amp;Dy161(n,<math>\gamma</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)</b> Dy165( $\beta^-$ )Ho165(n, $\gamma$ )Ho166( $\beta^-$ )Er166(n, $\gamma$ )Er167m <b>&amp;Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166(<math>\beta^-</math>)</b> Er166(n, $\gamma$ )Er167m <b>&amp;Dy160(n,<math>\gamma</math>)Dy161(n,<math>\gamma</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166(<math>\beta^-</math>)Er166(n,<math>\gamma</math>)Er167m</b> Dy164(n, $\gamma$ )Dy165m( $\beta^-$ )Ho165(n, $\gamma$ )Ho166( $\beta^-$ ) Er166(n, $\gamma$ )Er167m <b>&amp;Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166m(n,<math>\gamma</math>)</b> Ho167( $\beta^-$ )Er167m	27.6 23.4 21.6 20.8 3.5 0.3	0.5 47.4 0.3 49.6 0.8 1.4	2.9 93.9	88.1 0.5 9.4
Dy165	2.334 h	<b>&amp;Dy160(n,<math>\gamma</math>)Dy161(n,<math>\gamma</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)</b> Dy164(n, $\gamma$ )Dy165 <b>&amp;Dy158(n,<math>\gamma</math>)Dy159(n,<math>\gamma</math>)Dy160(n,<math>\gamma</math>)Dy161(n,<math>\gamma</math>)</b> Dy162(n, $\gamma$ )Dy163(n, $\gamma$ )Dy164(n, $\gamma$ )Dy165 <b>&amp;Dy161(n,<math>\gamma</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165</b> <b>&amp;Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165</b> <b>&amp;Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165</b> <b>&amp;Dy164(n,<math>\gamma</math>)Dy165</b>	64.4 10.9 8.8 8.7 3.0	2.0 16.5 22.3 59.0 0.1	0.3 7.9 91.7	100.0
Dy157	8.14 h	Dy156(n, $\gamma$ )Dy157 Dy158(n,2n)Dy157 Dy161(n,2n)Dy160(n,2n)Dy159(n,2n)Dy158(n,2n)Dy157 Dy160(n,2n)Dy159(n,2n)Dy158(n,2n)Dy157 Dy162(n,2n)Dy161(n,2n)Dy160(n,2n)Dy159(n,2n) Dy158(n,2n)Dy157	100.0	100.0	100.0	64.0 18.0 15.4 2.3
Ho166	1.117 d	<b>&amp;Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)</b> Ho165(n, $\gamma$ )Ho166 <b>&amp;Dy161(n,<math>\gamma</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)</b> Dy165( $\beta^-$ )Ho165(n, $\gamma$ )Ho166 <b>&amp;Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166</b> <b>&amp;Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166</b> <b>&amp;Dy160(n,<math>\gamma</math>)Dy161(n,<math>\gamma</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)</b> Dy164(n, $\gamma$ )Dy165( $\beta^-$ )Ho165(n, $\gamma$ )Ho166 Dy163(n, $\gamma$ )Dy164(n, $\gamma$ )Dy165m( $\beta^-$ )Ho165(n, $\gamma$ )Ho166 Dy164(n, $\gamma$ )Dy165m( $\beta^-$ )Ho165(n, $\gamma$ )Ho166	30.0 25.3 19.9 11.6 10.3	4.3 3.1 68.6 22.1 0.4	4.4 94.0	99.2 0.6

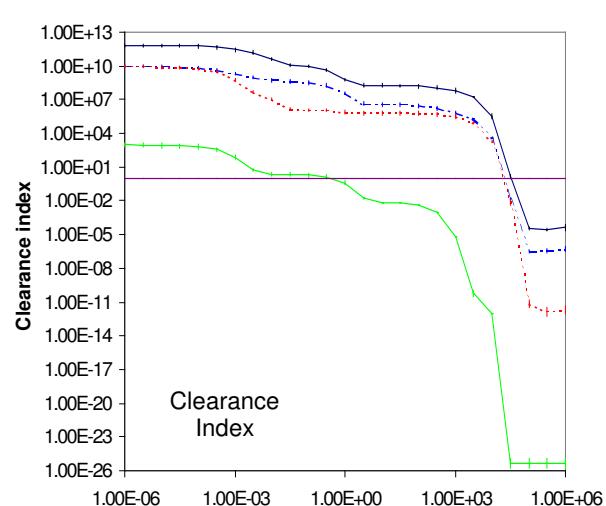
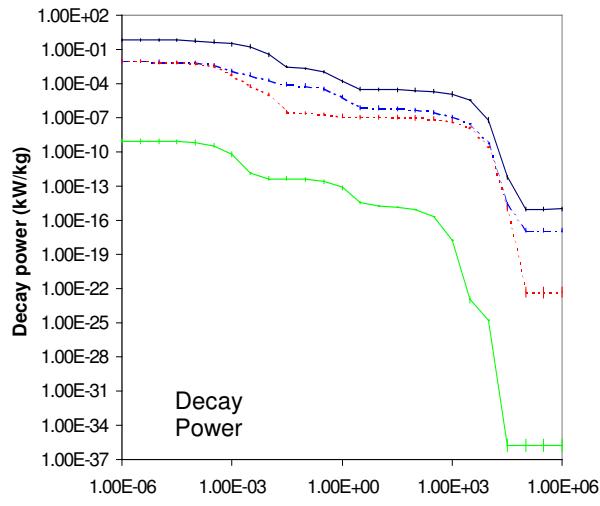
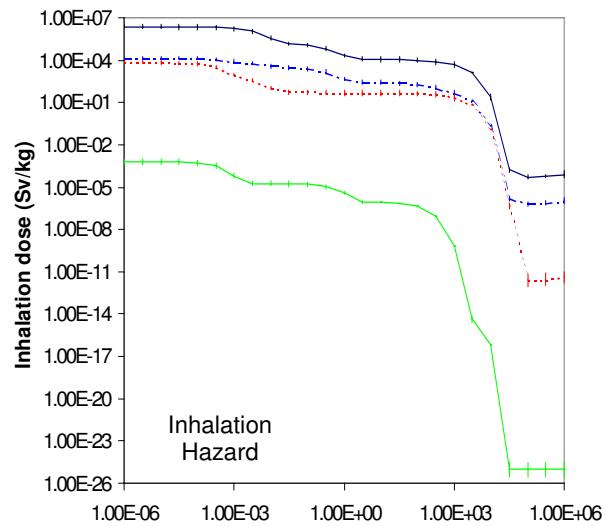
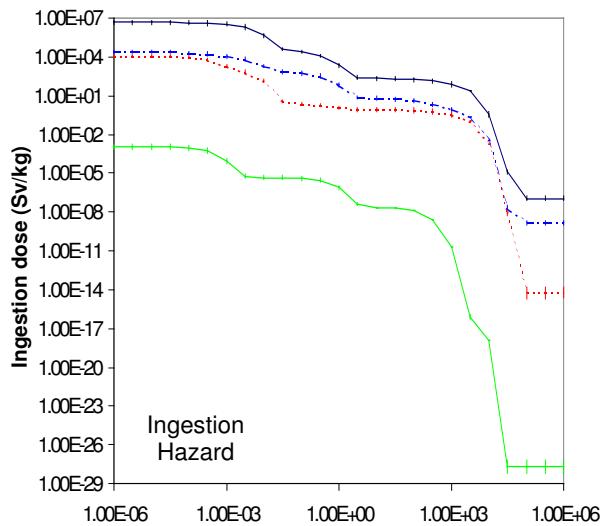
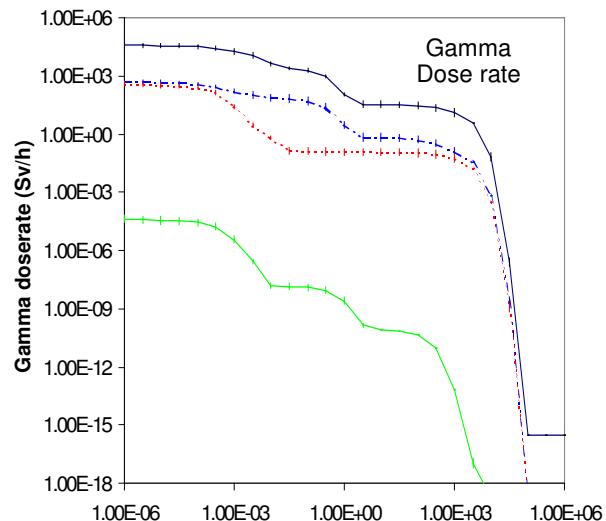
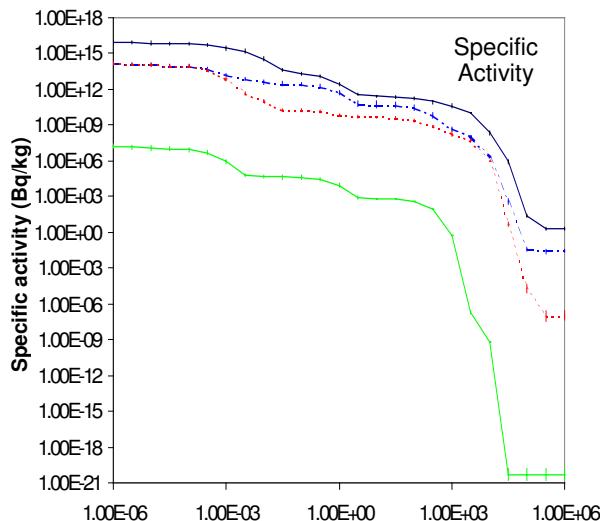




Tm171	1.92 y	<b>&amp;Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166(<math>\beta^-</math>)</b> Er166(n, $\gamma$ )Er167(n, $\gamma$ )Er168(n, $\gamma$ )Er169( $\beta^-$ )Tm169(n, $\gamma$ ) Tm170(n, $\gamma$ )Tm171 <b>&amp;Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)</b> Ho166( $\beta^-$ )Er166(n, $\gamma$ )Er167(n, $\gamma$ )Er168(n, $\gamma$ )Er169( $\beta^-$ ) Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171 <b>&amp;Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)</b> Ho165(n, $\gamma$ )Ho166( $\beta^-$ )Er166(n, $\gamma$ )Er167(n, $\gamma$ )Er168(n, $\gamma$ ) Er169( $\beta^-$ )Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171 <b>&amp;Dy161(n,<math>\gamma</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)</b> Dy165( $\beta^-$ )Ho165(n, $\gamma$ )Ho166( $\beta^-$ )Er166(n, $\gamma$ )Er167(n, $\gamma$ ) Er168(n, $\gamma$ )Er169( $\beta^-$ )Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171 <b>&amp;Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166m(n,<math>\gamma</math>)</b> Ho167( $\beta^-$ )Er167(n, $\gamma$ )Er168(n, $\gamma$ )Er169( $\beta^-$ )Tm169(n, $\gamma$ ) Tm170(n, $\gamma$ )Tm171 <b>&amp;Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)</b> Ho166m(n, $\gamma$ )Ho167( $\beta^-$ )Er167(n, $\gamma$ )Er168(n, $\gamma$ ) Er169( $\beta^-$ )Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171 <b>&amp;Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)</b> Ho165(n, $\gamma$ )Ho166m(n, $\gamma$ )Ho167( $\beta^-$ )Er167(n, $\gamma$ ) Er168(n, $\gamma$ )Er169( $\beta^-$ )Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171 <b>&amp;Dy161(n,<math>\gamma</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)</b> ( $\beta^-$ )Ho165(n, $\gamma$ )Ho166m(n, $\gamma$ )Ho167( $\beta^-$ )Er167(n, $\gamma$ ) Er168(n, $\gamma$ )Er169( $\beta^-$ )Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171 <b>&amp;Dy160(n,<math>\gamma</math>)Dy161(n,<math>\gamma</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)</b> Ho165(n, $\gamma$ )Ho166(n, $\gamma$ )Ho167(n, $\gamma$ )Er166(n, $\gamma$ )Er167(n, $\gamma$ ) Er168(n, $\gamma$ )Er169(n, $\gamma$ )Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171	28.8 22.3 20.6 14.6 2.2 1.8 1.8 1.3 1.1	51.6 29.7 0.1 0.1 9.1 5.8 0.1	86.5 1.1 9.4	
Hf178n	31.0 y	Very long Pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0	100.0		
Tb157	99.0 y	Dy156(n, $\gamma$ )Dy157( $\beta^+$ )Tb157 Dy158(n,2n)Dy157( $\beta^+$ )Tb157 <b>&amp;Dy160(n,2n)Dy159(<math>\beta^+</math>)Tb159(n,2n)Tb158(n,2n)Tb157</b> <b>&amp;Dy161(n,2n)Dy160(n,2n)Dy159(<math>\beta^+</math>)Tb159(n,2n)</b> Tb158(n,2n)Tb157 Dy160(n,2n)Dy159(n,2n)Dy158(n,2n)Dy157( $\beta^+$ )Tb157 Dy161(n,2n)Dy160(n,2n)Dy159(n,2n)Dy158(n,2n) Dy157( $\beta^+$ )Tb157	99.2	100.0	100.0	61.0 16.2 9.6 6.4 5.0
Tb158	180.62 y	<b>&amp;Dy156(n,<math>\gamma</math>)Dy157(<math>\beta^+</math>)Tb157(n,<math>\gamma</math>)Tb158</b> <b>&amp;Dy160(n,2n)Dy159(<math>\beta^+</math>)Tb159(n,2n)Tb158</b> <b>&amp;Dy161(n,2n)Dy160(n,2n)Dy159(<math>\beta^+</math>)Tb159(n,2n)Tb158</b> <b>&amp;Dy162(n,2n)Dy161(n,2n)Dy160(n,2n)Dy159(<math>\beta^+</math>)</b> Tb159(n,2n)Tb158	100.0	100.0	100.0	52.8 41.7 4.0
Ho166m	1200 y	<b>&amp;Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)</b> Ho165(n, $\gamma$ )Ho166m <b>&amp;Dy161(n,<math>\gamma</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)</b> Dy165( $\beta^-$ )Ho165(n, $\gamma$ )Ho166m <b>&amp;Dy163(n,<math>\gamma</math>)Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166m</b> <b>&amp;Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,<math>\gamma</math>)Ho166m</b> <b>&amp;Dy160(n,<math>\gamma</math>)Dy161(n,<math>\gamma</math>)Dy162(n,<math>\gamma</math>)Dy163(n,<math>\gamma</math>)</b> Dy164(n, $\gamma$ )Dy165( $\beta^-$ )Ho165(n, $\gamma$ )Ho166m Dy163(n, $\gamma$ )Dy164(n, $\gamma$ )Dy165m( $\beta^-$ )Ho165(n, $\gamma$ )Ho166m Dy164(n, $\gamma$ )Dy165m( $\beta^-$ )Ho165(n, $\gamma$ )Ho166m	60.1 25.4 19.9 11.6 10.3 1.0 0.5	1.8 1.3 64.5 30.7 95.5 1.5 0.6		99.3
Ho163	4570 y	<b>&amp;Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,2n)Ho164(<math>\beta^-</math>)</b> Er164(n,2n)Er163( $\beta^+$ )Ho163 <b>&amp;Dy164(n,<math>\gamma</math>)Dy165(<math>\beta^-</math>)Ho165(n,3n)Ho163</b>				98.1 1.2
La137	$6.0 \cdot 10^4$ y	Very long pathways of (n, $\alpha$ ), ( $\beta^+$ ), (n,n $\alpha$ ), etc				100.0

Gd150	$1.8 \cdot 10^6$ y	Dy156(n,n $\alpha$ )Gd152(n,2n)Gd151(n,2n)Gd150 Dy156(n,n $\alpha$ )Gd152(n,2n)Gd151( $\beta^+$ )Eu151(n,2n) Eu150m( $\beta^-$ )Gd150 Dy156(n,2n)Dy155( $\beta^+$ )Tb155( $\beta^+$ )Gd155(n,2n)Gd154(n,2n) Gd153(n,2n)Gd152(n,2n)Gd151(n,2n)Gd150 Dy156(n, $\alpha$ )Gd153(n,2n)Gd152(n,2n)Gd151(n,2n)Gd150 & Dy156(n, $\alpha$ )Gd153( $\beta^+$ )Eu153(n,2n)Eu152(n,2n) Eu151(n,2n)Eu150m( $\beta^-$ )Gd150 Dy156(n, $\alpha$ )Gd153(n,2n)Gd152(n,2n)Gd151( $\beta^+$ ) Eu151(n,2n)Eu150m( $\beta^-$ )Gd150 Dy156(n,2n)Dy155( $\beta^+$ )Tb155(n,n $\alpha$ )Eu151(n,2n) Eu150m( $\beta^-$ )Gd150					45.0 33.9  3.8  3.5 3.4  2.3  1.6  1.3
Dy154	$2.9 \cdot 10^6$ y	Dy156(n,2n)Dy155(n,2n)Dy154					100.0
Hf182	$9.0 \cdot 10^6$ y	Very long Pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0	100.0			
Lu176	$3.6 \cdot 10^{10}$ y	Very long Pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0	100.0	100.0		
La138	$1.1 \cdot 10^{11}$ y	Very long pathways of (n, $\alpha$ ), ( $\beta^+$ ), (n,n $\alpha$ ), etc					100.0
Gd152	$1.1 \cdot 10^{14}$ y	Dy156(n,n $\alpha$ )Gd152 Dy156(n,2n)Dy155( $\beta^+$ )Tb155( $\beta^+$ )Gd155(n,2n) Gd154(n,2n)Gd153(n,2n)Gd152 Dy156(n, $\alpha$ )Gd153(n,2n)Gd152 Dy156(n,2n)Dy155( $\beta^+$ )Tb155( $\beta^+$ )Gd155(n,2n) Gd154(n,2n)Gd153( $\beta^+$ )Eu153(n,2n)Eu152m( $\beta^-$ )Gd152 Dy156(n, $\alpha$ )Gd153( $\beta^+$ )Eu153(n,2n)Eu152m( $\beta^-$ )Gd152	99.2	99.2	100.0	71.4 16.7  6.8 2.2  1.7	

# Dysprosium activation characteristics

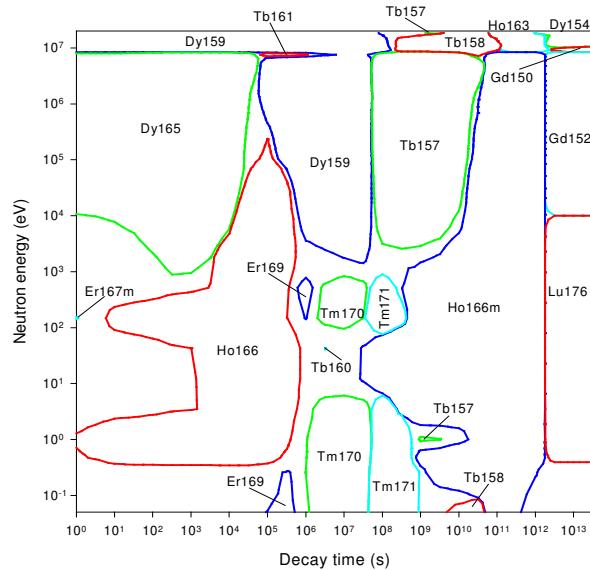


Decay time (years)

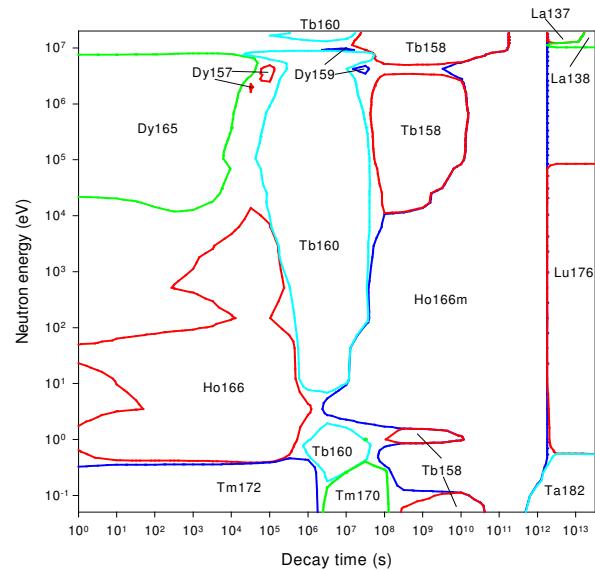
Decay time (years)

# Dysprosium importance diagrams & transmutation

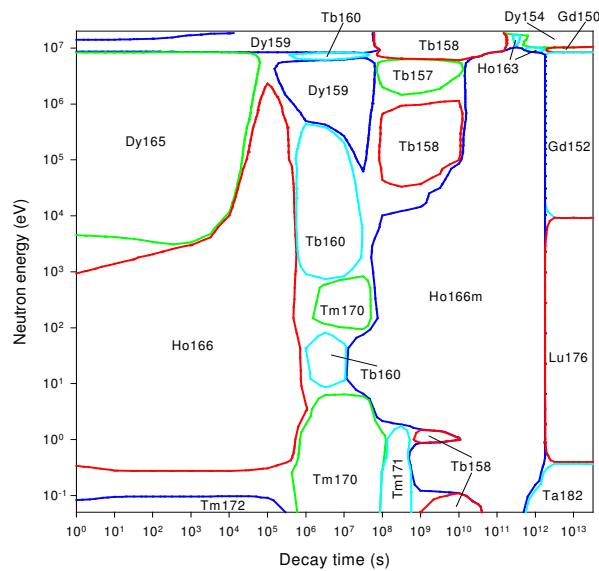
## Activity



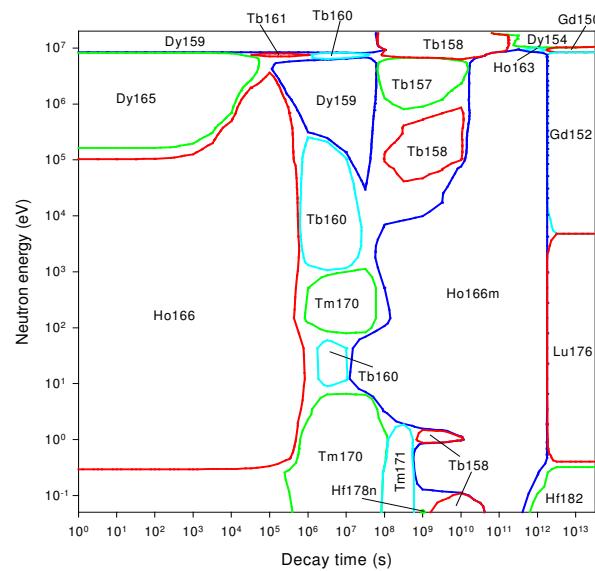
## Dose rate



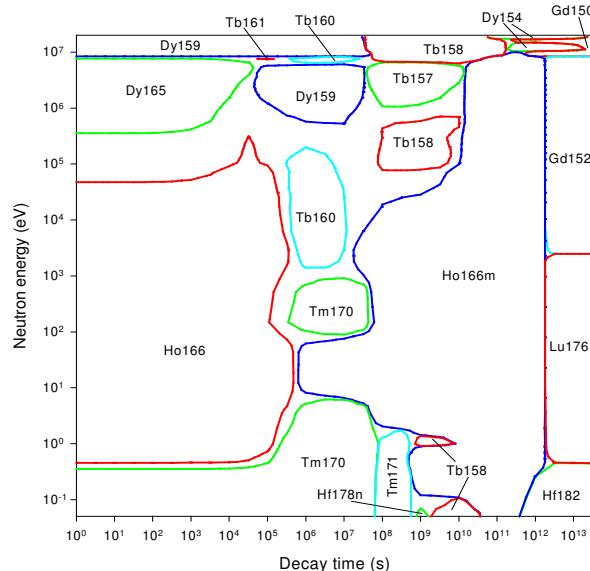
## Heat output



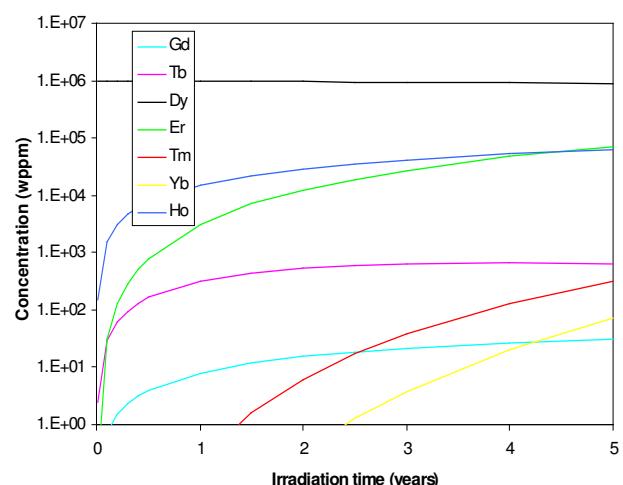
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Holmium

## General properties

Atomic number	67	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	1.3	Ho165	100.0
Melting point / K	1745		
Boiling point / K	2967		
Density / kgm <sup>-3</sup>	8795		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	16.2		
Electrical resistivity /Ωm	8.70 10 <sup>-7</sup>		
Coefficient of thermal expansion / K <sup>-1</sup>	1.12 10 <sup>-5</sup>		
Crystal structure	HCP		
Number of stable isotopes	1		
Mean atomic weight	164.93032		

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.43E16	8.73E15	1.74E15	5.90E13	2.38E11	4.43E2	kW kg <sup>-1</sup>	9.66E-1	7.79E-1	1.04E-1	2.70E-3	6.92E-5	1.88E-16
Ho166	41.18	67.37	35.18				Ho166	70.70	87.49	68.30			
Er167m	38.90	0.63					Er167m	19.19	0.23				
Er169	7.03	11.53	44.18				Ho167	4.55	5.53				
Er165	4.96	8.08	0.12				Tm170	1.82	2.26	16.65	91.14		
Ho167	3.38	5.44					Er169	1.72	2.13	12.20			
Tm170	2.30	3.76	18.55	77.72			Er165	0.51	0.62	0.01			
Ho164	0.89	1.38					Tm168	0.18	0.22	1.62	4.23		
Tm171	0.12	0.20	1.02	20.94			Tm171	0.01	0.01	0.07	1.91		
Ho166m			0.01	0.42	99.28		Ho166m	0.01	0.01	0.07	2.72	100.00	
Ho163					0.71	100.00	Ho163						99.93
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	7.21E4	5.17E4	6.15E3	2.08E2	7.36E1	3.49E-14	Sv kg <sup>-1</sup>	9.15E6	9.13E6	1.58E6	6.20E4	4.72E2	5.32E-9
Ho166	45.88	63.82	55.69				Ho166	90.18	90.17	54.14			
Er167m	27.94	0.38					Tm170	4.67	4.68	26.51	96.18		
Ho167	19.80	27.07					Er169	4.07	4.08	17.97			
Tm172	2.90	4.04	13.06				Ho167	0.44	0.43				
Tm168	2.50	3.49	28.55	57.30			Tm172	0.28	0.28	0.63			
Ho166m	0.11	0.15	1.27	37.55	100.00		Tm168	0.09	0.09	0.48	0.82		
Tm170	0.11*	0.15*	1.22*	5.13*			Tm171	0.02	0.02	0.12	2.19		
Lu176					90.02		Ho166m	0.01	0.01	0.03	0.81	100.00	
Ta182					9.71		Ho163						99.97
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	7.29E6	7.28E6	3.51E6	3.70E5	2.83E4	1.16E-8		1.57E12	8.60E11	9.54E10	2.88E9	4.07E8	1.17E-4
Ho166	52.58	52.53	11.31				Er167m	45.04	0.80				
Tm170	31.55	31.60	64.21	86.78			Ho166	37.67	68.38	64.02			
Er169	13.82	13.83	21.84				Ho167	11.90	21.22				
Ho167	0.47	0.46					Er165	1.74	3.15	0.08			
Ho166m	0.41	0.41	0.85	8.10	100.00		Tm170	0.81	1.47	12.99	61.21		
Tm168	0.34	0.34	0.69	0.45			Er169	0.66	1.21	8.29			
Tm171	0.34	0.34	0.70	4.68			Tm168	0.63	1.14	10.03	22.50		
Tm172	0.23	0.23	0.18				Tm172	0.51	0.93	3.22			
Yb169	0.11	0.11	0.21				Ho166m	0.03	0.05	0.45	14.95	100.00	
Ho163					99.37		Tm171		0.01	0.06	1.34		
Lu176					0.60		Ho163						99.54

# Holmium

## Pathway analysis

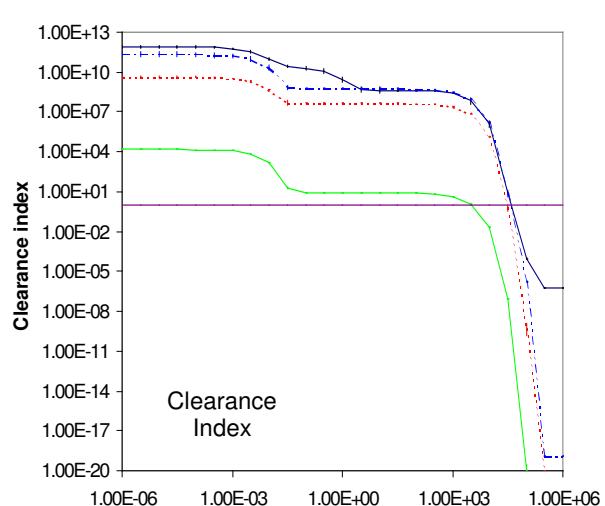
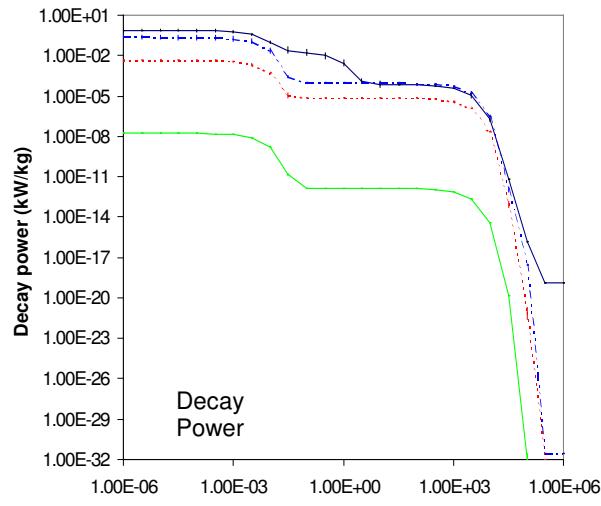
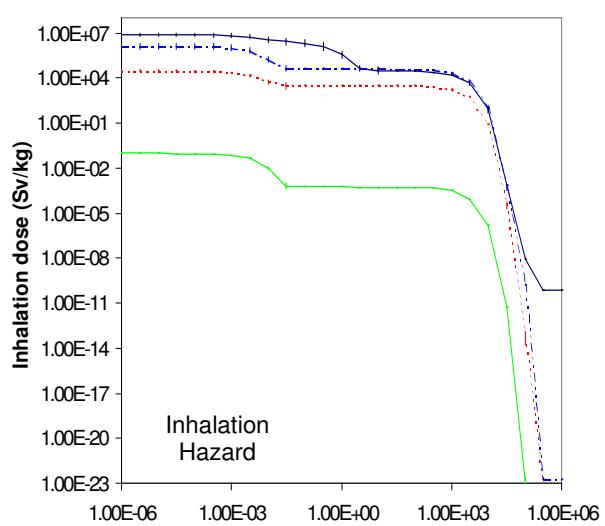
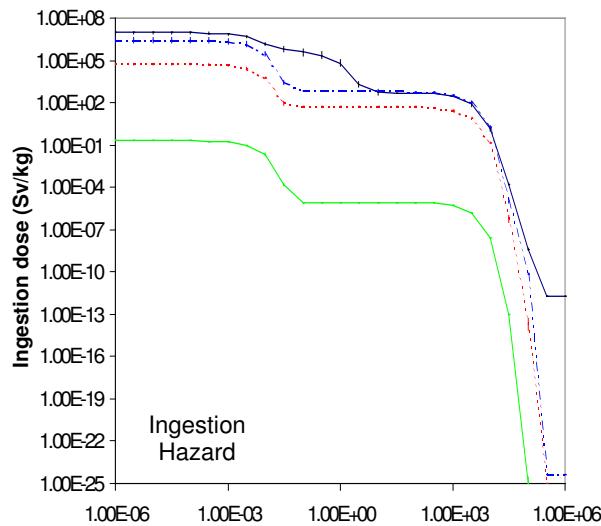
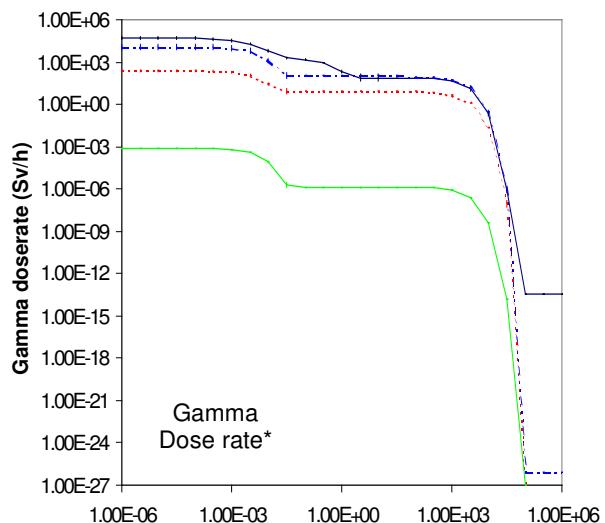
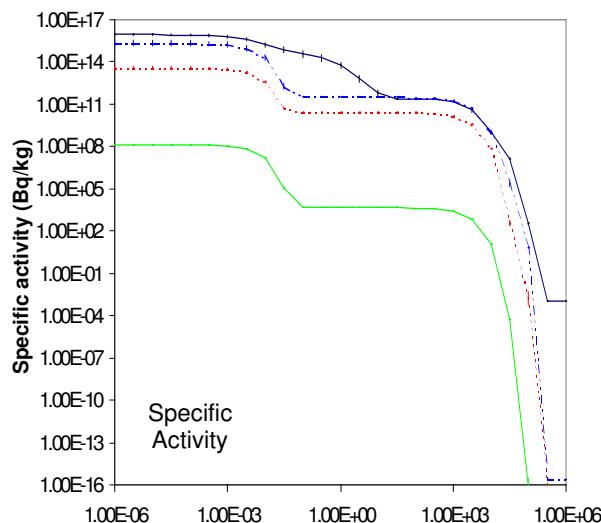
Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV	
Er167m	2.28 s	Ho165(n, $\gamma$ )Ho166( $\beta^-$ )Er166(n, $\gamma$ )Er167m Ho165(n, $\gamma$ )Ho166m(n, $\gamma$ )Ho167( $\beta^-$ )Er167m	99.9 0.1	99.7 0.3	98.4 1.4	88.6 10.1	
Ho164	28.6 m	&Ho165(n,2n)Ho164				100.0	
Ho162m	1.117 h	&Ho165(n,2n)Ho164( $\beta^-$ )Er164(n,2n)Er163( $\beta^+$ ) Ho163(n,2n)Ho162m				99.1	
Ho167	3.1 h	Ho165(n, $\gamma$ )Ho166m(n, $\gamma$ )Ho167 Ho165(n, $\gamma$ )Ho166(n, $\gamma$ )Ho167	94.3 5.7	96.5 3.5	98.3 1.7	99.5 0.3	
Ho166	1.117 d	Ho165(n, $\gamma$ )Ho166	100.0	100.0	100.0	99.6	
Tm172	2.651 d	&Ho165(n, $\gamma$ )Ho166( $\beta^-$ )Er166(n, $\gamma$ )Er167(n, $\gamma$ ) Er168(n, $\gamma$ )Er169( $\beta^-$ )Tm169(n, $\gamma$ )Tm170(n, $\gamma$ ) Tm171(n, $\gamma$ )Tm172 &Ho165(n, $\gamma$ )Ho166m(n, $\gamma$ )Ho167( $\beta^-$ )Er167(n, $\gamma$ )Er168 (n, $\gamma$ )Er169( $\beta^-$ )Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171(n, $\gamma$ )Tm172 &Ho165(n, $\gamma$ )Ho166(n, $\gamma$ )Ho167( $\beta^-$ )Er167(n, $\gamma$ )Er168(n, $\gamma$ ) Er169( $\beta^-$ )Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171(n, $\gamma$ )Tm172	91.9 6.8 0.4	84.3 13.8 1.7	89.1 9.6 0.8		
Er169	9.3 d	&Ho165(n, $\gamma$ )Ho166( $\beta^-$ )Er166(n, $\gamma$ )Er167(n, $\gamma$ ) Er168(n, $\gamma$ )Er169 &Ho165(n, $\gamma$ )Ho166m(n, $\gamma$ )Ho167( $\beta^-$ )Er167(n, $\gamma$ ) Er168(n, $\gamma$ )Er169 &Ho165(n, $\gamma$ )Ho166(n, $\gamma$ )Ho167( $\beta^-$ )Er167(n, $\gamma$ ) Er168(n, $\gamma$ )Er169	93.9 5.8 0.3	88.2 10.7 1.2	89.9 9.6 0.5	80.1 21.1 0.2	
Tb160	72.3 d	Ho165(n, $\alpha$ )Tb162( $\beta^-$ )Dy162(n, $\alpha$ )Gd159( $\beta^-$ ) Tb159(n, $\gamma$ )Tb160 Ho165(n, $\alpha$ )Tb162( $\beta^-$ )Dy162(n, $n\alpha$ )Gd158(n, $\gamma$ ) Gd159( $\beta^-$ )Tb159(n, $\gamma$ )Tb160 Ho165(n, $n\alpha$ )Tb161( $\beta^-$ )Dy161(n, $\alpha$ )Gd158(n, $\gamma$ ) Gd159( $\beta^-$ )Tb159(n, $\gamma$ )Tb160 &Ho165(n,2n)Ho164( $\beta^-$ )Er164(n,2n)Er163( $\beta^+$ )Ho163(n, $\alpha$ )Tb160	75.6 15.5 8.9	99.6 0.2 2.0	96.6 1.3 2.0		96.6
Ta182	114.7 d	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0	100.0			
Tm170	128.6 d	&Ho165(n, $\gamma$ )Ho166( $\beta^-$ )Er166(n, $\gamma$ )Er167(n, $\gamma$ ) Er168(n, $\gamma$ )Er169( $\beta^-$ )Tm169(n, $\gamma$ )Tm170 &Ho165(n, $\gamma$ )Ho166m(n, $\gamma$ )Ho167( $\beta^-$ )Er167(n, $\gamma$ ) Er168(n, $\gamma$ )Er169( $\beta^-$ )Tm169(n, $\gamma$ )Tm170 &Ho165(n, $\gamma$ )Ho166(n, $\gamma$ )Ho167( $\beta^-$ )Er167(n, $\gamma$ ) Er168(n, $\gamma$ )Er169( $\beta^-$ )Tm169(n, $\gamma$ )Tm170	93.1 6.5 0.4	85.6 12.9 1.5	89.6 9.7 0.7	78.8 20.8 0.3	
Dy159	144.4 d	&Ho165(n,2n)Ho164( $\beta^+$ )Dy164(n,3n)Dy162(n,2n) Dy161(n,2n)Dy160(n,2n)Dy159 &Ho165(n,2n)Ho164( $\beta^+$ )Dy164(n,2n)Dy163(n,2n) Dy162(n,2n)Dy161(n,2n)Dy160(n,2n)Dy159 &Ho165(n,2n)Ho164( $\beta^-$ )Er164(n,2n)Er163( $\beta^+$ )Ho163(n,2n) Ho162( $\beta^+$ )Dy162(n,2n)Dy161(n,2n)Dy160(n,2n)Dy159 Ho165(n, $n\alpha$ )Tb161( $\beta^-$ )Dy161(n,2n)Dy160(n,2n)Dy159 &Ho165(n,2n)Ho164( $\beta^-$ )Er164(n, $\alpha$ )Dy161(n,2n)Dy160(n,2n)Dy159 &Ho165(n,2n)Ho164( $\beta^-$ )Er164(n,2n)Er163( $\beta^+$ ) Ho163(n, $\alpha$ )Tb160( $\beta^-$ )Dy160(n,2n)Dy159 Ho165(n, $\alpha$ )Tb162( $\beta^-$ )Dy162(n,2n)Dy161(n,2n)Dy160(n,2n)Dy159 &Ho165(n,2n)Ho164( $\beta^-$ )Er164(n,2n)Er163( $\beta^+$ )Ho163(n,2n) Ho162m( $\beta^+$ )Dy162(n,2n)Dy161(n,2n)Dy160(n,2n)Dy159 &Ho165(n,2n)Ho164( $\beta^+$ )Dy164(n, $\alpha$ )Gd161( $\beta^-$ ) Tb161( $\beta^-$ )Dy161(n,2n)Dy160(n,2n)Dy159				36.7 17.4 12.2 9.5 6.4 5.3 4.8 3.4 2.1	

Tm171	1.92 y	&Ho165(n, $\gamma$ )Ho166( $\beta^-$ )Er166(n, $\gamma$ )Er167(n, $\gamma$ ) Er168(n, $\gamma$ )Er169( $\beta^-$ )Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171 &Ho165(n, $\gamma$ )Ho166m(n, $\gamma$ )Ho167( $\beta^-$ )Er167(n, $\gamma$ ) Er168(n, $\gamma$ )Er169( $\beta^-$ )Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171 &Ho165(n, $\gamma$ )Ho166(n, $\gamma$ )Ho167( $\beta^-$ )Er167(n, $\gamma$ ) Er168(n, $\gamma$ )Er169( $\beta^-$ )Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171	91.8 6.8 0.4	84.3 13.8 1.7	89.1 9.6 0.8	
Hf178n	31.0 y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0	100.0	100.0	
Tb158	180.62 y	&Ho165(n,2n)Ho164( $\beta^+$ )Dy164(n,3n)Dy162(n,2n) Dy161(n,2n)Dy160(n,2n)Dy159( $\beta^+$ )Tb159(n,2n)Tb158 &Ho165(n,2n)Ho164( $\beta^-$ )Er164(n,2n)Er163( $\beta^+$ ) Ho163(n,n $\alpha$ )Tb159(n,2n)Tb158 &Ho165(n,n $\alpha$ )Tb161( $\beta^-$ )Dy161(n,2n)Dy160(n,2n) Dy159( $\beta^+$ )Tb159(n,2n)Tb158 &Ho165(n,2n)Ho164( $\beta^+$ )Dy164(n,3n)Dy162(n, $\alpha$ ) Gd159( $\beta^-$ )Tb159(n,2n)Tb158 &Ho165(n,2n)Ho164( $\beta^+$ )Dy164(n,2n)Dy163(n,2n) (n,2n)Dy161(n,2n)Dy160(n,2n)Dy159( $\beta^+$ )Tb159(n,2n)Tb158 &Ho165(n,2n)Ho164( $\beta^+$ )Dy164(n,2n)Dy163(n,2n) Dy162(n, $\alpha$ )Gd159( $\beta^-$ )Tb159(n,2n)Tb158 &Ho165(n,2n)Ho164( $\beta^-$ )Er164(n, $\alpha$ )Dy161(n,2n) Dy160(n,2n)Dy159( $\beta^+$ )Tb159(n,2n)Tb158 &Ho165(n,2n)Ho164( $\beta^-$ )Er164(n,2n)Er163( $\beta^+$ ) Ho163(n,2n)Ho162( $\beta^+$ )Dy162(n,2n)Dy161(n,2n) Dy160(n,2n)Dy159( $\beta^+$ )Tb159(n,2n)Tb158 &Ho165(n,2n)Ho164( $\beta^-$ )Er164(n,2n)Er163( $\beta^+$ )Ho163(n, $\alpha$ ) Tb160( $\beta^-$ )Dy160(n,2n)Dy159( $\beta^+$ )Tb159(n,2n)Tb158 &Ho165(n,2n)Ho164( $\beta^+$ )Dy164(n,2n)Dy163(n, $\alpha$ ) Gd160(n,2n)Gd159( $\beta^-$ )Tb159(n,2n)Tb158 &Ho165(n,2n)Ho164( $\beta^-$ )Er164(n,2n)Er163( $\beta^+$ ) Ho163(n, $\alpha$ )Tb160(n,2n)Tb159(n,2n)Tb158 &Ho165(n,2n)Ho164( $\beta^+$ )Dy164(n, $\alpha$ )Gd161( $\beta^-$ )Tb161( $\beta^-$ ) Dy161(n,2n)Dy160(n,2n)Dy159( $\beta^+$ )Tb159(n,2n)Tb158 &Ho165(n,2n)Ho164( $\beta^-$ )Er164(n,2n)Er163( $\beta^+$ ) Ho163(n,2n)Ho162m( $\beta^+$ )Dy162(n,2n)Dy161(n,2n) Dy160(n,2n)Dy159( $\beta^+$ )Tb159(n,2n)Tb158 &Ho165(n, $\alpha$ )Tb162( $\beta^-$ )Dy162(n, $\alpha$ )Gd159( $\beta^-$ )Tb159(n,2n)Tb158				19.6 12.2 12.1 9.9 6.7 5.1 5.0 4.7 3.8 3.7 3.4 1.9 1.6 1.3 1.2
Ho166m	1200 y	Ho165(n, $\gamma$ )Ho166m	100.0	100.0	100.0	99.9
Ho163	4570 y	&Ho165(n,2n)Ho164( $\beta^-$ )Er164(n,2n)Er163( $\beta^+$ )Ho163				99.1
La137	$6.0 \cdot 10^4$ y	Very long pathways of (n, $\alpha$ ), ( $\beta^+$ ), (n,n $\alpha$ ), etc				100.0
Gd150	$1.8 \cdot 10^6$ y	Ho165(n,n $\alpha$ )Tb161( $\beta^-$ )Dy161(n,2n)Dy160(n,2n)Dy159(n,2n) Dy158(n,n $\alpha$ )Gd154(n,2n)Gd153(n,2n)Gd152(n,2n)Gd151(n,2n)Gd150 &Ho165(n,2n)Ho164( $\beta^+$ )Dy164(n,3n)Dy162(n,2n) Dy161(n,2n)Dy160(n,2n)Dy159(n,2n)Dy158(n,n $\alpha$ ) Gd154(n,2n)Gd153(n,2n)Gd152(n,2n)Gd151(n,2n)Gd150 Ho165(n,n $\alpha$ )Tb161( $\beta^-$ )Dy161(n,2n)Dy160(n,2n) Dy159(n,n $\alpha$ )Gd155(n,2n)Gd154(n,2n)Gd153(n,2n) Gd152(n,2n)Gd151(n,2n)Gd150 Ho165(n,n $\alpha$ )Tb161( $\beta^-$ )Dy161(n,2n)Dy160(n,n $\alpha$ ) Gd156(n,2n)Gd155(n,2n)Gd154(n,2n)Gd153(n,2n) Gd152(n,2n)Gd151(n,2n)Gd150 &Ho165(n,2n)Ho164( $\beta^+$ )Dy164(n,3n)Dy162(n,2n) Dy161(n,2n)Dy160(n,2n)Dy159(n,n $\alpha$ )Gd155(n,2n) Gd154(n,2n)Gd153(n,2n)Gd152(n,2n)Gd151(n,2n)Gd150 &Ho165(n,2n)Ho164( $\beta^-$ )Er164(n, $\alpha$ )Dy161(n,2n) Dy160(n,2n)Dy159(n,2n)Dy158(n,n $\alpha$ )Gd154(n,2n) Gd153(n,2n)Gd152(n,2n)Gd151(n,2n)Gd150				3.9 2.7 1.7 1.3 1.1 1.0 88.3*

Dy154	$2.9 \cdot 10^6$ y	$\&Ho165(n,2n)Ho164(\beta^+)Dy164(n,3n)Dy162(n,2n)$ $Dy161(n,2n)Dy160(n,2n)Dy159(n,2n)Dy158(n,2n)$ $Dy157(n,2n)Dy156(n,2n)Dy155(n,2n)Dy154$ $Ho165(n,n\alpha)Tb161(\beta^-)Dy161(n,2n)Dy160(n,2n)Dy159(n,2n)$ $Dy158(n,2n)Dy157(n,2n)Dy156(n,2n)Dy155(n,2n)Dy154$ $\&Ho165(n,2n)Ho164(\beta^+)Dy164(n,2n)Dy163(n,2n)$ $Dy162(n,2n)Dy161(n,2n)Dy160(n,2n)Dy159(n,2n)$ $Dy158(n,2n)Dy157(n,2n)Dy156(n,2n)Dy155(n,2n)Dy154$ $\&Ho165(n,2n)Ho164(\beta^-)Er164(n,\alpha)Dy161(n,2n)$ $Dy160(n,2n)Dy159(n,2n)Dy158(n,2n)Dy157(n,2n)$ $Dy156(n,2n)Dy155(n,2n)Dy154$ $Ho165(n,\alpha)Tb162(\beta^-)Dy162(n,2n)Dy161(n,2n)$ $Dy160(n,2n)Dy159(n,2n)Dy158(n,2n)Dy157(n,2n)$ $Dy156(n,2n)Dy155(n,2n)Dy154$ $\&Ho165(n,2n)Ho164(\beta^-)Er164(n,2n)Er163(\beta^+)$ $Ho163(n,\alpha)Tb160(\beta^-)Dy160(n,2n)Dy159(n,2n)Dy158$ $(n,2n)Dy157(n,2n)Dy156(n,2n)Dy155(n,2n)Dy154$ $\&Ho165(n,2n)Ho164(\beta^-)Er164(n,2n)Er163(\beta^+)Ho163(n,2n)$ $Ho162(\beta^+)Dy162(n,2n)Dy161(n,2n)Dy160(n,2n)Dy159(n,2n)$ $Dy158(n,2n)Dy157(n,2n)Dy156(n,2n)Dy155(n,2n)Dy154$ $\&Ho165(n,2n)Ho164(\beta^+)Dy164(n,\alpha)Gd161(\beta^-)$ $Tb161(\beta^-)Dy161(n,2n)Dy160(n,2n)Dy159(n,2n)$ $Dy158(n,2n)Dy157(n,2n)Dy156(n,2n)Dy155(n,2n)Dy154$ $\&Ho165(n,2n)Ho164(\beta^-)Er164(n,2n)Er163(\beta^+)Ho163(n,2n)$ $Ho162m(\beta^+)Dy162(n,2n)Dy161(n,2n)Dy160(n,2n)Dy159(n,2n)$ $Dy158(n,2n)Dy157(n,2n)Dy156(n,2n)Dy155(n,2n)Dy154$				29.9
					25.4	
					9.0	
					8.9	
					6.8	
					6.3	
					6.3	
					2.8	
					1.8	
Hf182	$9.0 \cdot 10^6$ y	Very long pathways of $(n,\gamma)$ , $(\beta^-)$	100.0	100.0		

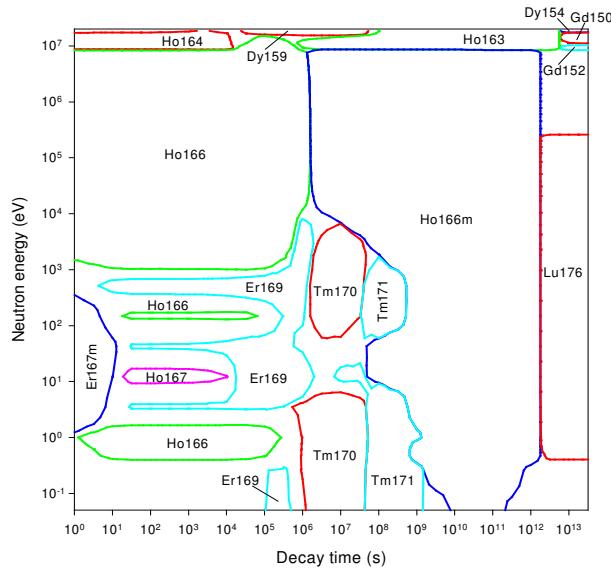


# Holmium activation characteristics

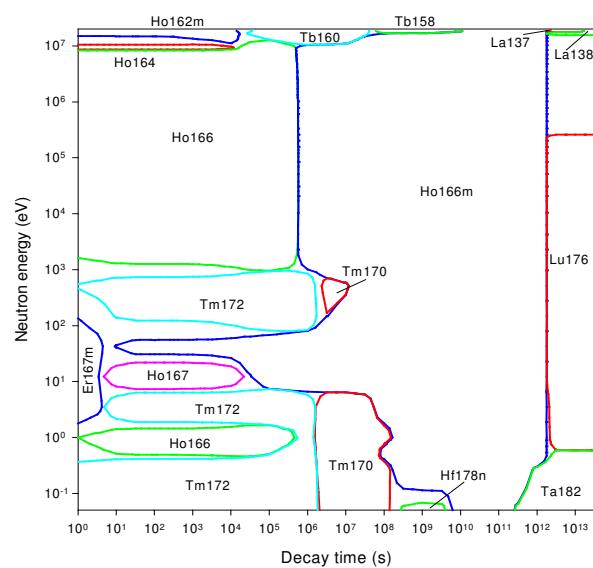


# Holmium importance diagrams & transmutation

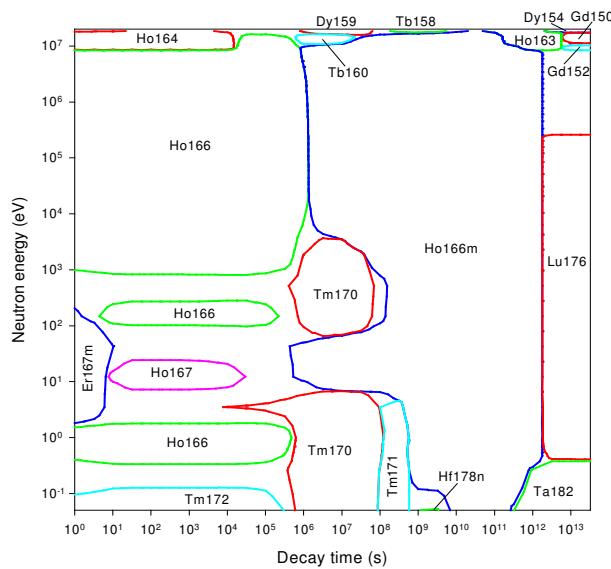
## Activity



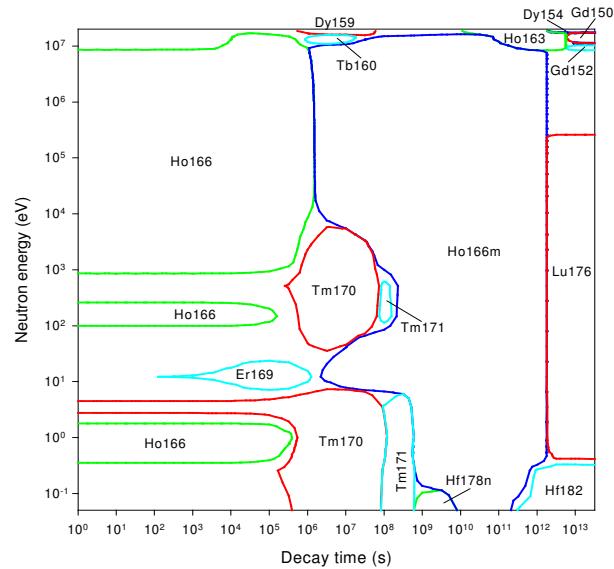
## Dose rate



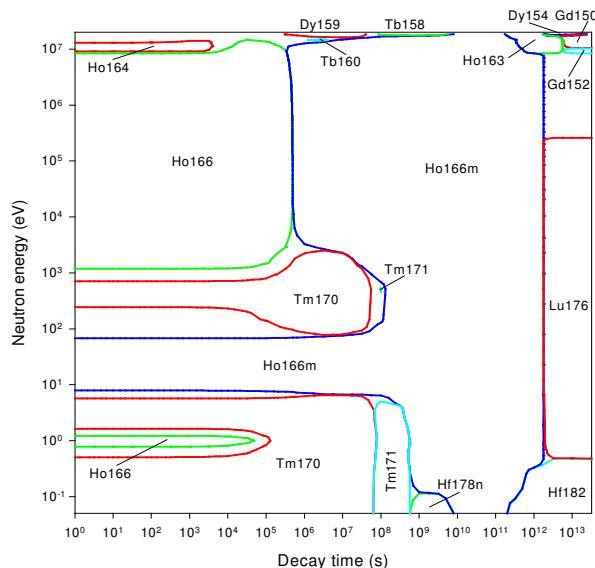
## Heat output



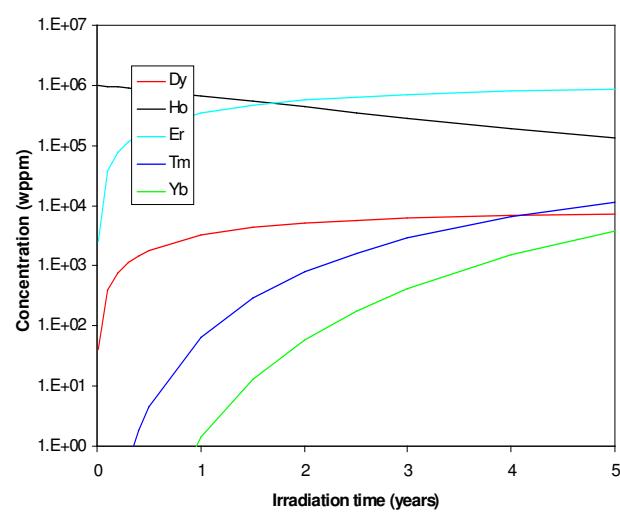
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Erbium

## General properties

Atomic number	68	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	3.5	Er162	0.139
Melting point / K	1802	Er164	1.601
Boiling point / K	3135	Er166	33.503
Density / kgm <sup>-3</sup>	9066	Er167	22.869
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	14.3	Er168	26.978
Electrical resistivity / Ωm	8.7 10 <sup>-7</sup>	Er170	14.910
Coefficient of thermal expansion / K <sup>-1</sup>	1.22 10 <sup>-5</sup>		
Crystal structure	HCP		
Number of stable isotopes	6		
Mean atomic weight	167.259		

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	
Bq kg <sup>-1</sup>	9.18E15	7.14E15	4.79E15	6.28E14	1.86E10	2.53E3	kW kg <sup>-1</sup>	4.28E-1	3.59E-1	1.79E-1	1.62E-2	2.63E-6	1.18E-15	
Er169	30.72	39.48	44.84				Tm170	23.58	28.07	55.19	86.82			
Er167m	22.03	0.03					Er171	19.23	22.71	0.01				
Tm170	20.51	26.37	38.55	41.89			Tm172	16.69	19.85	15.33				
Er171	7.11	9.06					Er167m	15.74	0.02					
Tm171	5.65	7.27	10.80	57.65			Er169	10.86	12.93	19.75				
Tm172	4.83	6.20	3.56				Ho166	9.24	10.97	2.28				
Ho166	3.72	4.77	0.74				Tm168	2.22	2.64	5.16	3.86			
Er165	3.68	4.71	0.02				Tm171	0.51	0.60	1.20	9.30			
Tm168	0.48	0.62	0.90	0.47			Yb169	0.48	0.57	1.06	0.01			
Ho164	0.34	0.40					Ho166m				0.02	99.84		
Yb169	0.32	0.41	0.57				Ho163					0.16	90.92	
Ho163					51.76	99.97	Lu176						7.75	
Ho166m					48.13		Ta182						1.12	
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	
Sv h <sup>-1</sup>	9.72E4	8.98E4	3.36E4	7.09E2	2.75E0	4.06E-11	Sv kg <sup>-1</sup>	5.09E6	5.08E6	3.65E6	3.84E5	1.80E1	3.19E-8	
Tm172	62.48	67.53	69.43				Tm170	48.11	48.15	65.71	88.91			
Er171	16.65	17.87	0.01				Er169	20.51	20.52	21.76				
Tm168	10.08	10.90	28.32	91.08			Tm172	14.82	14.81	7.94				
Er167m	7.25	0.01					Ho166	9.38	9.37	1.35				
Ho166	1.95	2.11	0.58				Er171	4.62	4.58					
Ho167	0.55	0.58					Tm171	1.12	1.12	1.56	10.35			
Tm170	0.44*	0.47*	1.24*	8.36*			Tm168	0.84	0.84	1.13	0.73			
Ho166m			0.01	0.41	100.0		Yb169	0.41	0.41	0.53				
Lu176						54.72	Ho166m				0.01	99.35		
Ta182						44.08	Ho163					0.64	95.10	
Hf182						1.20	Lu176						4.12	
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	
Sv kg <sup>-1</sup>	1.78E7	1.78E7	1.62E7	2.36E6	1.07E3	1.34E-7		9.88E11	7.28E11	2.50E11	1.48E10	1.54E7	1.13E-3	
Tm170	74.00	74.01	79.66	78.08			Er171	27.53	37.03	0.03				
Er169	15.83	15.83	13.24				Er167m	25.92	0.04					
Tm171	4.08	4.08	4.46	21.49			Tm172	23.63	32.01	35.92				
Tm172	2.74	2.74	1.16				Tm170	7.33	9.95	28.40	68.21			
Ho166	1.24	1.24	0.14				Tm168	5.47	7.42	21.04	24.03			
Er171	0.81	0.80					Ho166	3.45	4.67	1.41				
Tm168	0.77	0.77	0.82	0.38			Er169	2.94	3.99	8.86				
Yb169	0.50	0.50	0.51				Er165	1.32	1.77	0.02				
Ho166m	0.01	0.01	0.01	0.05	99.97		Yb169	1.00	1.35	3.64	0.02			
Ho163						0.02	48.86	Tm171	0.16	0.22	0.65	7.63		
Lu176						38.00	Ho166m				0.01	0.11	99.99	
Hf182						12.72	Ho163					0.02	58.70	
Ta182						0.41	Lu176						33.91	
							Ta182						6.33	
							Hf182						1.06	

# Erbium

## Pathway analysis

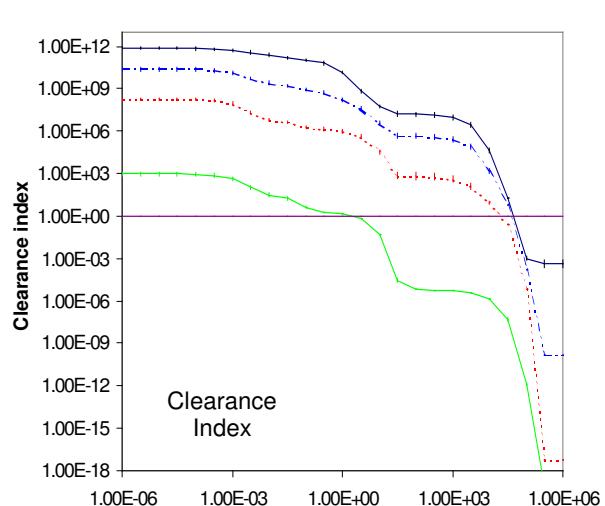
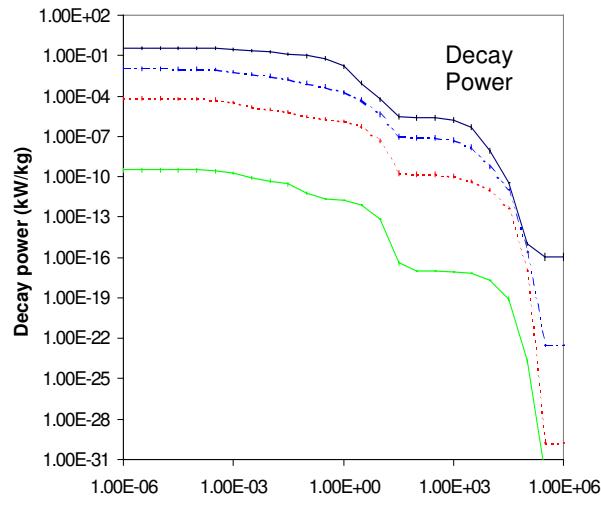
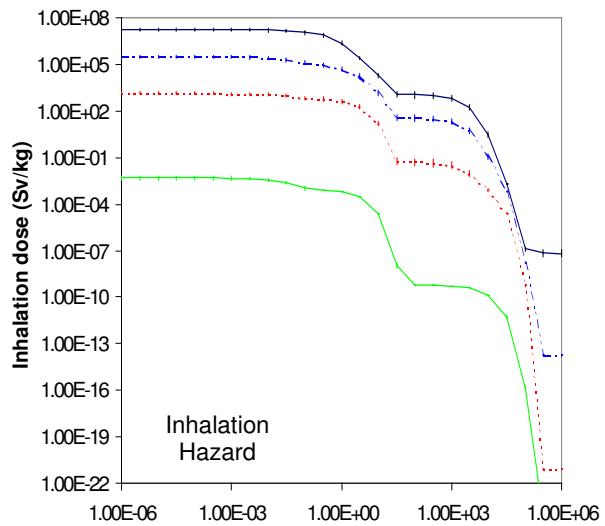
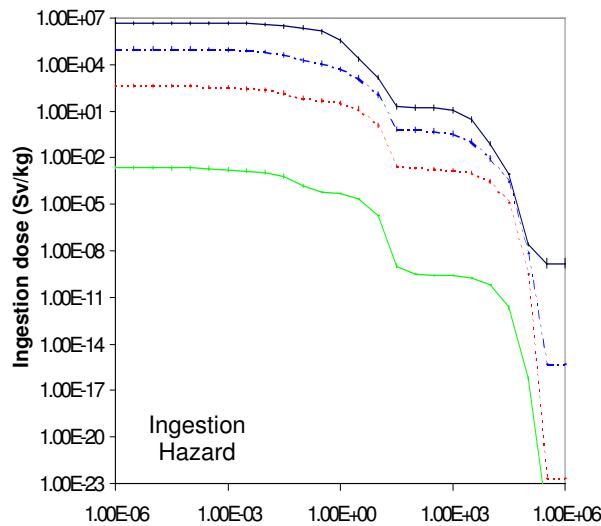
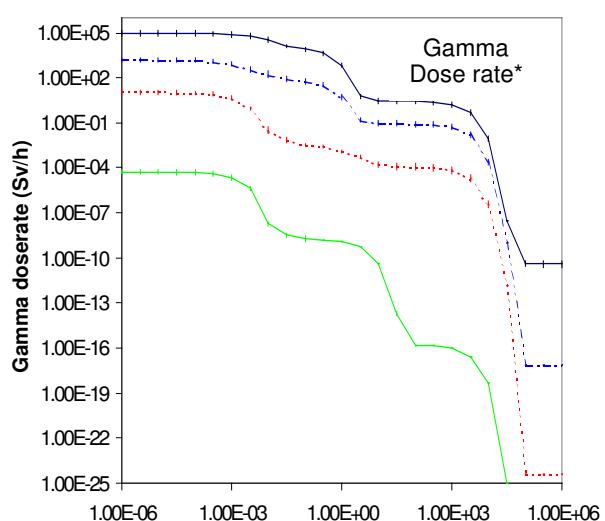
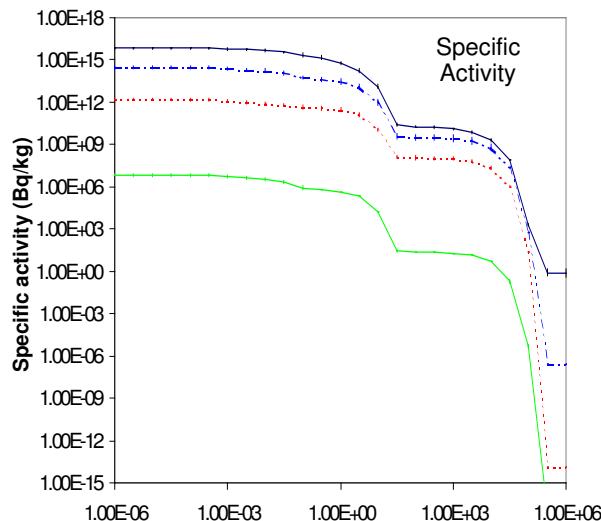
Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Er167m	2.28 s	Er166(n, $\gamma$ )Er167m Er164(n, $\gamma$ )Er165( $\beta^+$ )Ho165(n, $\gamma$ )Ho166( $\beta^-$ )Er166(n, $\gamma$ ) Er167m Er168(n,2n)Er167m Er170(n,2n)Er169( $\beta^-$ )Tm169(n,2n)Tm168( $\beta^+$ )Er168(n,2n)Er167m Er167(n,n')Er167m	89.9 9.4	94.2 5.3	100.0	94.7 2.2 1.3
Er171	7.519 h	Er170(n, $\gamma$ )Er171	98.3	99.8	100.0	99.9
Er165	10.361 h	Er164(n, $\gamma$ )Er165 <b>&amp;Er162(n,<math>\gamma</math>)Er163(<math>\beta^+</math>)Ho163(n,<math>\gamma</math>)Ho164(<math>\beta^-</math>)</b> Er164(n, $\gamma$ )Er165 Er166(n,2n)Er165 Er167(n,2n)Er166(n,2n)Er165 Er168(n,2n)Er167(n,2n)Er166(n,2n)Er165	95.6 4.4	0.8 99.2	99.9	78.8 17.3 2.9
Tm172	2.651 d	Er170(n, $\gamma$ )Er171( $\beta^-$ )Tm171(n, $\gamma$ )Tm172 <b>&amp;Er166(n,<math>\gamma</math>)Er167(n,<math>\gamma</math>)Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)</b> Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171(n, $\gamma$ )Tm172 Er168(n, $\gamma$ )Er169( $\beta^-$ )Tm169(n, $\gamma$ )Tm170(n, $\gamma$ ) Tm171(n, $\gamma$ )Tm172 Er167(n, $\gamma$ )Er168(n, $\gamma$ )Er169( $\beta^-$ )Tm169(n, $\gamma$ ) Tm170(n, $\gamma$ )Tm171(n, $\gamma$ )Tm172	44.5 19.8 18.7 15.9	57.1 8.1 18.7 15.6	99.3	99.9
Er169	9.3 d	<b>&amp;Er166(n,<math>\gamma</math>)Er167(n,<math>\gamma</math>)Er168(n,<math>\gamma</math>)Er169</b> Er168(n, $\gamma$ )Er169 Er167(n, $\gamma$ )Er168(n, $\gamma$ )Er169 Er170(n,2n)Er169	39.2 32.4 27.6	25.7 39.6 33.6	0.8 87.9 11.3	99.5
Tm168	93.102 d	Er170(n,2n)Er169( $\beta^-$ )Tm169(n,2n)Tm168				99.9
Ta182	114.7 d	Very long Pathways of (n, $\gamma$ ), ( $\beta^-$ ). (see Hf178n)	100.0	100.0	100.0	
Tm170	128.6 d	<b>&amp;Er166(n,<math>\gamma</math>)Er167(n,<math>\gamma</math>)Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)</b> Tm169(n, $\gamma$ )Tm170 Er168(n, $\gamma$ )Er169( $\beta^-$ )Tm169(n, $\gamma$ )Tm170 Er167(n, $\gamma$ )Er168(n, $\gamma$ )Er169( $\beta^-$ )Tm169(n, $\gamma$ )Tm170 Er170(n,2n)Er169( $\beta^-$ )Tm169(n, $\gamma$ )Tm170 Er170(n, $\gamma$ )Er171( $\beta^-$ )Tm171(n,2n)Tm170	37.3 33.6 28.6	21.0 42.5 35.8	0.2 94.1 5.7	67.1 32.8
Dy159	144.4 d	Er162(n, $\alpha$ )Dy159 Er162(n,2n)Er161( $\beta^+$ )Ho161( $\beta^+$ )Dy161(n,2n) Dy160(n,2n)Dy159 <b>&amp;Er164(n,2n)Er163(<math>\beta^+</math>)Ho163(n,2n)Ho162(<math>\beta^+</math>)</b> Dy162(n,2n)Dy161(n,2n)Dy160(n,2n)Dy159 Er164(n, $\alpha$ )Dy161(n,2n)Dy160(n,2n)Dy159 Er164(n,2n)Er163( $\beta^+$ )Ho163(n,2n)Ho162m( $\beta^+$ ) Dy162(n,2n)Dy161(n,2n)Dy160(n,2n)Dy159 Er164(n,2n)Er163( $\beta^+$ )Ho163(n, $\alpha$ )Tb160( $\beta^-$ ) Dy160(n,2n)Dy159	100.0	100.0	100.0	6.0 83.6 4.5 1.4 1.3 1.2
Tm171	1.92 y	Er170(n, $\gamma$ )Er171( $\beta^-$ )Tm171 <b>&amp;Er166(n,<math>\gamma</math>)Er167(n,<math>\gamma</math>)Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)</b> Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171 Er168(n, $\gamma$ )Er169( $\beta^-$ )Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171 Er167(n, $\gamma$ )Er168(n, $\gamma$ )Er169( $\beta^-$ )Tm169(n, $\gamma$ ) Tm170(n, $\gamma$ )Tm171	44.6 19.8 18.7 15.9	57.1 8.1 18.7 15.6	99.2 0.7	100.0

H3	12.33 y	<p>Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)Tm169(n,X)H1(n,<math>\gamma</math>)H2(n,<math>\gamma</math>)H3          Er167(n,<math>\gamma</math>)Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)Tm169(n,X)H1(n,<math>\gamma</math>)          H2(n,<math>\gamma</math>)H3  <b>&amp;Er166(n,<math>\gamma</math>)Er167(n,<math>\gamma</math>)Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)</b>          Tm169(n,X)H1(n,<math>\gamma</math>)H2(n,<math>\gamma</math>)H3          Er162(n,X)H1(n,<math>\gamma</math>)H2(n,<math>\gamma</math>)H3          Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)Tm169(n,<math>\gamma</math>)Tm170(n,X)H1(n,<math>\gamma</math>)          H2(n,<math>\gamma</math>)H3          Er167(n,<math>\gamma</math>)Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)Tm169(n,<math>\gamma</math>)          Tm170(n,X)H1(n,<math>\gamma</math>)H2(n,<math>\gamma</math>)H3          Er170(n,<math>\gamma</math>)Er171(<math>\beta^-</math>)Tm171(<math>\beta^-</math>)Yb171(n,X)H1(n,<math>\gamma</math>)          H2(n,<math>\gamma</math>)H3          Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)Tm169(n,<math>\gamma</math>)Tm170(<math>\beta^-</math>)          Yb170(n,<math>\gamma</math>)Yb171(n,X)H1(n,<math>\gamma</math>)H2(n,<math>\gamma</math>)H3          Er162(n,<math>\gamma</math>)Er163(<math>\beta^+</math>)Ho163(n,X)H1(n,<math>\gamma</math>)H2(n,<math>\gamma</math>)H3          Er166(n,<math>\gamma</math>)Er167(n,<math>\gamma</math>)Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)Tm169(n,<math>\gamma</math>)          Tm170(n,X)H1(n,<math>\gamma</math>)H2(n,<math>\gamma</math>)H3          Er164(n,<math>\gamma</math>)Er165(<math>\beta^+</math>)Ho165(n,<math>\gamma</math>)Ho166m(n,X)H1(n,<math>\gamma</math>)          H2(n,<math>\gamma</math>)H3          Er167(n,X)H3          Er166(n,X)H3          Er168(n,X)H3          Er170(n,2n)Er169(<math>\beta^-</math>)Tm169(n,X)H3          Er168(n,2n)Er167(n,X)H3          Er166(n,2n)Er165(<math>\beta^+</math>)Ho165(n,X)H3          Er167(n,2n)Er166(n,X)H3          Er170(n,X)H3          Er164(n,2n)Er163(<math>\beta^+</math>)Ho163(n,X)H3</p>	23.1 18.7 10.5 10.7 9.0 7.3 4.6 1.6 1.0 1.0 3.6	26.4 17.9 3.8 23.3 4.3 2.9 4.5 9.2 0.1		
Hf178n	31.0 y	<p>Er170(n,<math>\gamma</math>)Er171(<math>\beta^-</math>)Tm171(n,<math>\gamma</math>)Tm172(<math>\beta^-</math>)          Yb172(n,<math>\gamma</math>)Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)          Lu175(n,<math>\gamma</math>)Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178n          Er170(n,<math>\gamma</math>)Er171(<math>\beta^-</math>)Tm171(n,<math>\gamma</math>)Tm172(<math>\beta^-</math>)          Yb172(n,<math>\gamma</math>)Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)          Lu175(n,<math>\gamma</math>)Lu176m(<math>\beta^-</math>)Hf176(n,<math>\gamma</math>)Hf177(n,<math>\gamma</math>)Hf178n          Er170(n,<math>\gamma</math>)Er171(<math>\beta^-</math>)Tm171(n,<math>\gamma</math>)Tm172(n,<math>\gamma</math>)          Tm173(<math>\beta^-</math>)Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)          Lu175(n,<math>\gamma</math>)Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178n          Er170(n,<math>\gamma</math>)Er171(<math>\beta^-</math>)Tm171(n,<math>\gamma</math>)Tm172(n,<math>\gamma</math>)          Tm173(<math>\beta^-</math>)Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)Lu175          (n,<math>\gamma</math>)Lu176m(<math>\beta^-</math>)Hf176(n,<math>\gamma</math>)Hf177(n,<math>\gamma</math>)Hf178n          Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(n,<math>\gamma</math>)          Tm172(<math>\beta^-</math>)Yb172(n,<math>\gamma</math>)Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)          Lu175(n,<math>\gamma</math>)Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178n          Er167(n,<math>\gamma</math>)Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)Tm169(n,<math>\gamma</math>)          Tm170(n,<math>\gamma</math>)Tm171(n,<math>\gamma</math>)Tm172(<math>\beta^-</math>)Yb172(n,<math>\gamma</math>)          Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)Lu175(n,<math>\gamma</math>)          Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178n          Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(n,<math>\gamma</math>)          Tm172(<math>\beta^-</math>)Yb172(n,<math>\gamma</math>)Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)          Lu175(n,<math>\gamma</math>)Lu176m(<math>\beta^-</math>)Hf176(n,<math>\gamma</math>)Hf177(n,<math>\gamma</math>)Hf178n          Er170(n,<math>\gamma</math>)Er171(<math>\beta^-</math>)Tm171(<math>\beta^-</math>)Yb171(n,<math>\gamma</math>)Yb172(n,<math>\gamma</math>)          Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)Lu175(n,<math>\gamma</math>)          Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178n          Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(n,<math>\gamma</math>)          Tm172(<math>\beta^-</math>)Yb172(n,<math>\gamma</math>)Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)          Lu175(n,<math>\gamma</math>)Lu176m(<math>\beta^-</math>)Hf176(n,<math>\gamma</math>)Hf177(n,<math>\gamma</math>)Hf178n          Er167(n,<math>\gamma</math>)Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)Tm169(n,<math>\gamma</math>)          Tm170(n,<math>\gamma</math>)Tm171(n,<math>\gamma</math>)Tm172(n,<math>\gamma</math>)Tm173(<math>\beta^-</math>)          Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)Lu175(n,<math>\gamma</math>)          Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178n</p>	32.5 16.0 12.3 7.8 5.4 4.3 2.6 2.3 2.2 2.1	72.7 0.9 1.5 7.8 7.1 4.2 9.5 9.5 0.1	41.6 32.6 1.6 1.3 7.1 4.2 12.7 12.7 0.1	
More on next page						

Hf178n continued	31.0 y	Er167(n, $\gamma$ )Er168(n, $\gamma$ )Er169( $\beta^-$ )Tm169(n, $\gamma$ ) Tm170(n, $\gamma$ )Tm171(n, $\gamma$ )Tm172( $\beta^-$ )Yb172(n, $\gamma$ ) Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ )Lu175(n, $\gamma$ ) Lu176m( $\beta^-$ )Hf176(n, $\gamma$ )Hf177(n, $\gamma$ )Hf178n Er168(n, $\gamma$ )Er169( $\beta^-$ )Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171(n, $\gamma$ ) Tm172(n, $\gamma$ )Tm173( $\beta^-$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ ) Lu175(n, $\gamma$ )Lu176m( $\beta^-$ )Hf176(n, $\gamma$ )Hf177(n, $\gamma$ )Hf178n <b>&amp;Er166(n,<math>\gamma</math>)Er167(n,<math>\gamma</math>)Er168(n,<math>\gamma</math>)Er169(<math>\beta^-</math>)</b> Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171(n, $\gamma$ )Tm172(n, $\gamma$ ) Tm173( $\beta^-$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ ) Lu175(n, $\gamma$ )Lu176(n, $\gamma$ )Lu177( $\beta^-$ )Hf177(n, $\gamma$ )Hf178n Er167(n, $\gamma$ )Er168(n, $\gamma$ )Er169( $\beta^-$ )Tm169(n, $\gamma$ ) Tm170(n, $\gamma$ )Tm171(n, $\gamma$ )Tm172(n, $\gamma$ )Tm173( $\beta^-$ ) Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ )Lu175(n, $\gamma$ ) Lu176m( $\beta^-$ )Hf176(n, $\gamma$ )Hf177(n, $\gamma$ )Hf178n	1.7 1.3 1.1 1.1 1.0 0.1 10.0			
Ho166m	1200 y	Er164(n, $\gamma$ )Er165( $\beta^+$ )Ho165(n, $\gamma$ )Ho166m <b>&amp;Er162(n,<math>\gamma</math>)Er163(<math>\beta^+</math>)Ho163(n,<math>\gamma</math>)Ho164(<math>\beta^+</math>)</b> Dy164(n, $\gamma$ )Dy165( $\beta^-$ )Ho165(n, $\gamma$ )Ho166m <b>&amp;Er162(n,<math>\gamma</math>)Er163(<math>\beta^+</math>)Ho163(n,<math>\gamma</math>)Ho164(<math>\beta^-</math>)</b> Er164(n, $\gamma$ )Er165( $\beta^+$ )Ho165(n, $\gamma$ )Ho166m Er166(n,p)Ho166m Er170(n,2n)Er169( $\beta^-$ )Tm169(n, $\alpha$ )Ho166m Er167(n,2n)Er166(n,p)Ho166m Er166(n,2n)Er165( $\beta^+$ )Ho165(n, $\gamma$ )Ho166m Er167(n,d)Ho166m	91.7 4.9 3.0 75.2 11.8 12.7	100.0	100.0	74.6 9.0 8.2 3.9 1.9
Ho163	4570 y	Er162(n, $\gamma$ )Er163( $\beta^+$ )Ho163 Er164(n,2n)Er163( $\beta^+$ )Ho163 <b>&amp;Er166(n,2n)Er165(<math>\beta^+</math>)Ho165(n,2n)Ho164(<math>\beta^-</math>)</b> Er164(n,2n)Er163( $\beta^+$ )Ho163	100.0	100.0	100.0	85.8 13.1
La137	$6.0 \cdot 10^4$ y	Threshold of production above 14.7 MeV				
Gd150	$1.8 \cdot 10^6$ y	<b>&amp;Er162(n,n<math>\alpha</math>)Dy158(n,2n)Dy157(<math>\beta^+</math>)Tb157(n,n<math>\alpha</math>)</b> Eu153(n,2n)Eu152(n,2n)Eu151(n,2n)Eu150m( $\beta^-$ )Gd150 Er162(n,n $\alpha$ )Dy158(n,n $\alpha$ )Gd154(n,2n)Gd153(n,2n) Gd152(n,2n)Gd151(n,2n)Gd150 Er162(n,n $\alpha$ )Dy158(n,n $\alpha$ )Gd154(n,2n)Gd153( $\beta^+$ ) Eu153(n,2n)Eu152(n,2n)Eu151(n,2n)Eu150m( $\beta^-$ )Gd150 Er162(n,n $\alpha$ )Dy158(n,n $\alpha$ )Gd154(n,2n)Gd153(n,2n) Gd152(n,2n)Gd151( $\beta^+$ )Eu151(n,2n)Eu150m( $\beta^-$ )Gd150 Er162(n,n $\alpha$ )Dy158(n,2n)Dy157( $\beta^+$ )Tb157(n,n $\alpha$ ) Eu153(n,2n)Eu152m( $\beta^-$ )Gd152(n,2n)Gd151(n,2n)Gd150 Er162(n, $\alpha$ )Dy159(n,2n)Dy158(n,n $\alpha$ )Gd154(n,2n) Gd153(n,2n)Gd152(n,2n)Gd151(n,2n)Gd150 Er162(n,n $\alpha$ )Dy158(n,n $\alpha$ )Gd155(n,2n)Gd154(n,2n) Gd153(n,2n)Gd152(n,2n)Gd151(n,2n)Gd150 Er162(n,n $\alpha$ )Dy158(n,n $\alpha$ )Gd154(n,2n)Gd153( $\beta^+$ ) Eu153(n,2n)Eu152m( $\beta^-$ )Gd152(n,2n)Gd151(n,2n)Gd150 Er162(n, $\alpha$ )Dy159(n,n $\alpha$ )Gd155(n,2n)Gd154(n,2n) Gd153(n,2n)Gd152(n,2n)Gd151(n,2n)Gd150 *Plus other similar pathways			19.7 17.1 7.8 7.0 3.8 2.3 1.8 1.7 1.0 37.8*	
Dy154	$2.9 \cdot 10^6$ y	Er162(n,n $\alpha$ )Dy158(n,2n)Dy157(n,2n)Dy156(n,2n) Dy155(n,2n)Dy154 Er162(n,2n)Er161( $\beta^+$ )Ho161( $\beta^+$ )Dy161(n,2n) Dy160(n,2n)Dy159(n,2n)Dy158(n,2n)Dy157(n,2n) Dy156(n,2n)Dy155(n,2n)Dy154 Er162(n, $\alpha$ )Dy159(n,2n)Dy158(n,2n)Dy157(n,2n) Dy156(n,2n)Dy155(n,2n)Dy154			70.7 16.8 11.3	
Hf182	$9.0 \cdot 10^6$ y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ ). (see Hf178n)	100.0	100.0	100.0	



# Erbium activation characteristics

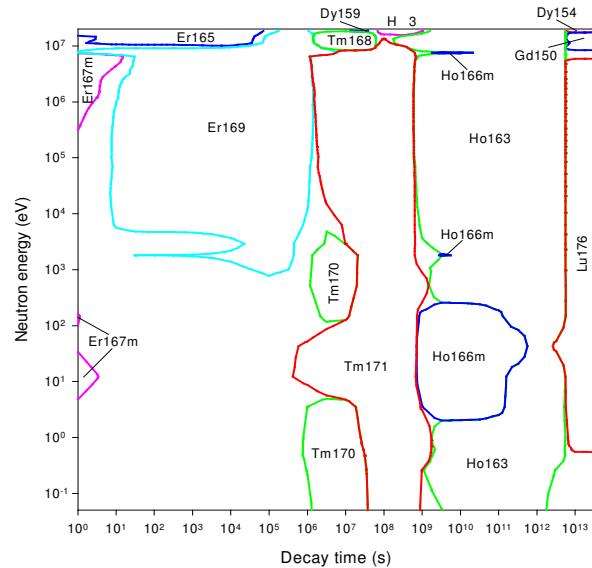


Decay time (years)

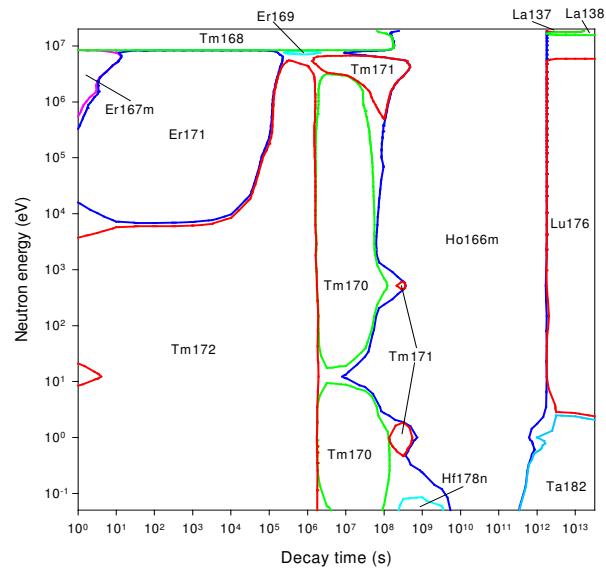
Decay time (years)

# Erbium importance diagrams & transmutation

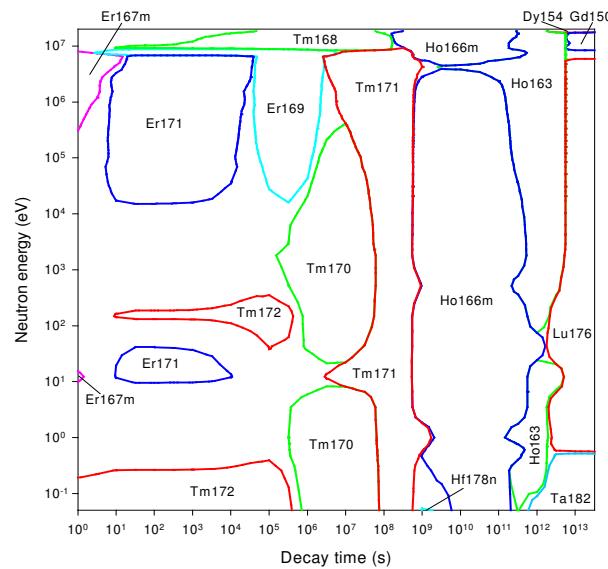
## Activity



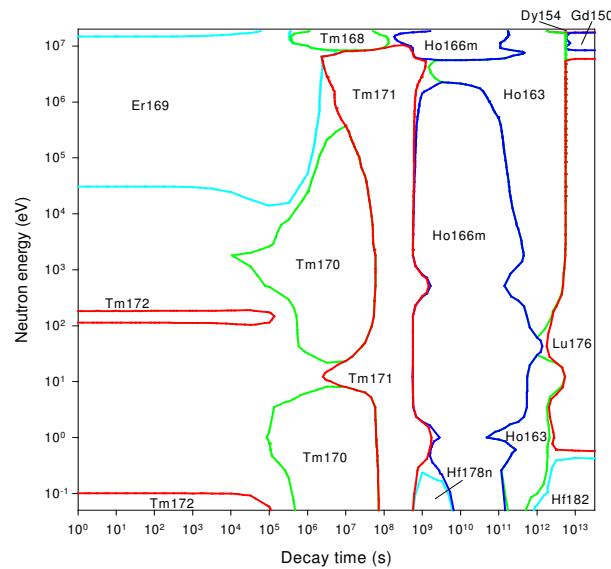
## Dose rate



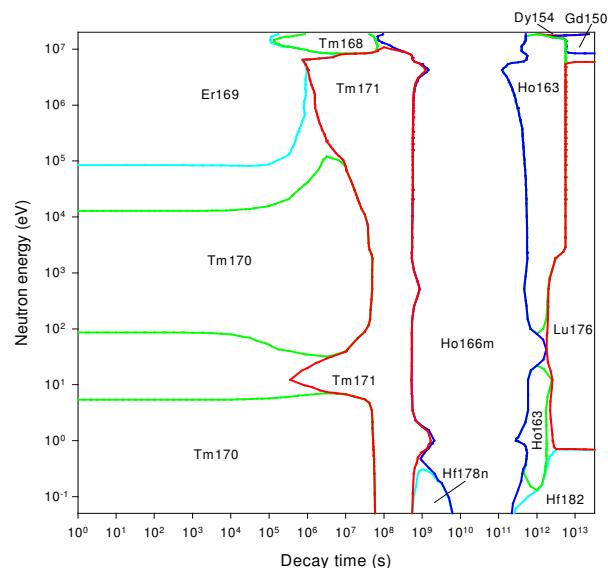
## Heat output



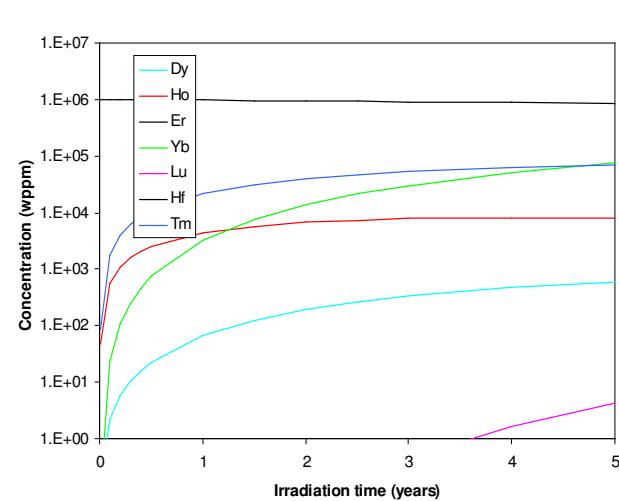
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Thulium

## General properties

Atomic number	69	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	0.52	Tm169	100.0
Melting point / K	1818		
Boiling point / K	2219		
Density / kgm <sup>-3</sup>	9321		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	16.8		
Electrical resistivity /Ωm	7.9 10 <sup>-7</sup>		
Coefficient of thermal expansion / K <sup>-1</sup>	1.33 10 <sup>-5</sup>		
Crystal structure	HCP		
Number of stable isotopes	1		
Mean atomic weight	168.93421		

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	8.50E15	8.46E15	7.70E15	1.60E15	2.02E8	6.04E0	kW kg <sup>-1</sup>	5.25E-1	5.25E-1	4.19E-1	4.86E-2	3.69E-8	7.68E-16
Tm170	68.42	68.68	74.07	50.61			Tm170	59.31	59.36	72.81	89.52		
Tm171	13.23	13.28	14.56	48.85			Tm172	29.46	29.45	14.19			
Tm172	11.31	11.34	4.80				Tm168	5.25	5.25	6.39	3.74		
Yb169	4.03	4.05	4.12	0.01			Yb169	4.53	4.53	5.24	0.02		
Tm168	1.51	1.52	1.63	0.53			Tm171	0.89	0.89	1.11	6.73		
Er169	0.94	0.95	0.79				Er169	0.25	0.25	0.24			
Ho166m					61.54		Ho166m					98.92	
H3					37.63		Hf178n					0.47	
Lu176						89.88	Lu176						88.64
Ta182						5.05	Ta182						9.55
Hf182						5.05	Hf182						1.81
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	1.61E5	1.61E5	7.99E4	2.02E3	3.78E-2	2.60E-10	Sv kg <sup>-1</sup>	9.72E6	9.72E6	8.53E6	1.15E6	2.56E-1	1.11E-8
Tm172	80.73	80.73	62.62				Tm170	77.78	77.80	86.87	91.79		
Tm168	17.34	17.36	34.02	91.11			Tm172	16.81	16.79	7.37			
Yb169	0.96	0.96	1.78	0.03			Yb169	2.50	2.51	2.64	0.01		
Tm170	0.78*	0.79*	1.55*	8.76*			Tm171	1.27	1.27	1.44	7.50		
Er171	0.08	0.08					Tm168	1.27	1.27	1.41	0.71		
Ho166m					99.50		Ho166m					97.21	
Hf178n					0.31		Hf178n					1.54	
Hf178m					0.19		H3					1.25	
Lu176						61.43	Lu176						87.68
Ta182						37.57	Hf182						8.21
Hf182						1.00	Ta182						4.11
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	4.48E7	4.48E7	4.33E7	6.81E6	1.52E1	4.78E-7		1.01E12	1.01E12	6.76E11	4.40E10	2.16E5	3.32E-3
Tm170	90.76	90.76	92.20	83.49			Tm172	50.07	50.09	28.76			
Tm171	3.51	3.51	3.62	16.12			Tm170	22.15	22.17	32.42	70.89		
Tm172	2.36	2.35	0.94				Tm168	15.52	15.54	22.55	23.45		
Yb169	2.29	2.29	2.20	0.01			Yb169	11.31	11.33	15.61	0.10		
Tm168	0.89	0.89	0.90	0.39			Tm171	0.35	0.35	0.52	5.56		
Ho166m					98.44		Ho166m					99.11	
Hf178n					1.44		Hf178n					0.48	
Lu176						79.56	Lu176						86.07
Hf182						19.80	Ta182						11.93
Ta182						0.64	Hf182						2.00

# Thulium

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Tm172	2.651 d	Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171(n, $\gamma$ )Tm172 Tm169(n, $\gamma$ )Tm170( $\beta^+$ )Er170(n, $\gamma$ )Er171( $\beta^-$ ) Tm171(n, $\gamma$ )Tm172	96.0 4.0	99.9	100.0	98.7 0.8
Yb175	4.185 d	Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171(n, $\gamma$ )Tm172( $\beta^-$ ) Yb172(n, $\gamma$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175 Tm169(n, $\gamma$ )Tm170( $\beta^-$ )Yb170(n, $\gamma$ )Yb171(n, $\gamma$ ) Yb172(n, $\gamma$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175 Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171(n, $\gamma$ )Tm172(n, $\gamma$ ) Tm173( $\beta^-$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175 Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171( $\beta^-$ )Yb171(n, $\gamma$ ) Yb172(n, $\gamma$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175	66.3 17.9 9.1 6.7	82.3 1.2 1.2 15.3	36.0 44.5 0.7 18.8	
Hf181	42.38 d	<b>&amp;Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(n,<math>\gamma</math>)Tm172(<math>\beta^-</math>)</b> Yb172(n, $\gamma$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ ) Lu175(n, $\gamma$ )Lu176(n, $\gamma$ )Lu177( $\beta^-$ )Hf177(n, $\gamma$ )Hf178(n, $\gamma$ ) <i>Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181</i> <b>&amp;Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(n,<math>\gamma</math>)Tm172(n,<math>\gamma</math>)</b> Tm173( $\beta^-$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ ) Lu175(n, $\gamma$ )Lu176(n, $\gamma$ )Lu177( $\beta^-$ )Hf177(n, $\gamma$ )Hf178(n, $\gamma$ ) <i>Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181</i> <b>&amp;Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(n,<math>\gamma</math>)Tm172(n,<math>\gamma</math>)</b> Yb172(n, $\gamma$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ ) Lu175(n, $\gamma$ )Lu176m( $\beta^-$ )Hf176(n, $\gamma$ )Hf177(n, $\gamma$ ) <i>Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181</i> <b>&amp;Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(n,<math>\gamma</math>)Tm172(n,<math>\gamma</math>)</b> Tm173( $\beta^-$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ ) Lu175(n, $\gamma$ )Lu176(n, $\gamma$ )Lu177(n, $\gamma$ )Lu178( $\beta^-$ ) <i>Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181</i> <b>&amp;Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(n,<math>\gamma</math>)Tm172(n,<math>\gamma</math>)</b> Tm173( $\beta^-$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ ) Lu175(n, $\gamma$ )Lu176m( $\beta^-$ )Hf176(n, $\gamma$ )Hf177(n, $\gamma$ ) <i>Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181</i> <b>&amp;Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(n,<math>\gamma</math>)Tm172(n,<math>\gamma</math>)</b> Tm173( $\beta^-$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ ) Lu175(n, $\gamma$ )Lu176m( $\beta^-$ )Hf176(n, $\gamma$ )Hf177(n, $\gamma$ ) <i>Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181</i> <b>&amp;Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(n,<math>\gamma</math>)Yb171(n,<math>\gamma</math>)</b> Yb172(n, $\gamma$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ ) Lu175(n, $\gamma$ )Lu176(n, $\gamma$ )Lu177( $\beta^-$ )Hf177(n, $\gamma$ )Hf178(n, $\gamma$ ) <i>Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181</i> <b>&amp;Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(<math>\beta^-</math>)Yb171(n,<math>\gamma</math>)</b> Yb172(n, $\gamma$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ ) Lu175(n, $\gamma$ )Lu176(n, $\gamma$ )Lu177(n, $\gamma$ )Lu178( $\beta^-$ ) <i>Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181</i> <b>&amp;Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(<math>\beta^-</math>)Yb171(n,<math>\gamma</math>)Yb172</b> (n, $\gamma$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ )Lu175(n, $\gamma$ )Lu176m( $\beta^-$ ) <i>Hf176(n,<math>\gamma</math>)Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181</i>	30.5 17.8 14.8 11.1 8.3 7.8 2.7 1.7 1.4 0.8 0.5	80.1 2.0 4.0 0.8 0.1 0.1 0.4 8.9 0.6 11.7 0.1	30.4 1.6 1.0 24.0 1.3 1.3 14.7 7.1 0.6 5.6	

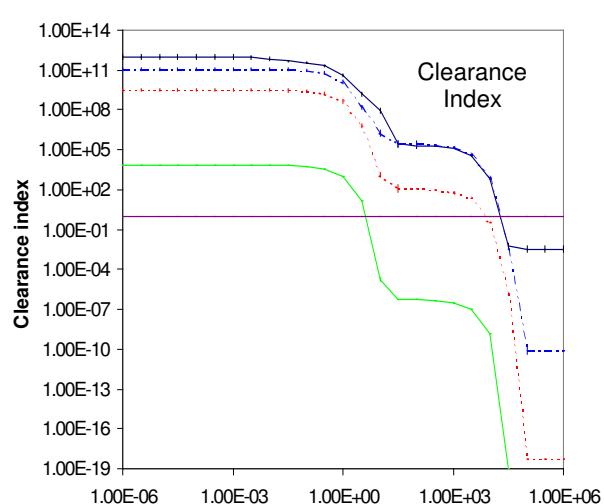
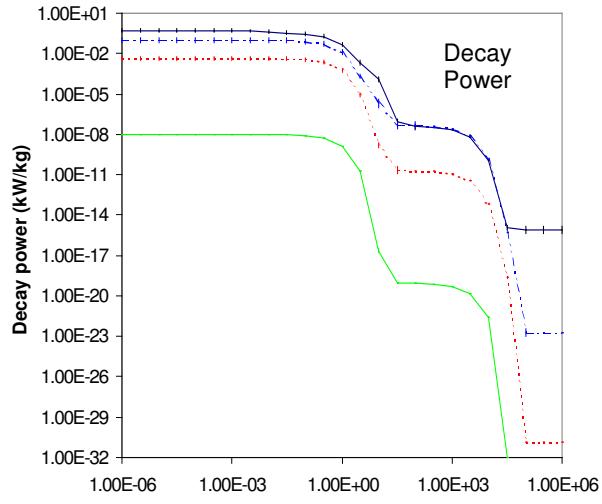
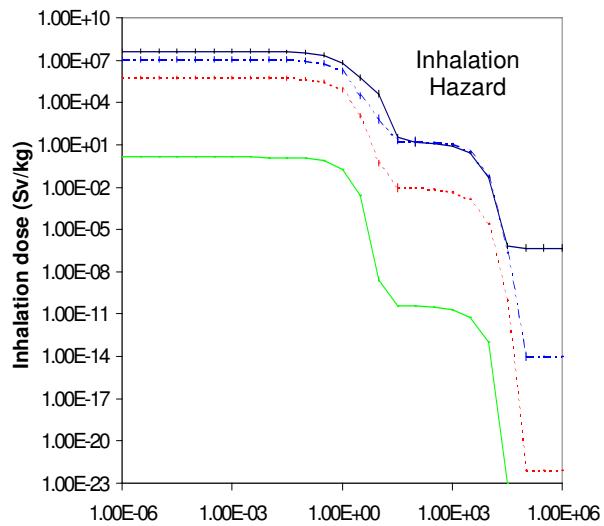
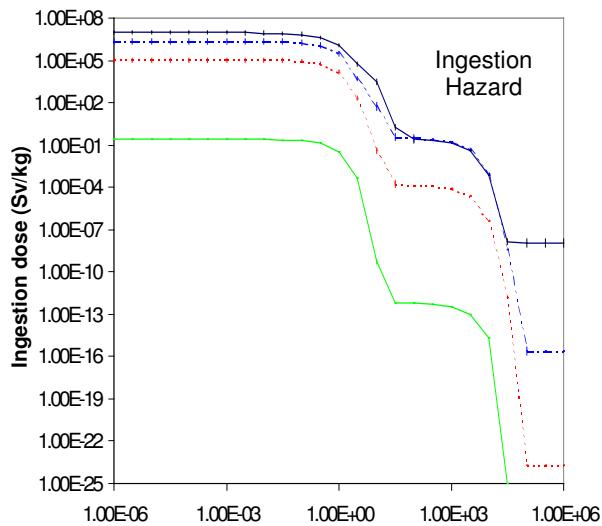
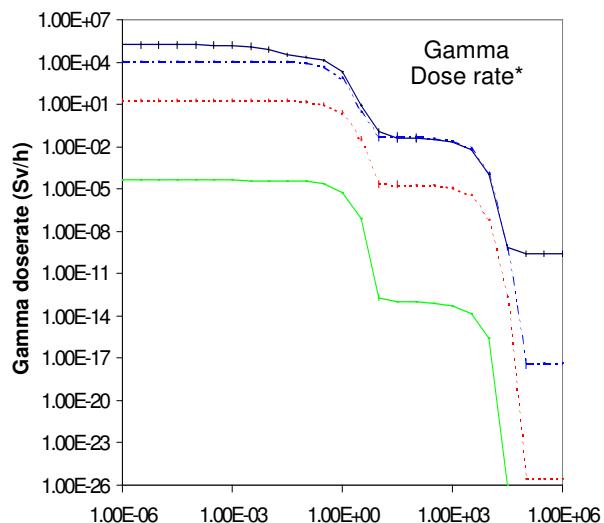
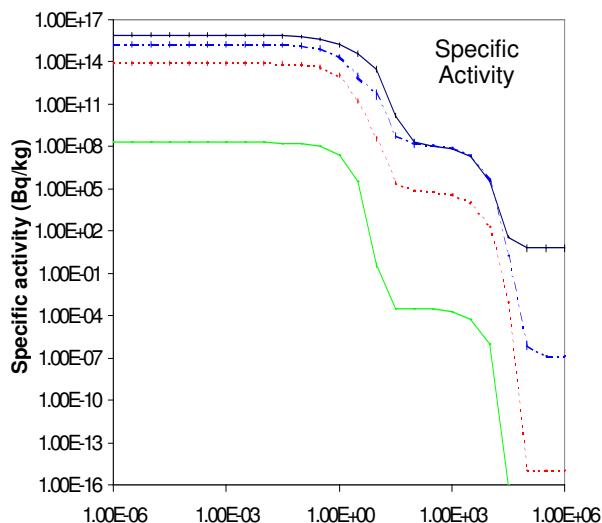
Tm168	93.102 d	Tm169(n,2n)Tm168				99.9
Ta182	114.7 d	<p><b>&amp;Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(n,<math>\gamma</math>)Tm172(<math>\beta^-</math>)</b>  Yb172(n,<math>\gamma</math>)Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)Lu175  (n,<math>\gamma</math>)Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)<i>Hf179</i>  (n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182</p> <p><b>&amp;Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(n,<math>\gamma</math>)Tm172(n,<math>\gamma</math>)</b>  Tm173(<math>\beta^-</math>)Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)Lu175  (n,<math>\gamma</math>)Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)<i>Hf179</i>  (n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182</p> <p><b>&amp;Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(n,<math>\gamma</math>)Tm172(<math>\beta^-</math>)</b>  Yb172(n,<math>\gamma</math>)Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)Lu175  (n,<math>\gamma</math>)Lu176m(<math>\beta^-</math>)Hf176(n,<math>\gamma</math>)Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)  <i>Hf179</i>(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182</p> <p><b>&amp;Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(n,<math>\gamma</math>)Tm172(n,<math>\gamma</math>)</b>  Tm173(<math>\beta^-</math>)Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)Lu175  (n,<math>\gamma</math>)Lu176(n,<math>\gamma</math>)Lu177(n,<math>\gamma</math>)Lu178(<math>\beta^-</math>)Hf178(n,<math>\gamma</math>)<i>Hf179</i>  (n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182</p> <p><b>&amp;Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(n,<math>\gamma</math>)Tm172(n,<math>\gamma</math>)</b>  Tm173(<math>\beta^-</math>)Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)Lu175  (n,<math>\gamma</math>)Lu176m(<math>\beta^-</math>)Hf176(n,<math>\gamma</math>)Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)  <i>Hf179</i>(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182</p> <p><b>&amp;Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(n,<math>\gamma</math>)Yb171(n,<math>\gamma</math>)Yb172</b>  (n,<math>\gamma</math>)Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)Lu175(n,<math>\gamma</math>)  Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)<i>Hf179</i>(n,<math>\gamma</math>)  Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182</p> <p><b>&amp;Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(<math>\beta^-</math>)Yb171(n,<math>\gamma</math>)</b>  Yb172(n,<math>\gamma</math>)Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)Lu175  (n,<math>\gamma</math>)Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)<i>Hf179</i>  (n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182</p> <p><b>&amp;Tm169(n,<math>\gamma</math>)Tm170(<math>\beta^-</math>)Yb170(n,<math>\gamma</math>)Yb171(n,<math>\gamma</math>)Yb172</b>  (n,<math>\gamma</math>)Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)Lu175(n,<math>\gamma</math>)  Lu176(n,<math>\gamma</math>)Lu177(n,<math>\gamma</math>)Lu178(<math>\beta^-</math>)Hf178(n,<math>\gamma</math>)<i>Hf179</i>(n,<math>\gamma</math>)  Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182</p> <p><b>&amp;Tm169(n,<math>\gamma</math>)Tm170(<math>\beta^-</math>)Yb170(n,<math>\gamma</math>)Yb171(n,<math>\gamma</math>)Yb172</b>  (n,<math>\gamma</math>)Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)Lu175(n,<math>\gamma</math>)  Lu176m(<math>\beta^-</math>)Hf176(n,<math>\gamma</math>)Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)<i>Hf179</i>  (n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182</p> <p><b>&amp;Tm169(n,<math>\gamma</math>)Tm170(n,<math>\gamma</math>)Tm171(<math>\beta^-</math>)Yb171(n,<math>\gamma</math>)</b>  Yb172(n,<math>\gamma</math>)Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)Lu175  (n,<math>\gamma</math>)Lu176m(<math>\beta^-</math>)Hf176(n,<math>\gamma</math>)Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)  <i>Hf179</i>(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182</p>	29.3 20.6 14.7 9.3 9.9 7.7 2.2 1.4 1.1 0.6 0.4	79.5 2.2 4.3 0.8 0.1 1.5 0.3 8.0 0.6 10.6 0.1	31.6 1.9 1.2 25.1 0.1 13.3 6.5 5.2	
Tm170	128.6 d	Tm169(n, $\gamma$ )Tm170	100.0	100.0	100.0	99.9
Tm171	1.92 y	Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171 Tm169(n, $\gamma$ )Tm170( $\beta^+$ )Er170(n, $\gamma$ )Er171( $\beta^-$ )Tm171	95.9 4.1	99.9 0.1	99.9 0.1	98.8 0.8
H3	12.33 y	Tm169(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Tm169(n, $\gamma$ )Tm170(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Tm169(n, $\gamma$ )Tm170( $\beta^-$ )Yb170(n, $\gamma$ )Yb171(n,X)H1(n, $\gamma$ ) H2(n, $\gamma$ )H3 Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171( $\beta^-$ )Yb171(n,X)H1(n, $\gamma$ ) H2(n, $\gamma$ )H3 Tm169(n,X)H3 Tm169(n,2n)Tm168( $\beta^+$ )Er168(n,X)H3	58.8 24.4 6.5 2.8	78.5 13.5 0.1 2.2	98.3 1.2 0.1 97.9	1.2

Hf178n	31.0 y	Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171(n, $\gamma$ )Tm172( $\beta^-$ ) Yb172(n, $\gamma$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ ) Lu175(n, $\gamma$ )Lu176(n, $\gamma$ )Lu177( $\beta^-$ )Hf177(n, $\gamma$ )Hf178n Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171(n, $\gamma$ )Tm172( $\beta^-$ ) Yb172(n, $\gamma$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ ) Lu175(n, $\gamma$ )Lu176m( $\beta^-$ )Hf176(n, $\gamma$ )Hf177(n, $\gamma$ )Hf178n Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171(n, $\gamma$ )Tm172(n, $\gamma$ ) Tm173( $\beta^-$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ ) Lu175(n, $\gamma$ )Lu176(n, $\gamma$ )Lu177( $\beta^-$ )Hf177(n, $\gamma$ )Hf178n Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171(n, $\gamma$ )Tm172(n, $\gamma$ ) Tm173( $\beta^-$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ ) Lu175(n, $\gamma$ )Lu176m( $\beta^-$ )Hf176(n, $\gamma$ )Hf177(n, $\gamma$ )Hf178n Tm169(n, $\gamma$ )Tm170( $\beta^-$ )Yb170(n, $\gamma$ )Yb171(n, $\gamma$ ) Yb172(n, $\gamma$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ ) Lu175(n, $\gamma$ )Lu176(n, $\gamma$ )Lu177( $\beta^-$ )Hf177(n, $\gamma$ )Hf178n Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171( $\beta^-$ )Yb171(n, $\gamma$ ) Yb172(n, $\gamma$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ ) Lu175(n, $\gamma$ )Lu176(n, $\gamma$ )Lu177( $\beta^-$ )Hf177(n, $\gamma$ )Hf178n Tm169(n, $\gamma$ )Tm170( $\beta^-$ )Yb170(n, $\gamma$ )Yb171(n, $\gamma$ ) Yb172(n, $\gamma$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ ) Lu175(n, $\gamma$ )Lu176m( $\beta^-$ )Hf176(n, $\gamma$ )Hf177(n, $\gamma$ )Hf178n	41.5 21.8 13.5 9.9 6.2 3.0 2.5 1.4	83.9 1.0 1.7 0.5 0.5 11.1 0.1 0.1	28.6 22.4 1.2 0.9 17.9 8.3 14.0 6.5	
Ho166m	1200 y	Tm169(n, $\alpha$ )Ho166m	100.0	100.0	100.0	99.8
Ho163	4570 y	&Tm169(n,2n)Tm168( $\beta^+$ )Er168(n,2n)Er167(n,2n)Er166(n,2n) Er165( $\beta^+$ )Ho165(n,2n)Ho164( $\beta^-$ )Er164(n,2n)Er163( $\beta^+$ )Ho163 &Tm169(n,n $\alpha$ )Ho165(n,2n)Ho164( $\beta^-$ )Er164(n,2n) Er163( $\beta^+$ )Ho163 &Tm169(n, $\alpha$ )Ho166m(n,2n)Ho165(n,2n)Ho164( $\beta^-$ ) Er164(n,2n)Er163( $\beta^+$ )Ho163 &Tm169(n,2n)Tm168(n,2n)Tm167( $\beta^+$ )Er167(n,2n)Er166(n,2n) Er165( $\beta^+$ )Ho165(n,2n)Ho164( $\beta^-$ )Er164(n,2n)Er163( $\beta^+$ )Ho163 &Tm169(n,2n)Tm168( $\beta^+$ )Er168(n, $\alpha$ )Dy165( $\beta^-$ ) Ho165(n,2n)Ho164( $\beta^-$ )Er164(n,2n)Er163( $\beta^+$ )Ho163 &Tm169(n, $\alpha$ )Ho166( $\beta^-$ )Er166(n,2n)Er165( $\beta^+$ ) Ho165(n,2n)Ho164( $\beta^-$ )Er164(n,2n)Er163( $\beta^+$ )Ho163 &Tm169(n,2n)Tm168(n, $\alpha$ )Ho165(n,2n)Ho164( $\beta^-$ ) Er164(n,2n)Er163( $\beta^+$ )Ho163 &Tm169(n,2n)Tm168(n,n $\alpha$ )Ho164( $\beta^-$ )Er164(n,2n) Er163( $\beta^+$ )Ho163			26.2 21.3 16.6 10.1 9.3 7.8 2.3 1.9	
La137	$6.0 \cdot 10^4$ y	Threshold for production above 14.7 MeV				
Gd150	$1.8 \cdot 10^6$ y	Very long pathways involving (n,2n), ( $\beta^+$ ), (n, $\alpha$ ), etc				100.0





# Thulium activation characteristics

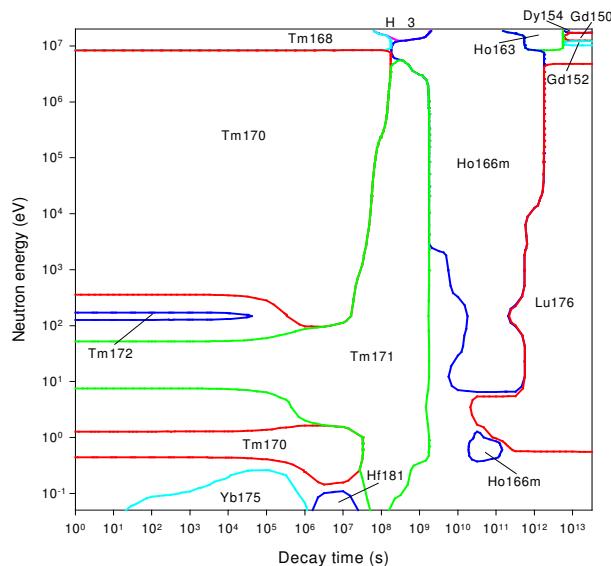


Decay time (years)

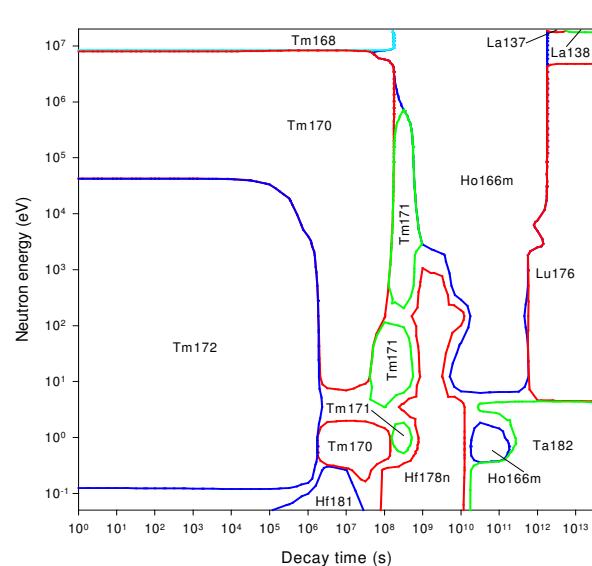
Decay time (years)

# Thulium importance diagrams & transmutation

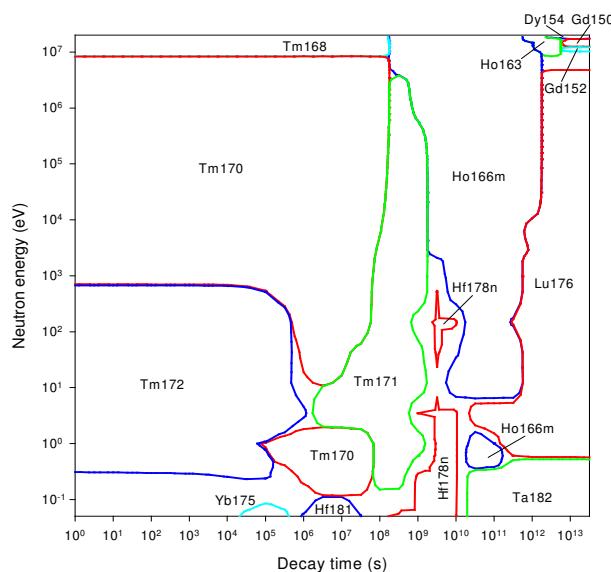
## Activity



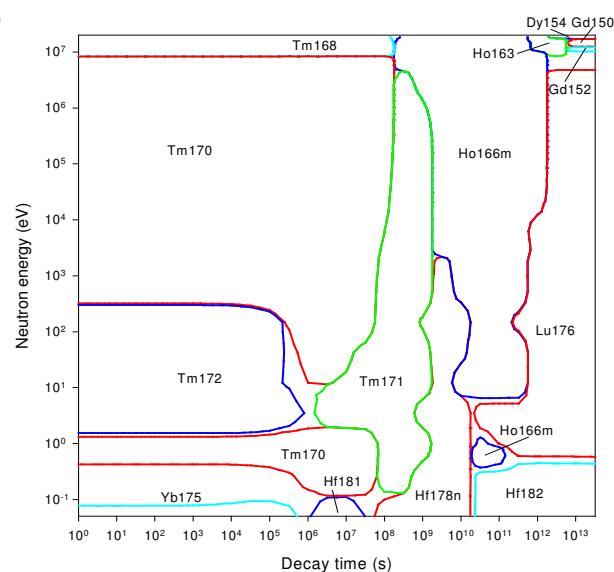
## Dose rate



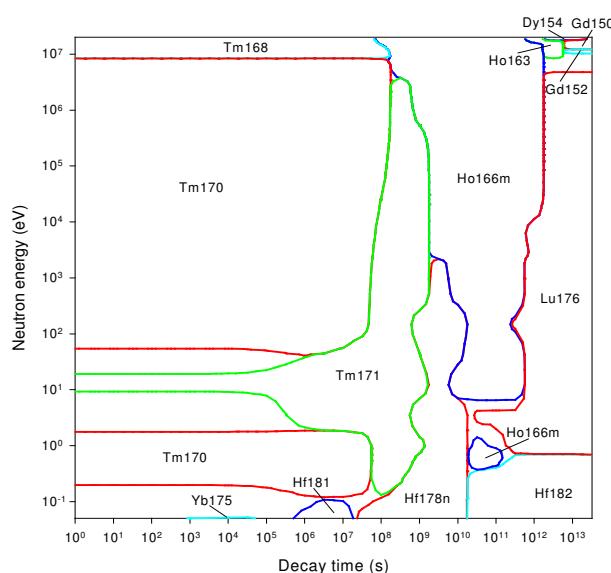
## Heat output



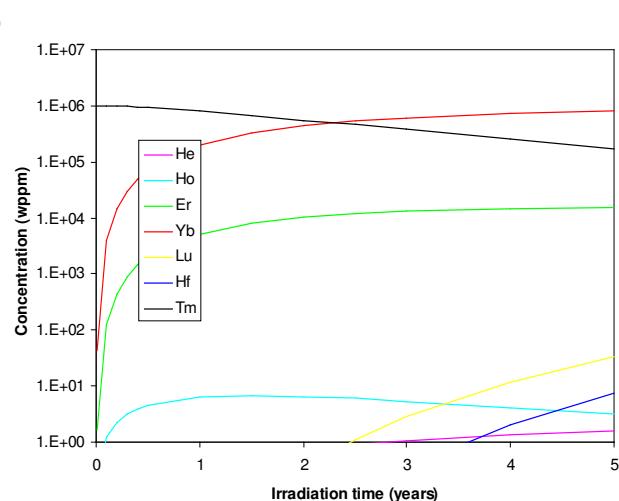
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Ytterbium

## General properties

Atomic number	70	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	3.2	Yb168	0.13
Melting point / K	1097	Yb170	3.04
Boiling point / K	1467	Yb171	14.28
Density / kgm <sup>-3</sup>	6903	Yb172	21.83
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	34.9	Yb173	16.13
Electrical resistivity /Ωm	2.9 10 <sup>-7</sup>	Yb174	31.83
Coefficient of thermal expansion / K <sup>-1</sup>	2.63 10 <sup>-5</sup>	Yb176	12.76
Crystal structure	FCC		
Number of stable isotopes	7		
Mean atomic weight	173.04		

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.69E15	1.45E15	5.89E14	9.55E12	9.55E9	7.95E4	kW kg <sup>-1</sup>	8.77E-2	7.34E-2	2.09E-2	3.60E-4	1.86E-6	1.13E-11
Yb175	40.20	46.83	62.79				Lu176m	32.29	37.96				
Lu176m	21.43	24.57					Yb175	24.95	29.81	57.24			
Lu177	13.26	15.45	26.14	0.05			Yb177	12.66	14.66				
Hf179m	9.66						Hf179m	10.65					
Yb177	6.79	7.66					Lu177	7.52	8.99	21.79	0.04		
Yb177m	3.39						Yb177m	3.42					
Tm170	1.50	1.75	4.21	36.97			Tm170	1.55	1.85	6.36	52.54		
Yb169	0.98	1.14	2.59	0.06			Yb169	1.31	1.56	5.08	0.12		
Lu178	0.49	0.50					Lu178	1.30	1.36				
Hf181	0.35	0.41	0.95	0.16			Hf181	0.80	0.95	3.15	0.49		
Hf175	0.34	0.39	0.93	1.60			Hf175	0.43	0.51	1.72	2.78		
Lu174m	0.21	0.24	0.58	6.07			Hf178m	0.38		0.04	2.22	46.94	
Lu174	0.18	0.21	0.52	29.09			Ta182	0.30	0.36	1.25	8.14		78.98
Tm171	0.18	0.21	0.51	22.18			Tm168	0.14	0.17	0.58	2.28		
Hf178m	0.11		0.01	0.46	49.85		Lu174m		0.13	0.46	4.61		
Ta182	0.07	0.08	0.18	1.28		46.57	Lu174		0.11	0.38	19.97		78.98
Lu173			0.02	0.78			Tm171			0.06	2.45		
Hf178n			0.46	49.85			Hf178n			0.04	2.51	53.05	
Hf182					46.57		Hf182						14.95
Lu176					6.87		Lu176						6.07
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	1.19E4	9.97E3	3.22E3	1.18E2	1.07E0	1.24E-5	Sv kg <sup>-1</sup>	5.55E5	5.53E5	3.05E5	6.45E3	2.24E1	1.76E-4
Yb177	38.18	44.31					Yb175	53.75	53.87	53.42			
Yb175	26.85	32.14	54.41				Lu177	21.35	21.41	26.79	0.04		
Hf179m	10.66						Lu176m	11.07	10.92				
Tm172	3.35	4.01	4.79				Tm170	5.93	5.94	10.57	71.22		
Ta182	2.99	3.58	10.84	33.24		96.23	Yb169	2.12	2.12	3.56	0.07		
Hf181	2.87	3.44	10.03	0.74			Yb177	1.81	1.76				
Lu178	2.65	2.80					Hf181	1.18	1.18	2.02	0.26		
Lu177	1.99	2.39	5.10				Tm172	0.90	0.90	0.63			
Hf178m	1.29		0.12	3.17	38.08		Hf175	0.42	0.42	0.74	0.97		
Hf175	1.15	1.38	4.12	3.13			Lu174m	0.33	0.33	0.59	4.77		
Tm174	1.15	0.70					Ta182	0.30	0.30	0.53	2.84		31.48
Tm168	1.06	1.27	3.82	7.05			Hf179n	0.21	0.21	0.35	0.00		
Hf177m	0.63	0.06	0.13	0.72			Lu174	0.15	0.15	0.27	11.64		
Hf179n	0.63	0.75	2.10				Tm168	0.10	0.10	0.18	0.57		
Yb169	0.61	0.73	2.08	0.02			Tm171	0.06	0.06	0.11	3.62		
Lu174	0.48	0.58	1.80	44.73			Hf178n	0.04	0.04	0.07	3.18	99.99	
Hf178n		0.06	0.19	5.16	61.90		Lu177m			0.05	0.52		
Hf182						2.50	Hf182						62.96
Lu176						1.28	Lu176						5.57

Inh	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Clear	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y
Sv kg <sup>-1</sup>	1.14E6	1.14E6	7.72E5	5.52E4	1.24E3	1.22E-2		1.99E11	1.42E11	5.73E10	9.23E8	1.07E7	5.90E1
Yb175	43.26	43.29	35.01				Yb175	30.98	43.43	58.67			
Lu177	23.45	23.47	23.96	0.01			Hf179m	20.47					
Tm170	15.48	15.50	22.49	44.75			Yb177	13.07	17.76				
Yb169	4.34	4.34	5.94	0.03			Lu176m	11.36	15.67				
Lu176m	3.79	3.73					Lu177	5.92	8.30	14.14	0.03		
Hf181	2.60	2.60	3.62	0.14			Yb177m	4.79					
Lu174m	1.27	1.27	1.85	4.41			Yb169	2.77	3.89	8.88	0.22		
Lu174	1.12	1.12	1.66	21.13			Hf181	1.66	2.33	5.42	0.91		
Hf178n	1.01	1.01	1.50	20.50	99.99		Hf175	1.06	1.49	3.55	6.14		
Ta182	0.97	0.97	1.41	2.21		3.03	Hf178m	0.92		0.08	4.82	45.25	
Yb177	0.69	0.67					Lu178	0.90	1.11				
Hf175	0.60	0.60	0.85	0.33			Tm172	0.78	1.09	1.04			
Tm171	0.37	0.37	0.55	5.37			Hf177m	0.74	0.08	0.14	1.81		
Hf179n	0.33	0.33	0.44				Ta182	0.72	1.02	2.46	17.17		81.49
Tm172	0.28	0.28	0.16				Tm170	0.49	0.69	1.66	14.72		
Tm168	0.16	0.16	0.23	0.22			Hf179n	0.45	0.63	1.42			
Lu177m	0.13	0.14	0.20	0.57			Tm168	0.36	0.50	1.20	5.07		
Er169	0.04	0.04	0.05				Lu174		0.26	0.64	36.29		
Ta183	0.04	0.04	0.03				Lu174m		0.17	0.42	4.49		
Lu173	0.03	0.03	0.04	0.32			Hf178n			0.10	5.83	54.74	
Hf182						93.85	Lu173			0.04	1.42		
Lu176						3.12	Hf182						13.64
							Lu176						4.87

# Ytterbium

## Pathway analysis

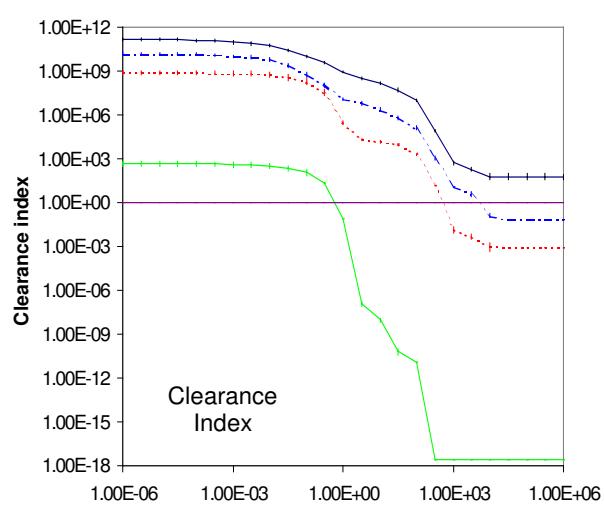
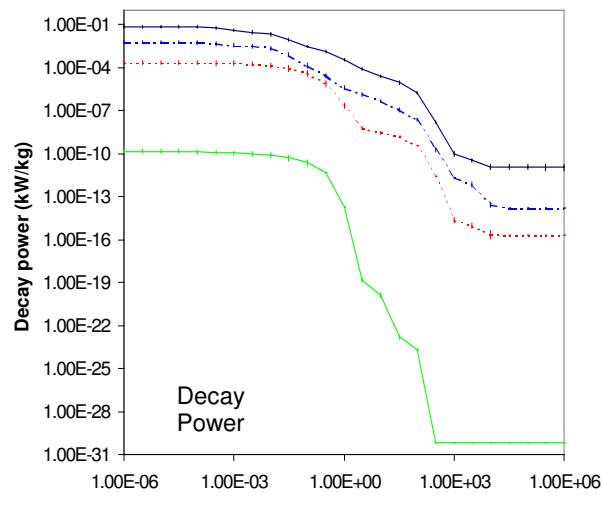
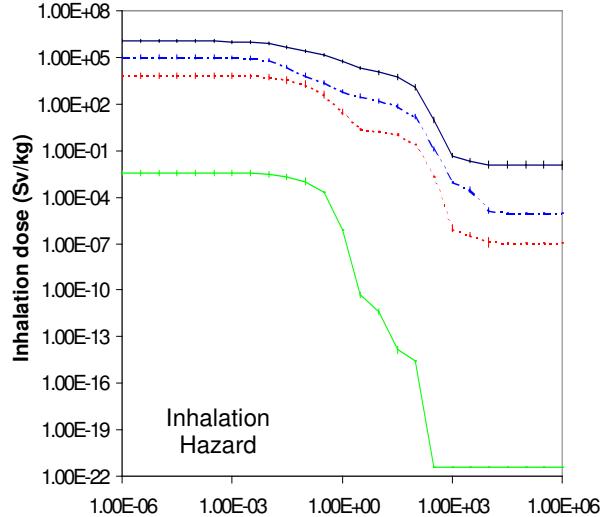
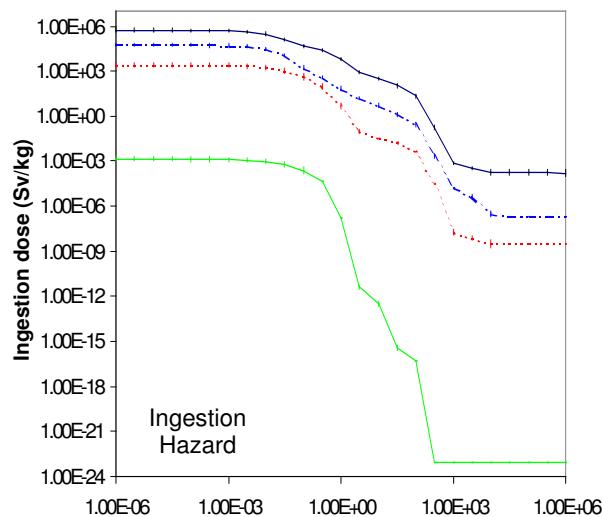
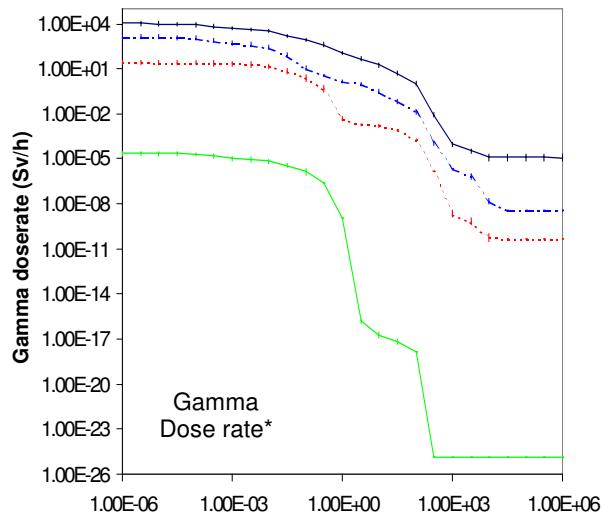
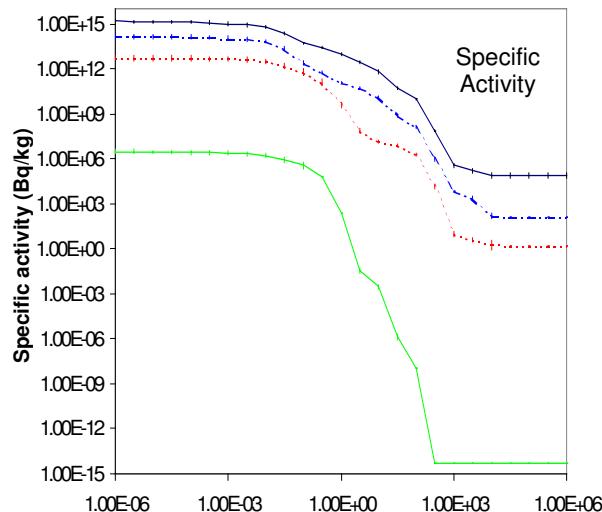
Nuclide	T <sub>1/2</sub>	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Hf178m	4.0 s	Yb174(n, $\gamma$ )Yb175( $\beta^-$ )Lu175(n, $\gamma$ )Lu176m( $\beta^-$ ) Hf176(n, $\gamma$ )Hf177(n, $\gamma$ )Hf178m <b>&amp;Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)Lu175(n,<math>\gamma</math>)Lu176(n,<math>\gamma</math>) Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178m</b> Yb174(n, $\gamma$ )Yb175( $\beta^-$ )Lu175(n, $\gamma$ )Lu176m( $\beta^-$ ) Hf176(n, $\gamma$ )Hf177(n, $\gamma$ )Hf178n(IT)Hf178m <b>&amp;Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)Lu175(n,<math>\gamma</math>) Lu176m(<math>\beta^-</math>)Hf176(n,<math>\gamma</math>)Hf177(n,<math>\gamma</math>)Hf178m</b> <b>&amp;Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)Lu175(n,<math>\gamma</math>) Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178m</b> <b>&amp;Yb176(n,<math>\gamma</math>)Yb177(<math>\beta^-</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178m</b> <b>&amp;Yb176(n,<math>\gamma</math>)Yb177(<math>\beta^-</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178(n,n')Hf178m</b>	35.9 20.8 12.8 11.5 9.7 8.0	0.4	0.3 0.5	
Yb176m	11.4 s	Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175(n, $\gamma$ )Yb176m Yb174(n, $\gamma$ )Yb175(n, $\gamma$ )Yb176m Yb172(n, $\gamma$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175(n, $\gamma$ )Yb176m Yb171(n, $\gamma$ )Yb172(n, $\gamma$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ ) Yb175(n, $\gamma$ )Yb176m Yb176(n,n')Yb176m	76.2 12.4 7.4 3.5	18.6 44.4 23.2 13.7	5.5 94.2 0.2	
Yb177	1.889 h	<b>&amp;Yb176(n,<math>\gamma</math>)Yb177</b> <b>&amp;Yb174(n,<math>\gamma</math>)Yb175(n,<math>\gamma</math>)Yb176(n,<math>\gamma</math>)Yb177</b> <b>&amp;Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(n,<math>\gamma</math>)Yb176(n,<math>\gamma</math>)Yb177</b>	97.8 1.6 0.5	100.0	100.0	100.0
Lu176m	3.681 h	Yb174(n, $\gamma$ )Yb175( $\beta^-$ )Lu175(n, $\gamma$ )Lu176m Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ )Lu175(n, $\gamma$ )Lu176m Yb172(n, $\gamma$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ ) Lu175(n, $\gamma$ )Lu176m Yb171(n, $\gamma$ )Yb172(n, $\gamma$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ ) Yb175( $\beta^-$ )Lu175(n, $\gamma$ )Lu176m Yb176(n,2n)Yb175( $\beta^-$ )Lu175(n, $\gamma$ )Lu176m	63.6 34.1 1.6 0.6	49.8 17.9 20.9 11.4	97.1 2.9	0.1
Yb175	4.185 d	Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175 Yb174(n, $\gamma$ )Yb175 Yb172(n, $\gamma$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175 Yb171(n, $\gamma$ )Yb172(n, $\gamma$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175 Yb176(n,2n)Yb175	76.2 12.4 7.4 3.5	18.6 44.4 23.3 13.7	5.5 94.2 0.2	0.1
Lu177	6.7 d	Yb174(n, $\gamma$ )Yb175( $\beta^-$ )Lu175(n, $\gamma$ )Lu176(n, $\gamma$ )Lu177 Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ )Lu175(n, $\gamma$ ) Lu176(n, $\gamma$ )Lu177 <b>&amp;Yb176(n,<math>\gamma</math>)Yb177(<math>\beta^-</math>)Lu177</b> Yb172(n, $\gamma$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ ) Lu175(n, $\gamma$ )Lu176(n, $\gamma$ )Lu177	49.8 26.6 21.3 1.3	0.8 0.2 98.1 0.3	2.1 97.9	99.8
Yb169	32.01 d	<b>&amp;Yb168(n,<math>\gamma</math>)Yb169</b> <b>&amp;Yb171(n,2n)Yb170(n,2n)Yb169</b> <b>&amp;Yb170(n,2n)Yb169</b> <b>&amp;Yb172(n,2n)Yb171(n,2n)Yb170(n,2n)Yb169</b>	100.0	100.0	99.7	51.6 34.9 12.1

Hf181	42.38 d	$\&Yb174(n,\gamma)Yb175(\beta^-)Lu175(n,\gamma)Lu176(n,\gamma)Lu177(\beta^-)Hf177(n,\gamma)Hf178(n,\gamma)Hf179(n,\gamma)Hf180(n,\gamma)Hf181$ $\&Yb174(n,\gamma)Yb175(\beta^-)Lu175(n,\gamma)Lu176m(\beta^-)Hf176(n,\gamma)Hf177(n,\gamma)Hf178(n,\gamma)Hf179(n,\gamma)Hf180(n,\gamma)Hf181$ $\&Yb174(n,\gamma)Yb175(\beta^-)Lu175(n,\gamma)Lu176(n,\gamma)Lu177(n,\gamma)Lu178(\beta^-)Hf178(n,\gamma)Hf179(n,\gamma)Hf180(n,\gamma)Hf181$ $\&Yb176(n,\gamma)Yb177(\beta^-)Lu177(\beta^-)Hf177(n,\gamma)$ $Hf178(n,\gamma)Hf179(n,\gamma)Hf180(n,\gamma)Hf181$ $\&Yb173(n,\gamma)Yb174(n,\gamma)Yb175(\beta^-)Lu175(n,\gamma)$ $Lu176(n,\gamma)Lu177(\beta^-)Hf177(n,\gamma)Hf178(n,\gamma)Hf179(n,\gamma)Hf180(n,\gamma)Hf181$ $\&Yb176(n,\gamma)Yb177(\beta^-)Lu177(\beta^-)Hf177(n,\gamma)$ $Hf178m(IT)Hf178(n,\gamma)Hf179(n,\gamma)Hf180(n,\gamma)Hf181$	34.2 24.9 14.7 10.4 5.1 4.4 2.9 2.3	0.1 0.1 95.9 97.7	0.1 0.1 88.5 0.2 1.3 10.8
Tm168	93.102 d	$Yb168(n,p)Tm168$ $\&Yb170(n,2n)Yb169(\beta^+)Tm169(n,2n)Tm168$ $\&Yb171(n,2n)Yb170(n,2n)Yb169(\beta^+)Tm169(n,2n)Tm168$ $\&Yb172(n,2n)Yb171(n,2n)Yb170(n,2n)Yb169(\beta^+)$ $Tm169(n,2n)Tm168$		100.0	100.0
Ta182	114.7 d	$\&Yb174(n,\gamma)Yb175(\beta^-)Lu175(n,\gamma)Lu176(n,\gamma)$ $Lu177(\beta^-)Hf177(n,\gamma)Hf178(n,\gamma)Hf179(n,\gamma)Hf180(n,\gamma)$ $Hf181(\beta^-)Ta181(n,\gamma)Ta182$ $\&Yb174(n,\gamma)Yb175(\beta^-)Lu175(n,\gamma)Lu176m(\beta^-)$ $Hf176(n,\gamma)Hf177(n,\gamma)Hf178(n,\gamma)Hf179(n,\gamma)Hf180(n,\gamma)$ $Hf181(\beta^-)Ta181(n,\gamma)Ta182$ $\&Yb174(n,\gamma)Yb175(\beta^-)Lu175(n,\gamma)Lu176(n,\gamma)$ $Lu177(n,\gamma)Lu178(\beta^-)Hf178(n,\gamma)Hf179(n,\gamma)Hf180(n,\gamma)$ $Hf181(\beta^-)Ta181(n,\gamma)Ta182$ $\&Yb176(n,\gamma)Yb177(\beta^-)Lu177(\beta^-)Hf177(n,\gamma)Hf178(n,\gamma)Hf179(n,\gamma)Hf180(n,\gamma)Hf181(\beta^-)Ta181(n,\gamma)Ta182$ $\&Yb176(n,\gamma)Yb177(\beta^-)Lu177(n,\gamma)Lu178(\beta^-)Hf178(n,\gamma)Hf179(n,\gamma)Hf180(n,\gamma)Hf181(\beta^-)Ta181(n,\gamma)Ta182$ $\&Yb173(n,\gamma)Yb174(n,\gamma)Yb175(\beta^-)Lu175(n,\gamma)$ $Lu176(n,\gamma)Lu177(\beta^-)Hf177(n,\gamma)Hf178(n,\gamma)Hf179(n,\gamma)Hf180(n,\gamma)Hf181(\beta^-)Ta181(n,\gamma)Ta182$ $\&Yb173(n,\gamma)Yb174(n,\gamma)Yb175(\beta^-)Lu175(n,\gamma)$ $Lu176m(\beta^-)Hf176(n,\gamma)Hf177(n,\gamma)Hf178(n,\gamma)Hf179(n,\gamma)Hf180(n,\gamma)Hf181(\beta^-)Ta181(n,\gamma)Ta182$ $\&Yb173(n,\gamma)Yb174(n,\gamma)Yb175(\beta^-)Lu175(n,\gamma)$ $Lu176(n,\gamma)Lu177(n,\gamma)Lu178(\beta^-)Hf178(n,\gamma)Hf179(n,\gamma)Hf180(n,\gamma)Hf181(\beta^-)Ta181(n,\gamma)Ta182$	36.5 20.7 16.3 11.9 5.3 4.2 2.0 2.0	0.1 0.1 95.2 97.1 3.5 1.7	
Tm170	128.6 d	$\&Yb168(n,\gamma)Yb169(\beta^+)Tm169(n,\gamma)Tm170$ $Yb172(n,\alpha)Er169(\beta^-)Tm169(n,\gamma)Tm170$ $Yb171(n,2n)Yb170(n,p)Tm170$ $Yb170(n,p)Tm170$ $Yb171(n,d)Tm170$ $Yb171(n,p)Tm171(n,2n)Tm170$ $Yb174(n,\alpha)Er171(\beta^-)Tm171(n,2n)Tm170$ $Yb172(n,2n)Yb171(n,d)Tm170$ $Yb172(n,2n)Yb171(n,2n)Yb170(n,p)Tm170$ $Yb172(n,2n)Yb171(n,p)Tm171(n,2n)Tm170$ $Yb172(n,t)Tm170$	98.3 1.0	100.0	100.0

Tm171	1.92 y	&Yb168(n, $\gamma$ )Yb169( $\beta^+$ )Tm169(n, $\gamma$ )Tm170(n, $\gamma$ )Tm171 &Yb168(n, $\gamma$ )Yb169( $\beta^+$ )Tm169(n, $\gamma$ )Tm170( $\beta^+$ ) Er170(n, $\gamma$ )Er171( $\beta^-$ )Tm171 Yb171(n,p)Tm171 Yb174(n, $\alpha$ )Er171( $\beta^-$ )Tm171 Yb172(n,2n)Yb171(n,p)Tm171 Yb172(n,d)Tm171 Yb173(n,2n)Yb172(n,2n)Yb171(n,p)Tm171 Yb173(n,t)Tm171	93.4 3.7	99.2	99.7	49.1 28.8 15.2 2.2 1.4 1.1
Lu174	3.559 y	&Yb176(n,2n)Yb175( $\beta^-$ )Lu175(n,2n)Lu174				99.2
H3	12.33 y	Yb174(n, $\gamma$ )Yb175( $\beta^-$ )Lu175(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Yb171(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ )Lu175(n,X)H1(n, $\gamma$ ) H2(n, $\gamma$ )H3 Yb170(n, $\gamma$ )Yb171(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 &Yb176(n, $\gamma$ )Yb177( $\beta^-$ )Lu177( $\beta^-$ )Hf177(n,X)H1(n, $\gamma$ ) H2(n, $\gamma$ )H3 Yb168(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 &Yb176(n, $\gamma$ )Yb177( $\beta^-$ )Lu177( $\beta^-$ )Hf177(n, $\gamma$ )Hf178(n, $\gamma$ ) Hf179(n, $\gamma$ )Hf180(n, $\gamma$ )Hf181( $\beta^-$ )Ta181(n,X)H3 &Yb176(n, $\gamma$ )Yb177( $\beta^-$ )Lu177(n, $\gamma$ )Lu178( $\beta^-$ )Hf178(n, $\gamma$ ) Hf179(n, $\gamma$ )Hf180(n, $\gamma$ )Hf181( $\beta^-$ )Ta181(n,X)H3 Yb171(n,X)H3 Yb173(n,X)H3 Yb172(n,2n)Yb171(n,X)H3 Yb174(n,X)H3 Yb172(n,X)H3 Yb176(n,2n)Yb175( $\beta^-$ )Lu175(n,X)H3 Yb176(n,X)H3 Yb174(n,2n)Yb173(n,X)H3 Yb170(n,2n)Yb169( $\beta^+$ )Tm169(n,X)H3	54.5 29.8 6.4 1.3 2.2 95.2 3.5 44.6 11.6 10.7 9.5 5.8 4.3 3.9 3.6 1.2	0.3 77.0 0.6		
Hf178n	31.0 y	Yb174(n, $\gamma$ )Yb175( $\beta^-$ )Lu175(n, $\gamma$ )Lu176m( $\beta^-$ ) Hf176(n, $\gamma$ )Hf177(n, $\gamma$ )Hf178n Yb174(n, $\gamma$ )Yb175( $\beta^-$ )Lu175(n, $\gamma$ )Lu176(n, $\gamma$ ) Lu177( $\beta^-$ )Hf177(n, $\gamma$ )Hf178n Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ )Lu175(n, $\gamma$ ) Lu176m( $\beta^-$ )Hf176(n, $\gamma$ )Hf177(n, $\gamma$ )Hf178n Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ )Lu175(n, $\gamma$ ) Lu176(n, $\gamma$ )Lu177( $\beta^-$ )Hf177(n, $\gamma$ )Hf178n &Yb176(n, $\gamma$ )Yb177( $\beta^-$ )Lu177( $\beta^-$ )Hf177(n, $\gamma$ )Hf178n &Yb176(n, $\gamma$ )Yb177( $\beta^-$ )Lu177( $\beta^-$ )Hf177(n, $\gamma$ )Hf178n	46.7 25.0 9.6 9.4 8.4 99.6	0.1 0.3 0.2 99.7		
Ho166m	1200 y	Yb168(n, $\alpha$ )Er165( $\beta^+$ )Ho165(n, $\gamma$ )Ho166m &Yb168(n, $\gamma$ )Yb169( $\beta^+$ )Tm169(n, $\alpha$ )Ho166m &Yb170(n,2n)Yb169( $\beta^+$ )Tm169(n, $\alpha$ )Ho166m &Yb171(n,2n)Yb170(n,2n)Yb169( $\beta^+$ )Tm169(n, $\alpha$ )Ho166m &Yb172(n,2n)Yb171(n,2n)Yb170(n,2n)Yb169( $\beta^+$ ) Tm169(n, $\alpha$ )Ho166m	60.5 34.8	99.8 46.7 53.2		63.3 31.6 3.7
Ho163	4570 y	Yb168(n, $\alpha$ )Er164(n,2n)Er163( $\beta^+$ )Ho163 &Yb168(n,2n)Yb167( $\beta^+$ )Tm167( $\beta^+$ )Er167(n,2n)Er166(n,2n) Er165( $\beta^+$ )Ho165(n,2n)Ho164( $\beta^-$ )Er164(n,2n)Er163( $\beta^+$ )Ho163 &Yb168(n, $\alpha$ )Er165( $\beta^+$ )Ho165(n,2n)Ho164( $\beta^-$ ) Er164(n,2n)Er163( $\beta^+$ )Ho163 &Yb170(n,n $\alpha$ )Er166(n,2n)Er165( $\beta^+$ )Ho165(n,2n) Ho164( $\beta^-$ )Er164(n,2n)Er163( $\beta^+$ )Ho163 &Yb170(n,2n)Yb169( $\beta^+$ )Tm169(n,n $\alpha$ )Ho165(n,2n) Ho164( $\beta^-$ )Er164(n,2n)Er163( $\beta^+$ )Ho163 Yb168(n,2n)Yb167( $\beta^+$ )Tm167(n,n $\alpha$ )Ho163 &Yb171(n,2n)Yb170(n,n $\alpha$ )Er166(n,2n)Er165( $\beta^+$ ) Ho165(n,2n)Ho164( $\beta^-$ )Er164(n,2n)Er163( $\beta^+$ )Ho163				49.1 21.1 12.4 4.0 1.3 1.2 1.2
Gd150	$1.8 \cdot 10^6$ y	Very long pathways of (n, $\alpha$ ), (n,2n), ( $\beta^+$ ), etc				100.0
Dy154	$2.9 \cdot 10^6$ y	Very long pathways of (n, $\alpha$ ), (n,2n), ( $\beta^+$ ), etc				100.0

Hf182	$9.0 \cdot 10^6$ y	<b>&amp;Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)Lu175(n,<math>\gamma</math>)Lu176(n,<math>\gamma</math>)</b> Lu177( $\beta^-$ )Hf177(n, $\gamma$ )Hf178(n, $\gamma$ ) <i>Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)</i> Hf181(n, $\gamma$ )Hf182 <b>&amp;Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)Lu175(n,<math>\gamma</math>)Lu176m(<math>\beta^-</math>)</b> Hf176(n, $\gamma$ )Hf177(n, $\gamma$ )Hf178(n, $\gamma$ ) <i>Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)</i> Hf181(n, $\gamma$ )Hf182 <b>&amp;Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)Lu175(n,<math>\gamma</math>)Lu176(n,<math>\gamma</math>)</b> Lu177(n, $\gamma$ )Lu178( $\beta^-$ )Hf178(n, $\gamma$ ) <i>Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)</i> Hf181(n, $\gamma$ )Hf182 <b>&amp;Yb176(n,<math>\gamma</math>)Yb177(<math>\beta^-</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)</b> Hf178(n, $\gamma$ ) <i>Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)</i> Hf181(n, $\gamma$ )Hf182 <b>&amp;Yb176(n,<math>\gamma</math>)Yb177(<math>\beta^-</math>)Lu177(n,<math>\gamma</math>)Lu178(<math>\beta^-</math>)</b> Hf178(n, $\gamma$ ) <i>Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)</i> Hf181(n, $\gamma$ )Hf182 <b>&amp;Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)Lu175(n,<math>\gamma</math>)</b> Lu176(n, $\gamma$ )Lu177(n, $\gamma$ )Lu178( $\beta^-$ )Hf178(n, $\gamma$ ) <i>Hf179(n,<math>\gamma</math>)</i> <i>Hf180(n,<math>\gamma</math>)</i> Hf181(n, $\gamma$ )Hf182 <b>&amp;Yb173(n,<math>\gamma</math>)Yb174(n,<math>\gamma</math>)Yb175(<math>\beta^-</math>)Lu175(n,<math>\gamma</math>)</b> Lu176(n, $\gamma$ )Lu177(n, $\gamma$ )Lu178( $\beta^-$ )Hf178(n, $\gamma$ ) <i>Hf179(n,<math>\gamma</math>)</i> <i>Hf180(n,<math>\gamma</math>)</i> Hf181(n, $\gamma$ )Hf182	36.4		0.1	
		20.2		0.1		
		16.3				
		12.0	94.9	96.8		
		5.3	3.5	1.6		
		4.2				
		1.9				
		1.9				
Lu176	$3.6 \cdot 10^{10}$ y	Yb174(n, $\gamma$ )Yb175( $\beta^-$ )Lu175(n, $\gamma$ )Lu176 Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ )Lu175(n, $\gamma$ )Lu176 Yb172(n, $\gamma$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ )Yb175( $\beta^-$ ) Lu175(n, $\gamma$ )Lu176 Yb171(n, $\gamma$ )Yb172(n, $\gamma$ )Yb173(n, $\gamma$ )Yb174(n, $\gamma$ ) Yb175( $\beta^-$ )Lu175(n, $\gamma$ )Lu176 Yb176(n,2n)Yb175( $\beta^-$ )Lu175(n, $\gamma$ )Lu176	63.6 34.1 1.6	53.7 17.2 19.2	98.3 1.7	0.1
				9.9		
						99.8

# Ytterbium activation characteristics

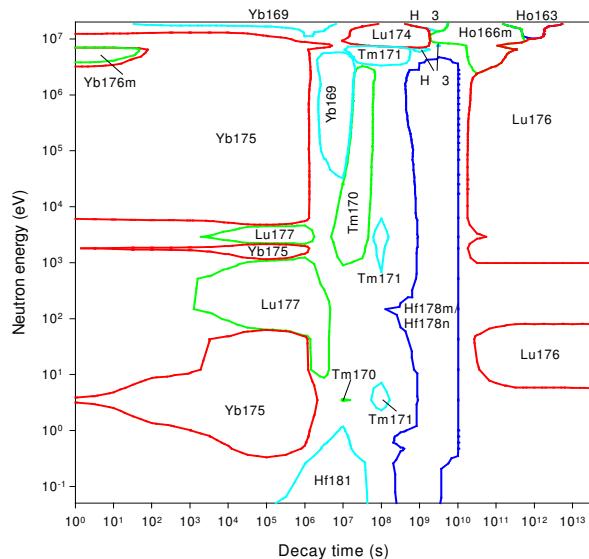


Decay time (years)

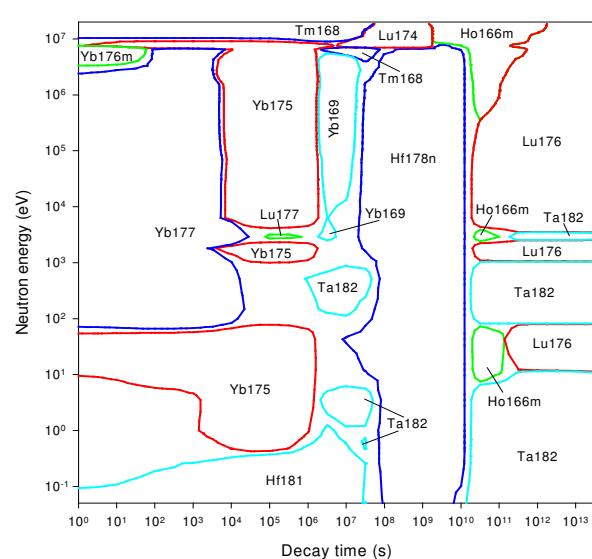
Decay time (years)

# Ytterbium importance diagrams & transmutation

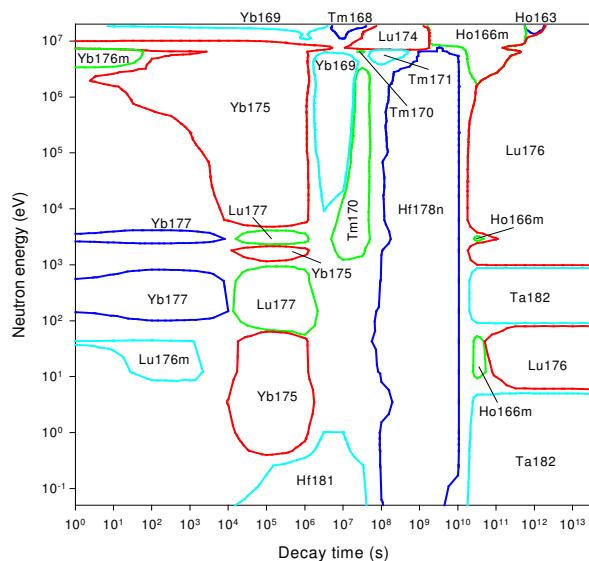
## Activity



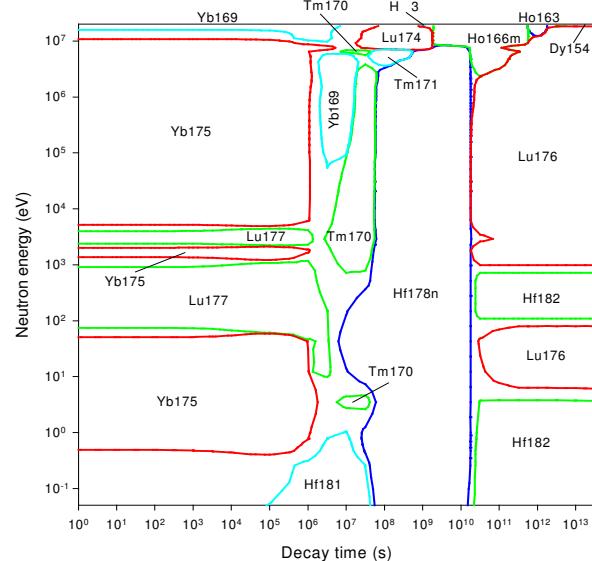
## Dose rate



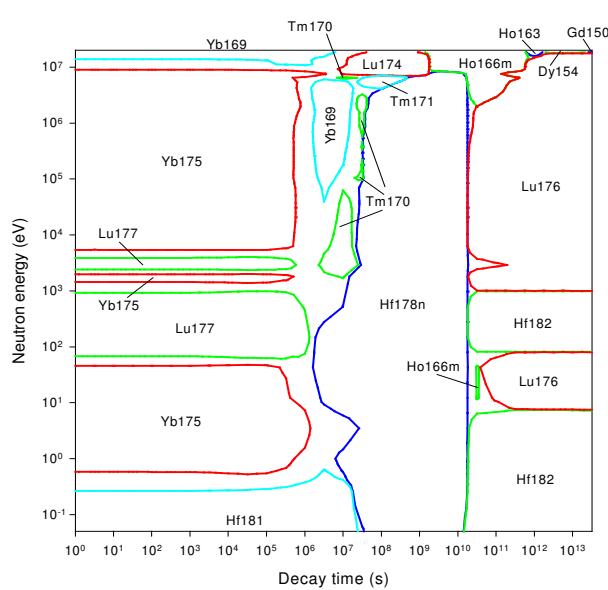
## Heat output



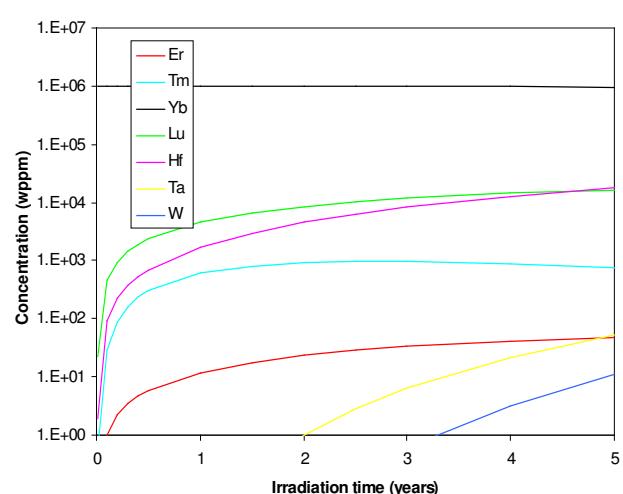
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Lutetium

## General properties

Atomic number	71	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	0.8	Lu175	97.41
Melting point / K	1936	Lu176	2.59 ( $T_{1/2} = 3.612 \cdot 10^{10}$ y)
Boiling point / K	3666		
Density / kgm <sup>-3</sup>	9841		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	16.4		
Electrical resistivity /Ωm	$7.9 \cdot 10^{-7}$		
Coefficient of thermal expansion / K <sup>-1</sup>	$9.9 \cdot 10^{-6}$		
Crystal structure	HCP		
Number of stable isotopes	1(2)		
Mean atomic weight	174.967		

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.63E16	8.98E15	3.32E15	9.94E13	4.16E11	4.03E6	kW kg <sup>-1</sup>	9.91E-1	5.53E-1	1.52E-1	5.07E-3	8.14E-5	5.72E-10
Hf179m	43.38						Hf179m	40.82					
Lu176m	26.68	47.49					Lu176m	34.31	60.46				
Lu177	22.88	41.40	76.68	0.19			Lu177	11.08	19.85	49.47	0.11		
Hf181	1.95	3.53	8.98	0.81			Hf181	3.77	6.75	23.11	1.87		
Hf175	1.40	2.53	6.60	6.15			Lu178	1.91	3.01				
Lu178	0.84	1.34					Hf178m	1.64	0.07	0.24	6.89	46.95	
Hf178m	0.54	0.02	0.06	1.91	49.99		Hf175	1.50	2.69	9.44	7.89		
Lu174	0.49	0.88	2.37	69.51			Ta182	1.40	2.51	8.91	30.07		80.78
Ta182	0.36	0.64	1.70	6.39		47.77	Hf180m	1.03	1.83				
Hf180m	0.34	0.62					Hf177m	1.03	0.15	0.43	2.68		
Lu174m	0.33	0.59	1.57	9.01			Hf179n	0.87	1.55	5.09	0.01		
Hf179n	0.30	0.54	1.33				Lu174	0.21	0.37	1.34	35.24		
Lu173	0.03	0.05	0.13	2.55			Lu174m	0.15	0.28	0.98	5.05		
Lu177m	0.03	0.05	0.12	0.84			Hf178n	0.04	0.07	0.27	7.79	53.05	
Hf178n	0.01	0.02	0.06	1.91	49.99		Lu173	0.02	0.03	0.10	1.73		
Hf182					47.77		Hf182						15.29
Lu176					4.45		Lu176						3.93
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	1.25E5	6.14E4	4.81E4	4.00E3	4.58E1	6.33E-4	Sv kg <sup>-1</sup>	3.40E6	3.38E6	1.98E6	4.74E4	9.77E2	8.98E-3
Hf179m	42.56						Lu177	58.05	58.27	68.13	0.21		
Ta182	14.68	29.87	37.29	50.48		96.76	Lu176m	21.71	21.44				
Hf181	14.28	29.05	34.93	1.14			Hf181	10.27	10.31	16.56	1.87		
Hf178m	5.91	0.27	0.34	3.99	38.06		Hf175	2.75	2.76	4.54	5.28		
Hf175	4.27	8.69	10.70	3.59			Ta182	2.55	2.56	4.27	20.07		32.14
Lu178	4.18	7.48					Hf179n	1.72	1.73	2.67	0.01		
Hf180m	3.91	7.87					Lu174m	0.83	0.83	1.40	10.00		
Lu177	3.06*	6.22*	5.44*	0.01			Lu174	0.63	0.63	1.07	39.31		
Hf179n	2.88	5.85	6.75				Hf178n	0.27	0.27	0.46	18.84	100.00	
Hf177m	2.10	0.36	0.35	0.88			Lu177m	0.20	0.20	0.34	3.00		
Lu174	1.19	2.41	3.08	32.49			Lu173	0.03	0.03	0.06	1.39		
Hf178n	0.21	0.43	0.55	6.49	61.94		Hf182						64.27
Hf182					2.45		Lu176						3.59

<b>Inh</b>	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>	<b>Clear</b>	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>
Sv kg <sup>-1</sup>	8.78E6	8.77E6	6.69E6	9.17E5	5.40E4	6.28E-1		2.86E12	9.55E11	5.20E11	2.55E10	4.69E8	3.01E3
Lu177	50.85	50.89	45.70	0.03			Hf179m	61.57					
Hf181	18.06	18.08	22.31	0.44			Lu176m	9.46	27.92				
Ta182	6.57	6.58	8.43	6.93		3.06	Lu177	6.84	20.49	25.82	0.04		
Lu176m	5.93	5.84					Hf181	6.15	18.44	31.92	1.76		
Hf178n	5.76	5.77	7.55	53.93	100.00		Hf178m	3.14	0.21	0.38	7.61	45.25	
Lu174	3.77	3.77	4.94	31.65			Hf175	2.94	8.83	15.64	8.88		
Hf175	3.11	3.12	3.93	0.80			Ta182	2.62	7.85	14.11	32.31		82.98
Lu174m	2.55	2.55	3.28	4.10			Hf180m	1.98	5.86				
Hf179n	2.11	2.11	2.50				Hf177m	1.84	0.46	0.65	2.76		
Lu177m	0.74	0.74	0.96	1.46			Hf179n	1.55	4.64	7.71	0.01		
Ta183	0.25	0.25	0.20				Lu178	1.04	2.74				
Lu173	0.12	0.12	0.15	0.66			Lu174	0.33	0.99	1.83	32.62		
Hf180m	0.08	0.08					Lu174m	0.13	0.40	0.72	2.51		
Hf182						94.94	Hf178n	0.08	0.25	0.46	9.20	54.75	
Lu176						2.00	Lu173	0.03	0.08	0.14	1.74		
							Hf182						13.89
							Lu176						3.13

# Lutetium

## Pathway analysis

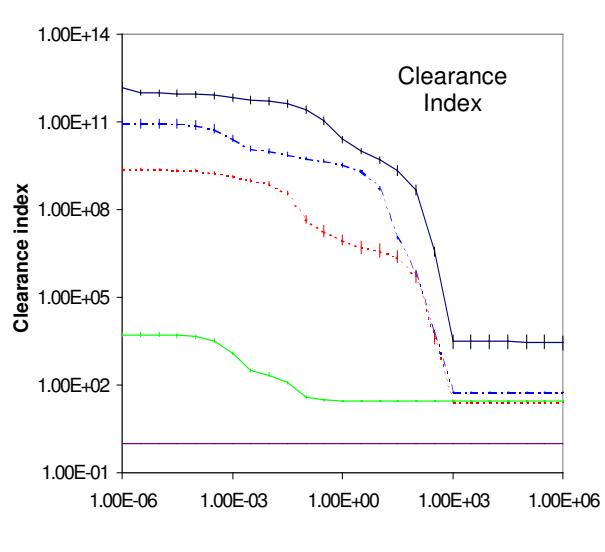
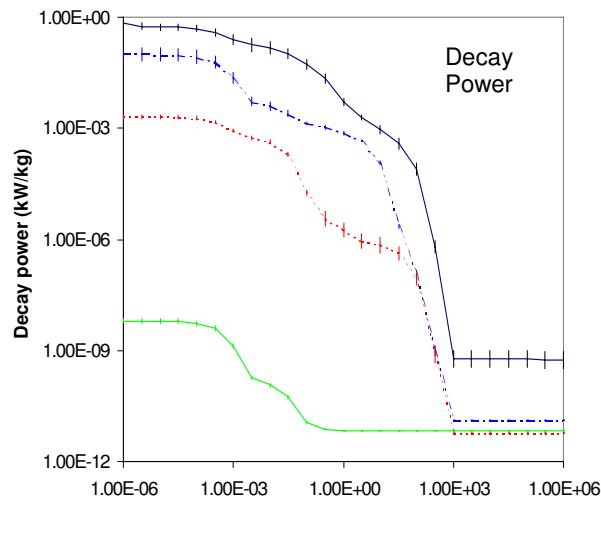
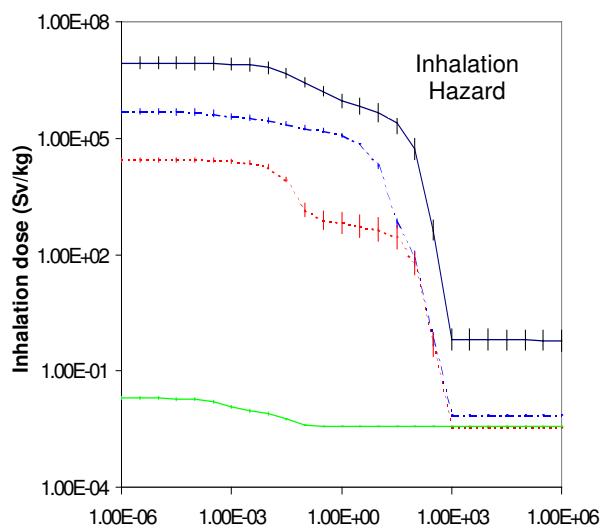
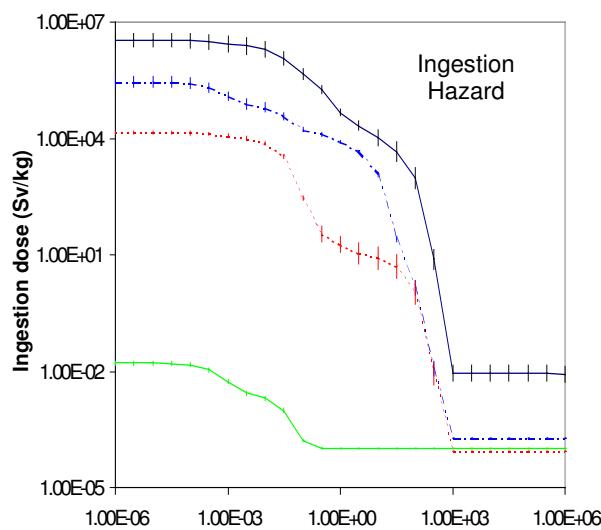
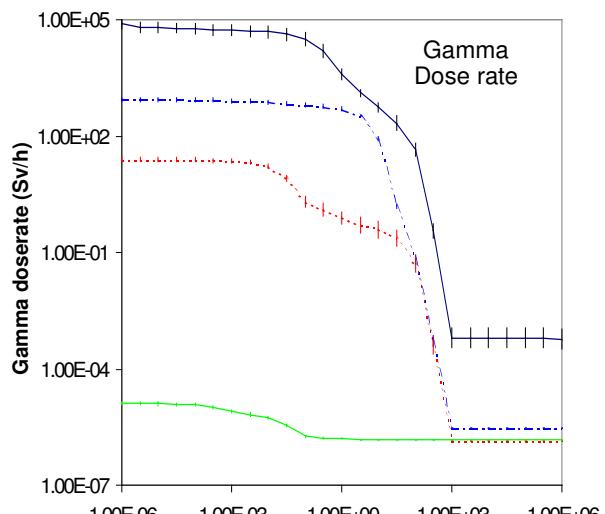
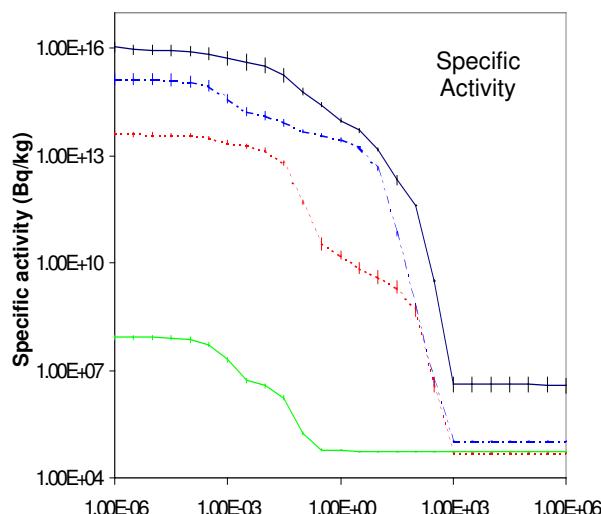
Nuclide	T <sub>½</sub>	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Hf177m	1.08 s	Lu175(n, $\gamma$ )Lu176m( $\beta^-$ )Hf176(n, $\gamma$ )Hf177m Lu175(n, $\gamma$ )Lu176(n, $\gamma$ )Lu177m( $\beta^-$ )Hf177m Lu176(n, $\gamma$ )Lu177m( $\beta^-$ )Hf177m <b>&amp;Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,n')Hf177m</b>	65.7 34.1	8.1 91.1 0.8	33.6 44.0 22.3	0.2 26.7 71.8
Hf178m	4.0 s	Lu175(n, $\gamma$ )Lu176m( $\beta^-$ )Hf176(n, $\gamma$ )Hf177(n, $\gamma$ )Hf178m <b>&amp;Lu175(n,<math>\gamma</math>)Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178m</b> Lu175(n, $\gamma$ )Lu176m( $\beta^-$ )Hf176(n, $\gamma$ )Hf177(n, $\gamma$ ) Hf178n(IT)Hf178m <b>&amp;Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178m</b> Lu176(n, $\gamma$ )Lu177( $\beta^-$ )Hf177(n, $\gamma$ )Hf178(n,n')Hf178m	55.9 22.5 21.5	1.9 90.4 2.1 5.5	20.4 36.2 7.4 36.5	0.4 97.0 2.0
Hf179m	18.67 s	<b>&amp;Lu175(n,<math>\gamma</math>)Lu176m(<math>\beta^-</math>)Hf176(n,<math>\gamma</math>)Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)Hf179m</b> <b>&amp;Lu175(n,<math>\gamma</math>)Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)Hf179m</b> Lu175(n, $\gamma$ )Lu176(n, $\gamma$ )Lu177(n, $\gamma$ )Lu178( $\beta^-$ )Hf178(n, $\gamma$ )Hf179m <b>&amp;Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)Hf179m</b>	66.0 24.1 9.3 0.1	2.5 87.9 2.3 6.7	24.5 32.0 0.3 43.3	0.3 99.8
Lu178	28.4 m	Lu175(n, $\gamma$ )Lu176(n, $\gamma$ )Lu177(n, $\gamma$ )Lu178 Lu176(n, $\gamma$ )Lu177(n, $\gamma$ )Lu178 <b>&amp;Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178(n,p)Lu178</b> Lu176(n, $\gamma$ )Lu177m(n, $\gamma$ )Lu178	99.4	99.6 0.3	69.6 30.6	0.5 63.3 26.9 8.9
Lu176m	3.681 h	Lu175(n, $\gamma$ )Lu176m Lu176(n,n')Lu176m	100.0	100.0	100.0	32.5 66.7
Tm172	2.651 d	Lu175(n, $\alpha$ )Tm172 Lu176(n,2n)Lu175(n, $\alpha$ )Tm172	99.7	99.2	99.9	96.0 0.8
Lu172	6.7 d	<b>&amp;Lu175(n,2n)Lu174(n,2n)Lu173(n,2n)Lu172</b> <b>&amp;Lu175(n,3n)Lu173(n,2n)Lu172</b> <b>&amp;Lu175(n,2n)Lu174m(n,2n)Lu173(n,2n)Lu172</b>				84.0 7.7 6.0
Lu177	6.7 d	Lu175(n, $\gamma$ )Lu176(n, $\gamma$ )Lu177 Lu176(n, $\gamma$ )Lu177	99.4	99.6 0.3	69.5 30.5	0.8 98.8
Hf181	42.38 d	<b>&amp;Lu175(n,<math>\gamma</math>)Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181</b> <b>&amp;Lu175(n,<math>\gamma</math>)Lu176m(<math>\beta^-</math>)Hf176(n,<math>\gamma</math>)Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181</b> <b>&amp;Lu175(n,<math>\gamma</math>)Lu176(n,<math>\gamma</math>)Lu177(n,<math>\gamma</math>)Lu178(<math>\beta^-</math>)Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181</b> <b>&amp;Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181</b> <b>&amp;Lu176(n,<math>\gamma</math>)Lu177(n,<math>\gamma</math>)Lu178(<math>\beta^-</math>)Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181</b> <b>&amp;Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178m(IT)Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181</b>	40.1 35.2 16.9 5.1 2.1	84.1 1.4 2.8 10.8 0.3	23.9 18.5 0.4 55.8 0.7	0.1 88.2 0.2 10.8
Ta182	114.7 d	<b>&amp;Lu175(n,<math>\gamma</math>)Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182</b> <b>&amp;Lu175(n,<math>\gamma</math>)Lu176m(<math>\beta^-</math>)Hf176(n,<math>\gamma</math>)Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182</b> <b>&amp;Lu175(n,<math>\gamma</math>)Lu176(n,<math>\gamma</math>)Lu177(n,<math>\gamma</math>)Lu178(<math>\beta^-</math>)Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182</b> <b>&amp;Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182</b> <b>&amp;Lu176(n,<math>\gamma</math>)Lu177(n,<math>\gamma</math>)Lu178(<math>\beta^-</math>)Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182</b>	42.1 27.7 18.4 7.7	81.6 1.1 3.0 12.7	20.5 16.0 0.4 61.1	
Lu177m	160.3 d	Lu175(n, $\gamma$ )Lu176(n, $\gamma$ )Lu177m Lu176(n, $\gamma$ )Lu177m	99.8	99.1 0.9	66.4 33.6	0.7 99.1

Lu174	3.559 y	&Lu175(n,2n)Lu174				97.5	
H3	12.33 y	Lu175(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Lu175(n, $\gamma$ )Lu176(n, $\gamma$ )Lu177( $\beta^-$ )Hf177(n,X)H1(n, $\gamma$ ) H2(n, $\gamma$ )H3 Lu175(n, $\gamma$ )Lu176(n, $\gamma$ )Lu177( $\beta^-$ )Hf177(n,X)H1(n, $\gamma$ ) H2(n, $\gamma$ )H3 Lu175(n, $\gamma$ )Lu176(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Lu176(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Lu176(n, $\gamma$ )Lu177( $\beta^-$ )Hf177(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 <b>&amp;Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)</b> <i>Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,X)H3</i> <b>&amp;Lu175(n,<math>\gamma</math>)Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,X)H3</b> <b>&amp;Lu175(n,<math>\gamma</math>)Lu176m(<math>\beta^-</math>)Hf176(n,<math>\gamma</math>)Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,X)H3</b> <b>&amp;Lu176(n,<math>\gamma</math>)Lu177(n,<math>\gamma</math>)Lu178(<math>\beta^-</math>)Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,X)H3</b> Lu175(n,X)H3	90.9 1.1 0.7 9.8 1.4 0.8 61.0 21.0 16.0 1.0	76.8 5.6 5.6 9.8 1.4 0.8 61.0 21.0 16.0 1.0	1.0	96.7	
Hf178n	31.0 y	Lu175(n, $\gamma$ )Lu176m( $\beta^-$ )Hf176(n, $\gamma$ )Hf177(n, $\gamma$ )Hf178n Lu175(n, $\gamma$ )Lu176(n, $\gamma$ )Lu177( $\beta^-$ )Hf177(n, $\gamma$ )Hf178n Lu176(n, $\gamma$ )Lu177( $\beta^-$ )Hf177(n, $\gamma$ )Hf178n Lu176(n, $\gamma$ )Lu177( $\beta^-$ )Hf177(n, $\gamma$ )Hf178(n,n')Hf178n	73.3 26.5	2.7 90.5 6.7	24.6 32.2 43.2	95.7 3.8	
Ho166m	1200 y	Lu175(n, $\alpha$ )Tm172( $\beta^-$ )Yb172(n, $\alpha$ )Er169( $\beta^-$ ) Tm169(n, $\alpha$ )Ho166m <b>&amp;Lu175(n,2n)Lu174(n,n<math>\alpha</math>)Tm170(<math>\beta^-</math>)Yb170(n,2n)</b> <i>Yb169(<math>\beta^+</math>)Tm169(n,<math>\alpha</math>)Ho166m</i> <b>&amp;Lu175(n,2n)Lu174(n,n<math>\alpha</math>)Lu173(n,n<math>\alpha</math>)Tm169(n,<math>\alpha</math>)Ho166m</b> <b>&amp;Lu175(n,2n)Lu174(n,n<math>\alpha</math>)Tm170(n,2n)Tm169(n,<math>\alpha</math>)Ho166m</b> <b>&amp;Lu175(n,n<math>\alpha</math>)Tm171(n,2n)Tm170(<math>\beta^-</math>)Yb170(n,2n)</b> <i>Yb169(<math>\beta^+</math>)Tm169(n,<math>\alpha</math>)Ho166m</i> <b>&amp;Lu175(n,<math>\alpha</math>)Tm172(<math>\beta^-</math>)Yb172(n,2n)Yb171(n,2n)</b> <i>Yb170(n,2n)Yb169(<math>\beta^+</math>)Tm169(n,<math>\alpha</math>)Ho166m</i> <b>&amp;Lu175(n,n<math>\alpha</math>)Tm171(<math>\beta^-</math>)Yb171(n,2n)Yb170(n,2n)</b> <i>Yb169(<math>\beta^+</math>)Tm169(n,<math>\alpha</math>)Ho166m</i> <b>&amp;Lu175(n,2n)Lu174(n,2n)Lu173(n,2n)Lu172(<math>\beta^+</math>)</b> <i>Yb172(n,<math>\alpha</math>)Er169(<math>\beta^-</math>)Tm169(n,<math>\alpha</math>)Ho166m</i> <b>Lu175(n,n<math>\alpha</math>)Tm171(n,2n)Tm170(n,2n)Tm169(n,<math>\alpha</math>)Ho166m</b> <b>&amp;Lu175(n,3n)Lu173(n,2n)Lu172(<math>\beta^+</math>)Yb172(n,2n)</b> <i>Yb171(n,2n)Yb170(n,2n)Yb169(<math>\beta^+</math>)Tm169(n,<math>\alpha</math>)Ho166m</i> <b>Lu175(n,3n)Lu173(n,n<math>\alpha</math>)Tm169(n,<math>\alpha</math>)Ho166m</b> <b>&amp;Lu175(n,2n)Lu174(n,2n)Lu173(n,<math>\alpha</math>)Tm170(<math>\beta^-</math>)</b> <i>Yb170(n,2n)Yb169(<math>\beta^+</math>)Tm169(n,<math>\alpha</math>)Ho166m</i> <b>&amp;Lu175(n,2n)Lu174m(n,n<math>\alpha</math>)Tm170(<math>\beta^-</math>)Yb170(n,2n)</b> <i>Yb169(<math>\beta^+</math>)Tm169(n,<math>\alpha</math>)Ho166m</i> <b>&amp;Lu175(n,2n)Lu174(n,<math>\alpha</math>)Tm171(n,2n)Tm170(<math>\beta^-</math>)</b> <i>Yb170(n,2n)Yb169(<math>\beta^+</math>)Tm169(n,<math>\alpha</math>)Ho166m</i> <b>&amp;Lu175(n,2n)Lu174(n,2n)Lu173(<math>\beta^+</math>)Yb173(n,2n)</b> <i>Yb172(n,<math>\alpha</math>)Er169(<math>\beta^-</math>)Tm169(n,<math>\alpha</math>)Ho166m</i> <b>Lu175(n,2n)Lu174m(n,2n)Lu173(n,n<math>\alpha</math>)Tm169(n,<math>\alpha</math>)Ho166m</b> <b>Lu175(n,2n)Lu174m(n,2n)Lu173(n,n<math>\alpha</math>)Tm169(n,<math>\alpha</math>)Ho166m</b> <b>&amp;Lu175(n,3n)Lu173(<math>\beta^+</math>)Yb173(n,2n)Yb172(n,2n)</b> <i>Yb171(n,2n)Yb170(n,2n)Yb169(<math>\beta^+</math>)Tm169(n,<math>\alpha</math>)Ho166m</i> <b>&amp;Lu175(n,2n)Lu174(n,2n)Lu173(n,<math>\alpha</math>)Tm170(n,2n)Tm169(n,<math>\alpha</math>)Ho166m</b> <b>&amp;Lu175(n,2n)Lu174(n,2n)Lu173(<math>\beta^+</math>)Yb173(n,<math>\alpha</math>)</b> <i>Er170(n,2n)Er169(<math>\beta^-</math>)Tm169(n,<math>\alpha</math>)Ho166m</i> <b>&amp;Lu175(n,2n)Lu174(n,<math>\alpha</math>)Tm171(n,2n)Tm170(n,2n)Tm169(n,<math>\alpha</math>)Ho166m</b>	100.0			0.8 15.5 11.8 7.9 5.9 3.7 3.5 3.0 2.9 2.7 2.4 1.8 1.7 1.6 1.6 1.5 1.5 1.2 1.1 1.0 1.0	25.9*

\*Plus other similar pathways

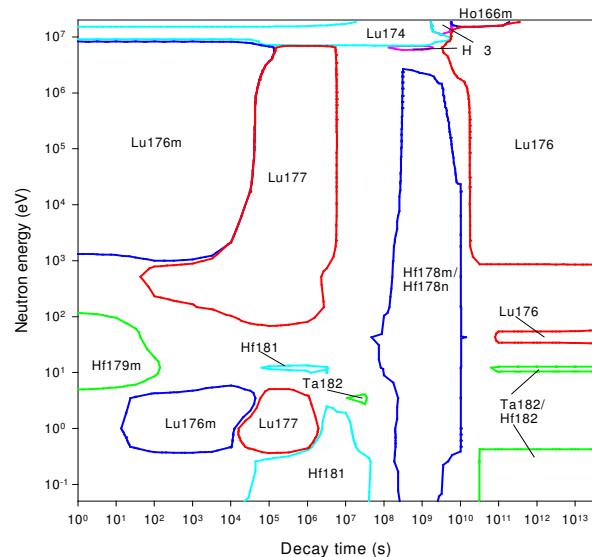
Hf182	$9.0 \cdot 10^6$ y	<b>&amp;Lu175(n,<math>\gamma</math>)Lu176(n,<math>\gamma</math>)Lu177(<math>\beta^-</math>)Hf177(n,<math>\gamma</math>)</b> Hf178(n, $\gamma$ ) <i>Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(n,<math>\gamma</math>)Hf182</i> <b>&amp;Lu175(n,<math>\gamma</math>)Lu176m(<math>\beta^-</math>)Hf176(n,<math>\gamma</math>)Hf177(n,<math>\gamma</math>)</b> Hf178(n, $\gamma$ ) <i>Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(n,<math>\gamma</math>)Hf182</i> <b>&amp;Lu175(n,<math>\gamma</math>)Lu176(n,<math>\gamma</math>)Lu177(n,<math>\gamma</math>)Lu178(<math>\beta^-</math>)</b> Hf178(n, $\gamma$ ) <i>Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(n,<math>\gamma</math>)Hf182</i> <b>&amp;Lu176(n,<math>\gamma</math>)Lu177(n,<math>\gamma</math>)Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)</b> <i>Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(n,<math>\gamma</math>)Hf182</i> <b>&amp;Lu176(n,<math>\gamma</math>)Lu177(n,<math>\gamma</math>)Lu178(<math>\beta^-</math>)Hf178(n,<math>\gamma</math>)</b> <i>Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(n,<math>\gamma</math>)Hf182</i>	41.9 27.0 18.4 7.9 3.4	81.1 1.1 3.1 12.9 0.5	21.2 16.5 0.4 59.5 1.0	
Lu176	$3.6 \cdot 10^{10}$ y	Lu175(n, $\gamma$ )Lu176 *Nuclide also present in starting material	99.9 0.1*	99.7 0.3*	64.4 35.6*	0.8 99.2*

# Lutetium activation characteristics

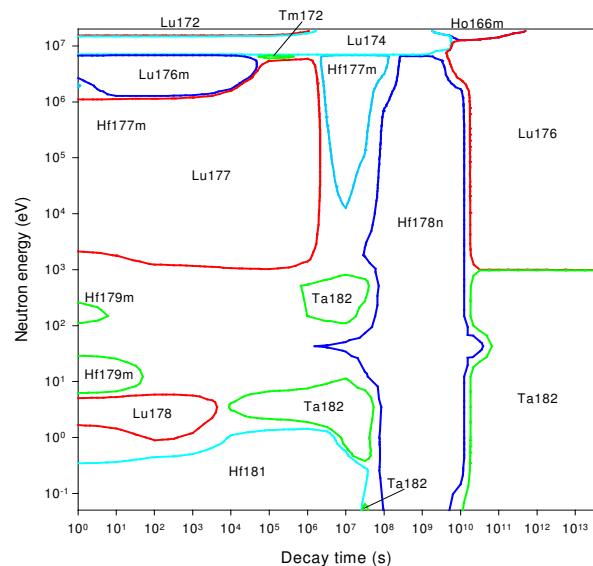


# Lutetium importance diagrams & transmutation

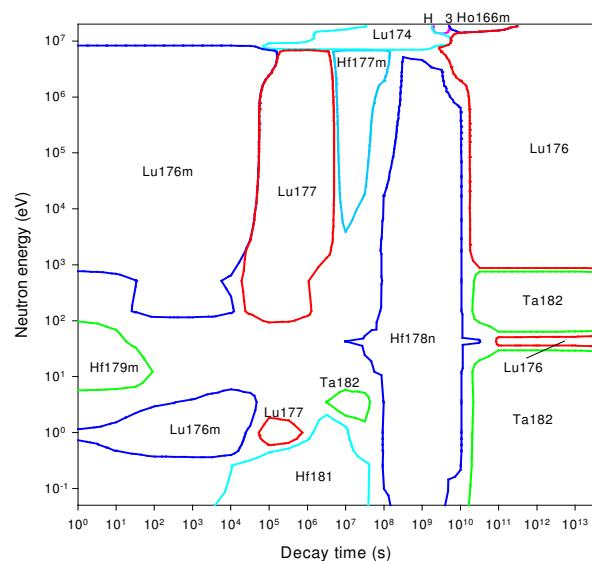
## Activity



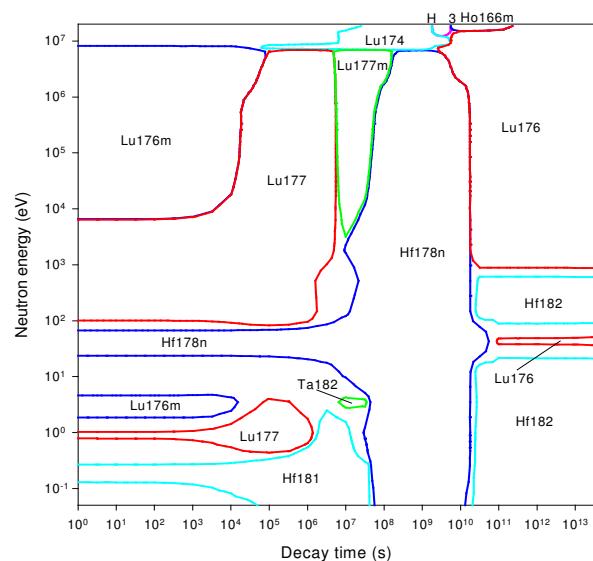
## Dose rate



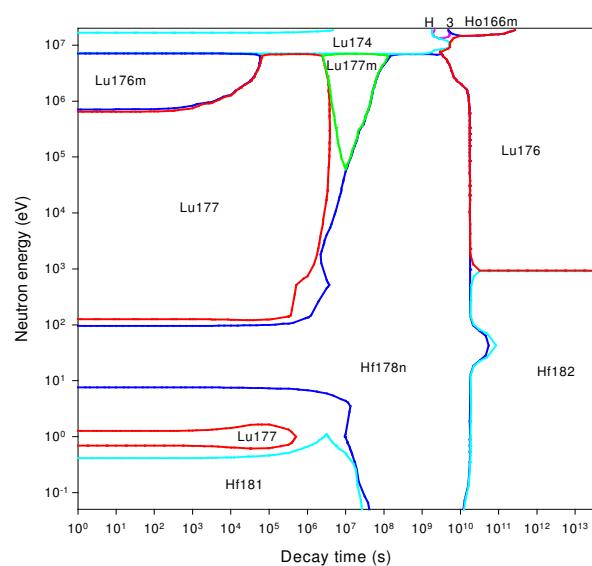
## Heat output



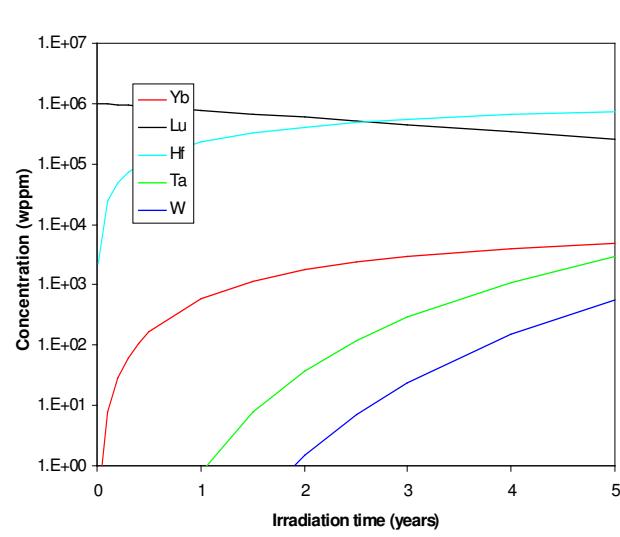
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Hafnium

## General properties

Atomic number	72	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	3.0	Hf174	0.16 ( $T_{1/2} = 2.0 \cdot 10^{15}$ y)
Melting point / K	2506	Hf176	5.26
Boiling point / K	4876	Hf177	18.60
Density / kgm <sup>-3</sup>	13310	Hf178	27.28
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	23.0	Hf179	13.62
Electrical resistivity /Ωm	$3.51 \cdot 10^{-7}$	Hf180	35.08
Coefficient of thermal expansion / K <sup>-1</sup>	$5.9 \cdot 10^{-6}$		
Crystal structure	HCP		
Number of stable isotopes	5(6)		
Mean atomic weight	178.49		

## Activation properties

Act	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Heat	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y
Bq kg <sup>-1</sup>	6.35E15	4.28E15	3.84E15	1.53E14	7.17E10	9.50E7	kW kg <sup>-1</sup>	7.89E-1	6.58E-1	6.04E-1	3.52E-2	1.40E-5	1.36E-8
Hf181	38.77	57.49	60.29	4.08			Ta182	39.45	47.33	50.45	97.30	0.08	84.08
Hf179m	29.81						Hf181	36.71	44.03	45.21	2.09		
Ta182	20.42	30.28	32.97	93.00	0.07	50.00	Hf179m	13.75					
Ta183	3.74	5.54	3.75				Ta183	3.06	3.67	2.44			
Hf178m	1.56		0.01	0.21	49.90		Hf178m	2.31	0.01	0.01	0.17	46.90	
Hf180m	1.18	1.73					Hf180m	1.73	2.05				
W183m	1.14	0.19	0.13				Hf179n	1.25	1.50	1.48			
Hf179n	0.89	1.32	1.32				Lu176m	0.23	0.28				
Hf175	0.39	0.58	0.62	0.44			Hf182m	0.21	0.24				
W181	0.29	0.43	0.47	1.49			Hf175	0.21	0.25	0.26	0.12		
Hf178n			0.01	0.21	49.90		Hf178n		0.01	0.01	0.19	53.00	
Hf182					0.07	50.00	Hf182					0.02	15.92
Dose	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Ing	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y
Sv h <sup>-1</sup>	5.86E5	5.63E5	5.37E5	4.57E4	7.77E0	1.55E-2	Sv kg <sup>-1</sup>	5.07E6	5.07E6	4.72E6	2.23E5	1.68E2	2.14E-1
Ta182	70.20	73.01	74.99	99.04	0.20	97.59	Hf181	53.35	53.36	54.00	3.09		
Hf181	23.27	24.20	23.94	0.76			Ta182	38.32	38.33	40.28	95.90	0.04	33.33
Hf179m	2.37						Ta183	6.08	6.08	3.97			
Hf178m	1.39	0.01	0.01	0.06	37.94		Hf179n	1.33	1.33	1.29			
Hf180m	1.09	1.13					Hf180m	0.25	0.25				
Hf179n	0.70	0.72	0.69				Hf175	0.20	0.20	0.21	0.12		
Hf178n	0.01	0.01	0.01	0.10	61.87		Hf178n	0.03	0.03	0.03	0.69	99.87	
Hf182					0.01	2.41	Hf182					0.09	66.66
Inh	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Clear	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y
Sv kg <sup>-1</sup>	2.61E7	2.61E7	2.49E7	1.54E6	9.32E3	1.52E1		3.88E12	3.29E12	3.04E12	1.90E11	8.08E7	7.20E4
Ta182	49.61	49.61	50.93	92.28	0.01	3.13	Ta182	43.42	51.21	54.18	97.56		85.66
Hf181	47.09	47.09	46.56	2.03			Hf181	35.26	41.59	42.37	1.83		
Ta183	1.91	1.91	1.22				Hf179m	12.20					
Hf179n	0.82	0.82	0.78				Hf178m	2.61	0.01	0.01	0.18		
Hf178n	0.33	0.33	0.35	5.51	99.84		Ta183	1.98	2.33	1.53			
Hf175	0.11	0.11	0.12	0.05			Hf180m	1.95	2.27				
Lu177	0.04	0.04	0.03				Hf179n	1.32	1.56	1.52			
Hf182					0.16	96.88	Hf182						14.34

# Hafnium

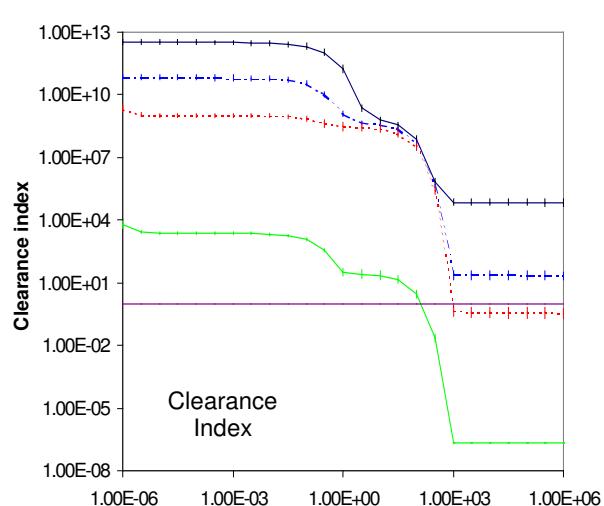
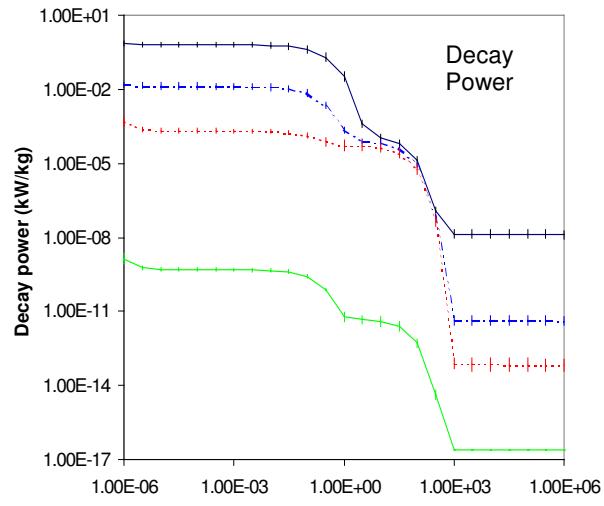
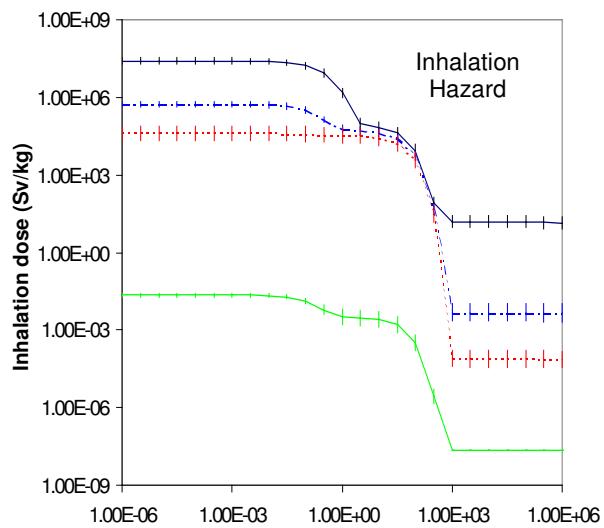
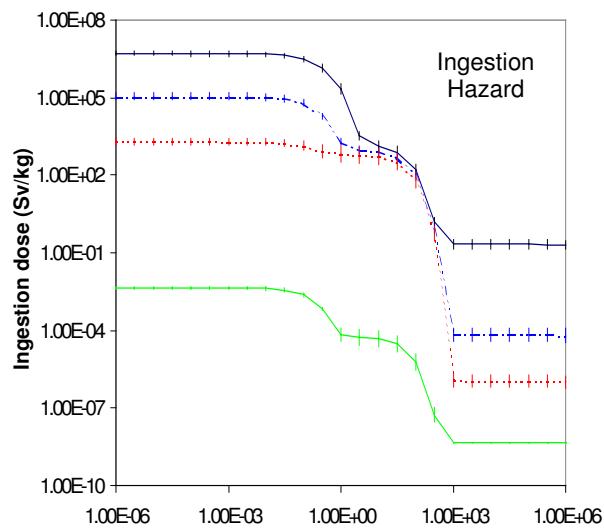
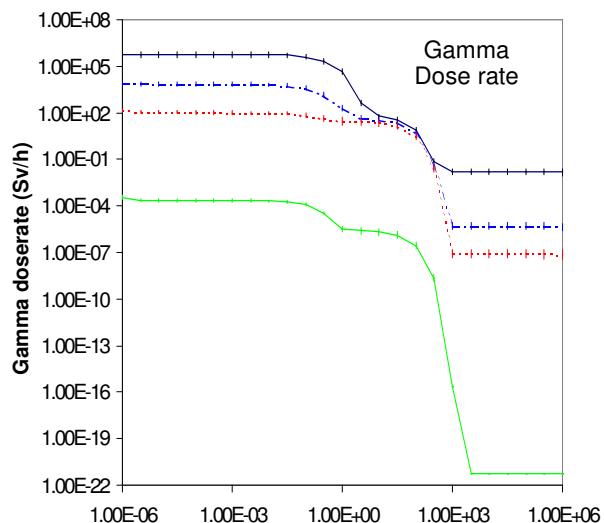
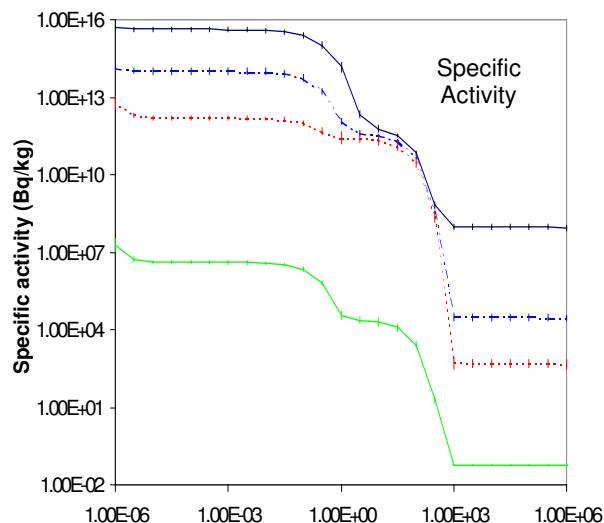
## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Hf177m	1.08 s	&Hf176(n, $\gamma$ )Hf177m &Hf174(n, $\gamma$ )Hf175( $\beta^-$ )Lu175(n, $\gamma$ )Lu176m( $\beta^-$ ) Hf176(n, $\gamma$ )Hf177m Hf174(n, $\gamma$ )Hf175( $\beta^-$ )Lu175(n, $\gamma$ )Lu176(n, $\gamma$ ) Lu177m( $\beta^-$ )Hf177m &Hf178(n,2n)Hf177m &Hf177(n,n')Hf177m &Hf178(n,2n)Hf177(n,n')Hf177m &Hf179(n,2n)Hf178(n,2n)Hf177m &Hf180(n,2n)Hf179(n,2n)Hf178(n,2n)Hf177m &Hf179(n,2n)Hf178(n,2n)Hf177(n,n')Hf177m	96.3 2.0 1.2	74.4 1.2 24.1	100.0	49.2 25.2 11.8 8.2 3.5 1.0
Hf178m	4.0 s	&Hf176(n, $\gamma$ )Hf177(n, $\gamma$ )Hf178m Hf177(n, $\gamma$ )Hf178n(IT)Hf178m &Hf174(n, $\gamma$ )Hf175(n, $\gamma$ )Hf176(n, $\gamma$ )Hf177(n, $\gamma$ )Hf178m Hf177(n, $\gamma$ )Hf178m Hf179(n,2n)Hf178m &Hf180(n,2n)Hf179(n,2n)Hf178m Hf178(n,n')Hf178m	92.2 4.9 1.8	1.1 98.2 0.2	1.6 51.8 46.6	50.8 43.4 3.8
Hf179m	18.67 s	&Hf176(n, $\gamma$ )Hf177(n, $\gamma$ )Hf178(n, $\gamma$ )Hf179m Hf178(n, $\gamma$ )Hf179m &Hf177(n, $\gamma$ )Hf178(n, $\gamma$ )Hf179m Hf180(n,2n)Hf179m	69.4 15.3 12.8	0.3 57.0 42.4	0.1 89.3 10.5	99.3
Ta183	5.09 d	&Hf180(n, $\gamma$ )Hf181( $\beta^-$ )Ta181(n, $\gamma$ )Ta182(n, $\gamma$ )Ta183 &Hf178(n, $\gamma$ )Hf179(n, $\gamma$ )Hf180(n, $\gamma$ )Hf181( $\beta^-$ ) Ta181(n, $\gamma$ )Ta182(n, $\gamma$ )Ta183 &Hf177(n, $\gamma$ )Hf178(n, $\gamma$ )Hf179(n, $\gamma$ )Hf180(n, $\gamma$ ) Hf181( $\beta^-$ )Ta181(n, $\gamma$ )Ta182(n, $\gamma$ )Ta183 &Hf179(n, $\gamma$ )Hf180(n, $\gamma$ )Hf181( $\beta^-$ )Ta181(n, $\gamma$ ) Ta182(n, $\gamma$ )Ta183 &Hf180(n, $\gamma$ )Hf181(n, $\gamma$ )Hf182(n, $\gamma$ )Hf183( $\beta^-$ )Ta183 &Hf176(n, $\gamma$ )Hf177(n, $\gamma$ )Hf178(n, $\gamma$ )Hf179(n, $\gamma$ ) Hf180(n, $\gamma$ )Hf181( $\beta^-$ )Ta181(n, $\gamma$ )Ta182(n, $\gamma$ )Ta183 &Hf178(n, $\gamma$ )Hf179(n, $\gamma$ )Hf180(n, $\gamma$ )Hf181(n, $\gamma$ ) Hf182(n, $\gamma$ )Hf183( $\beta^-$ )Ta183	41.0 23.2 15.2 13.5 2.5 1.3	56.1 12.5 6.8 20.5 2.5 0.4	95.4	97.3
Hf179n	25.116 d	&Hf176(n, $\gamma$ )Hf177(n, $\gamma$ )Hf178(n, $\gamma$ )Hf179n Hf178(n, $\gamma$ )Hf179n Hf177(n, $\gamma$ )Hf178(n, $\gamma$ )Hf179n &Hf174(n, $\gamma$ )Hf175( $\beta^-$ )Lu175(n, $\gamma$ )Lu176m( $\beta^-$ ) Hf176(n, $\gamma$ )Hf177(n, $\gamma$ )Hf178(n, $\gamma$ )Hf179n Hf180(n,2n)Hf179n Hf179(n,n')Hf179n &Hf180(n,2n)Hf179(n,n')Hf179n	67.7 16.5 13.7 1.1	0.3 57.1 42.5	89.5 10.5	47.6 28.3 23.4
Hf181	42.38 d	&Hf178(n, $\gamma$ )Hf179(n, $\gamma$ )Hf180(n, $\gamma$ )Hf181 Hf180(n, $\gamma$ )Hf181 &Hf177(n, $\gamma$ )Hf178(n, $\gamma$ )Hf179(n, $\gamma$ )Hf180(n, $\gamma$ )Hf181 &Hf179(n, $\gamma$ )Hf180(n, $\gamma$ )Hf181 &Hf176(n, $\gamma$ )Hf177(n, $\gamma$ )Hf178(n, $\gamma$ )Hf179(n, $\gamma$ ) Hf180(n, $\gamma$ )Hf181	30.7 30.6 21.0 14.7 2.7	17.8 51.4 10.6 20.0 4.6	0.2 95.2	99.1
Hf175	70.0 d	Hf174(n, $\gamma$ )Hf175 Hf177(n,2n)Hf176(n,2n)Hf175 Hf176(n,2n)Hf175 &Hf178(n,2n)Hf177(n,2n)Hf176(n,2n)Hf175	100.0	100.0	100.0	46.5 40.9 10.7

W185	75.1 d	<b>&amp;Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182(n,<math>\gamma</math>)</b> Ta183( $\beta^-$ )W183(n, $\gamma$ )W184(n, $\gamma$ )W185 <b>&amp;Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182(n,<math>\gamma</math>)Ta183(<math>\beta^-</math>)W183(n,<math>\gamma</math>)W184(n,<math>\gamma</math>)W185  <b>&amp;Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182(n,<math>\gamma</math>)Ta183(<math>\beta^-</math>)W183(n,<math>\gamma</math>)W184(n,<math>\gamma</math>)W185  <b>&amp;Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182(n,<math>\gamma</math>)Ta183(<math>\beta^-</math>)W183(n,<math>\gamma</math>)W184(n,<math>\gamma</math>)W185  <b>&amp;Hf180(n,<math>\gamma</math>)Hf181(n,<math>\gamma</math>)Hf182(n,<math>\gamma</math>)Hf183(<math>\beta^-</math>)Ta183(<math>\beta^-</math>)W183(n,<math>\gamma</math>)W184(n,<math>\gamma</math>)W185  <b>&amp;Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182(<math>\beta^-</math>)W182(n,<math>\gamma</math>)W183(n,<math>\gamma</math>)W184(n,<math>\gamma</math>)W185       </b> </b></b></b></b>	60.2 12.5 10.5 7.5 3.3 1.0	65.9 6.0 18.7 2.6 2.2 40.3	56.0 0.6 1.6 0.8 65.4	32.2
Ta182	114.7 d	Hf180(n, $\gamma$ )Hf181( $\beta^-$ )Ta181(n, $\gamma$ )Ta182 <b>&amp;Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182  <b>&amp;Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182  <b>&amp;Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182  <b>&amp;Hf176(n,<math>\gamma</math>)Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182          Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182          Hf180(n,<math>\gamma</math>)Hf181(<math>\beta^-</math>)Ta181(n,<math>\gamma</math>)Ta182m(IT)Ta182       </b></b></b></b>	43.3 24.6 16.2 14.3 1.4	58.3 13.0 7.1 21.4 2.2	97.7	54.2 44.5
Lu174	3.559 y	<b>&amp;Hf174(n,p)Lu174</b> <b>&amp;Hf176(n,2n)Hf175(<math>\beta^-</math>)Lu175(n,2n)Lu174</b> <b>&amp;Hf177(n,2n)Hf176(n,2n)Hf175(<math>\beta^-</math>)Lu175(n,2n)Lu174</b> <b>&amp;Hf178(n,2n)Hf177(n,2n)Hf176(n,2n)Hf175(<math>\beta^-</math>)Lu175(n,2n)Lu174</b> <b>&amp;Hf177(n,3n)Hf175(<math>\beta^-</math>)Lu175(n,2n)Lu174</b>	100.0	100.0	100.0	66.6 26.9 3.2 1.2
Hf178n	31.0 y	<b>&amp;Hf176(n,<math>\gamma</math>)Hf177(n,<math>\gamma</math>)Hf178n</b> Hf177(n, $\gamma$ )Hf178n <b>&amp;Hf174(n,<math>\gamma</math>)Hf175(<math>\beta^-</math>)Lu175(n,<math>\gamma</math>)Lu176m(<math>\beta^-</math>)</b> Hf176(n, $\gamma$ )Hf177(n, $\gamma$ )Hf178n Hf179(n,2n)Hf178n <b>&amp;Hf180(n,2n)Hf179(n,2n)Hf178n</b> Hf178(n,n')Hf178n	83.5 14.1 1.4	0.7 99.1	1.1 98.9	68.2 28.1 3.0
Ho166m	1200 y	<b>&amp;Hf174(n,n<math>\alpha</math>)Yb170(n,2n)Yb169(<math>\beta^-</math>)Tm169(n,<math>\alpha</math>)Ho166m</b> <b>&amp;Hf174(n,2n)Hf173(<math>\beta^-</math>)Lu173(n,2n)Lu172(<math>\beta^-</math>)Yb172(n,2n)</b> Yb171(n,2n)Yb170(n,2n)Yb169( $\beta^-$ )Tm169(n, $\alpha$ )Ho166m <b>&amp;Hf174(n,<math>\alpha</math>)Yb171(n,2n)Yb170(n,2n)Yb169(<math>\beta^-</math>)Tm169(n,<math>\alpha</math>)Ho166m</b> Tm169(n, $\alpha$ )Ho166m <b>&amp;Hf174(n,2n)Hf173(<math>\beta^-</math>)Lu173(<math>\beta^-</math>)Yb173(n,2n)Yb172(n,2n)</b> Yb171(n,2n)Yb170(n,2n)Yb169( $\beta^-$ )Tm169(n, $\alpha$ )Ho166m <b>&amp;Hf176(n,2n)Hf175(n,n<math>\alpha</math>)Yb171(n,2n)Yb170(n,2n)</b> Yb169( $\beta^-$ )Tm169(n, $\alpha$ )Ho166m <b>&amp;Hf176(n,n<math>\alpha</math>)Yb172(n,2n)Yb171(n,2n)Yb170(n,2n)</b> Yb169( $\beta^-$ )Tm169(n, $\alpha$ )Ho166m <b>&amp;Hf174(n,2n)Hf173(<math>\beta^-</math>)Lu173(n,<math>\alpha</math>)Tm170(<math>\beta^-</math>)</b> Yb170(n,2n)Yb169( $\beta^-$ )Tm169(n, $\alpha$ )Ho166m <b>&amp;Hf176(n,2n)Hf175(<math>\beta^-</math>)Lu175(n,2n)Lu174(n,no)</b> Tm170( $\beta^-$ )Yb170(n,2n)Yb169( $\beta^-$ )Tm169(n, $\alpha$ )Ho166m <b>&amp;Hf177(n,2n)Hf176(n,2n)Hf175(n,no)Yb171(n,2n)</b> Yb170(n,2n)Yb169( $\beta^-$ )Tm169(n, $\alpha$ )Ho166m <b>&amp;Hf176(n,2n)Hf175(<math>\beta^-</math>)Lu175(n,2n)Lu174(n,no)</b> Tm170(n,2n)Tm169(n, $\alpha$ )Ho166m <i>*Plus many other similar pathways</i>				15.5 13.6 8.6 6.1 5.6 3.0 2.6 1.6 1.3 1.1 41.0*
Ho163	4570 y	Very long Pathways of (n, $\alpha$ ), (n,2n), ( $\beta^-$ ), etc.				100.0

Hf182	$9.0 \cdot 10^6$ y	<b>&amp;Hf180(n,<math>\gamma</math>)Hf181(n,<math>\gamma</math>)Hf182</b> <b>&amp;Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(n,<math>\gamma</math>)Hf182</b> <b>&amp;Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)</b> <b>Hf181(n,<math>\gamma</math>)Hf182</b> <b>&amp;Hf179(n,<math>\gamma</math>)Hf180(n,<math>\gamma</math>)Hf181(n,<math>\gamma</math>)Hf182</b> <b>&amp;Hf176(n,<math>\gamma</math>)Hf177(n,<math>\gamma</math>)Hf178(n,<math>\gamma</math>)Hf179(n,<math>\gamma</math>)</b> <b>Hf180(n,<math>\gamma</math>)Hf181(n,<math>\gamma</math>)Hf182</b>	45.4 23.6 15.4  14.1 1.3	62.5 10.9 5.7  20.9 2.4	97.5	99.6
Lu176	$3.6 \cdot 10^{10}$ y	Hf174(n, $\gamma$ )Hf175( $\beta^-$ )Lu175(n, $\gamma$ )Lu176 Hf176(n,p)Lu176 Hf177(n,2n)Hf176(n,p)Lu176 Hf177(n,d)Lu176 Hf176(n,2n)Hf175( $\beta^-$ )Lu175(n, $\gamma$ )Lu176 <b>&amp;Hf178(n,2n)Hf177(n,d)Lu176</b> <b>&amp;Hf178(n,2n)Hf177(n,2n)Hf176(n,p)Lu176</b> Hf178(n,t)Lu176 Hf177(n,2n)Hf176(n,2n)Hf175( $\beta^-$ )Lu175(n, $\gamma$ )Lu176	99.9	100.0	100.0	36.0 21.9 19.1 7.3 4.7 3.6 2.9 2.8

# Hafnium activation characteristics

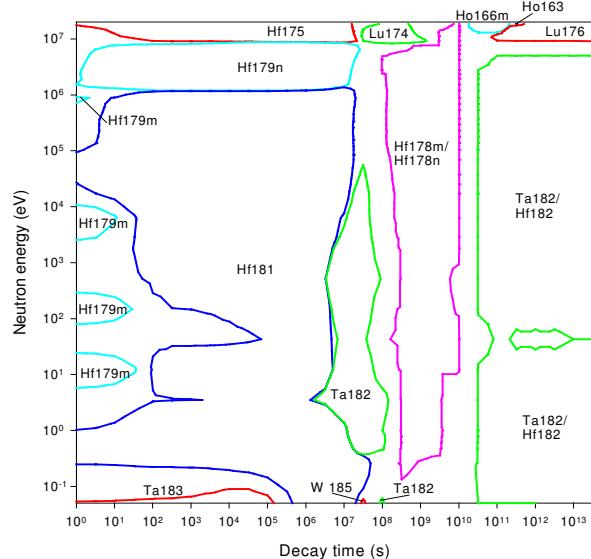


Decay time (years)

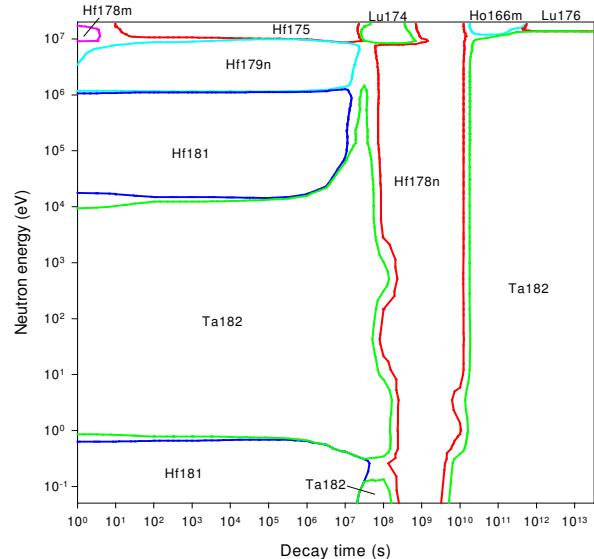
Decay time (years)

# Hafnium importance diagrams & transmutation

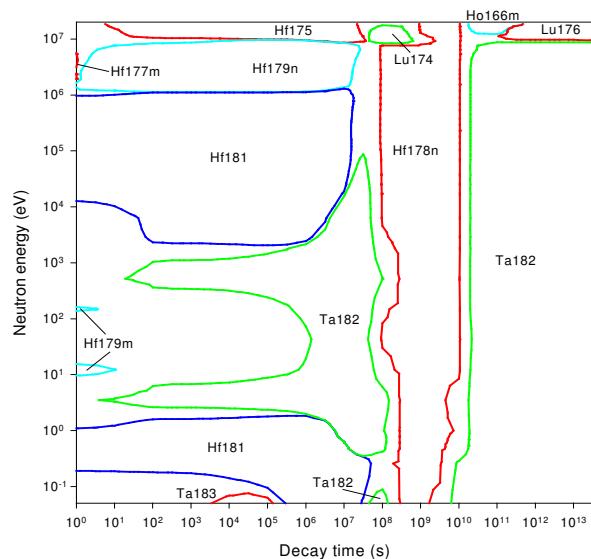
## Activity



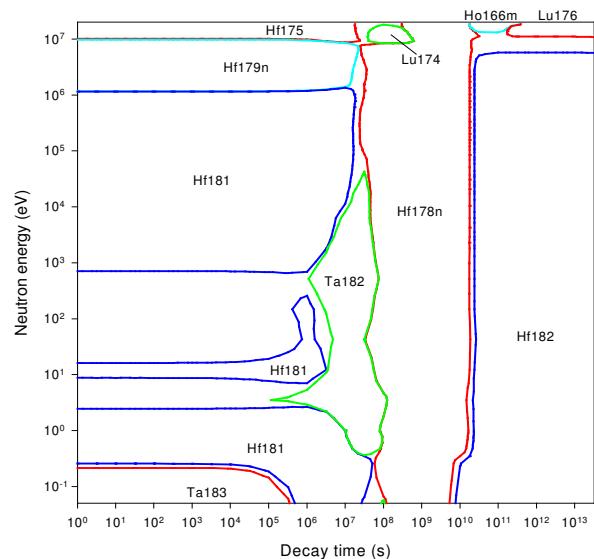
## Dose rate



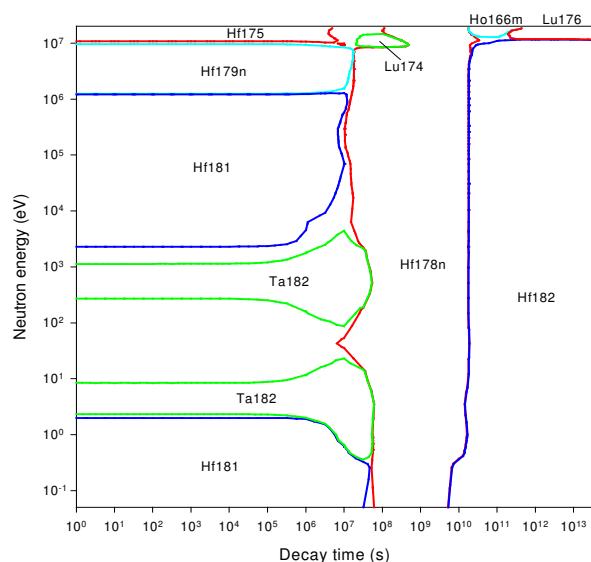
## Heat output



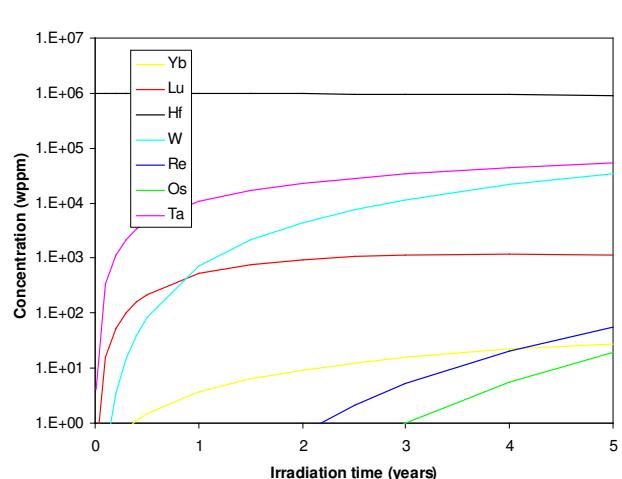
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Tantalum

## General properties

Atomic number	73	Isotopes	Isotopic abundances / %	
Crustal abundance / wppm	2	Ta180m	0.012 ( $T_{1/2} = 1.8 \cdot 10^{15}$ y)	
Melting point / K	3290	Ta181	99.988	
Boiling point / K	5731			
Density / kgm <sup>-3</sup>	16654			
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	57.5			
Electrical resistivity /Ωm	$1.245 \cdot 10^{-7}$			
Coefficient of thermal expansion / K <sup>-1</sup>	$6.3 \cdot 10^{-6}$			
Crystal structure	BCC			
Number of stable isotopes	1(2)			
Mean atomic weight	180.9479			

## Activation properties

Act	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Heat	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y
Bq kg <sup>-1</sup>	1.00E16	8.86E15	7.95E15	7.79E14	3.56E7	1.75E6	kW kg <sup>-1</sup>	1.78E0	1.72E0	1.63E0	1.74E-1	3.10E-9	2.12E-10
Ta182	65.31	73.83	80.53	92.41	1.95	39.40	Ta182	88.21	91.14	94.32	99.61	5.40	78.36
W183m	11.68	0.45	0.30				Ta183	6.67	6.89	4.43			
Ta181	11.64	13.16	8.93				W183m	3.26	0.11	0.07			
W181	3.68	4.16	4.54	5.83			Re186	0.47	0.49	0.26		0.48	5.00
W185	3.45	3.90	4.21	1.53			W185	0.40	0.41	0.42	0.14		
Re186	1.47	1.66	0.95		0.74	10.60	Hf181	0.26	0.27	0.27	0.01		
Ta180	1.22	1.37					W181	0.18	0.18	0.19	0.23		
H3					53.35		Hf178n					48.99	
Hf178m					20.51		Hf178m					43.35	
Hf178n					20.51		Hf182					1.02	14.83
Hf182					1.95	39.40	H3					0.56	
Re186m					0.74	10.60	Re186m					0.17	1.80
Dose	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Ing	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y
Sv h <sup>-1</sup>	2.08E6	2.08E6	2.02E6	2.27E5	1.77E-3	2.23E-4	Sv kg <sup>-1</sup>	1.18E7	1.18E7	1.09E7	1.09E6	3.92E-2	3.80E-3
Ta182	99.19	99.23	99.54	99.98	12.39	97.59	Ta182	83.20	83.21	88.45	99.16	2.66	27.29
Ta183	0.53	0.53	0.33				Ta183	12.86	12.85	8.50			
Hf181	0.10	0.10	0.10				Re186	1.87	1.87	1.04		1.01	7.35
Hf178n					54.16		W185	1.29	1.29	1.36	0.48		
Hf178m					33.14		Hf178n					87.50	
Hf182					0.30	2.35	Hf182					5.32	54.59
Re186m					0.01	0.03	H3					2.03	
Re186					0.01*	0.03*	Re186m					1.47	10.77
Inh	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Clear	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y
Sv kg <sup>-1</sup>	6.83E7	6.83E7	6.58E7	7.20E6	2.13E0	2.23E-1		9.13E12	8.96E12	8.59E12	9.37E11	1.76E4	1.07E3
Ta182	95.79	95.79	97.24	99.94	0.33	3.09	Ta182	93.09	94.81	96.75	99.76	5.15	83.89
Ta183	3.59	3.59	2.26				Ta183	4.12	4.20	2.66			
Hf181	0.29	0.29	0.28	0.01			W183m	1.83	0.06	0.04			
Re186	0.24	0.24	0.13		0.01	0.09	Hf178n					51.33	
Hf178n					89.15		Hf178m					42.43	
Hf182					10.13	95.82	Hf182					0.86	14.04
Re186m					1.00	Re186m						0.10	1.16

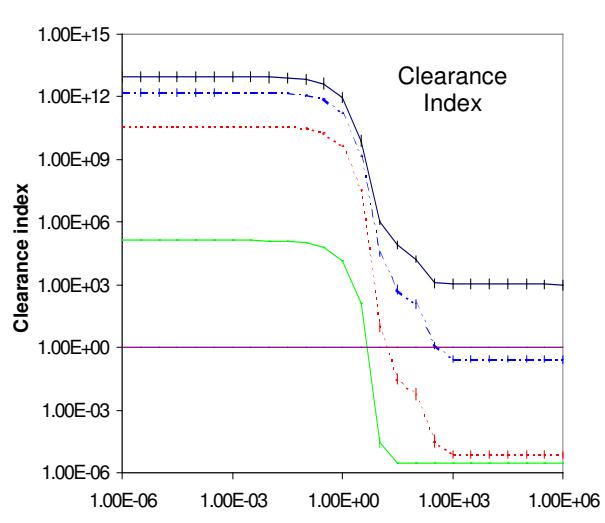
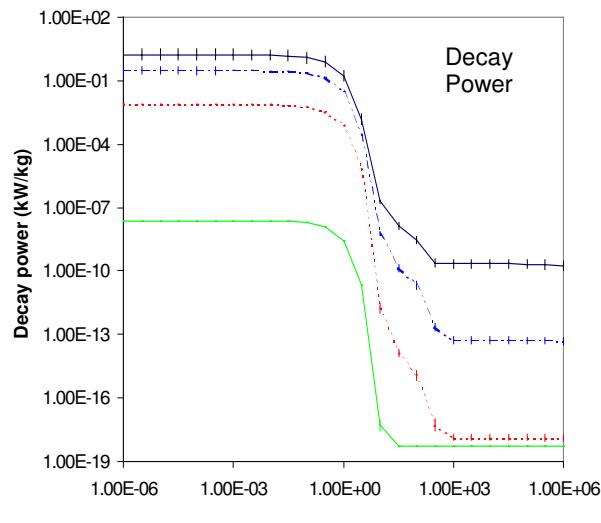
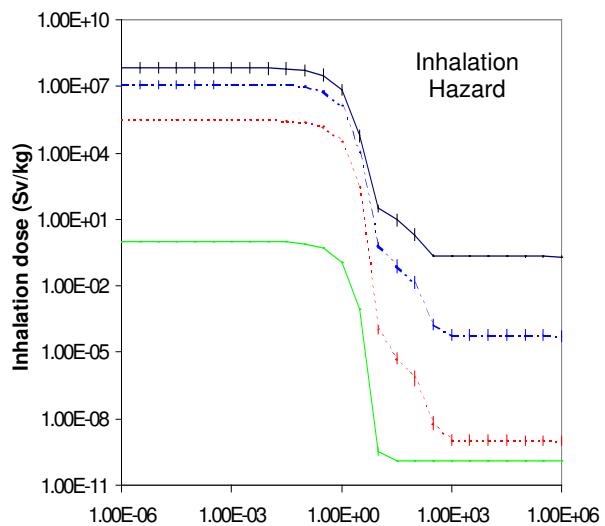
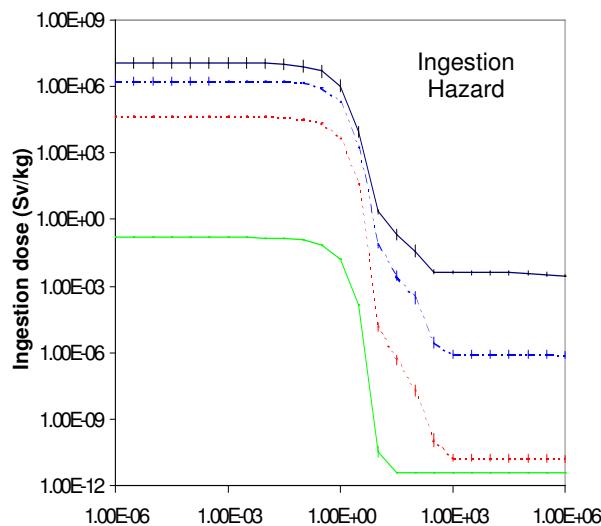
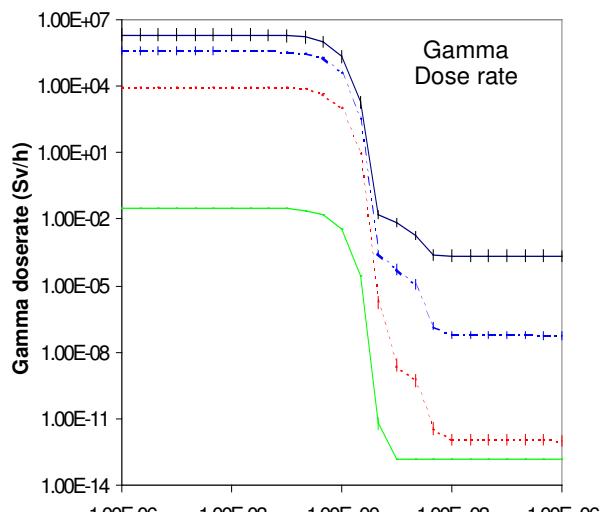
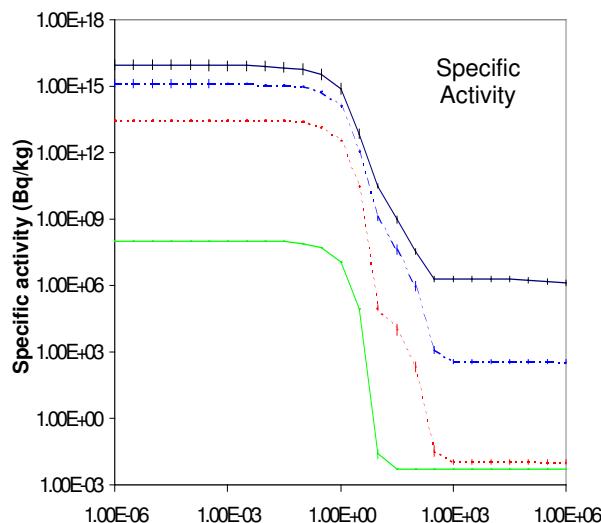
# Tantalum

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Ta178m	2.361 h	Ta181(n,2n)Ta180m(n,2n)Ta179(n,2n)Ta178m Ta181(n,2n)Ta180( $\beta^-$ )W180(n,2n)W179( $\beta^+$ )Ta179(n,2n)Ta178m Ta181(n,2n)Ta180m(n,3n)Ta178m				81.2 11.8 1.9
Ta180	8.08 h	Ta180m(n,n')Ta180 Ta181(n,2n)Ta180 Ta181(n,2n)Ta180m(n,n')Ta180		99.7	100.0	99.2 0.7
Ir194	19.15 h	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0	100.0		
Re186	3.777 d	&Ta181(n, $\gamma$ )Ta182(n, $\gamma$ )Ta183( $\beta^-$ )W183(n, $\gamma$ ) W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186 &Ta181(n, $\gamma$ )Ta182(n, $\gamma$ )Ta183(n, $\gamma$ )Ta184( $\beta^-$ ) W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186 &Ta181(n, $\gamma$ )Ta182( $\beta^-$ )W182(n, $\gamma$ )W183(n, $\gamma$ ) W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186	97.4  2.5  2.0	96.1 1.9 42.2	56.6 0.9 48.2	29.0 0.1 48.2
Ta183	5.09 d	Ta181(n, $\gamma$ )Ta182(n, $\gamma$ )Ta183 Ta181(n, $\gamma$ )Ta182m(IT)Ta182(n, $\gamma$ )Ta183	99.5	99.9	99.7 0.1	53.9 44.3
Ir192	73.831 d	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0	100.0	100.0	
W185	75.1 d	&Ta181(n, $\gamma$ )Ta182(n, $\gamma$ )Ta183( $\beta^-$ )W183(n, $\gamma$ ) W184(n, $\gamma$ )W185 Ta181(n, $\gamma$ )Ta182(n, $\gamma$ )Ta183(n, $\gamma$ )Ta184( $\beta^-$ )W184(n, $\gamma$ ) W185 &Ta181(n, $\gamma$ )Ta182( $\beta^-$ )W182(n, $\gamma$ )W183(n, $\gamma$ )W184(n, $\gamma$ )W185	97.7  2.2  2.4	95.7 1.8 49.1	50.1 0.6 73.0	26.4 0.1 73.0
Ta182	114.7 d	Ta181(n, $\gamma$ )Ta182 Ta181(n, $\gamma$ )Ta182m(IT)Ta182	99.9	99.9	99.8 0.1	54.2 44.5
Ta179	1.610 y	Ta181(n,2n)Ta180m(n,2n)Ta179 &Ta181(n,2n)Ta180( $\beta^-$ )W180(n,2n)W179( $\beta^+$ )Ta179				82.8 16.3
Os194	5.989 y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0	100.0		
H3	12.33 y	Ta181(n, $\gamma$ )Ta182(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Ta180m(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Ta181(n,X)H3 Ta181(n,X)H3( $\beta^-$ )He3(n,p)H3 &Ta181(n,2n)Ta180( $\beta^+$ )Hf180(n,2n)Hf179(n,X)H3 Ta181(n,2n)Ta180( $\beta^+$ )Hf180(n,X)H3 Ta181(n,2n)Ta180m(n,2n)Ta179(n,X)H3 Ta181(n,2n)Ta180m(n,2n)Ta179( $\beta^+$ )Hf179(n,X)H3 Ta181(n,2n)Ta180m(n,X)H3	25.5  1.9	94.3	97.8 2.2	83.3 5.1 3.6 2.3 2.0 1.5
Hf178n	31.0 y	Ta181(n, $\alpha\alpha$ )Lu177m( $\beta^-$ )Hf177m(IT)Hf177(n, $\gamma$ )Hf178n Ta181(n, $\alpha\alpha$ )Lu177( $\beta^-$ )Hf177(n, $\gamma$ )Hf178n Ta181(n, $\alpha\alpha$ )Lu177m(IT)Lu177( $\beta^-$ )Hf177(n, $\gamma$ )Hf178n Ta181(n, $\gamma$ )Ta182(n, $\gamma$ )Ta183( $\beta^-$ )W183(n, $\alpha$ )Hf180 (n, $\alpha$ )Yb177( $\beta^-$ )Lu177( $\beta^-$ )Hf177(n, $\gamma$ )Hf178n &Ta181(n,2n)Ta180( $\beta^+$ )Hf180(n,2n)Hf179(n,2n)Hf178n &Ta181(n,2n)Ta180m(n,2n)Ta179( $\beta^+$ )Hf179(n,2n)Hf178n &Ta181(n,2n)Ta180( $\beta^-$ )W180(n,2n)W179( $\beta^+$ ) Ta179( $\beta^+$ )Hf179(n,2n)Hf178n	46.2  35.4  9.6  5.1	39.6 49.1 11.3	34.3 56.0 9.7	67.8 25.8 5.0
Pt193	50.0 y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0	100.0	100.0	
Ir192n	240.84 y	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ )	100.0	100.0	100.0	
Re186m	$2.0 \cdot 10^5$ y	&Ta181(n, $\gamma$ )Ta182(n, $\gamma$ )Ta183( $\beta^-$ )W183(n, $\gamma$ ) W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186m &Ta181(n, $\gamma$ )Ta182( $\beta^-$ )W182(n, $\gamma$ )W183(n, $\gamma$ ) W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186m &Ta181(n, $\gamma$ )Ta182(n, $\gamma$ )Ta183(n, $\gamma$ )Ta184( $\beta^-$ ) W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186m	96.4  0.1  3.5	96.2 1.8 2.0	61.3 37.2 1.3	37.5 46.4 0.1

Hf182	$9.0 \cdot 10^6$ y	<b>&amp;Ta181(n,<math>\gamma</math>)Ta182(n,<math>\gamma</math>)Ta183(<math>\beta^-</math>)W183(n,<math>\alpha</math>)</b> Hf180(n, $\gamma$ )Hf181(n, $\gamma$ ) <i>Hf182</i> <b>&amp;Ta181(n,<math>\gamma</math>)Ta182(n,p)<i>Hf182</i></b> <b>&amp;Ta181(n,<math>\gamma</math>)Ta182(<math>\beta^-</math>)W182(n,<math>\gamma</math>)W183(n,<math>\alpha</math>)</b> Hf180(n, $\gamma$ )Hf181(n, $\gamma$ ) <i>Hf182</i> <b>&amp;Ta181(n,p)Hf181(n,<math>\gamma</math>)<i>Hf182</i></b>	99.0	96.8	99.3	92.3
Ta180m	$1.8 \cdot 10^{15}$ y	<b>&amp;Ta181(n,<math>\alpha</math>)Lu178(<math>\beta^-</math>)Hf178(n,<math>\gamma</math>)<i>Hf179(n,<math>\gamma</math>)</i></b> Hf180m( $\beta^-$ )Ta180m <b>&amp;Ta181(n,<math>\alpha</math>)Lu178m(<math>\beta^-</math>)Hf178(n,<math>\gamma</math>)<i>Hf179(n,<math>\gamma</math>)</i></b> Hf180m( $\beta^-$ )Ta180m <b>&amp;Ta181(n,<math>\gamma</math>)Ta182(n,<math>\gamma</math>)Ta183(<math>\beta^-</math>)W183(n,<math>\gamma</math>)</b> W184(n,n $\alpha$ )Hf180m( $\beta^-$ )Ta180m *Nuclide also present in starting material	64.9	33.4	1.5	100.0* 100.0* 100.0*

# Tantalum activation characteristics

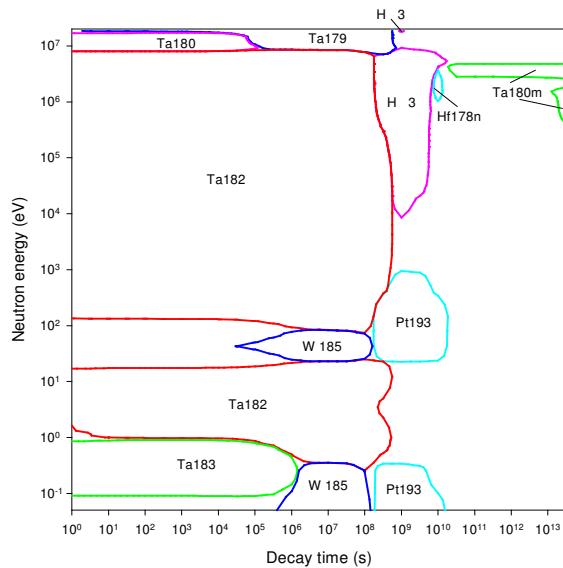


Decay time (years)

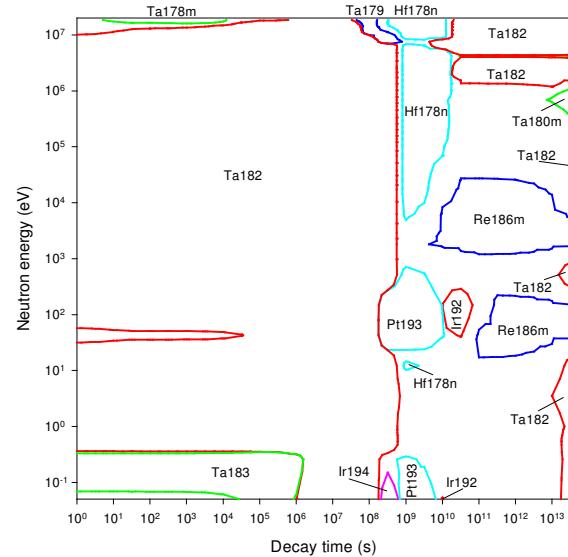
Decay time (years)

# Tantalum importance diagrams & transmutation

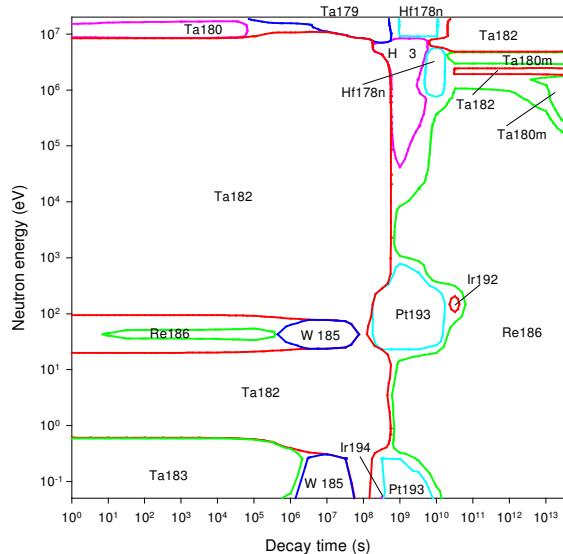
## Activity



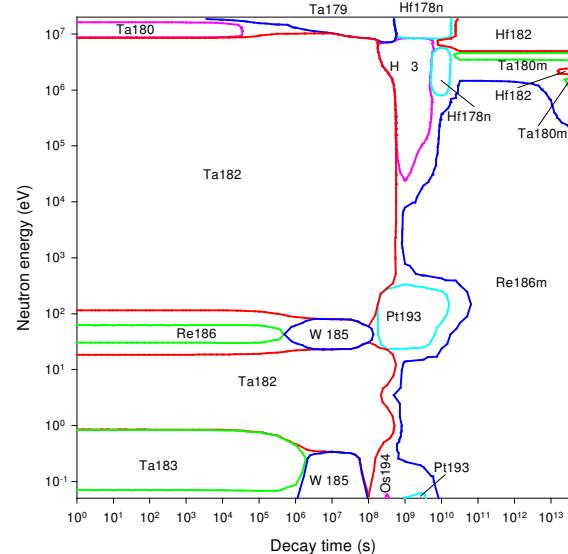
## Dose rate



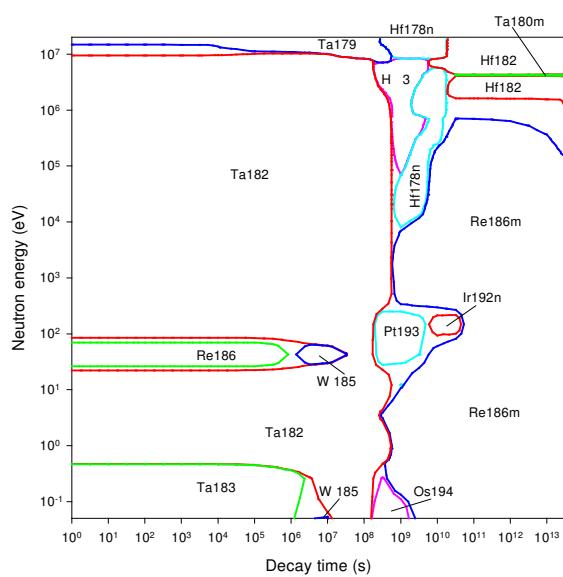
## Heat output



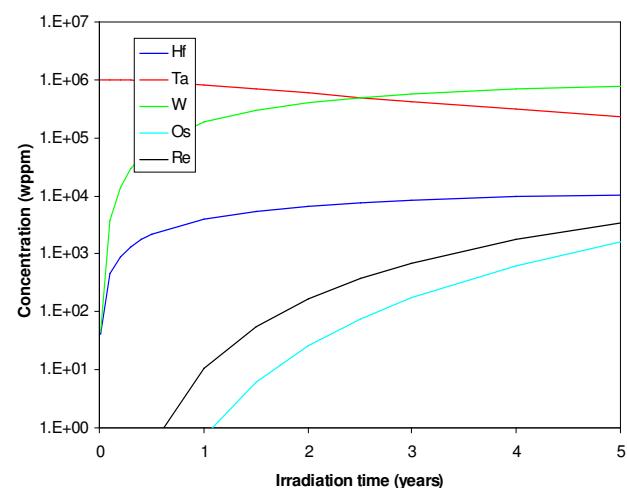
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Tungsten

## General properties

Atomic number	74	Isotopes	Isotopic abundances / %	
Crustal abundance / wppm	1.25	W180	0.12	
Melting point / K	3695	W182	26.50	
Boiling point / K	5828	W183	14.31	
Density / kgm <sup>-3</sup>	1.93 10 <sup>4</sup>	W184	30.64	
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	174	W186	28.43	
Electrical resistivity /Ωm	5.65 10 <sup>-8</sup>			
Coefficient of thermal expansion / K <sup>-1</sup>	4.5 10 <sup>-6</sup>			
Crystal structure	BCC			
Number of stable isotopes	5			
Mean atomic weight	183.84			

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	8.02E15	7.52E15	2.16E15	6.61E13	3.70E9	1.24E8	kW kg <sup>-1</sup>	7.32E-1	7.07E-1	1.14E-1	3.86E-3	3.27E-8	4.82E-9
Re188	31.83	33.80	3.51	0.19			Re188	46.82	48.26	8.96	0.44		
W187	25.94	27.57	7.53				W187	33.86	34.93	17.06			
W185	14.28	15.22	51.23	54.50			Re186	8.02	8.29	26.41		15.35	73.48
Re186	12.83	13.67	24.36		2.38	49.94	Ta182	3.24	3.35	20.38	67.52	0.01	0.04
W183m	5.27		0.02				W185	3.18	3.29	19.80	20.73		
Os189m	4.18	4.39					W183m	2.86		0.02			
W181	1.30	1.39	4.73	19.46			Os185	0.27	0.28	1.70	3.46		
Ta182	1.23	1.31	4.46	16.39		0.01	Re184	0.26	0.27	1.89	2.24		
Re188m	0.87	0.76					Ir192	0.23	0.23	1.41	1.39	4.83	
Os191	0.46	0.49	1.48				W181	0.12	0.13	0.78	2.88		
Os185	0.21	0.22	0.76	1.71			Re184m	0.03	0.03	0.19	1.25		
Re184	0.16	0.17	0.55	0.87			Pt193					70.98	
Ir192	0.13	0.13	0.45	0.49	0.26		Re186m					5.53	26.48
Pt193				0.02	94.04		Hf178n					1.33	
Re186m					2.38	49.94	Hf178m					1.17	
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	1.94E5	1.93E5	4.68E4	3.69E3	1.81E-3	4.58E-5	Sv kg <sup>-1</sup>	7.19E6	7.18E6	1.72E6	3.75E4	4.60E-1	2.30E-1
W187	70.98	71.10	22.99				Re188	49.66	49.61	6.18	0.47		
Ta182	15.92	15.98	64.42	91.96	0.13	5.07	Re186	21.46	21.49	45.94		28.67	40.53
Re188	9.76*	9.77*	1.20*	0.03			W187	18.21	18.21	5.97			
Re184	1.11	1.11	4.34	2.64			W185	7.00	7.02	28.34	46.19		
Os185	1.09	1.10	4.40	3.86			Ta182	2.05	2.06	8.41	43.39		0.01
Ir192	0.40	0.40	1.59	0.68	40.41		Os191	0.29	1.07				
Re186	0.18*	0.18*	0.38*		1.62*	45.26*	Ir192	0.20	0.20	0.79	1.21	2.91	
Ta183	0.08	0.08	0.21				Re184	0.18	0.18	0.70	1.53		
Re184m	0.07	0.07	0.28	0.78			Os185	0.12	0.12	0.49	1.54		
Pt193					31.51		W181	0.11	0.11	0.45	2.61		
Hf178n					14.76		Re184m	0.06	0.06	0.23	2.32		
Hf178m					9.02		Re186m					42.04	59.45
Re186m					1.77	49.55	Pt193					23.41	
Ir192n					0.77		Hf178n					2.13	

Inh	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>	Clear	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>
Sv kg <sup>-1</sup>	4.29E6	4.28E6	1.97E6	1.23E5	2.21E0	8.17E-1		1.64E12	1.58E12	2.91E11	1.68E10	1.40E5	7.43E3
Re188	32.14	32.08	2.08	0.06			W187	60.21	62.61	26.59			
Re186	26.40	26.43	29.39		4.38	8.37	Re188	20.97	21.78	3.52	0.10		
Ta182	22.98	23.01	48.92	88.47		0.01	Ta182	7.78	8.11	42.94	83.77	0.01	0.13
W187	9.22	9.21	1.57				W183m	3.67		0.02			
W185	3.20	3.21	6.74	3.85			Re186	3.29	3.43	9.51		3.31	44.05
Os191	1.63	1.63	3.08				W185	0.88	0.92	4.81	2.96		
Ir192	1.54	1.54	3.24	1.75	2.85		Os185	0.73	0.76	4.00	4.80		
Ta183	0.88	0.88	1.16				Re184	0.70	0.73	3.73	3.10		
Os185	0.63	0.63	1.33	1.47			Ta183	0.35	0.37	1.21			
Re184	0.56	0.56	1.15	0.89			W181	0.26	0.28	1.46	3.19		
Re184m	0.41	0.41	0.87	3.07			Ir192	0.20	0.21	1.11	0.64	2.28	
Os191m	0.10	0.10					Re184m	0.07	0.07	0.36	1.38		
W181	0.07	0.07	0.14	0.28			Pt193					85.74	
Re186m					47.74	91.34	Re186m					4.19	55.80
Hf178n					25.54		Hf178n						1.84
Ir192n					16.83		Hf178m						1.52
Pt193					3.30		Ir192n						1.10

# Tungsten

## Pathway analysis

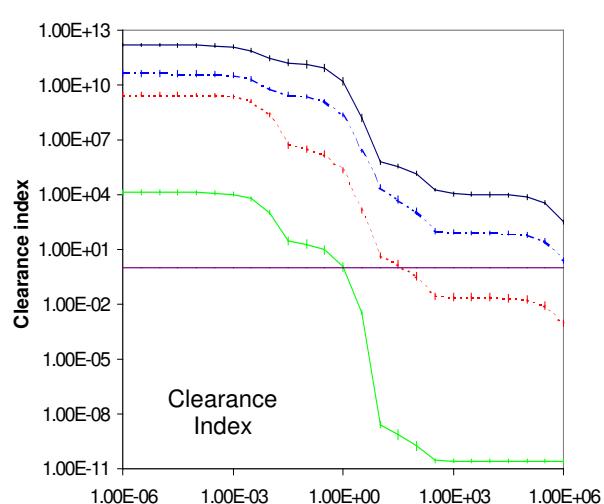
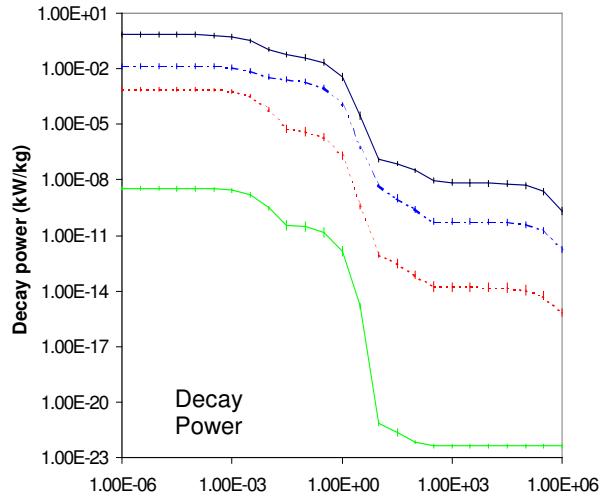
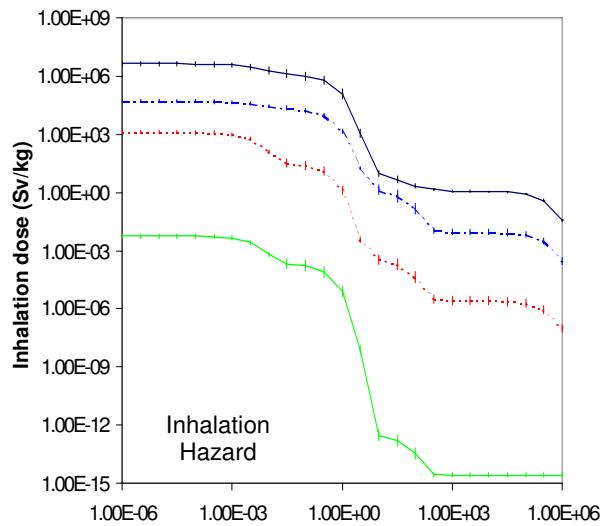
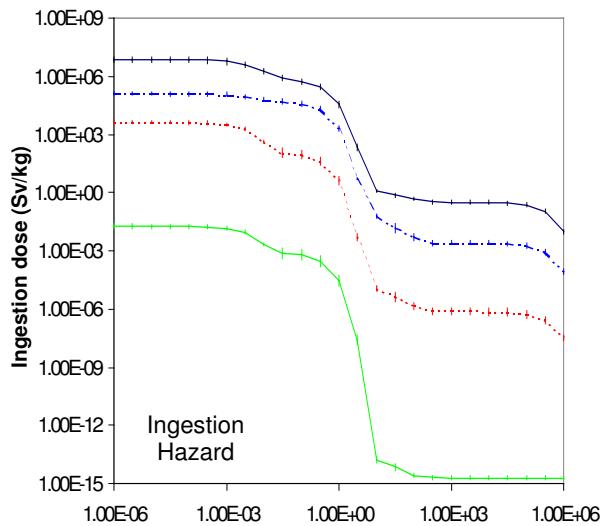
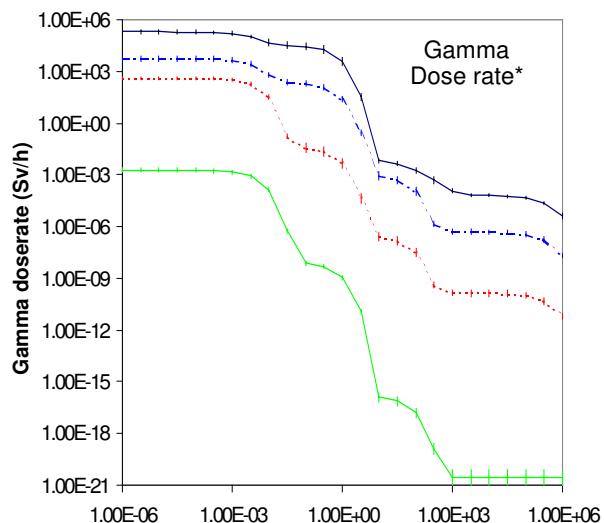
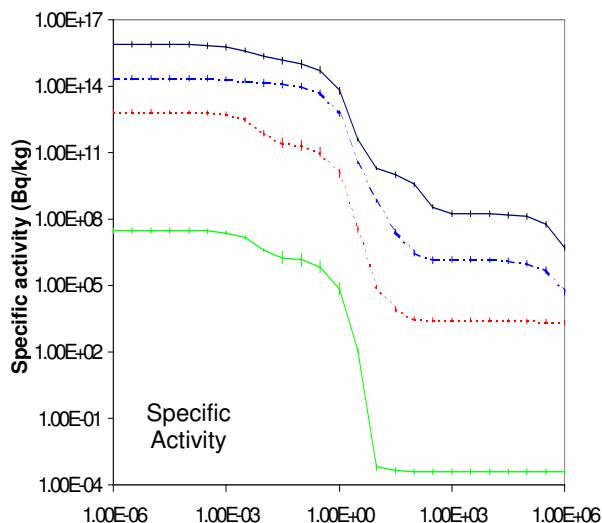
Nuclide	T <sub>½</sub>	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
W183m	5.25 s	W182(n, $\gamma$ )W183m W184(n,2n)W183m W183(n,n')W183m W186(n,3n)W184(n,2n)W183m W184(n,2n)W183(n,n')W183m W186(n,2n)W185( $\beta^-$ )Re185(n,2n)Re184( $\beta^+$ )W184(n,2n)W183m	99.7	99.0	100.0	87.1 4.0 2.5 2.0 1.3
Re188	16.981 h	W186(n, $\gamma$ )W187( $\beta^-$ )Re187(n, $\gamma$ )Re188 W186(n, $\gamma$ )W187( $\beta^-$ )Re187(n, $\gamma$ )Re188m(IT)Re188 &W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186( $\beta^+$ ) W186(n, $\gamma$ )W187( $\beta^-$ )Re187(n, $\gamma$ )Re188 &W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186(n, $\gamma$ )Re187(n, $\gamma$ )Re188 &W183(n, $\gamma$ )W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ ) Re186(n, $\gamma$ )Re187(n, $\gamma$ )Re188	94.3 2.6 1.6	80.5 2.2	100.0	100.0
Ir194	19.15 h	&W186(n, $\gamma$ )W187( $\beta^-$ )Re187(n, $\gamma$ )Re188( $\beta^-$ ) Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191( $\beta^-$ )Ir191(n, $\gamma$ ) Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194 &W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186( $\beta^-$ )Os186 (n, $\gamma$ )Os187(n, $\gamma$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ ) Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194 &W186(n, $\gamma$ )W187( $\beta^-$ )Re187(n, $\gamma$ )Re188( $\beta^-$ ) Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191(n, $\gamma$ ) Os192(n, $\gamma$ )Os193( $\beta^-$ )Ir193(n, $\gamma$ )Ir194 &W183(n, $\gamma$ )W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186( $\beta^-$ ) Os186(n, $\gamma$ )Os187(n, $\gamma$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ ) Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194 &W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186(n, $\gamma$ ) Re187(n, $\gamma$ )Re188( $\beta^-$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ ) Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194	93.6 3.3 1.4 0.2	30.9 48.5 14.5 2.8	98.4 1.2	
W187	23.85 h	W186(n, $\gamma$ )W187 W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186( $\beta^+$ )W186(n, $\gamma$ ) W187	94.0 3.7	98.8 0.3	100.0	99.9
Re186	3.777 d	&W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186 W183(n, $\gamma$ )W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186 &W182(n, $\gamma$ )W183(n, $\gamma$ )W184(n, $\gamma$ )W185( $\beta^-$ ) Re185(n, $\gamma$ )Re186 W186(n, $\gamma$ )W187( $\beta^-$ )Re187(n,2n)Re186 &W186(n,2n)W185( $\beta^-$ )Re185(n, $\gamma$ )Re186	71.6 15.2 13.1	67.4 31.5 1.0	98.5 1.5	87.1 12.9
Os191	15.405 d	&W186(n, $\gamma$ )W187( $\beta^-$ )Re187(n, $\gamma$ )Re188( $\beta^-$ ) Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191 &W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186( $\beta^-$ )Os186(n, $\gamma$ ) Os187(n, $\gamma$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191 &W183(n, $\gamma$ )W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ ) Re186( $\beta^-$ )Os186(n, $\gamma$ )Os187(n, $\gamma$ )Os188(n, $\gamma$ ) Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191 &W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186(n, $\gamma$ )Re187 (n, $\gamma$ )Re188( $\beta^-$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191 &W183(n, $\gamma$ )W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186(n, $\gamma$ ) Re187(n, $\gamma$ )Re188( $\beta^-$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191	95.1 4.0 0.2	23.2 53.2 19.4 2.7 1.0	99.8	97.7
Re184	37.963 d	&W186(n,2n)W185( $\beta^-$ )Re185(n,2n)Re184				99.8

Ir192	73.831 d	&W186(n, $\gamma$ )W187( $\beta^-$ )Re187(n, $\gamma$ )Re188( $\beta^-$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192 &W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186( $\beta^-$ )Os186(n, $\gamma$ )Os187(n, $\gamma$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192 &W183(n, $\gamma$ )W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186( $\beta^-$ )Os186(n, $\gamma$ )Os187(n, $\gamma$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192 &W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186(n, $\gamma$ )Re187(n, $\gamma$ )Re188( $\beta^-$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192	95.1 3.9 0.2 2.8	25.7 52.4 17.7 2.8	100.0	
W185	75.1 d	W184(n, $\gamma$ )W185 W183(n, $\gamma$ )W184(n, $\gamma$ )W185 W182(n, $\gamma$ )W183(n, $\gamma$ )W184(n, $\gamma$ )W185 W182(n, $\gamma$ )W183m(IT)W183(n, $\gamma$ )W184(n, $\gamma$ )W185 W184(n, $\gamma$ )W185m(IT)W185 W186(n,2n)W185	68.3 16.2 13.3 2.0	67.1 31.5 1.0 0.2	96.6 3.0 0.3	99.8
Ta182	114.7 d	W180(n, $\gamma$ )W181( $\beta^+$ )Ta181(n, $\gamma$ )Ta182 &W182(n,p)Ta182 &W182(n,2n)W181( $\beta^+$ )Ta181(n, $\gamma$ )Ta182 &W183(n,2n)W182(n,p)Ta182 &W183(n,d)Ta182 &W184(n,2n)W183(n,d)Ta182 &W186(n,2n)W185( $\beta^-$ )Re185(n, $\alpha$ )Ta182 &W184(n,2n)W183(n,2n)W182(n,p)Ta182	99.9	99.9	99.8	56.6 12.3 9.0 8.3 5.4 3.2 2.8
W181	120.98 d	W180(n, $\gamma$ )W181 W182(n,2n)W181 W183(n,2n)W182(n,2n)W181 &W184(n,2n)W183(n,2n)W182(n,2n)W181	100.0	100.0	100.0	82.0 12.9 4.3
Re184m	165.51 d	&W186(n,2n)W185( $\beta^-$ )Re185(n,2n)Re184m				99.6
Ir194m	171.3 d	&W186(n, $\gamma$ )W187( $\beta^-$ )Re187(n, $\gamma$ )Re188( $\beta^-$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194m &W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186( $\beta^-$ )Os186(n, $\gamma$ )Os187(n, $\gamma$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194m &W186(n, $\gamma$ )W187( $\beta^-$ )Re187(n, $\gamma$ )Re188( $\beta^-$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194 &W183(n, $\gamma$ )W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186( $\beta^-$ )Os186(n, $\gamma$ )Os187(n, $\gamma$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194m &W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186(n, $\gamma$ )Re187(n, $\gamma$ )Re188( $\beta^-$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194m	94.0 2.9 1.2 0.1	33.7 47.0 1.2 13.2 2.8	98.1 1.2	
Ta179	1.610 y	W182(n,2n)W181( $\beta^+$ )Ta181(n,2n)Ta180m(n,2n)Ta179 &W180(n,2n)W179( $\beta^+$ )Ta179 &W182(n,2n)W181(n,2n)W180(n,2n)W179( $\beta^+$ )Ta179 &W182(n,2n)W181( $\beta^+$ )Ta181(n,2n)Ta180( $\beta^-$ )W180(n,2n)W179( $\beta^+$ )Ta179 W183(n,2n)W182(n,2n)W181( $\beta^+$ )Ta181(n,2n)Ta180m(n,2n)Ta179				48.1 21.2 15.8 9.4 2.1

Os194	5.989 y	<b>&amp;W186(n,<math>\gamma</math>)W187(<math>\beta^-</math>)Re187(n,<math>\gamma</math>)Re188(<math>\beta^-</math>)</b> Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191(n, $\gamma$ ) Os192(n, $\gamma$ )Os193(n, $\gamma$ )Os194 <b>&amp;W184(n,<math>\gamma</math>)W185(<math>\beta^-</math>)Re185(n,<math>\gamma</math>)Re186(<math>\beta^-</math>)</b> Os186(n, $\gamma$ )Os187(n, $\gamma$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ ) Os190(n, $\gamma$ )Os191(n, $\gamma$ )Os192(n, $\gamma$ )Os193(n, $\gamma$ )Os194 <b>&amp;W186(n,<math>\gamma</math>)W187(<math>\beta^-</math>)Re187(n,<math>\gamma</math>)Re188(<math>\beta^-</math>)</b> Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191( $\beta^-$ )Ir191(n, $\gamma$ ) <i>Ir192(<math>\beta^+</math>)Os192(n,<math>\gamma</math>)Os193(n,<math>\gamma</math>)Os194</i> <b>&amp;W184(n,<math>\gamma</math>)W185(<math>\beta^-</math>)Re185(n,<math>\gamma</math>)Re186(<math>\beta^-</math>)</b> Os186(n, $\gamma$ )Os187(n, $\gamma$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ ) Os190(n, $\gamma$ )Os191(n, $\gamma$ )Os192(n, $\gamma$ )Os193(n, $\gamma$ )Os194 <b>&amp;W184(n,<math>\gamma</math>)W185(<math>\beta^-</math>)Re185(n,<math>\gamma</math>)Re186(<math>\beta^-</math>)Os186(n,<math>\gamma</math>)</b> Os187(n, $\gamma$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191( $\beta^-$ ) <i>Ir191(n,<math>\gamma</math>)Ir192(<math>\beta^+</math>)Os192(n,<math>\gamma</math>)Os193(n,<math>\gamma</math>)Os194</i> <b>&amp;W184(n,<math>\gamma</math>)W185(<math>\beta^-</math>)Re185(n,<math>\gamma</math>)Re186(n,<math>\gamma</math>)</b> <i>Re187(n,<math>\gamma</math>)Re188(<math>\beta^-</math>)Os188(n,<math>\gamma</math>)Os189(n,<math>\gamma</math>)Os190(n,<math>\gamma</math>)</i> <i>Os191(n,<math>\gamma</math>)Os192(n,<math>\gamma</math>)Os193(n,<math>\gamma</math>)Os194</i> <b>&amp;W183(n,<math>\gamma</math>)W184(n,<math>\gamma</math>)W185(<math>\beta^-</math>)Re185(n,<math>\gamma</math>)Re186(<math>\beta^-</math>)</b> Os186(n, $\gamma$ )Os187(n, $\gamma$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ ) <i>Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192(<math>\beta^+</math>)Os192(n,<math>\gamma</math>)Os193(n,<math>\gamma</math>)Os194</i>	95.7	32.2	73.2	
H3	12.33 y	<b>&amp;W184(n,<math>\gamma</math>)W185(<math>\beta^-</math>)Re185(n,X)H1(n,<math>\gamma</math>)H2(n,<math>\gamma</math>)H3</b> W180(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186( $\beta^-$ )Os186(n, $\gamma$ ) Os187(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 <b>&amp;W183(n,<math>\gamma</math>)W184(n,<math>\gamma</math>)W185(<math>\beta^-</math>)Re185(n,X)H1(n,<math>\gamma</math>)H2(n,<math>\gamma</math>)H3</b> <b>&amp;W186(n,<math>\gamma</math>)W187(<math>\beta^-</math>)Re187(n,<math>\gamma</math>)Re188(n,X)H1(n,<math>\gamma</math>)H2(n,<math>\gamma</math>)H3</b> <b>&amp;W182(n,<math>\gamma</math>)W183(n,<math>\gamma</math>)W184(n,<math>\gamma</math>)W185(<math>\beta^-</math>)Re185(n,X)H1(n,<math>\gamma</math>)H2(n,<math>\gamma</math>)H3</b> W180(n, $\gamma$ )W181(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 W184(n,X)H3 W184(n,X)H3( $\beta^-$ )He3(n,p)H3 W183(n, $\gamma$ )W184(n,X)H3 W183(n,X)H3 W186(n,X)H3 <b>&amp;W186(n,2n)W185(<math>\beta^-</math>)Re185(n,X)H3</b> W182(n,X)H3 <b>&amp;W184(n,2n)W183(n,X)H3</b> W182(n,2n)W181( $\beta^+$ )Ta181(n,X)H3 W183(n,2n)W182(n,X)H3 W182(n,2n)W181(n,X)H3	67.7 9.0 6.3 4.4 1.9 1.8 1.4	49.6 14.2 9.1 14.8 3.2	96.1 2.1 1.7	4.1
Hf178n	31.0 y	<b>&amp;W183(n,<math>\alpha</math>)Hf180(n,<math>\alpha</math>)Yb177(<math>\beta^-</math>)Lu177(<math>\beta^-</math>)</b> Hf177(n, $\gamma$ )Hf178n <b>&amp;W182(n,<math>\gamma</math>)W183(n,<math>\alpha</math>)Hf180(n,<math>\alpha</math>)Yb177(<math>\beta^-</math>)</b> Lu177( $\beta^-$ )Hf177(n, $\gamma$ )Hf178n W180(n, $\gamma$ )W181(n, $\alpha$ )Hf178n <b>&amp;W180(n,<math>\alpha</math>)Hf177(n,<math>\gamma</math>)Hf178n</b> <b>&amp;W180(n,<math>\gamma</math>)W181(<math>\beta^+</math>)Ta181(n,n<math>\alpha</math>)Lu177(<math>\beta^-</math>)</b> Hf177(n, $\gamma$ )Hf178n <b>&amp;W180(n,<math>\gamma</math>)W181(n,n<math>\alpha</math>)Hf177(n,<math>\gamma</math>)Hf178n</b> W182(n,n $\alpha$ )Hf178n <b>&amp;W182(n,2n)W181(<math>\beta^+</math>)Ta181(n,2n)Ta180(<math>\beta^+</math>)Hf180(n,2n)Hf179(n,2n)Hf178n</b> <b>&amp;W180(n,2n)W179(<math>\beta^+</math>)Ta179(<math>\beta^+</math>)Hf179(n,2n)Hf178n</b> W183(n,2n)W182(n,n $\alpha$ )Hf178n W182(n,2n)W181( $\beta^+$ )Ta181(n,2n)Ta180m(n,2n)Ta179( $\beta^+$ )Hf179(n,2n)Hf178n <b>&amp;W182(n,<math>\alpha</math>)Hf179(n,2n)Hf178n</b> <b>&amp;W182(n,2n)W181(n,2n)W180(n,2n)W179(<math>\beta^+</math>)</b> Ta179( $\beta^+$ )Hf179(n,2n)Hf178n <b>&amp;W184(n,2n)W183(n,2n)W182(n,n<math>\alpha</math>)Hf178n</b>	40.4 37.6 18.0 1.4 0.9 0.2	90.0 5.6 1.9 1.0	84.7 14.9	67.7 9.4 6.5 5.7 2.9 2.2 1.7 1.4

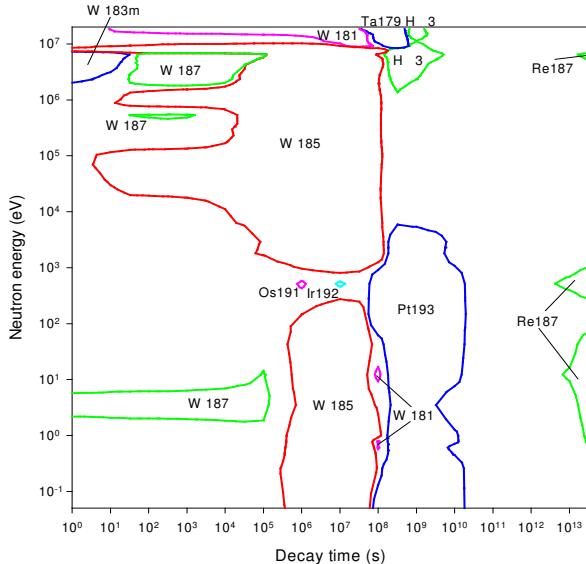
Pt193	50.0 y	$\&W186(n,\gamma)W187(\beta^-)Re187(n,\gamma)Re188(\beta^-)$ $Os188(n,\gamma)Os189(n,\gamma)Os190(n,\gamma)Os191(\beta^-)Ir191(n,\gamma)$ $Ir192(\beta^-)Pt192(n,\gamma)Pt193$ $\&W184(n,\gamma)W185(\beta^-)Re185(n,\gamma)Re186(\beta^-)Os186$ $(n,\gamma)Os187(n,\gamma)Os188(n,\gamma)Os189(n,\gamma)Os190(n,\gamma)$ $Os191(\beta^-)Ir191(n,\gamma)Ir192(\beta^-)Pt192(n,\gamma)Pt193$ $\&W183(n,\gamma)W184(n,\gamma)W185(\beta^-)Re185(n,\gamma)Re186(\beta^-)$ $Os186(n,\gamma)Os187(n,\gamma)Os188(n,\gamma)Os189(n,\gamma)Os190(n,\gamma)$ $Os191(\beta^-)Ir191(n,\gamma)Ir192(\beta^-)Pt192(n,\gamma)Pt193$ $\&W184(n,\gamma)W185(\beta^-)Re185(n,\gamma)Re186(n,\gamma)$ $Re187(n,\gamma)Re188(\beta^-)Os188(n,\gamma)Os189(n,\gamma)Os190(n,\gamma)$ $Os191(\beta^-)Ir191(n,\gamma)Ir192(\beta^-)Pt192(n,\gamma)Pt193$	96.7 2.3 0.1 2.8	33.2 47.2 13.4 2.8	100.0	
Ir192n	240.84 y	$\&W186(n,\gamma)W187(\beta^-)Re187(n,\gamma)Re188(\beta^-)Os188$ $(n,\gamma)Os189(n,\gamma)Os190(n,\gamma)Os191(\beta^-)Ir191(n,\gamma)Ir192n$ $\&W184(n,\gamma)W185(\beta^-)Re185(n,\gamma)Re186(\beta^-)$ $Os186(n,\gamma)Os187(n,\gamma)Os188(n,\gamma)Os189(n,\gamma)$ $Os190(n,\gamma)Os191(\beta^-)Ir191(n,\gamma)Ir192n$ $\&W183(n,\gamma)W184(n,\gamma)W185(\beta^-)Re185(n,\gamma)$ $Re186(\beta^-)Os186(n,\gamma)Os187(n,\gamma)Os188(n,\gamma)$ $Os189(n,\gamma)Os190(n,\gamma)Os191(\beta^-)Ir191(n,\gamma)Ir192n$ $\&W184(n,\gamma)W185(\beta^-)Re185(n,\gamma)Re186(n,\gamma)$ $Re187(n,\gamma)Re188(\beta^-)Os188(n,\gamma)Os189(n,\gamma)Os190(n,\gamma)$ $Os191(\beta^-)Ir191(n,\gamma)Ir192n$	94.7 3.8 0.2	26.1 52.2 17.4 2.8	99.8	
Re186m	$2.0 \cdot 10^5$ y	$W184(n,\gamma)W185(\beta^-)Re185(n,\gamma)Re186m$ $W183(n,\gamma)W184(n,\gamma)W185(\beta^-)Re185(n,\gamma)Re186m$ $\&W182(n,\gamma)W183(n,\gamma)W184(n,\gamma)W185(\beta^-)$ $Re185(n,\gamma)Re186m$ $W186(n,\gamma)W187(\beta^-)Re187(n,2n)Re186m$ $\&W186(n,2n)W185(\beta^-)Re185(n,\gamma)Re186m$	82.2 10.7 7.0	67.6 31.4 0.9	98.6 1.1	
Hf182	$9.0 \cdot 10^6$ y	$\&W183(n,\alpha)Hf180(n,\gamma)Hf181(n,\gamma)Hf182$ $\&W182(n,\gamma)W183(n,\alpha)Hf180(n,\gamma)Hf181(n,\gamma)Hf182$ $W186(n,n\alpha)Hf182$ $\&W186(n,2n)W185(n,\alpha)Hf182$ $\&W184(n,h)Hf182$ $W186(n,n\alpha)Hf182m(IT)Hf182$ $\&W182(n,p)Ta182(n,p)Hf182$	56.4 43.4	89.4 1.8 8.0	4.5 94.9	73.1 26.9
Re187	$5.0 \cdot 10^{10}$ y	$W186(n,\gamma)W187(\beta^-)Re187$ $W184(n,\gamma)W185(\beta^-)Re185(n,\gamma)Re186(n,\gamma)Re187$ $W183(n,\gamma)W184(n,\gamma)W185(\beta^-)Re185(n,\gamma)Re186(n,\gamma)Re187$	97.3	82.8 10.9 5.0	100.0	100.0

# Tungsten activation characteristics

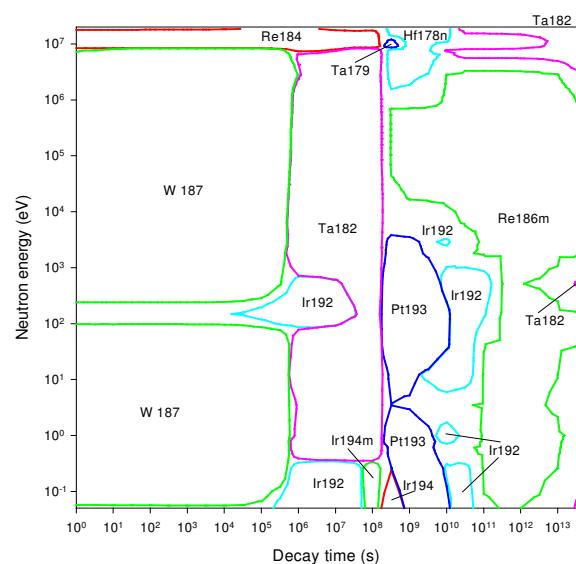


# Tungsten importance diagrams & transmutation

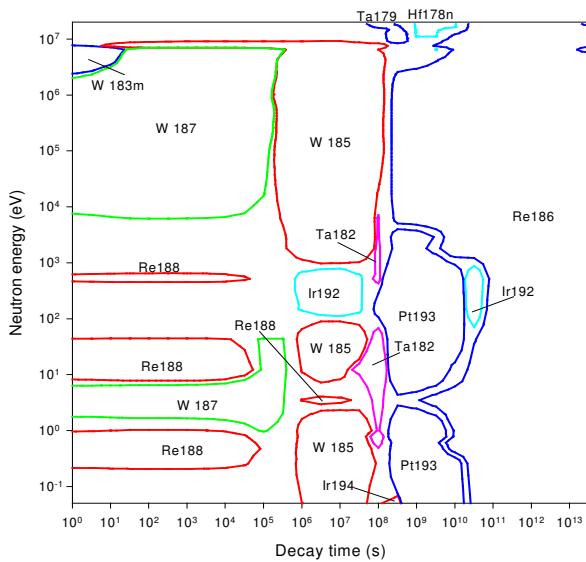
## Activity



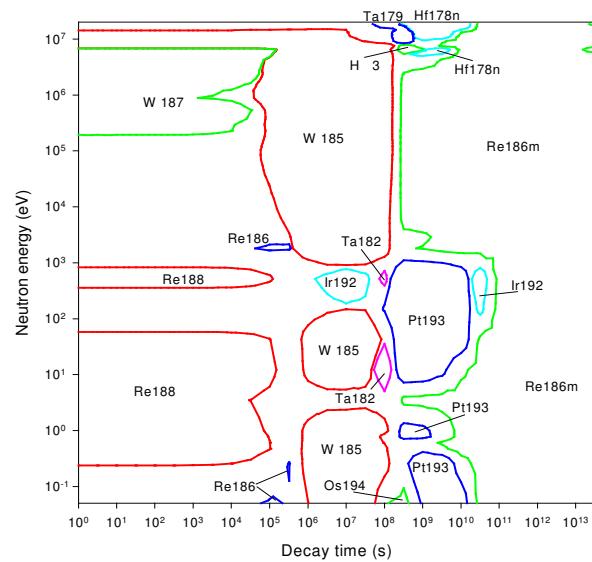
## Dose rate



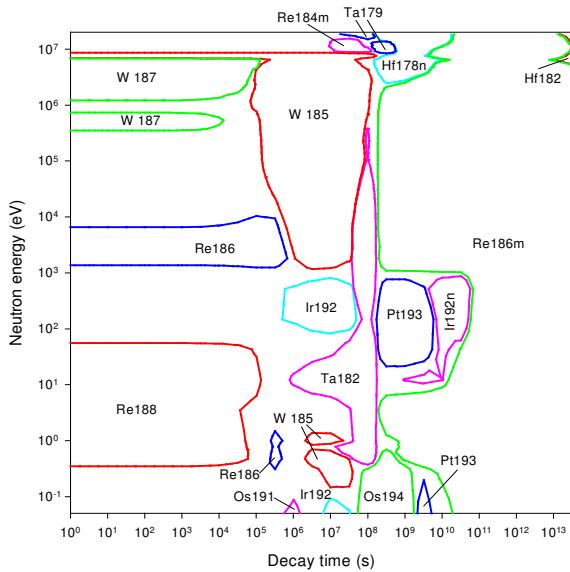
## Heat output



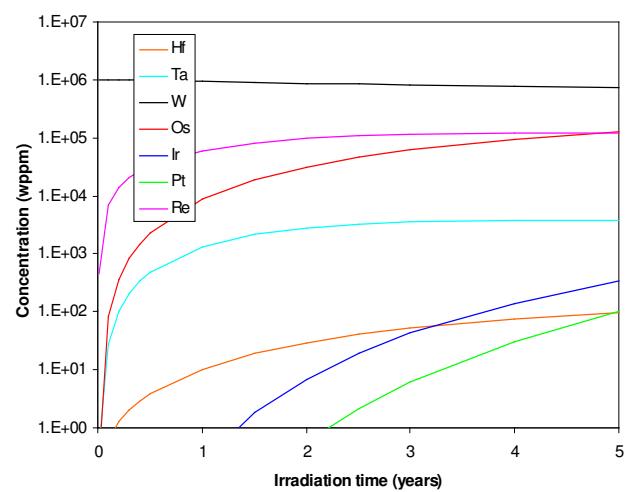
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Rhenium

## General properties

Atomic number	75	Isotopes	Isotopic abundances / %	
Crustal abundance / wppm	7.0 10 <sup>-4</sup>	Re185	37.4	
Melting point / K	3459	Re187	62.6 ( $T_{1/2} = 5.0 \cdot 10^{10}$ y)	
Boiling point / K	5869			
Density / kgm <sup>-3</sup>	21020			
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	47.9			
Electrical resistivity / Ωm	1.93 10 <sup>-7</sup>			
Coefficient of thermal expansion / K <sup>-1</sup>	6.2 10 <sup>-6</sup>			
Crystal structure	HCP			
Number of stable isotopes	1(2)			
Mean atomic weight	186.207			

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	9.64E15	9.47E15	1.81E15	1.75E13	4.57E10	3.08E8	kW kg <sup>-1</sup>	8.35E-1	8.30E-1	1.26E-1	2.11E-3	3.37E-7	1.19E-8
Re188	47.70	48.38	7.13	0.09			Re188	73.91	74.09	13.71	0.10		
Re186	22.41	22.80	61.04		0.48	49.96	Re186	14.76	14.83	49.88		3.69	73.51
Os189m	15.99	16.07					W187	3.88	3.90	2.01			
Os191	2.96	3.01	13.71				Os185	2.17	2.18	13.95	57.66		
W187	2.83	2.87	1.18				Ir192	1.85	1.86	11.81	23.70	4.95	
Os191m	2.13	2.16	0.11				Os189m	0.78	0.77				
Os185	1.59	1.62	8.24	58.97			Os191	0.68	0.69	3.94			
Re188m	1.30	1.09					Re184	0.53	0.53	3.33	11.36		
Ir192m	1.11	0.09					Re188m	0.38	0.31				
Ir192	0.97	0.99	4.99	17.33	0.22		Re184m	0.07	0.08	0.48	6.36		
Re184	0.31	0.31	1.54	9.11			W185	0.05	0.05	0.32	0.68		
W185	0.21	0.22	1.09	4.02			Ir190	0.07	0.07	0.38			
Re184m	0.08	0.08	0.41	9.23			Pt193				0.06	89.24	
Pt193			0.01	1.02	98.47		Re186m					1.33	26.49
Re186m					0.48	49.96	Ir192n						0.77
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	8.54E4	8.46E4	3.35E4	1.85E3	1.50E-2	1.04E-4	Sv kg <sup>-1</sup>	1.03E7	1.03E7	2.25E6	1.39E4	2.38E0	5.70E-1
Re188	39.32*	39.53*	2.82	0.01			Re188	62.22	62.16	8.03	0.16		
Os185	22.27	22.46	55.31	68.99			Re186	31.32	31.38	73.67		13.75	40.54
W187	20.73	20.86	4.14				W187	1.66	1.66	0.60			
Ir192	8.21	8.28	20.23	12.25	50.52		Os191	1.57	1.57	6.29			
Re184	5.77	5.82	13.96	14.40			Ir192	1.26	1.27	5.62	30.54	5.94	
Os190m	1.01	0.71					Os185	0.76	0.76	3.38	37.84		
Re184m	0.43	0.43	1.08	4.28			Re184	0.28	0.29	1.24	11.46		
Re186	0.82*	0.83*	1.07*		0.47*	48.05*	Re184m	0.11	0.11	0.49	17.42		
Ir190	0.50	0.50	1.02				W185	0.09	0.09	0.39	2.22		
Ta182	0.01	0.01	0.03	0.05		0.01	Pt193				0.04	58.72	
Pt193					47.55		Re186m					20.16	59.46
Re186m					0.51	51.94	Ir192n						1.32
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	6.49E6	6.48E6	2.71E6	5.02E4	8.42E0	2.02E0		1.09E12	1.08E12	2.66E11	1.05E10	1.63E6	1.84E4
Re188	38.28	38.22	2.57	0.02			Re188	57.21	57.55	6.56	0.02		
Re186	36.64	36.68	44.85		2.85	8.40	W187	11.94	12.02	3.82			
Ir192	9.51	9.52	21.98	39.86	7.92		Re186	10.47	10.56	21.87		0.70	44.12
Os191	8.35	8.37	17.40				Os185	10.07	10.17	40.05	70.18		
Os185	3.78	3.79	8.80	32.87			Ir192	2.87	2.90	11.32	9.63	2.07	
Re184	0.86	0.86	1.95	6.03			Re184	2.46	2.48	9.52	13.79		
W187	0.80	0.80	0.15				Os191	1.25	1.26	4.44			
Re184m	0.75	0.75	1.76	20.90			Ir190	0.32	0.33	1.07			
Ir192n				0.01	46.73		Re184m	0.27	0.28	1.10	6.15		
Pt193				0.01	11.24		Pt193				0.06	95.34	
Re186m				0.01	31.07	91.60	Re186m					0.89	55.88

# Rhenium

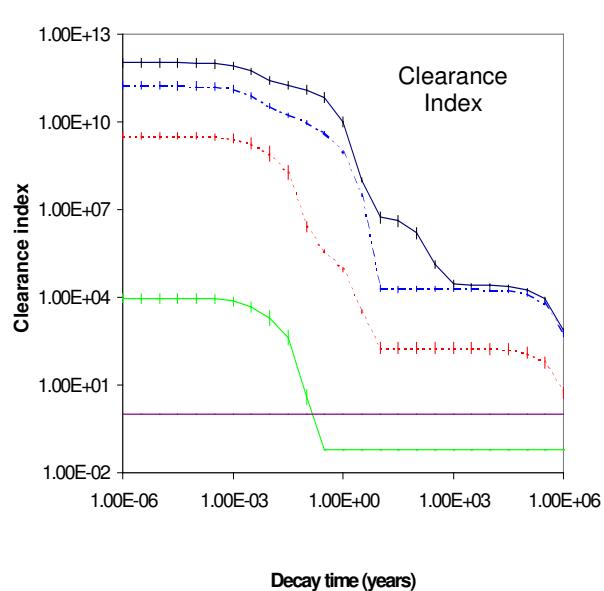
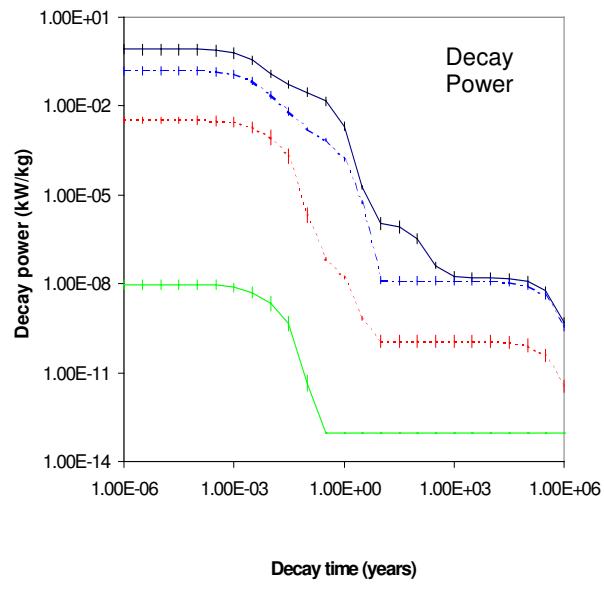
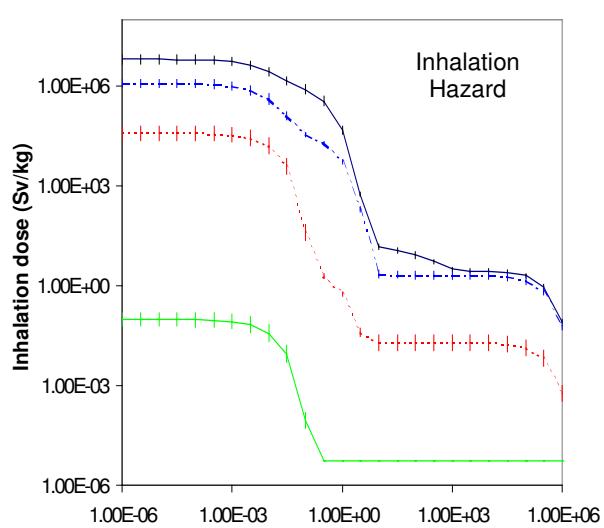
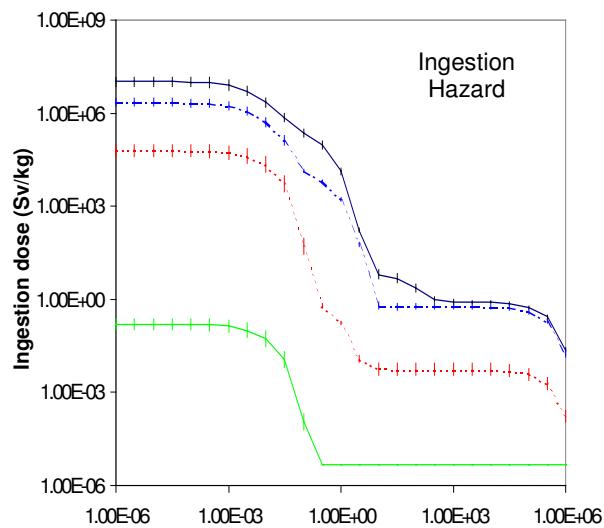
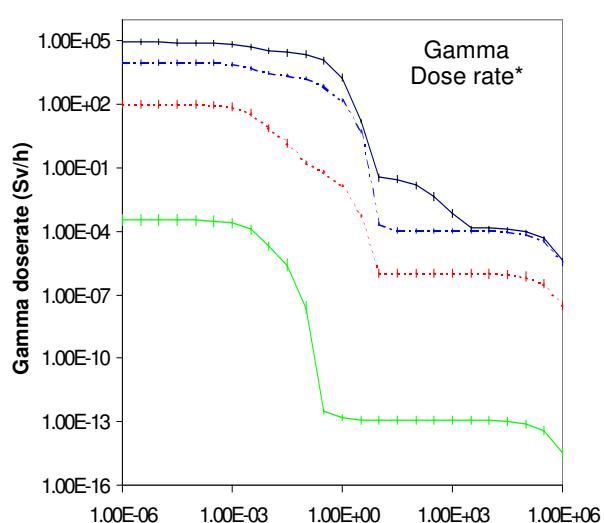
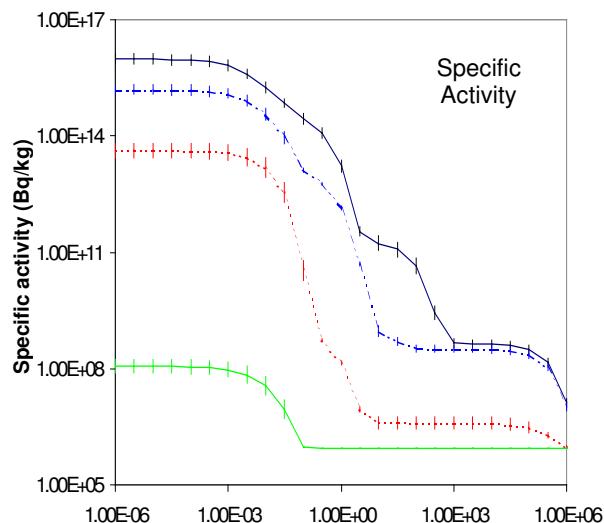
## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Re188	16.981 h	&Re187(n, $\gamma$ )Re188 &Re185(n, $\gamma$ )Re186( $\beta^+$ )W186(n, $\gamma$ )W187( $\beta^-$ ) Re187(n, $\gamma$ )Re188 &Re185(n, $\gamma$ )Re186(n, $\gamma$ )Re187(n, $\gamma$ )Re188	69.3 29.1	69.5 15.2 14.1	100.0	99.8
Ir194	19.15 h	&Re187(n, $\gamma$ )Re188( $\beta^-$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190 (n, $\gamma$ )Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194 &Re185(n, $\gamma$ )Re186( $\beta^-$ )Os186(n, $\gamma$ )Os187(n, $\gamma$ ) Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191( $\beta^-$ )Ir191(n, $\gamma$ ) Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194 &Re187(n, $\gamma$ )Re188( $\beta^-$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190 (n, $\gamma$ )Os191(n, $\gamma$ )Os192(n, $\gamma$ )Os193( $\beta^-$ )Ir193(n, $\gamma$ )Ir194	68.5 28.1 1.0	61.8 35.1 0.9	97.9	
W187	23.85 h	Re185(n, $\gamma$ )Re186( $\beta^+$ )W186(n, $\gamma$ )W187 Re187(n,p)W187 Re187(n,2n)Re186( $\beta^+$ )W186(n, $\gamma$ )W187	99.9	100.0	100.0	97.9 2.1
Re186	3.777 d	Re185(n, $\gamma$ )Re186 Re187(n,2n)Re186	99.8	100.0	100.0	99.4
Os191	15.405 d	&Re187(n, $\gamma$ )Re188( $\beta^-$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ ) Os190(n, $\gamma$ )Os191 &Re185(n, $\gamma$ )Re186( $\beta^-$ )Os186(n, $\gamma$ )Os187(n, $\gamma$ ) Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191 &Re185(n, $\gamma$ )Re186(n, $\gamma$ )Re187(n, $\gamma$ )Re188( $\beta^-$ ) Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191	68.9 30.0	46.0 51.8 1.8	100.0	99.4
Re184	37.963 d	&Re185(n,2n)Re184 &Re187(n,2n)Re186( $\beta^-$ )Os186(n,2n)Os185( $\beta^+$ )Re185(n,2n)Re184 &Re187(n,2n)Re186m(n,2n)Re185(n,2n)Re184 &Re187(n,3n)Re185(n,2n)Re184				90.7 5.3 1.7 1.0
W188	69.444 d	Re185(n, $\gamma$ )Re186( $\beta^+$ )W186(n, $\gamma$ )W187(n, $\gamma$ )W188 &Re187(n, $\gamma$ )Re188(n,p)W188 Re187(n,p)W187(n, $\gamma$ )W188	99.9	100.0	100.0	65.9 33.3
Ir192	73.831 d	&Re187(n, $\gamma$ )Re188( $\beta^-$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ ) Os190(n, $\gamma$ )Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192 &Re185(n, $\gamma$ )Re186( $\beta^-$ )Os186(n, $\gamma$ )Os187(n, $\gamma$ )Os188 (n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192 &Re185(n, $\gamma$ )Re186(n, $\gamma$ )Re187(n, $\gamma$ )Re188( $\beta^-$ )Os188 (n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192	68.9 29.8	51.2 46.5 1.5	100.0	95.9
W185	75.1 d	&Re187(n, $\gamma$ )Re188( $\beta^-$ )Os188(n, $\alpha$ )W185 &Re185(n, $\gamma$ )Re186( $\beta^-$ )Os186(n, $\gamma$ )Os187(n, $\gamma$ ) Os188(n, $\alpha$ )W185 &Re185(n, $\gamma$ )Re186( $\beta^+$ )W186(n, $\gamma$ )W187( $\beta^-$ ) Re187(n, $\gamma$ )Re188( $\beta^-$ )Os188(n, $\alpha$ )W185 &Re185(n, $\gamma$ )Re186( $\beta^-$ )Os186(n, $\alpha$ )W183(n, $\gamma$ ) W184(n, $\gamma$ )W185 &Re185(n, $\gamma$ )Re186( $\beta^-$ )Os186(n, $\gamma$ )Os187(n, $\alpha$ ) W184(n, $\gamma$ )W185 &Re185(n, $\gamma$ )Re186(n, $\gamma$ )Re187(n, $\gamma$ )Re188( $\beta^-$ ) Os188(n, $\alpha$ )W185 &Re185(n,p)W185 &Re187(n,2n)Re186( $\beta^+$ )W186(n,2n)W185 &Re187(n,t)W185	60.9 35.0 2.1 1.1 0.8 0.1	20.4 47.6 15.5 15.0 1.3 6.6	92.5 0.3 7.1 90.3 1.0	

Ta182	114.7 d	&Re185(n, $\gamma$ )Re186( $\beta^-$ )Os186(n, $\alpha$ )W183(n, $\alpha$ ) Hf180(n, $\gamma$ )Hf181( $\beta^-$ )Ta181(n, $\gamma$ )Ta182 Re185(n, $n\alpha$ )Ta181(n, $\gamma$ )Ta182 Re185(n, $\alpha$ )Ta182 Re185(n, $\alpha$ )Ta182m(IT)Ta182 Re185(n, $\alpha$ )Ta182n(IT)Ta182m(IT)Ta182 Re187(n,2n)Re186( $\beta^-$ )Os186(n,2n)Os185( $\beta^+$ )Re185(n, $\alpha$ )Ta182 &Re185(n,2n)Re184( $\beta^+$ )W184(n,2n)W183(n,d)Ta182 &Re187(n,2n)Re186m(n,2n)Re185(n, $\alpha$ )Ta182	56.9  41.7  0.2  0.2  0.2  	95.2  1.5  1.5  1.5  32.3  32.3  32.3  1.5  32.3  1.7  4.0  2.7  1.4	3.0  32.3  32.3  32.3  1.5  1.7  4.0  2.7  1.4	75.8  8.3  1.7  4.0  2.7  1.4
Re184m	165.51 d	Re185(n,2n)Re184m Re187(n,2n)Re186( $\beta^-$ )Os186(n,2n)Os185( $\beta^+$ )Re185(n,2n)Re184m Re187(n,2n)Re186m(n,2n)Re185(n,2n)Re184m				92.4  4.5  1.5
Ir194m	171.3 d	&Re187(n, $\gamma$ )Re188( $\beta^-$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190 (n, $\gamma$ )Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194m &Re185(n, $\gamma$ )Re186( $\beta^-$ )Os186(n, $\gamma$ )Os187(n, $\gamma$ ) Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191( $\beta^-$ )Ir191(n, $\gamma$ ) Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194m &Re187(n, $\gamma$ )Re188( $\beta^-$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190 (n, $\gamma$ )Os191(n, $\gamma$ )Os192(n, $\gamma$ )Os193( $\beta^-$ )Ir193(n, $\gamma$ )Ir194m	69.7  27.0  1.0	65.2  32.0  	97.6  1.0	
Os194	5.989 y	&Re187(n, $\gamma$ )Re188( $\beta^-$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ ) Os190(n, $\gamma$ )Os191(n, $\gamma$ )Os192(n, $\gamma$ )Os193(n, $\gamma$ )Os194 &Re185(n, $\gamma$ )Re186( $\beta^-$ )Os186(n, $\gamma$ )Os187(n, $\gamma$ ) Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191(n, $\gamma$ )Os192 (n, $\gamma$ )Os193(n, $\gamma$ )Os194 &Re187(n, $\gamma$ )Re188( $\beta^-$ )Os188(n, $\gamma$ )Os189(n, $\gamma$ ) Os190(n, $\gamma$ )Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192( $\beta^+$ )Os192(n, $\gamma$ ) Os193(n, $\gamma$ )Os194 &Re185(n, $\gamma$ )Re186( $\beta^-$ )Os186(n, $\gamma$ )Os187(n, $\gamma$ ) Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191( $\beta^-$ )Ir191(n, $\gamma$ ) Ir192( $\beta^+$ )Os192(n, $\gamma$ )Os193(n, $\gamma$ )Os194 &Re185(n, $\gamma$ )Re186(n, $\gamma$ )Re187(n, $\gamma$ )Re188( $\beta^-$ ) Os188(n, $\gamma$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191(n, $\gamma$ ) Os192(n, $\gamma$ )Os193(n, $\gamma$ )Os194	74.6  24.0  0.6  0.2  0.1	58.8  19.6  14.9  4.5  1.1	69.3  	
H3	12.33 y	Re185(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Re185(n, $\gamma$ )Re186( $\beta^-$ )Os186(n, $\gamma$ )Os187(n,X) H1(n, $\gamma$ )H2(n, $\gamma$ )H3 &Re185(n, $\gamma$ )Re186( $\beta^-$ )Os186(n, $\alpha$ )W183(n, $\gamma$ )W184(n,X)H3 Re187(n, $\alpha$ )Ta184( $\beta^-$ )W184(n,X)H3 Re185(n, $\gamma$ )Re186( $\beta^-$ )Os186(n, $\gamma$ )Os187(n, $\alpha$ )W184(n,X)H3 Re185(n, $n\alpha$ )Ta181(n,X)H3 Re187(n, $\gamma$ )Re188( $\beta^-$ )Os188(n, $n\alpha$ )W184(n,X)H3 Re187(n,X)H3 Re185(n,X)H3	81.3  9.6  	54.4  12.5  	3.8  55.4  25.4  8.1  5.3  1.1	61.7  35.4
Hf178n	31.0 y	&Re185(n,2n)Re184( $\beta^+$ )W184(n,2n)W183(n,2n)W182(n, $n\alpha$ )Hf178n &Re185(n,2n)Re184( $\beta^+$ )W184(n,3n)W182(n, $n\alpha$ )Hf178n &Re185(n,2n)Re184(n,2n)Re183( $\beta^+$ )W183(n,2n) W182(n, $n\alpha$ )Hf178n &Re185(n, $\alpha$ )Ta182( $\beta^-$ )W182(n, $n\alpha$ )Hf178n Re185(n,2n)Re184m(n,2n)Re183( $\beta^+$ )W183(n,2n) W182(n, $n\alpha$ )Hf178n &Re185(n,2n)Re184( $\beta^+$ )W184(n,2n)W183(n, $\alpha$ ) Hf180(n,2n)Hf179(n,2n)Hf178n &Re185(n,2n)Re184m( $\beta^+$ )W184(n,2n)W183(n,2n) W182(n, $n\alpha$ )Hf178n &Re185(n, $n\alpha$ )Ta181(n,2n)Ta180( $\beta^+$ )Hf180(n,2n) Hf179(n,2n)Hf178n Re185(n,3n)Re183( $\beta^+$ )W183(n,2n)W182(n, $n\alpha$ )Hf178n *Plus other similar pathways				55.8  12.6  5.6  4.2  3.7  2.9  2.2  1.1  1.1  1.1  10.8*

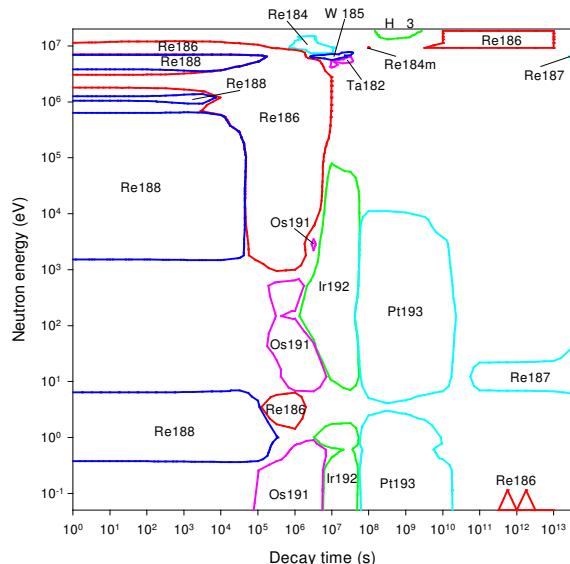
Pt193	50.0 y	<b>&amp;Re187(n,<math>\gamma</math>)Re188(<math>\beta^-</math>)Os188(n,<math>\gamma</math>)Os189(n,<math>\gamma</math>)Os190(n,<math>\gamma</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192(<math>\beta^-</math>)Pt192(n,<math>\gamma</math>)Pt193 &amp;Re185(n,<math>\gamma</math>)Re186(<math>\beta^-</math>)Os186(n,<math>\gamma</math>)Os187(n,<math>\gamma</math>)Os188(n,<math>\gamma</math>)Os189(n,<math>\gamma</math>)Os190(n,<math>\gamma</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192(<math>\beta^-</math>)Pt192(n,<math>\gamma</math>)Pt193</b>	74.5 24.7	64.2 33.9	100.0	
Ir192n	240.84 y	<b>&amp;Re187(n,<math>\gamma</math>)Re188(<math>\beta^-</math>)Os188(n,<math>\gamma</math>)Os189(n,<math>\gamma</math>)Os190(n,<math>\gamma</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192n &amp;Re185(n,<math>\gamma</math>)Re186(<math>\beta^-</math>)Os186(n,<math>\gamma</math>)Os187(n,<math>\gamma</math>)Os188(n,<math>\gamma</math>)Os189(n,<math>\gamma</math>)Os190(n,<math>\gamma</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192n &amp;Re185(n,<math>\gamma</math>)Re186(n,<math>\gamma</math>)Re187(n,<math>\gamma</math>)Re188(<math>\beta^-</math>)Os188(n,<math>\gamma</math>)Os189(n,<math>\gamma</math>)Os190(n,<math>\gamma</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192n</b>	69.0 29.8 1.7	52.3 45.6	100.0	94.6
Re186m	$2.0 \cdot 10^5$ y	Re185(n, $\gamma$ )Re186m Re187(n, $_2$ n)Re186m	100.0	100.0	100.0	99.9
Re187	$5.0 \cdot 10^{10}$ y	Re185(n, $\gamma$ )Re186( $\beta^+$ )W186(n, $\gamma$ )W187( $\beta^-$ )Re187 Re185(n, $\gamma$ )Re186(n, $\gamma$ )Re187 *Nuclide also present in starting material	29.9 70.1*	15.7 14.2 70.1*	100.0*	100.0*
Os186	$1.9 \cdot 10^{15}$ y	Re185(n, $\gamma$ )Re186( $\beta^-$ )Os186 Re187(n, $_2$ n)Re186( $\beta^-$ )Os186	100.0	100.0	100.0	100.0

# Rhenium activation characteristics

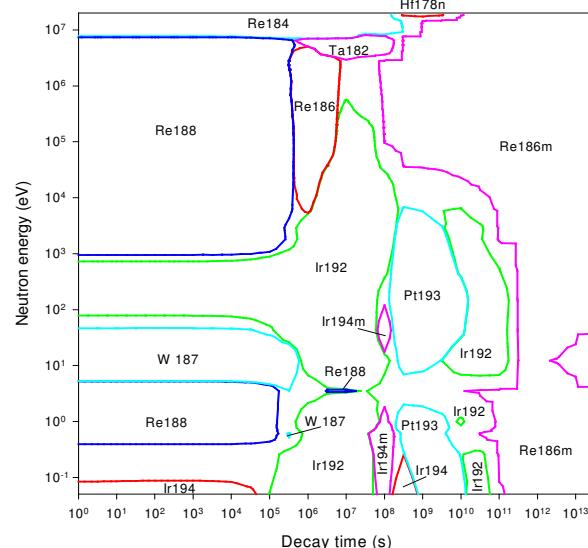


# Rhenium importance diagrams & transmutation

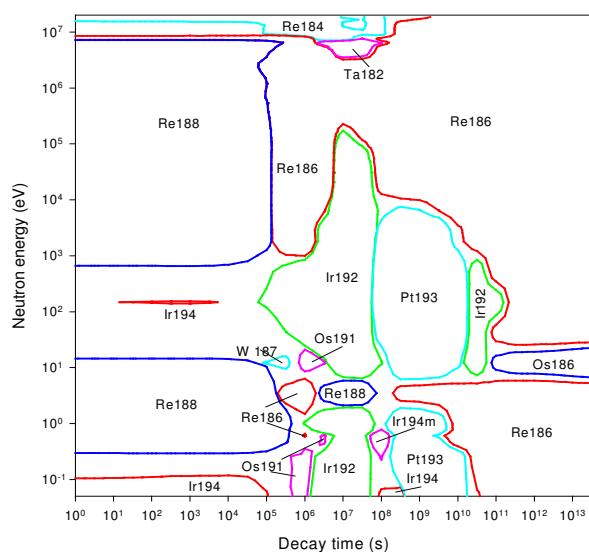
## Activity



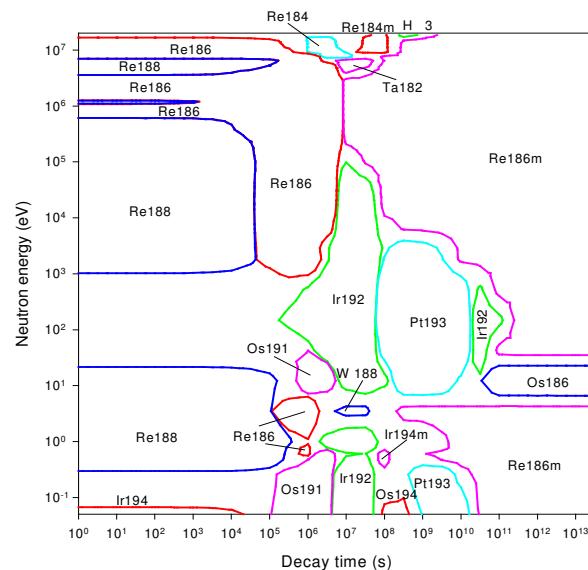
## Dose rate



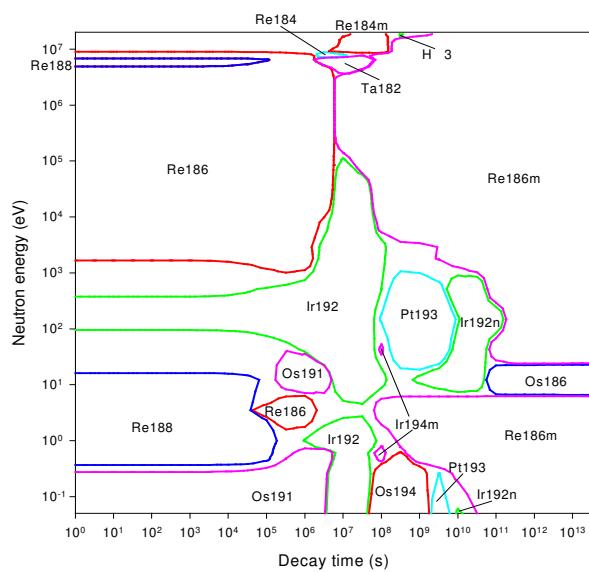
## Heat output



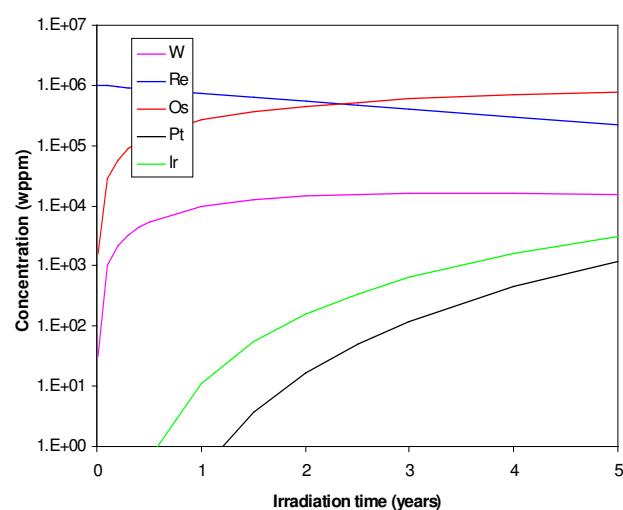
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Osmium

## General properties

	76	Isotopes	Isotopic abundances / %
Atomic number	1.5 10 <sup>-3</sup>	Os184	0.02
Crustal abundance / wppm	3306	Os186	1.59 ( $T_{1/2} = 1.9 \cdot 10^{15}$ y)
Melting point / K	5285	Os187	1.60
Boiling point / K	22570	Os188	13.29
Density / kgm <sup>-3</sup>	87.6	Os189	16.21
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	8.12 10 <sup>-8</sup>	Os190	26.36
Electrical resistivity /Ωm	5.1 10 <sup>-6</sup>	Os192	40.93
Coefficient of thermal expansion / K <sup>-1</sup>	HCP		
Crystal structure	6(7)		
Number of stable isotopes	190.23		
Mean atomic weight			

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	6.46E15	5.42E15	2.64E15	4.23E13	2.07E12	5.81E4	kW kg <sup>-1</sup>	3.44E-1	3.28E-1	2.08E-1	5.69E-3	1.44E-5	2.25E-12
Os191	25.08	29.90	53.19				Ir192	49.80	52.24	79.42	97.46	3.32	
Ir192m	16.54	1.57					Ir194	20.63	21.57	1.43	0.02		
Ir192	16.04	19.12	37.88	79.35	0.14		Os191	9.44	9.90	13.52			
Os191m	15.69	18.62	0.37				Os193	6.38	6.68	1.44			
Os189m	9.43	11.10					Os191m	3.51	3.67	0.06			
Ir194	7.60	9.04	0.78	0.02			Ir192m	2.90	0.24				
Os193	4.79	5.69	1.60				Ir190	1.70	1.78	2.27			
Pt193m	1.72	2.05	2.35				Os190m	1.52	1.14				
Ir193m	1.03	1.23	1.98				Ir191n	1.13					
Pt193	0.13	0.15	0.31	19.29	99.72		Pt193m	0.78	0.82	0.72			
Re186	0.12	0.14	0.15				Re186	0.13	0.13	0.11			73.51
Os185	0.10	0.12	0.24	1.05			Pt193		0.02	0.03	0.96	96.16	
Re186m						49.99	Re186m						26.49
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	9.75E4	9.33E4	7.94E4	2.56E3	5.35E-1	1.91E-8	Sv kg <sup>-1</sup>	3.49E6	3.49E6	2.34E6	4.77E4	6.91E1	1.08E-4
Ir192	78.42	81.99	93.04	96.73	39.82		Ir192	41.50	41.54	59.79	98.49	5.85	
Ir194	6.45*	6.72*					Os191	26.42	26.45	34.18			
Ir190	4.27	4.47	4.25				Ir194	18.27	18.23	1.14	0.03		
Os190m	3.73	2.78					Os193	7.16	7.16	1.46			
Ir191n	2.87						Os191m	2.78	2.77	0.04			
Os193	1.52	1.58	0.25				Pt193m	1.43	1.43	1.19			
Os185	0.83	0.87	0.99	2.13			Ir190	0.81	0.81	0.97			
Os191	0.66	0.69	0.70				Ir193m	0.51	0.51	0.60			
Ir194m	0.12	0.13	0.15	1.04			Re186	0.33	0.33	0.25			40.51
Pt193			0.05	59.43			Pt193	0.01	0.01	0.01	0.53	92.86	
Re186m						51.62	Ir192n					1.29	
Re186						48.29*	Re186m						59.41
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	1.07E7	1.07E7	9.45E6	2.25E5	1.75E2	3.81E-4		6.74E11	6.31E11	4.48E11	1.20E10	7.28E7	3.46E0
Ir192	63.88	63.90	69.87	98.65	10.89		Ir192	51.22	54.72	74.47	93.17	1.32	
Os191	28.76	28.76	28.24				Ir194	12.56	13.38	0.79	0.01		
Ir194	2.57	2.56	0.12				Os191	11.44	12.22	14.94			
Os191m	1.52	1.51	0.02				Ir190	5.19	5.55	6.33			
Os193	1.50	1.50	0.23				Os193	4.78	5.09	0.98			
Ir193m	0.81	0.81	0.72				Os190m	4.58	3.49				
Ir190	0.53	0.53	0.48				Ir191n	3.53					
Os185	0.10	0.10	0.11	0.32			Os191m	2.18	2.32	0.03			
Re186	0.08	0.08	0.05			8.39	Pt191	0.92	0.98	0.58			
Ir194m	0.05	0.05	0.05	0.53			Os185	0.70	0.75	1.02	2.63		
Os194	0.01	0.01	0.01	0.34	0.01		Ir194m	0.14	0.15	0.21	1.77		
Pt193					0.08	24.84	Re186	0.06	0.06	0.05			44.12
Ir192n					0.07	64.27	Pt193	0.04	0.05	0.06	2.34	98.04	
Re186m						91.55	Re186m						55.88

# Osmium

## Pathway analysis

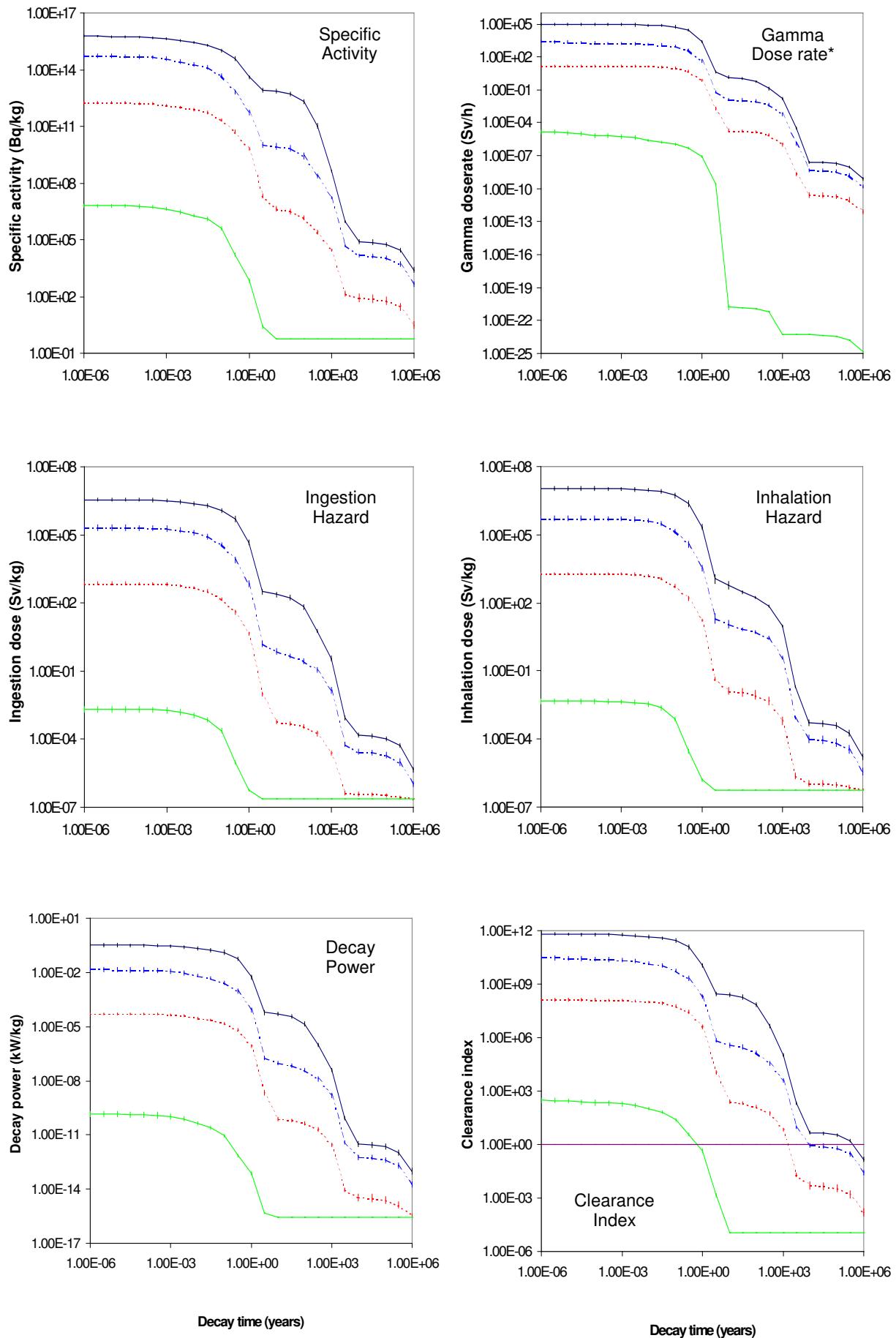
Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Os190m	9.9 m	Os189(n, $\gamma$ )Os190m <b>&amp;Os188(n,<math>\gamma</math>)Os189(n,<math>\gamma</math>)Os190m</b> <b>&amp;Os187(n,<math>\gamma</math>)Os188(n,<math>\gamma</math>)Os189(n,<math>\gamma</math>)Os190m</b> <b>&amp;Os186(n,<math>\gamma</math>)Os187(n,<math>\gamma</math>)Os188(n,<math>\gamma</math>)Os189(n,<math>\gamma</math>)Os190m</b>	56.4 35.4 4.2 3.9	50.4 15.0 34.2	95.1 4.9	
Os189m	4.806 h	Os188(n, $\gamma$ )Os189m Os186(n, $\gamma$ )Os187(n, $\gamma$ )Os188(n, $\gamma$ )Os189m Os187(n, $\gamma$ )Os188(n, $\gamma$ )Os189m Os189(n,n')Os189m Os190(n,2n)Os189m <b>&amp;Os192(n,2n)Os191(<math>\beta^-</math>)Ir191(n,2n)Ir190(<math>\beta^+</math>)Os190(n,2n)Os189m</b> <b>&amp;Os192(n,3n)Os190(n,2n)Os189m</b>	79.8 10.3 9.8 	47.9 36.9 14.9 	95.7 1.3 2.8 4.4 83.8 6.2 2.1	
Ir194	19.12 h	<b>&amp;Os190(n,<math>\gamma</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192(n,<math>\gamma</math>)Ir193(n,<math>\gamma</math>)Ir194</b> Os192(n, $\gamma$ )Os193( $\beta^-$ )Ir193(n, $\gamma$ )Ir194 <b>&amp;Os189(n,<math>\gamma</math>)Os190(n,<math>\gamma</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192(n,<math>\gamma</math>)Ir193(n,<math>\gamma</math>)Ir194</b> <b>&amp;Os188(n,<math>\gamma</math>)Os189(n,<math>\gamma</math>)Os190(n,<math>\gamma</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192(n,<math>\gamma</math>)Ir193(n,<math>\gamma</math>)Ir194</b> <b>&amp;Os190(n,<math>\gamma</math>)Os191(n,<math>\gamma</math>)Os192(n,<math>\gamma</math>)Os193(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192(n,<math>\gamma</math>)Ir193(n,<math>\gamma</math>)Ir194</b> <b>&amp;Os187(n,<math>\gamma</math>)Os188(n,<math>\gamma</math>)Os189(n,<math>\gamma</math>)Os190(n,<math>\gamma</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192(n,<math>\gamma</math>)Ir193(n,<math>\gamma</math>)Ir194</b> <b>&amp;Os186(n,<math>\gamma</math>)Os187(n,<math>\gamma</math>)Os188(n,<math>\gamma</math>)Os189(n,<math>\gamma</math>)Os190(n,<math>\gamma</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192(n,<math>\gamma</math>)Ir193(n,<math>\gamma</math>)Ir194</b>	39.4 25.8 24.3 4.1 2.4 0.5 0.3	31.7 25.6 31.1 4.4 4.8	0.4 99.6 97.9	
Os193	30.5 h	Os192(n, $\gamma$ )Os193 <b>&amp;Os190(n,<math>\gamma</math>)Os191(n,<math>\gamma</math>)Os192(n,<math>\gamma</math>)Os193</b> <b>&amp;Os189(n,<math>\gamma</math>)Os190(n,<math>\gamma</math>)Os191(n,<math>\gamma</math>)Os192(n,<math>\gamma</math>)Os193</b> <b>&amp;Os190(n,<math>\gamma</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192(<math>\beta^+</math>)Os192(n,<math>\gamma</math>)Os193</b> Os192(n, $\gamma$ )Os193 <b>&amp;Os188(n,<math>\gamma</math>)Os189(n,<math>\gamma</math>)Os190(n,<math>\gamma</math>)Os191(n,<math>\gamma</math>)Os192(n,<math>\gamma</math>)Os193</b>	87.4 8.8 3.3 0.1 0.3	90.0 3.4 2.1 1.1 1.7	100.0	99.9
Re186	3.777 d	Os184(n, $\gamma$ )Os185( $\beta^+$ )Re185(n, $\gamma$ )Re186 <b>&amp;Os188(n,<math>\alpha</math>)W185(<math>\beta^-</math>)Re185(n,<math>\gamma</math>)Re186</b> <b>&amp;Os186(n,<math>\gamma</math>)Os187(n,<math>\gamma</math>)Os188(n,<math>\alpha</math>)W185(<math>\beta^-</math>)Re185(n,<math>\gamma</math>)Re186</b> Re185(n, $\gamma$ )Re186 <b>&amp;Os187(n,<math>\gamma</math>)Os188(n,<math>\alpha</math>)W185(<math>\beta^-</math>)Re185(n,<math>\gamma</math>)Re186</b> Os186(n,p)Re186 Os190(n, $\alpha$ )W187( $\beta^-$ )Re187(n,2n)Re186 Os188(n,2n)Os187(n,2n)Os186(n,p)Re186 Os187(n,2n)Os186(n,p)Re186 Os188(n,2n)Os187(n,p)Re187(n,2n)Re186 Os187(n,p)Re187(n,2n)Re186 Os188(n,2n)Os187(n,d)Re186 Os188(n,t)Re186 Os189(n,2n)Os188(n,2n)Os187(n,2n)Os186(n,p)Re186 Os189(n,t)Re187(n,2n)Re186 Os189(n,2n)Os188(n,2n)Os187(n,p)Re187(n,2n)Re186 Os186(n,2n)Os185( $\beta^+$ )Re185(n, $\gamma$ )Re186	68.4 21.2 2.7 2.6	100.0	100.0	26.5 23.4 11.1 9.1 7.8 6.4 2.0 1.7 1.6 1.5 1.1 1.1
Ir190	12.0 d	<b>&amp;Os192(n,2n)Os191(<math>\beta^-</math>)Ir191(n,2n)Ir190</b>				99.0

Os191	15.405 d	<b>&amp;Os190(n,<math>\gamma</math>)Os191</b> <b>&amp;Os189(n,<math>\gamma</math>)Os190(n,<math>\gamma</math>)Os191</b> <b>&amp;Os188(n,<math>\gamma</math>)Os189(n,<math>\gamma</math>)Os190(n,<math>\gamma</math>)Os191</b> <b>&amp;Os187(n,<math>\gamma</math>)Os188(n,<math>\gamma</math>)Os189(n,<math>\gamma</math>)Os190(n,<math>\gamma</math>)Os191</b> <b>&amp;Os186(n,<math>\gamma</math>)Os187(n,<math>\gamma</math>)Os188(n,<math>\gamma</math>)Os189(n,<math>\gamma</math>)</b> Os190(n, $\gamma$ )Os191 <b>&amp;Os192(n,2n)Os191</b>	52.3 38.4 7.4 0.8 0.6	13.8 15.4 46.4 9.5 14.9	89.3 10.5	
Re184	37.963 d	<b>&amp;Os184(n,p)Re184</b> <b>&amp;Os186(n,2n)Os185(<math>\beta^+</math>)Re185(n,2n)Re184</b> <b>&amp;Os187(n,2n)Os186(n,2n)Os185(<math>\beta^+</math>)Re185(n,2n)Re184</b> <b>&amp;Os188(n,2n)Os187(n,2n)Os186(n,2n)Os185(<math>\beta^+</math>)</b> Re185(n,2n)Re184		99.9	99.9	77.3 11.9 8.6
Ir192	73.831 d	<b>&amp;Os190(n,<math>\gamma</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192</b> <b>&amp;Os189(n,<math>\gamma</math>)Os190(n,<math>\gamma</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192</b> <b>&amp;Os188(n,<math>\gamma</math>)Os189(n,<math>\gamma</math>)Os190(n,<math>\gamma</math>)Os191(<math>\beta^-</math>)</b> Ir191(n, $\gamma$ )Ir192 <b>&amp;Os187(n,<math>\gamma</math>)Os188(n,<math>\gamma</math>)Os189(n,<math>\gamma</math>)Os190(n,<math>\gamma</math>)</b> Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192 <b>&amp;Os186(n,<math>\gamma</math>)Os187(n,<math>\gamma</math>)Os188(n,<math>\gamma</math>)Os189(n,<math>\gamma</math>)</b> Os190(n, $\gamma$ )Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192 <b>&amp;Os192(n,2n)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192</b> <b>&amp;Os192(n,<math>\gamma</math>)Os193(<math>\beta^-</math>)Ir193(n,2n)Ir192</b>	53.1 38.3 7.2 0.7 0.2	16.8 18.4 44.7 8.3 11.7	94.5 5.0	
Os185	93.8 d	Os184(n, $\gamma$ )Os185 Os186(n,2n)Os185 Os188(n,2n)Os187(n,2n)Os186(n,2n)Os185 Os187(n,2n)Os186(n,2n)Os185 Os189(n,2n)Os188(n,2n)Os187(n,2n)Os186(n,2n)Os185	100.0	100.0	100.0	56.9 20.6 18.2 2.7
Re184m	165.51 d	Os184(n,p)Re184m Os186(n,2n)Os185( $\beta^+$ )Re185(n,2n)Re184m Os187(n,2n)Os186(n,2n)Os185( $\beta^+$ )Re185(n,2n)Re184m Os188(n,2n)Os187(n,2n)Os186(n,2n)Os185( $\beta^+$ ) Re185(n,2n)Re184m		100.0	100.0	78.9 11.2 7.6
Ir194m	171.3 d	<b>&amp;Os190(n,<math>\gamma</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192(n,<math>\gamma</math>)Ir193(n,<math>\gamma</math>)</b> Ir194m Os192(n, $\gamma$ )Os193( $\beta^-$ )Ir193(n, $\gamma$ )Ir194m <b>&amp;Os189(n,<math>\gamma</math>)Os190(n,<math>\gamma</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)</b> Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194m <b>&amp;Os188(n,<math>\gamma</math>)Os189(n,<math>\gamma</math>)Os190(n,<math>\gamma</math>)Os191(<math>\beta^-</math>)</b> Ir191(n, $\gamma$ )Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194m <b>&amp;Os190(n,<math>\gamma</math>)Os191(n,<math>\gamma</math>)Os192(n,<math>\gamma</math>)Os193(<math>\beta^-</math>)</b> Ir193(n, $\gamma$ )Ir194m <b>&amp;Os187(n,<math>\gamma</math>)Os188(n,<math>\gamma</math>)Os189(n,<math>\gamma</math>)Os190(n,<math>\gamma</math>)</b> Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194m <b>&amp;Os186(n,<math>\gamma</math>)Os187(n,<math>\gamma</math>)Os188(n,<math>\gamma</math>)Os189(n,<math>\gamma</math>)Os190(n,<math>\gamma</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192(n,<math>\gamma</math>)Ir193(n,<math>\gamma</math>)Ir194m</b>	42.4 25.4 23.2 3.4 2.1 0.4 0.3	34.5 0.7 26.8 29.0 3.8 3.7	99.6	98.0
Os194	5.989 y	Os192(n, $\gamma$ )Os193(n, $\gamma$ )Os194 <b>&amp;Os190(n,<math>\gamma</math>)Os191(n,<math>\gamma</math>)Os192(n,<math>\gamma</math>)Os193(n,<math>\gamma</math>)Os194</b> <b>&amp;Os189(n,<math>\gamma</math>)Os190(n,<math>\gamma</math>)Os191(n,<math>\gamma</math>)Os192(n,<math>\gamma</math>)</b> Os193(n, $\gamma$ )Os194 <b>&amp;Os188(n,<math>\gamma</math>)Os189(n,<math>\gamma</math>)Os190(n,<math>\gamma</math>)Os191(n,<math>\gamma</math>)</b> Os192(n, $\gamma$ )Os193(n, $\gamma$ )Os194	92.5 5.8 1.6 0.1	92.6 2.9 1.6 1.1	100.0	99.9



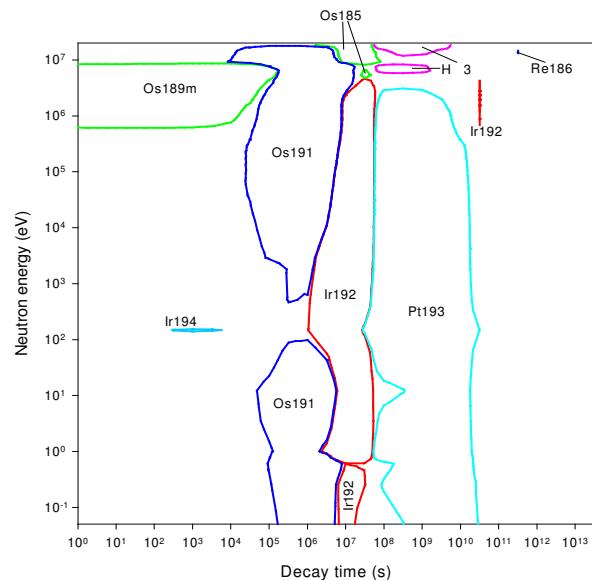
Os186	$1.9 \cdot 10^{15}$ y	Os184(n, $\gamma$ )Os185( $\beta^+$ )Re185(n, $\gamma$ )Re186( $\beta^-$ )Os186 Os184(n, $\gamma$ )Os185(n, $\gamma$ )Os186 Os188(n,2n)Os187(n,2n)Os186 Os187(n,2n)Os186 Os189(n,2n)Os188(n,2n)Os187(n,2n)Os186 *Nuclide also present in starting material	3.7 0.4     95.9*	36.3 13.0     50.7*			22.8 18.7 3.2   100.0*	55.3*
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# Osmium activation characteristics

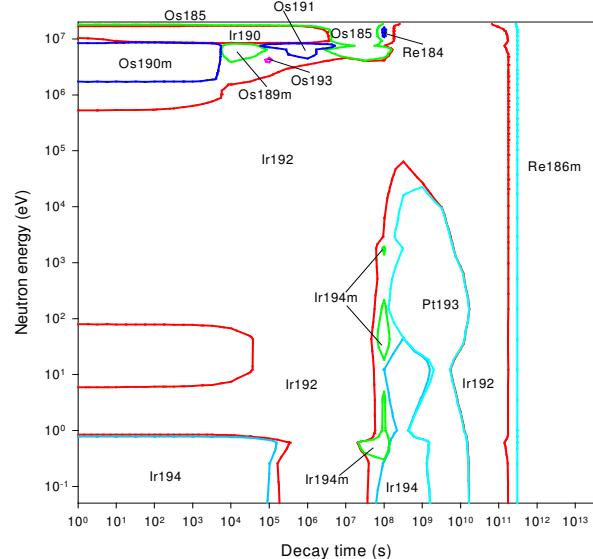


# Osmium importance diagrams & transmutation

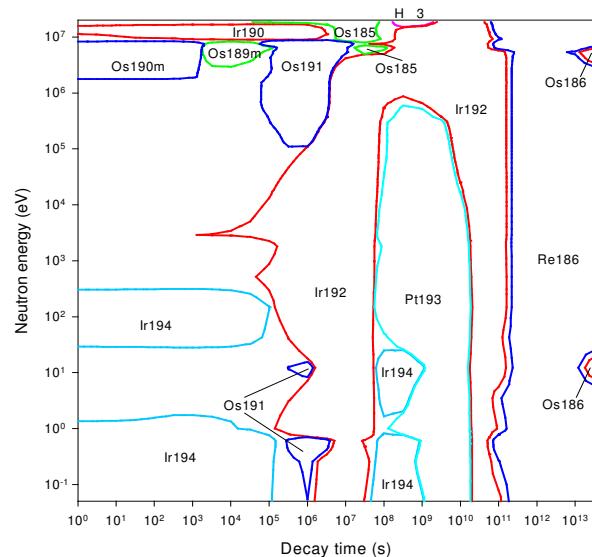
## Activity



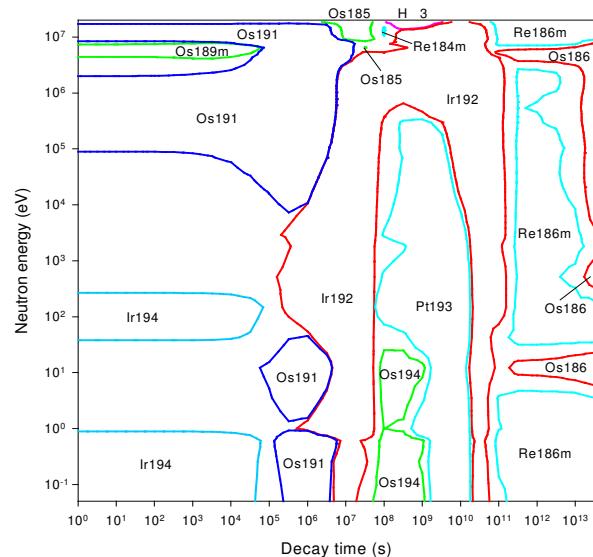
## Dose rate



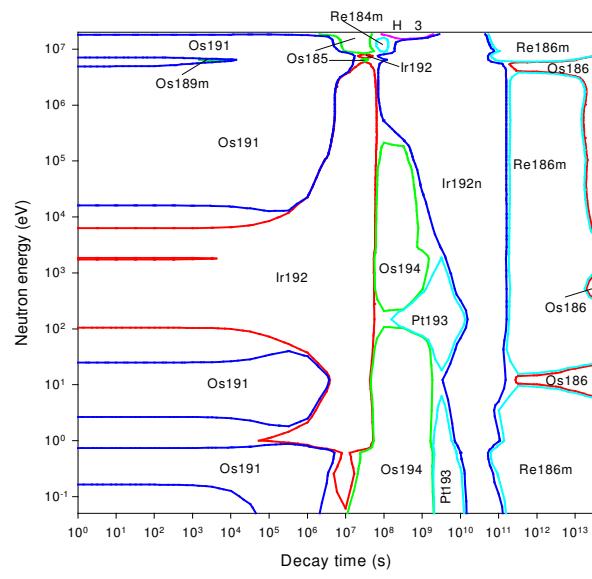
## Heat output



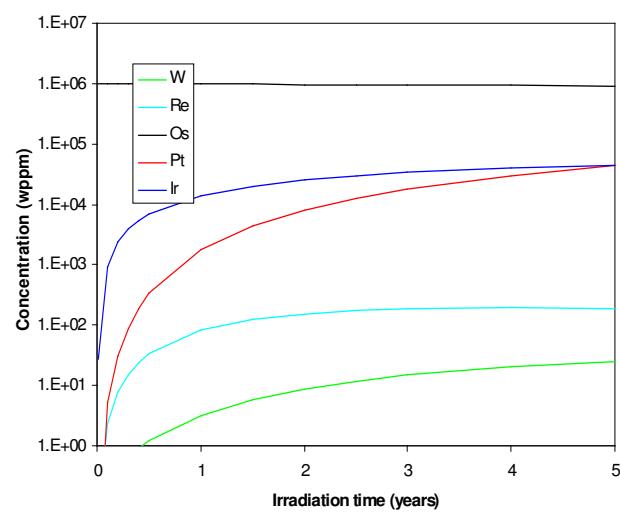
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Iridium

## General properties

Atomic number	77	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	1.0 10 <sup>-3</sup>	Ir191	37.3
Melting point / K	2719	Ir193	62.7
Boiling point / K	4701		
Density / kgm <sup>-3</sup>	22420		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	147		
Electrical resistivity /Ωm	5.3 10 <sup>-8</sup>		
Coefficient of thermal expansion / K <sup>-1</sup>	6.4 10 <sup>-6</sup>		
Crystal structure	FCC		
Number of stable isotopes	2		
Mean atomic weight	192.217		

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	8.84E15	7.99E15	2.15E15	1.37E14	2.58E13	1.55E2	kW kg <sup>-1</sup>	1.00E0	9.90E-1	2.27E-1	6.84E-3	1.77E-4	6.04E-15
Ir194	60.35	66.57	10.39				Ir194	76.79	77.61	14.21			
Ir192	11.91	13.17	47.28	24.93	0.11		Ir192	17.34	17.58	74.04	82.53	2.71	
Pt193m	10.73	11.86	24.60				Pt193m	2.28	2.31	5.62			
Ir192m	9.88	0.87					Ir192m	0.81	0.07				
Ir193m	1.81	2.00	5.86				Pt191	0.70	0.71	1.30			
Pt191	1.48	1.64	2.55				Ir190	0.47	0.47	1.67			
Pt193	1.16	1.29	4.78	74.05	99.78		Pt195m	0.36	0.36	0.85			
Pt195m	1.04	1.15	2.28				Ir194m	0.23	0.23	0.98	7.56		
Os191	0.31	0.35	1.11				Pt193	0.07	0.07	0.30	9.90	96.87	
Ir194m	0.07	0.07	0.27	0.98			Re186						72.96
Re186						49.92	Re186m						26.29
Re186m						49.92	Pt190						0.75
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	1.55E5	1.52E5	8.19E4	2.88E3	1.04E1	5.67E-11	Sv kg <sup>-1</sup>	9.06E6	9.04E6	2.09E6	5.38E4	8.47E2	2.87E-7
Ir192	49.15	50.06	89.62	85.57	20.14		Ir194	76.59	76.53	13.92			
Ir194	43.71*	44.38	3.45				Ir192	16.27	16.31	68.24	88.90	4.79	
Ir190	2.13	2.17	3.25				Pt193m	4.71	4.72	11.41			
Pt191	1.68	1.71	1.32				Pt195m	0.64	0.64	1.48			
Ir191n	1.43						Ir193m	0.48	0.48	1.63			
Ir194m	1.09	1.11	2.02	13.30			Ir194m	0.14	0.14	0.58	5.22		
Pt193	0.02	0.02	0.04	1.13	79.49		Pt193	0.04	0.04	0.15	5.85	94.14	
Ir192n					0.37		Ir192n				0.02	1.06	
Re186m						53.83	Re186m						59.31
Re186						46.17*	Re186						40.44
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	1.05E7	1.05E7	7.25E6	2.47E5	1.86E3	1.03E-6		1.42E12	1.39E12	4.54E11	1.80E10	9.02E8	9.23E-3
Ir192	66.29	66.35	92.68	91.45	10.28		Ir194	64.68	65.80	8.48			
Ir194	28.51	28.45	1.73				Ir192	24.67	25.18	74.66	63.25	1.07	
Ir193m	1.99	1.99	2.26				Pt191	2.56	2.61	3.35			
Pt193m	1.09	1.09	0.88				Ir190	1.98	2.02	5.01			
Ir194m	0.73	0.73	1.04	7.05			Pt193m	1.76	1.79	3.07			
Os191	0.50	0.50	0.63				Ir191n	1.34					
Pt193	0.02	0.02	0.03	0.86	29.02		Ir194m	0.96	0.98	2.96	17.28		
Ir192n	0.01	0.01	0.02	0.61	60.71		Pt195m	0.59	0.60	0.98			
Re186m						89.79	Pt193	0.25	0.25	0.78	19.44	98.41	
Re186						8.23	Re186m						55.88
Pt190						1.97	Re186						44.12

# Iridium

## Pathway analysis

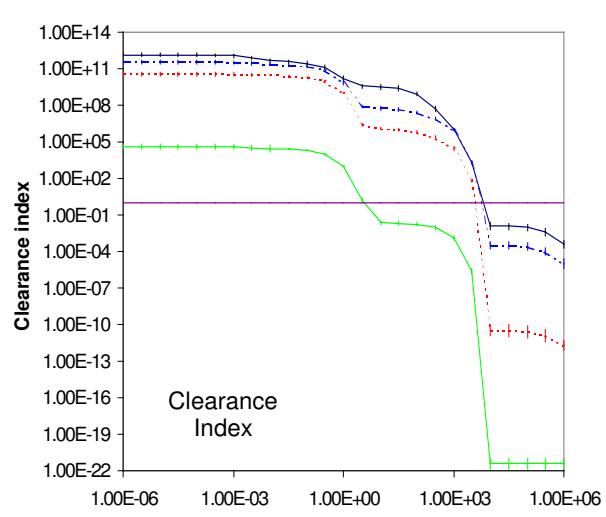
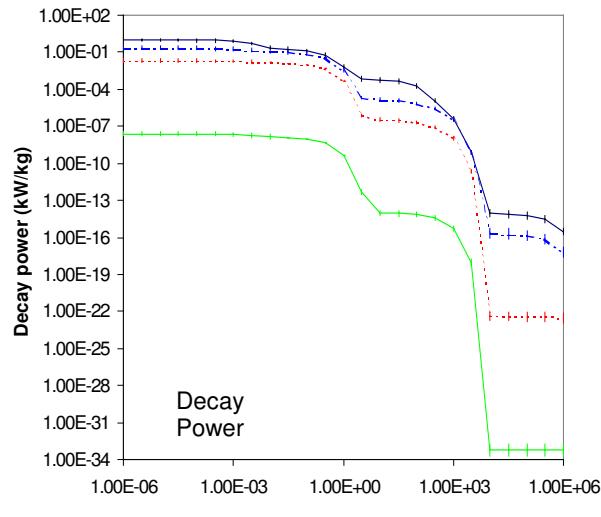
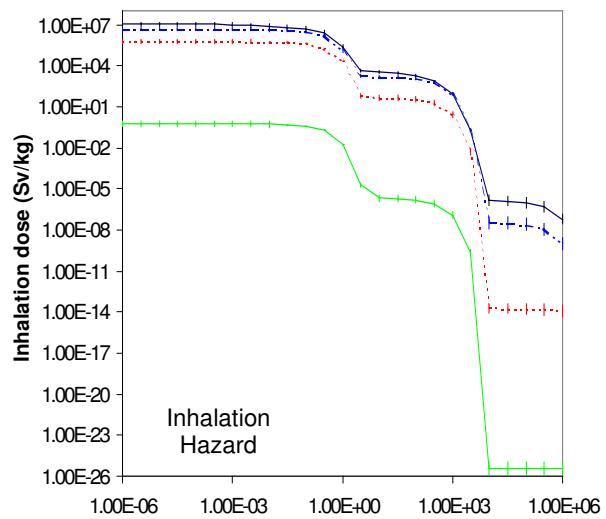
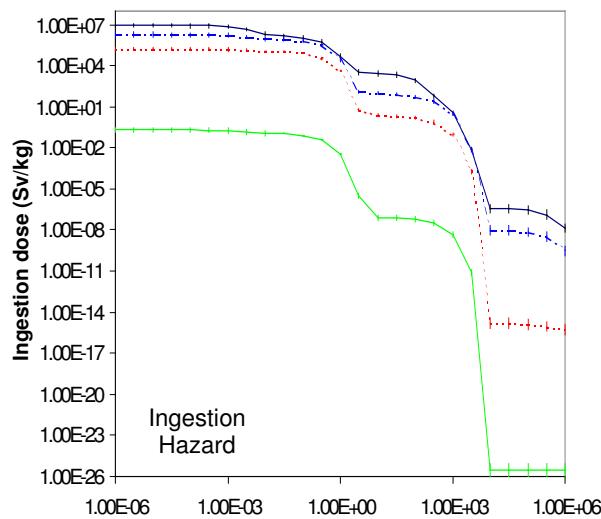
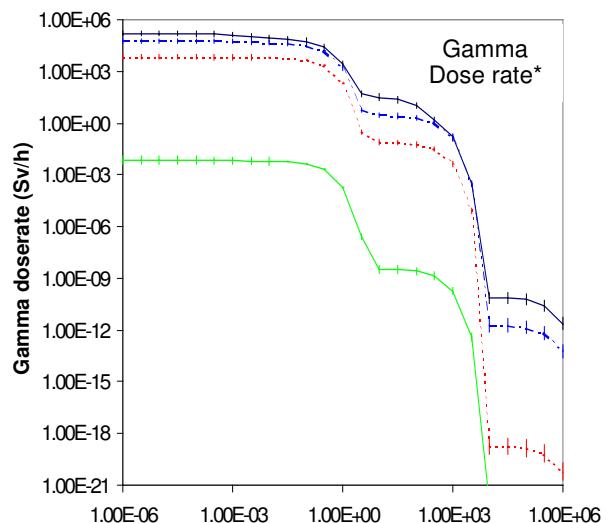
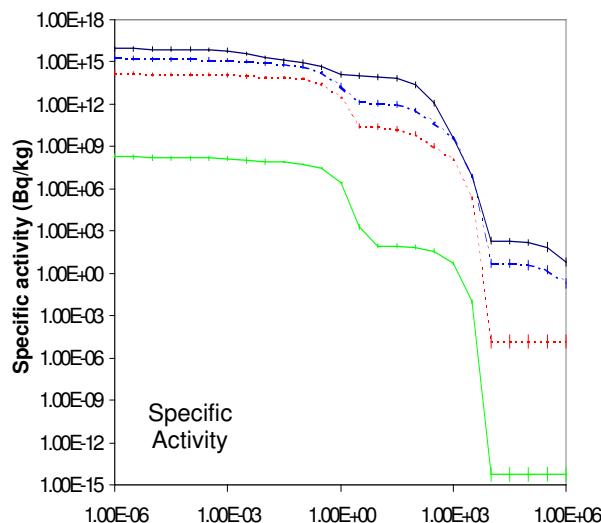
Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Ir191m	4.9 s	Ir191(n,n')Ir191n(IT)Ir191m Ir191(n,n')Ir191m Ir193(n,2n)Ir192n(n,2n)Ir191m &Ir193(n,2n)Ir192( $\beta^-$ )Pt192(n,2n)Pt191( $\beta^+$ )Ir191(n,n')Ir191m Ir193(n,3n)Ir191m &Ir193(n,2n)Ir192(n,2n)Ir191m				40.9 38.7 4.8 4.8 3.6 3.0
Ir194	19.12 h	Ir193(n, $\gamma$ )Ir194 &Ir191(n, $\gamma$ )Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194 &Ir191(n, $\gamma$ )Ir192( $\beta^-$ )Pt192(n, $\gamma$ )Pt193( $\beta^+$ ) Ir193(n, $\gamma$ )Ir194 &Ir191(n, $\gamma$ )Ir192( $\beta^+$ )Os192(n, $\gamma$ )Os193( $\beta^-$ ) Ir193(n, $\gamma$ )Ir194	45.1 30.1 17.2 7.5	63.6 35.2 0.2	99.7	95.8
Au198	2.694 d	&Ir193(n, $\gamma$ )Ir194(n, $\gamma$ )Ir195( $\beta^-$ )Pt195(n, $\gamma$ )Pt196(n, $\gamma$ ) Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198 &Ir193(n, $\gamma$ )Ir194( $\beta^-$ )Pt194(n, $\gamma$ )Pt195(n, $\gamma$ )Pt196(n, $\gamma$ ) Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198 &Ir191(n, $\gamma$ )Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194(n, $\gamma$ )Ir195( $\beta^-$ ) Pt195(n, $\gamma$ )Pt196(n, $\gamma$ )Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198 &Ir191(n, $\gamma$ )Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194( $\beta^-$ )Pt194(n, $\gamma$ ) Pt195(n, $\gamma$ )Pt196(n, $\gamma$ )Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198 &Ir193(n, $\gamma$ )Ir194(n, $\gamma$ )Ir195m( $\beta^-$ )Pt195(n, $\gamma$ )Pt196(n, $\gamma$ ) Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198 &Ir191(n, $\gamma$ )Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194(n, $\gamma$ )Ir195m( $\beta^-$ ) Pt195(n, $\gamma$ )Pt196(n, $\gamma$ )Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198 &Ir193(n, $\gamma$ )Ir194m(n, $\gamma$ )Ir195( $\beta^-$ )Pt195(n, $\gamma$ )Pt196(n, $\gamma$ ) Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198 &Ir191(n, $\gamma$ )Ir192( $\beta^-$ )Pt192(n, $\gamma$ )Pt193(n, $\gamma$ )Pt194(n, $\gamma$ ) Pt195(n, $\gamma$ )Pt196(n, $\gamma$ )Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198 &Ir191(n, $\gamma$ )Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194m(n, $\gamma$ )Ir195( $\beta^-$ ) Pt195(n, $\gamma$ )Pt196(n, $\gamma$ )Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198 &Ir193(n, $\gamma$ )Ir194m(n, $\gamma$ )Ir195m( $\beta^-$ )Pt195(n, $\gamma$ ) Pt196(n, $\gamma$ )Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198	34.3 25.3 16.5 11.9 4.8 2.3 0.1 0.1 0.1 4.1 2.2	0.7 52.4 0.2 11.7 0.1 9.2 15.9 0.1 9.2 2.2	0.1 99.9	97.4
Au199	3.139 d	&Ir193(n, $\gamma$ )Ir194(n, $\gamma$ )Ir195( $\beta^-$ )Pt195(n, $\gamma$ )Pt196(n, $\gamma$ ) Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198(n, $\gamma$ )Au199 &Ir193(n, $\gamma$ )Ir194( $\beta^-$ )Pt194(n, $\gamma$ )Pt195(n, $\gamma$ )Pt196(n, $\gamma$ ) Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198(n, $\gamma$ )Au199 &Ir191(n, $\gamma$ )Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194(n, $\gamma$ )Ir195( $\beta^-$ ) Pt195(n, $\gamma$ )Pt196(n, $\gamma$ )Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198(n, $\gamma$ ) Au199 &Ir191(n, $\gamma$ )Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194( $\beta^-$ )Pt194(n, $\gamma$ ) Pt195(n, $\gamma$ )Pt196(n, $\gamma$ )Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198(n, $\gamma$ ) Au199 &Ir193(n, $\gamma$ )Ir194(n, $\gamma$ )Ir195m( $\beta^-$ )Pt195(n, $\gamma$ )Pt196(n, $\gamma$ ) Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198(n, $\gamma$ )Au199 &Ir191(n, $\gamma$ )Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194(n, $\gamma$ )Ir195m( $\beta^-$ ) Pt195(n, $\gamma$ )Pt196(n, $\gamma$ )Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198(n, $\gamma$ )Au199 &Ir193(n, $\gamma$ )Ir194m(n, $\gamma$ )Ir195( $\beta^-$ )Pt195(n, $\gamma$ )Pt196(n, $\gamma$ ) Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198(n, $\gamma$ )Au199 &Ir191(n, $\gamma$ )Ir192( $\beta^-$ )Pt192(n, $\gamma$ )Pt193(n, $\gamma$ )Pt194(n, $\gamma$ ) Pt195(n, $\gamma$ )Pt196(n, $\gamma$ )Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198(n, $\gamma$ )Au199 &Ir191(n, $\gamma$ )Ir192(n, $\gamma$ )Ir193(n, $\gamma$ )Ir194m(n, $\gamma$ )Ir195( $\beta^-$ ) Pt195(n, $\gamma$ )Pt196(n, $\gamma$ )Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198(n, $\gamma$ )Au199 &Ir193(n, $\gamma$ )Ir194m(n, $\gamma$ )Ir195m( $\beta^-$ )Pt195(n, $\gamma$ ) Pt196(n, $\gamma$ )Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198(n, $\gamma$ )Au199	34.3 25.2 16.5 11.8 4.8 2.3 0.1 0.1 0.1 4.1 2.2	0.7 52.2 0.2 11.6 0.1 16.0 0.1 9.2 0.1 4.1 2.2	0.2 98.9	

Re186	3.777 d	<b>&amp;Ir191(n,<math>\gamma</math>)Ir192(<math>\beta^-</math>)Pt192(n,<math>\alpha</math>)Os189(n,n<math>\alpha</math>)</b> <i>W185(<math>\beta^-</math>)Re185(n,<math>\gamma</math>)Re186</i> <b>&amp;Ir191(n,<math>\gamma</math>)Ir192(<math>\beta^-</math>)Pt192(n,n<math>\alpha</math>)Os188(n,<math>\alpha</math>)</b> <i>W185(<math>\beta^-</math>)Re185(n,<math>\gamma</math>)Re186</i> <b>&amp;Ir191(n,<math>\alpha</math>)Re188(<math>\beta^-</math>)Os188(n,<math>\alpha</math>)W185(<math>\beta^-</math>)</b> <i>Re185(n,<math>\gamma</math>)Re186</i> <b>&amp;Ir191(n,n<math>\alpha</math>)Re187(n,<math>\gamma</math>)Re188(<math>\beta^-</math>)Os188(n,<math>\alpha</math>)</b> <i>W185(<math>\beta^-</math>)Re185(n,<math>\gamma</math>)Re186</i> <b>&amp;Ir191(n,<math>\gamma</math>)Ir192(n,n<math>\alpha</math>)Re188(<math>\beta^-</math>)Os188(n,<math>\alpha</math>)</b> <i>W185(<math>\beta^-</math>)Re185(n,<math>\gamma</math>)Re186</i> <b>&amp;Ir191(n,<math>\gamma</math>)Ir192(<math>\beta^+</math>)Os192(n,n<math>\alpha</math>)W188(<math>\beta^-</math>)</b> <i>Re188(<math>\beta^-</math>)Os188(n,<math>\alpha</math>)W185(<math>\beta^-</math>)Re185(n,<math>\gamma</math>)Re186</i> <b>&amp;Ir191(n,<math>\gamma</math>)Ir192(<math>\beta^+</math>)Os192(n,<math>\alpha</math>)W189(<math>\beta^-</math>)Re189(<math>\beta^-</math>)</b> <i>Os189(n,n<math>\alpha</math>)W185(<math>\beta^-</math>)Re185(n,<math>\gamma</math>)Re186</i> <b>&amp;Ir191(n,2n)Ir190(<math>\beta^+</math>)Os190(n,<math>\alpha</math>)W187(<math>\beta^-</math>)Re187(n,2n)Re186</b> <i>Ir191(n,n<math>\alpha</math>)Re187(n,2n)Re186</i> <i>Ir191(n,2n)Ir190n(<math>\beta^+</math>)Os190m(IT)Os190(n,<math>\alpha</math>)</i> <i>W187(<math>\beta^-</math>)Re187(n,2n)Re186</i> <b>&amp;Ir191(n,2n)Ir190(n,<math>\alpha</math>)Re187(n,2n)Re186</b>	73.4	36.3	34.7	
Pt195m	4.02 d	<i>Ir193(n,<math>\gamma</math>)Ir194(<math>\beta^-</math>)Pt194(n,<math>\gamma</math>)Pt195m</i> <b>&amp;Ir191(n,<math>\gamma</math>)Ir192(n,<math>\gamma</math>)Ir193(n,<math>\gamma</math>)Ir194(<math>\beta^-</math>)Pt194(n,<math>\gamma</math>)</b> <i>Pt195m</i> <b>&amp;Ir191(n,<math>\gamma</math>)Ir192(<math>\beta^-</math>)Pt192(n,<math>\gamma</math>)Pt193(n,<math>\gamma</math>)Pt194(n,<math>\gamma</math>)</b> <i>Pt195m</i> <i>Ir193(n,<math>\gamma</math>)Ir194(<math>\beta^-</math>)Pt194(n,<math>\gamma</math>)Pt195(n,n')Pt195m</i>	63.4 31.0	63.4 20.5	99.9	94.0
Pt193m	4.34 d	<b>&amp;Ir191(n,<math>\gamma</math>)Ir192(<math>\beta^-</math>)Pt192(n,<math>\gamma</math>)Pt193m</b> <i>Ir191(n,<math>\gamma</math>)Ir192m(<math>\beta^-</math>)Pt192(n,<math>\gamma</math>)Pt193m</i> <i>Ir193(n,<math>\gamma</math>)Ir194(<math>\beta^-</math>)Pt194(n,2n)Pt193m</i> <b>&amp;Ir193(n,2n)Ir192(<math>\beta^-</math>)Pt192(n,<math>\gamma</math>)Pt193m</b>	99.8 0.2	100.0	100.0	2.4 72.1 23.4
Ir193m	10.602 d	<b>&amp;Ir191(n,<math>\gamma</math>)Ir192(n,<math>\gamma</math>)Ir193m</b> <i>Ir191(n,<math>\gamma</math>)Ir192n(n,<math>\gamma</math>)Ir193m</i> <i>Ir193(n,n')Ir193m</i>	99.7 0.3	99.9	99.6 0.4	99.8
Ir190	12 d	<b>&amp;Ir191(n,2n)Ir190</b> <b>&amp;Ir193(n,2n)Ir192(<math>\beta^-</math>)Pt192(n,2n)Pt191(<math>\beta^+</math>)Ir191(n,2n)Ir190</b>				89.4 5.5



Re186m	$2.0 \cdot 10^5$ y	$\&Ir191(n,\gamma)Ir192(\beta^-)Pt192(n,\alpha)Os189(n,\alpha)$ $W185(\beta^-)Re185(n,\gamma)Re186m$ $\&Ir191(n,\alpha)Re188(\beta^-)Os188(n,\alpha)W185(\beta^-)$ $Re185(n,\gamma)Re186m$ $\&Ir191(n,\gamma)Ir192(\beta^-)Pt192(n,\alpha)Os188(n,\alpha)$ $W185(\beta^-)Re185(n,\gamma)Re186m$ $\&Ir191(n,\alpha)Re187(n,\gamma)Re188(\beta^-)Os188(n,\alpha)$ $W185(\beta^-)Re185(n,\gamma)Re186m$ $\&Ir191(n,\gamma)Ir192(n,\alpha)Re188(\beta^-)Os188(n,\alpha)$ $W185(\beta^-)Re185(n,\gamma)Re186m$ $\&Ir191(n,\gamma)Ir192(\beta^+)Os192(n,\alpha)W188(\beta^-)$ $Re188(\beta^-)Os188(n,\alpha)W185(\beta^-)Re185(n,\gamma)Re186m$ $\&Ir191(n,\gamma)Ir192(\beta^+)Os192(n,\alpha)W189(\beta^-)Re189(\beta^-)$ $Os189(n,\alpha)W185(\beta^-)Re185(n,\gamma)Re186m$ $Ir191(n,\alpha)Re187(n,2n)Re186m$ $\&Ir191(n,2n)Ir190(\beta^+)Os190(n,\alpha)W187(\beta^-)Re187(n,2n)Re186m$ $\&Ir191(n,2n)Ir190(n,\alpha)Re186m$ $\&Ir191(n,2n)Ir190(n,\alpha)Re187(n,2n)Re186m$	72.0	40.4	28.2	
Pb205	$1.5 \cdot 10^7$ y	$\&Ir193(n,\gamma)Ir194(n,\gamma)Ir195(\beta^-)Pt195(n,\gamma)Pt196(n,\gamma)$ $Pt197(\beta^-)Au197(n,\gamma)Au198(n,\gamma)Au199(\beta^-)Hg199(n,\gamma)$ $Hg200(n,\gamma)Hg201(n,\gamma)Hg202(n,\gamma)Hg203(\beta^-)$ $Tl203(n,\gamma)Tl204(\beta^-)Pb204(n,\gamma)Pb205$ $\&Ir193(n,\gamma)Ir194(\beta^-)Pt194(n,\gamma)Pt195(n,\gamma)Pt196(n,\gamma)$ $Pt197(\beta^-)Au197(n,\gamma)Au198(n,\gamma)Au199(\beta^-)Hg199(n,\gamma)$ $Hg200(n,\gamma)Hg201(n,\gamma)Hg202(n,\gamma)Hg203(\beta^-)$ $Tl203(n,\gamma)Tl204(\beta^-)Pb204(n,\gamma)Pb205$ $\&Ir193(n,\gamma)Ir194(n,\gamma)Ir195m(\beta^-)Pt195(n,\gamma)Pt196(n,\gamma)$ $Pt197(\beta^-)Au197(n,\gamma)Au198(n,\gamma)Au199(\beta^-)Hg199(n,\gamma)$ $Hg200(n,\gamma)Hg201(n,\gamma)Hg202(n,\gamma)Hg203(\beta^-)$ $Tl203(n,\gamma)Tl204(\beta^-)Pb204(n,\gamma)Pb205$ *Plus other similar long pathways – see Hg203	52.3			
Re187	$5.0 \cdot 10^{10}$ y	$\&Ir191(n,\gamma)Ir192(\beta^-)Pt192(n,\alpha)Os189(n,\gamma)$ $Os190(n,\alpha)W187(\beta^-)Re187$ $\&Ir191(n,\gamma)Ir192(\beta^-)Pt192(n,\alpha)Os189(n,\alpha)$ $W186(n,\gamma)W187(\beta^-)Re187$ $Ir191(n,\alpha)Re187$ $\&Ir191(n,2n)Ir190(\beta^+)Os190(n,\alpha)W187(\beta^-)Re187$ $Ir191(n,2n)Ir190n(\beta^+)Os190m(IT)Os190(n,\alpha)W187(\beta^-)Re187$ $\&Ir191(n,2n)Ir190(n,\alpha)Re187$	65.5			
			30.7	100.0	100.0	37.8
			3.5			53.2
						3.4
						1.4

# Iridium activation characteristics

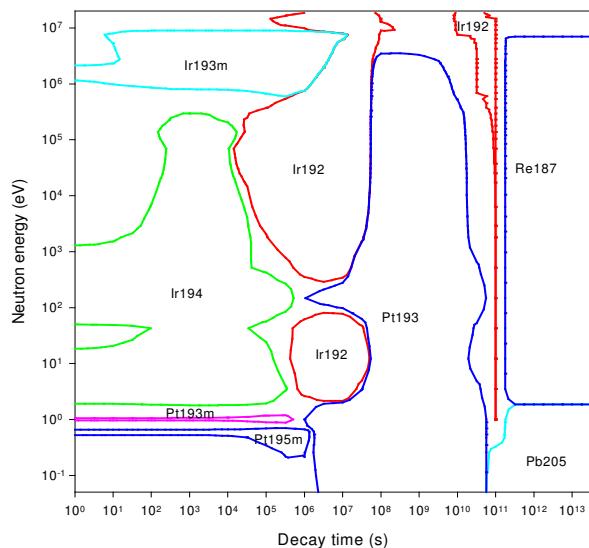


Decay time (years)

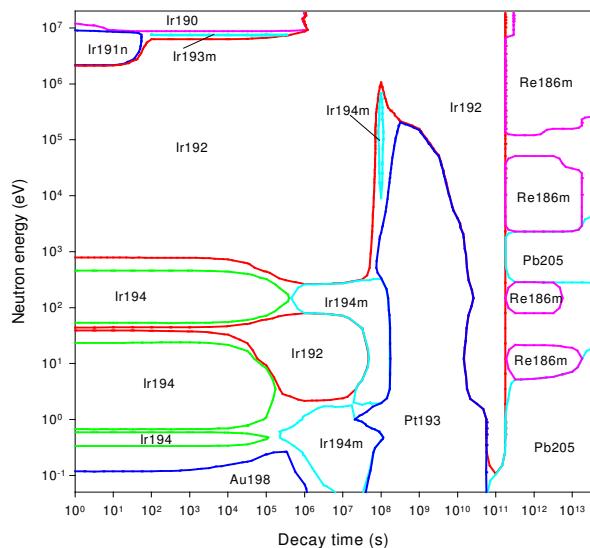
Decay time (years)

# Iridium importance diagrams & transmutation

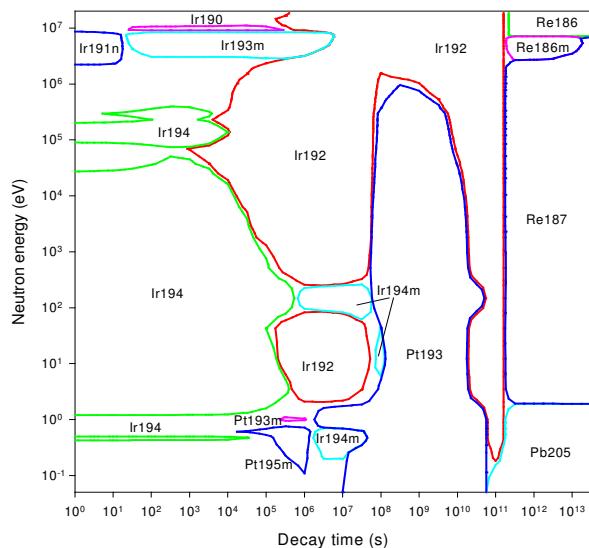
# Activity



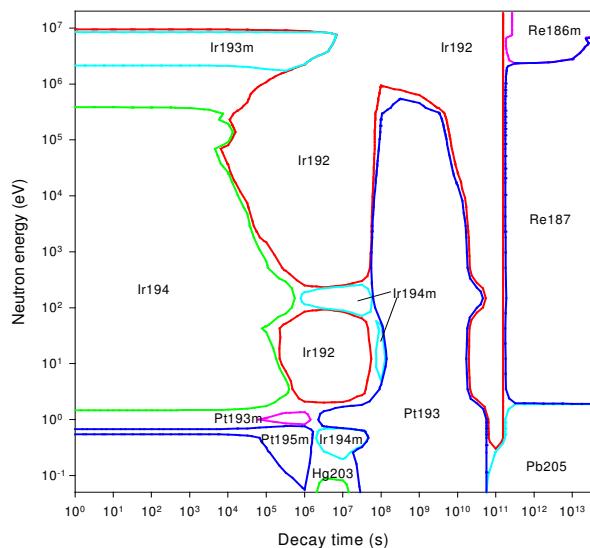
## Dose rate



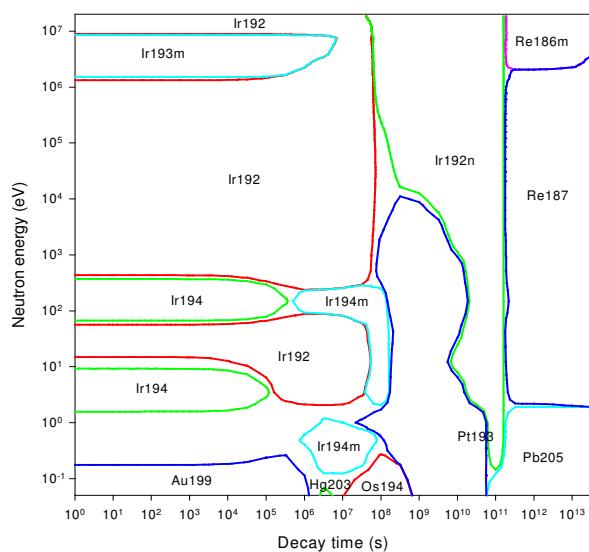
## Heat output



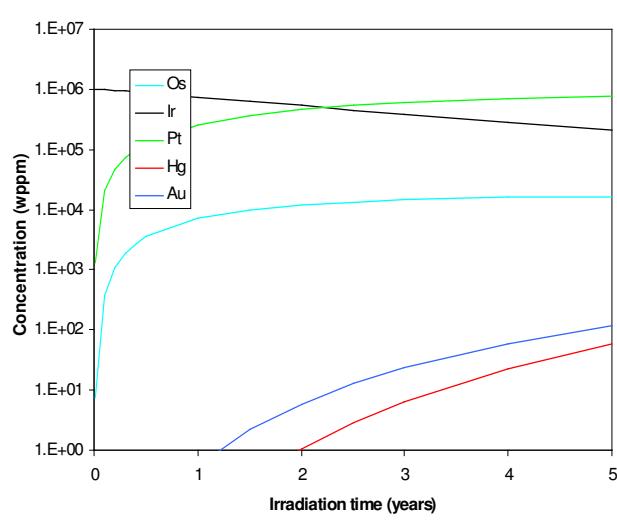
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Platinum

## General properties

		78	Isotopes	Isotopic abundances / %	
Atomic number				5.0 10 <sup>-3</sup>	0.014 ( $T_{1/2}=6.59 \cdot 10^{11}$ y)
Crustal abundance / wppm		2041.6	Pt190	0.782	
Melting point / K		4098	Pt192	32.967	
Boiling point / K		21450	Pt194	33.832	
Density / kgm <sup>-3</sup>		71.6	Pt195	25.242	
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>		1.06 10 <sup>-7</sup>	Pt196	7.163	
Electrical resistivity /Ωm		8.8 10 <sup>-6</sup>	Pt198		
Coefficient of thermal expansion / K <sup>-1</sup>		FCC			
Crystal structure		5(6)			
Number of stable isotopes		195.08			
Mean atomic weight					

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	2.42E15	2.37E15	7.14E14	1.48E13	3.72E12	7.19E0	kW kg <sup>-1</sup>	1.59E-1	1.54E-1	4.13E-2	1.20E-4	2.48E-5	3.62E-15
Pt197	25.41	25.87	4.08				Au198	35.36	36.44	53.12			
Au198	19.80	20.20	26.24				Pt199	21.66	19.85				
Pt195m	16.67	17.02	30.11				Pt197	17.32	17.82	3.16			
Au199	12.20	12.46	18.59				Pt195m	9.99	10.30	20.45			
Pt199	11.95	10.84					Au199	7.20	7.42	12.43			
Pt193m	8.46	8.63	16.00				Pt193m	3.11	3.20	6.67			
Pt197m	1.94	1.91					Pt197m	1.87	1.85				
Pt193	0.61	0.63	2.08	99.05	100.00		Ir194	0.91	0.94	0.15	0.03		
Au196	0.51	0.52	1.16				Au196	0.63	0.65	1.63			
Ir192	0.16	0.16	0.51	0.83			Ir192	0.40	0.41	1.47	16.95	0.03	
Pt190					98.02		Pt193	0.06	0.06	0.24	81.52	99.97	
Re186					0.99		Ir194m			0.02	1.41		
Re186m					0.99		Pt190						99.85
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	3.08E4	2.99E4	9.60E3	1.45E1	1.15E0	5.09E-14	Sv kg <sup>-1</sup>	1.25E6	1.25E6	4.57E5	6.39E2	1.15E2	5.80E-8
Au198	72.20	74.24	90.66				Au198	38.37	38.42	41.04			
Pt199	21.19	19.37					Pt195m	20.35	20.39	29.67			
Au196	1.15	1.18	2.46				Pt197	19.69	19.68	2.56			
Au199	1.09	1.12	1.58				Au199	10.40	10.43	12.79			
Pt195m	0.96	0.99	1.65				Pt193m	7.38	7.39	11.26			
Ir192	0.87	0.89	2.70	60.10	0.24		Ir194	1.04	1.04	0.12	0.06		
Pt197	0.50	0.52	0.08				Pt199	0.90	0.80				
Ir194m	0.02	0.02	0.06	8.48			Ir192	0.43	0.43	1.12	26.98	0.05	
Pt193		0.02	0.05	31.37	99.75		Pt193	0.04	0.04	0.10	71.18	99.94	
Re186m					53.15		Ir194m			0.01	1.43		
Re186					46.06*		Pt190						99.55
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	8.45E5	8.44E5	3.52E5	1.21E3	7.99E1	1.62E-6		3.62E11	3.51E11	1.08E11	5.57E8	1.28E8	1.14E-5
Au198	48.80	48.81	45.77				Au198	44.14	45.54	57.75			
Au199	27.62	27.66	29.79				Pt199	20.50	18.80				
Pt195m	8.60	8.61	10.99				Pt195m	10.14	10.46	18.07			
Pt197	6.19	6.18	0.70				Au199	9.07	9.36	13.64			
Ir192	2.97	2.97	6.88	66.94	0.32		Pt197	8.50	8.75	1.35			
Pt193m	2.91	2.91	3.89				Au196	1.63	1.68	3.63			
Ir194	0.66	0.66	0.07	0.01			Pt193m	1.49	1.54	2.78			
Au196	0.54	0.54	0.87				Pt197m	1.40	1.39				
Hg197	0.41	0.41	0.47				Ir192	0.35	0.36	1.13	7.36	0.01	
Pt193	0.04	0.04	0.09	25.38	97.77		Pt193	0.14	0.15	0.47	90.73	99.98	
Ir194m	0.03	0.03	0.07	4.67			Ir194m			0.04	1.82		
Os194			0.01	2.01			Re186m						41.44
Ir192n				0.17	1.90		Re186						32.72
Pt190					99.94	Pt190							25.69

# Platinum

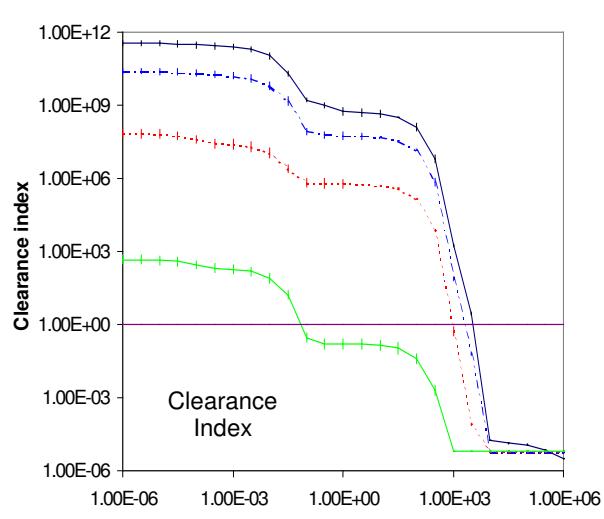
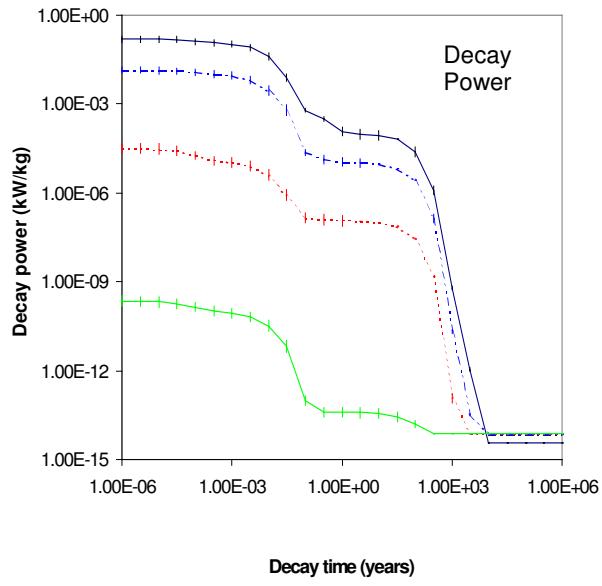
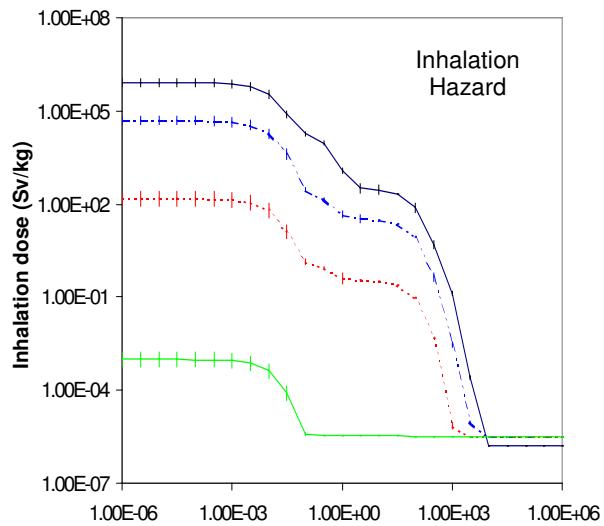
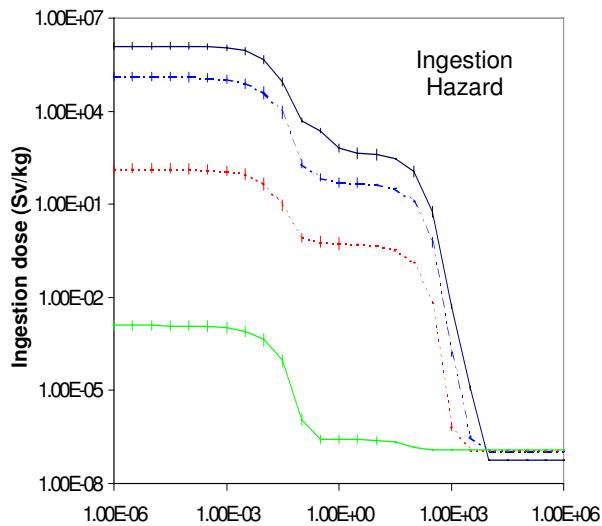
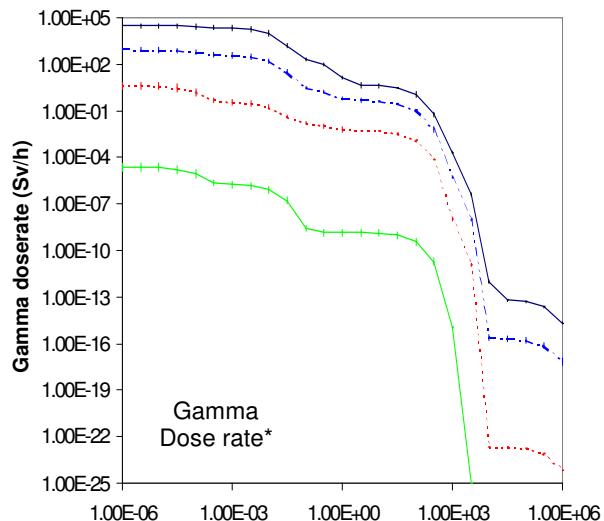
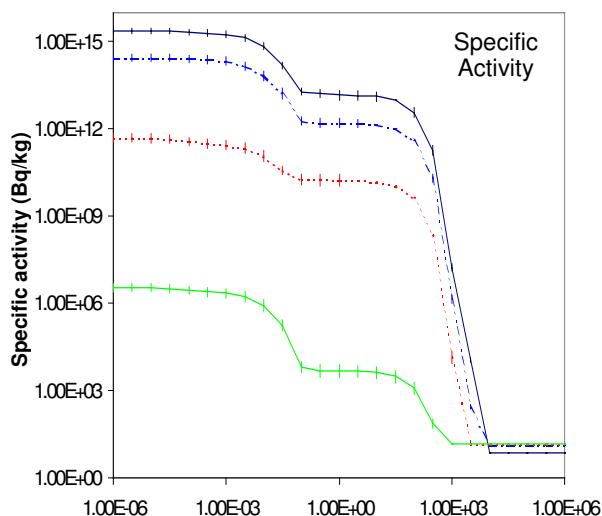
## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Pt199	30.8 m	&Pt198(n, $\gamma$ )Pt199	100.0	100.0	100.0	100.0
Pt197	19.891 h	&Pt195(n, $\gamma$ )Pt196(n, $\gamma$ )Pt197 &Pt196(n, $\gamma$ )Pt197 &Pt194(n, $\gamma$ )Pt195(n, $\gamma$ )Pt196(n, $\gamma$ )Pt197 &Pt198(n,2n)Pt197	52.3 44.7 3.0	57.2 42.7 0.3	15.8 83.8 0.3	0.5 99.4
Au194	1.585 d	&Pt198(n,2n)Pt197( $\beta^-$ )Au197(n,2n)Au196( $\beta^-$ ) Hg196(n,2n)Hg195( $\beta^+$ )Au195(n,2n)Au194 &Pt198(n,2n)Pt197( $\beta^-$ )Au197(n,2n)Au196( $\beta^-$ ) Hg196(n,2n)Hg195m( $\beta^+$ )Au195(n,2n)Au194 &Pt198(n,2n)Pt197( $\beta^-$ )Au197(n,2n)Au196(n,2n) Au195(n,2n)Au194				54.6 29.9 11.9
Au198	2.694 d	&Pt195(n, $\gamma$ )Pt196(n, $\gamma$ )Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198 &Pt196(n, $\gamma$ )Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198 &Pt194(n, $\gamma$ )Pt195(n, $\gamma$ )Pt196(n, $\gamma$ )Pt197( $\beta^-$ ) Au197(n, $\gamma$ )Au198 &Pt198(n,2n)Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198 Pt198(n,2n)Pt197m( $\beta^-$ )Au197m(IT)Au197(n, $\gamma$ )Au198	50.9 46.4 2.5	56.8 42.9	8.7 91.2	97.7 1.6
Au199	3.139 d	&Pt198(n, $\gamma$ )Pt199( $\beta^-$ )Au199 &Pt195(n, $\gamma$ )Pt196(n, $\gamma$ )Pt197( $\beta^-$ )Au197(n, $\gamma$ ) Au198(n, $\gamma$ )Au199 &Pt196(n, $\gamma$ )Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198(n, $\gamma$ )Au199 &Pt194(n, $\gamma$ )Pt195(n, $\gamma$ )Pt196(n, $\gamma$ )Pt197( $\beta^-$ )Au197(n, $\gamma$ ) Au198(n, $\gamma$ )Au199	37.5 31.7 29.0 1.5	99.0 0.5 0.4	100.0	99.8
Re186	3.777 d	&Pt190(n, $\alpha$ )Os187(n, $\gamma$ )Os188(n, $\alpha$ )W185( $\beta^-$ ) Re185(n, $\gamma$ )Re186 Pt190(n, $\alpha$ )Os187(n, $\alpha$ )W184(n, $\gamma$ )W185( $\beta^-$ )Re185(n, $\gamma$ ) Re186 &Pt192(n, $\alpha$ )Os189(n, $n\alpha$ )W185( $\beta^-$ )Re185(n, $\gamma$ )Re186 Pt192(n,2n)Pt191( $\beta^+$ )Ir191(n, $n\alpha$ )Re187(n,2n)Re186 &Pt192(n,2n)Pt191( $\beta^+$ )Ir191(n,2n)Ir190( $\beta^+$ ) Os190(n, $\alpha$ )W187( $\beta^-$ )Re187(n,2n)Re186 &Pt194(n,2n)Pt193(n,2n)Pt192(n,2n)Pt191( $\beta^+$ ) Ir191(n, $n\alpha$ )Re187(n,2n)Re186 &Pt194(n,2n)Pt193(n,2n)Pt192(n,2n)Pt191( $\beta^+$ )Ir191 (n,2n)Ir190( $\beta^+$ )Os190(n, $\alpha$ )W187( $\beta^-$ )Re187(n,2n)Re186 Pt192(n,2n)Pt191( $\beta^+$ )Ir191(n,2n)Ir190n( $\beta^+$ ) Os190m(IT)Os190(n, $\alpha$ )W187( $\beta^-$ )Re187(n,2n)Re186 &Pt192(n,2n)Pt191( $\beta^+$ )Ir191(n,2n)Ir190(n, $\alpha$ ) Re187(n,2n)Re186 &Pt195(n,2n)Pt194(n,2n)Pt193(n,2n)Pt192(n,2n) Pt191( $\beta^+$ )Ir191(n, $n\alpha$ )Re187(n,2n)Re186 * Plus many other similar pathways	97.6 2.4	86.4 13.6	31.9 50.3 17.5 34.4 32.3 13.4 7.5 2.1 1.3 1.0 8.0*	
Pt195m	4.02 d	Pt194(n, $\gamma$ )Pt195m &Pt192(n, $\gamma$ )Pt193(n, $\gamma$ )Pt194(n, $\gamma$ )Pt195m Pt196(n,2n)Pt195m Pt195(n,n')Pt195m &Pt198(n,2n)Pt197( $\beta^-$ )Au197(n,2n)Au196( $\beta^+$ ) Pt196(n,2n)Pt195m	99.1 0.9	97.7 2.3	100.0	0.1 84.9 10.5 1.2
Pt193m	4.34 d	Pt192(n, $\gamma$ )Pt193m &Pt190(n, $\gamma$ )Pt191( $\beta^+$ )Ir191(n, $\gamma$ )Ir192( $\beta^-$ )Pt192(n, $\gamma$ )Pt193m Pt194(n,2n)Pt193m Pt195(n,2n)Pt194(n,2n)Pt193m &Pt196(n,2n)Pt195(n,2n)Pt194(n,2n)Pt193m	99.6	46.0 53.2	100.0	69.2 24.5 3.1

Hg203	46.595 d	&Pt198(n, $\gamma$ )Pt199( $\beta^-$ )Au199( $\beta^-$ )Hg199(n, $\gamma$ ) Hg200(n, $\gamma$ )Hg201(n, $\gamma$ )Hg202(n, $\gamma$ )Hg203 &Pt196(n, $\gamma$ )Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198(n, $\gamma$ )Au199( $\beta^-$ ) Hg199(n, $\gamma$ )Hg200(n, $\gamma$ )Hg201(n, $\gamma$ )Hg202(n, $\gamma$ )Hg203 &Pt195(n, $\gamma$ )Pt196(n, $\gamma$ )Pt197( $\beta^-$ )Au197(n, $\gamma$ ) Au198(n, $\gamma$ )Au199( $\beta^-$ )Hg199(n, $\gamma$ )Hg200(n, $\gamma$ ) Hg201(n, $\gamma$ )Hg202(n, $\gamma$ )Hg203	59.8 27.4 11.8	99.6 0.2 0.2	99.1	99.7
Ir192	73.831 d	&Pt194(n, $\alpha$ )Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192 &Pt190(n, $\gamma$ )Pt191( $\beta^+$ )Ir191(n, $\gamma$ )Ir192 &Pt192(n, $\alpha$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191( $\beta^-$ ) Ir191(n, $\gamma$ )Ir192 &Pt194(n,2n)Pt193( $\beta^+$ )Ir193(n,2n)Ir192 &Pt195(n,2n)Pt194(n,2n)Pt193( $\beta^+$ )Ir193(n,2n)Ir192	52.7 32.5 13.5	100.0	100.0	84.6 9.1
Ir194m	171.3 d	&Pt192(n, $\gamma$ )Pt193( $\beta^+$ )Ir193(n, $\gamma$ )Ir194m &Pt190(n, $\gamma$ )Pt191( $\beta^+$ )Ir191(n, $\gamma$ )Ir192(n, $\gamma$ )Ir193(n, $\gamma$ ) Ir194m Pt195(n,d)Ir194m Pt194(n,p)Ir194m &Pt196(n,2n)Pt195(n,d)Ir194m Pt195(n,2n)Pt194(n,p)Ir194m Pt196(n,t)Ir194m	94.7 5.1	49.2 50.0	100.0	49.3 25.0 10.9 7.7 4.5
TL204	3.79 y	&Pt198(n, $\gamma$ )Pt199( $\beta^-$ )Au199( $\beta^-$ )Hg199(n, $\gamma$ )Hg200 (n, $\gamma$ )Hg201(n, $\gamma$ )Hg202(n, $\gamma$ )Hg203( $\beta^-$ )Tl203(n, $\gamma$ )Tl204 &Pt196(n, $\gamma$ )Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198(n, $\gamma$ ) Au199( $\beta^-$ )Hg199(n, $\gamma$ )Hg200(n, $\gamma$ )Hg201(n, $\gamma$ ) Hg202(n, $\gamma$ )Hg203( $\beta^-$ )Tl203(n, $\gamma$ )Tl204 Pt195(n, $\gamma$ )Pt196(n, $\gamma$ )Pt197( $\beta^-$ )Au197(n, $\gamma$ )Au198(n, $\gamma$ ) Au199( $\beta^-$ )Hg199(n, $\gamma$ )Hg200(n, $\gamma$ )Hg201(n, $\gamma$ ) Hg202(n, $\gamma$ )Hg203( $\beta^-$ )Tl203(n, $\gamma$ )Tl204 Pt198(n, $\gamma$ )Pt199( $\beta^-$ )Au199(n, $\gamma$ )Au200( $\beta^-$ )Hg200(n, $\gamma$ ) Hg201(n, $\gamma$ )Hg202(n, $\gamma$ )Hg203( $\beta^-$ )Tl203(n, $\gamma$ )Tl204	65.7 25.3 7.8	99.7 0.1 0.1	98.7	
Os194	5.989 y	&Pt190(n, $\gamma$ )Pt191( $\beta^+$ )Ir191(n, $\gamma$ )Ir192( $\beta^+$ )Os192(n, $\gamma$ ) Os193(n, $\gamma$ )Os194 Pt195(n, $\alpha$ )Os192(n, $\gamma$ )Os193(n, $\gamma$ )Os194 &Pt194(n, $\alpha$ )Os191(n, $\gamma$ )Os192(n, $\gamma$ )Os193(n, $\gamma$ )Os194 Pt198(n,n $\alpha$ )Os194 Pt196(n,h)Os194	85.0 9.4 4.0 0.7	82.3 17.6	99.7	1.2 96.4
Pt193	50 y	&Pt192(n, $\gamma$ )Pt193 &Pt190(n, $\gamma$ )Pt191( $\beta^+$ )Ir191(n, $\gamma$ )Ir192( $\beta^-$ )Pt192(n, $\gamma$ )Pt193 &Pt194(n,2n)Pt193 &Pt195(n,2n)Pt194(n,2n)Pt193 &Pt196(n,2n)Pt195(n,2n)Pt194(n,2n)Pt193	99.9 	92.8 7.1	100.0	83.2 15.1 1.3
Ir192n	240.84 y	&Pt194(n, $\alpha$ )Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192n Pt190(n, $\gamma$ )Pt191( $\beta^+$ )Ir191(n, $\gamma$ )Ir192n &Pt192(n, $\alpha$ )Os189(n, $\gamma$ )Os190(n, $\gamma$ )Os191( $\beta^-$ ) Ir191(n, $\gamma$ )Ir192n &Pt194(n,2n)Pt193( $\beta^+$ )Ir193(n,2n)Ir192n &Pt195(n,2n)Pt194(n,2n)Pt193( $\beta^+$ )Ir193(n,2n)Ir192n Pt196(n, $\alpha$ )Os193( $\beta^-$ )Ir193(n,2n)Ir192n &Pt195(n,t)Ir193(n,2n)Ir192n	52.7 32.6 14.0	100.0	100.0	86.6 7.7 1.0 0.9
Hg194	519.68 y	&Pt198(n,2n)Pt197( $\beta^-$ )Au197(n,2n)Au196( $\beta^-$ ) Hg196(n,2n)Hg195m(n,2n)Hg194 &Pt198(n,2n)Pt197( $\beta^-$ )Au197(n,2n)Au196( $\beta^-$ ) Hg196(n,2n)Hg195(n,2n)Hg194 Pt198(n,2n)Pt197m( $\beta^-$ )Au197m(IT)Au197(n,2n) Au196( $\beta^-$ )Hg196(n,2n)Hg195m(n,2n)Hg194				81.7 16.3 1.2

Re186m	$2.0 \cdot 10^5$ y	$\text{&Pt190(n,}\alpha\text{)Os187(n,}\gamma\text{)Os188(n,}\alpha\text{)W185(}\beta^-\text{)}$ $\text{Re185(n,}\gamma\text{)Re186m}$ $\text{Pt190(n,}\alpha\text{)Os187(n,}\alpha\text{)W184(n,}\gamma\text{)W185(}\beta^-\text{)Re185(n,}\gamma\text{)}$ $\text{Re186m}$ $\text{&Pt192(n,}\alpha\text{)Os189(n,}\alpha\text{)W185(}\beta^-\text{)Re185(n,}\gamma\text{)Re186m}$ $\text{Pt192(n,2n)Pt191(}\beta^+\text{)Ir191(n,}\alpha\text{)Re187(n,2n)Re186m}$ $\text{&Pt192(n,2n)Pt191(}\beta^+\text{)Ir191(n,2n)Ir190(}\beta^+\text{)}$ $\text{Os190(n,}\alpha\text{)W187(}\beta^-\text{)Re187(n,2n)Re186m}$ $\text{&Pt194(n,2n)Pt193(n,2n)Pt192(n,2n)Pt191(}\beta^+\text{)Ir191(n,2n)}$ $\text{Ir190(}\beta^+\text{)Os190(n,}\alpha\text{)W187(}\beta^-\text{)Re187(n,2n)Re186m}$ $\text{&Pt192(n,2n)Pt191(}\beta^+\text{)Ir191(n,2n)Ir190(n,}\alpha\text{)Re186m}$ $\text{Pt190(n,2n)Pt189(}\beta^+\text{)Ir189(n,}\alpha\text{)Re186m}$ $\text{&Pt192(n,2n)Pt191(}\beta^+\text{)Ir191(n,2n)Ir190(n,}\alpha\text{)}$ $\text{Re187(n,2n)Re186m}$ * Plus many other similar pathways	97.8	88.6	28.4	
Pb205	$1.5 \cdot 10^7$ y	$\text{&Pt198(n,}\gamma\text{)Pt199(}\beta^-\text{)Au199(}\beta^-\text{)Hg199(n,}\gamma\text{)}$ $\text{Hg200(n,}\gamma\text{)Hg201(n,}\gamma\text{)Hg202(n,}\gamma\text{)Hg203(}\beta^-\text{)}$ $\text{Tl203(n,}\gamma\text{)Tl204(}\beta^-\text{)Pb204(n,}\gamma\text{)Pb205}$ $\text{Pt196(n,}\gamma\text{)Pt197(}\beta^-\text{)Au197(n,}\gamma\text{)Au198(n,}\gamma\text{)Au199(}\beta^-\text{)}$ $\text{Hg199(n,}\gamma\text{)Hg200(n,}\gamma\text{)Hg201(n,}\gamma\text{)Hg202(n,}\gamma\text{)}$ $\text{Hg203(}\beta^-\text{)Tl203(n,}\gamma\text{)Tl204(}\beta^-\text{)Pb204(n,}\gamma\text{)Pb205}$ $\text{Pt195(n,}\gamma\text{)Pt196(n,}\gamma\text{)Pt197(}\beta^-\text{)Au197(n,}\gamma\text{)Au198(n,}\gamma\text{)}$ $\text{Au199(}\beta^-\text{)Hg199(n,}\gamma\text{)Hg200(n,}\gamma\text{)Hg201(n,}\gamma\text{)Hg202}$ $\text{(n,}\gamma\text{)Hg203(}\beta^-\text{)Tl203(n,}\gamma\text{)Tl204(}\beta^-\text{)Pb204(n,}\gamma\text{)Pb205}$ $\text{Pt198(n,}\gamma\text{)Pt199(}\beta^-\text{)Au199(n,}\gamma\text{)Au200(}\beta^-\text{)Hg200(n,}\gamma\text{)}$ $\text{Hg201(n,}\gamma\text{)Hg202(n,}\gamma\text{)Hg203(}\beta^-\text{)Tl203(n,}\gamma\text{)Tl204(}\beta^-\text{)}$ $\text{Pb204(n,}\gamma\text{)Pb205}$	70.2	99.8	98.3	
Pt190	$6.6 \cdot 10^{11}$ y	*Nuclide present in starting material $\text{Pt192(n,2n)Pt191(n,2n)Pt190}$ $\text{&Pt194(n,2n)Pt193(n,2n)Pt192(n,2n)Pt191(n,2n)Pt190}$	100.0*	100.0*	100.0*	97.7* 1.3 1.0

# Platinum activation characteristics

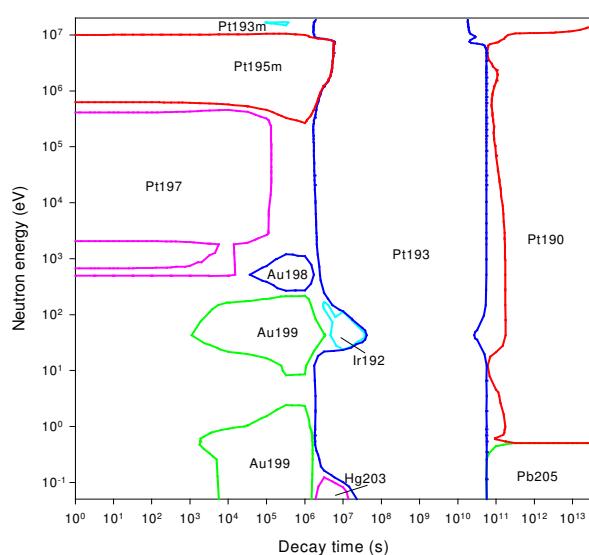


Decay time (years)

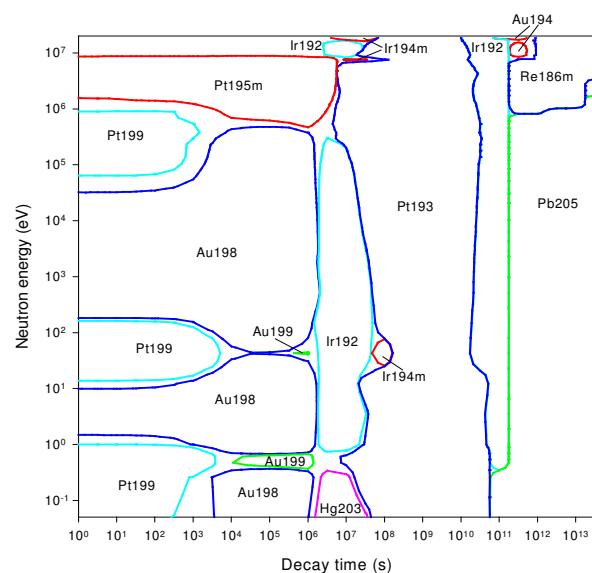
Decay time (years)

# Platinum importance diagrams & transmutation

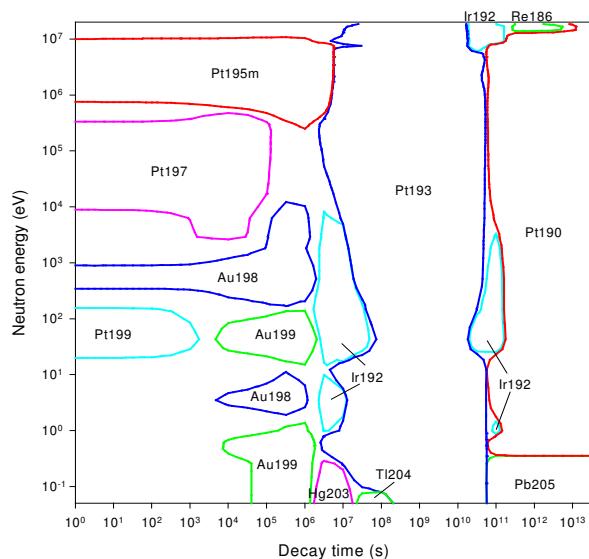
## Activity



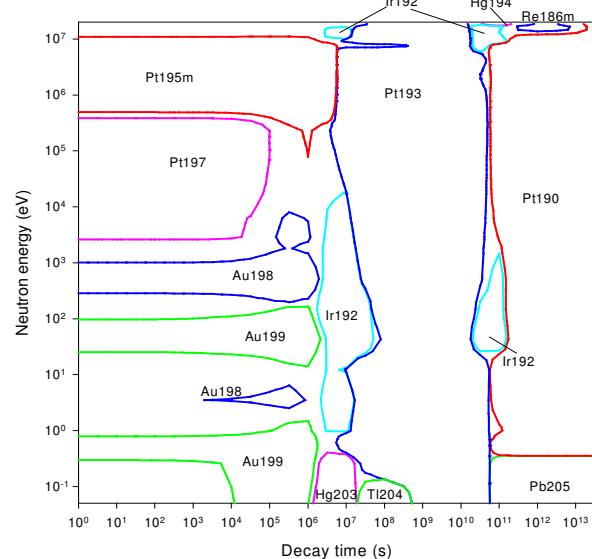
## Dose rate



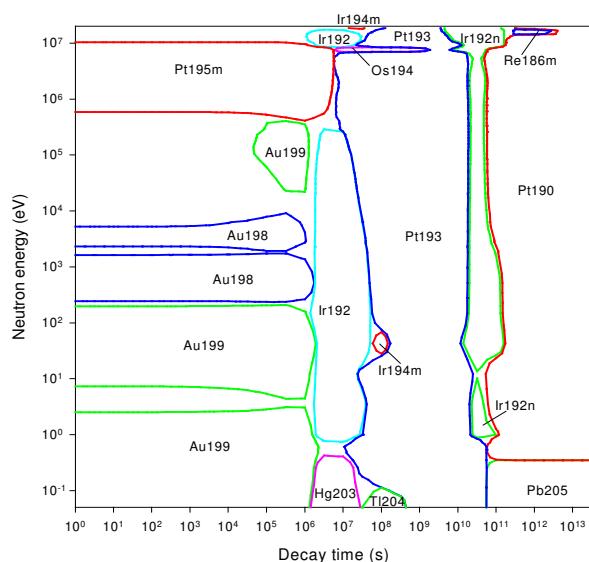
## Heat output



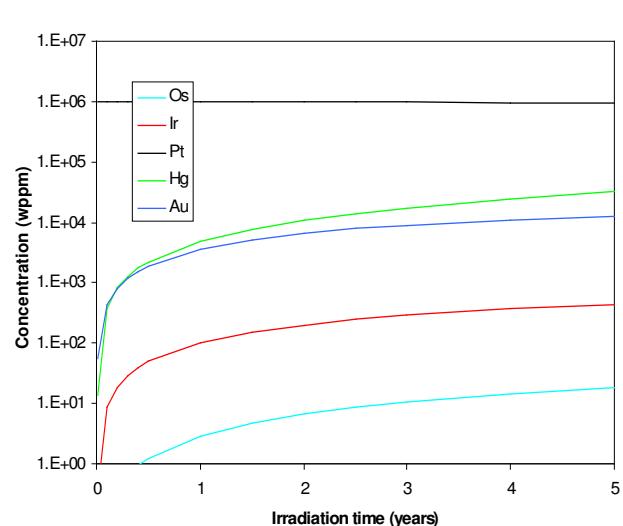
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Gold

## General properties

Atomic number	79	Isotopes	Isotopic abundances / %		
Crustal abundance / wppm	4.0 10 <sup>-3</sup>	Au197	100.0		
Melting point / K	1337.3				
Boiling point / K	3129				
Density / kgm <sup>-3</sup>	19300				
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	317				
Electrical resistivity /Ωm	2.35 10 <sup>-8</sup>				
Coefficient of thermal expansion / K <sup>-1</sup>	1.42 10 <sup>-5</sup>				
Crystal structure	FCC				
Number of stable isotopes	1				
Mean atomic weight	196.96655				

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	6.61E15	6.52E15	2.51E15	2.53E11	1.31E8	1.02E-03	kW kg <sup>-1</sup>	6.74E-1	6.68E-1	2.58E-1	5.02E-6	5.93E-10	1.29E-20
Au198	79.79	80.84	82.31				Au198	91.59	92.33	93.49			
Hg197	9.07	9.19	11.28				Hg197	2.03	2.05	2.50			
Hg197m	4.39	4.44	0.91				Hg197m	1.92	1.94	0.40			
Au196	2.06	2.09	3.63				Au196	1.64	1.66	2.86			
Au197m	1.46	0.38	0.08				Hg199m	0.98	0.91				
Au199	1.18	1.20	1.39				Au195			0.01	97.86		
Hg199m	1.17	1.09					Ir194m				1.77		
Au195	0.01	0.01	0.04	94.01			H3				0.27	8.62	
H3				5.76	42.74		Pt193				0.04	83.66	
Pt193				0.12	56.85		Au194					7.41	
Pb205						94.98	Pb205						81.97
Tl202						2.51	Tl202						15.51
Pb202						2.51	Pb202						2.51
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	2.44E5	2.43E5	9.60E4	2.37E-1	7.60E-5	1.56E-15	Sv kg <sup>-1</sup>	5.67E6	5.67E6	2.20E6	6.07E1	1.81E-2	5.08E-13
Au198	97.77	97.95	97.09				Au198	93.01	93.02	93.75			
Au196	1.56	1.56	2.63				Hg197	2.43	2.43	2.96			
Hg197	0.16	0.16	0.19				Hg197m	2.41	2.40	0.49			
Au195				73.11			Au196	1.06	1.06	1.82			
Ir194m				26.70			Au195			0.01	98.02		
Ir192				0.05	0.76		H3				1.01	12.98	
Pt193				0.04	28.99		Hg194				0.03	73.60	
Au194				0.03	70.21		Pt193				0.02	12.74	
Tl202						74.88	Pb205						53.40
Pb205						24.36	Pb202						44.30
Pb202						0.76	Tl202						2.27
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	5.00E6	5.00E6	1.94E6	4.13E2	2.02E-2	1.14E-12		1.96E12	1.94E12	7.62E11	2.22E7	2.85E3	7.10E-8
Au198	90.69	90.70	91.59				Au198	89.80	90.68	90.19			
Hg197	3.59	3.60	4.38				Au196	3.31	3.35	5.68			
Hg197m	3.08	3.07	0.63				Hg197	2.55	2.58	3.09			
Au199	1.24	1.24	1.42				Hg197m	1.48	1.50	0.30			
Au196	1.01	1.01	1.74				Au197m	1.21	0.31	0.06			
Au195	0.03	0.03	0.08	98.14			Au195			0.01	97.50		
H3				0.92	71.93		Ir194m				2.41		
Hg194					18.09		Pt193				0.05	89.84	
Pt193					7.73		Au194					9.34	
Ir192n					1.62		Pb205						80.27
Pb205						72.48	Tl202						17.15
Pb202						27.01	Pb202						2.57

# Gold

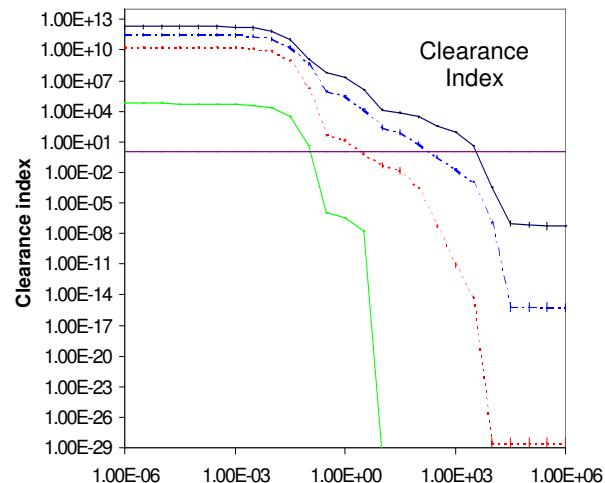
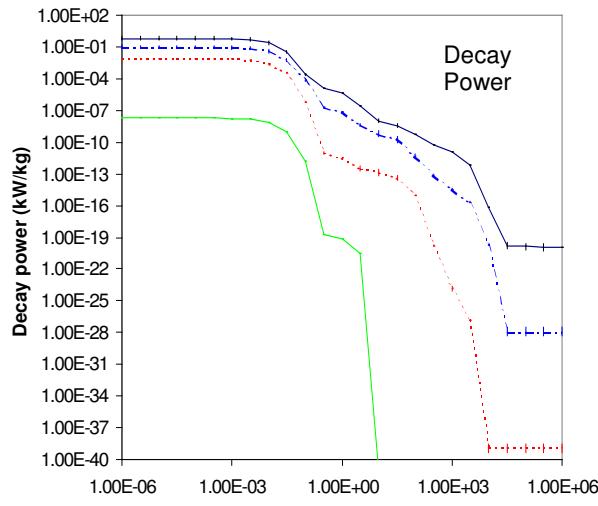
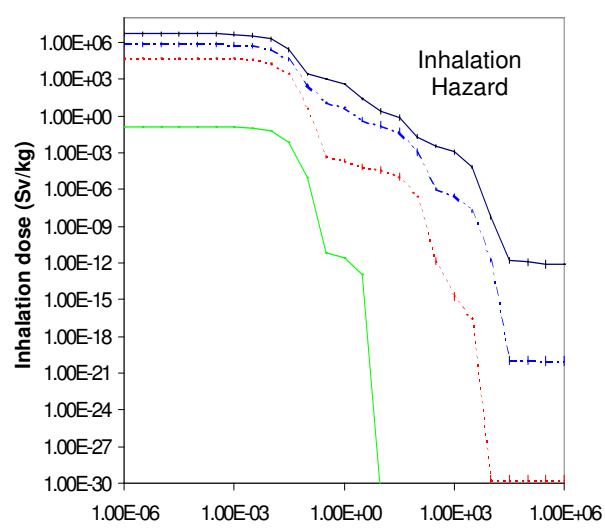
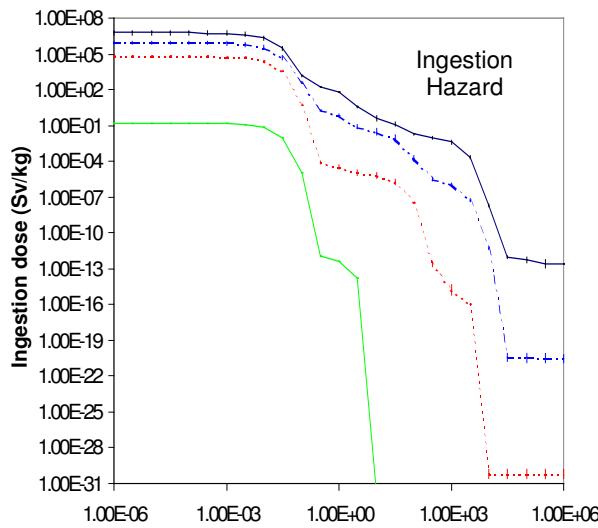
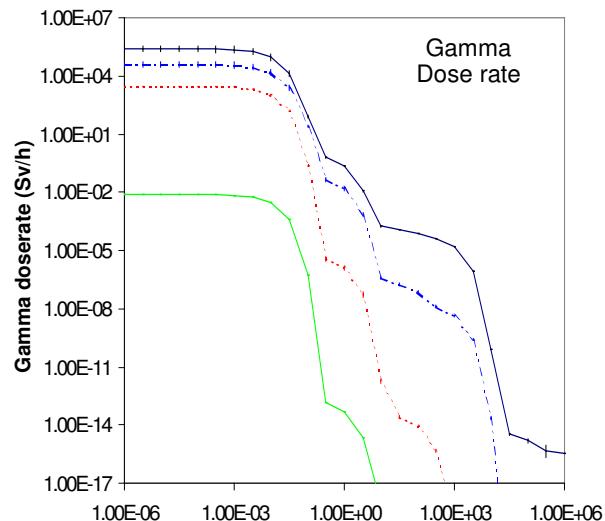
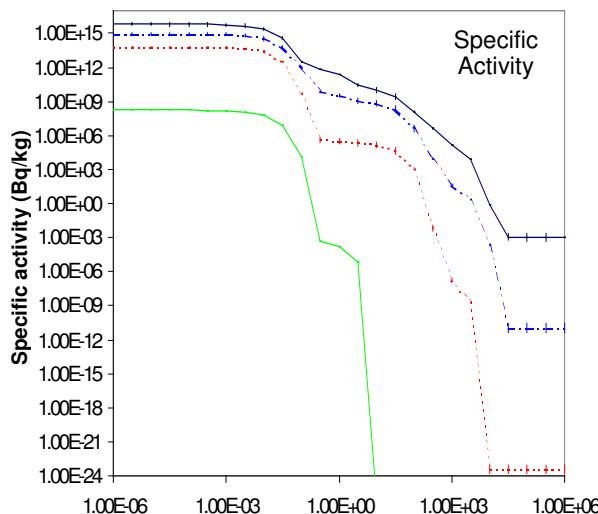
## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Au197m	7.74 s	Au197(n, $\gamma$ )Au198(n, $\gamma$ )Au199( $\beta^-$ )Hg199(n, $\gamma$ ) Hg200(n, $\alpha$ )Pt197m( $\beta^-$ )Au197m &Au197(n, $\gamma$ )Au198( $\beta^-$ )Hg198(n, $\gamma$ )Hg199(n, $\gamma$ ) Hg200(n, $\alpha$ )Pt197m( $\beta^-$ )Au197m &Au197(n, $\gamma$ )Au198( $\beta^-$ )Hg198(n, $\alpha$ )Pt195(n, $\gamma$ ) Pt196(n, $\gamma$ )Pt197m( $\beta^-$ )Au197m Au197(n, $\alpha$ )Ir194m( $\beta^-$ )Pt194(n, $\gamma$ )Pt195(n, $\gamma$ )Pt196(n, $\gamma$ ) Pt197m( $\beta^-$ )Au197m Au197(n, $\alpha$ )Ir194m(n, $\gamma$ )Ir195( $\beta^-$ )Pt195(n, $\gamma$ )Pt196(n, $\gamma$ ) Pt197m( $\beta^-$ )Au197m Au197(n,n')Au197m	97.3  1.7	92.6 6.6	4.5 78.1 10.7 1.7 1.0	99.9
Hg199m	42.1 m	Au197(n, $\gamma$ )Au198( $\beta^-$ )Hg198(n, $\gamma$ )Hg199m Au197(n, $\gamma$ )Au198( $\beta^-$ )Hg198(n, $\gamma$ )Hg199(n,n')Hg199m Au197(n, $\gamma$ )Au198m(IT)Au198( $\beta^-$ )Hg198(n, $\gamma$ )Hg199m	100.0	100.0	100.0	97.9 1.3 0.4
Ir194	19.15 h	&Au197(n,n $\alpha$ )Ir193(n, $\gamma$ )Ir194 Au197(n, $\alpha$ )Ir194 &Au197(n,2n)Au196( $\beta^+$ )Pt196(n,2n)Pt195(n,2n)Pt194(n,p)Ir194 &Au197(n,2n)Au196( $\beta^+$ )Pt196(n,t)Ir194	88.5 10.4	86.6 12.7	18.8 81.1	91.6 3.6 1.6
Au194	1.585 d	&Au197(n,2n)Au196( $\beta^-$ )Hg196(n,2n)Hg195( $\beta^+$ ) Au195(n,2n)Au194 &Au197(n,2n)Au196( $\beta^-$ )Hg196(n,2n)Hg195m( $\beta^+$ ) Au195(n,2n)Au194 &Au197(n,2n)Au196(n,2n)Au195(n,2n)Au194				60.0 32.4 6.0
Au198	2.694 d	Au197(n, $\gamma$ )Au198 Au197(n, $\gamma$ )Au198m(IT)Au198	100.0	99.2	99.9	99.4 0.4
Au199	3.139 d	Au197(n, $\gamma$ )Au198(n, $\gamma$ )Au199 &Au197(n, $\gamma$ )Au198( $\beta^-$ )Hg198(n, $\gamma$ )Hg199(n,p)Au199	99.8	99.9	99.9	86.3 12.7
Re186	3.777 d	Very long pathways involving (n, $\alpha$ ), (n,n $\alpha$ ), ( $\beta^-$ ), etc.				100.0
Au196	6.183 d	&Au197(n,2n)Au196				99.8
Hg203	46.595 d	Au197(n, $\gamma$ )Au198(n, $\gamma$ )Au199( $\beta^-$ )Hg199(n, $\gamma$ ) Hg200(n, $\gamma$ )Hg201(n, $\gamma$ )Hg202(n, $\gamma$ )Hg203 &Au197(n, $\gamma$ )Au198( $\beta^-$ )Hg198(n, $\gamma$ )Hg199(n, $\gamma$ ) Hg200(n, $\gamma$ )Hg201(n, $\gamma$ )Hg202(n, $\gamma$ )Hg203	98.8 0.6	96.5 3.3	9.0 90.9	
Ir192	73.831 d	&Au197(n,n $\alpha$ )Ir193(n, $\gamma$ )Ir194( $\beta^-$ )Pt194(n, $\alpha$ ) Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192 &Au197(n, $\alpha$ )Ir194( $\beta^-$ )Pt194(n, $\alpha$ )Os191( $\beta^-$ ) Ir191(n, $\gamma$ )Ir192 &Au197(n, $\alpha$ )Ir194m( $\beta^-$ )Pt194(n, $\alpha$ )Os191( $\beta^-$ ) Ir191(n, $\gamma$ )Ir192 &Au197(n, $\gamma$ )Au198( $\beta^-$ )Hg198(n,n $\alpha$ )Pt194(n, $\alpha$ ) Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192 &Au197(n,n $\alpha$ )Ir193m(n, $\gamma$ )Ir194( $\beta^-$ )Pt194(n, $\alpha$ ) Os191( $\beta^-$ )Ir191(n, $\gamma$ )Ir192 &Au197(n,2n)Au196( $\beta^+$ )Pt196(n, $\alpha$ )Os193( $\beta^-$ )Ir193(n,2n)Ir192 &Au197(n,2n)Au196( $\beta^+$ )Pt196(n,2n)Pt195(n,2n) Pt194(n,2n)Pt193( $\beta^+$ )Ir193(n,2n)Ir192 &Au197(n,2n)Au196( $\beta^+$ )Pt196(n,2n)Pt195(n,t)Ir193(n,2n)Ir192 &Au197(n,2n)Au196(n, $\alpha$ )Ir193(n,2n)Ir192 * Plus many other similar pathways	35.3 21.0 19.3 17.3 1.5 59.7 22.3 4.8 1.2 12.0*	25.9 18.0 12.6 38.4 0.5	3.4 53.6 40.5 1.4	
Ir194m	171.3 d	Au197(n, $\alpha$ )Ir194m &Au197(n,n $\alpha$ )Ir193(n, $\gamma$ )Ir194m &Au197(n,2n)Au196( $\beta^+$ )Pt196(n,2n)Pt195(n,d)Ir194m &Au197(n,2n)Au196( $\beta^+$ )Pt196(n,t)Ir194m	99.2 0.6	98.7 0.6	100.0	62.3 19.4 15.6

Au195	186.09 d	<b>&amp;Au197(n,2n)Au196(<math>\beta^-</math>)Hg196(n,2n)Hg195(<math>\beta^+</math>)Au195</b> <b>&amp;Au197(n,2n)Au196(<math>\beta^-</math>)Hg196(n,2n)Hg195m(<math>\beta^+</math>)Au195</b> <b>&amp;Au197(n,2n)Au196(n,2n)Au195</b>				60.1 33.0 6.9
Tl204	3.79 y	Au197(n, $\gamma$ )Au198(n, $\gamma$ )Au199( $\beta^-$ )Hg199(n, $\gamma$ )Hg200 (n, $\gamma$ )Hg201(n, $\gamma$ )Hg202(n, $\gamma$ )Hg203( $\beta^-$ )Tl203(n, $\gamma$ )Tl204 <b>&amp;Au197(n,<math>\gamma</math>)Au198(<math>\beta^-</math>)Hg198(n,<math>\gamma</math>)Hg199(n,<math>\gamma</math>)Hg200 (n,<math>\gamma</math>)Hg201(n,<math>\gamma</math>)Hg202(n,<math>\gamma</math>)Hg203(<math>\beta^-</math>)Tl203(n,<math>\gamma</math>)Tl204</b>	99.1 0.4	97.6 2.4	11.9 87.9	
Os194	5.989 y	<b>&amp;Au197(n,<math>\gamma</math>)Au198(<math>\beta^-</math>)Hg198(n,<math>\alpha</math>)Pt195(n,<math>\alpha</math>)</b> <i>Os192(n,<math>\gamma</math>)Os193(n,<math>\gamma</math>)Os194</i> <b>&amp;Au197(n,n<math>\alpha</math>)Ir193(n,<math>\gamma</math>)Ir194(<math>\beta^-</math>)Pt194(n,<math>\alpha</math>)</b> <i>Os191(n,<math>\gamma</math>)Os192(n,<math>\gamma</math>)Os193(n,<math>\gamma</math>)Os194</i> <b>&amp;Au197(n,<math>\alpha</math>)Ir194(<math>\beta^-</math>)Pt194(n,<math>\alpha</math>)Os191(n,<math>\gamma</math>)</b> <i>Os192(n,<math>\gamma</math>)Os193(n,<math>\gamma</math>)Os194</i> <b>&amp;Au197(n,<math>\alpha</math>)Ir194m(<math>\beta^-</math>)Pt194(n,<math>\alpha</math>)Os191(n,<math>\gamma</math>)</b> <i>Os192(n,<math>\gamma</math>)Os193(n,<math>\gamma</math>)Os194</i> <b>&amp;Au197(n,<math>\gamma</math>)Au198(<math>\beta^-</math>)Hg198(n,n<math>\alpha</math>)Pt194(n,<math>\alpha</math>)</b> <i>Os191(n,<math>\gamma</math>)Os192(n,<math>\gamma</math>)Os193(n,<math>\gamma</math>)Os194</i> <b>&amp;Au197(n,<math>\alpha</math>)Ir194m(n,<math>\gamma</math>)Ir195(<math>\beta^-</math>)Pt195(n,<math>\alpha</math>)</b> <i>Os192(n,<math>\gamma</math>)Os193(n,<math>\gamma</math>)Os194</i> <b>&amp;Au197(n,n<math>\alpha</math>)Ir193(n,<math>\gamma</math>)Ir194(n,<math>\gamma</math>)Ir195(<math>\beta^-</math>)</b> <i>Pt195(n,<math>\alpha</math>)Os192(n,<math>\gamma</math>)Os193(n,<math>\gamma</math>)Os194</i> <b>&amp;Au197(n,<math>\gamma</math>)Au198(n,<math>\gamma</math>)Au199(<math>\beta^-</math>)Hg199(n,n<math>\alpha</math>)</b> <i>Pt195(n,<math>\alpha</math>)Os192(n,<math>\gamma</math>)Os193(n,<math>\gamma</math>)Os194</i> <b>&amp;Au197(n,<math>\alpha</math>)Ir194(n,<math>\gamma</math>)Ir195(<math>\beta^-</math>)Pt195(n,<math>\alpha</math>)</b> <i>Os192(n,<math>\gamma</math>)Os193(n,<math>\gamma</math>)Os194</i> <b>&amp;Au197(n,n<math>\alpha</math>)Ir193(n,<math>\gamma</math>)Ir194(<math>\beta^-</math>)Pt194(n,<math>\gamma</math>)</b> <i>Pt195(n,<math>\alpha</math>)Os192(n,<math>\gamma</math>)Os193(n,<math>\gamma</math>)Os194</i> <i>Au197(n,<math>\alpha</math>)Ir194m(n,p)Os194</i> <i>Au197(n,<math>\gamma</math>)Au198(n,<math>\gamma</math>)Au199(<math>\beta^-</math>)Hg199(n,<math>\gamma</math>)</i> <i>Hg200(n,<math>\gamma</math>)Hg201(n,<math>\alpha</math>)Pt198(n,n<math>\alpha</math>)Os194</i> <b>&amp;Au197(n,<math>\alpha</math>)Ir194(<math>\beta^-</math>)Pt194(n,<math>\gamma</math>)Pt195(n,<math>\alpha</math>)</b> <i>Os192(n,<math>\gamma</math>)Os193(n,<math>\gamma</math>)Os194</i> <b>&amp;Au197(n,n<math>\alpha</math>)Ir193m(n,<math>\gamma</math>)Ir194(<math>\beta^-</math>)Pt194(n,<math>\alpha</math>)</b> <i>Os191(n,<math>\gamma</math>)Os192(n,g )Os193(n,<math>\gamma</math>)Os194</i> <i>Au197(n,<math>\gamma</math>)Au198(n,p)Pt198(n,n<math>\alpha</math>)Os194</i> <b>&amp;Au197(n,<math>\gamma</math>)Au198(<math>\beta^-</math>)Hg198(n,<math>\alpha</math>)Pt195(n,<math>\gamma</math>)</b> <i>Pt196(n,<math>\alpha</math>)Os193(n,<math>\gamma</math>)Os194</i> <b>&amp;Au197(n,n<math>\alpha</math>)Ir193(n,<math>\gamma</math>)Ir194(n,p)Os194</b> <b>&amp;Au197(n,2n)Au196(<math>\beta^+</math>)Pt196(n,h)Os194</b>	24.9 17.6 14.2 10.3 4.4 3.9 3.3 3.3 2.1 1.6 1.6 1.3 1.2 1.0 5.8 1.4 1.1			89.0 98.8 99.6
H3	12.33 y	Au197(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Au197(n, $\gamma$ )Au198(n, $\gamma$ )Au199( $\beta^-$ )Hg199(n,X)H1(n, $\gamma$ ) H2(n, $\gamma$ )H3 Au197(n, $\gamma$ )Au198(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Au197(n,X)H3 <b>&amp;Au197(n,2n)Au196(<math>\beta^+</math>)Pt196(n,2n)Pt195(n,X)H3</b> Au197(n,2n)Au196( $\beta^+$ )Pt196(n,X)H3	88.0 3.9 0.2	91.8 1.9 0.7	100.0	96.8 1.4 1.1

Pt193	50 y	<b>&amp;Au197(n,no)Ir193(n,<math>\gamma</math>)Ir194(<math>\beta^-</math>)Pt194(n,<math>\alpha</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192(<math>\beta^-</math>)Pt192(n,<math>\gamma</math>)Pt193</b> <b>&amp;Au197(n,<math>\alpha</math>)Ir194(<math>\beta^-</math>)Pt194(n,<math>\alpha</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192(<math>\beta^-</math>)Pt192(n,<math>\gamma</math>)Pt193</b> <b>&amp;Au197(n,<math>\alpha</math>)Ir194m(<math>\beta^-</math>)Pt194(n,<math>\alpha</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192(<math>\beta^-</math>)Pt192(n,<math>\gamma</math>)Pt193</b> <b>&amp;Au197(n,<math>\gamma</math>)Au198(<math>\beta^-</math>)Hg198(n,no)Pt194(n,<math>\alpha</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192(<math>\beta^-</math>)Pt192(n,<math>\gamma</math>)Pt193</b> <b>&amp;Au197(n,2n)Au196(<math>\beta^+</math>)Pt196(n,2n)Pt195(n,2n)Pt194(n,2n)Pt193</b> <b>&amp;Au197(n,2n)Au196(<math>\beta^-</math>)Hg196(n,2n)Hg195(<math>\beta^+</math>)Au195(<math>\beta^+</math>)Pt195(n,2n)Pt194(n,2n)Pt193</b> <b>&amp;Au197(n,<math>\alpha</math>)Ir194(<math>\beta^-</math>)Pt194(n,2n)Pt193</b> <b>&amp;Au197(n,2n)Au196(<math>\beta^+</math>)Pt196(n,3n)Pt194(n,2n)Pt193</b> <b>Au197(n,2n)Au196(<math>\beta^+</math>)Pt196(n,2n)Pt195(n,3n)Pt193</b> <i>*Plus other similar pathways</i>	42.3 26.5 20.0 9.1 	30.7 22.0 14.5 31.7 	2.6 60.3 37.1 0.9 	
Ir192n	240.84 y	<b>&amp;Au197(n,no)Ir193(n,<math>\gamma</math>)Ir194(<math>\beta^-</math>)Pt194(n,<math>\alpha</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192n</b> <b>&amp;Au197(n,<math>\alpha</math>)Ir194(<math>\beta^-</math>)Pt194(n,<math>\alpha</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192n</b> <b>&amp;Au197(n,<math>\alpha</math>)Ir194m(<math>\beta^-</math>)Pt194(n,<math>\alpha</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192n</b> <b>&amp;Au197(n,<math>\gamma</math>)Au198(<math>\beta^-</math>)Hg198(n,no)Pt194(n,<math>\alpha</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192n</b> <b>&amp;Au197(n,no)Ir193m(n,<math>\gamma</math>)Ir194(<math>\beta^-</math>)Pt194(n,<math>\alpha</math>)Os191(<math>\beta^-</math>)Ir191(n,<math>\gamma</math>)Ir192n</b> <b>&amp;Au197(n,2n)Au196(<math>\beta^+</math>)Pt196(n,<math>\alpha</math>)Os193(<math>\beta^-</math>)Ir193(n,2n)Ir192n</b> <b>&amp;Au197(n,2n)Au196(<math>\beta^+</math>)Pt196(n,2n)Pt195(n,2n)Pt194(n,2n)Pt193(<math>\beta^+</math>)Ir193(n,2n)Ir192n</b> <b>&amp;Au197(n,2n)Au196(<math>\beta^+</math>)Pt196(n,2n)Pt195(n,t)Ir193(n,2n)Ir192n</b> <b>&amp;Au197(n,2n)Au196(n,<math>\alpha</math>)Ir193(n,2n)Ir192n</b> <i>*Plus other similar pathways</i>	40.8 21.0 19.3 17.3 1.5 	30.2 18.2 12.8 37.9 0.5 		
Hg194	519.68 y	<b>&amp;Au197(n,2n)Au196(<math>\beta^-</math>)Hg196(n,2n)Hg195m(n,2n)Hg194</b> <b>&amp;Au197(n,2n)Au196(<math>\beta^-</math>)Hg196(n,2n)Hg195(n,2n)Hg194</b>				83.4 16.6
Re186m	$2.0 \cdot 10^5$ y	Very long pathways involving (n, $\alpha$ ), (n,no), ( $\beta^-$ ), etc.				100.0
Pb205	$1.5 \cdot 10^7$ y	Au197(n, $\gamma$ )Au198(n, $\gamma$ )Au199( $\beta^-$ )Hg199(n, $\gamma$ ) Hg200(n, $\gamma$ )Hg201(n, $\gamma$ )Hg202(n, $\gamma$ )Hg203( $\beta^-$ ) Tl203(n, $\gamma$ )Tl204( $\beta^-$ )Pb204(n, $\gamma$ )Pb205 <b>&amp;Au197(n,<math>\gamma</math>)Au198(<math>\beta^-</math>)Hg198(n,<math>\gamma</math>)Hg199(n,<math>\gamma</math>)          Hg200(n,<math>\gamma</math>)Hg201(n,<math>\gamma</math>)Hg202(n,<math>\gamma</math>)Hg203(<math>\beta^-</math>)          Tl203(n,<math>\gamma</math>)Tl204(<math>\beta^-</math>)Pb204(n,<math>\gamma</math>)Pb205</b>	99.2 0.3	98.2 1.8	14.8 85.0	
Pt190	$6.6 \cdot 10^{11}$ y	<b>&amp;Au197(n,2n)Au196(<math>\beta^+</math>)Pt196(n,2n)Pt195(n,2n)</b> <b>Pt194(n,2n)Pt193(n,2n)Pt192(n,2n)Pt191(n,2n)Pt190</b> <b>&amp;Au197(n,<math>\alpha</math>)Ir194(<math>\beta^-</math>)Pt194(n,2n)Pt193(n,2n)</b> <b>Pt192(n,2n)Pt191(n,2n)Pt190</b> <b>&amp;Au197(n,2n)Au196(<math>\beta^+</math>)Pt196(n,<math>\alpha</math>)Os193(<math>\beta^-</math>)</b> <b>Ir193(n,2n)Ir192(<math>\beta^-</math>)Pt192(n,2n)Pt191(n,2n)Pt190</b> <b>&amp;Au197(n,2n)Au196(<math>\beta^+</math>)Pt196(n,3n)Pt194(n,2n)</b> <b>Pt193(n,2n)Pt192(n,2n)Pt191(n,2n)Pt190</b> <b>&amp;Au197(n,2n)Au196(<math>\beta^+</math>)Pt196(n,2n)Pt195(n,3n)</b> <b>Pt193(n,2n)Pt192(n,2n)Pt191(n,2n)Pt190</b> <b>&amp;Au197(n,2n)Au196(<math>\beta^-</math>)Hg196(n,<math>\alpha</math>)Pt193(n,2n)</b> <b>Pt192(n,2n)Pt191(n,2n)Pt190</b> <i>*Plus other similar pathways</i>				75.8 4.9 3.9 2.2 1.5 1.2 10.5*
Pb204	$1.4 \cdot 10^{17}$ y	Au197(n, $\gamma$ )Au198(n, $\gamma$ )Au199( $\beta^-$ )Hg199(n, $\gamma$ ) Hg200(n, $\gamma$ )Hg201(n, $\gamma$ )Hg202(n, $\gamma$ )Hg203( $\beta^-$ ) Tl203(n, $\gamma$ )Tl204( $\beta^-$ )Pb204 <b>&amp;Au197(n,<math>\gamma</math>)Au198(<math>\beta^-</math>)Hg198(n,<math>\gamma</math>)Hg199(n,<math>\gamma</math>)          Hg200(n,<math>\gamma</math>)Hg201(n,<math>\gamma</math>)Hg202(n,<math>\gamma</math>)Hg203(<math>\beta^-</math>)          Tl203(n,<math>\gamma</math>)Tl204(<math>\beta^-</math>)Pb204</b>	99.2 0.3	98.0 2.0	13.4 86.4	

# Gold activation characteristics

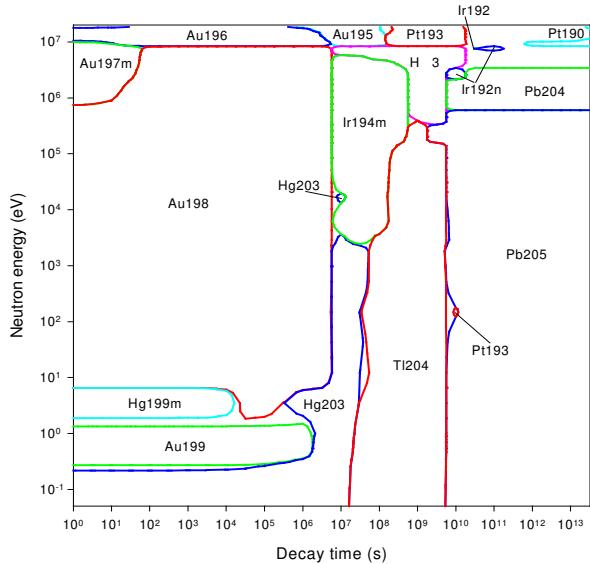


Decay time (years)

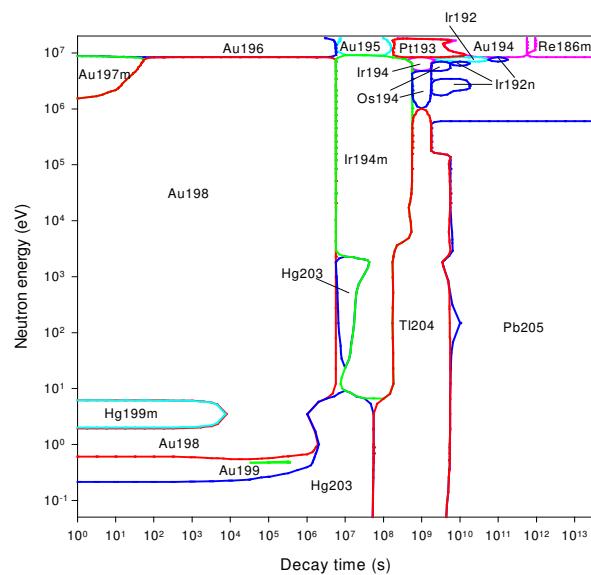
Decay time (years)

# Gold importance diagrams & transmutation

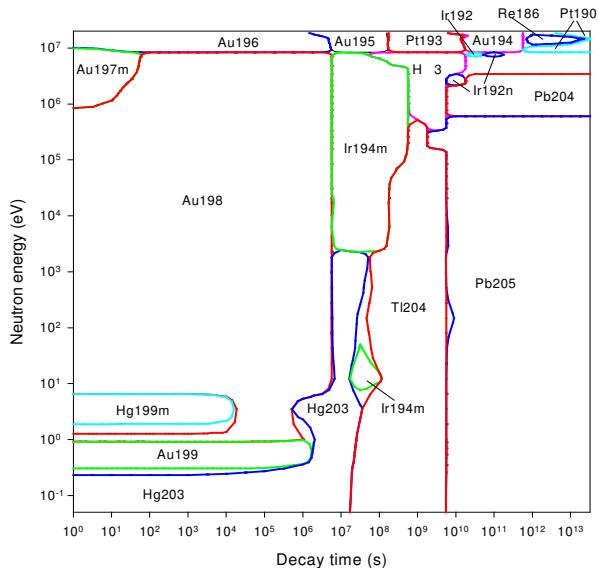
## Activity



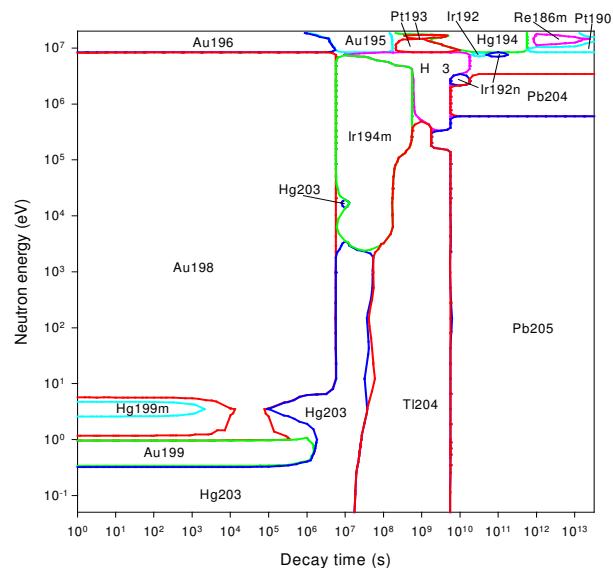
## Dose rate



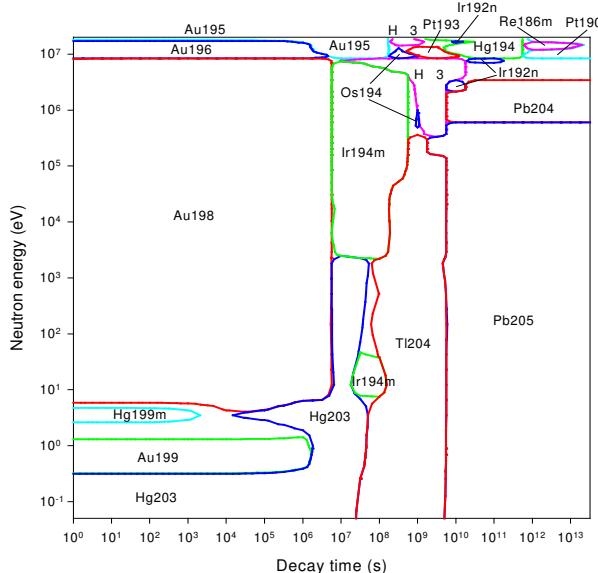
## Heat output



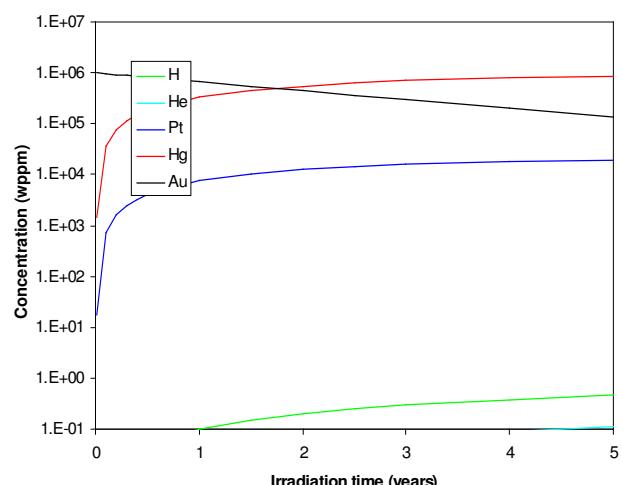
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Mercury

## General properties

Atomic number		80	Isotopes	Isotopic abundances / %	
Crustal abundance / wppm		8.5 10 <sup>-2</sup>	Hg196	0.15	
Melting point / K		234.3	Hg198	9.97	
Boiling point / K		629.9	Hg199	16.87	
Density / kgm <sup>-3</sup>		13546	Hg200	23.10	
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>		8.34	Hg201	13.18	
Electrical resistivity /Ωm		9.41 10 <sup>-7</sup>	Hg202	29.86	
Coefficient of thermal expansion / K <sup>-1</sup>		1.81 10 <sup>-4</sup>	Hg204	6.87	
Crystal structure		Rhombohedral			
Number of stable isotopes		7			
Mean atomic weight		200.59			

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	4.89E14	4.72E14	2.15E14	1.00E13	2.55E7	3.73E3	kW kg <sup>-1</sup>	3.30E-2	3.15E-2	1.22E-2	3.88E-4	1.38E-10	4.71E-14
Hg203	28.30	29.32	61.05	6.02			Hg199m	35.47	34.05				
Hg199m	28.08	26.68					Au198	25.66	26.84	27.12			
Hg197	15.13	15.66	15.98				Hg203	22.62	23.68	57.92	8.41		
Au198	14.81	15.33	13.19				Hg197	5.12	5.36	6.42			
Hg197m	6.63	6.86	1.19				Hg197m	4.38	4.58	0.93			
Tl204	2.27	2.35	5.17	92.20	0.50		Hg205	2.01	1.04				
Hg205	1.56	0.80					Tl204	1.28	1.34	3.45	90.67	3.48	
Tl202	1.07	1.11	1.99			2.44	Tl202	1.25	1.30	2.74			15.17
Au195	0.14	0.14	0.31	1.73			Au197m	0.75	0.58	0.12			
H3				0.04	58.50		Au196	0.48	0.50	0.87			
Pt193					38.48		Pt193						47.38
Au194					1.26		Au194						39.02
Hg194					1.26		H3						9.87
Pb205					0.01	95.11	Pb205						0.03
Pb202						2.44	Pb202						2.46
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	5.12E3	5.02E3	2.35E3	4.70E0	6.82E-5	5.48E-9	Sv kg <sup>-1</sup>	3.90E5	3.89E5	3.03E5	1.23E4	1.76E-2	1.84E-6
Au198	62.78	63.90	53.38				Hg203	67.44	67.53	82.25	9.34		
Hg203	17.33	17.65	35.69	82.36			Au198	18.58	18.58	9.35			
Hg199m	10.74	10.03					Hg197	4.36	4.37	2.61			
Tl202	4.59	4.68	8.12		0.02	74.59	Hg197m	3.91	3.91	0.40			
Au196	1.04	1.06	1.51				Tl204	3.42	3.42	4.40	90.31	0.87	
Hg197	0.90	0.91	0.90				Hg199m	1.09	1.00				
Au197m	0.43	0.33	0.05				Tl202	0.61	0.61	0.63			2.23
Tl204	0.02*	0.02*	0.04*	15.01*	0.01*		Hg194						93.04
Au195		0.01	0.02	2.60			H3						3.57
Au194		0.01			95.78		Pt193						1.73
Pt193					4.14		Pb202						0.02
Pb205						24.66	Pb205						43.68
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	4.47E5	4.46E5	3.58E5	5.36E3	8.71E-3	4.13E-6		1.04E11	1.01E11	4.85E10	3.93E8	6.75E2	2.59E-1
Hg203	74.30	74.39	87.90	27.09			Hg203	33.25	34.30	67.57	38.49		
Au198	13.93	13.94	6.80				Hg199m	28.69	27.15				
Hg197	4.96	4.97	2.88				Au198	23.20	23.92	19.46			
Hg197m	3.85	3.84	0.38				Hg197	5.92	6.11	5.89			
Hg199m	0.98	0.90					Hg197m	3.12	3.21	0.53			
Tl204	0.97	0.97	1.21	67.38	0.57		Tl202	2.40	2.48	4.19			0.02
Au195	0.26	0.26	0.32	5.51			Au196	0.89	0.92	1.28			
Tl202	0.22	0.22	0.23			0.42	Tl204	0.26	0.27	0.56	57.48	0.46	
H3				0.02	44.55		Au195	0.06	0.06	0.13	4.02		
Hg194					51.50		Pt193						50.16
Pt193					2.37		Au194						48.45
Pb202					0.05	26.51	Pb205						0.03
Pb205					0.04	73.07	Pb202						80.70
													2.52

# Mercury

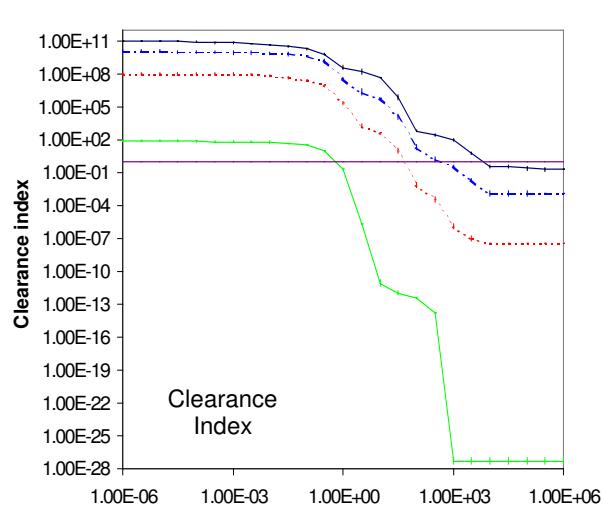
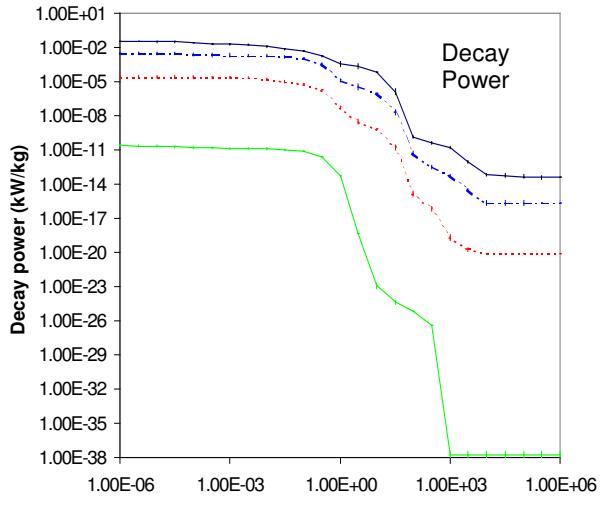
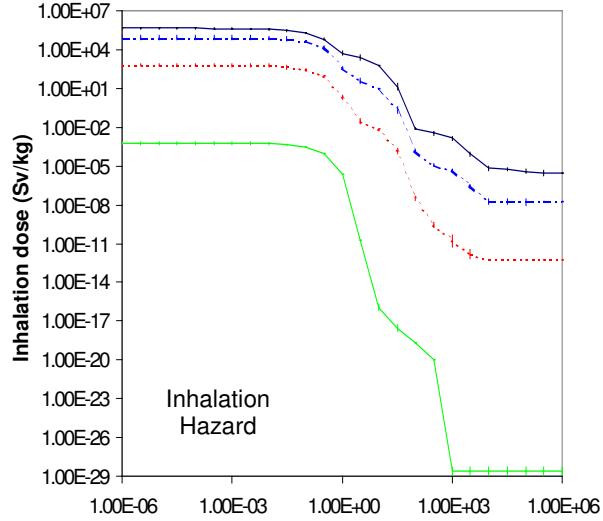
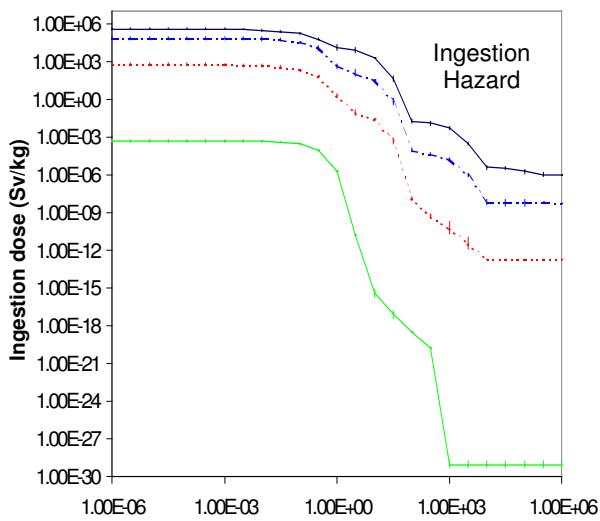
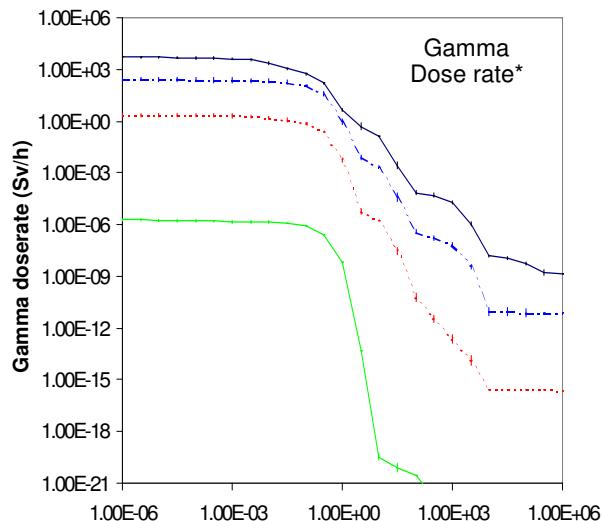
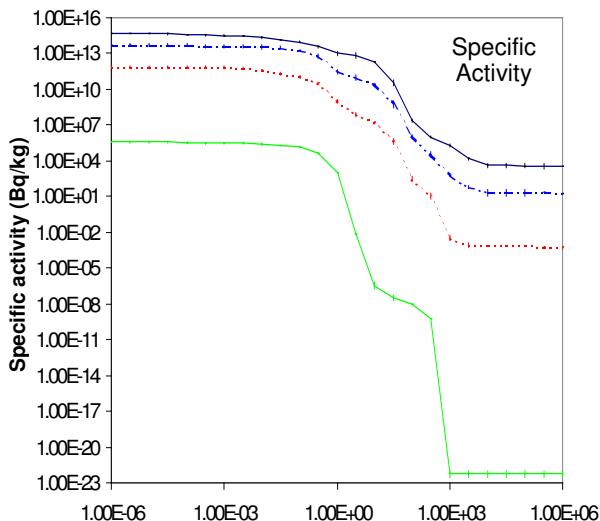
## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Hg205	5.2 m	Hg204(n, $\gamma$ )Hg205 Hg202(n, $\gamma$ )Hg203(n, $\gamma$ )Hg204(n, $\gamma$ )Hg205	98.1 1.6	100.0	100.0	99.9
Hg199m	42.1 m	Hg198(n, $\gamma$ )Hg199m Hg196(n, $\gamma$ )Hg197( $\beta^+$ )Au197(n, $\gamma$ )Au198( $\beta^-$ ) Hg198(n, $\gamma$ )Hg199m Hg200(n,2n)Hg199m Hg201(n,2n)Hg200(n,2n)Hg199m Hg202(n,2n)Hg201(n,2n)Hg200(n,2n)Hg199m Hg199(n,n')Hg199m	99.8 0.2	100.0	100.0	73.3 14.4 5.6 4.4
Au194	1.585 d	&Hg196(n,2n)Hg195( $\beta^+$ )Au195(n,2n)Au194 &Hg196(n,2n)Hg195m( $\beta^+$ )Au195(n,2n)Au194 &Hg198(n,2n)Hg197( $\beta^+$ )Au197(n,2n)Au196( $\beta^-$ ) Hg196(n,2n)Hg195( $\beta^+$ )Au195(n,2n)Au194 &Hg198(n,2n)Hg197( $\beta^+$ )Au197(n,2n)Au196( $\beta^-$ ) Hg196(n,2n)Hg195m( $\beta^+$ )Au195(n,2n)Au194 &Hg198(n,2n)Hg197( $\beta^+$ )Au197(n,2n)Au196(n,2n) Au195(n,2n)Au194				50.6 27.9 5.2 4.4 2.0
Hg197	2.692 d	Hg196(n, $\gamma$ )Hg197 Hg196(n, $\gamma$ )Hg197m(IT)Hg197 &Hg198(n,2n)Hg197 &Hg199(n,2n)Hg198(n,2n)Hg197 &Hg200(n,2n)Hg199(n,2n)Hg198(n,2n)Hg197		96.9 3.1	96.8 3.2	59.7 33.5 6.2
Au198	2.694 d	&Hg196(n, $\gamma$ )Hg197( $\beta^+$ )Au197(n, $\gamma$ )Au198 &Hg198(n,p)Au198 &Hg199(n,2n)Hg198(n,p)Au198 &Hg200(n,2n)Hg199(n,2n)Hg198(n,p)Au198 &Hg198(n,2n)Hg197( $\beta^+$ )Au197(n, $\gamma$ )Au198 Hg199(n,d)Au198 Hg200(n,t)Au198	99.8	99.7	100.0	54.6 30.7 5.6 3.5 1.5 1.2
Au196	6.183 d	Hg196(n,p)Au196 Hg196(n,p)Au196m(IT)Au196 &Hg198(n,2n)Hg197( $\beta^+$ )Au197(n,2n)Au196 &Hg199(n,2n)Hg198(n,2n)Hg197( $\beta^+$ )Au197(n,2n)Au196 &Hg198(n,2n)Hg197m( $\beta^+$ )Au197(n,2n)Au196		50.0 50.0	50.0 50.0	72.6 19.4 3.1
Tl202	12.24 d	Hg204(n,2n)Hg203( $\beta^-$ )Tl203(n,2n)Tl202 Hg202(n, $\gamma$ )Hg203( $\beta^-$ )Tl203(n,2n)Tl202				99.8 0.2
Hg203	46.595 d	Hg202(n, $\gamma$ )Hg203 Hg201(n, $\gamma$ )Hg202(n, $\gamma$ )Hg203 Hg200(n, $\gamma$ )Hg201(n, $\gamma$ )Hg202(n, $\gamma$ )Hg203 Hg199(n, $\gamma$ )Hg200(n, $\gamma$ )Hg201(n, $\gamma$ )Hg202(n, $\gamma$ )Hg203 Hg204(n,2n)Hg203	80.1 17.0 1.6 1.2	99.4 0.6	98.4 1.6	0.2    99.7
Au195	186.09 d	&Hg196(n,2n)Hg195( $\beta^+$ )Au195 Hg196(n,2n)Hg195m( $\beta^+$ )Au195 &Hg198(n,2n)Hg197( $\beta^+$ )Au197(n,2n)Au196( $\beta^-$ ) Hg196(n,2n)Hg195( $\beta^+$ )Au195 &Hg198(n,2n)Hg197( $\beta^+$ )Au197(n,2n)Au196( $\beta^-$ ) Hg196(n,2n)Hg195m( $\beta^+$ )Au195 &Hg198(n,2n)Hg197( $\beta^+$ )Au197(n,2n)Au196(n,2n)Au195 &Hg199(n,2n)Hg198(n,2n)Hg197( $\beta^+$ )Au197(n,2n) Au196( $\beta^-$ )Hg196(n,2n)Hg195( $\beta^+$ )Au195				50.5 27.8 9.0 5.1 2.1 1.0
Tl204	3.79 y	Hg202(n, $\gamma$ )Hg203( $\beta^-$ )Tl203(n, $\gamma$ )Tl204 Hg201(n, $\gamma$ )Hg202(n, $\gamma$ )Hg203( $\beta^-$ )Tl203(n, $\gamma$ )Tl204 Hg204(n,2n)Hg203( $\beta^-$ )Tl203(n, $\gamma$ )Tl204 Hg204(n, $\gamma$ )Hg205( $\beta^-$ )Tl205(n,2n)Tl204	91.2 8.1	99.8 0.2	99.4 0.6	0.1   51.0 48.9

H3	12.33 y	Hg202(n, $\gamma$ )Hg203( $\beta^-$ )Tl203(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Hg199(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Hg202(n, $\gamma$ )Hg203( $\beta^-$ )Tl203(n, $\gamma$ )Tl204(n,X)H1(n, $\gamma$ ) H2(n, $\gamma$ )H3 Hg201(n, $\gamma$ )Hg202(n, $\gamma$ )Hg203( $\beta^-$ )Tl203(n,X)H1(n, $\gamma$ ) H2(n, $\gamma$ )H3 Hg196(n, $\gamma$ )Hg197( $\beta^+$ )Au197(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Hg202(n, $\gamma$ )Hg203( $\beta^-$ )Tl203(n, $\gamma$ )Tl204( $\beta^-$ )Pb204(n,X) H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Hg196(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Hg199(n,X)H3 Hg201(n,X)H3 Hg202(n,X)H3 Hg200(n,X)H3 &Hg198(n,2n)Hg197( $\beta^+$ )Au197(n,X)H3 Hg202(n,2n)Hg201(n,X)H3 &Hg200(n,2n)Hg199(n,X)H3 Hg204(n,X)H3 Hg204(n,2n)Hg203( $\beta^-$ )Tl203(n,X)H3 Hg198(n,X)H3 &Hg199(n,2n)Hg198(n,2n)Hg197( $\beta^+$ )Au197(n,X)H3 Hg201(n,2n)Hg200(n,X)H3	66.8 12.9 7.6 3.0 1.6 1.2 0.2 2.1 1.0 25.3 16.3 13.6 11.5 8.3 6.3 4.7 3.2 2.6 2.5 1.6 1.2	0.2 92.7 99.0		
Pt193	50 y	&Hg196(n, $\alpha$ )Pt193 &Hg196(n,n $\alpha$ )Pt192(n, $\gamma$ )Pt193 &Hg196(n,2n)Hg195( $\beta^+$ )Au195( $\beta^+$ )Pt195(n,2n) Pt194(n,2n)Pt193 &Hg196(n,2n)Hg195m( $\beta^+$ )Au195( $\beta^+$ )Pt195(n,2n) Pt194(n,2n)Pt193 &Hg198(n,2n)Hg197( $\beta^+$ )Au197(n,2n)Au196( $\beta^+$ ) Pt196(n,2n)Pt195(n,2n)Pt194(n,2n)Pt193 &Hg196(n,2n)Hg195( $\beta^+$ )Au195(n,2n)Au194( $\beta^+$ ) Pt194(n,2n)Pt193 &Hg196(n,2n)Hg195m( $\beta^+$ )Au195(n,2n)Au194( $\beta^+$ ) Pt194(n,2n)Pt193 &Hg198(n,2n)Hg197( $\beta^+$ )Au197(n, $\alpha$ )Ir194( $\beta^-$ )Pt194(n,2n)Pt193 *Plus other similar pathways	43.7 37.7	66.7 33.3	97.6 2.4	3.0 33.8 18.6 13.9 6.7 3.7 1.0 19.3*
Hg194	519.68 y	Hg196(n,2n)Hg195m(n,2n)Hg194 &Hg196(n,2n)Hg195(n,2n)Hg194 &Hg198(n,2n)Hg197( $\beta^+$ )Au197(n,2n)Au196( $\beta^-$ ) Hg196(n,2n)Hg195m(n,2n)Hg194				75.5 15.1 5.6
Pb202	53000 y	&Hg204(n, $\gamma$ )Hg205( $\beta^-$ )Tl205(n,2n)Tl204( $\beta^-$ ) Pb204(n,2n)Pb203(n,2n)Pb202 &Hg204(n,2n)Hg203( $\beta^-$ )Tl203(n, $\gamma$ )Tl204( $\beta^-$ ) Pb204(n,2n)Pb203(n,2n)Pb202				50.9 49.1
Pb205	$1.5 \cdot 10^7$ y	Hg202(n, $\gamma$ )Hg203( $\beta^-$ )Tl203(n, $\gamma$ )Tl204( $\beta^-$ )Pb204(n, $\gamma$ ) Pb205 Hg201(n, $\gamma$ )Hg202(n, $\gamma$ )Hg203( $\beta^-$ )Tl203(n, $\gamma$ )Tl204( $\beta^-$ ) Pb204(n, $\gamma$ )Pb205 Hg204(n, $\gamma$ )Hg205( $\beta^-$ )Tl205(n, $\gamma$ )Tl206( $\beta^-$ )Pb206(n,2n)Pb205 Hg204(n, $\gamma$ )Hg205( $\beta^-$ )Tl205(n,2n)Tl204( $\beta^-$ )Pb204(n, $\gamma$ )Pb205 Hg204(n,2n)Hg203( $\beta^-$ )Tl203(n, $\gamma$ )Tl204( $\beta^-$ )Pb204(n, $\gamma$ )Pb205	95.1 4.6	99.9 0.1	99.7 0.3	75.4 12.3 11.9

Pt190	$6.6 \cdot 10^{11}$ y	<b>&amp;Hg196(n,2n)Hg195(<math>\beta^+</math>)Au195(<math>\beta^+</math>)Pt195(n,2n)</b> <b>Pt194(n,2n)Pt193(n,2n)Pt192(n,2n)Pt191(n,2n)Pt190</b> <b>&amp;Hg196(n,2n)Hg195m(<math>\beta^+</math>)Au195(<math>\beta^+</math>)Pt195(n,2n)</b> <b>Pt194(n,2n)Pt193(n,2n)Pt192(n,2n)Pt191(n,2n)Pt190</b> <b>&amp;Hg196(n,<math>\alpha</math>)Pt193(n,2n)Pt192(n,2n)Pt191(n,2n)Pt190</b> <b>&amp;Hg196(n,2n)Hg195(<math>\beta^+</math>)Au195(n,2n)Au194(<math>\beta^+</math>)</b> <b>Pt194(n,2n)Pt193(n,2n)Pt192(n,2n)Pt191(n,2n)Pt190</b> <b>&amp;Hg198(n,2n)Hg197(<math>\beta^+</math>)Au197(n,2n)Au196(<math>\beta^+</math>)Pt196(n,2n)</b> <b>Pt195(n,2n)Pt194(n,2n)Pt193(n,2n)Pt192(n,2n)Pt191(n,2n)Pt190</b> <b>&amp;Hg196(n,2n)Hg195m(<math>\beta^+</math>)Au195(n,2n)Au194(<math>\beta^+</math>)</b> <b>Pt194(n,2n)Pt193(n,2n)Pt192(n,2n)Pt191(n,2n)Pt190</b> <b>&amp;Hg198(n,2n)Hg197(<math>\beta^+</math>)Au197(n,<math>\alpha</math>)Ir194(<math>\beta^-</math>)</b> <b>Pt194(n,2n)Pt193(n,2n)Pt192(n,2n)Pt191(n,2n)Pt190</b> *Plus other similar pathways				31.4
						17.3
						11.5
						10.1
						7.4
						5.6
						1.1
						15.6*

# Mercury activation characteristics

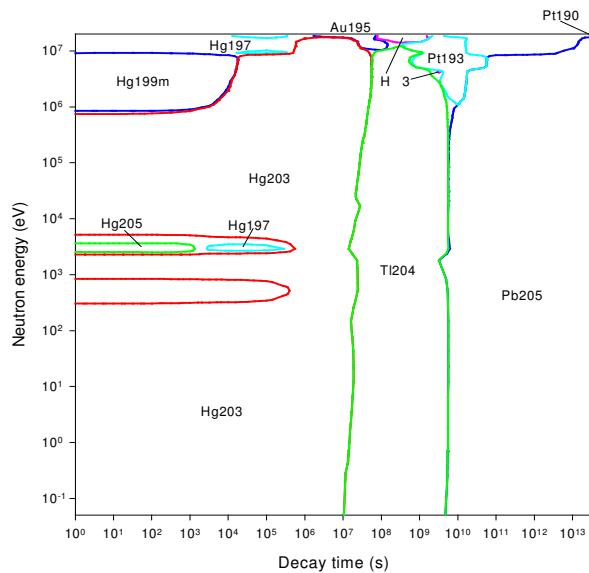


Decay time (years)

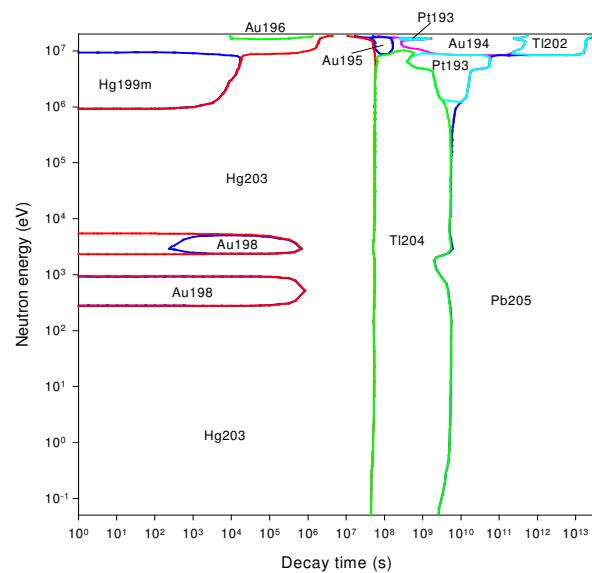
Decay time (years)

# Mercury importance diagrams & transmutation

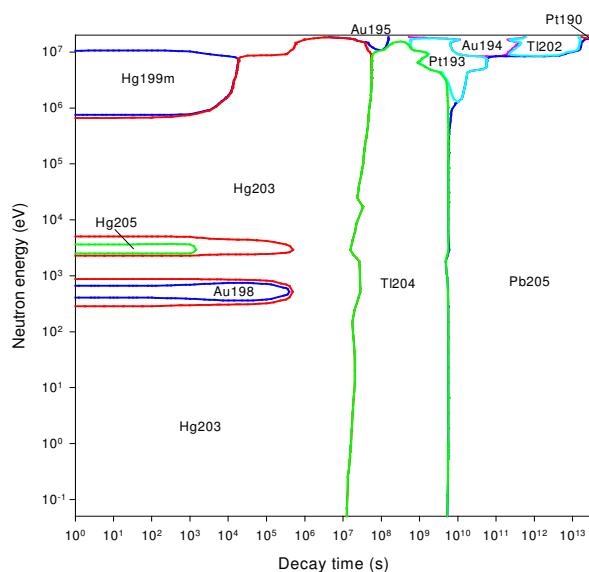
## Activity



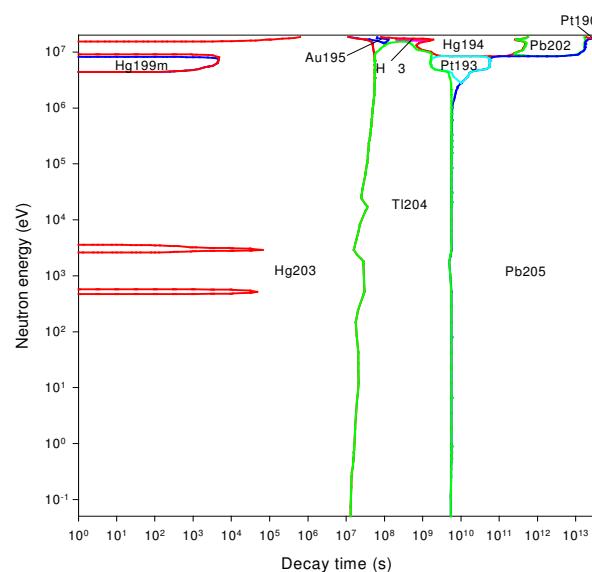
## Dose rate



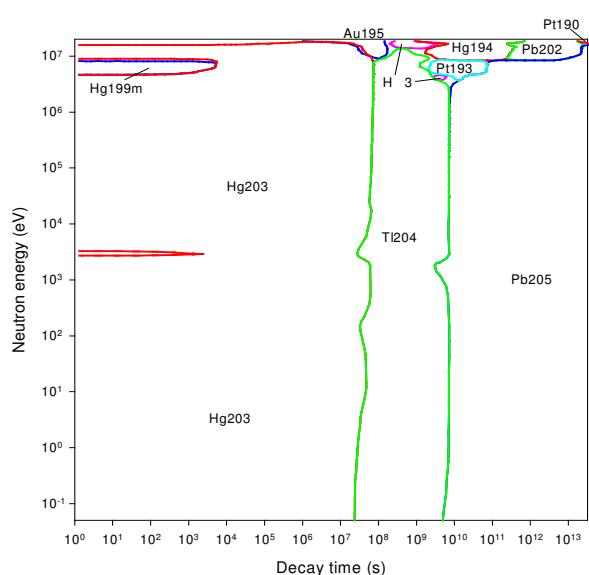
## Heat output



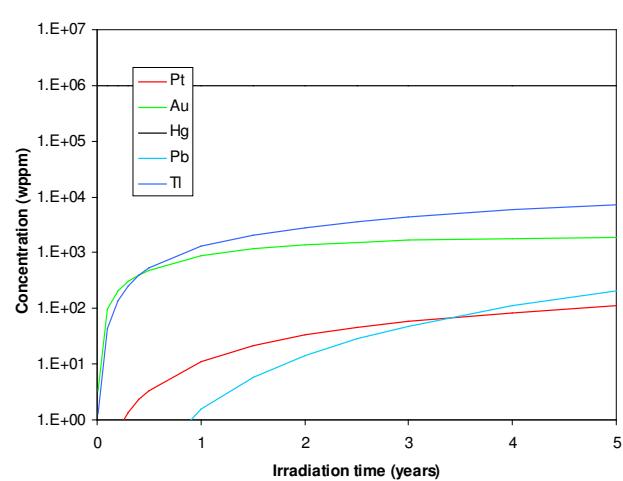
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Thallium

## General properties

Atomic number	81	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	0.85	Tl203	29.524
Melting point / K	577	Tl205	70.476
Boiling point / K	1746		
Density / kgm <sup>-3</sup>	11850		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	46.1		
Electrical resistivity /Ωm	1.8 10 <sup>-7</sup>		
Coefficient of thermal expansion / K <sup>-1</sup>	2.99 10 <sup>-5</sup>		
Crystal structure	Hexagonal		
Number of stable isotopes	2		
Mean atomic weight	204.3833		

## Activation properties

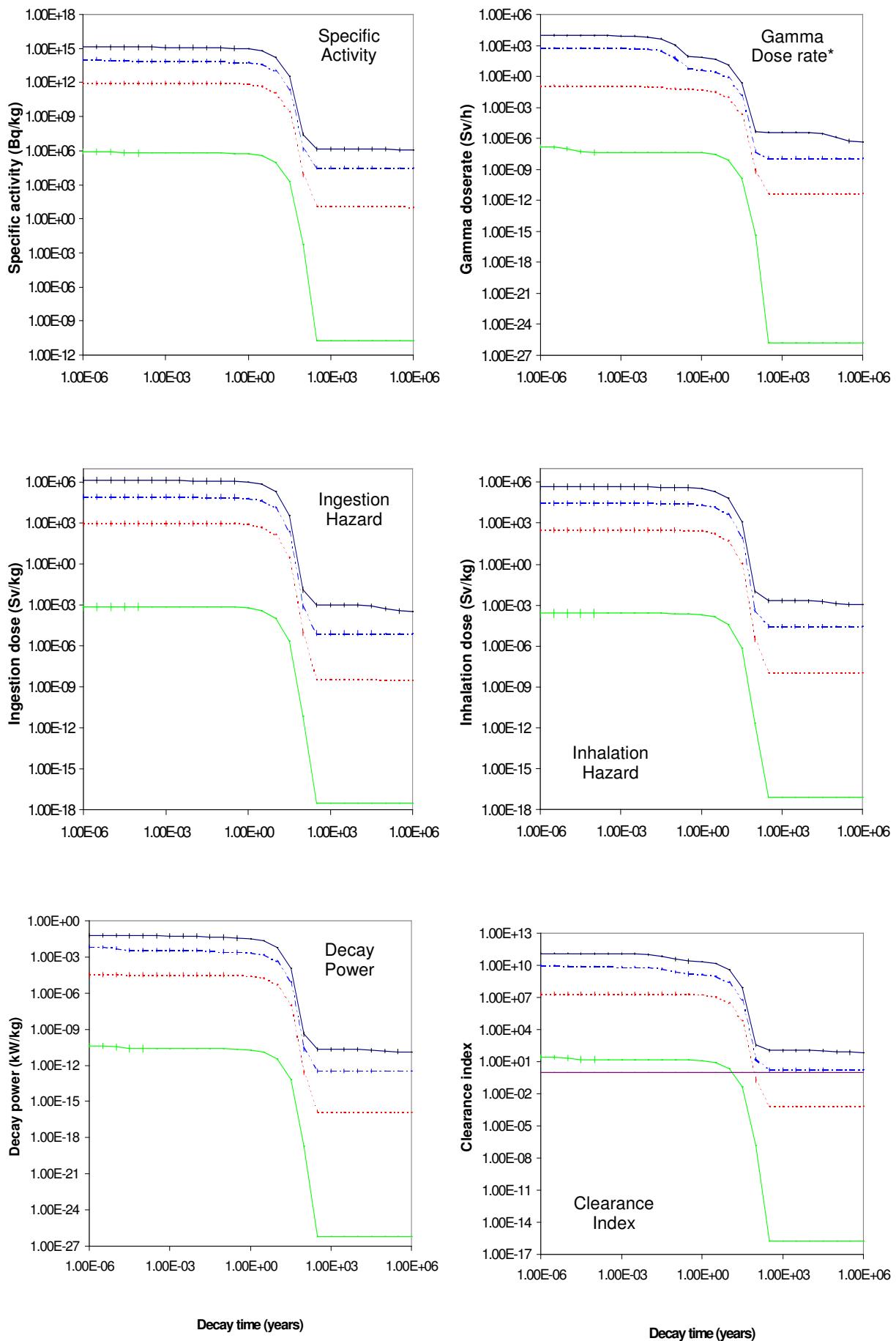
Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.37E15	1.30E15	1.21E15	8.74E14	3.23E7	1.33E6	kW kg <sup>-1</sup>	6.68E-2	5.99E-2	5.22E-2	3.32E-2	4.94E-10	1.60E-11
Tl204	76.36	80.40	86.64	100.00	37.01		Tl204	59.66	66.53	76.30	100.00	92.18	
Tl202	13.23	13.93	12.23		0.24	1.61	Tl202	21.31	23.76	22.20		1.25	10.49
Tl206	6.16	2.72					Tl206	10.92	5.12				
Pb203	2.39	2.51	0.84				Pb203m	3.77					
Pb203m	1.39						Pb203	2.89	3.22	1.15			
Hg203	0.26	0.28	0.28				Pb204m	0.93	0.99				
H3					58.52		H3					3.51	
Pb205					3.98	96.77	Pb205					2.86	87.80
Pb202					0.24	1.61	Pb202					0.20	1.70
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	1.18E4	9.11E3	6.73E3	6.57E1	4.91E-6	1.43E-6	Sv kg <sup>-1</sup>	1.36E6	1.36E6	1.33E6	1.05E6	1.62E-2	5.57E-4
Tl202	68.09	88.33	97.17		71.26	66.14	Tl204	92.85	92.85	94.33	99.99	88.39	
Pb203m	21.87						Tl202	6.03	6.03	4.99		0.22	1.73
Pb204m	5.79	7.11					Pb203	0.58	0.58	0.18			
Pb203	2.48	3.22	1.35				Hg203	0.50	0.50	0.48			
Tl204	0.67*	0.86*	1.17*	99.85*	18.30*		H3					4.89	
Hg203	0.19	0.25	0.32	0.15			Pb202					4.28	33.79
Pb205					9.73	33.21	Pb205					2.22	64.48
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	4.60E5	4.60E5	4.47E5	3.41E5	1.16E-2	1.35E-3		1.45E11	1.29E11	1.00E11	2.13E10	4.17E2	8.72E1
Tl204	88.95	88.96	91.39	99.99	40.08		Tl202	59.61	67.01	70.35		9.02	11.69
Tl202	7.51	7.51	6.29		0.13	0.30	Tl204	17.62	19.81	25.52	99.98	69.96	
Hg203	1.87	1.87	1.82	0.01			Pb203m	8.74					
Pb203	1.57	1.57	0.50				Pb203	7.29	8.18	3.28			
Pb204m	0.09	0.08					Tl206	3.24	1.53				
Tl206	0.01	0.01					Pb204m	2.55	2.72				
H3					42.25		Pb205					18.16	86.56
Pb205					9.40	80.70	H3					1.51	
Pb202					8.14	19.00	Pb202					1.35	1.75

# Thallium

## Pathway analysis

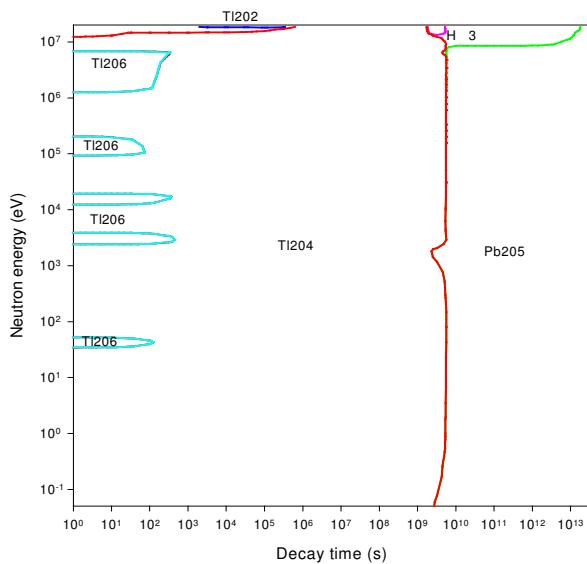
Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Tl206	4.2 m	Tl205(n, $\gamma$ )Tl206 Tl203(n, $\gamma$ )Tl204(n, $\gamma$ )Tl205(n, $\gamma$ )Tl206 Tl205(n, $\gamma$ )Tl206m(IT)Tl206	90.8 9.2	100.0	100.0	99.6 0.4
Pb204m	1.125 h	Tl205(n,2n)Tl204( $\beta^-$ )Pb204(n,n')Pb204m Tl205(n, $\gamma$ )Tl206( $\beta^-$ )Pb206(n,2n)Pb205(n,2n)Pb204m				99.4 0.5
Tl202	12.24 d	Tl203(n,2n)Tl202 Tl205(n,2n)Tl204(n,2n)Tl203(n,2n)Tl202 &Tl205(n,2n)Tl204( $\beta^-$ )Pb204(n,2n)Pb203( $\beta^+$ ) Tl203(n,2n)Tl202				88.2 8.7 2.6
Hg203	46.595 d	Tl203(n, $\alpha$ )Au200( $\beta^-$ )Hg200(n, $\gamma$ )Hg201(n, $\gamma$ ) Hg202(n, $\gamma$ )Hg203 Tl203(n,p)Hg203 Tl205(n, $\alpha$ )Au202( $\beta^-$ )Hg202(n, $\gamma$ )Hg203 Tl205(n, $\gamma$ )Tl206( $\beta^-$ )Pb206(n, $\alpha$ )Hg203 Tl205(n,2n)Tl204( $\beta^+$ )Hg204(n,2n)Hg203 Tl205(n,2n)Tl204(n,p)Hg204(n,2n)Hg203 Tl205(n,2n)Tl204(n,2n)Tl203(n,p)Hg203 Tl203(n,2n)Tl202( $\beta^+$ )Hg202(n, $\gamma$ )Hg203	99.5	0.1 98.2 1.3	0.2 96.6 2.4 0.6	22.0 69.4 2.2 2.1 1.9
Tl204	3.79 y	Tl203(n, $\gamma$ )Tl204 Tl205(n,2n)Tl204	100.0	100.0	100.0	100.0
H3	12.33 y	Tl203(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Tl203(n, $\gamma$ )Tl204(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Tl203(n, $\gamma$ )Tl204( $\beta^-$ )Pb204(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Tl203(n,X)H3 Tl205(n,X)H3 Tl205(n,2n)Tl204(n,X)H3 Tl205(n,2n)Tl204(n,2n)Tl203(n,X)H3 Tl203(n,2n)Tl202( $\beta^+$ )Hg202(n,X)H3 Tl205(n,2n)Tl204( $\beta^-$ )Pb204(n,X)H3	80.2 11.0 2.2	91.5 3.1 0.6	98.5 0.7 0.1	63.9 27.3 2.3 2.3 1.7 1.1
Pb202	$5.3 \cdot 10^4$ y	&Tl205(n,2n)Tl204( $\beta^-$ )Pb204(n,2n)Pb203(n,2n)Pb202				100.0
Pb205	$1.5 \cdot 10^7$ y	Tl203(n, $\gamma$ )Tl204( $\beta^-$ )Pb204(n, $\gamma$ )Pb205 Tl205(n, $\gamma$ )Tl206( $\beta^-$ )Pb206(n,2n)Pb205 Tl205(n,2n)Tl204( $\beta^-$ )Pb204(n, $\gamma$ )Pb205 Tl205(n, $\gamma$ )Tl206m(IT)Tl206( $\beta^-$ )Pb206(n,2n)Pb205	100.0	100.0	100.0	82.4 17.2 0.3

# Thallium activation characteristics

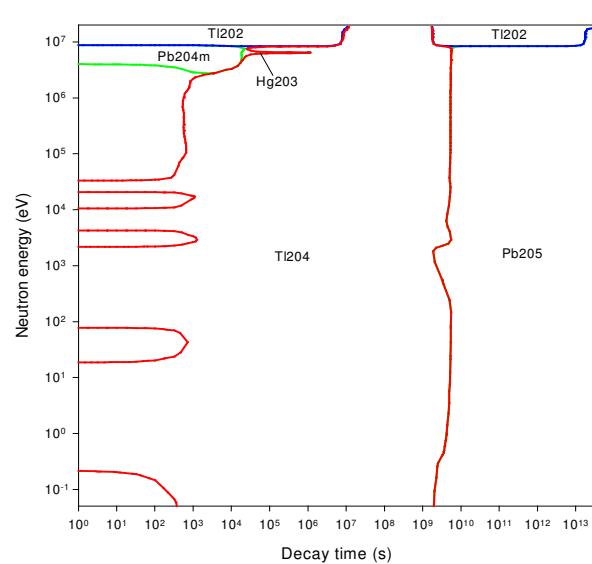


# Thallium importance diagrams & transmutation

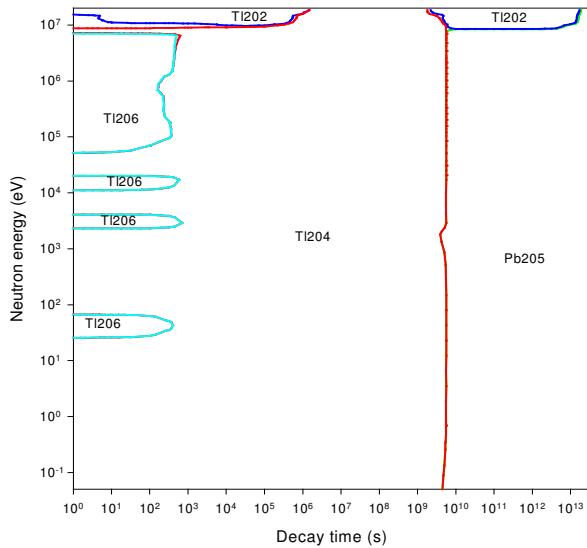
## Activity



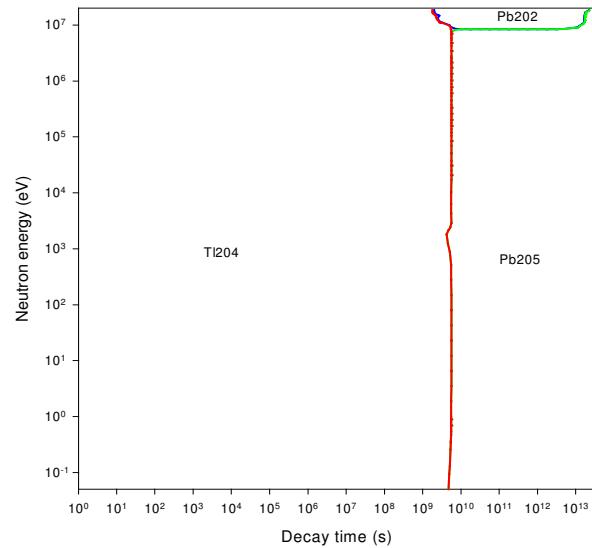
## Dose rate



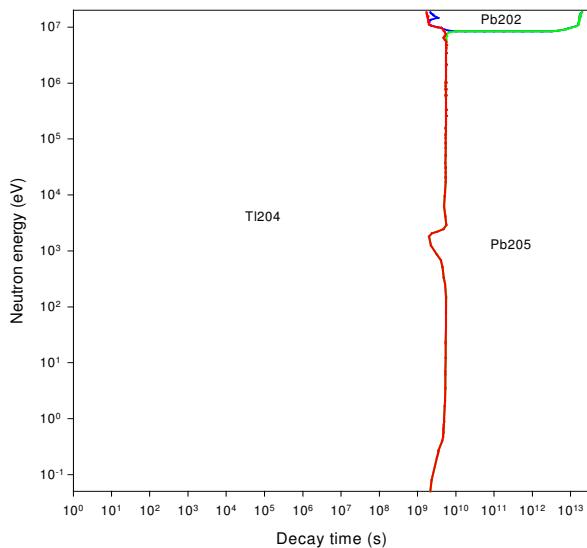
## Heat output



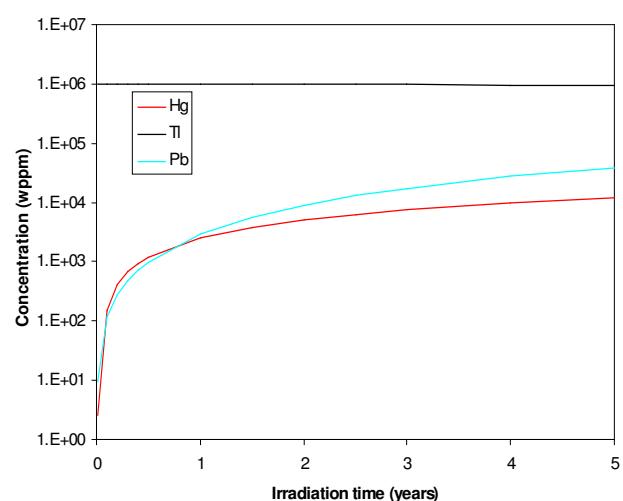
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Lead

## General properties

		82	Isotopes	Isotopic abundances / %	
Atomic number		14.0	Pb204	1.4	
Crustal abundance / wppm		600.6	Pb206	24.1	
Melting point / K		2022	Pb207	22.1	
Boiling point / K		11350	Pb208	52.4	
Density / kgm <sup>-3</sup>		35.3			
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>		2.07 10 <sup>-7</sup>			
Electrical resistivity /Ωm		2.89 10 <sup>-5</sup>			
Coefficient of thermal expansion / K <sup>-1</sup>		FCC			
Crystal structure		4			
Number of stable isotopes		207.2			
Mean atomic weight					

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	3.35E14	2.05E13	5.60E12	9.49E11	1.45E8	4.96E7	kW kg <sup>-1</sup>	8.39E-2	2.60E-3	3.14E-4	3.53E-5	2.12E-9	6.15E-10
Pb207m	91.44						Pb207m	95.47					
Pb203	3.85	62.94	71.35				Pb204m	2.12	64.90				
Pb203m	2.23						Pb203m	1.18					
Pb204m	1.52	23.59					Pb203	0.91	29.14	75.00			
Tl204	0.33	5.43	19.79	97.47	0.01		Tl204	0.05	1.62	13.43	99.50	0.02	
Pb209	0.25	4.01					Tl202	0.05	1.54	10.35		0.31	0.29
Tl202	0.15	2.49	7.40		0.06	0.05	Pb209	0.03	1.00				
Tl206	0.07	0.49					H3			0.01	0.06	3.88	
Hg203	0.02	0.28	0.97	0.03			Bi207				0.03	64.47	
H3	0.01	0.12	0.44	2.48	61.98		Pb205					25.55	87.84
Pb205				0.01	34.18	99.57	Bi208					4.12	11.79
Bi207					0.01	3.55	Po209						1.59
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	1.01E5	2.00E3	5.33E1	8.27E-2	1.67E-3	1.46E-4	Sv kg <sup>-1</sup>	7.01E3	6.93E3	3.64E3	1.29E3	5.85E-2	1.43E-2
Pb207m	96.82						Pb203	44.14	44.56	26.35			
Pb204m	1.91	91.54					Tl204	19.02	19.22	36.55	86.12	0.03	
Pb203m	0.99						Pb204m	15.99	15.31				
Pb203	0.11	5.61	65.39				Po210	15.13	15.29	29.07	13.75	0.47	
Tl208	0.10	1.53					Tl202	3.27	3.31	5.13		0.06	0.07
Tl202	0.02	1.11	33.79	0.02	0.22	0.67	Hg203	1.56	1.58	2.85	0.04		
Tl206m	0.01	0.19					H3	0.02	0.02	0.03	0.08	6.46	
Hg203		0.02	0.62	7.27			Po209				0.01	55.79	
Tl204			0.15*	90.67*			Bi207				0.01	11.44	
Bi207			0.02	24.99	89.53		Pb205					23.74	96.86
Bi208				1.85	9.17	86.98	Pb202					1.25	1.38
Pb205				0.18	1.08	12.34	Bi208					0.49	1.66
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	8.64E3	8.56E3	5.38E3	1.00E3	2.01E-1	4.38E-2		5.23E11	1.47E10	1.53E9	2.28E7	1.16E4	3.37E3
Po210	43.99	44.39	70.53	63.31	0.49		Pb207m	96.03					
Pb203	32.83	33.09	16.36				Pb204m	2.03	68.54				
Pb204m	13.56	12.97					Pb203m	0.95					
Tl204	5.02	5.06	8.04	35.96			Pb203	0.80	28.31	84.38			
Hg203	1.60	1.62	2.44	0.06			Tl208	0.08	0.86				
Tl202	1.12	1.13	1.47		0.01	0.01	Tl202	0.05	1.66	12.92		0.34	0.32
Bi210	1.07	1.08	1.04		0.01		Tl204	0.01	0.19	1.77	99.15		
H3	0.08	0.08	0.12	0.61	11.63		Hg203		0.10	0.89	0.28		
Bi207			0.01	0.03	14.34		Po210			0.02	0.22		
Po209				0.02	50.58		Bi207			0.01	0.31	69.48	
Pb205					20.96	95.82	H3				0.03	0.26	
Bi210m					0.45	2.01	Pb205				0.01	25.19	86.36
Bi208					0.41	1.55	Bi208					4.65	13.28

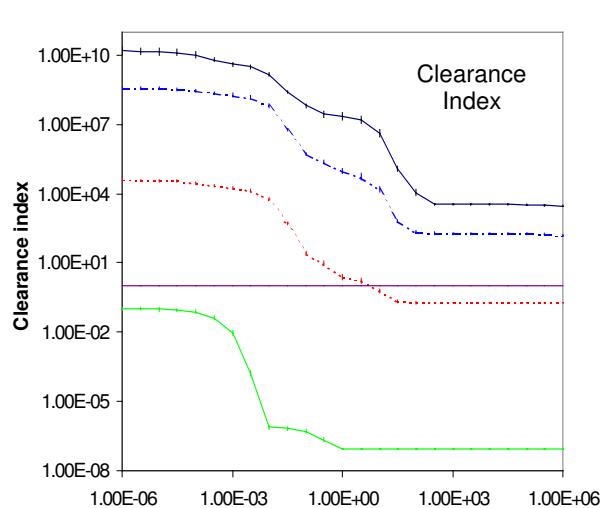
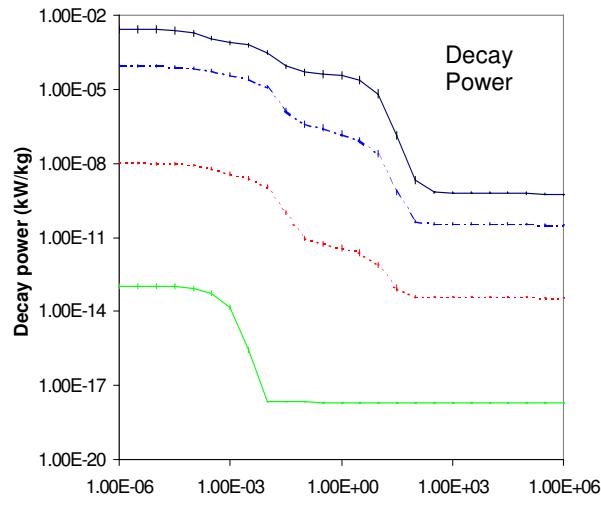
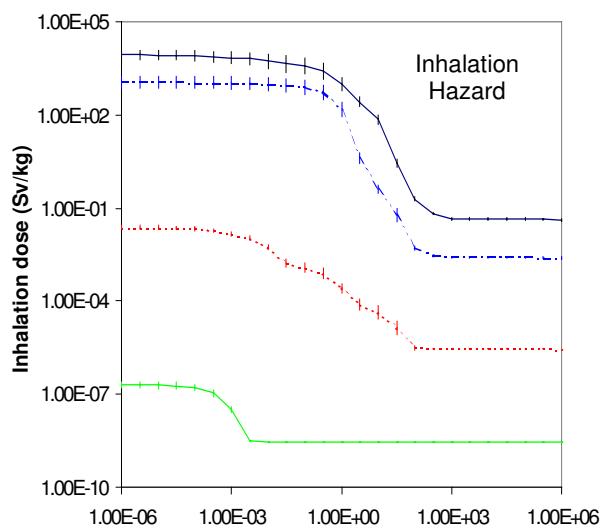
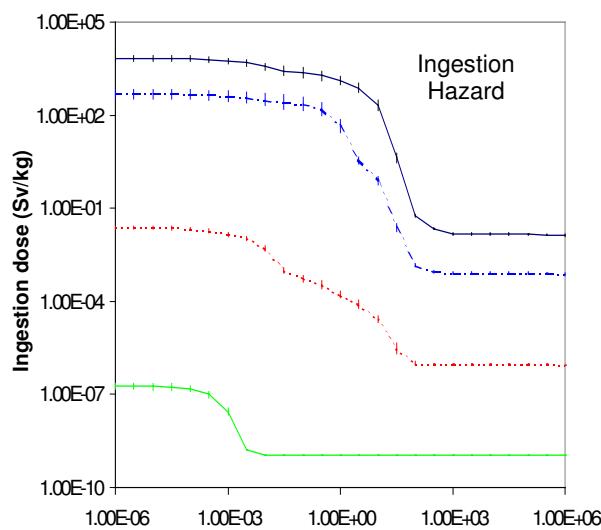
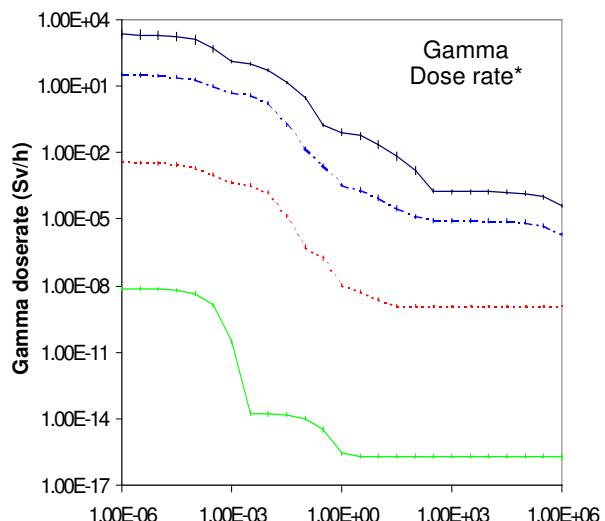
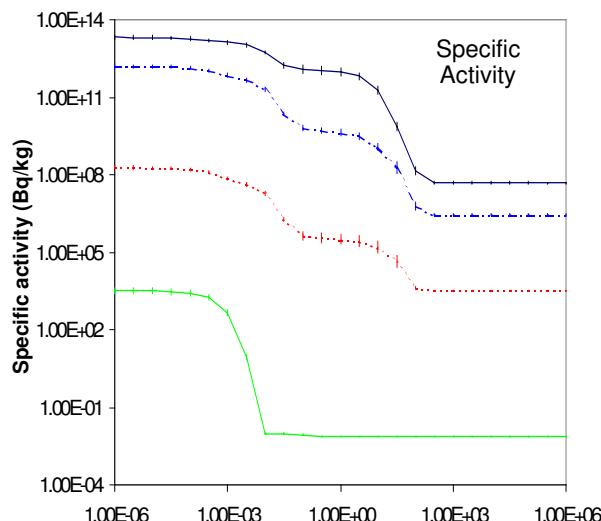
# Lead

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Pb207m	0.805 s	Pb206(n, $\gamma$ )Pb207m Pb208(n,2n)Pb207m Pb207(n,n')Pb207m Pb208(n,2n)Pb207(n,n')Pb207m	100.0	100.0	100.0	94.5 3.1 1.0
Hg205	5.2 m	Pb208(n, $\alpha$ )Hg205 Pb207(n, $\gamma$ )Pb208(n, $\alpha$ )Hg205 Pb207(n, $\alpha$ )Hg204(n, $\gamma$ )Hg205 Pb208(n,n $\alpha$ )Hg204(n, $\gamma$ )Hg205	98.0 2.0	99.9	97.5 2.3	99.0
Pb204m	1.125 h	Pb206(n,2n)Pb205(n,2n)Pb204m Pb207(n,2n)Pb206(n,2n)Pb205(n,2n)Pb204m <b>&amp;Pb208(n,2n)Pb207(n,2n)Pb206(n,2n)Pb205(n,2n)Pb204m</b>				82.4 12.4 3.2
Pb209	3.253 h	Pb208(n, $\gamma$ )Pb209 Pb207(n, $\gamma$ )Pb208(n, $\gamma$ )Pb209	98.0 2.0	99.9	99.9 0.1	100.0
Pb203	2.162 d	<b>&amp;Pb206(n,2n)Pb205(n,2n)Pb204(n,2n)Pb203</b> <b>&amp;Pb204(n,2n)Pb203</b> <b>&amp;Pb207(n,2n)Pb206(n,2n)Pb205(n,2n)Pb204(n,2n)Pb203</b>				48.1 45.7 4.8
Tl202	12.24 d	<b>&amp;Pb204(n,2n)Pb203(<math>\beta^+</math>)Tl203(n,2n)Tl202</b> <b>&amp;Pb206(n,2n)Pb205(n,2n)Pb204(n,2n)Pb203(<math>\beta^+</math>)</b> Tl203(n,2n)Tl202 <b>&amp;Pb207(n,2n)Pb206(n,2n)Pb205(n,2n)Pb204(n,2n)</b> <b>Pb203(<math>\beta^+</math>)Tl203(n,2n)Tl202</b>				72.4 24.4 1.8
Hg203	46.595 d	Pb206(n, $\alpha$ )Hg203 Pb207(n,n $\alpha$ )Hg203 Pb206(n,n $\alpha$ )Hg202(n, $\gamma$ )Hg203 Pb207(n, $\alpha$ )Hg204(n,2n)Hg203 <b>&amp;Pb208(n,2n)Pb207(n,<math>\alpha</math>)Hg204(n,2n)Hg203</b> Pb207(n,2n)Pb206(n, $\alpha$ )Hg203 <b>&amp;Pb204(n,2n)Pb203(<math>\beta^+</math>)Tl203(n,p)Hg203</b> <b>&amp;Pb208(n,2n)Pb207(n,2n)Pb206(n,<math>\alpha</math>)Hg203</b> <b>&amp;Pb208(n,2n)Pb207(n,n<math>\alpha</math>)Hg203</b> <b>&amp;Pb206(n,2n)Pb205(n,2n)Pb204(n,2n)Pb203(<math>\beta^+</math>)</b> Tl203(n,p)Hg203	46.1 40.3 13.2	99.5 47.8 0.5	51.5 47.8 0.5	33.7 2.5 31.1 11.5 9.8 3.7 3.6 1.9 1.2
Po210	138.4 d	Pb208(n, $\gamma$ )Pb209( $\beta^-$ )Bi209(n, $\gamma$ )Bi210( $\beta^-$ )Po210 Pb207(n, $\gamma$ )Pb208(n, $\gamma$ )Pb209( $\beta^-$ )Bi209(n, $\gamma$ )Bi210( $\beta^-$ ) Po210	99.3 0.7	100.0	100.0	100.0
Tl204	3.79 y	Pb206(n, $\alpha$ )Hg203( $\beta^-$ )Tl203(n, $\gamma$ )Tl204 Pb207(n,n $\alpha$ )Hg203( $\beta^-$ )Tl203(n, $\gamma$ )Tl204 Pb204(n,p)Tl204 Pb206(n,n $\alpha$ )Hg202(n, $\gamma$ )Hg203( $\beta^-$ )Tl203(n, $\gamma$ )Tl204 Pb208(n, $\alpha$ )Hg205( $\beta^-$ )Tl205(n,2n)Tl204 Pb206(n,2n)Pb205(n,d)Tl204 <b>&amp;Pb206(n,2n)Pb205(n,2n)Pb204(n,p)Tl204</b> Pb206(n,2n)Pb205(n,p)Tl205(n,2n)Tl204 Pb206(n,t)Tl204 Pb206(n,d)Tl205(n,2n)Tl204 <b>&amp;Pb204(n,2n)Pb203(<math>\beta^+</math>)Tl203(n,<math>\gamma</math>)Tl204</b> Pb207(n,t)Tl205(n,2n)Tl204 Pb207(n,2n)Pb206(n,2n)Pb205(n,d)Tl204	46.0 41.3 6.6 6.0	56.0 43.9 0.1	19.0 17.6 63.3	27.6 21.4 12.2 11.9 11.1 4.1 2.0 1.9 1.8 1.3

H3	12.33 y	Pb208(n, $\gamma$ )Pb209( $\beta^-$ )Bi209(n, $\gamma$ )Bi210m(n,X)H3 Pb204(n,X)H1(n, $\gamma$ )H2(n, $\gamma$ )H3 Pb208(n, $\gamma$ )Pb209( $\beta^-$ )Bi209(n, $\gamma$ )Bi210(n,X)H3 Pb208(n,X)H3 Pb207(n,X)H3 Pb206(n,2n)Pb205(n,X)H3 Pb206(n,X)H3 <b>&amp;Pb208(n,2n)Pb207(n,X)H3</b>	50.3 41.2 1.2	58.8 35.0 1.4	96.5 0.4 2.3	88.7 4.6 2.0 1.9 1.8
Pb210	22.3 y	Pb208(n, $\gamma$ )Pb209(n, $\gamma$ )Pb210 Pb207(n, $\gamma$ )Pb208(n, $\gamma$ )Pb209(n, $\gamma$ )Pb210 Pb208(n, $\gamma$ )Pb209( $\beta^-$ )Bi209(n, $\gamma$ )Bi210m(n,p)Pb210	98.9 1.1	100.0	99.9	95.6 3.6
Bi207	31.759 y	<b>&amp;Pb208(n,<math>\gamma</math>)Pb209(<math>\beta^-</math>)Bi209(n,2n)Bi208(n,2n)Bi207</b>				99.1
Pb202	$5.3 \cdot 10^4$ y	<b>&amp;Pb204(n,2n)Pb203(n,2n)Pb202</b> <b>&amp;Pb206(n,2n)Pb205(n,2n)Pb204(n,2n)Pb203(n,2n)Pb202</b> <b>&amp;Pb207(n,2n)Pb206(n,2n)Pb205(n,2n)Pb204(n,2n)</b> <b>Pb203(n,2n)Pb202</b>				72.2 25.1 1.9
Bi208	$3.7 \cdot 10^5$ y	<b>&amp;Pb208(n,<math>\gamma</math>)Pb209(<math>\beta^-</math>)Bi209(n,2n)Bi208</b>				100.0
Bi210m	$3.0 \cdot 10^6$ y	Pb208(n, $\gamma$ )Pb209( $\beta^-$ )Bi209(n, $\gamma$ )Bi210m Pb207(n, $\gamma$ )Pb208(n, $\gamma$ )Pb209( $\beta^-$ )Bi209(n, $\gamma$ )Bi210m	99.3 0.7	100.0	100.0	99.9
Pb205	$1.5 \cdot 10^7$ y	Pb204(n, $\gamma$ )Pb205 Pb206(n,2n)Pb205 Pb207(n,2n)Pb206(n,2n)Pb205 <b>&amp;Pb208(n,2n)Pb207(n,2n)Pb206(n,2n)Pb205</b>	100.0	100.0	100.0	84.0 12.7 3.3

# Lead activation characteristics

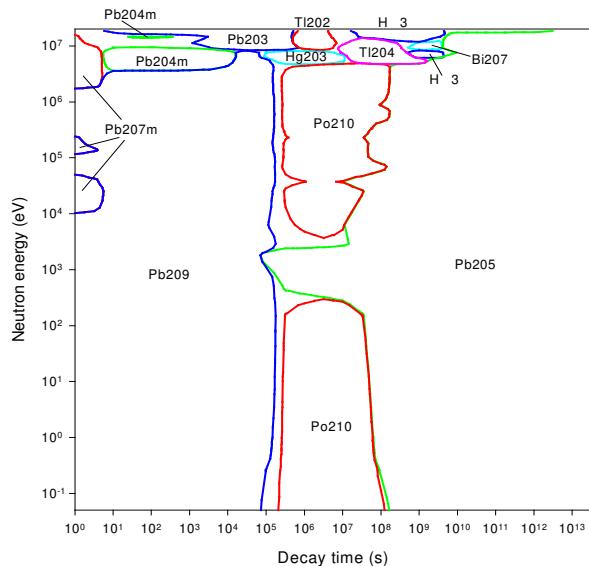


Decay time (years)

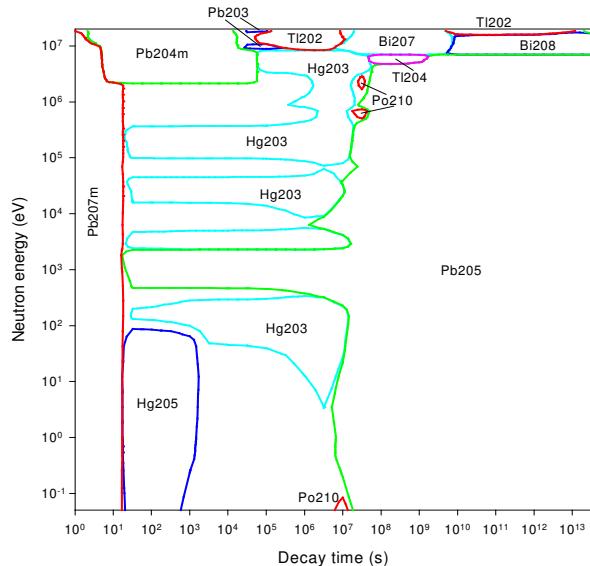
Decay time (years)

# Lead importance diagrams & transmutation

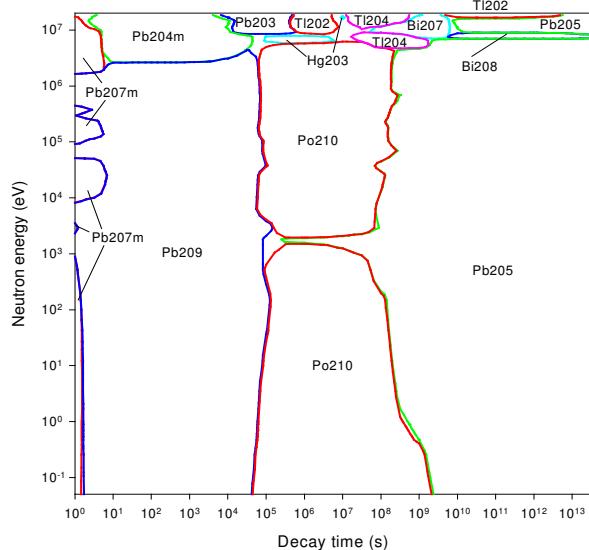
## Activity



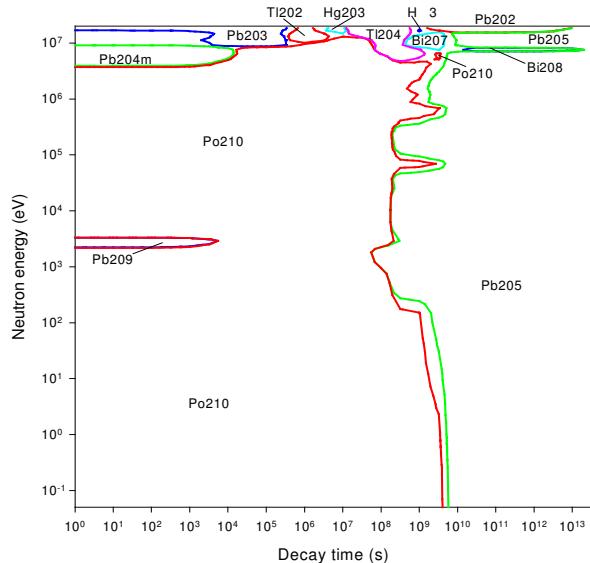
## Dose rate



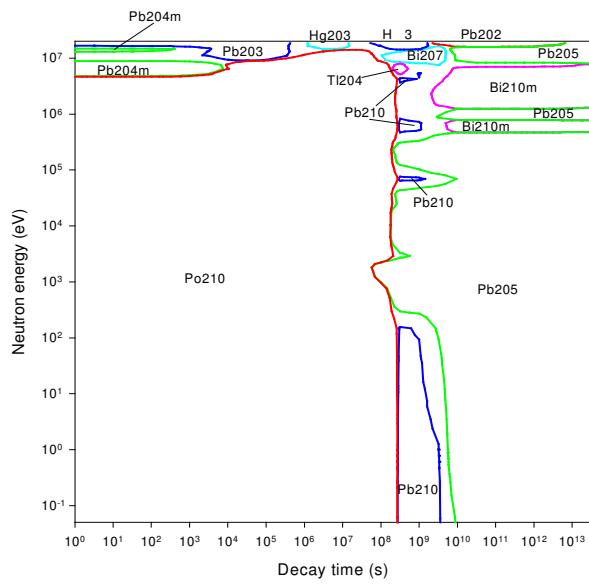
## Heat output



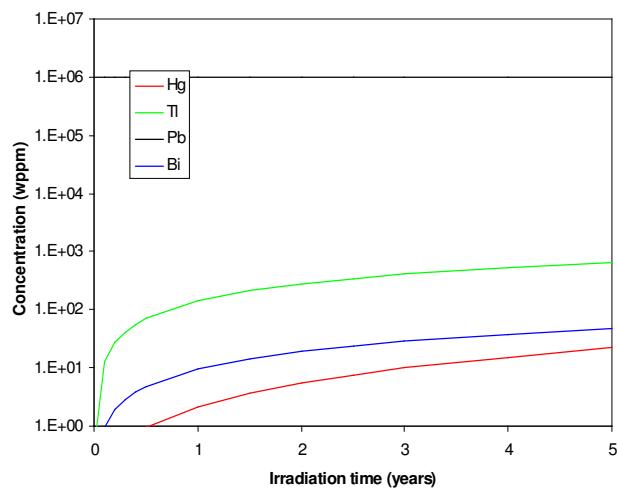
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Bismuth

## General properties

Atomic number		83	Isotopes	Isotopic abundances / %	
Crustal abundance / wppm		8.5 10 <sup>-3</sup>		Bi209	100.0
Melting point / K		544.6			
Boiling point / K		1837			
Density / kgm <sup>-3</sup>		9747			
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>		7.87			
Electrical resistivity /Ωm		1.068 10 <sup>-6</sup>			
Coefficient of thermal expansion / K <sup>-1</sup>		1.34 10 <sup>-5</sup>			
Crystal structure		Rhombohedral			
Number of stable isotopes		1			
Mean atomic weight		208.98038			

## Activation properties

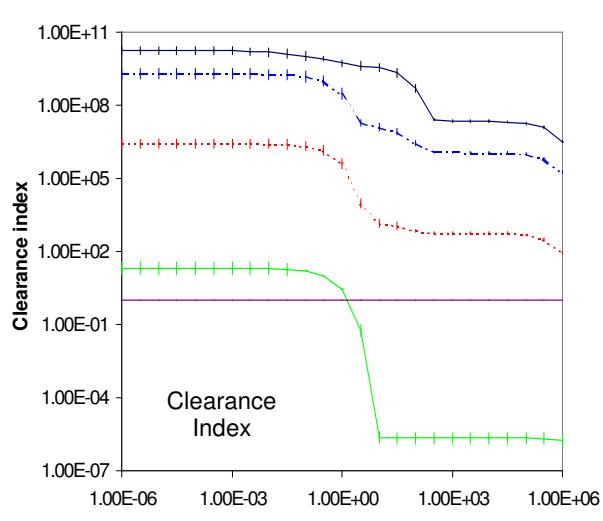
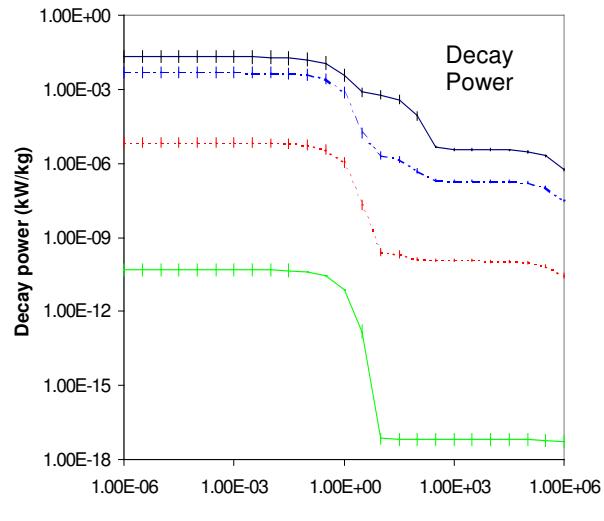
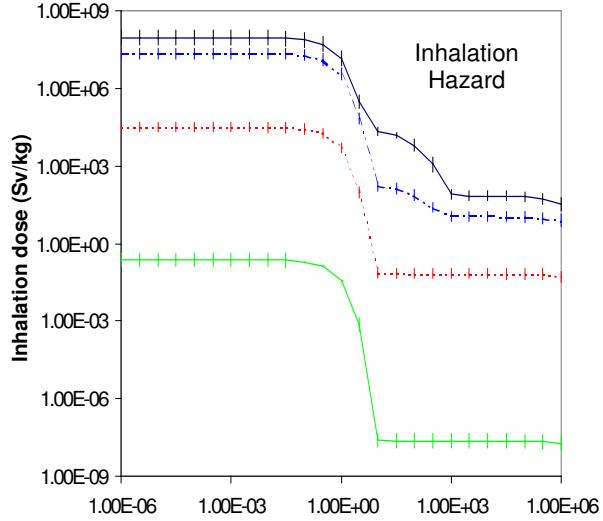
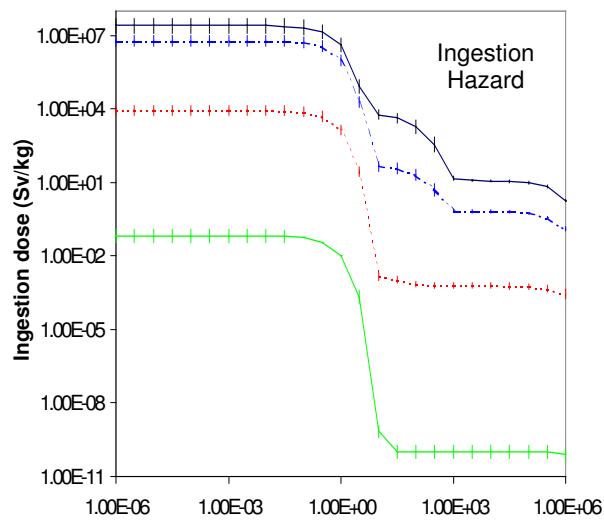
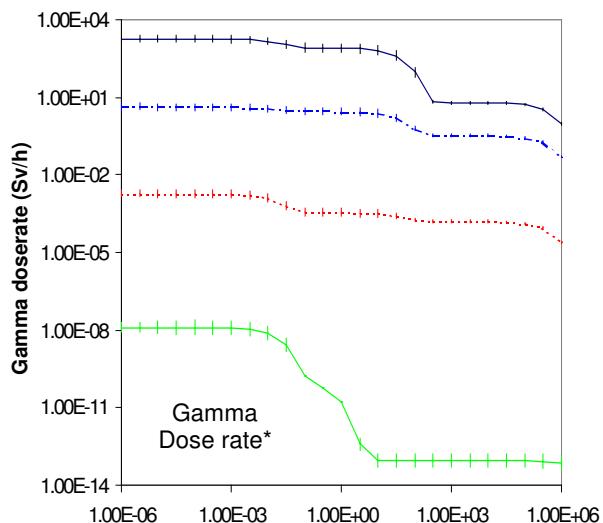
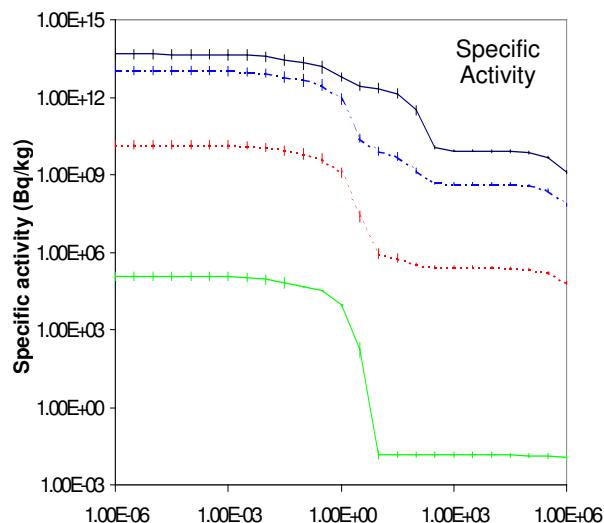
Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	1.93E14	4.62E13	3.69E13	6.18E12	3.24E11	7.03E9	kW kg <sup>-1</sup>	5.80E-2	2.08E-2	1.99E-2	3.70E-3	8.84E-5	3.01E-6
Bi208m	72.94						Bi208m	60.95					
Bi210	10.72	44.71	33.79				Po210	30.80	85.95	89.46	80.29		
Po210	10.72	44.69	55.72	55.53			Bi207m	3.14					
Bi207m	2.95						Bi210	2.22	6.18	3.90			
Bi207	1.44	6.02	7.53	43.95	96.76		Bi206	1.49	4.15	2.89			
Bi206	0.82	3.43	2.86				Bi207	1.27	3.55	3.71	19.48	94.15	
Pb209	0.18	0.75					Bi208	0.01	0.02	0.02	0.10	4.09	99.67
Bi208		0.02	0.02	0.14	2.62	99.69	Po209	0.01	0.02	0.02	0.08	1.75	
Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv h <sup>-1</sup>	3.85E4	1.82E3	1.48E3	7.80E2	9.54E1	5.17E0	Sv kg <sup>-1</sup>	2.48E7	2.48E7	2.47E7	4.13E6	1.92E3	9.98E0
Bi208m	91.05						Po210	99.85	99.85	99.90	99.81	0.15	
Bi207m	4.18						Bi210	0.11	0.11	0.07			
Bi206	2.65	55.97	46.00				Bi207	0.02	0.02	0.02	0.09	21.25	
Bi207	2.05	43.47	53.56	99.20	93.46		Po209	0.01	0.01	0.01	0.07	77.89	
Bi208	0.02	0.34	0.42	0.80	6.54	100.00	Bi208					0.62	98.39
Pb204m	0.01	0.17					Bi210m					0.01	1.61
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Sv kg <sup>-1</sup>	9.07E7	9.07E7	8.95E7	1.48E7	6.50E3	6.45E1		2.41E11	1.74E10	1.52E10	5.41E9	5.12E8	1.85E7
Po210	97.85	97.85	98.67	99.80	0.16		Bi208m	88.30					
Bi210	2.12	2.12	1.29				Bi207m	4.45					
Bi207	0.02	0.02	0.02	0.10	26.98		Po210	2.85	39.58	44.98	21.14		
Po209	0.01	0.01	0.01	0.06	71.57		Bi206	2.19	30.35	23.09			
Bi210m					0.57	56.50	Bi207	1.80	24.98	28.50	78.44	95.63	
Bi208					0.52	43.50	Bi210	0.34	4.75	3.27			
Pb210					0.20		Bi208	0.01	0.13	0.15	0.41	4.35	99.98

# Bismuth

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Tl206m	3.76 m	Bi209(n, $\alpha$ )Tl206m <b>&amp;Bi209(n,2n)Bi208(n,2n)Bi207(n,2n)Bi206(<math>\beta^+</math>)</b> Pb206(n,p)Tl206m <b>&amp;Bi209(n,2n)Bi208(n,h)Tl206m</b>	100.0	100.0	99.9	78.4 18.8 2.2
Tl206	4.2 m	Bi209(n, $\alpha$ )Tl206 Bi209(n, $\alpha$ )Tl206m(IT)Tl206 Bi209(n, $\gamma$ )Bi210( $\alpha$ )Tl206 Bi209(n,2n)Bi208(n,2n)Bi207(n,2n)Bi206( $\beta^+$ ) Pb206(n,p)Tl206	99.0 1.0	99.0 1.0	98.1 1.2 0.5	97.2 1.2 0.8
Bi210	5.013 d	Bi209(n, $\gamma$ )Bi210	100.0	100.0	100.0	99.8
Bi206	6.2431 d	<b>&amp;Bi209(n,2n)Bi208(n,2n)Bi207(n,2n)Bi206</b>				100.0
Po210	138.4 d	Bi209(n, $\gamma$ )Bi210( $\beta^-$ )Po210	100.0	100.0	100.0	99.8
H3	12.33 y	Bi209(n, $\gamma$ )Bi210m(n,X)H3 Bi209(n, $\gamma$ )Bi210m(n,X)H3( $\beta^-$ )He3(n,p)H3 Bi209(n, $\gamma$ )Bi210(n,X)H3 Bi209(n,X)H3 <b>&amp;Bi209(n,2n)Bi208(n,X)H3</b> <b>&amp;Bi209(n,2n)Bi208(n,2n)Bi207(n,X)H3</b>	89.8 8.6 1.4	91.7 6.7 1.5	97.4 1.1 1.5	97.2 1.6 0.9
Bi207	31.759 y	<b>&amp;Bi209(n,2n)Bi208(n,2n)Bi207</b> Bi209(n,3n)Bi207				99.4 0.6
Po209	102 y	Bi209(n, $\gamma$ )Bi210( $\beta^-$ )Po210(n,2n)Po209				100.0
Bi208	$3.7 \cdot 10^5$ y	Bi209(n,2n)Bi208 Bi209(n,2n)Bi208m(IT)Bi208				84.5 15.5
Bi210m	$3.0 \cdot 10^6$ y	Bi209(n, $\gamma$ )Bi210m	100.0	100.0	100.0	99.9

# Bismuth activation characteristics

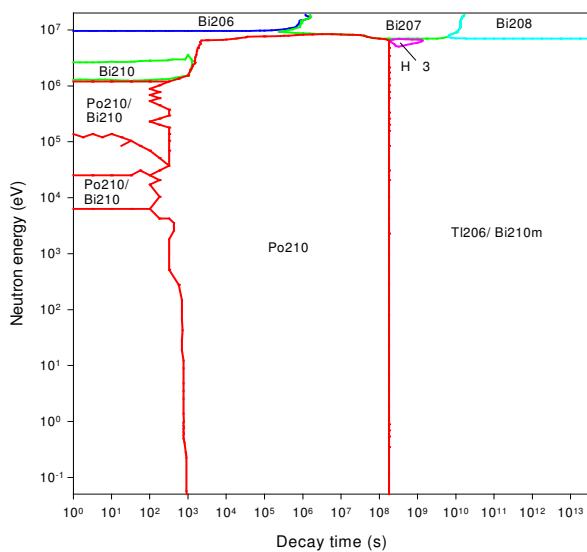


Decay time (years)

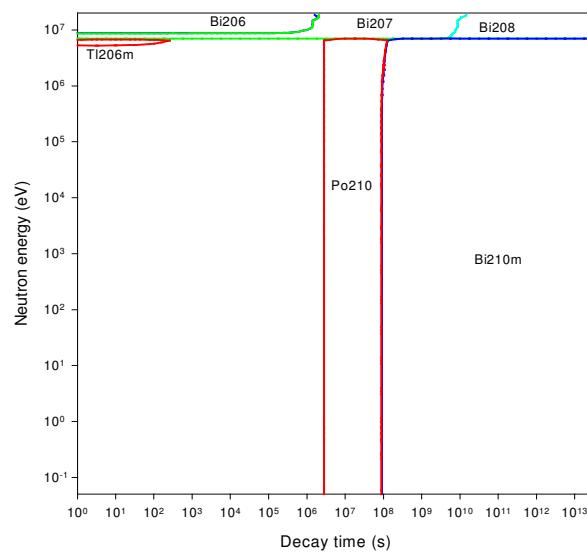
Decay time (years)

# Bismuth importance diagrams & transmutation

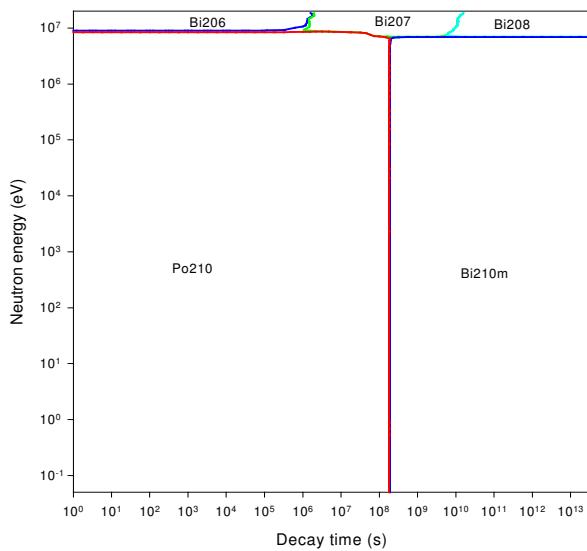
## Activity



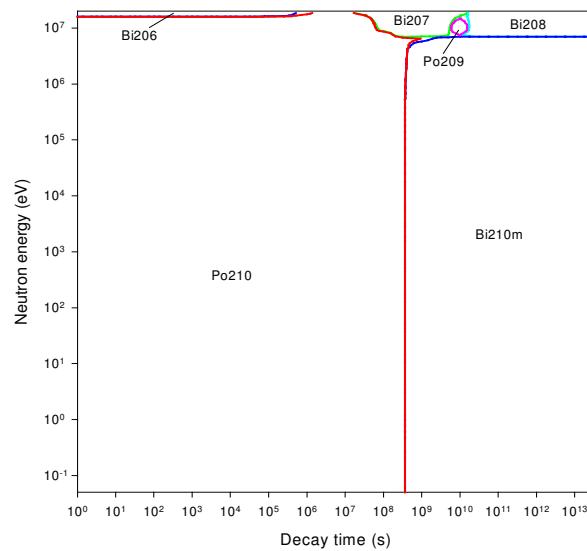
## Dose rate



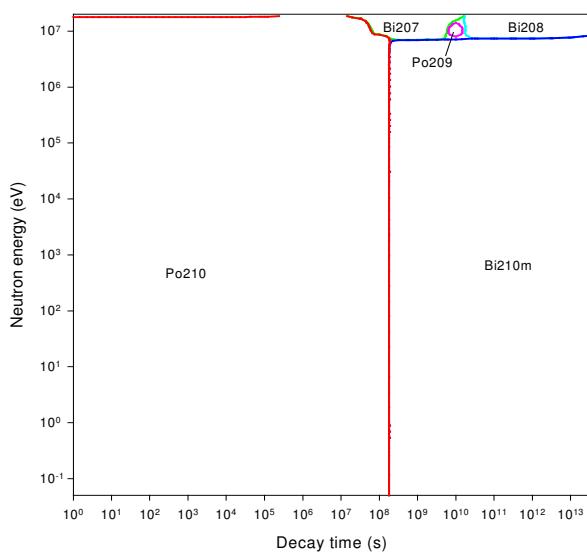
## Heat output



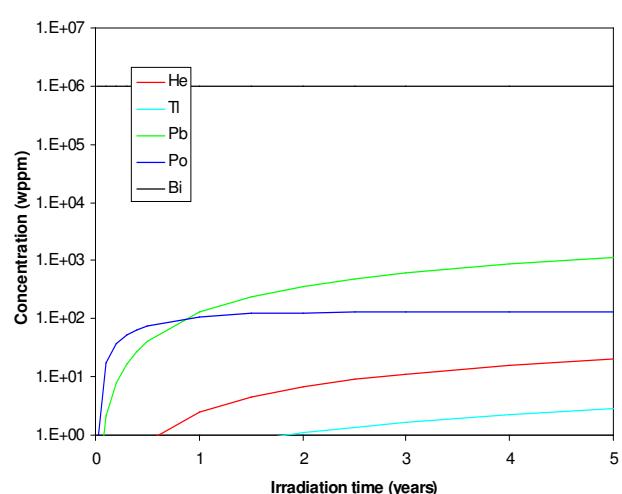
## Ingestion dose



## Inhalation dose



## First wall transmutation



# Thorium

## General properties

Atomic number	90	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	9.6	Th232	100.0 ( $T_{1/2} = 1.405 \cdot 10^{10}$ y)
Melting point / K	2023		
Boiling point / K	5061		
Density / kgm <sup>-3</sup>	11720		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	54		
Electrical resistivity /Ωm	$1.5 \cdot 10^{-9}$		
Coefficient of thermal expansion / K <sup>-1</sup>	$1.1 \cdot 10^{-5}$		
Crystal structure	CCP		
Number of stable isotopes	(1)		
Mean atomic weight	232.03805		

## Activation properties

Act	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y	Heat	0	$10^{-5}$ y	$10^{-2}$ y	1 y	100 y	$10^5$ y
Bq kg <sup>-1</sup>	2.79E16	2.15E16	7.14E15	3.65E14	3.07E13	4.00E11	kW kg <sup>-1</sup>	6.14E0	3.58E0	7.10E-1	6.79E-2	2.01E-2	2.74E-4
Th233	14.90	16.40					Th233	4.88	7.10				
Pa233	14.63	18.97	52.14				Pa233	4.40	7.53	34.61			
Th231	1.94	2.51	0.70				Br86	2.75					
Pa232	1.57	2.02	0.89				Rb90	2.65					
La140	1.01	1.31	3.52				Kr89	2.56					
Ba140	0.98	1.27	3.15				Cs140	2.34					
Ce141	0.96	1.25	3.50				La144	2.29					
Sr89	0.96	1.24	3.56				Cs138	2.23	3.75				
Rb89	0.94	1.11					Rb89	2.18	3.37				
La141	0.94	1.22					La140	2.09	3.59	16.13			
Ba139	0.94	1.21					La142	1.99	3.38				
Sr91	0.91	1.17					Se85	1.98					
Y92	0.91	1.17					I134	1.83	3.10				
Y91	0.90	1.17	3.41				Rb88	1.60	2.72				
Sr92	0.90	1.14					Sr93	1.58	1.64				
Pr143		1.07	2.92				Y94	1.57	2.35				
Zr95		2.94	1.15				Y95	1.35	1.68				
Pr144		2.94	23.85				Kr88	1.35	2.26				
Ce144		2.94	23.85				Pa232		2.15	1.58			
Nb95		2.94	2.47				Y92		1.92				
Xe133		1.93					Kr87		1.89				
Cs134			5.71				I132		1.54	3.60			
Pm147			5.04				Pr144			5.85	25.35		
Y90			4.95	5.46			Zr95			4.02	0.84		
Sr90			4.95	5.46			Nb95			3.83	1.72		
Cs137			4.03	4.93			Sr89			3.35			
Ba137m			3.82	4.66			Y91			3.33	0.49		
U232			2.14	9.49			Ba140			2.52			
Kr85			2.10				Cs136			1.84			
Pb212			1.30	9.76			Cs134			1.13	8.44		
Bi212			1.30	9.76			U232			0.96	9.96	12.60	
Po216			1.30	9.76			Po216				7.70	16.51	
Rn220			1.30	9.76			Rn220				7.14	15.32	
Ra224			1.30	9.76			Ra224				6.46	13.84	
Th228			1.29	9.76			Po212				6.39	13.71	
Po212				6.25			Th228				6.12	13.20	
Tl208				3.51			Y90				3.98	1.25	
U233				0.17	8.50		Bi212				3.15	6.76	
Pb209					8.91		Ba137m				2.17	0.76	
At217					8.91		Tl208				1.59	3.42	
Fr221					8.91		U233					0.21	9.75
Ra225					8.91		Po213						17.38
Ac225					8.91		At217						14.98
Th229					8.91		Fr221						13.55
Bi213					8.90		Ac225						12.31
Po213					8.71		Th229						10.72

Dose	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Ing	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	
Sv h <sup>-1</sup>	3.97E6	2.38E6	2.98E5	1.04E4	1.06E3	2.44E0	Sv kg <sup>-1</sup>	2.12E7	2.09E7	1.48E7	5.15E6	1.54E6	5.98E4	
Ba142	11.43	13.49					Pa233	16.80	17.02	21.94				
Br86	4.21						U232	12.25	12.40	17.60	49.93	62.33		
La140	3.82	6.36	45.47				I131	8.69	8.80	9.29				
Rb89	3.67	5.54					Ce144	5.20	5.27	7.39	8.79			
La142	3.54	5.85					I133	3.69	3.73					
Cs138	3.34	5.48					Th233	3.54	3.04					
Cs140	3.26						Ba140	3.37	3.41	3.96				
Rb90	3.26						Sr89	3.28	3.33	4.48	0.09			
Kr88	2.88	4.70					Y91	2.86	2.90	3.96	0.16			
I134	2.78	4.59					La140	2.66	2.70	3.40				
La144	2.72						Cs134	2.62	2.65	3.74	7.68			
Se85	2.57						Sr90	2.45	2.48	3.51	9.82	3.04		
Kr89	2.53	1.33					Te132	2.22	2.25	1.45				
Sr93	2.25	2.27					Zr97	1.74	1.76					
Sr92	2.19	3.56					Pa232	1.49	1.50					
I135	2.05	3.38					Kr88	1.37	1.36					
Y95	1.79	2.17					Pr143	1.31	1.32	1.70				
Pa232	1.68	2.79	3.25				Y93	1.29	1.30					
I132		1.95	7.26				Ce143	1.21	1.22					
Pa233		1.47	10.72	0.03			Xe133	1.15	1.16	1.21				
Nb95			7.80	9.75			Th228				1.64	6.57	13.98	
Zr95			7.47	4.32			Ra224				1.47	5.96	12.62	
Cs136			5.03				Cs137				1.33	3.72	1.28	
Cs134			2.22	46.24			Po210					2.11	0.34	8.01
Pm148m			2.22	0.14			Pb210					1.24	0.20	4.60
Pr144			0.49	5.94			Pa231					0.47	1.55	4.83
Ba137m			0.41	11.73	11.72		Ac227						2.31	7.49
Tl208			0.36	13.22	81.56	0.03	U233						0.17	2.90
Eu154				2.73	0.01		Th230						0.07	1.37
Bi212				0.93	5.70		Th229						0.05	29.16
Bi214					0.01	59.15	Fr221						0.04	21.43
Bi213						17.75	Rn222						0.02	10.01
Tl209						14.64	Ra225							5.89
Inh	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Clear	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	
Sv kg <sup>-1</sup>	5.30E8	5.30E8	5.19E8	5.17E8	2.65E8	1.37E7		2.06E13	1.26E13	2.66E12	2.17E11	3.10E10	7.81E7	
U232	54.79	54.81	56.08	55.86	40.74		Pa233	4.72	7.74	33.38				
Th228	25.17	25.18	25.83	36.43	45.28		Kr89	3.92	2.04					
U230	3.61	3.61	3.42				Br86	3.42						
Pa233	3.01	3.01	2.80				La140	3.25	5.34	22.52				
Ra224	2.13	2.13	2.18	3.11	3.85		Rb89	2.97	4.42					
Ce144	2.12	2.12	2.14	0.89			Rb90	2.90						
Pa231	0.89	0.89	0.91	0.92	1.78	4.17	Cs138	2.84	4.59					
Pa232	0.82	0.82					I134	2.84	4.62					
Pa230	0.75	0.75	0.67				La144	2.79						
Ra222	0.66	0.66	0.62				La142	2.78	4.53					
Sr90	0.56	0.56	0.57	0.56	0.10		Se85	2.36						
Pu238	0.48	0.48	0.49	0.49	0.44		Kr88	2.16	3.47					
Y91	0.42	0.42	0.42				Pa232	2.12	3.47	2.38				
Kr85	0.40	0.40	0.41	0.39			Sr93	2.00	2.00					
Sr89	0.40	0.40	0.39				Sr92	1.72	2.76					
Ba140	0.30	0.30	0.25				I135	1.65	2.69					
Zr95	0.24	0.24	0.24				Th233	1.55	2.16					
Ac227	0.24	0.24	0.24	0.35	6.73	16.38	I132		2.32	5.09				
U233				0.10	0.19	2.38	Zr95			6.08	1.49			
Th230				0.09	0.18	2.86	Nb95			6.08	3.21			
Th229				0.05	0.15	62.47	Cs134			3.65	32.06			
Fr221					0.01	5.99	Cs136			2.93				
Ac225					0.01	2.21	Cs137			1.89	22.66	16.31		
U234					0.01	0.20	Pr144			1.22	6.18			
Ra225						2.00	U232			0.99	11.99	31.40		
							Th228				7.24	32.28		
							Ba137m				3.78	2.72		
							Sr90				2.78	1.81		
							Tl208				2.70	12.00		
							Pb210				0.14	0.05	17.03	
							Th230				0.05	0.04	16.67	
							U234				0.04	12.50		

# Thorium

## Pathway analysis

Nuclide	T <sub>1/2</sub>	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Ba137m	2.553m	Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n,f)Xe137( $\beta^-$ ) Cs137( $\beta^-$ )Ba137m Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n,f)Cs137( $\beta^-$ ) Ba137m Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n, $\gamma$ )U234(n, $\gamma$ ) U235(n,f)Xe137( $\beta^-$ )Cs137( $\beta^-$ )Ba137m Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n,f)Ba137m Th232(n,f)Xe138( $\beta^-$ )Cs138( $\beta^-$ )Ba138(n,2n)Ba137m Th232(n,f)Xe137( $\beta^-$ )Cs137( $\beta^-$ )Ba137m Th232(n,2n)Th231( $\beta^-$ )Pa231(n,f)Xe138( $\beta^-$ )Cs138( $\beta^-$ ) Ba138(n,2n)Ba137m Th232(n,2n)Th231( $\beta^-$ )Pa231(n,f)Xe137( $\beta^-$ )Cs137( $\beta^-$ )Ba137m Th232(n,3n)Th230(n,f)Xe138( $\beta^-$ )Cs138( $\beta^-$ )Ba138(n,2n)Ba137m Th232(n,3n)Th230(n,f)Xe137( $\beta^-$ )Cs137( $\beta^-$ )Ba137m <b>&amp;Th232(n,2n)Th231(<math>\beta^-</math>)Pa231(n,f)Cs138(<math>\beta^-</math>) Ba138(n,2n)Ba137m &amp;Th232(n,f)Cs138(<math>\beta^-</math>)Ba138(n,2n)Ba137m</b>	81.0 11.6 2.8 2.0 2.0 2.6 2.8	84.8 9.6 1.4 30.1 23.2 16.1 13.8 3.7 3.2 3.2 1.2	87.7 9.4	
Tl208	3.055 m	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ ), ( $\alpha$ ), (n, $\alpha$ ), ( $\beta^+$ ), etc Th232(n,3n)Th230(n,3n)Th228( $\alpha$ )Ra224( $\alpha$ )Rn220( $\alpha$ ) Po216( $\alpha$ )Pb212( $\beta^-$ )Bi212( $\alpha$ )Tl208	100.0	100.0	100.0	30.9 69.1
Pr144	17.28 m	<b>&amp;Th232(n,<math>\gamma</math>)Th233(<math>\beta^-</math>)Pa233(<math>\beta^-</math>)U233(n,f)La144(<math>\beta^-</math>) Ce144(<math>\beta^-</math>)Pr144 &amp;Th232(n,<math>\gamma</math>)Th233(<math>\beta^-</math>)Pa233(<math>\beta^-</math>)U233(n,f)Ce144(<math>\beta^-</math>) Pr144 &amp;Th232(n,<math>\gamma</math>)Th233(<math>\beta^-</math>)Pa233(<math>\beta^-</math>)U233(n,f)La143(<math>\beta^-</math>) Ce143(<math>\beta^-</math>)Pr143(n,<math>\gamma</math>)Pr144 &amp;Th232(n,<math>\gamma</math>)Th233(<math>\beta^-</math>)Pa233(<math>\beta^-</math>)U233(n,f)Ba143(<math>\beta^-</math>) La143(<math>\beta^-</math>)Ce143(<math>\beta^-</math>)Pr143(n,<math>\gamma</math>)Pr144 &amp;Th232(n,<math>\gamma</math>)Th233(<math>\beta^-</math>)Pa233(<math>\beta^-</math>)U233(n,<math>\gamma</math>)U234(n,<math>\gamma</math>) U235(n,f)La144(<math>\beta^-</math>)Ce144(<math>\beta^-</math>)Pr144 &amp;Th232(n,f)La144(<math>\beta^-</math>)Ce144(<math>\beta^-</math>)Pr144 &amp;Th232(n,2n)Th231(<math>\beta^-</math>)Pa231(n,f)La144(<math>\beta^-</math>)Ce144(<math>\beta^-</math>)Pr144 &amp;Th232(n,3n)Th230(n,f)La144(<math>\beta^-</math>)Ce144(<math>\beta^-</math>)Pr144 &amp;Th232(n,3n)Th230(n,2n)Th229(n,f)La144(<math>\beta^-</math>)Ce144(<math>\beta^-</math>)Pr144 &amp;Th232(n,2n)Th231(<math>\beta^-</math>)Pa231(n,f)Ce144(<math>\beta^-</math>)Pr144</b>	78.9 8.5 1.9 4.9 3.6 42.7	84.5 7.4 1.0 3.2 2.1 42.7	92.2 7.7 43.9 42.3 8.0 2.7 1.4	
Sb126m	19.1 m	<b>&amp;Th232(n,<math>\gamma</math>)Th233(<math>\beta^-</math>)Pa233(<math>\beta^-</math>)U233(n,f)Sn125(<math>\beta^-</math>) Sb125(n,<math>\gamma</math>)Sb126m &amp;Th232(n,<math>\gamma</math>)Th233(<math>\beta^-</math>)Pa233(<math>\beta^-</math>)U233(n,f)In125(<math>\beta^-</math>) Sn125(<math>\beta^-</math>)Sb125(n,<math>\gamma</math>)Sb126m &amp;Th232(n,<math>\gamma</math>)Th233(<math>\beta^-</math>)Pa233(<math>\beta^-</math>)U233(n,f) Sn125m(<math>\beta^-</math>)Sb125(n,<math>\gamma</math>)Sb126m &amp;Th232(n,<math>\gamma</math>)Th233(<math>\beta^-</math>)Pa233(<math>\beta^-</math>)U233(n,f) In125m(<math>\beta^-</math>)Sn125m(<math>\beta^-</math>)Sb125(n,<math>\gamma</math>)Sb126m &amp;Th232(n,<math>\gamma</math>)Th233(<math>\beta^-</math>)Pa233(<math>\beta^-</math>)U233(n,f)In125(<math>\beta^-</math>) Sn125m(<math>\beta^-</math>)Sb125(n,<math>\gamma</math>)Sb126m &amp;Th232(n,f)Sn127(<math>\beta^-</math>)Sb127(n,2n)Sb126m &amp;Th232(n,f)In125(<math>\beta^-</math>)Sn125(<math>\beta^-</math>)Sb125(n,<math>\gamma</math>)Sb126m &amp;Th232(n,f)Sn127(<math>\beta^-</math>)Sb127(<math>\beta^-</math>)Te127(<math>\beta^-</math>)I127(n,2n) I126(<math>\beta^+</math>)Te126(n,p)Sb126m &amp;Th232(n,f)Sn125(<math>\beta^-</math>)Sb125(n,<math>\gamma</math>)Sb126m &amp;Th232(n,f)Sn127m(<math>\beta^-</math>)Sb127(n,2n)Sb126m &amp;Th232(n,2n)Th231(<math>\beta^-</math>)Pa231(n,f)Sn127(<math>\beta^-</math>)Sb127(n,2n)Sb126m &amp;Th232(n,3n)Th230(n,f)Sn127(<math>\beta^-</math>)Sb127(n,2n)Sb126m</b> *Plus other similar pathways	27.5 17.7 7.3 3.8 3.8	27.5 17.9 7.3 3.8 3.7	27.5 17.8 7.2 3.7 3.7	21.7 4.3 3.5 3.1 3.0 2.7 2.4 59.3*

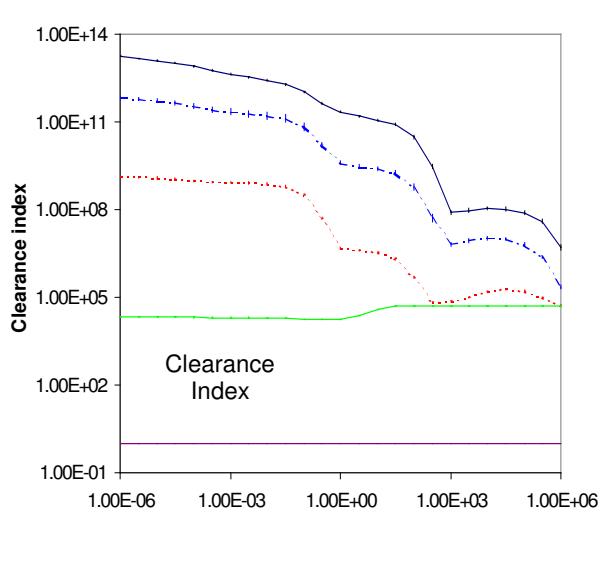
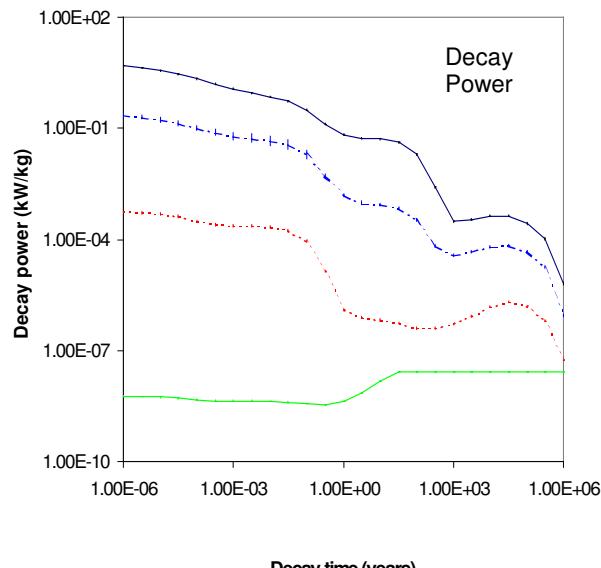
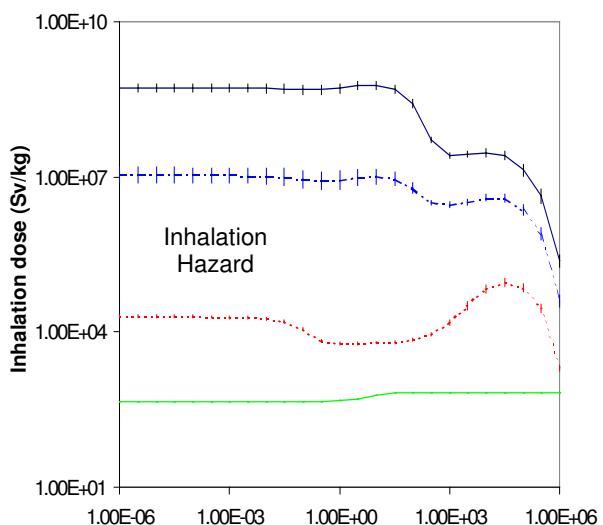
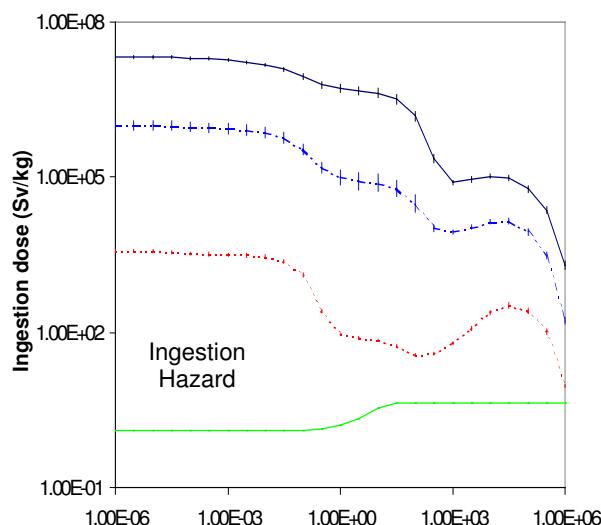
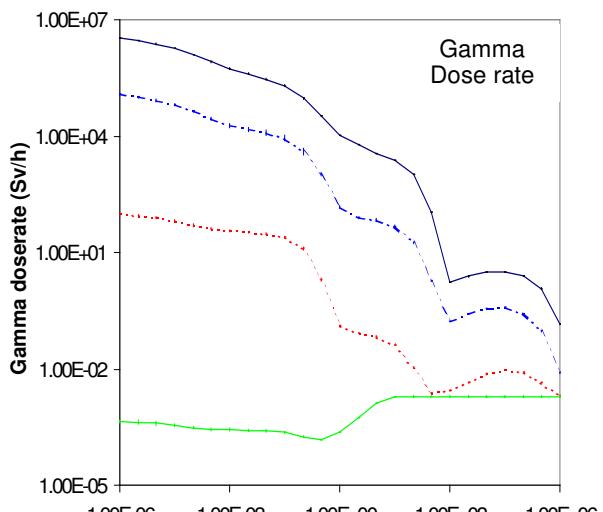
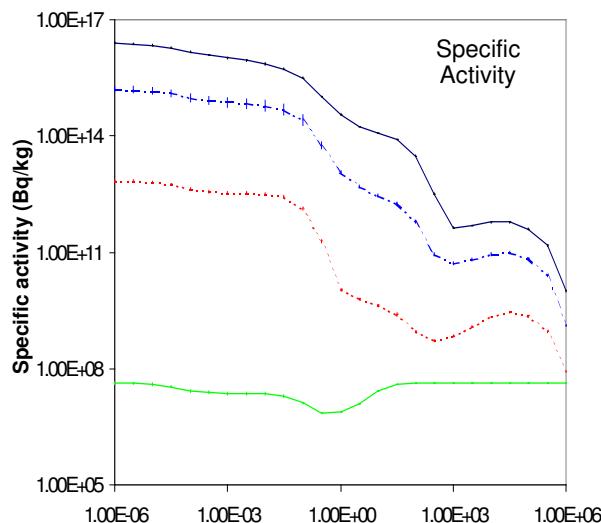


La140	1.679 d	Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n,f)Cs140( $\beta^-$ ) Ba140( $\beta^-$ )La140 Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n,f)Ba140( $\beta^-$ ) La140 Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n,f)Xe139( $\beta^-$ ) Cs139( $\beta^-$ )Ba139( $\beta^-$ )La139(n, $\gamma$ )La140 Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n,f)Cs139( $\beta^-$ ) Ba139( $\beta^-$ )La139(n, $\gamma$ )La140 Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n, $\gamma$ )U234(n, $\gamma$ ) U235(n,f)Cs140( $\beta^-$ )Ba140( $\beta^-$ )La140 Th232(n,2n)Th231( $\beta^-$ )Pa231(n,f)Cs140( $\beta^-$ )Ba140( $\beta^-$ )La140   Th232(n,f)Cs140( $\beta^-$ )Ba140( $\beta^-$ )La140 Th232(n,3n)Th230(n,f)Cs140( $\beta^-$ )Ba140( $\beta^-$ )La140 Th232(n,2n)Th231( $\beta^-$ )Pa231(n,f)Ba140( $\beta^-$ )La140 Th232(n,3n)Th230(n,2n)Th229(n,f)Cs140( $\beta^-$ )Ba140( $\beta^-$ )La140	43.4 20.9 14.5 14.5 2.1   41.5 37.2 7.6 6.9 3.1	67.7 28.0 0.1 0.1 1.9   41.5 37.2 7.6 6.9 3.1	71.2 28.2         41.5 37.2 7.6 6.9 3.1	
Y90	2.671 d	&Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n,f)Rb90( $\beta^-$ ) Sr90( $\beta^-$ )Y90 Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n,f)Kr89( $\beta^-$ ) Rb89( $\beta^-$ )Sr89( $\beta^-$ )Y89(n, $\gamma$ )Y90 Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n,f)Rb90m( $\beta^-$ ) Sr90( $\beta^-$ )Y90 Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n,f)Rb89( $\beta^-$ ) Sr89( $\beta^-$ )Y89(n,g)Y90 Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n,f)Sr90( $\beta^-$ )Y90 &Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n, $\gamma$ )U234(n, $\gamma$ ) U235(n,f)Rb90( $\beta^-$ )Sr90( $\beta^-$ )Y90 &Th232(n,f)Rb90( $\beta^-$ )Sr90( $\beta^-$ )Y90 &Th232(n,2n)Th231( $\beta^-$ )Pa231(n,f)Rb90( $\beta^-$ )Sr90( $\beta^-$ )Y90   Th232(n,f)Rb90m( $\beta^-$ )Sr90( $\beta^-$ )Y90 Th232(n,2n)Th231( $\beta^-$ )Pa231(n,f)Rb90m( $\beta^-$ )Sr90( $\beta^-$ )Y90   &Th232(n,2n)Th231( $\beta^-$ )Pa231(n,f)Sr91( $\beta^-$ )Y91(n,2n)Y90   &Th232(n,f)Sr91( $\beta^-$ )Y91(n,2n)Y90 &Th232(n,f)Sr91( $\beta^-$ )Y91( $\beta^-$ )Zr91(n,d)Y90 &Th232(n,3n)Th230(n,2n)Th229(n,f)Rb90( $\beta^-$ )Sr90( $\beta^-$ )Y90   &Th232(n,3n)Th230(n,f)Rb90( $\beta^-$ )Sr90( $\beta^-$ )Y90	41.3 31.4 14.4 7.4 2.6 1.4   45.5 21.6 9.0 6.9 5.3 4.6 1.2 1.1 1.0	70.6 1.6 21.3 0.3 3.6 1.1                   	73.3 1.4 21.3 0.3 3.5                   	
U230	20.8 d	Th232(n,2n)Th231( $\beta^-$ )Pa231(n,2n)Pa230( $\beta^-$ )U230				99.9
Pa233	27.0 d	Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233	100.0	99.9	99.9	99.1
Nb95	34.975 d	&Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n,f)Sr95( $\beta^-$ ) Y95( $\beta^-$ )Zr95( $\beta^-$ )Nb95 &Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n,f)Y95( $\beta^-$ ) Zr95( $\beta^-$ )Nb95 &Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n,f)Zr95( $\beta^-$ )Nb95   3.9 &Th232(n,2n)Th231( $\beta^-$ )Pa231(n,f)Sr95( $\beta^-$ )Y95( $\beta^-$ ) Zr95( $\beta^-$ )Nb95 &Th232(n,f)Sr95( $\beta^-$ )Y95( $\beta^-$ )Zr95( $\beta^-$ )Nb95 &Th232(n,2n)Th231( $\beta^-$ )Pa231(n,f)Y95( $\beta^-$ )Zr95( $\beta^-$ )Nb95   &Th232(n,f)Y95( $\beta^-$ )Zr95( $\beta^-$ )Nb95 &Th232(n,f)Sr96( $\beta^-$ )Y96( $\beta^-$ )Zr96(n,2n)Zr95( $\beta^-$ )Nb95   &Th232(n,3n)Th230(n,f)Sr95( $\beta^-$ )Y95( $\beta^-$ )Zr95( $\beta^-$ )Nb95   &Th232(n,f)Y96m( $\beta^-$ )Zr96(n,2n)Zr95( $\beta^-$ )Nb95 &Th232(n,2n)Th231( $\beta^-$ )Pa231(n,f)Y96m( $\beta^-$ ) Zr96(n,2n)Zr95( $\beta^-$ )Nb95 &Th232(n,2n)Th231( $\beta^-$ )Pa231(n,f)Sr96( $\beta^-$ )Y96( $\beta^-$ ) Zr96(n,2n)Zr95( $\beta^-$ )Nb95 &Th232(n,3n)Th230(n,2n)Th229(n,f)Sr95( $\beta^-$ ) Y95( $\beta^-$ )Zr95( $\beta^-$ )Nb95 &Th232(n,3n)Th230(n,f)Y95( $\beta^-$ )Zr95( $\beta^-$ )Nb95	57.0 37.6 3.9 36.1 3.3 3.2   26.8 13.3 7.0 3.4 3.2 2.6 2.4 2.2 2.1 1.5	59.8 36.1 3.3 35.8 3.2   	60.7 35.8 3.2 30.3   	
Po210	138.4 d	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ ), ( $\alpha$ ), (n, $\alpha$ ), ( $\beta^+$ ), etc	100.0	100.0	100.0	100.0

Th228	1.913 y	Th232(n, $\alpha$ )Ra229( $\beta^-$ )Ac229( $\beta^-$ )Th229(n, $\gamma$ )Th230 (n, $\gamma$ )Th231( $\beta^-$ )Pa231(n, $\gamma$ )Pa232( $\beta^-$ )U232( $\alpha$ )Th228	98.4	90.7	0.2	
		Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233( $\alpha$ )Th229(n, $\gamma$ )	0.4	6.3	0.3	
		Th230(n, $\gamma$ )Th231( $\beta^-$ )Pa231(n, $\gamma$ )Pa232( $\beta^-$ )U232( $\alpha$ )Th228		1.5	99.4	
		Th232( $\alpha$ )Ra228( $\beta^-$ )Ac228( $\beta^-$ )Th228				86.0
		Th232(n,3n)Th230(n,3n)Th228				7.5
		Th232(n,3n)Th230(n,2n)Th229(n,2n)Th228				4.0
		Th232(n,2n)Th231( $\beta^-$ )Pa231(n,2n)Pa230( $\beta^+$ )Th230(n,3n)Th228				1.8
		Th232(n,2n)Th231( $\beta^-$ )Pa231(n,3n)Pa229( $\beta^+$ )Th229(n,2n)Th228				
Cs134	2.065 y	&Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n,f)Te133( $\beta^-$ )	38.3	38.4	38.0	
		I133( $\beta^-$ )Xe133( $\beta^-$ )Cs133(n, $\gamma$ )Cs134				
		&Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n,f)	37.1	38.8	38.7	
		Te133m( $\beta^-$ )I133( $\beta^-$ )Xe133( $\beta^-$ )Cs133(n, $\gamma$ )Cs134				
		&Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n,f)I133( $\beta^-$ )	23.5	21.9	21.4	
		Xe133( $\beta^-$ )Cs133(n, $\gamma$ )Cs134				
		&Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n,f)Cs134	1.0	0.9	0.9	
		&Th232(n,f)Te135( $\beta^-$ )I135( $\beta^-$ )Xe135( $\beta^-$ )Cs135(n,2n)Cs134		0.1	1.1	37.2
		&Th232(n,f)I135( $\beta^-$ )Xe135( $\beta^-$ )Cs135(n,2n)Cs134				22.4
		&Th232(n,2n)Th231( $\beta^-$ )Pa231(n,f)I135( $\beta^-$ )Xe135( $\beta^-$ )				17.7
		Cs135(n,2n)Cs134				
		&Th232(n,2n)Th231( $\beta^-$ )Pa231(n,f)Te135( $\beta^-$ )I135( $\beta^-$ )				9.8
		Xe135( $\beta^-$ )Cs135(n,2n)Cs134				
		&Th232(n,2n)Th231( $\beta^-$ )Pa231(n,f)Xe135( $\beta^-$ )Cs135(n,2n)Cs134				4.1
		&Th232(n,3n)Th230(n,f)I135( $\beta^-$ )Xe135( $\beta^-$ )Cs135(n,2n)Cs134				2.9
		&Th232(n,3n)Th230(n,f)Te135( $\beta^-$ )I135( $\beta^-$ )				2.9
		Xe135( $\beta^-$ )Cs135(n,2n)Cs134				
Ac227	21.773 y	Th232(n, $\alpha$ )Ra229( $\beta^-$ )Ac229( $\beta^-$ )Th229(n, $\gamma$ )Th230( $\alpha$ )	47.7	8.4	12.1	
		Ra226(n, $\gamma$ )Ra227( $\beta^-$ )Ac227				
		Th232(n, $\alpha$ )Ra229( $\beta^-$ )Ac229( $\beta^-$ )Th229(n, $\gamma$ )	21.4	79.7	13.4	
		Th230(n, $\gamma$ )Th231( $\beta^-$ )Pa231( $\alpha$ )Ac227				
		Th232(n, $\alpha$ )Ra229( $\beta^-$ )Ac229( $\beta^-$ )Th229( $\alpha$ )Ra225(n, $\gamma$ )	17.0	3.0	2.7	
		Ra226(n, $\gamma$ )Ra227( $\beta^-$ )Ac227				
		Th232(n, $\alpha$ )Ra229( $\beta^-$ )Ac229( $\beta^-$ )Th229( $\alpha$ )Ra225( $\beta^-$ )	12.1	0.5	0.7	
		Ac225(n, $\gamma$ )Ac226( $\beta^+$ )Ra226(n, $\gamma$ )Ra227( $\beta^-$ )Ac227				
		Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233( $\alpha$ )Th229(n, $\gamma$ )	0.2	0.5	23.2	
		Th230( $\alpha$ )Ra226(n, $\gamma$ )Ra227( $\beta^-$ )Ac227				
		Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233( $\alpha$ )Th229(n, $\gamma$ )	0.1	5.6	26.0	
		Th230(n, $\gamma$ )Th231( $\beta^-$ )Pa231( $\alpha$ )Ac227				
		Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233( $\alpha$ )Th229( $\alpha$ )	0.1	0.2	6.4	
		Ra225(n, $\gamma$ )Ra226(n, $\gamma$ )Ra227( $\beta^-$ )Ac227				
		Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n, $\gamma$ )U234( $\alpha$ )		0.6	4.6	
		Th230(n, $\gamma$ )Th231( $\beta^-$ )Pa231( $\alpha$ )Ac227				
		Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n, $\gamma$ )U234( $\alpha$ )		0.1	4.1	
		Th230( $\alpha$ )Ra226(n, $\gamma$ )Ra227( $\beta^-$ )Ac227				
		Th232(n,3n)Th230(n, $\alpha$ )Ra227( $\beta^-$ )Ac227				81.8
		Th232(n,2n)Th231( $\beta^-$ )Pa231( $\alpha$ )Ac227				14.7
		Th232(n,2n)Th231( $\beta^-$ )Pa231(n,2n)Pa230( $\beta^+$ )				3.4
		Th230(n, $\alpha$ )Ra227( $\beta^-$ )Ac227				

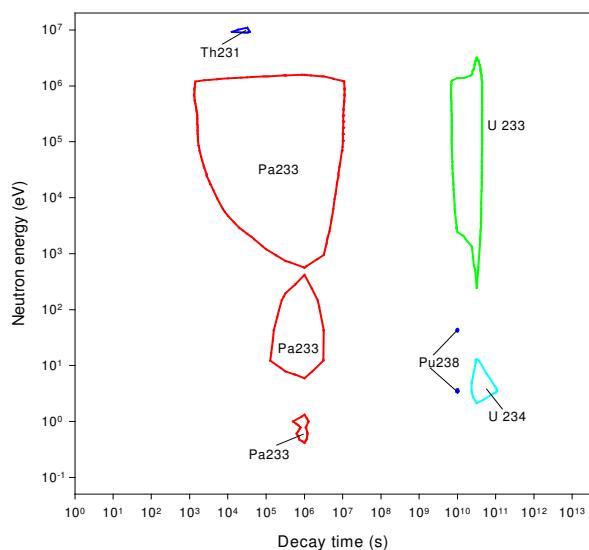
Sr90	28.868 y	<b>&amp;Th232(n,<math>\gamma</math>)Th233(<math>\beta^-</math>)Pa233(<math>\beta^-</math>)U233(n,f)Rb90(<math>\beta^-</math>)Sr90</b> Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n,f)Rb90m( $\beta^-$ )Sr90 <b>&amp;Th232(n,<math>\gamma</math>)Th233(<math>\beta^-</math>)Pa233(<math>\beta^-</math>)U233(n,<math>\gamma</math>)U234(n,<math>\gamma</math>)U235(n,f)Rb90(<math>\beta^-</math>)Sr90</b> Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n,f)Sr90 <b>&amp;Th232(n,<math>\gamma</math>)Th233(<math>\beta^-</math>)Pa233(n,<math>\gamma</math>)Pa234m(<math>\beta^-</math>)U234(n,<math>\gamma</math>)U235(n,f)Rb90(<math>\beta^-</math>)Sr90</b> <b>&amp;Th232(n,<math>\gamma</math>)Th233(<math>\beta^-</math>)Pa233(n,<math>\gamma</math>)Pa234(<math>\beta^-</math>)U234(n,<math>\gamma</math>)U235(n,f)Rb90(<math>\beta^-</math>)Sr90</b> <b>&amp;Th232(n,f)Rb90(<math>\beta^-</math>)Sr90</b> <b>&amp;Th232(n,2n)Th231(<math>\beta^-</math>)Pa231(n,f)Rb90(<math>\beta^-</math>)Sr90</b> Th232(n,f)Rb90m( $\beta^-$ )Sr90 Th232(n,2n)Th231( $\beta^-$ )Pa231(n,f)Rb90m( $\beta^-$ )Sr90 <b>&amp;Th232(n,3n)Th230(n,2n)Th229(n,f)Rb90(<math>\beta^-</math>)Sr90</b> <b>&amp;Th232(n,3n)Th230(n,f)Rb90(<math>\beta^-</math>)Sr90</b>	65.3 22.8 4.4 4.1 1.2 1.1 1.0	70.4 21.2 2.2 3.6 1.1 1.0	74.7 21.7 3.6	
Pu238	87.7 y	<b>&amp;Th232(n,<math>\gamma</math>)Th233(<math>\beta^-</math>)Pa233(<math>\beta^-</math>)U233(n,<math>\gamma</math>)U234(n,<math>\gamma</math>)U235(n,<math>\gamma</math>)U236(n,<math>\gamma</math>)U237(<math>\beta^-</math>)Np237(n,<math>\gamma</math>)Np238(<math>\beta^-</math>)Pu238</b> <b>&amp;Th232(n,<math>\gamma</math>)Th233(<math>\beta^-</math>)Pa233(n,<math>\gamma</math>)Pa234m(<math>\beta^-</math>)U234(n,<math>\gamma</math>)U235(n,<math>\gamma</math>)U236(n,<math>\gamma</math>)U237(<math>\beta^-</math>)Np237(n,<math>\gamma</math>)Np238(<math>\beta^-</math>)Pu238</b> <b>&amp;Th232(n,<math>\gamma</math>)Th233(<math>\beta^-</math>)Pa233(n,<math>\gamma</math>)Pa234(<math>\beta^-</math>)U234(n,<math>\gamma</math>)U235(n,<math>\gamma</math>)U236(n,<math>\gamma</math>)U237(<math>\beta^-</math>)Np237(n,<math>\gamma</math>)Np238(<math>\beta^-</math>)Pu238</b>	65.8 17.5 16.7	47.7 26.8 25.5	69.4 15.7 15.0	88.9 2.2 9.3
Th229	7340 y	Th232(n, $\alpha$ )Ra229( $\beta^-$ )Ac229( $\beta^-$ )Th229 Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233( $\alpha$ )Th229 Th232(n,3n)Th230(n,2n)Th229 Th232(n,2n)Th231( $\beta^-$ )Pa231(n,3n)Pa229( $\beta^+$ )Th229 Th232(n,2n)Th231( $\beta^-$ )Pa231(n,2n)Pa230( $\beta^+$ )Th230(n,2n)Th229	99.4 0.4	89.7 10.2	16.9 83.1	0.3 78.1 18.2 3.2
Th230	$7.5 \cdot 10^4$ y	Th232(n, $\alpha$ )Ra229( $\beta^-$ )Ac229( $\beta^-$ )Th229(n, $\gamma$ )Th230 Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233( $\alpha$ )Th229(n, $\gamma$ )Th230 Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n, $\alpha$ )Th230 Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n, $\gamma$ )U234( $\alpha$ )Th230 Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233(n, $\gamma$ )Pa234m( $\beta^-$ )U234( $\alpha$ )Th230 Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233(n, $\gamma$ )Pa234( $\beta^-$ )U234( $\alpha$ )Th230 Th232(n,3n)Th230 Th232(n,2n)Th231( $\beta^-$ )Pa231(n,2n)Pa230( $\beta^+$ )Th230	98.9 0.4 0.3 0.2 0.1 0.1	89.2 8.5 0.2 1.1 0.4 0.4	19.9 64.6 1.3 11.5 1.4 1.3	94.1 5.9
U233	$1.6 \cdot 10^5$ y	Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233	100.0	100.0	100.0	99.9
U234	$2.5 \cdot 10^5$ y	Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233( $\beta^-$ )U233(n, $\gamma$ )U234 Th232(n, $\gamma$ )Th233( $\beta^-$ )Pa233(n, $\gamma$ )Pa234m( $\beta^-$ )U234 <b>&amp;Th232(n,<math>\gamma</math>)Th233(<math>\beta^-</math>)Pa233(n,<math>\gamma</math>)Pa234(<math>\beta^-</math>)U234</b>	66.7 17.1 16.3	60.3 20.3 19.4	86.2 7.2 6.9	95.8 0.8 3.4

# Thorium activation characteristics

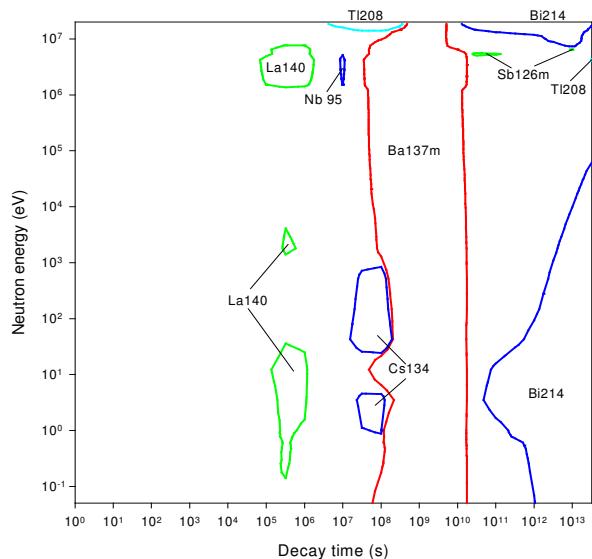


# Thorium importance diagrams & transmutation

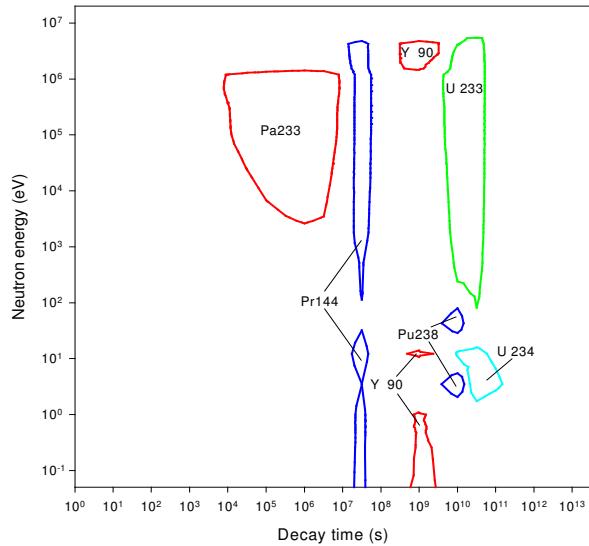
## Activity



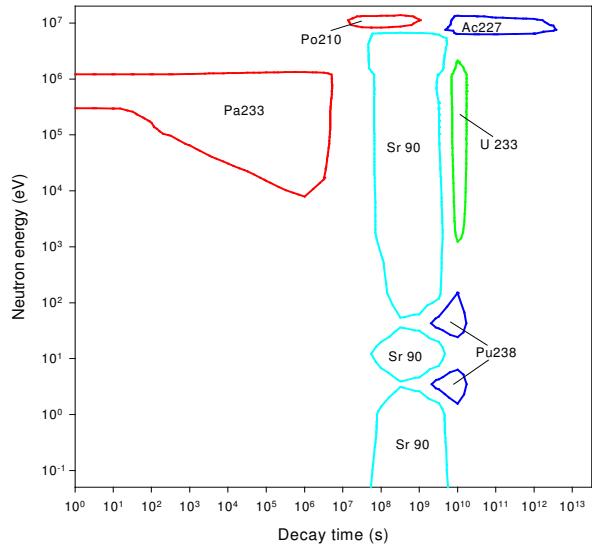
## Dose rate



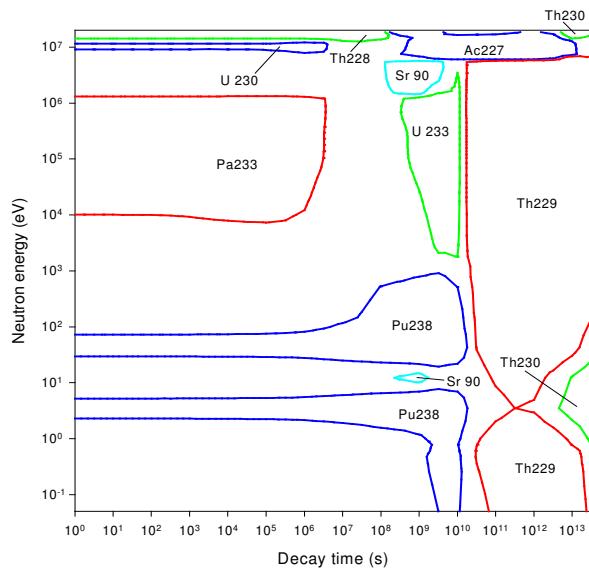
## Heat output



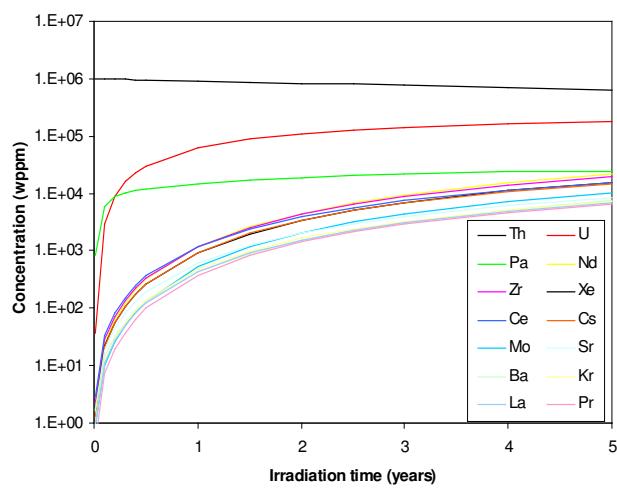
## Ingestion dose



## Inhalation dose



## First wall transmutation





# Uranium

## General properties

Atomic number	92	Isotopes	Isotopic abundances / %
Crustal abundance / wppm	2.7	U234	0.0054 ( $T_{1/2} = 2.457 \cdot 10^5$ y)
Melting point / K	1408	U235	0.7204 ( $T_{1/2} = 7.038 \cdot 10^8$ y)
Boiling point / K	4404	U238	99.2742 ( $T_{1/2} = 4.468 \cdot 10^9$ y)
Density / kgm <sup>-3</sup>	18950		
Thermal conductivity / Wm <sup>-1</sup> K <sup>-1</sup>	27.6		
Electrical resistivity /Ωm	2.8 $\cdot 10^{-9}$		
Coefficient of thermal expansion / K <sup>-1</sup>	1.39 $\cdot 10^{-5}$		
Crystal structure	orthorhombic		
Number of stable isotopes	(3)		
Mean atomic weight	238.02891		

## Activation properties

Act	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y	Heat	0	10 <sup>-5</sup> y	10 <sup>-2</sup> y	1 y	100 y	10 <sup>5</sup> y
Bq kg <sup>-1</sup>	3.62E16	2.72E16	6.62E15	5.79E14	1.54E13	8.10E10	kW kg <sup>-1</sup>	7.68E0	4.36E0	7.09E-1	6.63E-2	7.17E-3	3.65E-5
U239	14.69	16.73					U239	5.13	7.72				
Np239	14.58	19.39	27.43		0.04		Np239	4.90	8.63	18.26			
I134	0.98	1.28					I134	2.38	4.15				
Xe135	0.95	1.27					Cs138	2.22	3.83				
Xe133	0.94	1.25	3.77				Tc104	2.21	3.36				
I133	0.91	1.21					Nb100	1.94					
Tc101	0.89	1.15					Cs140	1.84					
I135	0.88	1.17					La140	1.65	2.91	15.91			
Mo99	0.88	1.17	1.91				La142	1.59	2.77				
Rh103m	0.87	1.16	4.39				I136	1.53					
Ru103	0.86	1.15	4.42				Zr99	1.50					
Cs138	0.81	1.06					La144	1.48					
Ba139		1.04					I132	1.42	2.50	7.16			
Tc99m		1.04	1.86				Mo101	1.34	1.84				
La140		1.02	3.74				Y94	1.32	2.04				
Ce141		0.99	3.80				I135	1.31	2.28				
Ba140		0.99	3.34				Tc102		1.62				
Nb95			3.60	1.77			Y95		1.55				
Zr95			3.60	0.82			Ba141		1.47				
Pr143			3.10				Pr144			4.83	21.44		
Pr144			2.62	12.41			Rh106			4.75	25.69		
Ce144			2.62	12.41			Zr95			4.57	0.97		
Y91			2.47	0.39			Nb95			4.36	2.00		
U237			2.32				Cm242			3.77	8.67	0.13	
I131			1.98				Ru103			3.73			
Pu241			1.97	21.51	6.88		Cs136			2.98			
Rh106			1.96	11.34			Ba140			2.48			
Ru106			1.96	11.34			Cs134			2.32	17.80		
Cs134				7.41			Y91			2.24	0.34		
Pm147				3.77			I131			1.70			
Cs137				3.54	13.68		Mo99			1.54			
Ba137m				3.35	12.94		Pu238				7.21	30.71	
Y90				1.81	6.29		Ba137m				3.10	2.95	
Sr90				1.81	6.29		Y90				2.36	2.02	
Cm242				1.00	0.06		Ce144				1.93		
Pu238				0.92	15.95		Cm244				1.08	0.23	
Am241					26.12		Pu239				0.67	6.14	68.61
Pu239					3.40	36.83	Am241				0.65	50.73	
U235m					3.40	36.83	Pu240				0.55	5.04	
Pu240					2.79		Po214					3.56	
Sm151					1.37		U234					3.19	
Tc99						2.31	Po218					2.78	
U234						1.85	Rn222					2.55	
Pa233						1.40	Np237					2.47	
Np237						1.40	Po210					2.46	
Po218						1.28	Ra226					2.22	
Rn222						1.28	Th230					2.12	

Dose	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>	Ing	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>
Sv h <sup>-1</sup>	4.22E6	2.57E6	3.29E5	1.65E4	1.70E2	4.23E-1	Sv kg <sup>-1</sup>	2.50E7	2.48E7	1.51E7	4.64E6	1.68E6	1.22E4
Ba142	10.45	12.18					Np239	16.90	17.06	9.61			
I134	4.15	6.76					I131	15.47	15.61	19.06			
Cs138	3.85	6.22					I133	5.67	5.72				
La140	3.48	5.72	39.72				Pu238	4.83	4.88	8.01	26.44	33.64	
La142	3.27	5.35					Cs134	4.56	4.60	7.52	17.56		
Cs140	2.95						Te132	3.73	3.76	2.82			
I135	2.91	4.74					Ru106	3.66	3.69	6.01	9.90		
Tc104	2.89	4.10					Ce144	3.64	3.67	5.96	8.05		
I136	2.43						Ba140	2.80	2.83	3.80			
Mo101	2.27	2.91					Pu241	2.51	2.53	4.15	12.89	0.30	
I132	2.12	3.48	12.66				La140	2.23	2.25	3.27			
Tc106	2.03						Zr97	2.21	2.23				
La144	2.02						Xe133	1.77	1.78	2.15			
Sr93	1.94	1.94					Y91	1.62	1.64	2.59	0.12		
Y95	1.86	2.22					Cm242	1.30	1.31	2.13	1.49	0.01	
Xe138	1.65	2.09					Sr89	1.20	1.21	1.89			
Sr92		2.30					Sr90	1.20	1.21	1.98	6.31	1.62	
Rb89		2.16					I135	1.19	1.19				
Nb95			7.74	6.68			Cs137	1.09	1.10	1.81	5.75	1.63	
Zr95			7.39	2.96			Pr143	1.08	1.09	1.63			
Cs136			7.17				Zr95			1.50			
Cs134			4.00	57.56			Ru103			1.41			
Ru103			3.98	0.14			Ce141			1.18			
Np238			2.39				Pu239				2.83	7.79	60.97
Pm148m			2.31	0.10			Pu240				2.33	6.39	0.02
Rh106			1.07	10.86			Am241				2.06	47.92	
Ba137m			0.50	9.87	98.14		Cm244				1.96	0.12	
Pr144			0.36	3.01			Rn222						12.73
Eu154			0.27	5.01	0.17		Po210						10.16
Sb126m					0.02	4.63	Pb210						5.85
Pa233						2.18	Ra226						2.38
Bi214						87.16	Th230						1.75
Pb214						2.44	Th229						1.49
Inh	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>	Clear	<b>0</b>	<b>10<sup>-5</sup> y</b>	<b>10<sup>-2</sup> y</b>	<b>1 y</b>	<b>100 y</b>	<b>10<sup>5</sup> y</b>
Sv kg <sup>-1</sup>	1.29E9	1.29E9	1.28E9	1.14E9	7.78E8	3.96E6		2.48E13	1.51E13	2.77E12	3.18E11	2.54E10	1.22E8
Pu238	44.93	44.93	45.37	51.57	34.77		Np239	4.44	7.28	13.63		0.01	
Pu241	23.37	23.37	23.54	25.18	0.31		I134	3.85	6.25				
Cm242	12.43	12.43	12.40	2.99	0.01		Cs138	2.95	4.75				
Pu239	4.89	4.89	4.94	5.54	8.08	90.41	La140	2.67	4.38	21.20			
Pu240	4.03	4.03	4.06	4.56	6.63	0.03	Tc104	2.58	3.65				
Cm244	3.49	3.49	3.52	3.80	0.13		I132	2.33	3.82	9.67			
Am241	2.04	2.04	2.07	4.02	49.71		La142	2.32	3.77				
Pu236	0.89	0.89	0.90	0.79			I135	2.12	3.44				
Ce144	0.72	0.72	0.72	0.34			Mo101	1.97	2.51				
Ru106	0.67	0.67	0.67	0.38			U239	1.95	2.74				
Np239	0.41	0.41	0.14				Sr93	1.57	1.56				
Cm243	0.18	0.18	0.18	0.20	0.03		Xe138	1.30	1.65				
Sr90	0.13	0.13	0.13	0.15	0.02					7.18	44.89		
Am242m	0.13	0.13	0.13	0.15	0.13		Cs134				6.60	2.48	
Ba140	0.12	0.12	0.10				Nb95				6.60	1.15	
Y91	0.12	0.12	0.11				Zr95				5.27		
Pu242				0.01	1.53	Cs136				4.52			
Np237					1.43	Cs137				2.52	21.47	27.65	
U234					0.36	Pm148m				2.14			
Th230					2.57	Rh106				1.67	7.36		
Th229					2.25	Ru106				1.56	6.87		
Ra226					0.25	Pr144				0.96	3.47		
Fr221					0.22	Ba137m				3.58	4.62		
Rn222					0.19	Sr90				1.09	1.27		
Ac227					0.18	Pu239				0.55	6.87	81.68	
Pb210					0.15	Am241				0.50	52.81		
						Pu240				0.45	5.63	0.03	
						U234					0.01	4.10	
						Np237					0.01	3.10	
						Ra226						2.84	
						Pb210						2.84	
						Th230						2.78	

# Uranium

## Pathway analysis

Nuclide	$T_{1/2}$	Pathway	0.26 eV	148 eV	37.6 keV	14.7 MeV
Ba137m	2.553 m	U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n,f)Xe137( $\beta^-$ ) Cs137( $\beta^-$ )Ba137m U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n, $\gamma$ )Pu240(n, $\gamma$ ) Pu241(n,f)Xe137( $\beta^-$ )Cs137( $\beta^-$ )Ba137m U235(n,f)Xe137( $\beta^-$ )Cs137( $\beta^-$ )Ba137m U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n,f)Cs137( $\beta^-$ ) Ba137m U238(n,f)Xe138( $\beta^-$ )Cs138( $\beta^-$ )Ba138(n,2n)Ba137m U238(n,f)Xe137( $\beta^-$ )Cs137( $\beta^-$ )Ba137m U238(n,2n)U237( $\beta^-$ )Np237(n,f)Xe138( $\beta^-$ )Cs138( $\beta^-$ ) Ba138(n,2n)Ba137m U238(n,2n)U237( $\beta^-$ )Np237(n,f)Xe137( $\beta^-$ )Cs137( $\beta^-$ )Ba137m U238(n,3n)U236(n,f)Xe138( $\beta^-$ )Cs138( $\beta^-$ )Ba138(n,2n)Ba137m U238(n,3n)U236(n,f)Xe137( $\beta^-$ )Cs137( $\beta^-$ )Ba137m <b>&amp;U238(n,f)Cs138(<math>\beta^-</math>)Ba138(n,2n)Ba137m</b>	54.4 33.3 5.8 4.2	59.3 31.3 3.0 4.3	73.2 20.4 5.1	42.5 38.1 4.7 3.9 3.5 2.5 1.0
Tl208	3.055 m	Very long pathways of (n, $\gamma$ ), ( $\beta^-$ ), ( $\alpha$ ), (n, $\alpha$ ), ( $\beta^+$ ), etc U234(n,3n)U232( $\alpha$ )Th228( $\alpha$ )Ra224( $\alpha$ )Rn220( $\alpha$ ) Po216( $\alpha$ )Pb212( $\beta^-$ )Bi212( $\alpha$ )Tl208	100.0	100.0	100.0	99.4 0.6
Sb126m	19.1 m	<b>&amp;U238(n,<math>\gamma</math>)U239(<math>\beta^-</math>)Np239(<math>\beta^-</math>)Pu239(n,f)Sn125(<math>\beta^-</math>)</b> Sb125(n, $\gamma$ ) <b>Sb126m</b> <b>&amp;U238(n,<math>\gamma</math>)U239(<math>\beta^-</math>)Np239(<math>\beta^-</math>)Pu239(n,f)In125(<math>\beta^-</math>)</b> Sn125( $\beta^-$ )Sb125(n, $\gamma$ ) <b>Sb126m</b> <b>&amp;U238(n,<math>\gamma</math>)U239(<math>\beta^-</math>)Np239(<math>\beta^-</math>)Pu239(n,<math>\gamma</math>)Pu240(n,<math>\gamma</math>)</b> Pu241(n,f)Sn125( $\beta^-$ )Sb125(n, $\gamma$ ) <b>Sb126m</b> <b>&amp;U238(n,<math>\gamma</math>)U239(<math>\beta^-</math>)Np239(<math>\beta^-</math>)Pu239(n,f)</b> Sn125m( $\beta^-$ )Sb125(n, $\gamma$ ) <b>Sb126m</b> <b>&amp;U238(n,<math>\gamma</math>)U239(<math>\beta^-</math>)Np239(<math>\beta^-</math>)Pu239(n,<math>\gamma</math>)Pu240(n,<math>\gamma</math>)</b> Pu241(n,f)Sn125m( $\beta^-$ )Sb125(n, $\gamma$ ) <b>Sb126m</b> <b>&amp;U238(n,<math>\gamma</math>)U239(<math>\beta^-</math>)Np239(<math>\beta^-</math>)Pu239(n,f)</b> In125m( $\beta^-$ )Sn125m( $\beta^-$ )Sb125(n, $\gamma$ ) <b>Sb126m</b> <b>&amp;U238(n,<math>\gamma</math>)U239(<math>\beta^-</math>)Np239(<math>\beta^-</math>)Pu239(n,f)In125(<math>\beta^-</math>)</b> Sn125m( $\beta^-$ )Sb125(n, $\gamma$ ) <b>Sb126m</b> <b>&amp;U235(n,f)In125(<math>\beta^-</math>)Sn125(<math>\beta^-</math>)Sb125(n,<math>\gamma</math>)Sb126m</b> <b>&amp;U235(n,f)Sn125(<math>\beta^-</math>)Sb125(n,<math>\gamma</math>)Sb126m</b> <b>&amp;U238(n,f)Sn127(<math>\beta^-</math>)Sb127(n,2n)Sb126m</b> <b>&amp;U238(n,f)Sn127(<math>\beta^-</math>)Sb127(<math>\beta^-</math>)Te127(<math>\beta^-</math>)I127(n,2n)</b> I126( $\beta^+$ )Te126(n,p) <b>Sb126m</b> <b>&amp;U238(n,f)Sn127m(<math>\beta^-</math>)Sb127(n,2n)Sb126m</b> <b>&amp;U238(n,f)Sn125(<math>\beta^-</math>)Sb125(n,<math>\gamma</math>)Sb126m</b> <b>&amp;U238(n,2n)U237(<math>\beta^-</math>)Np237(n,f)Sn127(<math>\beta^-</math>)Sb127(n,2n)Sb126m</b> <b>&amp;U238(n,f)In125m(<math>\beta^-</math>)Sn125m(<math>\beta^-</math>)Sb125(n,<math>\gamma</math>)Sb126m</b> <b>&amp;U238(n,f)In125(<math>\beta^-</math>)Sn125m(<math>\beta^-</math>)Sb125(n,<math>\gamma</math>)Sb126m</b> <b>&amp;U238(n,f)Sn126(n,2n)Sn125(<math>\beta^-</math>)Sb125(n,<math>\gamma</math>)Sb126m</b> <b>&amp;U238(n,3n)U236(n,f)Sn127(<math>\beta^-</math>)Sb127(n,2n)Sb126m</b>	30.1 22.6 17.3 12.4 7.2 6.0 3.1 0.3 0.3	30.2 22.8 17.4 12.5 7.2 6.0 3.1 0.1 0.1	40.0 30.1 15.1 7.5 3.9 3.0 1.1 1.0	35.7 5.3 4.8 4.3 1.6 1.2 1.1 1.1 1.0
		*Plus other similar pathways				32.3*

Bi214	19.9 m	U234( $\alpha$ )Th230( $\alpha$ )Ra226( $\alpha$ )Rn222( $\alpha$ )Po218( $\alpha$ ) Pb214( $\beta^-$ )Bi214 *Plus other long decay pathways of ( $\alpha$ ) and ( $\beta^-$ ) U238(n,2n)U237( $\beta^-$ )Np237(n,2n)Np236m( $\beta^-$ )Pu236( $\alpha$ ) U232(n,2n)U231( $\beta^+$ )Pa231(n,2n)Pa230( $\beta^+$ )Th230( $\alpha$ ) Ra226( $\alpha$ )Rn222( $\alpha$ )Po218( $\alpha$ )Pb214( $\beta^-$ )Bi214 U238(n,2n)U237( $\beta^-$ )Np237(n,2n)Np236m( $\beta^-$ )Pu236( $\alpha$ ) U232(n,2n)U231( $\beta^+$ )Pa231(n,3n)Pa229( $\beta^+$ )Th229(n, $\alpha$ ) Ra226( $\alpha$ )Rn222( $\alpha$ )Po218( $\alpha$ )Pb214( $\beta^-$ )Bi214 U238(n,2n)U237( $\beta^-$ )Np237(n,2n)Np236m( $\beta^-$ )Pu236( $\alpha$ ) U232(n,2n)U231( $\beta^+$ )Pa231(n,2n)Pa230( $\alpha$ )Ac226( $\beta^+$ ) Ra226( $\alpha$ )Rn222( $\alpha$ )Po218( $\alpha$ )Pb214( $\beta^-$ )Bi214 U235(n, $\alpha$ )Th232(n,3n)Th230( $\alpha$ )Ra226( $\alpha$ )Rn222( $\alpha$ ) Po218( $\alpha$ )Pb214( $\beta^-$ )Bi214 U238(n,3n)U236(n,3n)U234(n,3n)U232(n,2n) U231( $\beta^+$ )Pa231(n,2n)Pa230( $\beta^+$ )Th230( $\alpha$ )Ra226( $\alpha$ ) Rn222( $\alpha$ )Po218( $\alpha$ )Pb214( $\beta^-$ )Bi214 U238(n,3n)U236(n,3n)U234(n,3n)U232(n,2n) U231( $\beta^+$ )Pa231(n,3n)Pa229( $\beta^+$ )Th229(n, $\alpha$ )Ra226( $\alpha$ ) Rn222( $\alpha$ )Po218( $\alpha$ )Pb214( $\beta^-$ )Bi214 U238(n,3n)U236(n,3n)U234(n,3n)U232(n,2n) U231( $\beta^+$ )Pa231(n,2n)Pa230( $\alpha$ )Ac226( $\beta^+$ )Ra226( $\alpha$ ) Rn222( $\alpha$ )Po218( $\alpha$ )Pb214( $\beta^-$ )Bi214 U238(n,2n)U237( $\beta^-$ )Np237(n,2n)Np236m( $\beta^-$ ) Pu236( $\alpha$ )U232(n, $\alpha$ )Th229(n, $\alpha$ )Ra226( $\alpha$ )Rn222( $\alpha$ ) Po218( $\alpha$ )Pb214( $\beta^-$ )Bi214 †Plus other similar pathways	100.0	94.1	62.3	0.1
La140	1.679 d	U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n,f)Cs140( $\beta^-$ ) Ba140( $\beta^-$ )La140 U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n, $\gamma$ )Pu240(n, $\gamma$ ) Pu241(n,f)Cs140( $\beta^-$ )Ba140( $\beta^-$ )La140 U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n,f)Xe139( $\beta^-$ ) Cs139( $\beta^-$ )Ba139( $\beta^-$ )La139(n, $\gamma$ )La140 U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n,f)Cs139( $\beta^-$ ) Ba139( $\beta^-$ )La139(n, $\gamma$ )La140 U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n,f)Ba140( $\beta^-$ )La140 U235(n,f)Xe139( $\beta^-$ )Cs139( $\beta^-$ )Ba139( $\beta^-$ )La139(n, $\gamma$ ) La140 U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n, $\gamma$ )Pu240(n, $\gamma$ ) Pu241(n,f)Ba140( $\beta^-$ )La140 U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n,f)Ba139( $\beta^-$ ) La139(n, $\gamma$ )La140 U235(n,f)Cs139( $\beta^-$ )Ba139( $\beta^-$ )La139(n, $\gamma$ )La140 U235(n,f)Cs140( $\beta^-$ )Ba140( $\beta^-$ )La140 U238(n,f)Cs140( $\beta^-$ )Ba140( $\beta^-$ )La140 U238(n,2n)U237( $\beta^-$ )Np237(n,f)Cs140( $\beta^-$ )Ba140( $\beta^-$ )La140 U238(n,3n)U236(n,f)Cs140( $\beta^-$ )Ba140( $\beta^-$ )La140 U238(n,2n)U237( $\beta^-$ )Np237(n,f)Ba140( $\beta^-$ )La140	36.2	40.2	71.9	
Np239	2.355 d	U238(n, $\gamma$ )U239( $\beta^-$ )Np239	100.0	99.9	100.0	99.9

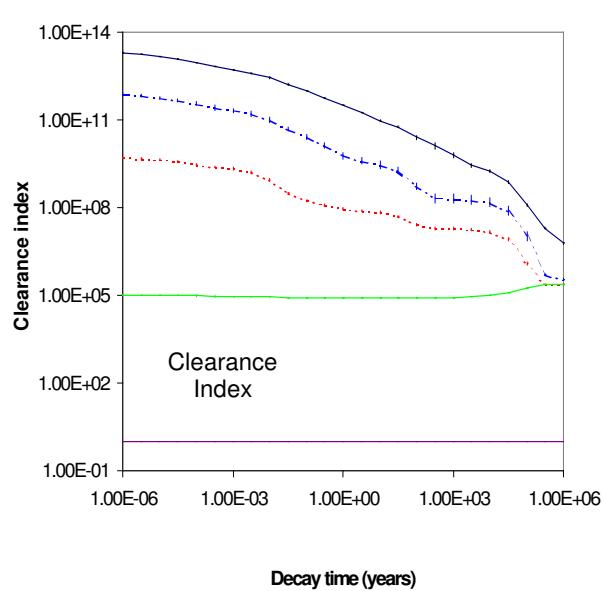
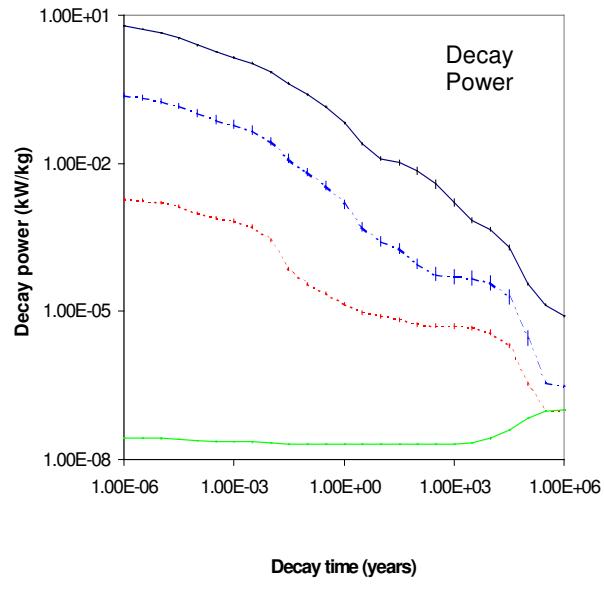
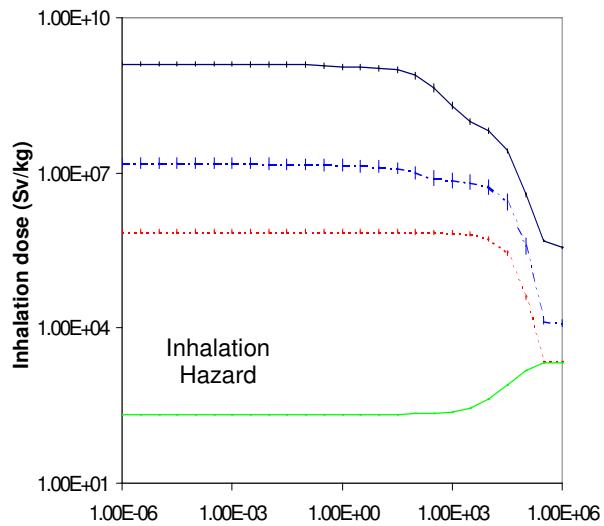
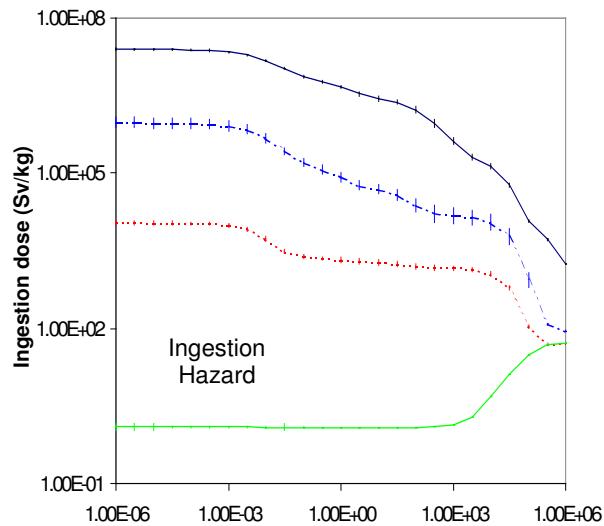
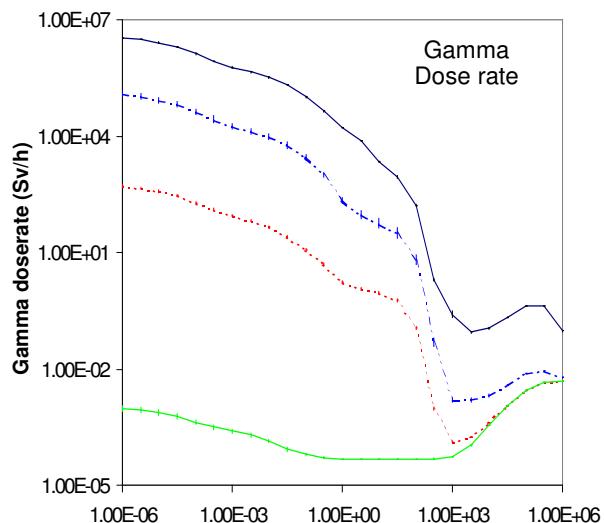
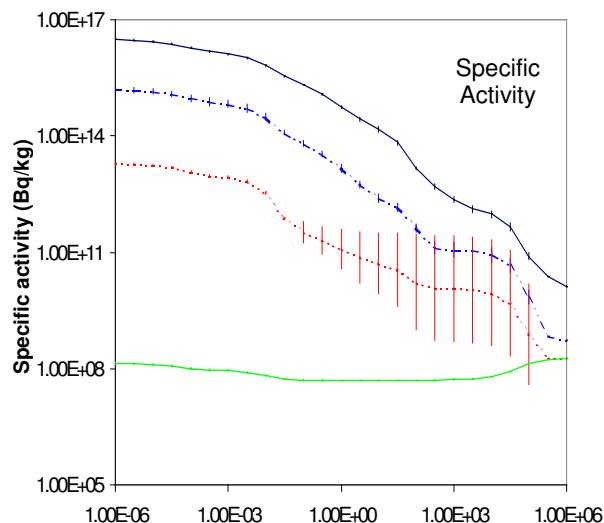
Cs134	2.065 y	<b>&amp;U238(n,<math>\gamma</math>)U239(<math>\beta^-</math>)Np239(<math>\beta^-</math>)Pu239(n,f)</b> Te133m( $\beta^-$ )I133( $\beta^-$ )Xe133( $\beta^-$ )Cs133(n, $\gamma$ ) <i>Cs134</i> <b>&amp;U238(n,<math>\gamma</math>)U239(<math>\beta^-</math>)Np239(<math>\beta^-</math>)Pu239(n,f)Te133(<math>\beta^-</math>)</b> I133( $\beta^-$ )Xe133( $\beta^-$ )Cs133(n, $\gamma$ ) <i>Cs134</i> <b>&amp;U238(n,<math>\gamma</math>)U239(<math>\beta^-</math>)Np239(<math>\beta^-</math>)Pu239(n,f)II133(<math>\beta^-</math>)</b> Xe133( $\beta^-$ )Cs133(n, $\gamma$ ) <i>Cs134</i> <b>&amp;U235(n,f)Te133(<math>\beta^-</math>)I133(<math>\beta^-</math>)Xe133(<math>\beta^-</math>)Cs133(n,<math>\gamma</math>)</b> <i>Cs134</i> <b>&amp;U235(n,f)Te133(<math>\beta^-</math>)I133(<math>\beta^-</math>)Xe133(<math>\beta^-</math>)Cs133(n,<math>\gamma</math>)</b> <i>Cs134</i> <b>&amp;U235(n,f)II133(<math>\beta^-</math>)Xe133(<math>\beta^-</math>)Cs133(n,<math>\gamma</math>)</b> <i>Cs134</i> <b>&amp;U238(n,f)Te135(<math>\beta^-</math>)I135(<math>\beta^-</math>)Xe135(<math>\beta^-</math>)Cs135(n,2n)</b> <i>Cs134</i> <b>&amp;U238(n,f)I135(<math>\beta^-</math>)Xe135(<math>\beta^-</math>)Cs135(n,2n)</b> <i>Cs134</i> <b>&amp;U238(n,2n)U237(<math>\beta^-</math>)Np237(n,f)I135(<math>\beta^-</math>)Xe135(<math>\beta^-</math>)</b> Cs135(n,2n) <i>Cs134</i> <b>&amp;U238(n,3n)U236(n,f)Te135(<math>\beta^-</math>)I135(<math>\beta^-</math>)Xe135(<math>\beta^-</math>)</b> Cs135(n,2n) <i>Cs134</i> <b>&amp;U238(n,2n)U237(<math>\beta^-</math>)Np237(n,f)Te135(<math>\beta^-</math>)I135(<math>\beta^-</math>)</b> Xe135( $\beta^-$ )Cs135(n,2n) <i>Cs134</i> <b>&amp;U238(n,3n)U236(n,f)I135(<math>\beta^-</math>)Xe135(<math>\beta^-</math>)Cs135(n,2n)</b> <i>Cs134</i>	39.3 38.3 15.9 3.6 2.2 0.3 	39.8 38.6 15.6 3.3 2.0 0.2 	30.5 29.5 11.8 16.8 9.7 1.2 		63.1 21.8 5.0 3.0 2.5 1.5
Pu236	2.9 y	U238(n,2n)U237( $\beta^-$ )Np237(n,2n)Np236m( $\beta^-$ )Pu236					99.9
Pu241	14.4 y	U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n, $\gamma$ )Pu240(n, $\gamma$ ) Pu241 U238(n, $\gamma$ )U239( $\beta^-$ )Np239(n, $\gamma$ )Np240m( $\beta^-$ )Pu240(n, $\gamma$ ) Pu241 <b>&amp;U238(n,<math>\gamma</math>)U239(<math>\beta^-</math>)Np239(n,<math>\gamma</math>)Np240(<math>\beta^-</math>)Pu240(n,<math>\gamma</math>)</b> Pu241	97.0 1.2 0.6	97.7 1.3 0.8	97.6 1.6 0.8	99.8 0.2	
Cm244	18.1 y	U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n, $\gamma$ )Pu240(n, $\gamma$ ) Pu241(n, $\gamma$ )Pu242(n, $\gamma$ )Pu243( $\beta^-$ )Am243(n, $\gamma$ ) Am244m( $\beta^-$ )Cm244 U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n, $\gamma$ )Pu240(n, $\gamma$ ) Pu241(n, $\gamma$ )Pu242(n, $\gamma$ )Pu243( $\beta^-$ )Am243(n, $\gamma$ ) Am244( $\beta^-$ )Cm244 U238(n, $\gamma$ )U239( $\beta^-$ )Np239(n, $\gamma$ )Np240m( $\beta^-$ )Pu240(n, $\gamma$ ) Pu241(n, $\gamma$ )Pu242(n, $\gamma$ )Pu243( $\beta^-$ )Am243(n, $\gamma$ ) Am244m( $\beta^-$ )Cm244 <b>&amp;U238(n,<math>\gamma</math>)U239(<math>\beta^-</math>)Np239(n,<math>\gamma</math>)Np240(<math>\beta^-</math>)Pu240(n,<math>\gamma</math>)</b> Pu241(n, $\gamma$ )Pu242(n, $\gamma$ )Pu243( $\beta^-$ )Am243(n, $\gamma$ ) Am244m( $\beta^-$ )Cm244 U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n, $\gamma$ )Pu240(n, $\gamma$ )Pu241( $\beta^-$ ) Am241(n, $\gamma$ )Am242( $\beta^-$ )Cm242(n, $\gamma$ )Cm243(n, $\gamma$ )Cm244	91.6 6.1 1.1 0.6	88.1 5.9 1.8 1.1	85.3 5.8 3.0 1.8		
Sr90	28.868 y	<b>&amp;U238(n,<math>\gamma</math>)U239(<math>\beta^-</math>)Np239(<math>\beta^-</math>)Pu239(n,f)Rb90(<math>\beta^-</math>)</b> Sr90 <b>&amp;U238(n,<math>\gamma</math>)U239(<math>\beta^-</math>)Np239(<math>\beta^-</math>)Pu239(n,<math>\gamma</math>)Pu240(n,<math>\gamma</math>)</b> Pu241(n,f)Rb90( $\beta^-$ )Sr90 <b>&amp;U235(n,f)Rb90(<math>\beta^-</math>)Sr90</b> U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n,f)Rb90m( $\beta^-$ ) Sr90 U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n, $\gamma$ )Pu240(n, $\gamma$ ) Pu241(n,f)Rb90m( $\beta^-$ )Sr90 U235(n,f)Rb90m( $\beta^-$ )Sr90 U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n,f)Sr90 <b>&amp;U238(n,f)Rb90(<math>\beta^-</math>)Sr90</b> U238(n,f)Rb90m( $\beta^-$ )Sr90 <b>&amp;U238(n,3n)U236(n,f)Rb90(<math>\beta^-</math>)Sr90</b> <b>&amp;U238(n,2n)U237(<math>\beta^-</math>)Np237(n,f)Rb90(<math>\beta^-</math>)Sr90</b> U238(n,2n)U237( $\beta^-$ )Np237(n,f)Rb90m( $\beta^-$ )Sr90	41.1 22.9 14.8 12.4 4.0 2.3 1.4	47.9 21.9 8.3 14.3 3.7 1.1 1.6	41.4 0.9 39.6 12.3 4.9 0.6 1.4		

U232	69.8 y	U234( $\alpha$ )Th230(n, $\gamma$ )Th231( $\beta^-$ )Pa231(n, $\gamma$ )Pa232( $\beta^-$ ) U232 U235( $\alpha$ )Th231( $\beta^-$ )Pa231(n, $\gamma$ )Pa232( $\beta^-$ )U232 U238(n,2n)U237( $\beta^-$ )Np237(n,2n)Np236m( $\beta^-$ )Pu236( $\alpha$ )U232 U238(n,3n)U236(n,3n)U234(n,3n)U232 U235(n,2n)U234(n,3n)U232	98.8	95.1	21.8	
Pu238	87.7 y	U235(n, $\gamma$ )U236(n, $\gamma$ )U237( $\beta^-$ )Np237(n, $\gamma$ )Np238( $\beta^-$ ) Pu238 U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n, $\gamma$ )Pu240(n, $\gamma$ ) Pu241( $\beta^-$ )Am241(n, $\gamma$ )Am242( $\beta^-$ )Cm242( $\alpha$ )Pu238 &U234(n, $\gamma$ )U235(n, $\gamma$ )U236(n, $\gamma$ )U237( $\beta^-$ )Np237(n, $\gamma$ ) Np238( $\beta^-$ )Pu238 U238(n, $\gamma$ )U239( $\beta^-$ )Np239(n, $\gamma$ )Np240m( $\beta^-$ )Pu240(n, $\gamma$ ) Pu241( $\beta^-$ )Am241(n, $\gamma$ )Am242( $\beta^-$ )Cm242( $\alpha$ )Pu238 U238(n, $\gamma$ )U239( $\beta^-$ )Np239(n, $\gamma$ )Np240( $\beta^-$ )Pu240(n, $\gamma$ ) Pu241( $\beta^-$ )Am241(n, $\gamma$ )Am242( $\beta^-$ )Cm242( $\alpha$ )Pu238 U238(n,2n)U237( $\beta^-$ )Np237(n, $\gamma$ )Np238( $\beta^-$ )Pu238 U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n,2n)Pu238	78.3	26.4	94.5	
Sm151	90.0 y	U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n,f)Nd151( $\beta^-$ ) Pm151( $\beta^-$ )Sm151 U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n,f)Ce149( $\beta^-$ ) Pr149( $\beta^-$ )Nd149( $\beta^-$ )Pm149( $\beta^-$ )Sm149(n, $\gamma$ ) Sm150(n, $\gamma$ )Sm151 U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n, $\gamma$ )Pu240(n, $\gamma$ ) Pu241(n,f)Nd151( $\beta^-$ )Pm151( $\beta^-$ )Sm151 U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n,f)Pr149( $\beta^-$ ) Nd149( $\beta^-$ )Pm149( $\beta^-$ )Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151 U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n,f)Ce148( $\beta^-$ ) Pr148( $\beta^-$ )Nd148(n, $\gamma$ )Nd149( $\beta^-$ )Pm149( $\beta^-$ ) Sm149(n, $\gamma$ )Sm150(n, $\gamma$ )Sm151 U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n, $\gamma$ )Pu240(n, $\gamma$ ) Pu241(n,f)Pr149( $\beta^-$ )Nd149( $\beta^-$ )Pm149( $\beta^-$ )Sm149(n, $\gamma$ ) Sm150(n, $\gamma$ )Sm151 U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n,f)Pr150( $\beta^-$ ) Nd150(n, $\gamma$ )Nd151( $\beta^-$ )Pm151( $\beta^-$ )Sm151 U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n,f)Pr148m( $\beta^-$ ) Nd148(n, $\gamma$ )Nd149( $\beta^-$ )Pm149( $\beta^-$ )Sm149(n, $\gamma$ ) Sm150(n, $\gamma$ )Sm151 U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n,f)Pm151( $\beta^-$ ) Sm151 U235(n,f)Nd151( $\beta^-$ )Pm151( $\beta^-$ )Sm151 U238(n,f)Nd151( $\beta^-$ )Pm151( $\beta^-$ )Sm151 U238(n,f)Nd152( $\beta^-$ )Pm152( $\beta^-$ )Sm152(n,2n)Sm151 U238(n,2n)U237( $\beta^-$ )Np237(n,f)Nd151( $\beta^-$ )Pm151( $\beta^-$ )Sm151 U238(n,3n)U236(n,f)Nd151( $\beta^-$ )Pm151( $\beta^-$ )Sm151	26.6	30.5	85.2	
Ag108m	418.0 y	U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n,f)Ag108m U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n,f)Ru107( $\beta^-$ ) Rh107( $\beta^-$ )Pd107( $\beta^-$ )Ag107(n, $\gamma$ )Ag108m U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n, $\gamma$ )Pu240(n, $\gamma$ ) Pu241(n,f)Ag108m U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n, $\gamma$ )Pu240(n, $\gamma$ ) Pu241( $\beta^-$ )Am241(n, $\gamma$ )Am242m(n,f)Ag108m &U238(n,f)Ru109( $\beta^-$ )Rh109( $\beta^-$ )Pd109( $\beta^-$ )Ag109(n,2n)Ag108m &U238(n,f)Ru109m( $\beta^-$ )Rh109( $\beta^-$ )Pd109( $\beta^-$ )Ag109(n,2n)Ag108m &U238(n,2n)U237( $\beta^-$ )Np237(n,f)Ru109( $\beta^-$ ) Rh109( $\beta^-$ )Pd109( $\beta^-$ )Ag109(n,2n)Ag108m	79.1	87.8	99.3	
			14.0	1.8	0.5	
			6.4	8.5		
			0.1	1.1		
						90.3
						6.9
						1.0



Tc99	$2.1 \cdot 10^5$ y	<b>&amp;U238(n,<math>\gamma</math>)U239(<math>\beta^-</math>)Np239(<math>\beta^-</math>)Pu239(n,f)Zr99(<math>\beta^-</math>)</b> Nb99( $\beta^-$ )Mo99( $\beta^-$ )Tc99 <b>&amp;U238(n,<math>\gamma</math>)U239(<math>\beta^-</math>)Np239(<math>\beta^-</math>)Pu239(n,f)Zr99(<math>\beta^-</math>)</b> Nb99m( $\beta^-$ )Mo99( $\beta^-$ )Tc99 <b>&amp;U238(n,<math>\gamma</math>)U239(<math>\beta^-</math>)Np239(<math>\beta^-</math>)Pu239(n,f)Nb99(<math>\beta^-</math>)</b> Mo99( $\beta^-$ )Tc99 <b>&amp;U235(n,f)Zr99(<math>\beta^-</math>)Nb99(<math>\beta^-</math>)Mo99(<math>\beta^-</math>)Tc99</b> <b>&amp;U238(n,<math>\gamma</math>)U239(<math>\beta^-</math>)Np239(<math>\beta^-</math>)Pu239(n,f)Nb99m(<math>\beta^-</math>)</b> Mo99( $\beta^-$ )Tc99 <b>&amp;U238(n,f)Zr99(<math>\beta^-</math>)Nb99m(<math>\beta^-</math>)Mo99(<math>\beta^-</math>)Tc99</b> <b>&amp;U238(n,f)Zr99(<math>\beta^-</math>)Nb99(<math>\beta^-</math>)Mo99(<math>\beta^-</math>)Tc99</b> <b>&amp;U238(n,f)Zr99(<math>\beta^-</math>)Nb99m(<math>\beta^-</math>)Mo99(<math>\beta^-</math>)Tc99</b> <b>&amp;U238(n,f)Nb100(<math>\beta^-</math>)Mo100(n,2n)Mo99(<math>\beta^-</math>)Tc99</b> <b>&amp;U238(n,2n)U237(<math>\beta^-</math>)Np237(n,f)Zr99(<math>\beta^-</math>)Nb99(<math>\beta^-</math>)</b> Mo99( $\beta^-$ )Tc99 <b>&amp;U238(n,f)Nb99(<math>\beta^-</math>)Mo99(<math>\beta^-</math>)Tc99</b> <b>&amp;U238(n,2n)U237(<math>\beta^-</math>)Np237(n,f)Zr99(<math>\beta^-</math>)Nb99m(<math>\beta^-</math>)</b> Mo99( $\beta^-$ )Tc99 <b>&amp;U238(n,3n)U236(n,f)Zr99(<math>\beta^-</math>)Nb99(<math>\beta^-</math>)Mo99(<math>\beta^-</math>)Tc99</b> <b>&amp;U238(n,3n)U236(n,f)Zr99(<math>\beta^-</math>)Nb99m(<math>\beta^-</math>)Mo99(<math>\beta^-</math>)Tc99</b>	50.1 30.1 10.7 3.4 2.5 2.0 2.0	51.9 31.1 10.5 2.0 2.4 1.2 1.2	42.3 25.4 8.4 12.8 1.9 7.7 44.8	
Pu242	$3.7 \cdot 10^5$ y	U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n, $\gamma$ )Pu240(n, $\gamma$ ) Pu241(n, $\gamma$ )Pu242 U238(n, $\gamma$ )U239( $\beta^-$ )Np239(n, $\gamma$ )Np240m( $\beta^-$ )Pu240(n, $\gamma$ ) Pu241(n, $\gamma$ )Pu242 U238(n, $\gamma$ )U239( $\beta^-$ )Np239(n, $\gamma$ )Np240( $\beta^-$ )Pu240(n, $\gamma$ ) Pu241(n, $\gamma$ )Pu242 U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n, $\gamma$ )Pu240(n, $\gamma$ ) Pu241( $\beta^-$ )Am241(n, $\gamma$ )Am242( $\beta^+$ )Pu242	97.5 1.2 0.6 0.1	95.2 1.5 0.9 2.4	93.9 2.2 1.3 3.0	98.0 0.1 0.3 1.6
Np237	$2.1 \cdot 10^6$ y	U235(n, $\gamma$ )U236(n, $\gamma$ )U237( $\beta^-$ )Np237 <b>&amp;U234(n,<math>\gamma</math>)U235(n,<math>\gamma</math>)U236(n,<math>\gamma</math>)U237(<math>\beta^-</math>)Np237</b> U238(n, $\gamma$ )U239( $\beta^-$ )Np239( $\beta^-$ )Pu239(n, $\gamma$ )Pu240( $\alpha$ ) U236(n, $\gamma$ )U237( $\beta^-$ )Np237 U238(n,2n)U237( $\beta^-$ )Np237	99.1 0.8 0.1	98.1 0.6 0.5	100.0	100.0

# Uranium activation characteristics

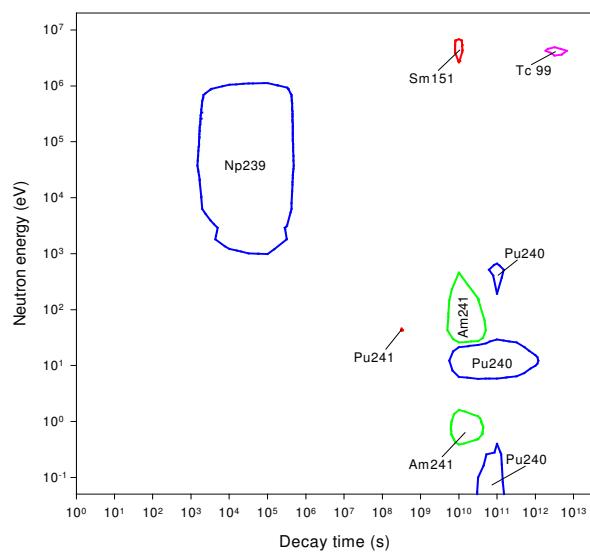


Decay time (years)

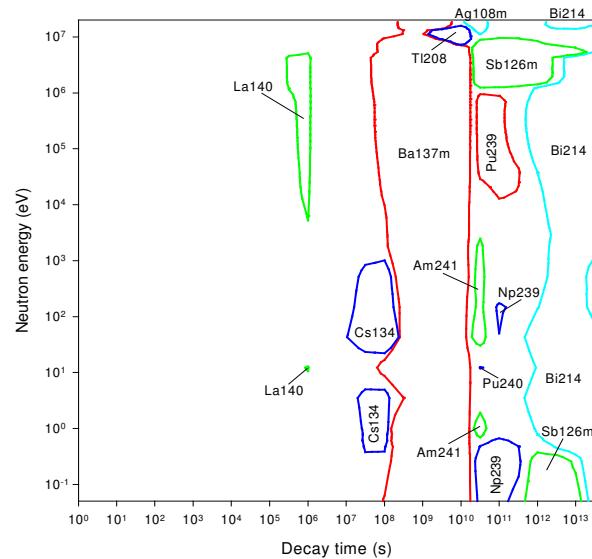
Decay time (years)

# Uranium importance diagrams & transmutation

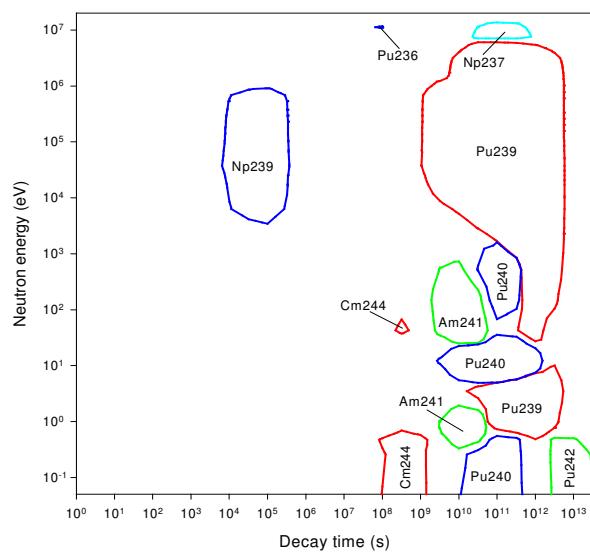
## Activity



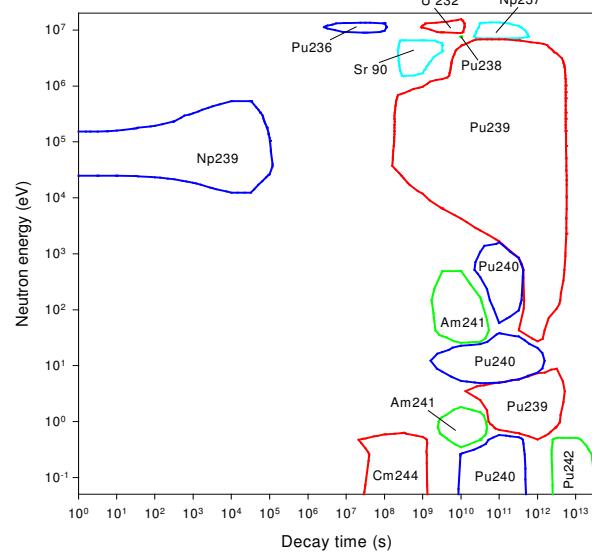
## Dose rate



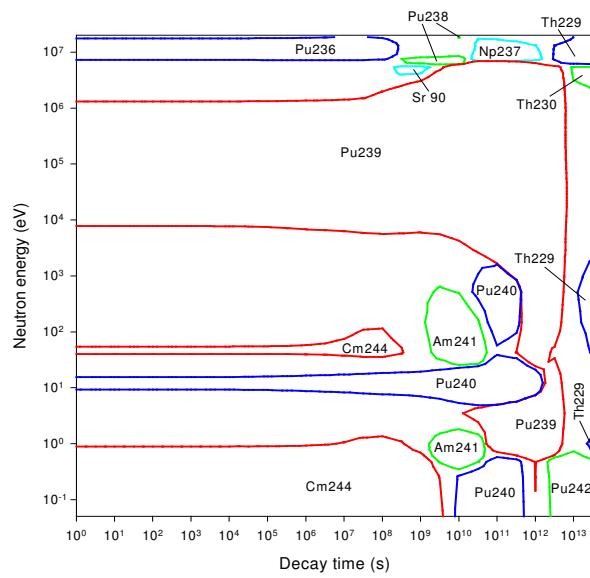
## Heat output



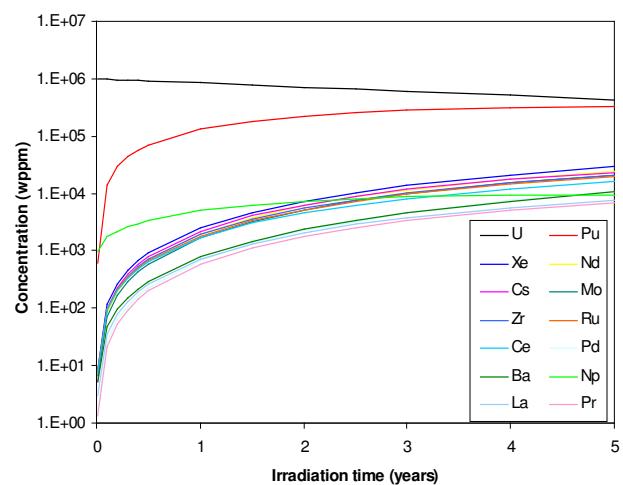
## Ingestion dose



## Inhalation dose



## First wall transmutation





## **PART 2:**

### **The Summary Tables**

# Summary of Primary and Secondary nuclides

Nuclide	$T_{1/2}$	Contributing elements	
		Primary	Secondary
Ac225	10.0 d		Th, U
Ac227	21.773 y	Th	U
Ac228	6.15 h		Th
Ag105	41.3 d		Ag, Cd
Ag106	24.0 m		Ag, Cd
Ag106m	8.46 d	Ag, Cd	Pd, Cd, In, Sn, Sb
Ag107m	44.1 s	Ag	Cd
Ag108	2.4 m	Ag	Pd, Cd, In, Sn, Sb
Ag108m	418 y	Rh, Pd, Ag, Cd, In, Sn, Sb, U	Th
Ag109m	39.8 s	Ag	Rh, Pd, Cd, In, Sn
Ag110	24.7 s	Pd, Ag	Rh, Cd
Ag110m	249.79 d	Ru, Rh, Pd, Ag, Cd, In	Sn
Ag111	7.45 d	Pd, Ag	Rh, Cd
Ag111m	1.08 m		Pd, Ag, Cd
Ag112	3.14 h		Pd, Cd, In
Ag113	5.37 h		Cd
Ag114	4.7 s		Cd
Ag116	2.64 m		Cd
Al26	$7.2 \cdot 10^5$ y	Na, Mg, Al, Si, P, S	Cl, Ar
Al26m	6.345 s		Al
Al28	2.241 m	Al, Si, P, S	Mg, Cl, Ar
Al29	6.56 m	Si, S	P, Cl
Al30	3.65 s		Si, P, S
Am241	432.7 y	U	Th
Am243	7364.8 y		Th, U
Ar37	35.04 d	Ar, K, Ca	Cl
Ar39	269 y	Cl, Ar, K, Ca, Sc, Ti, V, Cr, Mn	P, S, Fe
Ar41	1.827 h	Cl, Ar, K	S, Ca, Sc
Ar42	33 y	Ar, K, Sc, Ti, V, Cr, Mn	Fe
As73	80.301 d	As, Se	Ge, Br
As74	17.78 d	Ge, As, Se, Br	
As76	1.097 d	Ge, As, Se, Br	
As77	1.618 d	Ge, As	Se, Br
As78	1.5117 h		Se, Br
As79	9.01 m		Se
As80	16.5 s		Se
At217	0.0323 s		Th, U
Au194	1.5845 d	Pt, Au, Hg	Tl
Au195	186.09 d	Au, Hg	Pt
Au195m	30.5 s		Au, Hg
Au196	6.1829 d	Au, Hg	Pt
Au196m	8.1 s		Au
Au196n	9.6944 h		Au, Hg
Au197m	7.74 s	Au	Pt, Hg
Au198	2.6943 d	Ir, Pt, Au, Hg	
Au199	3.139 d	Ir, Pt, Au	Os, Hg
Au200	48.4 m		Ir, Pt, Au, Hg, Tl
Au200m	18.694 h		Hg
Au202	28.8 s		Hg, Tl
Au204	39.8 s		Hg
Ba129	2.38 h		Ba
Ba129m	2.14 h		Ba
Ba131	11.55 d	Ba	Cs
Ba131m	14.6 m		Ba
Ba133	10.574 y	Xe, Cs, Ba, La, Ce	Pr
Ba133m	1.5917 d		Ba, La
Ba135m	1.196 d	Ba, La	Cs
Ba136m	0.3084 s		Ba, La
Ba137m	2.553 m	Te, I, Xe, Cs, Ba, La, Ce, Pr, Th, U	Sb, Nd
Ba139	1.384 h	Ba, La	Ce
Ba140	12.74 d		Th, U

Nuclide	$T_{1/2}$	Contributing elements	
		Primary	Secondary
Ba142	10.6 m		Th, U
Be10	$1.6 \cdot 10^6$ y	Be, B, C, N, O, F, Ne, Na, Mg, Al, Si, P	
Be11	13.81 s	Be, B, C, N,	O
Bi205	15.313 d		Bi
Bi206	6.2431 d	Bi	
Bi207	$31.759 \cdot 10^5$ y	Pb, Bi	
Bi208	$3.68 \cdot 10^5$ y	Pb, Bi	
Bi210	5.013 d	Bi	Pb, Th
Bi210m	$3.0 \cdot 10^6$ y	Pb, Bi	
Bi211	2.17 m		Bi, Th
Bi212	1.0092 h		Th, U
Bi213	45.59 m		Th, U
Bi214	19.9 m	Th, U	
Br77	2.3765 d		Kr
Br78	6.46 m	Br, Kr	
Br79m	4.88 s	Br	Kr
Br80	17.6 m	Br	As, Se, Kr, Rb
Br80m	4.41 h	Br	As, Se, Kr, Rb
Br82	1.472 d	As, Se, Br, Kr, Rb	
Br82m	1.4717 d		Se, Br, Kr, Rb
Br83	2.39 h		Se, Kr, Rb
Br84	31.8 m		Kr, Rb
Br84m	6.0 m		Kr, Rb
Br85	$2.8667 \cdot 10^5$ m		Kr
Br86	55.0 s		Kr, Th
C14	5730 y	B, C, N, O, F, Ne, Na, Mg, Al, Si, P	
C15	2.449 s	C, N, O	Ne
Ca39	0.8596 s		Ca
Ca41	$1.03 \cdot 10^5$ y	Ca, Sc, Ti, V, Cr	
Ca45	162.7 d	K, Ca, Sc, Ti, V, Cr, Mn	Ar
Ca47	4.538 d	Ca, Ti, Mn	V, Cr
Ca49	8.72 m	Ca	
Cd105	55.5 m		Cd
Cd107	6.52 h		Ag, Cd
Cd109	1.267 y	Ag, Cd	In, Sn
Cd111m	48.54 m	Cd	Pd, Ag, In
Cd113	$9.3 \cdot 10^{15}$ y	Cd	Ag
Cd113m	13.7 y	Pd, Ag, Cd, In, Sn	Rh, Sb
Cd115	2.225 d	Cd	Pd, Ag, In
Cd115m	44.6 d		Pd, Ag, In
Cd117	2.49 h		Cd, Sn
Cd117m	3.36 h		Cd, Sn
Ce135	17.694 h		Ce
Ce137	9.0 h	Ce	Pr
Ce137m	1.4329 d		Ce, Pr
Ce139	137.65 d	Ce, Pr, Nd	La
Ce139m	56.1 s	Ce	Pr, Nd
Ce141	32.5 d	Ba, La, Ce, Pr	Nd, Th, U
Ce142	$5.0 \cdot 10^{16}$ y	Ce, Pr	La
Ce143	1.375 d	Ce	
Ce144	284.9 d	La, Ce, Pr	Th, U
Cl34	1.526 s		Cl
Cl34m	32.1 m	Cl	K
Cl36	$3.07 \cdot 10^5$ y	Mg, Al, Si, P, S, Cl, Ar, K, Ca, Sc, Ti, Mn	V, Cr
Cl38	37.2 m	S, Cl, Ar, K, Ca	
Cl38m	0.715 s		S, Cl, Ar, K, Ca
Cl39	55.6 m	Ar	K, Ca
Cl40	1.35 m		Ar
Cm242	162.94 d		U
Cm243	30.0 y		U
Cm244	18.1 y	U	Th
Cm246	4730.0 y		U
Co56	77.26 d		Ni

Nuclide	$T_{1/2}$	Contributing elements	
		Primary	Secondary
Co57	271.79 d	Ni	Co
Co58	70.86 d	Co, Ni	Cu
Co58m	8.94 h		Co, Ni, Cu
Co60	5.272 y	Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se	
Co60m	10.47 m	Co	
Co61	1.65 h		Fe, Co, Ni, Cu
Co62	1.5 m		Cu
Co62m	13.91 m		Cu
Cr49	41.9 m		Cr
Cr51	27.706 d	Cr	Fe
Cr55	3.54 m	Cr, Mn	
Cs129	1.3417 d		Ba
Cs131	9.69 d	Ba	Cs
Cs132	6.53 d	Cs	Xe, Ba
Cs134	2.065 y	Te, I, Xe, Cs, Ba, La, Pr, Th, U	Ce
Cs134m	2.908 h		Xe, Cs, Ba
Cs135	2.4 $10^6$ y	I, Xe, Cs, Ba, La, Ce, Pr	Te, U
Cs135m	53.0 m		Xe, Cs, La
Cs136	13.03 d	I, Xe, Cs, Ba, La	Te, Ce, Pr, Th, U
Cs136m	19.0 s		Cs, La
Cs137	30.171 y	Te, I, Xe, Cs, Ba, La, Ce, Pr	Th, U
Cs138	32.2 m		Ba, Th, U
Cs140	1.0617 m		U
Cu62	9.75 m	Cu	Zn
Cu64	12.702 h	Ni, Cu, Zn	Ga
Cu66	5.1 m	Cu	Ni, Zn, Ga
Cu67	2.579 d	Ga	Zn, Ge
Cu68	31.1 m		Zn, Ga
Cu68m	3.75 m		Zn, Ga
Dy154	2.852 $10^6$ y	Dy, Ho, Er, Tm, Yb	Tb
Dy155	10.0 h		Dy
Dy157	8.14 h	Dy	Ho
Dy159	144.4 d	Dy, Ho, Er	
Dy165	2.334 h	Dy	Nd, Sm, Eu, Gd, Tb, Ho
Dy165m	1.258 m		Sm, Eu, Gd, Tb, Dy
Dy166	3.4 d		Eu, Gd, Tb, Dy
Er160	1.191 d		Ho
Er161	3.2111 h		Ho, Er
Er163	1.25 h		Ho, Er
Er165	10.361 h	Er	Ho, Tm
Er167m	2.28 s	Dy, Ho, Er	Sm, Eu, Gd, Tb, Tm
Er169	9.3 d	Dy, Ho, Er	Sm, Eu, Gd, Tb, Tm
Er171	7.5194 h	Er	Dy, Ho, Tm
Eu148	54.514 d		Eu, Gd
Eu149	93.1 d	Eu	Gd
Eu150	36.359 y	Nd, Sm, Eu	Gd
Eu150m	12.8 h		Eu, Gd
Eu152	13.522 y	Pr, Nd, Sm, Eu, Gd	U
Eu152m	9.275 h		Sm, Eu, Gd
Eu152n	1.6 h		Sm, Eu
Eu154	8.5927 y	La, Ce, Pr, Nd, Sm, Eu, Gd	Tb, Dy, Th, U
Eu154m	46.4 m		Eu, Gd
Eu155	4.846 y	Nd, Sm, Eu, Gd, Tb	La, Ce, Pr
Eu156	15.2 d	Pr, Nd, Sm, Eu, Gd	Ce, Tb, Dy, Th, U
Eu157	15.181 h		Pr, Nd, Sm, Eu, Gd
Eu158	45.9 m		Sm, Eu, Gd
Eu159	18.7 m		Gd
Eu160	52.8 s		Gd
F18	1.828 h	O, F, Ne	Na
F20	11.03 s	F, Ne, Na	Mg, Al
F21	4.32 s	Ne	Na, Mg
F22	4.24 s		Ne, Na

Nuclide	$T_{1/2}$	Contributing elements	
		Primary	Secondary
Fe53	8.51 m		Fe
Fe53m	2.58 m		Fe
Fe55	2.7351 y	Fe, Ni	Mn, Co
Fe59	44.502 d	Ti, V, Mn, Fe, Co, Ga	Cr, Ni, Cu, Ge, As
Fe60	$1.5 \cdot 10^6$ y	Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As	
Fr221	4.9 m		Th, U
Ga67	3.261 d		Ga
Ga68	1.127 h	Ga	Ge, As, Se
Ga70	21.14 m	Zn, Ga, Ge	
Ga72	14.1 h	Ga, Ge, As	Zn, Se
Ga73	4.87 h		Ge
Ga74	8.1167 m		Ge
Ga74m	9.5 s		Ge
Gd148	74.467 y	Eu, Gd	Sm
Gd149	9.375 d		Eu
Gd150	$1.82 \cdot 10^6$ y	Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb	Sm
Gd151	124.0 d		Sm, Eu, Gd
Gd152	$1.079 \cdot 10^{14}$ y	Eu, Gd, Tb, Dy, Ho, Tm	Sm, Tb, Dy
Gd153	240.5 d	Eu, Gd	Nd, Sm, Eu, Tb, Dy
Gd159	18.56 h	Gd	Dy
Gd161	3.667 m	Gd	Ga, Ge
Ge68	270.82 d		
Ge69	1.627 d	Ga, Ge	Zn, Se
Ge71	11.435 d	Ga, Ge, As	Ga, Ge, As
Ge73m	0.5 s		Se
Ge75	1.380 h	Ge, As	Ge, As
Ge75m	47.7 s		Se
Ge77	11.3 h	Ge, As	Ge
Ge77m	52.9 s		
H3	12.33 y	H, He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Al, Si, P, S, Cl, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ga, Ge, As, Se, Br, Rb, Sr, Y, Zr, Ru, Rh, Pd, Te, I, Xe, Cs, La, Ce, Pr, Tb, Er, Tm, Yb, Lu, Ta, W, Re, Os, Au, Hg, Tl, Pb, Bi	Ar, K, Ni, Cu, Zn, Kr, Nb, Mo, Ag, In, Sn, Sb, Nd, Gd, Dy, Ho, Hf, Ir, Pt
He6	0.808 s	Li, Be, B, C	O, N
Hf173	23.9 h		Hf
Hf174	$2.0 \cdot 10^{15}$ y		Hf
Hf175	70.0 d	Hf	Ta
Hf177m	1.08 s	Lu, Hf	Tm, Yb, Ta
Hf177n	51.4 m		Yb, Lu, Hf
Hf178m	4.0 s	Yb, Lu, Hf	Tb, Dy, Ho, Er, Tm, Ta, W, Re, Os
Hf178n	31.0 y	Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, W, Re	Tb, Os
Hf179m	18.67 s	Lu, Hf	Tm, Yb, Ta
Hf179n	25.116 d	Hf	Yb, Lu, Ta, W
Hf180m	5.5 h		Tm, Yb, Lu, Hf, Ta
Hf181	42.38 d	Tm, Yb, Lu, Hf	Dy, Ho, Er, Ta, W
Hf182	$8.9937 \cdot 10^6$ y	Nd, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, W	Pr, Sm, Re, Ir
Hf183	1.0667 h		Tm, Yb, Lu, Hf
Hg194	519.68 y	Pt, Au, Hg	Tl
Hg195	9.8889 h		Au, Hg
Hg195m	1.7361 d		Au, Hg
Hg197	2.6917 d	Hg	
Hg197m	23.9 h		Hg
Hg199m	42.1 m	Au, Hg	Tl
Hg203	46.595 d	Ir, Pt, Au, Hg, Tl, Pb	
Hg205	5.2 m	Hg, Pb	
Ho160	25.3 m		Ho, Er
Ho161	2.48 h		Ho
Ho161m	6.77 s		Ho
Ho162	1.5 m		Ho, Er

Nuclide	$T_{1/2}$	Contributing elements	
		Primary	Secondary
Ho162m	1.1167 h	Ho	Er
Ho163	4570.0 y	Dy, Ho, Er, Tm, Yb, Hf	Lu
Ho163m	1.1 s		Ho, Er
Ho164	28.6 m	Ho	Er
Ho164m	37.6 m		Ho, Er
Ho166	1.1167 d	Tb, Dy, Ho	Nd, Sm, Eu, Gd, Er, Tm
Ho166m	1200.0 y	Cs, Ba, La, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf	Ce, Ta, U
Ho167	3.1 h	Ho	Eu, Gd, Tb, Dy, Er, Tm
Ho168	3.0 m		Er
Ho169	4.4 m		Er
Ho170	2.78 m		Er
I125	59.43 d	I, Xe	Te
I126	12.98 d	Te, I	Xe
I128	24.99 m	Te, I	Xe
I129	$1.569 \cdot 10^7$ y	Sn, Sb, Te, I, Xe, Cs, Ba	Th
I130	12.36 h	Te, I	Xe, Cs
I130m	9.0 m		Te
I131	8.04 d	Te	Xe, Cs, Th, U
I132	2.283 h		Xe, Th, U
I133	20.8 h		Th, U
I134	52.6 m		Xe, Th, U
I135	6.61 h		Th, U
I136	1.4 m		U
In111	2.8047 d		In, Sn
In112	14.7 m		Cd, In, Sn
In112m	20.7 m		In
In113m	1.658 h	In, Sn	Cd
In114	1.198 m	In	Cd, Sn
In114m	50 d	In	Cd, Sn
In115	$4.41 \cdot 10^{14}$ y	Pd, Ag, Cd, In	Rh, Sn, Sb
In115m	4.486 h	In	Ag, Cd, Sn
In116	14.2 s		Ag, Cd, In, Sn
In116m	54.6 m	Ag, Cd, In	Pd, Sn
In116n	2.17 s		In
In117	43.8 m		Cd, Sn
In117m	1.9417 h		Cd, Sn
In118	5.0 s		Sn
In118m	4.45 m		Sn, Sb
In119	2.4 m		Sn
In120	3.08 s		Sn
In120m	44.4 s		Sn, Sb
In120n	46.2 s		Sn
In124	3.2 s		Sn
Ir188	1.7292 d		Ir, Pt
Ir189	13.194 d		Os, Ir, Pt
Ir190	12.0 d	Os, Ir	Pt
Ir190m	1.12 h		Os, Ir
Ir190n	3.087 h		Ir
Ir191m	4.9 s	Ir	Os
Ir191n	5.5 s		Os, Ir, Pt
Ir192	73.831 d	Ta, W, Re, Os, Ir, Pt, Au	Hg
Ir192m	1.44 m		W, Re, Os, Ir
Ir192n	240.84 y	Ta, W, Re, Os, Ir, Pt, Au	Hg
Ir193m	10.602 d		W, Re, Os, Pt
Ir194	19.15 h	Ta, W, Re, Os, Ir, Au	Pt
Ir194m	171.3 d	W, Re, Os, Ir, Pt, Au	Hg
Ir195	2.5 h		W, Re, Os, Ir
Ir195m	3.8056 h		W, Re, Os
Ir196m	1.4 h		Pt
K38	7.61 m	K, Ca	K, Ca
K38m	0.924 s		
K40	$1.28 \cdot 10^9$ y	K, Ca, Sc, Ti, Cr, Mn	Ar, V

Nuclide	$T_{1/2}$	Contributing elements	
		Primary	Secondary
K42	12.37 h	Cl, Ar, K, Ca, Sc, Ti, V, Cr, Mn	S, Fe
K43	22.2 h	Ca	K, Sc, Mn
K44	22.13 m		Ca, Sc
K48	6.8 s		Ca
Kr77	1.2389 h		Kr
Kr79	1.46 d	Br, Kr	Se
Kr79m	50.0 s		Br, Kr
Kr81	$2.1 \cdot 10^5$ y	Cu, Zn, Ga, Ge, As, Se, Br, Kr, Rb, Sr, Y	Br, Kr
Kr81m	13.2 s		Se, Br, Rb, Sr
Kr83m	1.83 h	Kr	Th, U
Kr85	10.73 y	Ga, Ge, As, Se, Br, Kr, Rb, Sr, Y, Zr	Rb, Sr
Kr85m	4.48 h	Kr	Rb
Kr87	1.272 h	Kr	Th
Kr88	2.84 h		Th
Kr89	3.17 m		Th
La135	19.5 h		La
La136	9.87 m	La	Ce
La137	$6.0 \cdot 10^4$ y	Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm	
La138	$1.05 \cdot 10^{11}$ y	Cs, Ba, La, Pr, Ce, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm	
La140	1.679 d	Ba, La, Ce, Pr, Th, U	Nd
La142	1.5194 h		Ce, Th, U
Li8	0.838 s	Li, Be, B, C, N	Be
Li9	0.178 s		Lu, Hf
Lu171	8.25 d		Yb, Hf
Lu172	6.7 d	Lu	Lu
Lu172m	3.7 m		Yb, Lu, Hf
Lu173	1.3361 y		Ta
Lu174	3.5592 y		Yb, Lu, Hf
Lu174m	142.0 d		Ta
Lu176	$3.612 \cdot 10^{10}$ y	Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf	Ta
Lu176m	3.6806 h	Yb, Lu	Er, Tm, Ta
Lu177	6.7 d	Yb, Lu	Tm
Lu177m	160.3 d	Lu	Tm, Yb
Lu178	28.4 m	Lu	Tm, Yb
Lu178m	23.1 m		Lu, Hf
Lu180	5.7 m		Hf, Ta
Mg23	11.317 s		Mg
Mg27	9.458 m	Mg, Al	Si, P, S
Mn52	5.5914 d		Fe
Mn52m	21.1 m		Fe
Mn53	$3.68 \cdot 10^6$ y	Cr, Mn, Fe, Co, Ni	
Mn54	312.3 d	Mn, Fe, Co	Cr, Ni
Mn56	2.579 h	Ti, V, Cr, Mn, Fe	Co
Mn57	1.61 m		Co, Ni
Mn58	1.0867 m		Co
Mo91	15.49 m		Mo
Mo91m	1.0867 m		Mo
Mo93	3011.6 y	Zr, Mo, Ru	
Mo93m	6.85 h		Mo
Mo99	2.748 d	Mo	Zr, Ru, U
Mo101	14.6 m	Mo	
N13	9.965 m	N, O	C
N16	7.13 s	N, O, F	Ne, C
N17	4.17 s		F
Na22	2.603 y	Ne, Na, Mg, Al, Si, P, S, Cl	
Na24	14.965 h	O, F, Ne, Na, Mg, Al, Si, P, S	Cl, Ar
Na25	59.6 s	Mg	Al
Na26	1.08 s		Mg
Nb90	14.6 h	Mo	Nb
Nb90m	18.82 s		Nb, Mo

Nuclide	$T_{1/2}$	Contributing elements	
		Primary	Secondary
Nb91	680 y	Nb, Mo	Ru
Nb91m	60.9 d	Mo	Nb
Nb92	$3.5 \cdot 10^7$ y	Nb, Mo	Zr
Nb92m	10.15 d	Nb, Mo	
Nb93m	16.126 y	Rb, Sr, Y, Zr, Nb, Mo, Ru	Th, U
Nb94	$1.999 \cdot 10^4$ y	Zr, Nb, Mo, Ru	Y, Rh, Pd, Ag, Cd, In, U
Nb94m	6.26 m	Nb	Mo
Nb95	34.975 d	Zr, Nb, Mo, Th	Ru, U
Nb95m	3.6083 d		Nb
Nb96	23.35 h	Nb	Zr, Mo
Nb97	1.2017 h		Zr, Mo, U
Nb97m	1.0 m		Zr
Nb98m	51.3 m		Mo
Nd140	3.37 d		Nd
Nd141	2.4889 h	Nd	Sm
Nd141m	1.04 m	Nd	Sm
Nd144	$2.099 \cdot 10^{15}$ y	La, Pr, Nd	Ce
Nd147	11.02 d	Pr, Nd	Ce, Sm
Nd149	1.725 h	Nd	
Nd151	12.433 m	Nd	Sm
Ne23	37.2 s	Ne, Na	F, Mg
Ni57	1.4875 d		Ni
Ni59	76000 y	Co, Ni, Cu, Zn, Ga, As	Ge
Ni63	99 y	Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As	Sc
Ni65	2.52 h	Ni	Cu, Zn
Np236	$1.52 \cdot 10^5$ y		U
Np237	$2.14 \cdot 10^6$ y	U	
Np239	2.355 d	U	
O15	2.037 m	O	
O19	26.91 s	O, F, Ne	
Os183	13.0 h		Os
Os183m	9.8889 h		Os
Os185	93.8 d	Os	Re, Ir
Os186	$1.901 \cdot 10^{15}$ y	Re, Os	Ta, W
Os189m	4.8056 h	Os	Ta, W, Re, Ir
Os190m	9.9 m	Os	Ir, Pt
Os191	15.405 d	W, Re, Os	Ta, Pt
Os191m	13.1 h		W, Re, Os
Os192m	5.9 s		Re, Os
Os193	1.2708 d	Os	W, Re, Ir
Os194	5.989 y	Ta, W, Re, Os, Ir, Pt, Au	Hg
P30	2.498 m	P	Si, S, Cl
P32	14.27 d	Na, Mg, Al, Si, P, S, Cl, Ar, K	Ca
P33	25.4 d	S, Ar, K	Mg, Al, Si, P, Cl, Ca
P34	12.4 s		Cl, S, Ca
P35	47.3 s		Cl
P36	5.6 s		Ar
Pa230	17.4 d		Th
Pa231	$3.276 \cdot 10^4$ y		Th, U
Pa233	27.0 d	Th	U
Pa234	6.78 h		Th
Pa234m	1.17 m		U
Pb201	9.4 h		Pb
Pb202	$5.3 \cdot 10^4$ y	Hg, Tl, Pb	
Pb203	2.1621 d	Pb	Tl, Bi
Pb203m	6.29 s		Tl, Pb
<b>Pb204</b>	$1.4 \cdot 10^{17}$ y	Au	
Pb204m	1.125 h	Tl, Pb	Bi
Pb205	$1.53 \cdot 10^7$ y	Ir, Pt, Au, Hg, Tl, Pb	
Pb207m	0.805 s	Pb	Tl, Bi
Pb209	3.253 h	Pb	Th, U
Pb210	22.3 y	Pb	Bi, Th, U

Nuclide	$T_{1/2}$	Contributing elements	
		Primary	Secondary
Pb211	36.1 m		Th, U
Pb212	10.64 h		Th, U
Pb214	26.8 m		Th, U
Pd101	8.4694 h		Rh, Pd
Pd103	16.98 d	Pd	Ag
Pd107	$6.5 \cdot 10^6$ y	Rh, Pd, Ag, Cd, In, Sn	Ru, Sb
Pd107m	21.3 s		Rh, Pd, Ag
Pd109	13.46 h	Pd, Ag	Rh
Pd109m	4.71 m		Pd, Ag
Pd111	23.4 m		Pd
Pd111m	5.5 h	Pd	
Pm142	40.5 s		Sm
Pm143	266.0 d		Nd, Sm
Pm144	363.0 d	Sm	Nd
Pm145	17.7 y	Nd, Sm	
Pm146	5.5305 y	Nd, Sm	Th, U
Pm147	2.622 y	La, Ce, Pr, Nd	Sm, Th, U
Pm148	5.368 d		Ce, Pr, Nd, Sm, Eu
Pm148m	41.05 d	Pr, Nd	Ce, Sm, Eu
Pm149	2.2117 d		Pr, Nd, Sm, Eu
Pm150	2.68 h		Ce, Pr, Nd, Sm, Eu
Pm151	1.1708 d		Nd, Sm
Pm152m	7.5 m		Nd, Sm
Pm152n	14.4 m		Nd
Pm154	1.7 m		Sm
Pm154m	2.7 m		Sm
Po208	2.93 y		Pb, Bi
Po209	102.0 y	Bi	Pb
Po210	138.4 d	Pb, Bi, Th	U
Po212	$3.0 \cdot 10^{-7}$ s		Th
Po213	$4.2 \cdot 10^{-6}$ s		Th, U
Po214	$1.65 \cdot 10^{-4}$ s		Th, U
Po215	$1.78 \cdot 10^{-3}$ s		Th
Po216	0.145 s		Th, U
Po218	3.05 m		Th, U
Pr139	4.4111 h		Pr
Pr140	3.39 m	Pr	Ce, Nd
Pr142	19.13 h	Ce, Pr	Ba, La, Nd
Pr142m	14.6 m		La, Ce, Pr, Nd
Pr143	13.56 d	Ce, Pr	Nd
Pr144	17.28 m	La, Ce, Pr, Th	Nd, U
Pr144m	6.9 m		Ce
Pr145	5.98 h		Nd
Pr146	24.15 m		Nd
Pt188	10.185 d		Pt
Pt189	10.889 h		Pt
Pt190	$6.591 \cdot 10^{11}$ y	Pt, Au, Hg	Ir
Pt191	2.9051 d		Pt
Pt193	50.0 y	Ta, W, Re, Os, Ir, Pt, Au, Hg	Hf
Pt193m	4.34 d	Ir, Pt	W, Re, Os, Au
Pt195m	4.0197 d	Ir, Pt	Os, Au, Hg
Pt197	19.892 h	Pt	Ir, Au
Pt197m	1.5883 h		Ir, Pt, Au
Pt199	30.8 m	Pt	
Pt199m	13.6 s		Pt
Pu236	2.9 y	U	
Pu238	87.7 y	Th, U	
Pu239	$2.411 \cdot 10^4$ y	U	Th
Pu240	6563.0 y	U	Th
Pu241	14.4 y	U	
Pu242	$3.735 \cdot 10^5$ y	U	
Ra222	38.0 s		Th, U
Ra224	3.62 d		Th

Nuclide	$T_{1/2}$	Contributing elements	
		Primary	Secondary
Ra225	14.8 d		Th, U
Ra226	1600.0 y		Th, U
Ra228	5.75 y		Th
Rb83	86.2 d	Sr	Kr, Rb
Rb84	33.5 d	Kr, Rb, Sr	
Rb84m	20.4 m		Kr, Rb, Sr
Rb86	18.63 d	Br, Kr, Rb, Sr, Y	As, Se, Zr
Rb86m	1.0167 m		Kr, Rb, Sr, Y
Rb87	$4.797 \cdot 10^{10}$ y	Rb, Sr, Y	
Rb88	17.8 m		Rb, Sr, Y
Rb89	15.4 m		Th
Rb90	2.55 m		Th
Re182	2.6667 d		Re, Os
Re183	70.023 d		W, Re, Os
Re184	37.963 d	W, Re, Os	
Re184m	165.51 d	W, Re, Os	
Re186	3.7766 d	Ta, W, Re, Os, Ir, Pt, Au	Hg
Re186m	$1.996 \cdot 10^5$ y	Ta, W, Re, Os, Ir, Pt, Au	Hg
Re187	$4.997 \cdot 10^{10}$ y	W, Re, Ir	Ta, Os
Re188	16.981 h	W, Re	Ta, Os
Re188m	18.6 m		W, Re
Re189	1.0125 d		Os
Re190	3.1 m		Os
Re192	6.2 s		Os
Rh100	20.806 h		Rh, Pd
Rh101	3.2956 y		Ru, Rh, Ag
Rh101m	4.3403 d		Rh, Pd
Rh102	2.902 y	Ru, Rh, Pd	Ag, Cd, U
Rh102m	208.0 d		Ru, Rh, Pd, Ag
Rh103m	56.115 m	Rh	Mo, Ru, Pd, Ag
Rh104	42.3 s	Ru, Rh	Pd, Ag
Rh104m	4.34 m	Rh	Ru, Pd
Rh105	1.474 d	Rh	Ru, Pd
Rh105m	40.0 s		Ru, Rh, Pd
Rh106	30.1 s	Ru, Rh	Pd, Ag, Th
Rh106m	2.2 h	Pd	Ru, Rh, Ag
Rh107	21.7 m		Pd
Rh108	5.9 m		Pd
Rh108m	16.8 s		Pd
Rh110m	28.5 s		Pd
Rn218	0.035 s		Th
Rn219	3.96 s		Th
Rn220	55.6 s		Th, U
Rn222	3.825 d		Th, U
Ru95	1.6389 h		Ru
Ru97	2.9 d	Ru	
Ru103	39.26 d	Mo, Ru, Rh	Pd, Ag, U
Ru105	4.439 h	Rh	Ru, Pd
Ru106	1.008 y	Ru, Rh	Th
S31	2.572 s		S
S35	87.5 d	P, S, Cl, Ar, K, Ca	Mg, Al, Si
S37	4.99 m	S, Cl, Ar, Ca	K
Sb119	1.5958 d		Sb
Sb120	15.9 m		Sn, Sb, Te
Sb120m	5.76 d		Sn, Sb, Te
Sb122	2.696 d	Sn, Sb	Te
Sb122m	4.19 m		Sn, Sb
Sb124	60.24 d	Sn, I	Te, Xe
Sb124m	1.55 m		Sb, I
Sb125	2.759 y	Sn, Sb, Te, I	In, Th, U
Sb126	12.41 d		Sn, Te, I, Xe, Th, U
Sb126m	19.1 m	Sn, Te, I, Xe, Th, U	
Sb126n	11.0 s		Sn, I

Nuclide	$T_{1/2}$	Contributing elements	
		Primary	Secondary
Sb127	3.84 d		Te
Sb128	9.01 h		Te
Sb128m	10.4 m		Te
Sb129	4.36 h		Te
Sb130	40.0 m		Te
Sb130m	6.3 m		Te
Sc44	3.927 h	Sc	Ti, V, Cr
Sc44m	2.442 d	Sc	Ti
Sc45m	0.316 s	Sc	Ti
Sc46	83.79 d	Ar, K, Ca, Sc, Ti, V, Cr, Mn	Cl
Sc46m	18.7 s		Ca, Sc, Ti, V
Sc47	3.346 d	Ti, V, Cr, Mn	Ca, Sc
Sc48	1.820 d	Ti, V, Cr, Mn	
Sc49	57.2 m		Ca, Ti, V, Cr
Sc50	1.7083 m		Ti, V
Se73	7.1389 h		As, Se
Se73m	39.833 m		As, Se
Se75	119.64 d	As, Se, Br, Kr	
Se77m	17.36 s	As, Se	Ge, Br
Se79	$1.12 \cdot 10^6$ y	Zn, Ga, Ge, As, Se, Br, Kr, Rb	Cu, Sr, Y
Se79m	3.9 m	As	Se, Br
Se81	18.5 m	Se, Br	As
Se81m	57.25 m		As, Se, Br
Se82	$1.394 \cdot 10^{20}$ y	Rb	Se
Se83	22.333 m		Se, Br
Se83m	1.1683 m		Se
Si31	2.62 h	Mg, Al, Si, P, S	Cl, Mg
Si32	330 y	Na, Mg, Al, Si, P, S, Cl	Ar
Sm143	8.83 m		Sm
Sm143m	1.1 m		Sm
Sm145	340.0 d	Sm	Nd
Sm146	$1.0 \cdot 10^8$ y	Nd, Sm, Eu, Tb	
Sm147	$1.06 \cdot 10^{11}$ y	La, Ce, Pr, Nd, Sm, Eu, Gd, Tb	
Sm148	$6.971 \cdot 10^{15}$ y		Eu, Tb
Sm149	$2.0 \cdot 10^{15}$ y	Tb	Eu, Gd
Sm151	90.0 y	La, Pr, Nd, Sm, Eu, Gd, Tb, U	Ce, Th
Sm153	1.9292 d	Sm	Pr, Nd, Eu, Gd
Sm155	22.1 m	Sm	Nd
Sn111	35.3 m		In, Sn
Sn113	115.09 d	Sn	In
Sn113m	20.9 m		In, Sn
Sn117m	13.6 d	In, Sn	Cd, Sb
Sn119m	293 d	In, Sn, Sb	Te
Sn121	1.121 d	In, Sn, Sb, Te, I	
Sn121m	55 y	In, Sn, Sb, Te, I	
Sn123	129.2 d	Sn, Sb	I
Sn123m	40.1 m		Sn
Sn125	9.64 d		Sn
Sn125m	9.52 m		Sn
Sn126	$2.42 \cdot 10^5$ y	Sn, I	U
Sn127	2.1 h		Te
Sr83	1.3504 d		Sr
Sr85	64.849 d	Rb, Sr	
Sr85m	1.1268 h		Sr
Sr87m	2.808 h	Sr	Kr, Rb, Y, Zr
Sr89	50.52 d	Rb, Sr, Y	Zr, Nb, Mo, Th, U
Sr90	28.868 y	Rb, Sr, Y, Zr, Th, U	Nb, Mo
Sr91	9.52 h		Zr
Sr92	2.71 h		U
Ta177	2.35 d		Ta
Ta178	9.31 m		Ta, W, Re
Ta178m	2.3611 h	Ta	W, Re
Ta179	1.6099 y	Ta, W	Hf, Re, Os

Nuclide	$T_{1/2}$	Contributing elements	
		Primary	Secondary
Ta180	8.08 h	Ta	W, Re
Ta180m	$1.8 \cdot 10^{15}$ y	Ta	
Ta182	114.7 d	Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, W, Re	
Ta182m	0.283 s		Ta
Ta183	5.09 d	Hf, Ta	Tm, Yb, Lu, W, Re
Ta184	8.7 h		Tm, Yb, Lu, Hf, Ta, W, Re
Ta185	49.0 m		W, Re
Ta186	10.5 m		W, Re
Tb155	5.3241 d		Tb, Dy
Tb156	5.17 d	Tb	Gd, Dy, Ho
Tb156m	1.0167 d		Tb
Tb156n	5.1 h		Tb
Tb157	99.0 y	Tb, Dy	Gd, Ho, Er
Tb158	180.62 y	Gd, Tb, Dy, Ho	Er
Tb158m	10.5 s	Tb	Gd, Dy
Tb160	72.3 d	Sm, Eu, Gd, Tb, Dy, Ho	Ce, Pr, Nd, Er
Tb161	6.89 d	Eu, Gd, Tb, Dy	Nd, Sm, Ho
Tb162	7.6 m		Sm, Eu, Gd, Tb, Dy, Ho
Tb163	19.5 m		Dy
Tb164	3.0 m		Dy, Ho
Tc95	20.0 h		Ru
Tc95m	60.995 d		Ru
Tc96	4.28 d	Ru	Ru
Tc96m	51.5 m		Ru
Tc97	$2.6 \cdot 10^6$ y	Ru	Mo, Rh
Tc97m	90.2 d	Ru	Mo
Tc98	$4.197 \cdot 10^6$ y	Mo, Ru, Rh, Pd, Ag, Cd, In, Sn	Sn
Tc99	$2.113 \cdot 10^5$ y	Zr, Nb, Mo, Ru, Rh, Pd, Ag, Cd, U	Zr, Mo, Ru
Tc99m	6.01 h		Zr, Mo, Ru, Rh
Tc100	15.8 s		Mo, Ru, Rh
Tc101	14.2 m		Ru
Tc102	5.28 s		Ru
Tc102m	4.35 m		Ru
Tc104	18.4 m		Ru
Te119m	4.6875 d		Te
Te121	19.16 d	Sb, Te	Sn, I, Xe
Te121m	154 d	Sb	Sn, Te, I, Xe
Te123	$9.993 \cdot 10^{12}$ y	Sb, I	Sn
Te123m	119.7 d	Sb, Te	Sn, I, Xe
Te125m	58.0 d	Te	Sn, Sb, I, Xe
Te127	9.35 h	Te, I	Xe
Te127m	109.0 d	Te, I	Xe
Te129	1.16 h	Te, I	
Te129m	33.8 d	Te, I	
Te131	25.0 m		Te
Te132	3.23 d		U
Th227	18.718 d		Th
Th228	1.913 y	Th	U
Th229	7340.0 y	Th, U	
Th230	$7.54 \cdot 10^4$ y	Th, U	
Th231	1.0633 d	Th	
Th233	22.3 m		Th
Ti45	3.08 h		Ti
Ti51	5.8 m	Ti, V	Cr
Tl200	1.088 d		Pb
Tl201	3.041 d		Tl, Pb
Tl202	12.24 d	Hg, Tl, Pb	
Tl204	3.79 y	Pt, Au, Hg, Tl, Pb	Ir
Tl206	4.2 m	Tl, Bi	Hg, Pb
Tl206m	3.76 m	Bi	Hg, Tl, Pb
Tl207	4.77 m		Pb
Tl207m	1.33 s		Bi

Nuclide	$T_{1/2}$	Contributing elements	
		Primary	Secondary
Tl208	3.055 m	Th, U	Pb
Tl209	2.2 m		Th, U
Tm166	7.7 h		Er, Tm , Yb
Tm167	9.2396 d		Er, Tm , Yb
Tm168	93.102 d	Er, Tm, Yb	
Tm170	128.6 d	Gd, Tb, Dy, Ho, Er, Tm, Yb	Nd, Sm, Ho
Tm171	1.9203 y	Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb	Sm, Lu
Tm172	2.6505 d	Tb, Dy, Ho, Er, Tm, Lu	Eu, Gd, Yb
Tm173	8.25 h		Ho, Er, Tm, Yb
Tm174	5.4 m		Yb
Tm176	1.9 m		Yb
U230	20.8 d	Th	U
U232	69.8 y	U	Th
U233	$1.593 \cdot 10^5$ y	Th	U
U234	$2.457 \cdot 10^5$ y	Th	U
U236	$2.342 \cdot 10^7$ y		U
U237	6.75 d		U
U238	$4.468 \cdot 10^9$ y		U
U239	23.47 m		U
V48	15.974 d		V, Cr
V49	330 d	V, Cr	
V50	$1.49 \cdot 10^{17}$ y	V, Cr, Mn	
V52	3.745 m	Ti, V, Cr, Mn	Fe
V53	1.62 m		Cr, Mn
V54	49.8 s		Cr, Mn
W178	21.6 d		Ta, W, Re
W179	37.5 m		Ta, W, Re
W179m	6.4 m		Ta, W, Re
W181	120.98 d	W	Ta, Re, Os
W183m	5.25 s	W	Yb, Lu, Hf, Ta, Re
W185	75.1 d	Hf, Ta, W, Re	Tm, Yb, Lu, Os
W185m	1.6667 m		W
W187	23.85 h	W, Re	Ta
W188	69.444 d	Re	W, Os
Xe123	2.0806 h		Xe
Xe125	16.9 h		I, Xe
Xe125m	56.0 s		I, Xe
Xe127	36.44 d	Xe	Te, Cs, Ba
Xe127m	1.16 m		Xe
Xe129m	8.87 d	I, Xe	Te, Cs
Xe131m	11.87 d	Xe, Cs	Te, I, Ba
Xe133	5.243 d	Xe	Te, I, Cs, Ba, U
Xe133m	2.19 d		Xe, Cs
Xe134m	0.29 s	Xe	
Xe135	9.09 h	Xe	Ba
Xe135m	15.65 m		Xe
Xe137	3.8183 m		Xe
Y87	3.3461 d		Y
Y87m	12.889 h		Y
Y88	106.63 d	Y, Zr, Nb, Mo	Sr, Th, U
Y89m	16.05 s	Y, Zr	Sr, Nb, Mo
Y90	2.671 d	Rb, Sr, Y , Zr, Nb, Th	Mo, U
Y90m	3.19 h	Y, Nb	Zr
Y91	58.7 d	Y, Zr	Nb, Th, U
Y91m	58.7 d		Y, Zr
Y92	3.54 h		Zr, Th
Y94	19.1 m		Zr
Yb167	17.5 m		Yb
Yb169	32.01 d	Yb	
Yb169m	46.0 s		Yb
Yb175	4.185 d	Tm, Yb	Dy, Ho, Er, Lu
Yb176m	11.4 s	Yb	
Yb177	1.8889 h	Yb	Lu

Nuclide	$T_{1/2}$	Contributing elements	
		Primary	Secondary
Yb177m	6.41 s		Yb
Zn63	38.4 m	Zn	Cu
Zn65	244.26 d	Cu, Zn, Ga, Ge, As, Se	Ni, Br
Zn69	57 m	Zn, Ga	Ge
Zn69m	13.76 h	Zn, Ga	Ge
Zn71	2.45 m		Ga
Zn71m	3.94 h		Ga, Ge
Zn72	1.9375 d		Ge
Zr89	3.267 d	Zr	Nb, Mo
Zr89m	4.18 m		Zr
Zr90m	0.83 s	Zr, Nb	Mo
Zr93	$1.53 \cdot 10^6$ y	Sr, Y, Zr, Nb	Mo, Ru, Th, U
Zr95	64.03 d	Zr, Mo	Ru, Th, U
Zr97	16.9 h	Zr	

# Summary of Major reactions

Reaction	Daughter nuclide	Uncertainty (%)	Score	Exp data	
				Diff	Int
<b>H1(n,<math>\gamma</math>)H2</b>	H3	19.0	5	•	
<b>H2(n,<math>\gamma</math>)H3</b>	H3	32.0	5	•	
<b>He3(n,p)H3</b>	H3	50.0	4	•	
<b>Li6(n,<math>\alpha</math>)H3</b>	H3	11.0	4	•	
<b>Li6(n,p)He6</b>	He6	15.0	4	•	
<b>Li7(n,d)He6</b>	He6	67.0	2	•	
<b>Li7(n,<math>\gamma</math>)Li8</b>	Li8	32.0	4	•	
<b>Li7(n,n<math>\alpha</math>)H3</b>	H3	200.0	0		
<b>Be9(n,<math>\alpha</math>)He6</b>	He6	30.0	4	•	
<b>Be9(n,<math>\gamma</math>)Be10</b>	Li8, Be11, H3, Be10	32.0	2	•	
<b>Be9(n,t)Li7</b>	Li8, H3	5.0	4	•	
Be10(n, $\gamma$ )Be11	Li8, Be11	43.0	0		
Be10(n,n $\alpha$ )He6	He6	200.0	0		
<b>B10(n,<math>\alpha</math>)Li7</b>	Li8	20.0	4	•	
<b>B10(n,p)Be10</b>	Be11, Be10	40.0	2	•	
<b>B10(n,2<math>\alpha</math>)H3</b>	H3	46.0	6*	•	
<b>B10(n,n<math>\alpha</math>)Li6</b>	He6	200.0	0		
<b>B11(n,<math>\alpha</math>)Li8</b>	Li8	10.0	4	•	
<b>B11(n,p)Be11</b>	Be11	20.0	2	•	
<b>B11(n,d)Be10</b>	He6, Be10	29.0	2	•	
<b>B11(n,n2<math>\alpha</math>)H3</b>	H3	33.0	2	•	
<b>B11(n,<math>\gamma</math>)B12</b>	C14	35.0	2	•	
<b>C12(n,<math>\gamma</math>)C13</b>	C14	35.0	4	•	
<b>C12(n,<math>\alpha</math>)Be9</b>	He6, H3	20.0	4	•	
<b>C13(n,<math>\gamma</math>)C14</b>	C14, C15, H3	92.0	2	•	
<b>C13(n,<math>\alpha</math>)Be10</b>	Be10	60.0	0		
<b>C13(n,t)B11</b>	Li8, Be11, H3	30.0	2	•	
C14(n, $\gamma$ )C15	C15	71.0	2	•	
C14(n, $\alpha$ )Be11	Be11	60.0	0		
<b>N14(n,p)C14</b>	C15, Be11, H3, C14	20.0	4	•	
<b>N14(n,<math>\alpha</math>)B11</b>	Li8, Be11	15.0	4	•	
<b>N14(n,<math>\gamma</math>)N15</b>	N16	29.0	5	•	
<b>N14(n,2n)N13</b>	N13	8.0	6	•	
<b>N14(n,3<math>\alpha</math>)H3</b>	H3	33.0	4	•	
<b>N14(n,d)C13</b>	Be10	100.0	0	•	
<b>N15(n,2n)N14</b>	N13	40.0	0		
<b>N15(n,p)C15</b>	C15	20.0	2	•	
<b>N15(n,<math>\gamma</math>)N16</b>	N16	130.0	2	•	
<b>N15(n,d)C14</b>	C14	130.0	0		
<b>N15(n,n3<math>\alpha</math>)H3</b>	H3	60.0	0		
<b>O16(n,p)N16</b>	N16	10.0	6	•	
<b>O16(n,<math>\alpha</math>)C13</b>	H3, Be10	20.0	4	•	
<b>O16(n,d)N15</b>	C15, N13, H3, C14	51.0	2	•	
<b>O17(n,<math>\alpha</math>)C14</b>	C15, N16, H3, C14	36.0	4	•	
<b>O18(n,<math>\gamma</math>)O19</b>	O19, F18, Na24, F20	140.0	4	•	
<b>O18(n,n<math>\alpha</math>)C14</b>	C14	200.0	0		
<b>O18(n,<math>\alpha</math>)C15</b>	C15	22.0	2	•	
<b>F19(n,2n)F18</b>	F18	10.0	6	•	
<b>F19(n,p)O19</b>	O19	15.0	6	•	
<b>F19(n,t)O17</b>	H3	60.0	0		
<b>F19(n,nt)O16</b>	Be10	400.0	0		
<b>F19(n,<math>\alpha</math>)N16</b>	N16, Be10	11.0	4	•	
<b>F19(n,n<math>\alpha</math>)N15</b>	C14	200.0	0		
<b>F19(n,<math>\gamma</math>)F20</b>	Na24, F20, O19	47.0	4	•	
<b>F19(n,d)O18</b>	C14	100.0	0		
<b>Ne20(n,<math>\gamma</math>)Ne21</b>	Na24, O19, F20	30.0	1	•	
<b>Ne20(n,p)F20</b>	F20	50.0	0		

Reaction	Daughter nuclide	Uncertainty (%)	Score	Exp data	
				Diff	Int
Ne20(n,d)F19	F18, H3	110.0	0		
Ne20(n, $\alpha$ )O17	C14	30.0	2	•	
Ne20(n,n $\alpha$ )O16	Be10	200.0	0		
Ne21(n, $\gamma$ )Ne22	Na24	29.0	1	•	
Ne21(n, $\alpha$ )O18	O19, F20, C14	60.0	2	•	
Ne21(n,p)F21	F21	50.0	0		
Ne22(n, $\alpha$ )O19	O19	60.0	0		
Ne22(n,d)F21	F21	200.0	0		
Ne22(n, $\gamma$ )Ne23	Na24, Ne23, Na22	30.0	1	•	
Ne22(n,2n)Ne21	F21	40.0	0		
Na23(n, $\gamma$ )Na24	Na24, Ne23, P32, Si32, Al26	16.0	6*	•	•
Na23(n,2n)Na22	Na22	20.0	6	•	•
Na23(n,t)Ne21	H3	21.0	2	•	
Na23(n, $\alpha$ )F20	F20, C14, Be10	15.0	4	•	
Na23(n,p)Ne23	Ne23	20.0	5	•	•
Mg24(n, $\gamma$ )Mg25	Ne23, P32, Si32, Al26	30.0	2*	•	
Mg24(n,p)Na24	Na24	61.0	6	•	•
Mg24(n,d)Na23	Na22, H3	110.0	0		
Mg24(n,n $\alpha$ )Ne20	Ne23, C14, Be10	20.0	2*	•	
Mg24(n, $\alpha$ )Ne21	C14	30.0	2*	•	
Mg25(n, $\alpha$ )Ne22	Ne23, Na24	20.0	2	•	
Mg25(n,p)Na25	Na25	11.0	6	•	•
Mg25(n,d)Na24	Na24	160.0	0		
Mg25(n,n $\alpha$ )Ne21	C14	200.0	0		
Mg25(n,t)Na23	H3	60.0	0		
Mg25(n, $\gamma$ )Mg26	P32, Si32, Al26	32.0	2	•	
Mg26(n, $\gamma$ )Mg27	P32, Si32, Al26, Mg27, S131, Cl36	22.0	4	•	
Al26(n,n $\alpha$ )Na22	Na22	200.0	0		
Al27(n, $\gamma$ )Al28	P32, Si32, Si31, Cl36, Al28	37.0	4	•	
Al27(n, $\alpha$ )Na24	Na24, C14, Be10	60.0	6	•	•
Al27(n,2n)Al26	Al26, Na22	65.0	4/3	•	
Al27(n,t)Mg25	H3	20.0	4	•	
Al27(n,p)Mg27	Mg27	10.0	6	•	•
Si28(n, $\gamma$ )Si29	P32, Si32, Si31, Cl36	25.0	4	•	
Si28(n,p)Al28	Al28	5.0	6	•	•
Si28(n,d)Al27	Na24, Na22, Al26	23.0	1	•	
Si28(n, $\alpha$ )Mg25	Na24, C14	10.0	2	•	
Si28(n,n $\alpha$ )Mg24	Be10, C14	50.0	0		
Si29(n, $\gamma$ )Si30	P32, Si32, Si31, Cl36	42.0	2	•	
Si29(n,p)Al29	Al29	10.0	6	•	•
Si29(n,t)Al27	H3	60.0	0		
Si29(n, $\alpha$ )Mg26	Na22	30.0	2	•	
Si30(n, $\gamma$ )Si31	P32, Si32, Si31, Cl36	25.0	4	•	
Si31(n, $\gamma$ )Si32	Si32	79.0	2	•	
P31(n, $\gamma$ )P32	P32, Cl36, Si31, S35, Si32	32.0	4	•	
P31(n, $\alpha$ )Al28	Al28, C14	10.0	6	•	•
P31(n,n $\alpha$ )Al27	Na24, Na22, C14, Al26, Be10	200.0	0		
P31(n,p)Si31	Si31	10.0	6*	•	•
P31(n,2n)P30	P30	30.0	4	•	
P31(n,t)Si29	H3	60.0	0		
P32(n,p)Si32	Si32	50.0	0		
S32(n, $\gamma$ )S33	Cl36, Si31, S35, Si32, P32, P33, H3	24.0	2	•	
S32(n,d)P31	Al26, Al28, Na24, H3	120.0	2	•	
S32(n, $\alpha$ )Si29	Si31, Al29, Na22, H3	60.0	4	•	
S32(n,n $\alpha$ )Si28	Al26, Al28, Na24, Na22	200.0	0		
S32(n,p)P32	Si32, P32	10.0	6	•	•
S32(n,2p)Si31	Si31	200.0	0		
S33(n, $\gamma$ )S34	Cl36, S35	23.0	2	•	
S33(n, $\alpha$ )Si30	Si31, Si32, P32	60.0	3	•	
S33(n,2p)Si32	Si32	200.0	0		

Reaction	Daughter nuclide	Uncertainty (%)	Score	Exp data	
				Diff	Int
S33(n,p)P33	P33, H3	40.0	2	•	
S34(n, $\gamma$ )S35	Cl36, S35, Si32, Cl38, P32, H3, S37	27.0	2	•	
S34(n, $\alpha$ )Si31	Si31	12.0	5	•	•
S34(n,d)P33	P33	160.0	0		
S35(n, $\gamma$ )S36	S37	800.0	0		
S35(n, $\alpha$ )Si32	Si32	60.0	0		
S36(n,2n)S35	Cl36, S35	40.0	0		
S36(n, $\gamma$ )S37	S37, Cl36, Cl38	59.0	2	•	
S36(n,n $\alpha$ )Si32	Si32	200.0	0		
S36(n, $\alpha$ )Si33	P33	60.0	0		
Cl35(n, $\alpha$ )P32	P32	60.0	4	•	
Cl35(n, $\gamma$ )Cl36	Cl36, Cl38, S37, Ar41, Ar39	17.0	2	•	
Cl35(n,p)S35	S37, S35, Si32, H3	20.0	4	•	
Cl35(n,2n)Cl34m	Cl34m	30.0	6	•	•
Cl35(n,n $\alpha$ )P31	Na22	200.0	0		
Cl35(n,t)S33	H3	60.0	0		
Cl36(n, $\gamma$ )Cl37	Cl38, Ar41, Ar39	67.0	2	•	
Cl36(n, $\alpha$ )P33	P33	20.0	0		
Cl36(n,p)S36	S37	20.0	2	•	
Cl36(n,n $\alpha$ )P32	P32	200.0	0		
Cl37(n, $\gamma$ )Cl38	Cl38, Ar41, K42, Ar39	65.0	4/2	•	
Cl37(n,t)S35	H3	60.0	0		
Cl37(n,p)S37	S37	20.0	5	•	•
Cl37(n,d)S36	Si32	110.0	0		
Cl37(n,2n)Cl36	Cl36	40.0	0		
Cl37(n,n $\alpha$ )P33	P33	200.0	0		
Ar36(n,p)Cl36	S37, Cl36	50.0	2	•	
Ar36(n, $\gamma$ )Ar37	S37, Cl38, P32, Ar37, S35, Cl36	25.0	2	•	
Ar36(n, $\alpha$ )S33	P33	30.0	2	•	
Ar37(n,p)Cl37	H3	50.0	2	•	
Ar37(n, $\alpha$ )S34	S37, P32, Cl36, S35	51.0	2	•	
Ar38(n, $\gamma$ )Ar39	Ar41, K42, Ar39, K40	60.0	2	•	
Ar38(n,2n)Ar37	Ar37	40.0	0		
Ar39(n,d)Cl38	Cl38	130.0	0		
Ar39(n,n $\alpha$ )S35	P32, S35	200.0	0		
Ar39(n,2n)Ar38	Ar37	40.0	0		
Ar39(n, $\gamma$ )Ar40	Ar41, K42	83.0	2	•	
Ar40(n,2n)Ar39	Cl38, Cl38, P32, Ar37, S35, Ar39	40.0	0		
Ar40(n,d)Cl39	Cl39	180.0	0		
Ar40(n, $\alpha$ )S37	S37, P33, Cl36	17.0	4	•	
Ar40(n, $\gamma$ )Ar41	Ar41, K42, Cl39, Sc46, Ar42	27.0	2	•	
Ar40(n,n $\alpha$ )S36	P33	200.0	0		
Ar41(n, $\gamma$ )Ar42	Ar42	50.0	2	•	
K39(n,2n)K38	K38	20.0	6/4	•	•
K39(n, $\gamma$ )K40	Cl38, Ar41, K42, Ar42, Ar39, K40	24.0	4	•	
K39(n,p)Ar39	Cl38, S35, Ar39	20.0	2	•	
K39(n,d)Ar38	Ar37	110.0	0		
K39(n, $\alpha$ )Cl36	P32, P33, Ar37, S35, Cl36	60.0	4	•	
K39(n,n $\alpha$ )Cl35	P32	20.0	4	•	
K40(n,p)Ar40	Ar41, Ar42	50.0	2	•	
K40(n, $\alpha$ )Cl37	Cl38, Ar39	60.0	2	•	
K40(n, $\gamma$ )K41	K42	61.0	2	•	
K40(n,n $\alpha$ )Cl36	Cl36	200.0	0		
K41(n, $\alpha$ )Cl38	Cl38	61.0	6	•	•
K41(n,2n)K40	K40	40.0	0		
K41(n,p)Ar41	Ar41	10.0	4	•	
K41(n, $\gamma$ )K42	K42, Cl39, Sc46, Ca45, Ar42, K43	38.0	4	•	
K41(n,n $\alpha$ )Cl37	Cl36	200.0	0		
K42(n, $\gamma$ )K43	K43	250.0	0		
K42(n,p)Ar42	Ar42	50.0	0		

Reaction	Daughter nuclide	Uncertainty (%)	Score	Exp data	
				Diff	Int
K42(n, $\alpha$ )Cl39	Cl39	60.0	0		
<b>Ca40(n,<math>\alpha</math>)Ar37</b>	S37, Cl38, Ar37, S35, H3, Cl36	20.0	4	•	
<b>Ca40(n,d)K39</b>	K38, Ar39, Cl36	100.0	0		
<b>Ca40(n,<math>\gamma</math>)Ca41</b>	K42, K43, H3, Ar39, Ca41, K40	53.0	4	•	
<b>Ca40(n,p)K40</b>	K40	20.0	2	•	
<b>Ca40(n,t)K38</b>	K38, H3	67.0	5/0	•	•
<b>Ca40(n,2p)Ar39</b>	Cl38, S35, Ar39	200.0	0		
<b>Ca41(n,p)K41</b>	K42, K43, H3	50.0	2	•	
<b>Ca41(n,<math>\alpha</math>)Ar38</b>	Ar39, K40	60.0	2	•	
<b>Ca41(n,d)K40</b>	K40, Cl36	100.0	0		
<b>Ca42(n,2n)Ca41</b>	Ca41, K40, Cl36	40.0	0		
<b>Ca42(n,<math>\gamma</math>)Ca43</b>	Sc46, Ca45	26.0	2	•	
<b>Ca42(n,p)K42</b>	K42	10.0	4	•	
<b>Ca42(n,<math>\alpha</math>)Ar39</b>	Ar39, K40	60.0	0		
<b>Ca43(n,<math>\gamma</math>)Ca44</b>	Sc46, Ca45	13.0	2	•	
<b>Ca43(n,p)K43</b>	K43	13.0	4	•	
<b>Ca43(n,no<math>\alpha</math>)Ar39</b>	Ar39	200.0	0		
<b>Ca44(n,<math>\gamma</math>)Ca45</b>	Sc46, Ca45, Ca47	42.0	2	•	
<b>Ca44(n,2n)Ca43</b>	K43	40.0	0		
<b>Ca44(n,<math>\alpha</math>)Ar41</b>	K40	10.0	4	•	
<b>Ca45(n,<math>\gamma</math>)Ca46</b>	Ca47	76.0	2	•	
<b>Ca45(n,<math>\alpha</math>)Ar42</b>	Ar42	60.0	0		
<b>Ca46(n,2n)Ca45</b>	Ca45	40.0	0		
<b>Ca46(n,<math>\gamma</math>)Ca47</b>	Ca47	26.0	2	•	
<b>Ca48(n,2n)Ca47</b>	Ca47, Sc46	10.0	6	•	•
<b>Ca48(n,<math>\gamma</math>)Ca49</b>	Ca49	25.0	2	•	
<b>Sc45(n,<math>\gamma</math>)Sc46</b>	Sc46	43.0	3	•	
<b>Sc45(n,n')Sc45m</b>	Sc45m	100.0	2*	•	
<b>Sc45(n,2n)Sc44</b>	Sc44	15.0	5*	•	•
<b>Sc45(n,2n)Sc44m</b>	Sc44m	15.0	6*	•	•
<b>Sc45(n,<math>\alpha</math>)K42</b>	K42, Ar39, Ca41, K40	8.0	6*	•	•
<b>Sc45(n,p)Ca45</b>	Ca45, H3, Ar42	10.0	4	•	
<b>Sc45(n,t)Ca43</b>	H3	60.0	0		
<b>Sc45(n,no<math>\alpha</math>)K41</b>	Cl36, K40	200.0	0		
<b>Sc47(n,<math>\gamma</math>)Sc48</b>	Sc48	140.0	0		
<b>Ti46(n,p)Sc46</b>	Sc46	20.0	6*/4	•	•
<b>Ti46(n,no<math>\alpha</math>)Ca42</b>	Ar39, Ca41, Cl36, K40	200.0	0		
<b>Ti46(n,<math>\alpha</math>)Ca43</b>	Ar39	60.0	0		
<b>Ti46(n,d)Sc45</b>	K42	120.0	0	•	
<b>Ti47(n,d)Sc46</b>	Sc46	130.0	0		
<b>Ti47(n,p)Sc47</b>	Sc48, Sc47, H3	10.0	6*	•	•
<b>Ti47(n,<math>\alpha</math>)Ca44</b>	Sc46, Ca45, K40	60.0	0		
<b>Ti47(n,t)Sc45</b>	H3	85.0	0		
<b>Ti47(n,no<math>\alpha</math>)Ca43</b>	Ar39	200.0	0		
<b>Ti48(n,p)Sc48</b>	Sc48	10.0	6	•	•
<b>Ti48(n,<math>\gamma</math>)Ti49</b>	Ti51, Ca47	23.0	2	•	
<b>Ti48(n,<math>\alpha</math>)Ca45</b>	K42, Ca45, Ar42, Ar39, Ca41	10.0	4	•	
<b>Ti48(n,d)Sc47</b>	Sc47	79.0	2	•	
<b>Ti48(n,2n)Ti47</b>	Sc47, H3	40.0	1	•	
<b>Ti49(n,<math>\gamma</math>)Ti50</b>	Ti51	31.0	2	•	
<b>Ti49(n,<math>\alpha</math>)Ca46</b>	Ca47	60.0	0		
<b>Ti49(n,2n)Ti48</b>	K42, Ca45, Ar42	40.0	0		
<b>Ti50(n,<math>\gamma</math>)Ti51</b>	V52, Ti51, Mn56	15.0	4	•	
<b>Ti50(n,<math>\alpha</math>)Ca47</b>	Ca47	8.0	5	•	•
<b>V49(n,<math>\alpha</math>)Sc46</b>	Sc46	85.0	0		
<b>V50(n,p)Ti50</b>	Ti51, H3	50.0	2	•	
<b>V50(n,<math>\alpha</math>)Sc47</b>	Sc48, Sc47	15.0	2	•	
<b>V50(n,no<math>\alpha</math>)Sc46</b>	Sc46	67.0	0	•	
<b>V50(n,2n)V49</b>	Sc46, V49	16.0	2	•	
<b>V51(n,<math>\gamma</math>)V52</b>	V52, Mn56, Fe59, Fe60	19.0	6	•	•

Reaction	Daughter nuclide	Uncertainty (%)	Score	Exp data	
				Diff	Int
<b>V51(n,2n)V50</b>	Sc47, Sc46, V49, V50	20.0	4	•	
<b>V51(n,p)Ti51</b>	Ti51	10.0	6	•	•
<b>V51(n,t)Ti49</b>	H3	30.0	2	•	
<b>V51(n,<math>\alpha</math>)Sc48</b>	K42, Sc48, Ca45, Ar42, Ar39, Ca41	6.0	6	•	•
<b>Cr50(n,<math>\gamma</math>)Cr51</b>	V52, Cr51, H3	17.0	2	•	
<b>Cr50(n,d)V49</b>	Sc46, V49	49.0	2	•	
<b>Cr50(n,<math>\alpha</math>)Ti47</b>	Sc47, Sc46, Ar39, K40	20.0	2	•	
<b>Cr50(n,n<math>\alpha</math>)Ti46</b>	Ca41	200.0	0		
<b>Cr51(n,p)V51</b>	H3	50.0	0		
<b>Cr52(n,<math>\gamma</math>)Cr53</b>	Mn56, Fe59, Fe60	9.7	4	•	
<b>Cr52(n,p)V52</b>	V52	10.0	6	•	•
<b>Cr52(n,<math>\alpha</math>)Ti49</b>	K42, Ca45, Ar42	50.0	2	•	
<b>Cr52(n,2n)Cr51</b>	Sc48, Sc47, Cr51, V50	5.0	6	•	•
<b>Cr52(n,d)V51</b>	Sc48	31.0	2	•	
<b>Cr52(n,t)V50</b>	H3	60.0	0		
<b>Cr53(n,<math>\gamma</math>)Cr54</b>	Mn56, Fe59, Fe60, Cr55, Co60	24.0	2	•	
<b>Cr53(n,t)V51</b>	H3	60.0	0		
<b>Cr53(n,<math>\alpha</math>)Ti50</b>	Ca47	8.0	2	•	
<b>Cr54(n,<math>\gamma</math>)Cr55</b>	Mn56, Fe59, Fe60, Cr55, Co60, Mn53	36.0	2	•	
<b>Cr54(n,n<math>\alpha</math>)Ti50</b>	Ca47	200.0	0		
<b>Cr54(n,2n)Cr53</b>	Ca47	40.0	0		
<b>Mn54(n,2n)Mn53</b>	Mn53	40.0	0		
<b>Mn54(n,n<math>\alpha</math>)V50</b>	Sc47, Sc46, V50	200.0	0		
<b>Mn55(n,2n)Mn54</b>	Mn53, Sc47, Ca47, Sc46, Mn54, V50	10.0	6	•	•
<b>Mn55(n,<math>\gamma</math>)Mn56</b>	Mn56, Fe59, Fe60, Co60, Cr55, Ni63	9.0	6	•	•
<b>Mn55(n,p)Cr55</b>	Cr55	20.0	6	•	•
<b>Mn55(n,<math>\alpha</math>)V52</b>	V52, K42, Ca45, Ar42	15.0	6	•	•
<b>Mn55(n,t)Cr53</b>	H3	20.0	2	•	
<b>Mn55(n,n<math>\alpha</math>)V51</b>	K42, Sc48, Ca45, Ar42, V50	200.0	0		
<b>Fe54(n,<math>\gamma</math>)Fe55</b>	Mn56, Fe55	28.0	2	•	
<b>Fe54(n,p)Mn54</b>	Mn54, H3	10.0	6	•	•
<b>Fe54(n,d)Mn53</b>	Mn53	50.0	2	•	
<b>Fe55(n,t)Mn53</b>	H3	60.0	0		
<b>Fe56(n,2n)Fe55</b>	Mn54, Fe55, H3	5.0	4	•	
<b>Fe56(n,<math>\alpha</math>)Cr53</b>	Cr55	5.0	4	•	
<b>Fe56(n,<math>\gamma</math>)Fe57</b>	Fe59, Fe60, Co60, Cr55, Ni63	30.0	4	•	
<b>Fe56(n,p)Mn56</b>	Mn56	3.0	6	•	•
<b>Fe56(n,t)Mn54</b>	H3	15.0	2	•	
<b>Fe57(n,<math>\gamma</math>)Fe58</b>	Fe59, Fe60, Co60, Ni63	42.0	2	•	
<b>Fe57(n,<math>\alpha</math>)Cr54</b>	Cr55	15.0	1	•	
<b>Fe58(n,<math>\gamma</math>)Fe59</b>	Fe59, Fe60, Co60, Ni63	46.0	6	•	
<b>Fe59(n,<math>\gamma</math>)Fe60</b>	Fe60	34.0	2	•	
<b>Co57(n,n<math>\alpha</math>)Mn53</b>	Mn53	200.0	0		
<b>Co58(n,n<math>\alpha</math>)Mn54</b>	Mn54, Mn53	200.0	0		
<b>Co59(n,2n)Co58</b>	Co58, Mn54, Mn53	40.0	1/5	•	•
<b>Co59(n,p)Fe59</b>	Fe59	15.0	6*	•	•
<b>Co59(n,<math>\gamma</math>)Co60</b>	Co60, Ni63, Fe59, H3, Ni59, Fe60	98.0	0	•	•
<b>Co59(n,<math>\gamma</math>)Co60m</b>	Co60m	98.0	5	•	•
<b>Co59(n,n<math>\alpha</math>)Mn55</b>	Mn54, Mn53	200.0	0		
<b>Co59(n,t)Fe57</b>	H3	30.0	4	•	
<b>Co60(n,<math>\gamma</math>)Co61</b>	Ni63, Fe59, Fe60	96.0	2	•	
<b>Co60(n,p)Fe60</b>	H3, Fe60	50.0	0		
<b>Ni58(n,p)Co58</b>	Co58	20.0	4	•	•
<b>Ni58(n,d)Co57</b>	Co57, Mn53	11.0	6	•	•
<b>Ni58(n,<math>\alpha</math>)Fe55</b>	Fe55	5.0	4	•	
<b>Ni58(n,<math>\gamma</math>)Ni59</b>	Co60, Ni59, Fe60	18.0	2	•	
<b>Ni58(n,n<math>\alpha</math>)Fe54</b>	Mn53	25.0	1	•	
<b>Ni59(n,p)Co59</b>	Co60	20.0	4	•	
<b>Ni59(n,<math>\alpha</math>)Fe56</b>	Fe60	40.0	2	•	
<b>Ni60(n,<math>\gamma</math>)Ni61</b>	Fe59, Ni63	23.0	4	•	

Reaction	Daughter nuclide	Uncertainty (%)	Score	Exp data	
				Diff	Int
<b>Ni60</b> (n,2n)Ni59	Ni59	20.0	1	•	
<b>Ni60</b> (n,p)Co60	Co60, Fe60	30.0	6	•	•
<b>Ni61</b> (n, $\gamma$ ) <b>Ni62</b>	Ni63	29.0	2	•	
<b>Ni61</b> (n,d)Co60	Co60	150.0	1	•	
<b>Ni61</b> (n, $\alpha$ ) <b>Fe58</b>	Fe59, Fe60, Co60	40.0	2	•	
<b>Ni62</b> (n, $\gamma$ )Ni63	Ni63, Ni65, Cu64, Fe60	8.8	2	•	
<b>Ni63</b> (n, $\gamma$ ) <b>Ni64</b>	Ni65	86.0	2	•	
Ni63(n, $\alpha$ )Fe60	Fe60	60.0	0		
<b>Ni64</b> (n, $\gamma$ )Ni65	Ni65, Cu64	32.0	4	•	
<b>Ni64</b> (n,2n)Ni63	Ni63	7.0	2	•	
<b>Cu63</b> (n,2n)Cu62	Cu62	5.0	6	•	•
<b>Cu63</b> (n, $\gamma$ )Cu64	Cu64, Zn65, Fe60	54.0	5*	•	•
<b>Cu63</b> (n, $\alpha$ )Co60	Co60, Ni59, Fe60	30.0	3	•	•
<b>Cu63</b> (n,p)Ni63	Ni63, Fe60	50.0	2	•	
<b>Cu65</b> (n, $\gamma$ )Cu66	Cu66, Zn65	12.0	6*	•	•
<b>Cu65</b> (n,2n)Cu64	Cu64, Zn65, Ni63, Co60, Ni59	8.0	6	•	•
<b>Zn64</b> (n,2n)Zn63	Zn63	10.0	6	•	•
<b>Zn64</b> (n, $\gamma$ )Zn65	Zn65	55.0	4	•	
<b>Zn64</b> (n,p)Cu64	Cu64, Ni63	12.0	6*	•	•
<b>Zn64</b> (n, $\alpha$ ) <b>Ni61</b>	Fe60, Co60	30.0	4	•	
<b>Zn64</b> (n,d) <b>Cu63</b>	Co60	100.0	0		
<b>Zn64</b> (n,n $\alpha$ ) <b>Ni60</b>	Co60, Ni59	30.0	2	•	
Zn65(n,n $\alpha$ ) <b>Ni61</b>	Co60	200.0	0		
Zn65(n,2n) <b>Zn64</b>	Ni59	40.0	0		
<b>Zn66</b> (n,2n)Zn65	Zn65, Cu64, Co60, Ni59	5.0	4	•	
<b>Zn66</b> (n, $\alpha$ )Ni63	Cu64, Co60, Ni63, Fe60, Zn65	60.0	2	•	
<b>Zn66</b> (n, $\gamma$ ) <b>Zn67</b>	Cu67	28.0	2	•	
<b>Zn67</b> (n,p)Cu67	Cu67	15.0	3	•	
<b>Zn67</b> (n,n $\alpha$ )Ni63	Ni63, Fe60	200.0	0		
<b>Zn68</b> (n, $\gamma$ )Zn69	Ga70, Zn69	96.0	4	•	
<b>Zn68</b> (n, $\gamma$ )Zn69m	Zn69m	95.0	5*	•	•
<b>Zn68</b> (n,2n) <b>Zn67</b>	Ni63, Fe60	20.0	1	•	
<b>Zn70</b> (n,2n)Zn69	Ga70, Zn69	30.0	2	•	
<b>Zn70</b> (n,2n)Zn69m	Zn69m	30.0	4	•	
<b>Zn70</b> (n, $\gamma$ )Zn71	Ga70	88.0	2	•	
<b>Zn70</b> (n, $\gamma$ )Zn71m	Ga70	80.0	2	•	
<b>Ga69</b> (n, $\gamma$ )Ga70	Ga70, Cu67, Ge71, H3	34.0	4	•	
<b>Ga69</b> (n,2n)Ga68	Ga68, Ni63, Fe60	10.0	6	•	•
<b>Ga69</b> (n,p)Zn69	Zn69	30.0	2	•	
<b>Ga69</b> (n,p)Zn69m	Zn69m	30.0	2	•	
<b>Ga69</b> (n, $\alpha$ )Cu66	Cu67, Zn65, Ni63, Fe60	7.0	4	•	
<b>Ga69</b> (n,t) <b>Zn67</b>	H3	60.0	0		
<b>Ga69</b> (n,n $\alpha$ ) <b>Cu65</b>	Zn65, Ni59	200.0	0		
<b>Ga71</b> (n, $\gamma$ )Ga72	Zn69, Zn69m, Ga72, Ge71, H3, Se79	28.0	4	•	
<b>Ga71</b> (n,2n)Ga70	Ga70, Ge69, Ge71	15.0	6	•	•
<b>Ga71</b> (n,n $\alpha$ )Cu67	Cu67	60.0	2	•	
<b>Ga71</b> (n,t)Zn69	H3	85.0	0		
Ga72(n, $\gamma$ )Ga73	Se79	96.0	0		
Ga72(n,p)Zn72	H3	50.0	0		
<b>Ge70</b> (n, $\gamma$ )Ge71	Ge71, H3, Ga72	18.0	2	•	
<b>Ge70</b> (n,2n)Ge69	Ge69	12.0	4	•	
<b>Ge70</b> (n, $\alpha$ ) <b>Zn67</b>	Cu67, Ni63, Fe60	60.0	0		
<b>Ge70</b> (n,p)Ga70	Ga70	20.0	2	•	
<b>Ge70</b> (n,n $\alpha$ ) <b>Zn66</b>	Zn65, Co60, Ni63, Fe60, Ni59	200.0	0		
Ge71(n,p) <b>Ga71</b>	H3	50.0	0		
<b>Ge72</b> (n, $\alpha$ )Zn69	Zn69, Ga70	20.0	2	•	
<b>Ge72</b> (n, $\alpha$ )Zn69m	Zn69m	20.0	3	•	
<b>Ge72</b> (n,2n)Ge71	Ge71, Ga70, H3	40.0	0		
<b>Ge72</b> (n, $\gamma$ ) <b>Ge73</b>	Se79	62.0	0	•	
<b>Ge72</b> (n,p)Ga72	Ga72	7.0	4	•	

Reaction	Daughter nuclide	Uncertainty (%)	Score	Exp data	
				Diff	Int
<b>Ge73(n,<math>\gamma</math>)Ge74</b>	Se79	78.0	2	•	
<b>Ge73(n,t)Ga71</b>	H3	60.0	0		
<b>Ge74(n,<math>\gamma</math>)Ge75</b>	Se79, Ge75, As76, Kr81	72.0	2	•	
<b>Ge76(n,<math>\gamma</math>)Ge77</b>	Ge77, As77, Kr81, Se79	92.0	2	•	
<b>Ge76(n,<math>\gamma</math>)Ge77m</b>	As77, Kr81, Se79	92.0	2	•	
<b>Ge76(n,2n)Ge75</b>	Ge75, As76, As74	40.0	6	•	•
<b>As75(n,<math>\gamma</math>)As76</b>	Se79, As76, Kr81, Se77m, Se79m, Ge75, Br82, As77, Se75, H3	23.0	4	•	
<b>As75(n,2n)As74</b>	As74, Ge71, As73, Se75, Zn65, Co60, Ni63, Ni59, Fe60	10.0	4*	•	
<b>As75(n,p)Ge75</b>	Ge75	30.0	6	•	•
<b>As75(n,<math>\alpha</math>)Ga72</b>	Ga72, Ge71	10.0	4	•	
<b>As75(n,t)Ge73</b>	H3	85.0	0		
<b>As76(n,<math>\gamma</math>)As77</b>	As77	94.0	0		
<b>Se74(n,<math>\alpha</math>)Ge71</b>	Ge71	60.0	0		
<b>Se74(n,d)As73</b>	As73	100.0	0		
<b>Se74(n,2n)Se73</b>	As73	20.0	4	•	
<b>Se74(n,<math>\gamma</math>)Se75</b>	Se75, Se77m, As76	23.0	2	•	
<b>Se74(n,n<math>\alpha</math>)Ge70</b>	Zn65, Co60, Ni63, Ni59, Fe60	200.0	0		
<b>Se75(n,<math>\gamma</math>)Se76</b>	Se77m	92.0	2	•	
<b>Se76(n,<math>\gamma</math>)Se77</b>	Se79, Kr81, Se79m, Ge75, Br82, As77, H3	69.0	2	•	
<b>Se76(n,<math>\gamma</math>)Se77m</b>	Se77m	61.0	2	•	
<b>Se76(n,2n)Se75</b>	Se75, As74	15.0	4	•	
<b>Se76(n,p)As76</b>	As76	20.0	4	•	
<b>Se77(n,<math>\gamma</math>)Se78</b>	Se79, Kr81, Se79m, Ge75, Br82	39.0	2	•	
<b>Se77(n,<math>\alpha</math>)Ge74</b>	Ge75	60.0	2	•	
<b>Se77(n,p)As77</b>	As77, H3	14.0	4	•	
<b>Se77(n,t)As75</b>	H3	60.0	0		
<b>Se77(n,2n)Se76</b>	Se75	40.0	0		
<b>Se78(n,<math>\gamma</math>)Se79</b>	Se79, Br82	90.0	2	•	
<b>Se78(n,<math>\gamma</math>)Se79m</b>	Kr81, Se79m	91.0	2	•	
<b>Se78(n,2n)Se77</b>	Se75	61.0	0*		
<b>Se78(n,2n)Se77m</b>	Se77m	20.0	6	•	•
<b>Se78(n,<math>\alpha</math>)Ge75</b>	Ge75	30.0	1	•	
<b>Se79(n,<math>\gamma</math>)Se80</b>	Br82	96.0	1	•	
<b>Se79(n,t)As77</b>	H3	60.0	0		
<b>Se80(n,<math>\gamma</math>)Se81</b>	Br82, Se81, Kr85	68.0	4/3	•	
<b>Se80(n,2n)Se79</b>	H3, Se79	20.0	4/6	•	•
<b>Se82(n,2n)Se81</b>	Se81, Br82, Kr81	20.0	5*/2	•	•
<b>Se82(n,<math>\gamma</math>)Se83m</b>	Kr85	68.0	2	•	
<b>Se82(n,<math>\gamma</math>)Se83</b>	Kr85	69.0	2	•	
<b>Br79(n,<math>\gamma</math>)Br80</b>	Kr81, Br80, Se81, Br82	83.0	4	•	
<b>Br79(n,<math>\gamma</math>)Br80m</b>	Br80m	83.0	4	•	
<b>Br79(n,n')Br79m</b>	Br79m	60.0	4	•	
<b>Br79(n,2n)Br78</b>	Br78, Se75	15.0	6	•	•
<b>Br79(n,<math>\alpha</math>)As76</b>	As76, Se75	13.0	4	•	
<b>Br79(n,p)Se79</b>	H3, Se79	62.0	2	•	
<b>Br79(n,t)Se77</b>	H3	85.0	0		
<b>Br79(n,n<math>\alpha</math>)As75</b>	As74	200.0	0		
<b>Br81(n,<math>\gamma</math>)Br82</b>	Br82, Kr85, Kr81, Rb86, Se79	92.0	2	•	
<b>Br81(n,2n)Br80</b>	Kr81, Br80, Kr79, Se79	20.0	6	•	•
<b>Br81(n,2n)Br80m</b>	Br80m	20.0	2	•	
<b>Br81(n,p)Se81</b>	Se81	65.0	1/2	•	
<b>Br81(n,t)Se79</b>	H3	85.0	0		
<b>Br82(n,<math>\gamma</math>)Br83</b>	Rb86, Kr85	90.0	0		
<b>Kr78(n,p)Br78</b>	Br78	50.0	0		
<b>Kr78(n,<math>\gamma</math>)Kr79</b>	Kr79, Br82	80.0	2	•	
<b>Kr78(n,<math>\alpha</math>)Se75</b>	Se75	60.0	0		
<b>Kr80(n,2n)Kr79</b>	Kr79, Br78	30.0	2	•	
<b>Kr80(n,<math>\gamma</math>)Kr81</b>	Kr81, Br82	94.0	2	•	

Reaction	Daughter nuclide	Uncertainty (%)	Score	Exp data	
				Diff	Int
<b>Kr80(n,<math>\gamma</math>)Kr81m</b>	Br82	94.0	2	•	
<b>Kr82(n,<math>\gamma</math>)Kr83</b>	Kr85, Rb86	97.0	2	•	
<b>Kr82(n,<math>\gamma</math>)Kr83m</b>	Kr83m	97.0	2	•	
<b>Kr82(n,2n)Kr81</b>	Kr81	63.0	0/2	•	
<b>Kr82(n,<math>\alpha</math>)Se79</b>	Se79	85.0	0		
<b>Kr82(n,p)Br82</b>	Br82	62.0	0	•	
<b>Kr83(n,<math>\gamma</math>)Kr84</b>	Kr85, Rb86	31.0	4*	•	
<b>Kr83(n,<math>\alpha</math>)Se80</b>	Se79	60.0	0		
<b>Kr83(n,2n)Kr82</b>	Kr81	40.0	0		
<b>Kr84(n,<math>\gamma</math>)Kr85</b>	Kr85	64.0	2	•	
<b>Kr84(n,<math>\gamma</math>)Kr85m</b>	Rb86, Kr85m	64.0	2	•	
<b>Kr84(n,2n)Kr83</b>	Kr81, Se79	72.0	0		
<b>Kr84(n,2n)Kr83m</b>	Kr83m	72.0	0		
<b>Kr84(n,h)Se82</b>	Se82	90.0	0		
Kr85(n, $\alpha$ )Se82	Se82	60.0	0		
<b>Kr86(n,<math>\gamma</math>)Kr87</b>	Kr87, Rb86	45.0	2	•	
<b>Kr86(n,2n)Kr85</b>	Rb84, Kr85	63.0	0		
<b>Kr86(n,2n)Kr85m</b>	Kr85m, Rb84	63.0	2	•	
<b>Rb85(n,2n)Rb84</b>	Rb84, Kr81, Se79, Se82	30.0	3/6	•	•
<b>Rb85(n,<math>\gamma</math>)Rb86</b>	Rb86	79.0	4	•	
<b>Rb85(n,<math>\alpha</math>)Br82</b>	Br82, Kr81, Se79	40.0	0	•	
<b>Rb85(n,p)Kr85</b>	Kr85, H3, Se82	20.0	0/3	•	
<b>Rb85(n,t)Kr83</b>	H3	85.0	0		
<b>Rb85(n,n<math>\alpha</math>)Br81</b>	Se79	200.0	0		
Rb86(n, $\gamma$ )Rb87	Rb87	86.0	2	•	
<b>Rb87(n,2n)Rb86</b>	Rb86, Sr85	30.0	4/6	•	•
<b>Rb87(n,<math>\gamma</math>)Rb88</b>	Y90, Sr89, Nb93m, Sr90	25.0	4	•	
<b>Rb87(n,t)Kr85</b>	H3	85.0	0		
<b>Sr84(n,<math>\gamma</math>)Sr85</b>	Rb86, Sr85, Kr85	81.0	2/5*	•	•
<b>Sr84(n,2n)Sr83</b>	Rb83	61.0	0	•	•
<b>Sr84(n,<math>\alpha</math>)Kr81</b>	Kr81	85.0	0		
<b>Sr86(n,<math>\gamma</math>)Sr87</b>	Sr89	90.0	2	•	
<b>Sr86(n,<math>\gamma</math>)Sr87m</b>	Sr87m, Rb87	91.0	5*	•	•
<b>Sr86(n,2n)Sr85</b>	Sr85, Rb84	40.0	3/4	•	•
<b>Sr86(n,p)Rb86</b>	Rb86	20.0	4	•	
<b>Sr86(n,<math>\alpha</math>)Kr83</b>	Kr85, Kr81	85.0	0		
<b>Sr87(n,<math>\gamma</math>)Sr88</b>	Sr89	70.0	2	•	
<b>Sr87(n,<math>\alpha</math>)Kr84</b>	Kr85	60.0	0		
<b>Sr87(n,p)Rb87</b>	H3, Rb87	6.0	1	•	
<b>Sr87(n,t)Rb85</b>	H3	60.0	0		
<b>Sr88(n,<math>\gamma</math>)Sr89</b>	Y90, Sr89, Nb93m, Sr90, Zr93, Y89m	73.0	4	•	
<b>Sr88(n,2n)Sr87</b>	H3	20.0	2	•	
<b>Sr88(n,2n)Sr87m</b>	Sr87m	10.0	6	•	•
<b>Sr88(n,t)Rb86</b>	H3	72.0	2/0	•	
<b>Sr88(n,d)Rb87</b>	Rb87	190.0	0		
<b>Sr88(n,<math>\alpha</math>)Kr85</b>	Kr85	30.0	2/4	•	
Sr89(n, $\gamma$ )Sr90	Sr90	83.0	2	•	
<b>Y89(n,<math>\gamma</math>)Y90</b>	Y90, Nb93m, Zr93, Sr89, Y91, H3, Sr90	66.0	4	•	
<b>Y89(n,<math>\gamma</math>)Y90m</b>	Y90m	47.0	4	•	
<b>Y89(n,n')Y89m</b>	Y89m	15.0	6	•	•
<b>Y89(n,<math>\alpha</math>)Rb86</b>	Rb86, Sr89, Kr85, Kr81, Rb87	20.0	4/6	•	•
<b>Y89(n,p)Sr89</b>	Sr89, Sr90	12.0	4	•	
<b>Y89(n,2n)Y88</b>	Y88, Kr85, Rb87	10.0	6	•	•
<b>Y89(n,t)Sr87</b>	H3	72.0	1/0	•	
Y90(n, $\gamma$ )Y91	Nb93m, Zr93, Sr89, Y91	95.0	0	•	
Y90(n,p)Sr90	H3, Sr90	50.0	0		
Y91(n, $\gamma$ )Y92	Nb93m	86.0	2	•	
<b>Zr90(n,<math>\gamma</math>)Zr91</b>	Nb93m, Zr93, Y91	73.0	2	•	
<b>Zr90(n,<math>\alpha</math>)Sr87</b>	Sr89	30.0	2/4	•	
<b>Zr90(n,n')Zr90m</b>	Zr90m	30.0	3	•	

Reaction	Daughter nuclide	Uncertainty (%)	Score	Exp data	
				Diff	Int
Zr90(n,2n)Zr89	Y89m, Zr89, Y88, Kr85	20.0	6	•	•
Zr90(n,p)Y90	Y90	20.0	3/5*	•	•
Zr90(n,t)Y88	H3	40.0	2	•	
Zr91(n, $\alpha$ )Sr88	Sr89, Y89m, Y90, Sr90	60.0	0	•	
Zr91(n, $\gamma$ )Zr92	Nb93m, Zr93, Sr89	12.0	4	•	
Zr91(n,p)Y91	Y91	15.0	2/4	•	
Zr91(n,2n)Zr90m	Zr90m	30.0	2*	•	
Zr91(n,t)Y89	H3	85.0	0	•	
Zr92(n, $\gamma$ )Zr93	Nb93m, Zr93, Sr90, Nb94	70.0	2	•	
Zr92(n, $\alpha$ )Sr89	Sr89, Y89m, Y90, Sr90	11.0	4	•	
Zr93(n, $\alpha$ )Sr90	Sr90	60.0	0	•	
Zr94(n,2n)Zr93	Sr90, Zr93, Zr90m	40.0	0	•	
Zr94(n, $\gamma$ )Zr95	Nb95, Zr95	29.0	6*	•	•
Zr94(n, $\alpha$ )Sr91	Y91	9.0	4	•	
Zr94(n,n $\alpha$ )Sr90	Sr90	200.0	0	•	
Zr96(n, $\gamma$ )Zr97	Zr97, Tc99	29.0	5*	•	•
Zr96(n,2n)Zr95	Nb95, Zr95, Nb93m, Mo93, Nb94	5.0	6	•	•
Nb91(n,2n)Nb90	Nb90	72.0	0		
Nb91(n, $\alpha$ )Y88	Y88	60.0	0		
Nb92(n,2n)Nb91	Nb91	72.0	0		
Nb93(n,n')Nb93m	Nb93m	15.0	4	•	
Nb93(n, $\gamma$ )Nb94	Nb96, Nb95, Nb93m, Nb94, Tc99, Zr93	84.0	4	•	
Nb93(n, $\gamma$ )Nb94m	Nb94m	84.0	5*	•	•
Nb93(n, $\alpha$ )Y90	Y90	20.0	5*	•	•
Nb93(n, $\alpha$ )Y90m	Y90m	20.0	6	•	•
Nb93(n,p)Zr93	Nb93m, Zr93	25.0	2	•	
Nb93(n,2n)Nb92	Nb91, Nb92	10.0	4	•	
Nb93(n,2n)Nb92m	Zr90m, Nb92m	10.0	6	•	•
Nb93(n,n $\alpha$ )Y89	Y88	40.0	0/6	•	•
Nb93m(n, $\gamma$ )Nb94	Nb94, Nb95	99.0	0		
Nb94(n,2n)Nb93m	Nb93m	72.0	0		•
Nb94(n, $\gamma$ )Nb95	Nb96, Nb95, Nb93m, Tc99, Zr93	68.0	2	•	
Nb95(n, $\gamma$ )Nb96	Nb96	96.0	2	•	
Nb95(n,2n)Nb94	Nb93m, Nb94	72.0	0		
Mo92(n, $\gamma$ )Mo93	Nb95, Nb93m, Mo93, Nb94	67.0	1/3	•	
Mo92(n,p)Nb92	Nb92	20.0	5*	•	•
Mo92(n,p)Nb92m	Nb92m	20.0	6	•	•
Mo92(n, $\alpha$ )Zr89	Y88	20.0	4	•	•
Mo92(n,d)Nb91	Nb90, Y88, Nb91	120.0	1	•	
Mo92(n,d)Nb91m	Nb91m	40.0	6	•	•
Mo94(n,2n)Mo93	Mo93	10.0	2/4	•	
Mo94(n,p)Nb94	Nb94	20.0	1/3	•	
Mo94(n,d)Nb93m	Nb93m	99.0	0	•	
Mo95(n,2n)Mo94	Nb93m, Mo93	40.0	0		
Mo95(n, $\alpha$ )Zr92	Nb93m	60.0	2	•	
Mo95(n, $\gamma$ )Mo96	Tc99, Zr93	13.0	4	•	
Mo95(n,p)Nb95	Nb95	20.0	6/5*	•	•
Mo95(n,d)Nb94	Nb94	180.0	0		
Mo96(n, $\gamma$ )Mo97	Tc99	49.0	4	•	
Mo96(n, $\alpha$ )Zr93	Zr93	20.0	2	•	
Mo97(n, $\alpha$ )Zr94	Zr95	60.0	2	•	
Mo97(n, $\gamma$ )Mo98	Tc99	46.0	4	•	
Mo98(n, $\gamma$ )Mo99	Tc99, Mo99	29.0	6*	•	•
Mo98(n, $\alpha$ )Zr95	Zr95	10.0	6	•	•
Mo100(n, $\gamma$ )Mo101	Mo101, Ru103	22.0	6*	•	•
Mo100(n,2n)Mo99	Mo99, Tc99, Tc98	8.0	6	•	•
Tc97(n,2n)Tc96	Tc96	72.0	0		
Tc97(n, $\gamma$ )Tc98	Tc99, Tc98	94.0	0		
Tc97(n, $\alpha$ )Nb94	Nb94	85.0	0		
Tc98(n, $\gamma$ )Tc99	Tc99	88.0	0	•	

Reaction	Daughter nuclide	Uncertainty (%)	Score	Exp data	
				Diff	Int
Tc99(n,2n)Tc98	Tc98	18.0	2	•	
<b>Ru96(n,<math>\gamma</math>)Ru97</b>	Ru97, Tc97m, Tc99, Tc97, Tc98, nb94	80.0	2	•	
<b>Ru96(n,p)Tc96</b>	Tc96, H3	63.0	0	•	
<b>Ru96(n,<math>\alpha</math>)Mo93</b>	Mo93, Nb93m	85.0	0		
<b>Ru96(n,2n)Ru95</b>	Nb94	10.0	6	•	•
<b>Ru98(n,2n)Ru97</b>	Ru97, Tc96, Tc97	12.0	2	•	
<b>Ru98(n,d)Tc97m</b>	Tc97m	130.0	0		
<b>Ru99(n,2n)Ru98</b>	Ru97, Tc97m, Tc97	40.0	0		
<b>Ru99(n,p)Tc99</b>	H3, Tc99	30.0	0/4	•	
<b>Ru99(n,t)Tc97</b>	H3	85.0	0		
<b>Ru99(n,d)Tc98</b>	Tc98	130.0	0		
<b>Ru101(n,<math>\gamma</math>)Ru102</b>	Ru103	30.0	2	•	
<b>Ru101(n,t)Tc99</b>	H3	85.0	0		
<b>Ru102(n,<math>\gamma</math>)Ru103</b>	Ru103, Rh104, Rh103m	72.0	2	•	
<b>Ru102(n,<math>\alpha</math>)Mo99</b>	Tc99	16.0	4	•	
<b>Ru104(n,2n)Ru103</b>	Rh104, Ru103, Rh102	12.0	4	•	
<b>Ru104(n,<math>\gamma</math>)Ru105</b>	Rh106, Ag110m, Ru106, Ru105, Rh105, Rh106m	65.0	4	•	
<b>Ru105(n,<math>\gamma</math>)Ru106</b>	Ru106	82.0	2	•	
Rh102(n,n $\alpha$ )Tc98	Tc98	200.0	0		
<b>Rh103(n,<math>\gamma</math>)Rh104</b>	Rh104, Rh106, Rh104, Rh103m, Ru105, Rh105, Ru103, Ag110m, Ru106, Ag108m, Tc99, Pd107, Rh106m	88.0	5	•	•
<b>Rh103(n,<math>\gamma</math>)Rh104m</b>	Rh104m	88.0	5	•	•
<b>Rh103(n,n')Rh103m</b>	Rh103m	10.0	5	•	•
<b>Rh103(n,2n)Rh102</b>	Rh102, Tc98	30.0	4	•	
<b>Rh103(n,p)Ru103</b>	Ru103, H3	15.0	4	•	
<b>Rh103(n,t)Ru101</b>	H3	40.0	2	•	
<b>Rh103(n,n<math>\alpha</math>)Tc99</b>	Tc99, Tc98	60.0	0/2*	•	
Rh105(n, $\gamma$ )Rh106	Rh106, Ag110m	93.0	1	•	
Rh105(n, $\gamma$ )Rh106m	Rh106m	93.0	1	•	
<b>Pd102(n,<math>\gamma</math>)Pd103</b>	Rh106m, Pd103	52.0	2	•	
<b>Pd104(n,2n)Pd103</b>	Pd103, Rh102, Tc99, Tc98	40.0	0		
<b>Pd104(n,<math>\gamma</math>)Pd105</b>	Rh106, Rh103m, Rh105, Ru103, Ag110m, Ag108m, Tc99, Pd107	34.0	1	•	
<b>Pd105(n,<math>\gamma</math>)Pd106</b>	Rh106, Ag110m, Ag108m, Pd107	81.0	2	•	
<b>Pd105(n,p)Rh105</b>	Rh105, H3	67.0	1	•	
<b>Pd105(n,<math>\alpha</math>)Ru102</b>	Rh103m, Ru103, Tc99	20.0	2	•	
<b>Pd105(n,2n)Pd104</b>	Pd103	40.0	0		
<b>Pd105(n,t)Rh103</b>	H3	85.0	0		
<b>Pd106(n,<math>\gamma</math>)Pd107</b>	Ag110m, Ag108m, Pd107	69.0	2	•	
<b>Pd106(n,p)Rh106</b>	Rh106	20.0	1	•	
<b>Pd106(n,p)Rh106m</b>	Rh106m	15.0	6	•	•
<b>Pd107(n,<math>\gamma</math>)Pd108</b>	Ag110m	74.0	2	•	
<b>Pd108(n,<math>\gamma</math>)Pd109</b>	Ag110m, Ag110, Rh106m, Pd109, Ag111, Cd113m, In115, Ag109m	98.0	2/1	•	
<b>Pd108(n,2n)Pd107</b>	Pd107	30.0	1/6	•	•
<b>Pd110(n,<math>\gamma</math>)Pd111</b>	Ag111, Cd113m, In115	30.0	4	•	
<b>Pd110(n,<math>\gamma</math>)Pd111m</b>	Pd111m	61.0	4	•	
<b>Pd110(n,2n)Pd109</b>	Ag110, Pd109, Ag110m, Ag108m	20.0	2/6	•	•
<b>Ag107(n,<math>\gamma</math>)Ag108</b>	Ag110, Ag109m, Ag108, Pd109, Ag111, Ag110m, Cd109, Pd107	80.0	4	•	
<b>Ag107(n,<math>\gamma</math>)Ag108m</b>	Ag108m, Ag109m	78.0	2	•	
<b>Ag107(n,2n)Ag106m</b>	Ag106m	10.0	4	•	
<b>Ag107(n,p)Pd107</b>	Pd107	20.0	0/4	•	
<b>Ag107(n,n<math>\alpha</math>)Rh103</b>	Tc99, Tc98	210.0	0		
<b>Ag107(n,n')Ag107m</b>	Ag107m	30.0	4	•	
Ag108m(n, $\gamma$ )Ag109m	Ag109m	94.0	0		
Ag108m(n,2n)Ag107m	Ag107m	72.0	0		
<b>Ag109(n,<math>\gamma</math>)Ag110</b>	Ag110, Cd113m, In115, In116m, Cd109, Pd107, Ag111	96.0	4	•	

Reaction	Daughter nuclide	Uncertainty (%)	Score	Exp data	
				Diff	Int
<b>Ag109(n,<math>\gamma</math>)Ag110m</b>	Ag110m, Ag111	96.0	4	•	
<b>Ag109(n,n')Ag109m</b>	Ag109m	30.0	4	•	
<b>Ag109(n,2n)Ag108</b>	Ag107m, Ag108, Cd109	20.0	6	•	•
<b>Ag109(n,2n)Ag108m</b>	Ag108m, Ag107m	20.0	4	•	
<b>Ag109(n,<math>\alpha</math>)Rh106m</b>	Rh106m	30.0	2	•	
<b>Ag109(n,p)Pd109</b>	Pd109	20.0	2/4	•	
<b>Ag110m(n,<math>\gamma</math>)Ag111</b>	Ag111	110.0	0	•	
<b>Cd106(n,<math>\gamma</math>)Cd107</b>	Ag108m	48.0	4	•	
<b>Cd106(n,p)Ag106m</b>	Ag106m	20.0	2	•	
<b>Cd106(n,<math>\alpha</math>)Pd103</b>	Tc99, Tc98	40.0	1	•	
<b>Cd108(n,<math>\gamma</math>)Cd109</b>	Ag110, Ag109m, Ag111, Ag110m, Cd109, Pd107	50.0	4	•	
<b>Cd108(n,2n)Cd107</b>	Ag107m, Ag106m	20.0	2	•	
<b>Cd108(n,n<math>\alpha</math>)Pd104</b>	Tc98	200.0	0		
<b>Cd109(n,<math>\alpha</math>)Pd106</b>	Pd107	60.0	2	•	
<b>Cd110(n,<math>\gamma</math>)Cd111</b>	Cd113m, In115, In116m	94.0	4	•	•
<b>Cd110(n,<math>\gamma</math>)Cd111m</b>	Cd111m	89.0	3	•	
<b>Cd110(n,2n)Cd109</b>	Cd109, Ag109m, Ag108m	15.0	2	•	
<b>Cd110(n,<math>\alpha</math>)Pd107</b>	Pd107	85.0	0		
<b>Cd110(n,p)Ag110m</b>	Ag110m	30.0	2	•	
<b>Cd111(n,<math>\gamma</math>)Cd112</b>	Cd113m, In115, In116m, Cd113	75.0	4	•	
<b>Cd111(n,2n)Cd110</b>	Pd107	40.0	0		
<b>Cd111(n,<math>\alpha</math>)Pd108</b>	Pd107	60.0	0		
<b>Cd112(n,<math>\gamma</math>)Cd113</b>	In115, In116m, Cd113	94.0	2	•	
<b>Cd112(n,<math>\gamma</math>)Cd113m</b>	Cd113m, In115	93.0	2	•	
<b>Cd112(n,2n)Cd111m</b>	Cd111m	20.0	6	•	•
<b>Cd113(n,<math>\gamma</math>)Cd114</b>	In115, In116m	27.0	4	•	
<b>Cd113m(n,<math>\gamma</math>)Cd114</b>	In115	91.0	2	•	
<b>Cd114(n,<math>\gamma</math>)Cd115</b>	In115, In116m, Cd115	89.0	4	•	
<b>Cd114(n,<math>\gamma</math>)Cd115m</b>	In115, Cd115m	89.0	2	•	
<b>Cd114(n,2n)Cd113</b>	Cd113	72.0	0		
<b>Cd114(n,2n)Cd113m</b>	Cd113m	72.0	2	•	
<b>Cd116(n,2n)Cd115</b>	In116m, Cd115, In115	20.0	4	•	
<b>Cd116(n,2n)Cd115m</b>	In116m, Cd115m, In115	20.0	2	•	
<b>In113(n,<math>\gamma</math>)In114</b>	In114	84.0	1	•	
<b>In113(n,<math>\gamma</math>)In114m</b>	In116m, In115m, In114m, In115	84.0	4	•	
<b>In113(n,<math>\alpha</math>)Ag110</b>	Pd107	61.0	0		
<b>In113(n,<math>\alpha</math>)Ag110m</b>	Ag110m, Pd107	61.0	0		
<b>In113(n,p)Cd113m</b>	Cd113m	78.0	0		
<b>In113(n,2n)In112</b>	Ag108m	20.0	4/5*	•	•
<b>In114m(n,<math>\gamma</math>)In115</b>	In116m, In115	100.0	0		
<b>In114m(n,<math>\gamma</math>)In115m</b>	In115m	100.0	0		
<b>In115(n,<math>\gamma</math>)In116</b>	Sn117m, Sn121, Sn119m, Sn121m	13.0	2	•	•
<b>In115(n,<math>\gamma</math>)In116m</b>	In116m, Sn117m, Sn121, Sn119m, Cd113m, Sn121m	23.0	5*	•	•
<b>In115(n,2n)In114</b>	In114, In113m	10.0	5*	•	•
<b>In115(n,2n)In114m</b>	In114m, Cd113m	15.0	4	•	
<b>In115(n,n')In115m</b>	In115m	7.0	4	•	
<b>Sn112(n,<math>\alpha</math>)Cd109</b>	Ag108m, Pd107	22.0	2	•	
<b>Sn112(n,<math>\gamma</math>)Sn113</b>	In113m, Sn113	87.0	1	•	
<b>Sn112(n,n<math>\alpha</math>)Cd108</b>	Tc98	200.0	0		
<b>Sn112(n,2n)Sn111</b>	Pd107	15.0	5*	•	•
<b>Sn114(n,2n)Sn113</b>	In113m, Sn113	40.0	2	•	
<b>Sn115(n,2n)Sn114</b>	In113m, Sn113	40.0	0		
<b>Sn115(n,<math>\alpha</math>)Cd112</b>	Cd113m	60.0	2	•	
<b>Sn116(n,<math>\gamma</math>)Sn117</b>	Sn121, Sn119m, Sn121m	48.0	4	•	
<b>Sn116(n,<math>\gamma</math>)Sn117m</b>	Sn117m	85.0	4	•	
<b>Sn116(n,<math>\alpha</math>)Cd113m</b>	Cd113m	85.0	0		
<b>Sn116(n,2n)Sn115</b>	In113m, Sn113	40.0	0		
<b>Sn117(n,<math>\gamma</math>)Sn118</b>	Sn121, Sn119m, Sn121m	57.0	1	•	

Reaction	Daughter nuclide	Uncertainty (%)	Score	Exp data	
				Diff	Int
<b>Sn118(n,<math>\gamma</math>)Sn119</b>	Sn121, Sn121m	79.0	4	•	
<b>Sn118(n,<math>\gamma</math>)Sn119m</b>	Sn119m	73.0	2	•	
<b>Sn118(n,2n)Sn117m</b>	Sn117m	20.0	6*	•	•
<b>Sn119(n,<math>\gamma</math>)Sn120</b>	Sn121, Sn121m	45.0	4	•	
<b>Sn120(n,<math>\gamma</math>)Sn121</b>	Sn121, Sb122, Sb124	82.0	4	•	
<b>Sn120(n,<math>\gamma</math>)Sn121m</b>	Sn121m	56.0	2	•	
<b>Sn120(n,2n)Sn119m</b>	Sn119m	30.0	5	•	•
<b>Sn122(n,2n)Sn121</b>	Sn121	30.0	0		
<b>Sn122(n,2n)Sn121m</b>	Sn121m	20.0	2	•	
<b>Sn122(n,<math>\gamma</math>)Sn123</b>	Sn123	77.0	2	•	
<b>Sn122(n,<math>\gamma</math>)Sn123m</b>	Sb124	76.0	4	•	
<b>Sn124(n,<math>\gamma</math>)Sn125</b>	Sb126m, Sb125, Sn126	96.0	2	•	
<b>Sn124(n,<math>\gamma</math>)Sn125m</b>	Sb126m, Sb125, I129	98.0	4	•	
<b>Sn124(n,2n)Sn123</b>	Sb122, Sb124, Sn123	20.0	6	•	•
<b>Sn124(n,2n)Sn123m</b>	Sb122, Sb124	10.0	6	•	•
<b>Sn125(n,<math>\gamma</math>)Sn126</b>	Sn126	99.0	0		
<b>Sb121(n,<math>\gamma</math>)Sb122</b>	Sb122, Sb124, Sn121, Te123m, Sn123, Sn119m, Te123, Sb126m, Sb125	28.0	3	•	
<b>Sb121(n,p)Sn121</b>	Sn121	30.0	2	•	
<b>Sb121(n,p)Sn121m</b>	Sn121m	64.0	0		
<b>Sb121(n,2n)Sb120</b>	Sn119m	15.0	6	•	•
<b>Sb121(n,2n)Sb120m</b>	Sb120m	20.0	4	•	
<b>Sb121(n,<math>\alpha</math>)In118m</b>	Sn119m	85.0	0		
<b>Sb122(n,<math>\gamma</math>)Sb123</b>	Sb124, Sb126m, Sb125	89.0	0		
<b>Sb123(n,2n)Sb122</b>	Sb122, Sn121, Te121, Te123m, Te121m, Sn121m, Te123	20.0	1/2	•	
<b>Sb123(n,<math>\gamma</math>)Sb124</b>	Sb124, Te123m, Sb125, I129, Te123, Sb126m	91.0	4/2/2	•	
<b>Sb123(n,p)Sn123</b>	Sn123	64.0	1/2	•	
<b>Sb124(n,<math>\gamma</math>)Sb125</b>	Sb125, I129, Sb126m	81.0	2	•	
<b>Sb124(n,<math>\alpha</math>)In121</b>	Sn121, Sn121m, Te123	85.0	0		
<b>Sb124(n,<math>\alpha</math>)In121m</b>	Sn121, Te123	85.0	0		
<b>Sb125(n,<math>\gamma</math>)Sb126</b>	I129	110.0	0		
<b>Sb125(n,<math>\gamma</math>)Sb126m</b>	Sb126m, I129	110.0	0		
<b>Sb126(n,<math>\gamma</math>)Sb127</b>	I129	92.0	0		
<b>Sb126(n,p)Sn126</b>	Sn126	50.0	0		
<b>Sb127(n,2n)Sb126m</b>	Sb126m	72.0	0		
<b>Te120(n,<math>\gamma</math>)Te121</b>	Sb126m, Te121, Sb125	47.0	2	•	
<b>Te122(n,<math>\gamma</math>)Te123</b>	Sn121, Te123	94.0	2	•	
<b>Te122(n,<math>\gamma</math>)Te123m</b>	Te123m	94.0	1	•	
<b>Te122(n,2n)Te121</b>	Te121	10.0	4	•	
<b>Te122(n,2n)Te121m</b>	Te121m	10.0	4	•	
<b>Te122(n,<math>\alpha</math>)Sn119m</b>	Sn119m	85.0	0		
<b>Te123(n,<math>\alpha</math>)Sn120</b>	Sn121	40.0	2	•	
<b>Te124(n,2n)Te123</b>	Te123	30.0	0		
<b>Te124(n,2n)Te123m</b>	Te123m	15.0	4	•	
<b>Te124(n,<math>\gamma</math>)Te125</b>	I129	75.0	4	•	
<b>Te124(n,<math>\gamma</math>)Te125m</b>	Te125m	63.0	2	•	
<b>Te124(n,<math>\alpha</math>)Sn121</b>	Sn121	63.0	1	•	
<b>Te124(n,<math>\alpha</math>)Sn121m</b>	Sn121m	63.0	0		
<b>Te125(n,<math>\gamma</math>)Te126</b>	I129, Te127, Te127m	44.0	4	•	
<b>Te125(n,2n)Te124</b>	Te123m, Sn121, Sn121m, Te123	40.0	0		
<b>Te125(n,p)Sb125</b>	Sb125, H3, Sb126m	50.0	0		
<b>Te126(n,<math>\gamma</math>)Te127</b>	I129, I128, Te127, H3	90.0	4	•	
<b>Te126(n,<math>\gamma</math>)Te127m</b>	I129, Te127m	89.0	2	•	
<b>Te126(n,p)Sb126</b>	Sn126	63.0	2	•	
<b>Te126(n,p)Sb126m</b>	Sb126m	63.0	2	•	
<b>Te126(n,2n)Te125</b>	Sn121, Sn121m, Te123	61.0	0		
<b>Te126(n,2n)Te125m</b>	Te125m	61.0	2	•	
<b>Te126(n,d)Sb125</b>	Sb125	200.0	0		
<b>Te127m(n,<math>\gamma</math>)Te128</b>	I129	46.0	2	•	

Reaction	Daughter nuclide	Uncertainty (%)	Score	Exp data	
				Diff	Int
<b>Te128(n,<math>\gamma</math>)Te129</b>	I129, Te129, I130	47.0	4	•	
<b>Te128(n,<math>\gamma</math>)Te129m</b>	Te129m, Sn126	12.0	2	•	
<b>Te128(n,<math>\alpha</math>)Sn125</b>	Sb126m, Sb125, Sn126	20.0	2	•	
<b>Te128(n,<math>\alpha</math>)Sn125m</b>	Sb126m, Sb125	20.0	4	•	
<b>Te128(n,2n)Te127</b>	Te127, I126	15.0	4	•	
<b>Te128(n,2n)Te127m</b>	Te127m	15.0	2	•	
Te129m(n, $\alpha$ )Sn126	Sn126	60.0	0		
<b>Te130(n,<math>\gamma</math>)Te131</b>	Ba137m, I131, Cs134, Cs137	73.0	2	•	
<b>Te130(n,<math>\gamma</math>)Te131m</b>	I131, Cs134	70.0	4	•	
<b>Te130(n,2n)Te129</b>	I128, Te129, I130, H3, I129	15.0	6	•	•
<b>Te130(n,2n)Te129m</b>	Te129m	15.0	4	•	
<b>I125(n,<math>\gamma</math>)I126</b>	Sb126m, I129	43.0	2	•	
<b>I126(n,<math>\gamma</math>)I127</b>	Sb126m, I129	200.0	2	•	
<b>I127(n,<math>\gamma</math>)I128</b>	I129, I128, Ba137m, Sb126m, Te129, I130, Xe129m, Cs136, Te127m, Cs134, Sb125, Cs137, Sn126, Cs135	14.0	5	•	•
<b>I127(n,p)Te127</b>	H3, Te127	30.0	2	•	
<b>I127(n,p)Te127m</b>	Te127m	30.0	2	•	
<b>I127(n,2n)I126</b>	I126, Sb126m, Sn121, I125, Sb125, Sn121m, Sn126, Te123	11.0	6*	•	•
<b>I127(n,<math>\alpha</math>)Sb124</b>	Sb126m, Sn121, Sb124, Sb125, Sn121m, Te123	20.0	4/2/1	•	
<b>I127(n,t)Te125</b>	H3	85.0	0		
I129(n,2n)I128	I128	20.0	2	•	
I129(n, $\gamma$ )I130	I130	83.0	2	•	
I129(n,t)Te127	H3	85.0	0		
<b>Xe124(n,<math>\gamma</math>)Xe125</b>	Sb126m, I125, I129	69.0	2	•	
<b>Xe126(n,2n)Xe125</b>	Sn121, I125, Te123	20.0	2	•	
<b>Xe126(n,<math>\gamma</math>)Xe127</b>	Sb126m, Xe127, I129	50.0	2	•	
<b>Xe128(n,<math>\gamma</math>)Xe129</b>	Ba137m, Cs136, Te127m, Cs134, Cs137, Cs135	84.0	2	•	
<b>Xe128(n,<math>\gamma</math>)Xe129m</b>	Xe129m	83.0	2	•	
<b>Xe128(n,<math>\alpha</math>)Te125</b>	Te127m	85.0	0		
<b>Xe128(n,2n)Xe127</b>	Sb126m, Xe127	15.0	2	•	
<b>Xe129(n,<math>\gamma</math>)Xe130</b>	Ba137m, Cs136, Te127m, Cs134, Cs137, Cs135, Xe131m	58.0	2	•	
<b>Xe129(n,2n)Xe128</b>	Sb126m, Xe127	40.0	0		
<b>Xe129(n,n')Xe129m</b>	Xe129m	100.0	0		
<b>Xe129(n,p)I129</b>	H3, I129	50.0	0		
<b>Xe129(n,t)I127</b>	H3	60.0	0		
<b>Xe130(n,<math>\gamma</math>)Xe131</b>	Ba137m, Cs136, Cs134, Cs137, Cs135	68.0	2	•	
<b>Xe130(n,<math>\gamma</math>)Xe131m</b>	Xe131m	67.0	2	•	
<b>Xe130(n,<math>\alpha</math>)Te127m</b>	Te127m	85.0	0		
<b>Xe130(n,2n)Xe129m</b>	Xe129m	30.0	1	•	
<b>Xe131(n,<math>\gamma</math>)Xe132</b>	Ba137m, Cs134, Cs137, Cs136, Cs135, Xe134m, Xe133, I129	33.0	2	•	
<b>Xe131(n,2n)Xe130</b>	Xe129m	40.0	0		
<b>Xe131(n,t)I129</b>	H3, I129	60.0	0		
<b>Xe132(n,<math>\gamma</math>)Xe133</b>	Ba137m, Cs134, Cs137, Cs136, Cs135, Xe134m, Xe133	65.0	2	•	
<b>Xe132(n,<math>\gamma</math>)Xe133m</b>	Xe134m	64.0	2	•	
<b>Xe132(n,2n)Xe131m</b>	Xe131m	20.0	2	•	
<b>Xe132(n,<math>\alpha</math>)Te129</b>	I129	85.0	0		
<b>Xe133(n,<math>\gamma</math>)Xe134m</b>	Xe134m	110.0	0	•	
<b>Xe133m(n,<math>\gamma</math>)Xe134m</b>	Xe134m	110.0	0	•	
<b>Xe134(n,n')Xe134m</b>	Xe134m	100.0	0		
<b>Xe134(n,<math>\gamma</math>)Xe135</b>	Xe135, Cs136, Cs135	68.0	2	•	
<b>Xe134(n,2n)Xe133</b>	Xe133	15.0	2	•	
<b>Xe136(n,<math>\gamma</math>)Xe137</b>	Ba137m, Cs136, Cs137	63.0	2	•	
<b>Xe136(n,2n)Xe135</b>	Xe135, Cs136, Cs134, Ba133, Cs135	10.0	2	•	
<b>Cs131(n,<math>\gamma</math>)Cs132</b>	I129	92.0	0		

Reaction	Daughter nuclide	Uncertainty (%)	Score	Exp data	
				Diff	Int
Cs132(n, $\alpha$ )I129	I129	60.0	2	•	
<b>Cs133(n,<math>\gamma</math>)Cs134</b>	Ba137m, Cs134, Cs137, Cs136, Cs135, Xe131m, Ba133, H3, I129, La138	19.0	4/3	•	
<b>Cs133(n,<math>\alpha</math>)I130</b>	Xe131m	63.0	2	•	
<b>Cs133(n,2n)Cs132</b>	Xe131m	20.0	6	•	•
<b>Cs133(n,p)Xe133</b>	H3	30.0	2	•	
<b>Cs133(n,t)Xe131</b>	H3	85.0	0		
<b>Cs133(n,n<math>\alpha</math>)I129</b>	I129	200.0	0		
Cs134(n, $\gamma$ )Cs135	Ba137m, Cs137, Cs136, Cs135, I129, La138	94.0	2/0	•	
<b>Cs134(n,p)Xe134</b>	H3	78.0	0		
Cs135(n, $\gamma$ )Cs136	Ba137m, Cs137, Cs136, La138	56.0	2/0	•	
Cs135(n,2n)Cs134	Cs134, Ba133	72.0	0		
Cs135(n, $\alpha$ )I132	I129	85.0	0		
Cs136(n, $\gamma$ )Cs137	Ba137m, Cs137	75.0	0		
Cs136(n, $\alpha$ )I133	Cs134	85.0	0		
Cs137(n,2n)Cs136	Cs136	72.0	0		
<b>Ba130(n,<math>\gamma</math>)Ba131</b>	Cs131, Ba131, I129	28.0	2	•	
<b>Ba130(n,2n)Ba129</b>	I129	40.0	0	•	
<b>Ba130(n,2n)Ba129m</b>	I129	40.0	2	•	
<b>Ba132(n,2n)Ba131</b>	Cs131, Ba131	20.0	1/4	•	•
<b>Ba132(n,<math>\gamma</math>)Ba133</b>	Cs136, Cs134, Ba133, Cs137, Cs135	86.0	2	•	
<b>Ba133(n,2n)Ba132</b>	Cs131, Ba131	40.0	0		
<b>Ba134(n,2n)Ba133</b>	Ba133, Cs131, Ba131, I129	20.0	3/6	•	•
<b>Ba134(n,<math>\gamma</math>)Ba135</b>	Ba137m	87.0	4	•	•
<b>Ba134(n,<math>\gamma</math>)Ba135m</b>	Ba135m	87.0	4	•	
<b>Ba134(n,<math>\alpha</math>)Xe131</b>	I129	85.0	0	•	
<b>Ba134(n,<math>\alpha</math>)Xe131m</b>	Xe131m	85.0	0		
<b>Ba134(n,p)Cs134</b>	Cs134	67.0	2/0	•	
<b>Ba135(n,<math>\gamma</math>)Ba136</b>	Ba137m	87.0	4/2	•	
<b>Ba135(n,2n)Ba134</b>	Ba133	40.0	0		
<b>Ba136(n,<math>\gamma</math>)Ba137</b>	La138	75.0	4	•	•
<b>Ba136(n,<math>\gamma</math>)Ba137m</b>	Ba137m	66.0	2	•	
<b>Ba136(n,2n)Ba135</b>	Ba133	15.0	1	•	
<b>Ba136(n,2n)Ba135m</b>	Ba135m	10.0	6	•	•
<b>Ba136(n,p)Cs136</b>	Cs136	63.0	1/0	•	
<b>Ba136(n,<math>\alpha</math>)Xe133</b>	Cs134	67.0	0/1	•	
<b>Ba137(n,<math>\gamma</math>)Ba138</b>	La138, Ba139	54.0	4	•	
<b>Ba137(n,2n)Ba136</b>	Ba135m	25.0	0/1	•	
<b>Ba137(n,p)Cs137</b>	Cs137	25.0	2	•	
<b>Ba138(n,<math>\gamma</math>)Ba139</b>	La138, Ba139, La140, Ce141, La137	50.0	5*	•	•
<b>Ba138(n,2n)Ba137</b>	Cs137	20.0	2	•	
<b>Ba138(n,2n)Ba137m</b>	Ba137m	15.0	6	•	•
<b>Ba138(n,<math>\alpha</math>)Xe135</b>	Cs134, Cs135	20.0	2/4	•	
La137(n,p)Ba137m	Ba137m, H3	78.0	0		
La137(n,2n)La136	La136, Ba135m, Ba133	72.0	0		
La137(n, $\alpha$ )Cs134	Cs134, Cs137, Cs135	85.0	0		
La137(n, $\gamma$ )La138	La140, Cs137, Cs135, La138	95.0	0		
<b>La138(n,2n)La137</b>	La137, La136, Ba135m, Cs134, Ba133	40.0	0		
<b>La138(n,d)Ba137m</b>	Ba137m	130.0	0		
<b>La138(n,<math>\alpha</math>)Cs135</b>	Cs134, Cs135, Cs137	85.0	0		
<b>La138(n,p)Ba138</b>	H3	50.0	0		
<b>La138(n,<math>\gamma</math>)La139</b>	La140, Cs137	57.0	2	•	
<b>La139(n,<math>\gamma</math>)La140</b>	La138, La140, Ce141, Ba137m, Pr144, Ba139, Ce144, Pm147, H3, Cs137, Sm147, Nd144	24.0	4	•	
<b>La139(n,<math>\alpha</math>)Cs136</b>	Ba137m, Cs136, Cs134, Cs137	30.0	2	•	
<b>La139(n,<math>\alpha</math>)Cs136m</b>	Cs134	40.0	1	•	
<b>La139(n,2n)La138</b>	La137, La138, Ba137m, La136, Ba135m, Cs134, Ba133, Cs135	40.0	0		
<b>La139(n,d)Ba138</b>	Ba137m	130.0	0		
<b>La139(n,p)Ba139</b>	Ba139	18.0	6	•	•

Reaction	Daughter nuclide	Uncertainty (%)	Score	Exp data	
				Diff	Int
<b>La139(n,t)Ba137</b>	H3	20.0	0/2	•	
<b>La139(n,h)Cs137</b>	Cs137	90.0	0		
La140(n, $\gamma$ )La141	Ce141, La138, Pr144, Ce141, Ce144, Pm147, Sm147, Nd144	19.0	2	•	
La140(n, $\alpha$ )Cs137	Cs137	60.0	0		
La141(n, $\gamma$ )La142	Pr144, Ce144, Pm147, Sm147, Nd144	95.0	0		
<b>Ce136(n,<math>\gamma</math>)Ce137</b>	Ce137, La140, H3, Cs137, La137, Cs135, La138	83.0	2	•	
<b>Ce136(n,<math>\alpha</math>)Ba133</b>	Ba133, Cs135	85.0	0		
<b>Ce136(n,2n)Ce135</b>	Ba133	20.0	0	•	
<b>Ce136(n,p)La136</b>	H3	78.0	0		
<b>Ce138(n,<math>\gamma</math>)Ce139</b>	La140, Ce139, Cs137	75.0	2	•	
<b>Ce138(n,<math>\gamma</math>)Ce139m</b>	Ce139m	72.0	2	•	
<b>Ce138(n,2n)Ce137</b>	Ce137	20.0	1/4	•	
<b>Ce139(n,2n)Ce138</b>	Ce137	40.0	0		
<b>Ce140(n,<math>\gamma</math>)Ce141</b>	La138, Ce141, Pr144, Ce144, Pm147, H3, Sm147, Nd144, Pr142	27.0	2	•	
<b>Ce140(n,<math>\alpha</math>)Ba137</b>	Ba139, Cs137	40.0	0	•	
<b>Ce140(n,<math>\alpha</math>)Ba137m</b>	Ba137m	30.0	6	•	•
<b>Ce140(n,2n)Ce139</b>	Ce137, Ce139, H3, La137, Cs135, La138, Cs134	20.0	2	•	
<b>Ce140(n,2n)Ce139m</b>	Ce139m	20.0	6	•	•
<b>Ce140(n,p)La140</b>	La140	10.0	4	•	
<b>Ce140(n,t)La138</b>	H3	60.0	0		
Ce141(n, $\gamma$ )Ce142	Pr144, Ce144	73.0	2	•	
<b>Ce142(n,<math>\gamma</math>)Ce143</b>	Pr144, Ce144, Pm147, Sm147, Nd144, Ce143, Pr143	26.0	4	•	
<b>Ce142(n,2n)Ce141</b>	Pr142, Ce141	5.0	4	•	
Ce143(n, $\gamma$ )Ce144	Ce144	65.0	2	•	
<b>Pr141(n,<math>\alpha</math>)La138</b>	La138, La140, Cs137, Cs135	25.0	2	•	
<b>Pr141(n,<math>\gamma</math>)Pr142</b>	Pr144, Pm147, Sm147, Nd144, Pr142, Ba137m, La140, Nd147, Pr143, Ce141, Pm148m, Ce139, Ce144, Ce142	93.0	2	•	
<b>Pr141(n,p)Ce141</b>	H3, Ce141	17.0	4	•	
<b>Pr141(n,2n)Pr140</b>	Ba137m, Pr140, La140, Ce139, Cs134, Cs137, La137, Cs135, La138	15.0	5	•	•
<b>Pr141(n,t)Ce139</b>	H3	72.0	1/0	•	
Pr142(n, $\gamma$ )Pr143	Pr144, Pr143	54.0	2	•	
Pr143(n, $\gamma$ )Pr144	Pr144	65.0	0	•	
<b>Nd142(n,<math>\gamma</math>)Nd143</b>	Pm147, Sm147, Nd144, Ba137m, Pr144, Nd147, Pr143, Ce141, Pm148m, La138	46.0	4	•	
<b>Nd142(n,<math>\alpha</math>)Ce139</b>	La140, Ce139, La137, La138	30.0	2/1	•	
<b>Nd142(n,2n)Nd141</b>	Nd141, Ce139, La137, La138	20.0	2	•	
<b>Nd142(n,2n)Nd141m</b>	Nd141m	20.0	5	•	•
<b>Nd143(n,<math>\gamma</math>)Nd144</b>	Pm147, Sm147, Nd144, Pr144, Nd147, Pm148m	66.0	4	•	
<b>Nd143(n,<math>\alpha</math>)Ce140</b>	Ba137m, Ce141, La138	40.0	4	•	
<b>Nd143(n,p)Pr143</b>	Pr143	20.0	2	•	
<b>Nd144(n,<math>\gamma</math>)Nd145</b>	Pm147, Sm147, Nd147, Pm148m	33.0	4	•	
<b>Nd144(n,p)Pr144</b>	Pr144	63.0	1	•	
<b>Nd145(n,<math>\gamma</math>)Nd146</b>	Pm147, Sm147, Nd147, Pm148m	43.0	4	•	
<b>Nd146(n,<math>\gamma</math>)Nd147</b>	Pm147, Sm147, Nd147, Pm148m	39.0	4	•	
<b>Nd148(n,<math>\gamma</math>)Nd149</b>	Nd149, Eu156, Eu155, Eu154, Eu152, Sm151	43.0	4	•	
<b>Nd148(n,2n)Nd147</b>	Nd147, Pm147, Pm146, Pm145, Sm146, Sm147	12.0	4	•	
<b>Nd150(n,<math>\gamma</math>)Nd151</b>	Nd151, Eu156, Eu155, Eu154, Eu152, Eu150, Sm151	39.0	4	•	
<b>Nd150(n,2n)Nd149</b>	Nd149, Pm148m	10.0	5	•	•
Pm145(n, $\gamma$ )Pm146	Pm146	92.0	0		
Pm145(n,2n)Pm144	Pm144	40.0	0		
Pm146(n,2n)Pm145	Pm145	40.0	0		

Reaction	Daughter nuclide	Uncertainty (%)	Score	Exp data	
				Diff	Int
Pm147(n, $\gamma$ )Pm148m	Pm148m	90.0	2	•	
Pm147(n,2n)Pm146	Pm146, Pm145	40.0	0		
Pm149(n,2n)Pm148m	Pm148m	72.0	0		
<b>Sm144(n,<math>\gamma</math>)Sm145</b>	Sm145, Pm146, Pm145, Sm146	47.0	4	•	
<b>Sm144(n,p)Pm144</b>	Pm144	21.0	2	•	
<b>Sm144(n,n<math>\alpha</math>)Nd140</b>	La137, La138	200.0	0		
<b>Sm144(n,<math>\alpha</math>)Nd141</b>	La138	40.0	0	•	
Sm145(n, $\gamma$ )Sm146	Sm146	41.0	2	•	
Sm146(n,2n)Sm145	Sm145, Pm144, Pm145	40.0	0		
Sm146(n,p)Pm146	Pm146	50.0	0		
<b>Sm147(n,2n)Sm146</b>	Sm146, Sm145, Pm144, Pm146, Pm145	40.0	0		
<b>Sm147(n,<math>\gamma</math>)Sm148</b>	Sm153, Eu154, Eu152, Sm151	19.0	4	•	
<b>Sm147(n,d)Pm146</b>	Pm146	180.0	0		
<b>Sm147(n,p)Pm147</b>	Pm146	50.0	0		
<b>Sm148(n,p)Pm148m</b>	Pm148m	63.0	2	•	
<b>Sm148(n,<math>\gamma</math>)Sm149</b>	Sm153, Eu154, Eu152, sm151	89.0	4	•	
<b>Sm148(n,2n)Sm147</b>	Sm147	10.0	2*	•	
<b>Sm149(n,<math>\gamma</math>)Sm150</b>	Eu156, Eu155, Eu154, Eu152, Sm151, Sm153	41.0	4	•	
<b>Sm149(n,2n)Sm148</b>	Pm148m, Sm147	40.0	0		
<b>Sm149(n,<math>\alpha</math>)Nd146</b>	Sm147	40.0	4	•	
<b>Sm150(n,<math>\gamma</math>)Sm151</b>	Eu156, Eu155, Eu154, Eu152, Sm151, Sm153	28.0	4	•	
<b>Sm151(n,<math>\gamma</math>)Sm152</b>	Eu156, Eu155, Eu154, Sm153	17.0	2	•	
<b>Sm152(n,<math>\gamma</math>)Sm153</b>	Eu156, Eu155, Eu154, Sm153, Tb160	30.0	4*	•	
<b>Sm152(n,2n)Sm151</b>	Eu150, Sm151	8.0	2*	•	
Sm153(n, $\gamma$ ) <b>Sm154</b>	Eu156, Eu155	74.0	2	•	
<b>Sm154(n,<math>\gamma</math>)Sm155</b>	Sm155, Eu156, Tb160, Eu155, Eu154	51.0	4	•	
<b>Sm154(n,2n)Sm153</b>	Sm153, Eu154, Eu152, Eu150	7.0	5*	•	•
Eu150(n,2n)Eu149	Eu149, Sm147	40.0	0		
<b>Eu151(n,<math>\gamma</math>)Eu152</b>	Eu152, Tb161, Eu156, Tb160, Eu155, Eu154	26.0	2	•	
<b>Eu151(n,<math>\gamma</math>)Eu152m</b>	Gd153, Gd152, Eu156, Eu155, Eu154, Sm151, Sm147	25.0	5	•	•
<b>Eu151(n,2n)Eu150</b>	Eu150, Eu149, Sm147	10.0	4	•	
<b>Eu151(n,2n)Eu150m</b>	Gd148, Gd150, Eu149, Sm146	10.0	4	•	
<b>Eu151(n,p)Sm151</b>	Sm151	50.0	0		
<b>Eu151(n,n<math>\alpha</math>)Pm147</b>	Sm147	200.0	0		
<b>Eu152(n,2n)Eu151</b>	Eu150, Gd150	40.0	0		
<b>Eu152(n,<math>\gamma</math>)Eu153</b>	Tb161, Eu156, Tb160, Eu155, Eu154	43.0	2	•	
<b>Eu153(n,<math>\gamma</math>)Eu154</b>	Eu156, Eu155, Eu154, Tb160, Tb161, Gd153, Sm151, Ho166m	62.0	4/0	•	
<b>Eu153(n,2n)Eu152</b>	Eu152, Eu150, Sm151, Gd150	10.0	4	•	
<b>Eu153(n,2n)Eu152m</b>	Gd153, Sm151, Gd152	10.0	4	•	
<b>Eu153(n,n<math>\alpha</math>)Pm149</b>	Sm147, Sm149	200.0	0		
Eu154(n, $\gamma$ )Eu155	Eu156, Eu155, Tb160, Tb161, Ho166m	43.0	2	•	
Eu154(n, $\alpha$ )Pm151	Sm151	60.0	0		
Eu155(n, $\gamma$ )Eu156	Eu156, Tb160, Tb161, Ho166m	64.0	2	•	
Eu155(n,2n)Eu154	Eu154	72.0	0		
Eu156(n, $\gamma$ )Eu157	Tb160, Tb161, Ho166m	98.0	0		
Gd149(n,2n)Gd148	Gd148	40.0	0		
Gd150(n,2n)Gd149	Gd148, Eu149	40.0	0		
Gd150(n,n $\alpha$ )Sm146	Sm146	200.0	0		
Gd151(n,2n)Gd150	Gd148, Gd150	40.0	0		
<b>Gd152(n,<math>\gamma</math>)Gd153</b>	Eu156, Gd153, Eu155, Eu154, Sm151	82.0	4	•	
<b>Gd152(n,<math>\alpha</math>)Sm149</b>	Eu152, Sm151, Sm147	40.0	2	•	
<b>Gd152(n,2n)Gd151</b>	Gd148, Gd150	13.0	2	•	
<b>Gd152(n,n<math>\alpha</math>)Sm148</b>	Sm147	200.0	0		
Gd153(n, $\gamma$ ) <b>Gd154</b>	Sm151	90.0	2	•	
<b>Gd154(n,<math>\alpha</math>)Sm151</b>	Eu156, Eu155, Eu154, Eu152, Sm151	60.0	2	•	
<b>Gd154(n,2n)Gd153</b>	Gd153, Eu152	14.0	2	•	
<b>Gd154(n,p)Eu154</b>	Eu154	61.0	0	•	
<b>Gd155(n,<math>\gamma</math>)Gd156</b>	Tb160, Tb161	20.0	4	•	

Reaction	Daughter nuclide	Uncertainty (%)	Score	Exp data	
				Diff	Int
<b>Gd155(n,2n)Gd154</b>	Gd153, Eu154, Eu152, Sm151	9.0	2*	•	
<b>Gd155(n,p)Eu155</b>	Eu155	50.0	0		
<b>Gd156(n,<math>\gamma</math>)Gd157</b>	Tb160, Tb161, Ho166m	39.0	4	•	
<b>Gd156(n,p)Eu156</b>	Eu156	15.0	2	•	
<b>Gd157(n,<math>\gamma</math>)Gd158</b>	Tb160, Gd159, Tb161, Ho166m, Eu155	31.0	4	•	
<b>Gd157(n,<math>\alpha</math>)Sm154</b>	Eu155	40.0	2	•	
<b>Gd158(n,<math>\gamma</math>)Gd159</b>	Tb160, Gd159, Tb161, Ho166m	27.0	4	•	
<b>Gd158(n,<math>\alpha</math>)Sm155</b>	Eu155	22.0	5*	•	•
<b>Gd160(n,<math>\gamma</math>)Gd161</b>	Gd161, Tb161, Ho166m	41.0	6	•	•
<b>Gd160(n,2n)Gd159</b>	Gd159, Tb160, Tb158	8.0	5*	•	•
Tb157(n,2n)Tb156	Tb156	72.0	0		
<b>Tb157(n,n<math>\alpha</math>)Eu153</b>	Gd150, Sm147, Gd152, Sm149	200.0	0		
Tb157(n, $\gamma$ )Tb158	Tb161, Tb160, Tb158	84.0	0		
Tb158(n,2n)Tb157	Tb156, Tb157, Gd150, Sm147, Gd152, Sm149	40.0	0		
Tb158(n, $\alpha$ )Eu155	Eu155	60.0	0		
Tb158(n, $\gamma$ ) <b>Tb159</b>	Tb161, Tb160	73.0	0		
<b>Tb159(n,<math>\gamma</math>)Tb160</b>	Tb160, Tb161, Ho166m, Ho166, Tm172, Tm170, Tm171, Eu155, H3	29.0	4	•	
<b>Tb159(n,n<math>\alpha</math>)Eu155</b>	Eu155	200.0	0		
<b>Tb159(n,2n)Tb158</b>	Tb158, Tb156, Eu155, Tb157, Gd150, Sm147, Gd152, Sm149	10.0	4	•	
<b>Tb159(n,2n)Tb158m</b>	Tb158m	20.0	5	•	•
<b>Tb159(n,t)Gd157</b>	H3	60.0	0		
Tb160(n, $\gamma$ )Tb161	Tb161, Ho166m, Ho166, Tm172, Tm170, Tm171, H3	64.0	2	•	
<b>Tb160(n,p)Gd160</b>	H3	50.0	0		
Dy155(n,2n)Dy154	Dy154	40.0	0		
<b>Dy156(n,<math>\gamma</math>)Dy157</b>	Dy157, Tb161, Tb160, Tb157, Tb158	33.0	4	•	
<b>Dy156(n,n<math>\alpha</math>)Gd152</b>	Gd150, Gd152	200.0	0		
<b>Dy156(n,2n)Dy155</b>	Dy154	8.0	6*	•	•
Dy157(n,2n) <b>Dy156</b>	Dy154	40.0	0		
<b>Dy158(n,2n)Dy157</b>	Dy157, Tb157, Dy154	8.0	6*	•	•
<b>Dy158(n,<math>\gamma</math>)Dy159</b>	Tb161, Tb160, Dy159	44.0	2*	•	
<b>Dy159(n,2n)Dy158</b>	Dy154	40.0	0		
<b>Dy160(n,<math>\gamma</math>)Dy161</b>	Ho166m, Ho166, Tm172, Tm170, Tm171, H3, Dy165	37.0	4	•	
<b>Dy160(n,<math>\alpha</math>)Gd157</b>	Eu155	60.0	2	•	
<b>Dy160(n,p)Tb160</b>	Tb160	30.0	2	•	
<b>Dy160(n,2n)Dy159</b>	Dy159, Tb158, Dy154	11.0	2	•	
<b>Dy161(n,<math>\gamma</math>)Dy162</b>	Ho166m, Ho166, Tm172, Tm170, Tm171, Er167m, Dy165	48.0	4	•	
<b>Dy161(n,p)Tb161</b>	H3, Tb161	15.0	2	•	
<b>Dy161(n,2n)Dy160</b>	Tb160, Dy159, Tb158, Dy154	40.0	0		
<b>Dy162(n,<math>\gamma</math>)Dy163</b>	Ho166m, Ho166, Tm172, Tm170, Tm171, Er167m, Dy165, Er169	39.0	4	•	
<b>Dy162(n,2n)Dy161</b>	Tb161, Dy159, Dy154	40.0	0		
<b>Dy162(n,<math>\alpha</math>)Gd159</b>	Tb160	23.0	2	•	
<b>Dy163(n,<math>\gamma</math>)Dy164</b>	Ho166m, Ho166, Tm172, Tm170, Tm171, Er167m, Dy165, Er169	65.0	4	•	
<b>Dy164(n,<math>\gamma</math>)Dy165</b>	Ho166m, Ho166, Tm172, Tm170, Tm171, Er167m, Dy165, Er169, Ho163	68.0	5/6*	•	•
<b>Dy164(n,3n)Dy162</b>	Dy159, Dy154	200.0	0		
Ho163(n,2n)Ho162m	Ho162m	72.0	0		
Ho163(n, $\alpha$ )Tb160	Tb160	60.0	0		
Ho163(n, $\gamma$ )Ho164	Er165	87.0	0*		
<b>Ho165(n,<math>\gamma</math>)Ho166</b>	Ho166, Tm172, Tm170, Tm171, Er167m, Er169, Lu176	20.0	4	•	
<b>Ho165(n,<math>\gamma</math>)Ho166m</b>	Ho166m, Er169, Ho167, Tm170	65.0	2	•	
<b>Ho165(n,2n)Ho164</b>	Ho163, Ho164, Ho162m, Tb160, Dy159, Dy154	20.0	5	•	•

Reaction	Daughter nuclide	Uncertainty (%)	Score	Exp data	
				Diff	Int
<b>Ho165(n,<math>\alpha</math>)Tb162</b>	Tb160	33.0	4	•	
Ho166m(n, $\gamma$ )Ho167	Er169, Ho167, Tm170	88.0	2	•	
<b>Er162(n,<math>\gamma</math>)Er163</b>	Er165, Ho163	31.0	2	•	
<b>Er162(n,<math>\alpha</math>)Dy159</b>	Dy159	60.0	2	•	
<b>Er162(n,2n)Er161</b>	Dy159	7.0	2	•	
<b>Er162(n,p)Ho162</b>	H3	78.0	0		
<b>Er162(n,n<math>\alpha</math>)Dy158</b>	Dy154	200.0	0		
<b>Er164(n,2n)Er163</b>	Ho163, Ho162m, Tb160	15.0	2	•	
<b>Er164(n,<math>\gamma</math>)Er165</b>	Er165, Ho166m	27.0	3	•	
<b>Er166(n,<math>\gamma</math>)Er167</b>	Tm172, Tm170, Tm171, Er169, Lu176	89.0	2	•	
<b>Er166(n,<math>\gamma</math>)Er167m</b>	Er167m	89.0	2	•	
<b>Er166(n,2n)Er165</b>	Er165, Ho163	20.0	6	•	•
<b>Er166(n,p)Ho166m</b>	Ho166m	62.0	0		
<b>Er167(n,<math>\gamma</math>)Er168</b>	Tm172, Tm170, Tm171, Er169, Lu176	55.0	4	•	
<b>Er167(n,t)Ho165</b>	H3	60.0	0		
<b>Er167(n,2n)Er166</b>	Ho163	40.0	0		
<b>Er168(n,<math>\gamma</math>)Er169</b>	Tm172, Tm170, Tm171, Er169, Lu176, H3	37.0	4	•	
<b>Er168(n,2n)Er167</b>	Ho163	20.0	0		
<b>Er168(n,2n)Er167m</b>	Er167m	20.0	2	•	
<b>Er170(n,<math>\gamma</math>)Er171</b>	Er171, Tm172, Tm170, Tm171, Hf178n, Lu176	44.0	4	•	
<b>Er170(n,2n)Er169</b>	Er169, Tm168, Tm170	20.0	2	•	
<b>Tm169(n,<math>\gamma</math>)Tm170</b>	Tm172, Tm170, Tm171, Lu176, Yb175, Hf181, Ta182, Hf178n, Hf182	38.0	4	•	
<b>Tm169(n,2n)Tm168</b>	Tm168, Ho163	8.0	6	•	•
<b>Tm169(n,p)Er169</b>	H3	50.0	0		
<b>Tm169(n,t)Er167</b>	H3	85.0	0		
<b>Tm169(n,<math>\alpha</math>)Ho166m</b>	Ho166m	78.0	2	•	
<b>Tm169(n,n<math>\alpha</math>)Ho165</b>	Ho163	200.0	0		
<b>Tm170(n,p)Er170</b>	H3	50.0	0		
<b>Tm170(n,<math>\gamma</math>)Tm171</b>	Tm172, Tm171, Lu176, Yb175, Hf181, Ta182, H3, Hf178n, Hf182	47.0	2	•	
<b>Tm171(n,<math>\gamma</math>)Tm172</b>	Tm172, Lu176, Hf178n, Yb175, Hf181, Ta182, Hf182	72.0	2	•	
<b>Tm171(n,2n)Tm170</b>	Tm170	40.0	0		
<b>Tm172(n,<math>\gamma</math>)Tm173</b>	Lu176, Ta182, Hf182	89.0	0		
<b>Yb168(n,<math>\gamma</math>)Yb169</b>	Yb169, Tm170, Tm171, Ho166m	86.0	1/0	•	
<b>Yb168(n,p)Tm168</b>	Tm168	50.0	0		
<b>Yb168(n,<math>\alpha</math>)Er165</b>	Ho166m	60.0	2	•	
<b>Yb168(n,n<math>\alpha</math>)Er164</b>	Ho163	200.0	0		
<b>Yb168(n,2n)Yb167</b>	Ho163	15.0	6	•	•
<b>Yb170(n,<math>\gamma</math>)Yb171</b>	Lu176, Yb175	26.0	4	•	
<b>Yb170(n,2n)Yb169</b>	Yb169, Tm168, Ho166m	20.0	0	•	
<b>Yb170(n,p)Tm170</b>	Tm170	50.0	0		
<b>Yb171(n,<math>\gamma</math>)Yb172</b>	Lu176, Yb175	26.0	4	•	
<b>Yb171(n,2n)Yb170</b>	Yb169, Tm168, Tm170, Ho166m	40.0	0		
<b>Yb171(n,p)Tm171</b>	Tm171, H3	50.0	0		
<b>Yb171(n,t)Tm169</b>	H3	60.0	0		
<b>Yb172(n,<math>\gamma</math>)Yb173</b>	Lu176, Hf178n, Yb175, Hf181, Ta182, Hf182, Yb176m, Lu176m	32.0	4	•	
<b>Yb172(n,<math>\alpha</math>)Er169</b>	Ho166m	22.0	2	•	
<b>Yb173(n,<math>\gamma</math>)Yb174</b>	Lu176, Hf178n, Yb175, Hf181, Ta182, Hf182, Yb176m, Lu176m, Lu177	22.0	4	•	
<b>Yb174(n,<math>\gamma</math>)Yb175</b>	Lu176, Hf178n, Yb175, Hf181, Ta182, Hf182, Hf178m, Yb176m, Lu176m, Lu177, H3	68.0	4	•	
<b>Yb174(n,<math>\alpha</math>)Er171</b>	Tm171	45.0	2	•	
<b>Yb175(n,<math>\gamma</math>)Yb176m</b>	Yb176m	110.0	0*		
<b>Yb176(n,<math>\gamma</math>)Yb177</b>	Hf178m, Yb177, Lu177, Hf181, Ta182, H3, Hf178n, Hf182	79.0	4/0	•	
<b>Yb176(n,n')Yb176m</b>	Yb176m	50.0	5	•	•

Reaction	Daughter nuclide	Uncertainty (%)	Score	Exp data	
				Diff	Int
<b>Yb176(n,2n)Yb175</b>	Lu176m, Yb175, Lu174, Lu176	15.0	2	•	
Lu173(n,2n)Lu172	Lu172	72.0	0		
Lu174(n,2n)Lu173	Lu172	40.0	0		
<b>Lu175(n,<math>\gamma</math>)Lu176</b>	Lu176, Hf178n, Hf181, Ta182, Hf182, Hf178m, Lu177, Hf177m, Hf179m, Lu178, Lu177m	84.0	2	•	
<b>Lu175(n,<math>\gamma</math>)Lu176m</b>	Hf178n, Hf181, Ta182, Hf182, Hf178m, Lu176m, Hf177m, Hf179m	16.0	6	•	•
<b>Lu175(n,2n)Lu174</b>	Lu174, Lu172	10.0	4	•	
<b>Lu175(n,p)Yb175</b>	H3	18.0	2	•	
<b>Lu175(n,<math>\alpha</math>)Tm172</b>	Tm172, Ho166m	20.0	2	•	
<b>Lu175(n,t)Yb173</b>	H3	60.0	0		
<b>Lu176(n,<math>\gamma</math>)Lu177</b>	Hf178n, Hf181, Ta182, Hf182, Hf178m, Lu177, Hf179m, Lu178, H3	20.0	4	•	
<b>Lu176(n,<math>\gamma</math>)Lu177m</b>	Hf177m, Lu177m	66.0	2	•	
<b>Lu176(n,n')Lu176m</b>	Lu176m	100.0	0		
<b>Lu177(n,<math>\gamma</math>)Lu178</b>	Lu178	110.0	0	•	
<b>Hf174(n,<math>\gamma</math>)Hf175</b>	Hf177m, Hf175, Lu176	34.0	2	•	
<b>Hf174(n,p)Lu174</b>	Lu174	78.0	0		
<b>Hf176(n,<math>\gamma</math>)Hf177</b>	Hf178n, Hf181, Ta182, Hf182, Hf178m, Hf179m, Hf179n	58.0	4	•	
<b>Hf176(n,<math>\gamma</math>)Hf177m</b>	Hf177m	58.0	0		
<b>Hf176(n,2n)Hf175</b>	Hf175, Lu174	8.0	6	•	•
<b>Hf176(n,p)Lu176</b>	Lu176	78.0	0		
<b>Hf177(n,<math>\gamma</math>)Hf178</b>	Hf181, Ta182, Hf182, H3, Hf179m, Lu178, Hf179n	97.0	4	•	
<b>Hf177(n,<math>\gamma</math>)Hf178m</b>	Hf178m	97.0	2	•	
<b>Hf177(n,<math>\gamma</math>)Hf178n</b>	Hf178n	97.0	2	•	
<b>Hf177(n,n')Hf177m</b>	Hf177m	100.0	0		
<b>Hf177(n,2n)Hf176</b>	Hf175, Lu174, Lu176	40.0	0		
<b>Hf178(n,<math>\gamma</math>)Hf179</b>	Hf181, Ta182, Hf182, H3, Ta183, Ta180m	99.0	2	•	
<b>Hf178(n,<math>\gamma</math>)Hf179m</b>	Hf179m	99.0	2	•	
<b>Hf178(n,<math>\gamma</math>)Hf179n</b>	Hf179n	99.0	2	•	
<b>Hf178(n,p)Lu178</b>	Lu178	20.0	5/6	•	•
<b>Hf178(n,2n)Hf177m</b>	Hf177m	72.0	0		
<b>Hf179(n,<math>\gamma</math>)Hf180</b>	Hf181, Ta182, Hf182, H3, Ta183	14.0	4	•	
<b>Hf179(n,<math>\gamma</math>)Hf180m</b>	Ta180m	91.0	2	•	
<b>Hf179(n,2n)Hf178m</b>	Hf178m	10.0	2	•	
<b>Hf179(n,2n)Hf178n</b>	Hf178n	10.0	4	•	
<b>Hf179(n,n')Hf179n</b>	Hf179n	100.0	3	•	
<b>Hf180(n,<math>\gamma</math>)Hf181</b>	Hf181, Ta182, Hf182, H3, Ta183, W185	18.0	5	•	•
<b>Hf180(n,2n)Hf179</b>	Hf178m, Hf179n, Hf178n	40.0	0		
<b>Hf180(n,2n)Hf179m</b>	Hf179m	20.0	5*	•	•
<b>Hf180(n,2n)Hf179n</b>	Hf179n	25.0	2	•	
<b>Hf181(n,<math>\gamma</math>)Hf182</b>	Hf182	110.0	2/0	•	
Ta179(n,2n)Ta178m	Ta178m	72.0	0		
<b>Ta180m(n,2n)Ta179</b>	Ta178m, Ta179, Hf178n	40.0	0		
<b>Ta180m(n,n')Ta180</b>	Ta180	100.0	0		
<b>Ta181(n,<math>\gamma</math>)Ta182</b>	Ta182, Ta183, W185, Re186, H3, Re186m, Hf182	84.0	6	•	•
<b>Ta181(n,t)Hf179</b>	H3	73.0	0	•	
<b>Ta181(n,2n)Ta180</b>	Ta180, Hf178n	20.0	6	•	•
<b>Ta181(n,2n)Ta180m</b>	Ta178m, Ta179, Hf178n	30.0	3	•	
<b>Ta181(n,<math>\alpha</math>)Lu177m</b>	Hf178n	210.0	0		
<b>Ta181(n,<math>\alpha</math>)Lu178</b>	Ta180m	20.0	4	•	
<b>Ta181(n,<math>\alpha</math>)Lu178m</b>	Ta180m	20.0	4	•	
Ta182(n, $\gamma$ )Ta183	Ta183, W185, Re186, Re186m, Hf182	63.0	2	•	
Ta182(n,p)Hf182	H3, Hf182	78.0	0		
<b>W180(n,<math>\gamma</math>)W181</b>	Ta182, W181, Hf178n	33.0			
<b>W180(n,2n)W179</b>	Ta179	20.0	/6	•	•
<b>W181(n,<math>\alpha</math>)Hf178n</b>	Hf178n	85.0			

Reaction	Daughter nuclide	Uncertainty (%)	Score	Exp data	
				Diff	Int
<b>W182(n,<math>\gamma</math>)W183</b>	W185, Re186, Re186m, Hf182	74.0	4	•	
<b>W182(n,<math>\gamma</math>)W183m</b>	W183m	74.0	0		
<b>W182(n,p)Ta182</b>	Ta182	30.0	2/4	•	•
<b>W182(n,2n)W181</b>	W181, Ta179	8.0	6	•	•
<b>W182(n,n<math>\alpha</math>)Hf178n</b>	Hf178n	90.0	2	•	
<b>W183(n,<math>\gamma</math>)W184</b>	W185, Re186, Re186m, H3	41.0	4	•	
<b>W183(n,<math>\alpha</math>)Hf180</b>	Hf182, Ta182	67.0	0/5	•	•
<b>W183(n,t)Ta181</b>	H3	60.0	0		
<b>W183(n,2n)W182</b>	Hf178n	12.0	4	•	
<b>W184(n,<math>\gamma</math>)W185</b>	W185, Re186, Re186m, Ir194, Os191, Ir192, Ir194m, Os194, H3, Pt193, Ir192n	86.0	4/2	•	
<b>W184(n,2n)W183</b>	Hf178n	20.0	0		
<b>W184(n,2n)W183m</b>	W183m	20.0	2	•	
<b>W184(n,t)Ta182</b>	H3	85.0	0		
<b>W184(n,h)Hf182</b>	Hf182	110.0	0		
W185(n, $\alpha$ )Hf182	Hf182	85.0	0		
<b>W186(n,<math>\gamma</math>)W187</b>	Re188, Ir194, W187, Re186, Os191, Ir192, Ir194m, Os194, Pt193, Ir192n, Re186m, Re187, W188	29.0	6	•	•
<b>W186(n,2n)W185</b>	Re184, W185, Re184m, Re186m, Hf182	20.0	6	•	•
<b>W186(n,n<math>\alpha</math>)Hf182</b>	Hf182	210.0	0/5	•	•
W187(n, $\gamma$ )W188	W188	57.0	2	•	
<b>Re185(n,<math>\gamma</math>)Re186</b>	Re186, Ir194, Os191, Ir192, Ir194m, Os194, Pt193, Ir192n, Re188, W187, W188, W185, Ta182, H3, Re187, Os186	69.0	4	•	
<b>Re185(n,<math>\gamma</math>)Re186m</b>	Re186m	71.0	2	•	
<b>Re185(n,2n)Re184</b>	Re184, Hf178n	15.0	5*	•	•
<b>Re185(n,2n)Re184m</b>	Re184m	20.0	6	•	•
<b>Re185(n,p)W185</b>	H3	67.0	0/5	•	
<b>Re185(n,n<math>\alpha</math>)Ta181</b>	Ta182	200.0	0		
<b>Re185(n,<math>\alpha</math>)Ta182</b>	Ta182	64.0	0	•	
<b>Re185(n,t)W183</b>	H3	85.0	0		
<b>Re187(n,<math>\gamma</math>)Re188</b>	Re188, Ir194, Os191, Ir192, Ir194m, Os194, Pt193, Ir192n, W188, W185	72.0	4/5*	•	•
<b>Re187(n,2n)Re186</b>	Re186, W185, Os186	15.0	6	•	•
<b>Re187(n,2n)Re186m</b>	Re186m	20.0	4	•	
<b>Re187(n,p)W187</b>	W187, Re188	9.0	4	•	
<b>Re187(n,<math>\alpha</math>)Ta184</b>	H3	20.0	4	•	
<b>Re187(n,t)W185</b>	H3	85.0	0		
Re188(n,p)W188	W188	50.0	0		
<b>Os184(n,<math>\gamma</math>)Os185</b>	Re186, Os185, Re186m, Os186	26.0	2	•	
<b>Os184(n,p)Re184</b>	Re184	78.0	0		
<b>Os184(n,p)Re184m</b>	Re184m	78.0	0		
<b>Os184(n,<math>\alpha</math>)W181</b>	H3	60.0	2	•	
<b>Os186(n,<math>\gamma</math>)Os187</b>	Ir194, Os191, Ir192, Ir194m, Os194, Pt193, Ir192n, W185, Os190m, Os189m	42.0	4	•	
<b>Os186(n,<math>\alpha</math>)W183</b>	Ta182, H3	85.0	0		
<b>Os186(n,p)Re186</b>	Re186	67.0	2	•	
<b>Os186(n,p)Re186m</b>	Re186m	67.0	0		
<b>Os186(n,2n)Os185</b>	Re184, Os185, Re184m	10.0	2	•	
<b>Os187(n,<math>\gamma</math>)Os188</b>	Ir194, Os191, Ir192, Ir194m, Os194, Pt193, Ir192n, W185, Os190m, Os189m, Re186, Re186m	39.0	4	•	
<b>Os187(n,2n)Os186</b>	Os185, Os186	40.0	0		
<b>Os187(n,p)Re187</b>	H3	50.0	0		
<b>Os187(n,<math>\alpha</math>)W184</b>	H3, Re186, Re186m	60.0	2		
<b>Os188(n,<math>\gamma</math>)Os189</b>	Ir194, Os191, Ir192, Ir194m, Os194, Pt193, Ir192n, Os190m	70.0	0	•	
<b>Os188(n,<math>\gamma</math>)Os189m</b>	Os189m	70.0	0		
<b>Os188(n,<math>\alpha</math>)W185</b>	W185, Re186, Re186m	72.0	0		
<b>Os188(n,2n)Os187</b>	Os185, Os186	40.0	0		

Reaction	Daughter nuclide	Uncertainty (%)	Score	Exp data	
				Diff	Int
<b>Os189(n,<math>\gamma</math>)Os190</b>	Ir194, Os191, Ir192, Ir194m, Os194, Pt193, Ir192n, Re187	29.0	4	•	
<b>Os189(n,<math>\gamma</math>)Os190m</b>	Os190m	46.0	2	•	
<b>Os189(n,n<math>\alpha</math>)W185</b>	Re186, Re186m	210.0	0		
<b>Os189(n,<math>\alpha</math>)W186</b>	Re187	60.0	2	•	
<b>Os190(n,<math>\gamma</math>)Os191</b>	Ir194, Os191, Ir192, Ir194m, Os194, Pt193, Ir192n, H3	77.0	2	•	
<b>Os190(n,2n)Os189m</b>	Os189m	72.0	0		
<b>Os190(n,<math>\alpha</math>)W187</b>	Re186, Re186m, Re187	25.0	4	•	
<b>Os191(n,<math>\gamma</math>)Os192</b>	Os194	98.0	0		
<b>Os192(n,<math>\gamma</math>)Os193</b>	Os194, Ir194, Os193, Ir192, Pt193, Ir192n	82.0	4	•	
<b>Os192(n,2n)Os191</b>	Ir190, Os191, Ir192, H3, Pt193, Ir192n	20.0	2	•	
<b>Os193(n,<math>\gamma</math>)Os194</b>	Os194	78.0	2	•	
<b>Ir191(n,<math>\gamma</math>)Ir192</b>	Ir194, Ir192, Ir194m, Os194, Pt193, Re186, Pt195m, Pt193m, Ir193m, Hg203, Re186m, Re187	82.0	2/2	•	
<b>Ir191(n,<math>\gamma</math>)Ir192n</b>	Ir192n	79.0	2	•	
<b>Ir191(n,2n)Ir190</b>	Ir190, Re186, Re186m, Re187	20.0	2/4/6	•	•
<b>Ir191(n,p)Os191</b>	H3	62.0	0	•	
<b>Ir191(n,t)Os189</b>	H3	85.0	0		
<b>Ir191(n,n<math>\alpha</math>)Re187</b>	Re186, Re186m, Re187	200.0	0		
<b>Ir191(n,n')Ir191m</b>	Ir191m	30.0	2	•	
<b>Ir191(n,<math>\alpha</math>)Re188</b>	Re186, Re186m	30.0	0	•	
<b>Ir192(n,<math>\gamma</math>)Ir193</b>	Ir194, Ir194m, Pt195m, Hg203	89.0	2	•	
<b>Ir192(n,<math>\gamma</math>)Ir193m</b>	Ir193m	89.0	0		
<b>Ir193(n,<math>\gamma</math>)Ir194</b>	Ir194, Pt193, Au198, Au199, Pt195m, Pt193m, Hg203, Os194, Pb205, Ir192, Ir192n	64.0	4	•	
<b>Ir193(n,<math>\gamma</math>)Ir194m</b>	Ir194m, Hg203, Os194	63.0	0		
<b>Ir193(n,2n)Ir192</b>	Ir192, Pt193, Pt193m	20.0	0/5	•	•
<b>Ir193(n,2n)Ir192n</b>	Ir192n	20.0	2	•	
<b>Ir193(n,n')Ir193m</b>	Ir193m	30.0	3	•	
<b>Ir193(n,p)Os193</b>	Os194	25.0	3	•	
<b>Ir194(n,p)Os194</b>	Os194	50.0	0		
<b>Ir194(n,<math>\gamma</math>)Ir195</b>	Au198, Au199, Hg203, Pb205	110.0	2/0	•	
<b>Ir194m(n,p)Os194</b>	Os194	50.0	0		
<b>Pt190(n,<math>\alpha</math>)Os187</b>	Re186, Re186m	60.0	2	•	
<b>Pt190(n,<math>\gamma</math>)Pt191</b>	Ir192, Ir194m, Os194, Ir192n	67.0	2	•	
<b>Pt191(n,2n)Pt190</b>	Pt190	40.0	0		
<b>Pt192(n,<math>\gamma</math>)Pt193</b>	Pt193, Ir194m	80.0	2	•	
<b>Pt192(n,<math>\gamma</math>)Pt193m</b>	Pt193m	80.0	2	•	
<b>Pt192(n,2n)Pt191</b>	Re186, Re186m, Pt190	8.0	2	•	
<b>Pt192(n,<math>\alpha</math>)Os189</b>	Re186, Re186m, Re187	85.0	0		
<b>Pt193(n,2n)Pt192</b>	Pt190	40.0	0		
<b>Pt194(n,2n)Pt193</b>	Pt193, Ir192, Ir192n, Pt190	72.0	0		
<b>Pt194(n,2n)Pt193m</b>	Pt193m	72.0	0		
<b>Pt194(n,<math>\gamma</math>)Pt195</b>	Au198, Au199, Hg203	46.0	4	•	
<b>Pt194(n,<math>\gamma</math>)Pt195m</b>	Pt195m	45.0	2	•	
<b>Pt194(n,<math>\alpha</math>)Os191</b>	Ir192, Ir192n, Pt193	73.0	0	•	
<b>Pt194(n,p)Ir194m</b>	Ir194m	30.0	2	•	
<b>Pt195(n,<math>\gamma</math>)Pt196</b>	Au198, Au199, Hg203, Pb205, Pt197	38.0	2	•	
<b>Pt195(n,2n)Pt194</b>	Pt193m, Ir192, Pt193, Pt190	40.0	0		
<b>Pt195(n,d)Ir194m</b>	Ir194m	120.0	0		
<b>Pt195(n,<math>\alpha</math>)Os192</b>	Os194	85.0	0		
<b>Pt196(n,<math>\gamma</math>)Pt197</b>	Au198, Au199, Hg203, Pb205, Pt197, Tl204	52.0	4	•	
<b>Pt196(n,2n)Pt195m</b>	Pt195m	130.0	0		
<b>Pt196(n,h)Os194</b>	Os194	90.0	0		
<b>Pt196(n,<math>\alpha</math>)Os193</b>	Ir192, Ir192n	20.0	2	•	
<b>Pt196(n,2n)Pt195</b>	Ir192, Pt193, Pt190	140.0	0	•	
<b>Pt198(n,<math>\gamma</math>)Pt199</b>	Pt199, Au199, Hg203, Tl204, Pb205	91.0	4/2	•	
<b>Pt198(n,2n)Pt197</b>	Pt197, Au194, Au198, Hg194	20.0	/6	•	•
<b>Pt198(n,n<math>\alpha</math>)Os194</b>	Os194	200.0	0		

Reaction	Daughter nuclide	Uncertainty (%)	Score	Exp data	
				Diff	Int
Au195(n,2n)Au194	Au194	72.0	0		
<b>Au197(n,2n)Au196</b>	Au194, Hg194, Au196, Ir192, Au195, Os194, Pt193, Ir192n, Pb205, Pt190	10.0	4/5/5	•	•
<b>Au197(n,<math>\gamma</math>)Au198</b>	Au198, Au199, Hg203, Pb205, Tl204, Au197m, Hg199m, Ir192, Os194, Pt193, Ir192n, Pb204	49.0	6*	•	•
<b>Au197(n,n')Au197m</b>	Au197m	15.0	5	•	•
<b>Au197(n,<math>\alpha</math>)Ir193</b>	Ir194, Ir192, Pt193, Ir192n	210.0	0		
<b>Au197(n,<math>\alpha</math>)Ir194</b>	Ir194, Ir192, Pt193, Ir192n	30.0	4	•	
<b>Au197(n,<math>\alpha</math>)Ir194m</b>	Ir192, Ir194m, Os194, Pt193	30.0	4	•	
<b>Au197(n,p)Pt197</b>	H3	20.0	2/4	•	
<b>Au197(n,t)Pt195</b>	H3	85.0	0		
Au198(n, $\gamma$ )Au199	Au199, Hg203, Pb205, Tl204, Au197m, Pb204	81.0	2	•	
Hg195m(n,2n)Hg194	Hg194	40.0	0		
<b>Hg196(n,2n)Hg195</b>	Au194, Au195, Pt193, Pt190	20.0	2	•	
<b>Hg196(n,2n)Hg195m</b>	Au194, Hg194, Au195	20.0	2	•	
<b>Hg196(n,<math>\gamma</math>)Hg197</b>	Hg197, Au198	28.0	4/2	•	
<b>Hg196(n,p)Au196</b>	Au196	61.0	0		
<b>Hg196(n,<math>\alpha</math>)Pt193</b>	Pt193	85.0	0		
<b>Hg196(n,<math>\alpha</math>)Pt192</b>	Pt193	200.0	0		
<b>Hg198(n,<math>\gamma</math>)Hg199</b>	Au197m, Hg203, Tl204, Pb205, Pb204	12.0	4	•	•
<b>Hg198(n,<math>\gamma</math>)Hg199m</b>	Hg199m	90.0	2	•	
<b>Hg198(n,<math>\alpha</math>)Pt194</b>	Ir192, Pt193, Ir192n	200.0	0		
<b>Hg198(n,<math>\alpha</math>)Pt195</b>	Os194	85.0	0		
<b>Hg198(n,2n)Hg197</b>	Hg197, Au196	20.0	4	•	
<b>Hg198(n,p)Au198</b>	Au198	62.0	0	•	
<b>Hg199(n,<math>\gamma</math>)Hg200</b>	Hg203, Pb205, Tl204, Au197m, Pb204	13.0	4/2	•	
<b>Hg199(n,2n)Hg198</b>	Hg197, Au198	40.0	0		
<b>Hg199(n,p)Au199</b>	H3	20.0	2	•	
<b>Hg199(n,t)Au197</b>	H3	85.0	0		
<b>Hg200(n,<math>\gamma</math>)Hg201</b>	Hg203, Pb205, Tl204, Pb204	52.0	4	•	
<b>Hg200(n,<math>\alpha</math>)Pt197m</b>	Au197m	67.0	0	•	
<b>Hg200(n,2n)Hg199m</b>	Hg199m	20.0	6	•	•
<b>Hg201(n,<math>\gamma</math>)Hg202</b>	Hg203, Pb205, Tl204, Pb204	77.0	4	•	
<b>Hg202(n,<math>\gamma</math>)Hg203</b>	Hg203, Pb205, Tl204, Pb204, H3	17.0	4	•	
<b>Hg204(n,<math>\gamma</math>)Hg205</b>	Hg205, Pb202, Tl204, Pb205	41.0	4	•	
<b>Hg204(n,2n)Hg203</b>	Tl202, Hg203, Tl204, Pb202	10.0	4	•	
<b>Tl203(n,<math>\gamma</math>)Tl204</b>	Pb205, Tl204, Pb204, Pb202	97.0	4	•	
<b>Tl203(n,2n)Tl202</b>	Tl202	15.0	6	•	•
<b>Tl203(n,p)Hg203</b>	H3, Hg203	19.0	2	•	
<b>Tl203(n,<math>\alpha</math>)Au200</b>	Hg203	300.0	2	•	
<b>Tl203(n,t)Hg201</b>	H3	60.0	0		
<b>Tl205(n,2n)Tl204</b>	Tl204, Pb202, Pb204m, Hg203	20.0	4	•	
<b>Tl205(n,<math>\gamma</math>)Tl206</b>	Pb205, Tl206	52.0	4/0	•	•
<b>Tl205(n,t)Hg203</b>	H3	40.0	2	•	
Pb203(n,2n)Pb202	Pb202	72.0	0		
<b>Pb204(n,<math>\gamma</math>)Pb205</b>	Pb205	27.0	4	•	
<b>Pb204(n,2n)Pb203</b>	Pb202, Pb203, Tl202	25.0	2/5	•	•
<b>Pb204(n,n')Pb204m</b>	Pb204m	20.0	6	•	•
<b>Pb204(n,p)Tl204</b>	Tl204, H3	50.0	0		
Pb205(n,2n)Pb204	Pb203, Tl202, Pb202	72.0	0		
Pb205(n,2n)Pb204m	Pb204m	72.0	0		
<b>Pb206(n,2n)Pb205</b>	Pb205, Pb204m, Pb203, Tl202, Pb202	8.0	2*	•	
<b>Pb206(n,<math>\gamma</math>)Pb207m</b>	Pb207m	74.0	2	•	
<b>Pb206(n,<math>\alpha</math>)Hg203</b>	Hg203, Tl204	20.0	4	•	
<b>Pb207(n,<math>\alpha</math>)Hg204</b>	Hg205, Hg203	31.0	2	•	
<b>Pb207(n,n<math>\alpha</math>)Hg203</b>	Hg203, Tl204	200.0	0		
<b>Pb208(n,2n)Pb207m</b>	Pb207m	15.0	4	•	
<b>Pb208(n,<math>\alpha</math>)Hg205</b>	Hg205, Tl204	30.0	4	•	

Reaction	Daughter nuclide	Uncertainty (%)	Score	Exp data	
				Diff	Int
Pb208(n, $\gamma$ )Pb209	Pb209, Po210, H3, Pb210, Bi207, Bi208, Bi210m	30.0	4	•	
Pb208(n,t)Tl206	H3	85.0	0		
Pb209(n, $\gamma$ )Pb210	Pb210	670.0	0		
Bi207(n,2n)Bi206	Bi206	40.0	0		
Bi208(n,2n)Bi207	Bi207, Bi206	61.0	0		
Bi209(n, $\gamma$ )Bi210	Po210, Bi210, Po209	89.0	4	•	
Bi209(n, $\gamma$ )Bi210m	H3, Bi210m	91.0	2	•	
Bi209(n,2n)Bi208	Bi207, Bi208, Bi206	10.0	0/4	•	
Bi209(n, $\alpha$ )Tl206	Tl206	50.0	6	•	•
Bi209(n, $\alpha$ )Tl206m	Tl206m	78.0	5	•	•
Bi209(n,t)Pb207	H3	72.0	0	•	
Bi210m(n,t)Pb208	H3	60.0	0		
Po210(n,2n)Po209	Po209	40.0	0		
Ra225(n, $\gamma$ )Ra226	Bi214	90.0	0		
Ra226(n, $\gamma$ )Ra227	Ac227	47.0	2	•	
Th228(n, $\gamma$ )Th229	Th229	73.0			
Th229(n, $\gamma$ )Th230	Bi214, Th231, Th228, Ac227, Th230	83.0			
Th230(n,3n)Th228	Tl208, Th228	200.0			
Th230(n, $\gamma$ )Th231	Th231, Th228, Ac227, U232, Th229	29.0			
Th230(n, $\alpha$ )Ra227	Ac227	50.0			
Th230(n,2n)Th229	Th229	40.0			
Th232(n, $\gamma$ )Th233	Ba137m, Pr144, Sb126m, Bi214, Th231, La140, Y90, Pa233, Nb95, Cs134, Ac227, Sr90, Pu238, Th229, Th230, U233, U234	10.0	4	•	
Th232(n,f)Rb90	Y90, Sr90	50.0	6*	•	•
Th232(n,f)Sr95	Nb95	50.0	6*	•	•
Th232(n,f)Sn127	Sb126m	50.0	6*	•	•
Th232(n,f)Te135	Cs134	50.0	6*	•	•
Th232(n,f)I135	Cs134	50.0	6*	•	•
Th232(n,f)Xe137	Ba137m	50.0	6*	•	•
Th232(n,f)Xe138	Ba137m	50.0	6*	•	•
Th232(n,f)Cs140	La140	50.0	6*	•	•
Th232(n,f)La144	Pr144	50.0	6*	•	•
Th232(n,3n)Th230	Tl208, Bi214, Th228, Ac227, Th229, Th230	67.0	1	•	
Th232(n,2n)Th231	Pr144, Th231, La140, Y90, U230, Nb95, Sr90	15.0	4	•	
Th232(n, $\alpha$ )Ra229	Bi214, Th231, Th228, Ac227, Th229, Th230	60.0	2	•	
Pa231(n,f)Rb90	Y90, Sr90	50.0	6*	•	•
Pa231(n,f)Sr95	Nb95	50.0	6*	•	•
Pa231(n,f)Cs140	La140	50.0	6*	•	•
Pa231(n,f)La144	Pr144	50.0	6*	•	•
Pa231(n,2n)Pa230	U230, Th230	40.0	0		
Pa231(n, $\gamma$ )Pa232	Th228, U232, Th229	43.0	2	•	
Pa231(n,3n)Pa229	Th229	200.0	0		
Pa233(n, $\gamma$ )Pa234	Pu238	55.0	2	•	
Pa233(n, $\gamma$ )Pa234m	Pu238, U234	54.0	2	•	
U232(n,2n)U231	Th229, Th230	40.0	0		
U233(n,f)Kr89	Y90	11.0	6*	•	•
U233(n,f)Rb90	Y90, Sr90	11.0	6*	•	•
U233(n,f)Rb90m	Y90, Sr90	11.0	6*	•	•
U233(n,f)Sr95	Nb95	11.0	6*	•	•
U233(n,f)Y95	Nb95	11.0	6*	•	•
U233(n,f)In125	Sb126m	11.0	6*	•	•
U233(n,f)Sn125	Sb126m	11.0	6*	•	•
U233(n,f)Te133	Cs134	11.0	6*	•	•
U233(n,f)Te133m	Cs134	11.0	6*	•	•
U233(n,f)I133	Cs134	11.0	6*	•	•
U233(n,f)Xe137	Ba137m	11.0	6*	•	•
U233(n,f)La144	Pr144	11.0	6*	•	•
U233(n,f)Cs140	La140	11.0	6*	•	•

Reaction	Daughter nuclide	Uncertainty (%)	Score	Exp data	
				Diff	Int
U233(n,f)Ba140	La140	11.0	6*	•	•
U233(n, $\gamma$ )U234	Pu238, U234	24.0	4	•	•
<b>U234(n,<math>\gamma</math>)U235</b>	Pu238	95.0	0	•	
<b>U235(n,<math>\gamma</math>)U236</b>	Pu238, Np237	12.0	4	•	
<b>U235(n,f)Rb90</b>	Sr90	14.0	6*	•	•
<b>U235(n,f)Xe137</b>	Ba137m	14.0	6*	•	•
U236(n, $\gamma$ )U237	Pu238, Np237	12.0	4	•	
<b>U238(n,<math>\gamma</math>)U239</b>	Ba137m, Sb126m, La140, Np239, Cs134, Pu241, Cm244, Sr90, Pu238, Sm151, Ag108m, Am241, Pu240, Pu239, Tc99, Pu242	9.8	4	•	
<b>U238(n,f)Rb90</b>	Sr90	50.0	6*	•	•
<b>U238(n,f)Zr99</b>	Tc99	50.0	6*	•	•
<b>U238(n,f)Ru109</b>	Ag108m	50.0	6*	•	•
<b>U238(n,f)Sn127</b>	Sb126m	50.0	6*	•	•
<b>U238(n,f)Te135</b>	Cs134	50.0	6*	•	•
<b>U238(n,f)Xe137</b>	Ba137m	50.0	6*	•	•
<b>U238(n,f)Xe138</b>	Ba137m	50.0	6*	•	•
<b>U238(n,f)Cs140</b>	La140	50.0	6*	•	•
<b>U238(n,f)I135</b>	Cs134	50.0	6*	•	•
<b>U238(n,f)Nd151</b>	Sm151	50.0	6*	•	•
<b>U238(n,2n)U237</b>	Pu236, U232, Pu238, Th229, Th230, Np237	10.0	5*	•	•
Np237(n, $\gamma$ )Np238	Pu238	23.0	4	•	
Np237(n,2n)Np236m	Pu236, U232, Th229, Th230	15.0	5*	•	•
Pu239(n, $\gamma$ )Pu240	Ba137m, La140, Pu241, Cm244, Sr90, Pu238, Sm151, Am241, Pu240, Pu242	27.0	4	•	
Pu239(n,f)Rb90	Sr90	12.0	6*	•	•
Pu239(n,f)Zr99	Tc99	12.0	6*	•	•
Pu239(n,f)Ag108m	Ag108m	12.0	6*	•	•
Pu239(n,f)In125	Sb126m	12.0	6*	•	•
Pu239(n,f)Sn125	Sb126m	12.0	6*	•	•
Pu239(n,f)Te133	Cs134	12.0	6*	•	•
Pu239(n,f)Te133m	Cs134	12.0	6*	•	•
Pu239(n,f)Xe137	Ba137m	12.0	6*	•	•
Pu239(n,f)Cs140	La140	12.0	6*	•	•
Pu239(n,f)Ce149	Sm151	12.0	6*	•	•
Pu239(n,f)Nd151	Sm151	12.0	6*	•	•
Pu240(n, $\gamma$ )Pu241	Ba137m, La140, Pu241, Cm244, Sr90, Pu238, Sm151, Am241, Pu242	11.0	4	•	
Pu241(n, $\gamma$ )Pu242	Cm244, Pu242	19.0	4	•	
Pu241(n,f)Rb90	Sr90	17.0	6*	•	•
Pu241(n,f)Xe137	Ba137m	17.0	6*	•	•
Pu241(n,f)Cs140	La140	17.0	6*	•	•
Pu241(n,f)Nd151	Sm151	17.0	6*	•	•
Pu242(n, $\gamma$ )Pu243	Cm244	26.0	4	•	
Am241(n, $\gamma$ )Am242	Pu238	24.0	4	•	
Am243(n, $\gamma$ )Am244m	Cm244	24.0	2	•	