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Movement of Active Components in the Shutdown Dose Rate Analysis of the ITER Neutral Beam Injectors

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The requirement for maintenance in areas with relatively high shutdown dose rate fields is a key issue to address in the design and engineering of ITER, next generation devices and future commercial fusion reactors. In order to estimate the shutdown dose rate during maintenance and intervention scenarios CCFE's Mesh Coupled implementation of the Rigorous 2 Step method (MCR2S) has been modified to allow components to be moved from on-load locations to new locations for the purpose of shutdown dose rate calculations. Scenarios, such as opening of doors, removal of shielding and other processes, can be modelled in a more physically accurate manner.

The new MCR2S capability has been applied to three intervention scenarios within the ITER Neutral Beam Cell. Here, calculations show that by moving these components a significant increase in the dose rate in certain locations of the Neutral Beam Cell can be expected and need to be taken into account when designing the Neutral Beam Cell remote handling equipment and maintenance procedures.

Keywords: Nuclear analysis, MCNP, MCR2S, ITER, neutral beam, shutdown dose rate.

1. Introduction

Estimation and minimisation of radiation fields in current and future fusion machines is a key part of the engineering effort towards commercial fusion. In order to estimate such fields computational codes are required.

On-load neutron and prompt photon dose fields arising during plasma operations are relatively straight forward to map using standard radiation transport codes such as MCNP [1]. However, the so called 'shutdown' dose arising from the decay and subsequent emission of radionuclides generated by neutron activation of materials requires the coupling of particle transport and inventory codes.

In order to produce 3-D maps of the shutdown dose fields tools have previously been developed. One such tool is CCFE's Mesh Coupled implementation of the Rigorous 2 Step method [2] (MCR2S [3]). MCR2S calculations consist of:

1. a neutron transport calculation (carried out by MCNP [1]) to ascertain the on-load neutron field spatially across the geometry,
2. a series of activation calculations (carried out by FISPACT [4]) using the neutron field results and irradiation history parameters to ascertain the decay photon source,
3. and finally a photon transport run (again carried out by MCNP [1]) to ascertain the photon field arising from such a decay source.

A significant disadvantage of the previous versions of MCR2S was the need to use the same geometry for both the neutron activation calculation and the shutdown photon transport calculation. This meant that it was not possible to model activated components that were moved during shutdown in an area which was also activated, as would be the case for maintenance and/or intervention scenarios.

MCR2S has been modified to allow multiple components to be moved to multiple different locations, taking account of both the activity and the potentially reduced shielding, while keeping other activated components in their original positions. All of this can be carried out in a single shutdown dose rate calculation.

In order to demonstrate the application of this development it has been used on three intervention scenarios within the ITER Neutral Beam Cell (NB Cell). In ITER, there will be three neutral beam injectors used as one of the primary plasma heating systems. These injectors are made up of several components including the front end components, beam line components and a beam source. The three NB cell intervention scenarios covered by this paper are removal of the beam source, removal of an internal beam line component and removal of a front end component

Shutdown photon dose rate have been ascertained for a number of materials to ensure survivability of sensitive remote handling equipment.

This paper includes: an overview of the modification made to MCR2S, a description of the three NBI intervention scenarios, the results from these intervention scenarios and concludes with a discussion of the results.

2. Overview of the MCR2S modification

The modifications made to MCR2S to allow geometrical transformation of the source, does not affect the first two steps of the MCR2S approach. This means that an MCNP neutron calculation is carried out, with all components in their on-load locations, followed by a series of activation calculation across the geometry. This

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results in the MCR2S shutdown photon source for the model in its on-load configuration.

In order to carry out the second step, the shutdown dose rate calculations, with components in locations other than their on-load position, the MCNP model geometry has to be modified. This geometry can then be used alongside a modified version of the MCR2S photon source reader to map the shutdown dose field.

To translate the components to their new shutdown locations new parts are created within the MCNP model. These parts contain a copy of the moved components. Transform cards are applied to the parts to relocate the moved components. It should be noted that the original components stay in the same place but their material definition is turned to 'void' i.e. vacuum.

A method using cells lists linked to a geometrical transform list was adopted for transforming the shutdown photon source locations for certain components while keeping the location of others the same.

A cells list contains a list of the cells making up an original part - which are set to void in the shutdown MCNP model. Any source particle starting in one of the cells listed is automatically transformed by the associated rotation and translation.

As there can be multiple cells lists and transforms it is possible to move several different components to several different locations all in the same MCNP shutdown dose calculation.

3. MCR2S Testing

3.1 Scenario Modelling

Previously a MCNP NB Cell model [5] has been developed. A 3-D view of the on-load NB Cell MCNP model is shown in Figure 1.

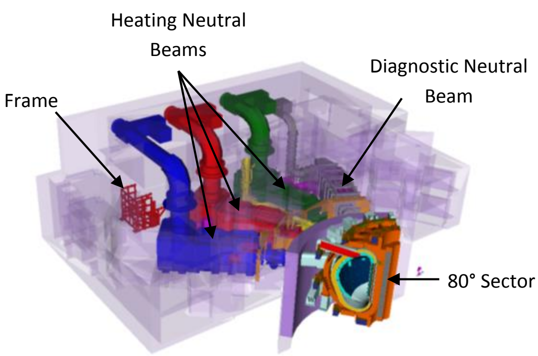

Fig 1. 3D view of the MCNP model, including the 3 NBIs, DNB, 80 degree sector of ITER and NB cell concrete (translucent).

The model contains the 80 degree A-Lite sector model along with the NB Cell and surrounding rooms. The NB cell contains three heating NBIs, the diagnostic neutral beam and associated ancillary equipment, such as remote handling equipment and maintenance platforms.

The FENDL-2.1 [6] neutron cross section data library has been used in the MCNP radiation transport simulations. ENDF-B-VII [7] data was used for those nuclides where .ace format FENDL-2.1 data does not exist.

Three different NB Cell shutdown intervention scenarios have been modelled. All of these scenarios are expected to be carried out using remote handling equipment, and work will only be carried out on an individual NBI at a time. As the shutdown dose rate around each of the machines during each scenario will be very similar, the scenarios have only been applied to the middle of the three heating NBIs. The three scenarios are:

1. Removal of the ion source (see Fig. 2). This scenario involves the opening of the rear plates of the Passive Magnetic Shield (PMS) and the Beam Source Vessel (BSV) rear lid.

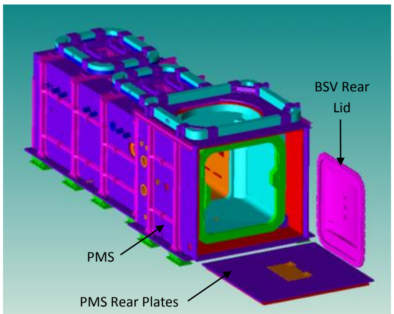

Fig 2. Scenario 1, Opening of the rear PMS and BSV rear lid

2. Removal of internal beam line component (see Fig. 3). This scenario involves the removal of the Active Correction Coils (ACCs), top section of the PMS and the opening of the Beam Line Vessel (BLV). The removed components are stored on the frame located next to the north wall.

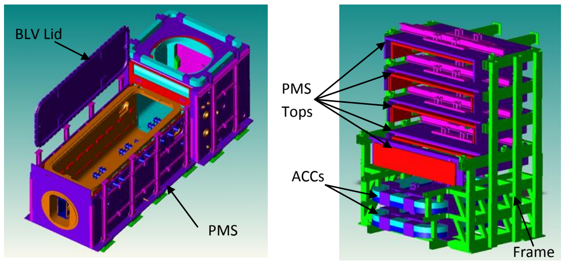

Fig 3. Scenario 2, opening of the top PMS and BLV Lid

3. Removal of front end component (see Fig. 4). This scenario involves the opening of the balcony plate above the front end components.

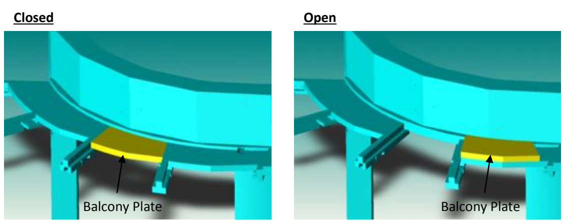

Fig 4. Scenario 3, opening of the balcony plate

Table 1. Dose Rate to Silicon and photon transport relative statistical error for various locations and scenarios

Point	Scenario 1		Scenario 2		Scenario 3	
	Dose to Silicon (µGy/hr)	Relative Statistical Error	Dose to Silicon (µGy/hr)	Relative Statistical Error	Dose to Silicon (µGy/hr)	Relative Statistical Error
1	2.54×10^3	8.3%	2.93×10^2	4.9%	2.47×10^2	5.9%
2	6.56×10^2	4.6%	1.87×10^4	6.9%	7.75×10^2	8.4%
3	2.83×10^2	2.4%	3.91×10^2	4.1%	3.18×10^1	5.2%
4	2.66×10^2	20.3%	9.25×10^2	15.3%	3.56×10^4	8.5%

Shutdown dose rate calculations have been carried out for the three scenarios. From these calculations the biological shutdown dose rate along with the dose rates to silicon, aluminium, steel and stainless steel were recorded on mesh tallies. Only results for dose to silicon will be discussed in this paper as they are the most pertinent for sensitive electronics on the remote handling equipment.

The neutron flux calculations used the ITER reference 80 degree 500 MW plasma neutron source [9] with reflecting sector boundary, corresponding to a neutron source normalisation factor of 3.94×10^{19} n/s. Global variance reduction techniques [10] were used on the neutron calculation to minimise the error throughout the geometry for a given computation load.

MCR2S was used to conduct activation calculations using FISPACT 2007 [4], an industry standard activation code. FISPACT solves the Bateman equation to calculate the inventories resulting from the transmutation of a given material by a specified neutron spectrum for a fixed irradiation scenario. The activation data used in FISPACT for this project is EAF2007 [8].

The ITER recommended SA2 irradiation scenario [11] was used during this work. As the three intervention scenarios may be carried out at any point during ITER lifetime, the worst case shutdown dose rates were calculated at 10^6s after ITER end of life.

3.2 Shutdown Dose Results

The dose rate to silicon for each of the three scenarios can be seen in Table 1. The results are given at the four points around the NB cell. These are labelled in Figures 5, 6 and 7. The relative statistical errors for the photon transport run are also given in this table.

The relative statistical error for the majority of results are low i.e <10%. The relative statistical errors above the balcony plate (see point 4) are between 15.3 % and 20.3% when the balcony plate has not been removed. This is due to the relatively high attenuation provided by the balcony plate and no variance reduction being carried out on the shutdown photon calculations. Although these errors are relatively high they are unlikely to affect the conclusions of this report as the dose rate in this area is significantly (approximately two orders of magnitude) higher when the balcony plate is opened.

The shutdown dose rate to silicon for scenario 1 has been plotted and shown in Figure 5. This shows an X-Y slice through the NBIs.

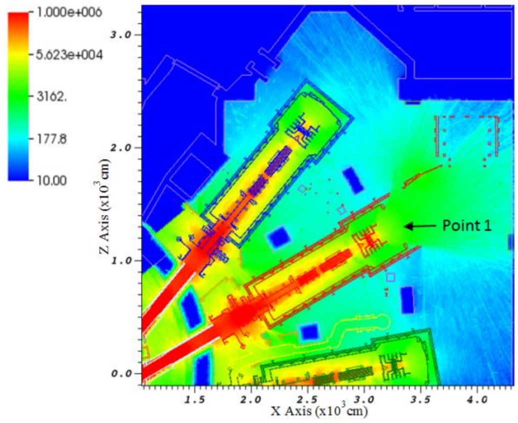

Fig. 5. Scenario 1, Dose Rate to Silicon (µGy/hr) at 106s after shutdown, horizontal slice at beam mid plane

Figure 5 shows the elevated dose rate at the rear of HNB2. This is due to the exposed activated ion source and beam line components. With the PMS and BLV doors open the dose rate to silicon around the rear of HNB 2 (Point 1) is in the region of 2500 µGy/hr.

The shutdown dose rate to silicon for scenario 2 has been plotted and shown in Figure 6. This shows an X-Y slice across the top of HNB 2, a vertical slice along the central axis of HNB 2 and a vertical slice through the storage frame.

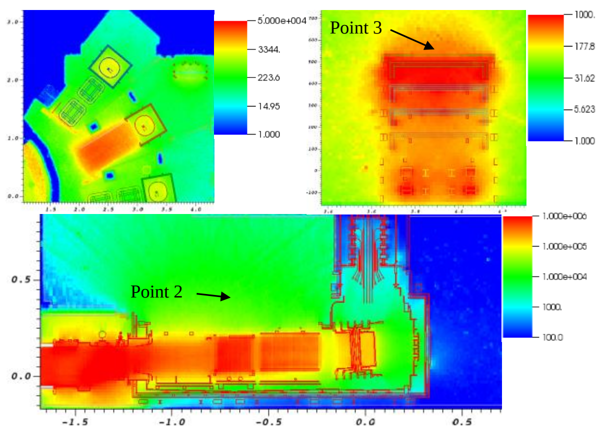

Fig. 6. Scenario 2, Dose Rate to Silicon (µGy/hr) at 106s after shutdown, top left: Slice across the top of HNB2, top right: Vertical slice across the storage frame, bottom: Vertical slice through HNB 2, spatial scales in x103cm

As would be expected, there is a large increase in the dose rate to silicon above HNB2. This is caused by the removal of the ACCs, PMS plates and BLV lid. During shutdown they act as a shield for the highly activated beam line components. The shutdown dose rate to silicon just above HNB 2 (Point 2) is approximately 18500 μGy/hr.

The ACCs and PMS plates themselves are activated during on-load operations. Although not as highly active as the beam line components, they are more active than the frame they are stored on. This can be seen in Figure 6.

The PMS plate at the top of the storage frame exhibits the highest activation levels. This is to be expected as it is located at the front of the HNB and will therefore experience the highest neutron flux levels during plasma operation. The dose rate to silicon just above this plate (Point 3) is approximately 400 μGy/hr.

The shutdown dose rate to silicon for scenario 3 can be seen in Figure 7. This shows a vertical slice through HNB 2.

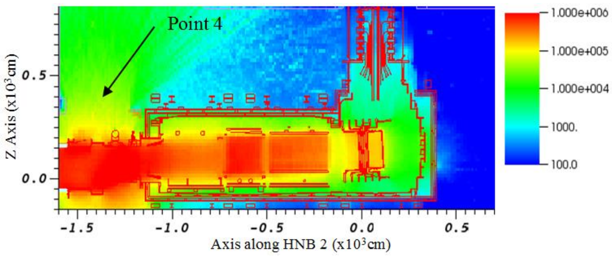

Fig. 7. Scenario 3, Dose Rate to Silicon (μGy/hr) at 10^6s after shutdown, vertical slice through HNB 2

Figure 7 clearly shows the shine path that is created with the removal of the balcony plate. This would significantly increase the dose rate to any remote handling equipment situated above the balcony. The front end components see the highest neutron flux of any NBI component and are therefore the most active. The dose rate to silicon increases into the region of 35000 μGy/hr when the balcony plate is removed (Point 4).

3.3 Uncertainties

Error propagation through an R2S calculation is an active area of research. However during this work a significant amount of computational effort was used to reduce the statistical uncertainties on the neutron and gamma transport steps.

4. Discussion & Conclusions

4.1 MCR2S Development

The modification to MCR2S allows multiple components to be moved to multiple locations while keeping other activated components in their original positions. All of this can be carried out in a single shutdown dose rate calculation.

One disadvantage of the method used is the new and old position of the component cannot overlap. This is due to the requirement for the original cells to be kept in order to work out whether a source particle needs to be transformed to a new location.

4.2 NB Cell Results

The results from the intervention scenarios in the NB cells show the importance of modelling maintenance scenarios in a physically correct way. This is essential for accurately estimating the dose received to remote handling equipment during the three scenarios.

Dose rate results to other materials, including steel, stainless steel and aluminium, showed similar increases for each scenario. This increase in dose rate needs to be taken into account when designing the remote handling equipment and maintenance procedures.

Acknowledgments

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References

[1] X-5 Monte Carlo Team, "MCNP — A general Monte Carlo N-particle transport code, version 5", LANL report, LA-CP-03-0245, April 2003 (rev. March 2005)

[2] Y. Chen et al., Fusion Engineering and Design 63–64 (2002), p107.

[3] A. Davis and R. Pampin, Fus. Eng. Des. 85 (2010) p87

[4] R.A. Forrest, "FISPACT-2007 user manual", UKAEA report FUS 534, March 2007

[5] S. Lilley, T Eade & M Lis, NBI Phase 2 Nuclear Analysis Model Development & Baseline Results, Private Communication

[6] D. Lopez Al-dama and A. Trkov, "FENDL-2.1: update of an evaluated nuclear data library for fusion applications", IAEA Report INDC(NDS)-46, 2004

[7] M.B. Chadwick et al. ENDF/B-VII.1: Nuclear Data for Science and Technology: Cross Sections, Covariances, Fission Product Yields and Decay Data", Nucl. Data Sheets 112(2011)2887

[8] R.A. Forrest, "The European Activation File: EAF-2007 neutron-induced cross section library", UKAEA report FUS 535, March 2007

[9] E.Polunovskiy, SDEF card for the ITER standard neutron source, Version 1.4, June 2010, Private Communication

[10] A. Davis and, A. Turner, Comparison of global variance reduction techniques for Monte Carlo radiation transport simulations of ITER, Fusion Engineering and Design, Volume 86, Issues 9–11, October 2011, Pages 2698-2700

[11] M Loughlin & N Taylor, Recommendation on Plasma Scenarios, Version 1.2, 10th December 2009, Private Communication.