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Fusion reactor radioactive materials and national waste management regulations

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Abstract

National regulations on waste management do not seem adequate to cope with the fusion case. The paper shows the relevance of this problem, showing some aspects of application of national radioactive waste management practices and regulations to fusion. In particular, the case of Italian waste management regulations is considered. The waste management strategy proposed in the SEAFP and PPCS studies, based upon recycling and clearance techniques, is compared to Italian national regulations. If those regulations were applied to fusion, a relevant part of the fusion radioactive materials should be classified in the Italian High Level Waste category. Also in the case of other national regulations, fusion waste would be rated mostly in the local 'high-level' category. An evolution of those regulations in the future, in order to take into account the special characteristics of fusion radioactive materials, is recommended.

1. Introduction

In the frame of the IEA Co-operative Program on the Environmental, Safety and Economic Aspects of Fusion Power, a collaborative study of fusion radioactive waste has been set up [1]. The main goal of this activity is the definition of waste management strategies for fusion. This strategy/set of concepts should be very 'general purpose', in order to cope with the different projects and studies being developed in the fusion community, but also with the different national regulations concerning radioactive waste. In fact, most of the national 'fission-oriented' regulations on waste management do not seem, in certain cases, adequate to cope with the fusion case. The paper concentrates upon this aspect, showing how relevant this problem could become in the future.

2. Fusion waste management: a review of some past results

Most radioactive waste generated from fusion power reactor operation and decommissioning is activated solid metallic material from the main machine components and concrete from the bioshield. Some component will also have surface contamination including tritium. The dominating waste stream is generated in the decommissioning stage, while – for fission – spent fuel is the main issue. A great deal of the decommissioning waste has a very low activity concentration, especially when a long period of intermediate decay is anticipated. Radioactive nuclides in fusion waste are mainly metallic activation products and tritium. Therefore, fusion waste is quite different from fission waste, both in type of material and isotopic composition: fusion waste does not include plutonium, fission products, transuranics and normally no alpha-emitting nuclides, and it is generally shorter-lived than fission waste.

In most countries with a nuclear program, the waste management strategies are based on deep geological disposal of HLW and/or long lived waste, including spent fuel, while a less sophisticated disposal method, mostly a near-surface type repository is used for

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low-level or intermediate-level waste (LLW/ILW), short-lived or not-heat-generating waste. The acceptance criteria in terms of isotope specific or total activity concentration limits are generally referred to nuclear fission waste disposal [2].

The options for handling fusion waste in the future will depend upon the strategy for radioactive waste management in the considered host country. We will have here two different options:

- National waste management strategies, all fission-oriented, will not be reviewed for fusion application, and applied as-they-are.
- A revision will be carried out, possibly proposing an international common strategy for fusion, which may integrate the national fission-oriented regulations for the fusion case. Generally speaking, fusion waste radiotoxicity is much lower than for fission, and this cannot be taken into account by regulations that use only activity to classify materials.

We want to show here that a revision is preferable: the application of present national regulations to fusion waste would imply sometimes a rather misleading classification of large volumes of fusion waste in the 'high-level waste' (HLW) category.

A few examples of past results of application of national fission-oriented regulations to fusion are given in the following.

2.1. United States Regulations and ESECOM

The ESECOM (Senior Committee on Environmental, Safety, and Economic Aspects of Magnetic Fusion Energy) study was organised in 1985, and compared a variety of fusion reactors with standard and advanced fission reactors including breeders [3].

For main in-vessel components, waste disposal characteristics are given in terms of indices based on the NRC regulation 10CFR61 for shallow burial [4]. ESECOM calculations were performed using the Waste Disposal Rating codes developed in [5].

Without going into detail, it was found that, depending upon the design variants, a fusion power reactor of 1 GWe would generate in its lifetime a permanent radwaste volume of 1600–2400 m^3 to be disposed of. A comparison with a fission reactor of the same power showed that, for instance, the maximum annual production of low-level power plant wastes was even higher for fusion than for fission (1100 versus 1000 m^3).

The ESECOM pointed out that the use of indices based on the NRC shallow-burial criteria did not mean to endorse this disposal method as the most appropriate for fusion waste.

2.2. National Regulations (France, USA, Japan, Sweden) and old ITER studies

In ITER Non-Site Specific Safety Report (NSSR-2) of 1997, the waste management and decommissioning is described in Volume V [6]. Waste streams and activity characteristics are separately documented [7]. Examples of repository volume requirements for ITER wastes based on those data are calculated in [8] for a French, Italian and Swedish disposal scenario and with the application of IAEA and ICRP clearance levels (see Section 3). The results in terms of repository volumes for the French scenario were the following: material needing deep geological disposal, according to French regulations, amounted to 5700 m^3, while other 4500–20 000 m^3 of material could be classified for near-surface disposal, according to different design options, decay times, etc. The results for the Italian and Swedish disposal scenario were similar to the French one.

Disposal criteria in USA, Japan and Sweden were applied in a study for the earlier ITER TAC-4 design [9]. Clearance possibilities were not considered in this study. Applying US regulations or Japan regulations, 31 400 tonnes of waste for near-surface disposal, and 13 800 tonnes of waste for deep geological disposal were calculated. For Sweden, 30 700 tonnes for shallow geological disposal and 14 500 tonnes for deep geological disposal.

It has to be remarked the present recent ITER studies, however, lead to quite different and much better results [10].

2.3. National Regulations (Germany, Sweden, Japan) and early SEAFP

The Safety and Environmental Assessment of Fusion Power (SEAFP) was undertaken within the Fusion Programme 1990–1994 for the Commission of the European Union, to study the conceptual designs of tokamak power reactors and investigate their characteristics [11]. It was continued until 1999. The initial reference waste management strategy for SEAFP dealt with the disposal of reactor waste, mostly coming from decommissioning, into fission waste disposal sites. German and Swedish sites were considered. The utilised criteria considered the planned German deep geological repositories KONRAD for non-heat generating waste and GORLEBEN for all types of waste and the Swedish shallow geological repository SFR for ILW and LLW in operation, and the planned deep geological repository SFL for all types of long-lived waste. Waste volumes turned out to be considerably high. For instance, for one of the Plant Models (PM-1), 37 000 m^3 of waste for KONRAD would be generated, or 33 000 m^3 of waste for SFR and 3000 m^3 of waste for SFL [12].

The waste from the two plant models of SEAFP-2 (PM1 and PM2) was also evaluated using the waste management criteria in Japan [13]. The tendency in Japan is to adopt the shallow-land (near-surface) concrete pit burial disposal if the waste can qualify as low-level waste (LLW) as defined by the Nuclear Safety Commission for the fission waste [14]. Radwaste that does not qualify as LLW is classified as medium-level waste (MLW). The results showed that about 67% (PM1) and 76% (PM2) of the waste from SEAFP had been classified as LLW.

3. Recycling and clearance: a fusion-oriented strategy

Since most of fusion waste comes from relatively low activated material, in shielded position from the plasma, it is appropriate to explore the possibility of finding alternative pathways for the management of such waste, in order to minimise the use of final repositories. For this purpose, an alternative management strategy for SEAFP has been developed during the later studies. It is based upon two main concepts:

1. Recycling of moderately radioactive materials within the nuclear industry.
2. Declassification of the lowest activated materials to non-active material (Clearance), based upon an extension to fusion [15] of two documents [16,17] issued by IAEA and ICRP.

This strategy appears to have great potential interest, since it is shown that its application could reduce the amount of Permanent Disposal Waste (PDW) of SEAFP plant models to almost zero, while about 70% of the total could be recycled and 30% cleared to non-active material [12,15,18,19].

More recently, the European Fusion Long Term Work Programme has carried on this fusion-oriented waste management strategy – including recycling and clearance – in the Power Plant Conceptual Study (PPCS) [20]. The main objective of PPCS is to demonstrate the safety and environmental advantages and the economic viability of fusion.

A first categorisation of radioactive materials has been recently done in the frame of PPCS [21,22], confirming the good results of the application of this strategy to fusion: if a sufficient interim decay period is allowed (up to 100 years) no reactor spent material has to be classified as Permanent Disposal Waste (PDW). Good safety and environmental characteristics of PPCS have been also shown in [23]. An alternative strategy without recycling has also been studied in the frame of PPCS [24]: in that case, after 100 years of decay, the materials that are not cleared may be eligible for Shallow Geological Repository, while no material needs Deep Geological Disposal [24].

4. Application of Italian waste management regulations to PPCS

We will briefly report here the result of the application of Italian waste management regulations to PPCS (described in the Section 3). Italian regulations deal with National Laws on radioactive materials [25], and with Technical Guides from the Italian nuclear regulatory committee ('Guida Tecnica 26' and others [26]). Wastes are classified into three categories ('I Categoria' = First category = low-level waste, 'II Categoria' = Second category = intermediate-level waste, 'III Categoria' = Third category = high-level waste) according to concentration limits for radionuclides.

Without going into detail, the boundary between second and third category, for activated metallic materials, is a concentration of 3700 Bq/g for long-lived nuclides ($T_{1/2} > 100$ year), 37 000 Bq/g for medium-lived nuclides ($5y < T_{1/2} < 100$ year) and 37×10^6 Bq/g for short-lived nuclides. This limit deals with waste that has been conditioned and treated for disposal.

Concerning clearance, a recent regulation has been issued in Italy [27], concerning the 'Allontanamento' (Italian word for 'clearance') of solid radioactive spent materials. This regulation is necessary for the ongoing decommissioning activities of the four shut down Italian fission reactors. Concentration limits are issued for each relevant nuclide, however they may be partially summarised – for our purposes – as follows: a non-alpha-emitter metallic material may be cleared, if its specific activity is less than 1 Bq/g. For other materials than metallic ones and concrete, the limit is 0.1 Bq/g, while for concrete the limit is almost half-way, depending on the type of nuclides [27]. Recycling in Italy is permitted for cleared material only.

We have applied this set of regulations to PPCS Plant Model B [20]. Activation data were taken from [28]. The main results of the study are the following: if Italian regulations were applied as-they-are to this Plant Model, a relevant part of its radioactive materials should be classified in the Italian High Level Waste category ('III Categoria'), even if an intermediate storage of 100 years is allowed. Results are shown in Table 1, compared with results obtained applying the reference PPCS Waste management strategies.

In particular, the following materials are classified as ILW (*II Categoria*): Inboard Toroidal Field Coils and Manifold, Outboard Vacuum Vessel and Manifold, Divertor Manifold. The Toroidal Field Coils behind the divertor zone may be classified as LLW (*I Categoria*), while the Outboard Toroidal Field Coils are eligible for

Table 1
Activated materials (Tonnes × 1000) arising from PPCS Plant Model B

	PPCS Strategy (1)	PPCS Strategy (2)	PPCS Strategy (3)	Application of Italian WM Regulations
Intermediate storage	50 years	100 years	100 years	100 years
PDW, permanent disposal waste	13.8	0	0 (Deep Geological Repository)	III Categoria (HLW): 26.6 II Categoria (ILW): 10.7 I Categoria (LLW): 4.8
CRM, complex recycle material	11.3	7.7	38.1 (Shallow Geological Repository)	Not foreseen
SRM, simple recycle material	17.0	30.4		Not foreseen
Total (SRM + CRM + PDW)	42.1	38.1	38.1	42.1 (*I, II, III Categoria*)
NAW, non-active waste (below clearance limit)	32.1	36.0	36.0	32.1 (*Allontanamento*)

Comparison of the classification according to the reference waste management strategy, based upon recycling and clearance (Strategy 1–2), of an alternative waste management strategy with no recycling (Strategy 3 [24]), and the application of the Italian National waste management (WM) regulations [25–27].

'*Allontanamento*' (Clearance, Non-Active Waste). It must be noticed that the application of the new Italian regulation on 'Allontanamento' leads to results comparable or equal to the ones resulting from the application of the clearance limits adopted in PPCS.

All the other materials (first wall, blanket structure and breeder, shield, inboard vacuum vessel, divertor) are HLW (*III Categoria*): about 42.1×10^3 Tonnes of material, not so different however from the amount of radioactive waste eligible for Shallow Geological Repository (38.1×10^3 Tonnes) in the PPCS no-recycling strategy [24].

The adoption of EUROFER reduced-activation steel for PPCS Manifold permits this component to avoid the classification as HLW (*III Categoria*), both inboard and outboard; the Inboard Vessel material (316 SS), however, does not obtain the same result, and that component is HLW, even if less irradiated than Inboard Manifold: this is due to the presence in 316 SS of activation products of Ni and Mo, which in EUROFER are present only as impurities (Ni = 50 ppm, Mo = 12 ppm). In fact, comparing the long-term activities of the Inboard Manifold (EUROFER) and Inboard Vessel (316 SS), the activity of EUROFER is still 6 times higher than that of 316 SS after 10 years of decay; however it decays much more rapidly, and it becomes 15 times lower, if 100 years of decay are assumed.

5. Conclusions and proposals

Many examples have shown that – if certain national waste management regulations were applied as-they-are – relevant quantities of fusion wastes would be rated in the local 'high-level' category. A detailed case study for Italy has been carried out. This finding is in contrast with one of the main goals of the environmental studies for fusion: reduction of permanent waste, since fusion power should not generate radioactive waste that could be a burden for future generations.

We identified in recycling – for moderately activated materials, and clearance – for low-activated materials, the two solutions to solve this problem.

Concerning recycling, it is a question dealing not only with radiation protection, but also with metallurgy, materials science, shielding and remote handling techniques. A wide experience in these fields is available from fission research: a study of the application of existing techniques to fusion radioactive materials is quite useful, to assess whether and when recycling of such materials is feasible or convenient; radiological, technical, economic and strategic questions have to be considered. An example of this may be found in [29].

Clearance is a question that must be defined by law. Although all national regulations have some 'exemption limits' that allow materials clearance, some of them do not consider explicitly fusion-relevant nuclides, while other ones are too restrictive. Implementation into national regulations of clearance rules following the IAEA and ICRP recommendations [16,17] is a solution. A first example of this can be found in the new German radiation protection ordnance [30], issued in July 2001: this regulation permits Clearance, using a nuclide-by-nuclide clearance index similar to the IAEA approach. The Italian regulation about 'Allontanamento', applied here for the first time, turns out to be well applicable to fusion too.

Further conclusions are therefore the following:

- Fusion studies in the field of waste management should take into account application of national regulations in that field.

- An evolution/revision of those regulations and practices, in order to take into account the characteristics of fusion radioactive materials (lower radiotoxicity than fission waste) and the question of clearance, is recommended.
- An international common strategy for fusion radioactive materials should be proposed, focusing especially on materials recycling: this might integrate the national regulations for the fusion case.

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