KEY ISSUES FOR THE SAFETY AND LICENSING OF FUSION

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Studies of the safety and environmental impacts of fusion, both of future power plants and of ITER, have shown that a good performance can be achieved. Although it is difficult to anticipate the regulatory regime in which future fusion power stations will be licensed, the areas of public and occupational safety and short and long-term environmental impact are likely to remain important. In each of these areas, the outcome of various studies have been reviewed, leading to a list of issues which should be given attention to facilitate eventual licensing of a fusion power plant. Many of these relate to reducing conservatisms and uncertainties in the analyses, but also included are improved understanding of tritium retention and of dust generation, and development of materials to provide long component lifetimes. A full appraisal is also recommended of the viability of recycling of active materials after end of plant life.

I. INTRODUCTION

The excellent safety and environmental characteristics of fusion as a power generating source provide important motivations for its development. The low stored energies, benign reaction products, absence of climate-changing emissions, and rapid termination of power excursions are amongst the features that naturally give fusion a safety advantage. But in order to license the construction and operation of a fusion power plant, a high degree of assurance of these benefits may be required. Although the regulatory regime in which future power stations will be approved is not well known, some requirements can be anticipated, particularly with the benefit of experience so far in preparations for the licensing of ITER. This is done in section II below.

Over the past ten years, various studies of conceptual fusion power plant designs, as well as the engineering design of ITER, have included comprehensive analyses of safety and environmental performance. Drawing mainly on the conclusions of the series of conceptual fusion power plant studies performed in Europe, each of the areas of anticipated regulatory concern are reviewed in section III. This allows, in section IV, some of the key areas to be identified for future studies.

II. PREDICTING LICENSING REQUIREMENTS

It is not easy to anticipate the specific requirements of a regulatory authority at the future time of licensing the construction and operation of a commercial fusion power plant. These will reflect the concerns of the public at the time, and history shows how difficult this is to predict: 50 years ago it would have been hard to foresee the current societal interest in environmental matters, including limitation of greenhouse gas emissions, the importance of probabilistic safety assessments in some industries, or the recent preoccupation with vulnerability to terrorist attack. The fact that fusion power could be expected to be welcomed with present attitudes does not guarantee that it will be universally acceptable in the culture of the mid-21st century.

It is reasonable to assume, however, that high in the requirements for licensing a future power plant will be a demonstration of adequate performance in each of these standard areas of safety:

- safety of members of the public in normal operation and following abnormal events;
- safety of personnel in normal operation, during maintenance procedures, and in abnormal events;
- minimal impact on the environment, during normal operation and abnormal events;
- minimal long-term environmental consequences of waste disposal.

The specific criteria that will be applied in each of these areas cannot be anticipated. In some, increasingly restrictive targets may be expected; for example in occupational safety, where the risk of harm to workers during very unlikely accidents may become a concern where it has previously been regarded as acceptable. Although the low environmental impact referred to in the last two points is currently seen as an imperative, the nature of the impacts that are the focus of attention may change, particularly if the effects of climate change begin to be experienced.

It is important to recognize that it is not sufficient to achieve, or believe that we can achieve, a good performance from fusion in each of these areas. What is required is a *clear demonstration* of this. For each of the areas covered by these points, the outcome of studies for conceptual power plants and for ITER are now reviewed, to identify those areas in which the performance of fusion is weak or the demonstration is inadequate.

III. REVIEW OF SAFETY AND ENVIRONMENTAL PERFORMANCE

Studies of the safety and environmental performance of conceptual fusion power plant designs have been performed over at least the last ten years. At the same time, the engineering design of ITER has included extensive safety analysis, including, more recently, preparations for possible licensing in candidate host countries. Thus much is known about the expected safety and environmental impact of fusion.

The outcomes of European studies in the 1990s, in which a range of conceptual power plant designs were assessed for their safety and environmental performance, have been summarized in [1], referred to here as SEIF. Since then, the conclusions have been confirmed by studies of updated design concepts and with improved analyses [2] in the Power Plant Conceptual Study (PPCS). Extensive international studies of ITER safety culminated in 2001 with the most comprehensive fusion safety analysis to date [3], since further developed in preparation for potential licensing [4]. The following summaries are based on the conclusions of all of these studies.

III.A. Public safety

III.A.1. Accident analyses

Extensive analyses have been performed of the consequences of postulated accident sequences initiated by a fault within the plant. Systematic approaches have been used to identify the events to be studied, both for power plant designs and for ITER, with more detailed sequence analyses in the latter case [3] owing to the more developed design. These analyses have been both for incidents and accidents accommodated by the safety design (sometimes called “within design basis” events), and hypothetical sequences of extremely low frequency. The latter have been studied, sometimes with assumptions that are deliberately pessimistic rather than physically realistic, in order to ensure that an ultimate margin of safety is assured.

In general, efforts have been made to ensure that the range of accident analyses performed provide results that are guaranteed to envelope the consequences of all more likely event sequences. In ITER studies this was done by analyzing a set of Reference Events and then reviewing the full catalogue of systematically identified events to ensure that each is covered by one of these analyses. It became clear in preliminary regulatory discussions that greater transparency was required in the presentation of event selection, leading to a new approach [4]. This is likely to remain important when licensing a power plant, to fully and clearly justify the selection of accident analyses as fully comprehensive.

In SEIF and PPCS, although systematic methods have also been employed for accident identification, the conceptual nature of the designs precludes a detailed catalogue of events, and a “functional” approach has been taken to accident identification. Confidence in the ultimate safety performance in postulated accidents is provided by analyzing a Bounding Accident based on a set of very conservative assumptions.

In all these analyses it is supposed that the potential to do harm to the public could arise from a release of radioactive material from the plant. The criteria for success have been based on limits adopted for such releases, either in terms of mass of material released in various categories, or in terms of the dose delivered to an individual at the site boundary. This latter measure requires a calculation of atmospheric dispersion and dose uptake over some period (typically 7 days following the event), where again there is an opportunity for conservatism in the assumptions made.

One particular criterion that has often been used is the avoidance of the need to evacuate the public from the area around the site. This is quantified by calculating the “early dose”, the dose commitment to the Maximum Exposed Individual (MEI) at 1 km from the plant during a 7-day exposure, and ensuring that this figure is below the 50 mSv of avertable dose recommended by the IAEA as a trigger for evacuation [5].

The results of all these analyses have been highly satisfactory. Targets for release limits have been met in all cases, and the need for evacuation has been avoided. By way of example, for the Bounding Accident analysis for two of the PPCS models [6] the scenario is a total and instantaneous loss of all cooling from every part of the plant for a prolonged period (up to three months) with no active safety system operational. Even with no heat removal other than passive conduction through the layers of the plant to the cooler outside, the maximum temperature reached in the blanket is 1140ºC, this peak occurring more than 40 days after the onset of the accident. This bounding scenario leads to a maximum MEI dose of 18 mSv for a plant design based on a helium-cooled pebble bed blanket, and just 1.2 mSv for one based on a water-cooled lithium-lead concept.

The good outcome from the assessment of accidents is consistent with expectations; the low stored energy densities and naturally good confinement provided by vacuum and cryostat vessels and bioshield should result in a low potential to mobilize and release active material. Another helpful factor is the modest inventory of hazardous materials that is being confined. But herein lies an important uncertainty.

III.A.2 Source term uncertainties

In the tokamak itself, there are four principal classes of radioactive source term:

- in-vessel tritium, chiefly that absorbed in or co-deposited on plasma-facing surfaces, and in the blanket awaiting recovery;
- tokamak erosion dust, generated from activated plasma-facing material, mainly lying at the bottom of the vessel;
- activated corrosion products in cooling circuits (significant in water-cooled systems only);
- activation products in solid structural material, with the potential for volatilization principally through oxidation.

The latter two points have been the subject of extensive and quite detailed computational modeling, supported by experimental validation of codes and data in many cases. However the first two, which provide the dominant radioactive source term in many scenarios, remain relatively uncertain and the subject of assumptions based on engineering judgement. For ITER, this is done by setting administrative limits on the quantities of in-vessel tritium and of dust, so that it will become an operational requirement to measure these levels, and to shut down for removal of tritium and dust if the limits are reached. The limits are 450g of mobilizable in-vessel tritium (the safety analyses conservatively assumed 1kg would be available), and 100kg of tungsten dust (350kg assumed in analyses). There are also some more detailed guidelines. For conceptual power plants, accident analyses in SEIF and PPCS have assumed the mobilization of 1kg of in-vessel tritium and 10kg of dust (a mixture of steel and tungsten).

These estimates are believed to be conservative. They have been derived by judgement by extrapolation from what is currently known from present-day tokamaks, where there is experience in tritium retention and recovery [7], and where dust generation has been measured [8]. The lower dust inventory assumed for a power plant, compared with ITER, reflects the supposition that plasma disruptions will have been eliminated. But nevertheless, the values are estimates, and despite sophisticated modeling of the processes by which the material may be released in a postulated event, the results for the consequential public dose depend directly on the values chosen. (The dependence may not be exactly linear, depending on effects such as aerosol agglomeration at certain ranges of density.)

Of course, by the time the licensing of a commercial fusion power plant is embarked upon, the uncertainties should have been removed. Experience in ITER, and then in a prototype power plant (DEMO), will provide empirical data. But at the present time the in-vessel tritium retention and erosion dust generation and accumulation must be regarded as key issues. Their resolution depends firstly on selection of plasma-facing materials with low propensity for tritium retention and the development of effective methods of tritium removal that could be used routinely, and secondly on developing an understanding of the mechanisms by which dust is generated, approaches to limiting this if possible, and techniques for its removal from the vessel.

III.A.3 External hazards

Increased public concern about the effects of an externally-initiated event, particularly an act of terrorism, is likely to ensure that the issue remains one to be addressed in the licensing of a power plant. The principal safety function is one of confinement, and the good safety performance in respect of internally-initiated events results in part from there being insufficient stored energy to cause a large confinement breach. This naturally raises the issue of external events, and the potential to introduce enough energy for serious confinement damage. Analyses of the possible structural damage arising from earthquake or aircraft impact are likely to be required as part of site-specific studies in support of licensing, just as they have been for a candidate site for ITER [9].

However, a more satisfactory demonstration of the limited consequences of an external event could be made on the basis of the limited inventories available for release. This approach is currently hampered by the same uncertainties in important components of the source term as discussed above in III.A.2. Nevertheless, it is interesting to consider the worst consequences of releasing the assumed vulnerable inventory, in order to see how feasible is the development of an inventory-based case.

Using the dispersion and dose calculations performed for PPCS [10], an upper limit can be obtained for the early dose (the one-year dose commitment from a 7-day exposure) to the MEI at 1 km from the plant during and after a one-hour release. To be conservative, the 95% percentile values are used from the probabilistic distribution of doses with weather conditions. On this basis, the maximum dose arising from the release of all

1kg in-vessel tritium (assumed fully oxidized as HTO) plus all 10kg of dust would be just 1 Sv. In a water-cooled plant this could be augmented by activated corrosion products (ACPs) - for the PPCS water-cooled plant model, a maximum of 505g ACPs was considered mobilizable from each coolant loop, leading to maximum total of 300 mSv if this release is postulated from all six loops. Activation products in solid blanket and divertor materials are not readily mobilizable - apart from that portion already accounted for as having formed dust - unless a significant temperature rise is postulated. Decay heat alone would be insufficient to cause this, so some other source of energy must be hypothesized to yield any significant dose contribution from this source. There are many uncertainties here, but if a further 10kg of solid activation products is postulated to be mobilized in a form that could be transported by atmospheric dispersion to the MEI 1km away, another 500mSv could result.

Thus, using these assumptions for the mobilizable inventories, there is an upper limit of between 1 - 2 Sv for the total MEI dose in a hypothetical event in which all of these inventories are released. This is, of course, well in excess of the dose limit implied by the no-evacuation criterion, if that limit is regarded as appropriate for very rare external events. But to attain an acceptable maximum dose the mobilizable inventories need to be reduced by only modest factors, which may be partly accomplished merely by improved analysis, for example

- improved determination of the source term inventories for tritium and dust;
- estimate of the fraction of mobilized tritium that could actually be released in oxidized form, HTO;
- estimate of the fraction of in-vessel dust that could actually be released through a major confinement breach without re-deposition;
- if water-cooling of high neutron fluence components is essential, a study of possible improvements in water chemistry to reduce corrosion;
- a better understanding of the volatility of activation products in solid materials, in the scenario of external energy input.

To give some quantification of the improvements required, based on the PPCS results, Table I gives, for each component of the inventory, the maximum mass release to ensure that the resulting dose remains below the 50mSv no-evacuation limit. The factor by which the presently assumed mobilizable inventory must be reduced is also indicated. Solid activation products are not included, as there is no clear mobilizable inventory in the current assumptions, rather some scenario must be developed in which an additional energy input is provided.

TABLE I. RELEASE MASS LIMITS IN HIGHLY ENERGETIC EXTERNAL EVENTS, to comply with 50mSv limit to early dose to the most exposed individual

Source term	Mass release for 50mSv	Approx. reduction factor required on present assumption of complete release of vulnerable inventory
Tritium as HTO	110 g	9
Dust (W and steel)	930 g	11
ACPs (water-cooled plants only)	500 g	6

The figure for tritium in Table I assumes that it is all oxidized in HTO form. If it is instead in HT form, as much of the vulnerable inventory will be, some 10 - 70 times greater release would have to occur to reach the same dose [11]. Apart from the implications for the tokamak, this is also important for other buildings with a tritium inventory, those housing the fuel cycle plant and tritium store. In these facilities the tritium is stored mainly in elemental (gaseous) form or as a hydride, so an external event leading to a release has much less potential to result in a significant public dose, provided oxidation can be avoided before it is released.

III.B. Occupational Safety

Ensuring low doses for workers at the plant in routine operations is certain to be a regulatory requirement, probably with the need to demonstrate that they are as low as reasonably achievable (ALARA). Almost all personnel doses can be confined to maintenance operations, but quantification of the expected doses depends heavily on the detail of these operations. With designs for fusion power stations at only a conceptual stage, it is not possible to define this detail.

In earlier European studies of power plant concepts, summarized in the SEIF report [1], occupational doses were assessed by making conservative assumptions. The results for a helium-cooled plant in terms of a collective dose are about 0.2 person-Sv/yr, with water cooling it is about 2 person-Sv/yr. The former value is acceptable, in line with current nuclear fission plant practice, while the latter is clearly too high. The dose results mainly from activated corrosion products in the water coolant. It is to be expected that substantial improvements can be made, by design optimization, including improved shielding in selected locations, and by adjustment of the water chemistry to minimize corrosion [12]. But it is difficult, at this stage in conceptual design development, to provide a convincing demonstration that adequate reduction in the dose can be achieved. Much of the final adjustments to maintenance procedures, to localized shielding, and to water chemistry can be made only once the plant is operating - this is what has happened in the fission reactor industry, where the good current performance is the result of hundreds of reactor-years of experience.

Assessments of occupational doses for ITER are rather better developed, since they have been based on a more detailed design of the plant. But nevertheless, the details of maintenance procedures remain to be determined and uncertainties about corrosion products need to be reduced. A preliminary estimate for the collective dose of 0.26 person-Sv/yr [13] is likely to be reduced as a result.

Reducing the frequency of maintenance operations is to be achieved by increasing the lifetime and reliability of components. Thus the development of suitable materials, as well as testing to fully characterize their behavior, has a direct impact on maintenance needs and the consequent doses.

The above discussion relates to personnel exposure to radiation in routine maintenance operations, including anticipated but unlikely repair or replacement operations following equipment faults or failures. However, not included is the risk of harm to workers as a direct consequence of accidents. This has received little attention in fusion safety studies because the potential public consequences of accidents are seen as more important, and because some level of occupational risk from unlikely events is probably acceptable. A preliminary assessment has indicated that significant individual does (over 50 mSv) should be infrequent (less than 1.7×10^{-3}/year) [14]. However, a more rigorous analysis may become necessary to assess the occupational hazards of the same events already shown to pose minimal public hazard.

III.C. Environmental impact of operation

Radioactive effluents, in liquid and gaseous form, could in principle arise from normal operation of a fusion power plant, due to leakages from coolant systems, water detritiation systems, through ventilation systems and from the fuel cycle plant. The SEIF report [1] summarizes earlier analyses of the possible magnitude of such routine releases and concludes that the consequent public doses are very low, well below internationally accepted limits.

The releases were re-assessed, for updated conceptual power plant designs, in the PPCS study [15]. Tritium, both oxidized and non-oxidized, is the principal component of the release, and a water-cooled plant is assessed to have higher releases than a helium-cooled plant. The resulting releases (in Bq/year), if converted to doses using the same dose conversion factors as the earlier studies, which were based on conservative weather assumptions, result in the values listed in Table II.

TABLE II. MAXIMUM PUBLIC DOSES (μSv/yr) ARISING FROM EFFLUENTS
from normal operation of a fusion power plant

	Water-cooled power plant		Helium-cooled power plant	
	gas	liquid	gas	liquid
Tritium (HT + HTO)	0.87	0.05	0.28	0.003
Activation products	0.02	0.02	0.004	0
total	0.89	0.07	0.28	0.003

These figures, which represent an upper bound for the annual dose to the most exposed member of the public, at less than 1 μSv/year, indicate that routine effluents are unlikely to become a difficulty for fusion licensing. A site-specific study will probably be required for each power plant, as has already been done for ITER in preparations for licensing at the candidate site at Cadarache, France [16], where local conditions also led to an assessed maximum dose of around 1 μSv/year, compared to the local natural background radiation dose of 2400 μSv/year.

In addition to liquid and gaseous effluent, there are operational wastes in the form of active components, such as divertor modules, removed from the plant as they are replaced in scheduled maintenance operations. But since these have a potential long-term impact beyond the life of the plant, they are best included with decommissioning wastes, and are discussed in the following section.

III.D. Long-term environmental impact

At the end of life of a fusion power plant, there will be a large volume of material that has been exposed to some level of neutron flux and has thus become activated. It will be augmented by those components, principally blanket and divertor modules, that have been removed in routine replacements during operation. Although a large proportion of the material will have been activated only to a low level, there remains a considerable volume that is initially highly active. This activity decays much more rapidly than that of nuclear fuel from a fission power station, but nevertheless it is sure to be a regulatory concern. To license a fusion power plant, it is likely to be necessary to be certain about the treatment and long-term destination of the material.

In many of the massive components outside of the vacuum vessel, such as the toroidal field coils and their supporting structure, the activity falls to very low values after some years of decay. Thus there is much incentive to be able to dispose of this as non-active waste or recycle it as normal non-active scrap. The removal from regulatory control of previously active material, because it no longer poses a radiological hazard, is known as "clearance". Currently, the regulations governing radioactive waste management vary significantly from country to country [17].

In 1996, the IAEA proposed guidelines [18] for the clearance of material based on setting a clearance level for every nuclide in the inventory, to restrict the maximum individual public dose to 10μSv/year. The application of this to fusion materials by the computation of a clearance index has become widespread in studies of conceptual power plant designs, particularly in Europe [19]. Different sets of clearance levels may be appropriate, depending on the destination of the material, for example for disposal as non-active waste, or free release for recycling for any purpose whatsoever (referred to as "unconditional" clearance). The European Commission recommended a set of levels for unconditional clearance [20], as guidance for implementing the EC Basic Safety Standards [21]. The first country to set such principles into law is Germany, for which a variety of sets of clearance levels were defined [22] according to the origin and destination of the material. This precedent permits optimism that by the time fusion power plants are being licensed, the principles of clearance based on nuclide-by-nuclide levels will be widespread in regulations. More recently the IAEA have issued a revised set of general clearance limits [23], the impact of which have yet to be assessed for fusion materials.

Nevertheless, there remains a substantial volume of material (typically about 50% of the total) that will not fall into the unconditional clearance category in a suitable period of time. For this, it is convenient to propose that the material could be reused or recycled within regulatory control, for example in the fabrication of components for future fusion power plants. If it is assumed that the only restriction on doing this is the ability to handle and process the material, it is possible to set radiological criteria for different categories [19]. In PPCS and earlier European studies, the criteria summarized in Table III have been used to categorize active material from the plant, if it does not meet the clearance criterion. Three types of recycling are indicated: hands-on for material that can be readily handled by operators, and two categories of material that would require some degree of remote handling in the process, in the "complex" case a fully remote operation is foreseen. Material above 20 mSv/hr contact gamma dose, or 10 W/m^3 heat output, is assumed to require permanent repository disposal.

TABLE III. Categorization of active material from a fusion power plant, as used in European studies [19]

Category	Gamma dose rate	Decay heat
Hands-on recycle	< 10 μSv/hr	
Simple recycle	< 2 mSv/hr	< 1 W/m^3
Complex recycle	2 – 20 mSv/hr	1 – 10 W/m^3
Permanent disposal	> 20 mSv/hr	> 10 W/m^3

In PPCS studies these categories have been applied to the complete inventory of active material arising from 25 years of plant operation at 1.5 GW electrical output. The materials compositions assumed in the analyses included a realistic set of impurities - for the martensitic-ferritic steel structure these were based on measured compositions of samples of EUROFER97. All material is assumed to be in interim storage after the end of plant life for a period of 100 years, at the end of which the categorization is as shown in Figure 1.

Most of the material in the "cleared" category, which is all of the outboard toroidal field (TF) coils and their support structure, actually satisfies the clearance criterion at much earlier times. The hands-on recycle material comes from parts of the inboard TF coils, and the simple recycle material is the remainder of this TF coil material, together with most of the vacuum vessel and the majority of in-vessel components including all divertors. Remaining in the complex recycle category at 100 years is the rest of the vacuum vessel, all low temperature shields and some other parts of the blanket modules, and the first wall from the last two blanket replacements (those from earlier replacements having decayed into the simple recycle category).

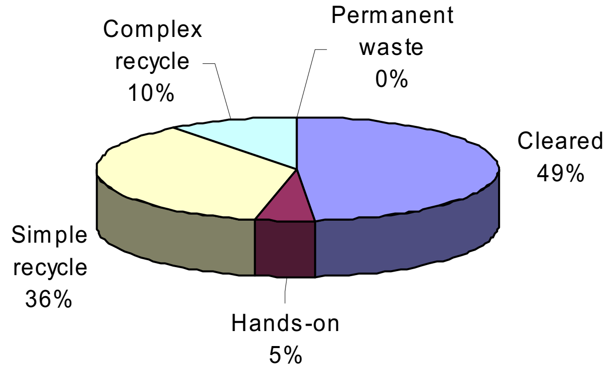

Fig. 1. Categorization (by % mass) of active material from a fusion power station 100 years after end of plant life.

The important result in figure 1 is that there is no material requiring permanent disposal. This figure shows results for the plant design based on a helium-cooled pebble bed blanket with ferritic-martensitic steel structure, and there is some variation in the results for other plant models assessed. However, the conclusion that no material requires permanent disposal after 100 years storage is generally true for all design variants studied.

The criteria listed in Table III for these categories are somewhat arbitrary, and would benefit from re-evaluation. In particular, it is supposed that material with a contact gamma dose above 20 mSv/hr is unsuitable for recycling operations even by advance remote handling techniques. This assumption may be unduly conservative – an upward revision would not change the categorization of figure 1, but would achieve the result at an earlier time.

These results serve to illustrate the low radiological hazard presented by the material. But whether recycling of material, by either simple or complex operations, would be a realistic option depends on other factors. There has been little assessment of the feasibility of recycling operations for many of the materials involved, in particular the economic viability that would be essential for recycling to be attractive. The avoidance of long-term wastes, and associated costs, provides some motivation, but needs to be balanced against the costs of material processing and component fabrication.

Until the viability of recycling of materials has been properly assessed, the promising results for the radiological aspects are insufficient to guarantee that fusion waste will not pose an issue for licensing. If it were decided that some material does require long-term disposal, studies have shown that waste repositories currently used for low and intermediate-level fission reactor waste would be suitable for most fusion waste, with a small quantity possibly requiring deep geological disposal [24].

IV. CONCLUSIONS

Studies of the safety and environmental impacts of fusion, both in conceptual power plant designs and in the detailed design of ITER, have shown that a good performance can be achieved. If the regulatory requirements for licensing the construction and operation of a future fusion power station remain as currently anticipated, a positive outcome can be expected. The studies have addressed many of the key issues, with good results. However this review has noted a number of areas where improvements, or further studies, appear to be required to facilitate licensing of a fusion power plant. These are listed below.

- The selection of off-normal event sequences chosen for analysis as accidents must be done systematically and presented in a transparent manner. This has already been done for ITER, and will also be necessary for power plant licensing.
- Uncertainties in source terms for accident analyses should be reduced. In particular in-vessel tritium and dust inventories must be better determined. This implies better understanding of tritium retention and of dust generation, and the development of improved techniques for tritium and dust removal.
- Improved analyses may be possible to enable an inventory-based approach to assessing the limiting consequences of an external event. For example a more reliable estimate of the fraction of mobilizable tritium that could be released as HTO.
- Development of materials is important to improve component lifetimes and reliability, thereby reducing maintenance requirements to reduce occupational radiation exposure.
- Uncertainties related to occupational doses should be reduced where possible, particularly in relation to activated corrosion products in water-cooled plant.
- More complete assessments may be needed of the potential direct consequences to personnel of postulated accident sequences.
- A revision of the criteria used to categorize active material as suitable for recycling operations may permit these to take place at an earlier time after end of plant life.
- A full appraisal of the feasibility of recycling of active materials, including economic viability, is certainly needed to complete the assessment of waste management possibilities.

Addressing these issues would provide a greater confidence that the excellent safety and environmental performance of fusion can be achieved and demonstrated to the satisfaction of a licensing authority.

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