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Methodology to identify appropriate detritiation techniques and practical applications

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Operation of fusion facilities using deuterium and tritium for fuelling the fusion reaction will lead to generation of radioactive waste. Because most of this waste is expected to be contaminated with tritium, specific waste management strategies need to be developed taking into account all relevant parameters. The reference strategy for tritiated waste that cannot be accepted directly for disposal was already established and is based on a 50-year interim storage, corresponding to 4 tritium radioactive periods (i.e. a tritium inventory reduction factor of 16). The most tritiated categories of the waste may require alternative strategies or additional processing to an interim storage in order to reduce tritium contents in the waste or tritium outgassing.

This article is mainly aimed on definition of methodology of identifying the Best Available Technique (BAT) to reduce the tritium activity of the waste. Furthermore the methodology is demonstrated on the case of purely tritiated metallic waste made from stainless steel. The methodology has been divided into three main steps: 1) Identification of the most relevant detritiation techniques; 2) Comparative analysis; and 3) Economical assessment. In order to simplify the first step, a software tool has been developed by CEA and its main features are described in this article. The results given by this tool are further analysed in the second step, which takes into account different non-economic criteria. The results of the comparative analysis show that detritiation of purely tritiated metallic waste made from stainless steel appears to be very attractive, allowing a significant decrease of interim storage duration. The last step, briefly described in this article, is ongoing and will economically assess the results from the previous steps.

Keywords: Best Available Technique, tritiated waste management, detritiation, comparative analysis, case study

1. Introduction

Operation of fusion facilities using deuterium and tritium as fuel will lead to generation of radioactive waste during an operational and decommissioning phase. This waste will be either activated by neutrons resulting from the fusion reaction, or contaminated by tritium. Because most of the waste will be tritiated, specific waste management strategies need to be developed, taking into account the unique features of tritium behaviour, available options to reduce a tritium content in the waste, and disposal limits of final repositories.

In France, the reference strategy for waste exceeding tritium acceptance limits of a final repository is an interim storage phase allowing for tritium decay prior to final disposal. However, in the case of highly tritiated waste, alternative strategies or complements to the reference strategy may be required and therefore other options for reducing the tritium content in the waste have been investigated.

This article is mainly aimed on defining a methodology to identify the Best Available Technique (BAT) and applies this methodology to two selected scenarios of purely tritiated waste made from stainless steel.

2. Tritium behaviour

Tritium (T or ^3H) is a radioactive isotope of hydrogen with similar chemical properties and behaviours as hydrogen. Tritium has a very small radiotoxicity and exists in three main chemical forms: gaseous tritium (HT), tritiated water (HTO), and organically bounded tritium (OBT).

Tritium, used as fuel for fusion applications, is artificially produced in fission reactors and, in the future, will be produced in tritium breeding blankets of fusion reactors, by nuclear reaction $^6Li(n, \alpha)^3H$. Regardless of its origin, tritium is extremely mobile in the environment and in all biological systems, which means it can be easily absorbed into most materials and after absorption, tritium is subsequently outgassed. The parameters defining uptake and transport of tritium through materials include diffusivity, solubility, permeability, trapping, and recombination. Thus all of these parameters affect the choice of materials for fusion machines. Because most of the materials used to build fusion machines are metals with relatively high permeability, tritium permeation is identified as one of the critical issues that can cause a large tritium inventory in the most contaminated parts and therefore may significantly complicate maintenance and waste management of fusion facilities.[1]

Although the mechanism of tritium release from solid materials is a complex process, it allows reduction of tritium inventory and also tritium outgassing, which represents a good opportunity for waste processing.

3. Options to reduce tritium content in the waste

Different options are available to reduce tritium content in the waste. This paper outlines the main features of the current strategy, interim storage, as well as other detritiation techniques.

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3.1 Interim storage

Interim storage is the current reference strategy for waste that cannot be directly routed to a final disposal facility. The duration of the storage is estimated to last about 50 years, based on feedback from existing storage facilities. The detritiation factor of a 50-year interim storage is about 16, corresponding to 4 radioactive periods.[2]

The main advantages of interim storage are its applicability to all types of waste and no production of secondary waste. On the other hand, its main disadvantage is that the waste needs to be stored for a relatively long period of time after which it will have to comply with acceptance limits of a final repository that can evolve during the storage period.

3.2 Detritiation techniques

As part of optimising management of tritiated waste, the relevance of integrating a detritiation process applied to the radioactive waste into the management strategy prior to storage should always be investigated. The main advantages of this additional stage lie in:

- Possible downgrading of the initial waste category in case of purely tritiated waste
- Possible volume reduction
- Reduction in the tritium inventory, resulting in:
    - Reduction in atmospheric releases
    - Reduction in interim storage duration

Many techniques are available for reducing tritium inventories in different types of the waste. These techniques should be always adapted to the type of the waste, the size of contaminated components, the type of contamination (superficial or in the bulk), and activity levels of tritium and other radionuclides. The amount of tritium removed from the waste depends on many factors, the main operational parameters effecting efficiency of treatment are temperature, duration of the treatment, and atmosphere in which the waste is treated.

After treatment of the waste, tritiated water containing all extracted tritium needs to be appropriately managed, depending on the activity of the tritium, the volume of tritiated water and its purity. The cost of tritium makes its reuse as fusion fuel very attractive and therefore, in some cases, one of the main purposes of detritiating the waste is recovering the tritium.

4. Methodology of selecting waste management strategies

Selecting of suitable management strategies is a complex process involving many technical and non-technical parameters affecting the final choice of the management strategy. The selection process may be divided into three main steps following one after another, and a subsequent step uses results of a previous step as input data. These steps are:

- Identification of all relevant strategies
- Comparative analysis
- Economical assessment

4.1 Case study

The methodology was used for a case study identifying the BAT for the following two waste scenarios. Common assumptions for both scenarios are:

- The waste is made from stainless steel
- The waste is purely tritiated
- Annual tritium outgassing rate is 1% of the tritium inventory in waste
- The tritium disposal acceptance limits are 10kBq/g on specific activity.

The first scenario (S1) assumed the following waste:

- 50 tons of waste with a tritium specific activity up to 3.10^6Bq/g.
- Waste produced during an operational phase of an experimental fusion facility.

The second waste scenario (S2) assumed:

- 300 tons of waste with a tritium specific activity up to 1.10^7Bq/g.
- Waste produced during a deactivation phase of an experimental fusion facility.

4.2 Step 1 – Identification of all relevant strategies

Before starting with selection of most suitable management strategies, a preliminary characterisation of the waste is required in order to identify of the amount of tritium. This characterisation includes several steps, such as taking smear-test, measuring a tritium outgassing rate, and investigation of operational conditions to which the waste has been exposed (tritium pressure, total duration of contact with tritium, chemical form of tritium). In the case of future tritiated waste, the characterisation is based on feedback from similar facilities and modelling tritium transport. Other parameters also taken into account are the type of the waste, the size of contaminated parts, and the type of contamination (superficial or in the bulk).

All the data obtained by the preliminary characterisation are used for verifying compliance with different acceptance limits of final repositories. Because the verification process comprises many calculations that need to be updated if any parameter has been changed, CEA decided to develop a software tool that would allow waste management experts to easily simulate and compare different tritiated waste scenarios or disposal in several final repositories. In the case that the waste would not comply with the tritium acceptance criteria of the selected final repository, the tool would propose management strategies to reach disposal in the repository. The main features of this tool, which is called TWIT, are described in the following chapter.

4.2.1 TWIT – Tritiated Waste Investigation Tool

4.2.1.1 TWIT presentation

The main algorithm of TWIT is shown in Figure 1, and as can be seen in this figure, the whole calculation process comprises several steps, which can be divided into two groups, input data and code calculation.

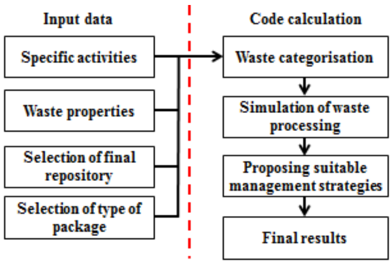

Fig. 1. General algorithm of TWIT

To simplify and accelerate the process of entering data, TWIT offers number of predefined values but to preserve flexibility of the tool, wherever possible, users may manually set parameters according to their needs. This is the case for example with entering specific activities of radionuclides contained in the waste, users can set specific activities one by one or may choose one of the predefined lists of radionuclides and only enter a total radioactivity of the waste.

Currently TWIT comprises more than 500 radionuclides, interim storage option, 5 detritiation options for different types of waste, and more than 10 types of package, (including user-defined package). The following figure shows all possible strategies that can be simulated by TWIT.

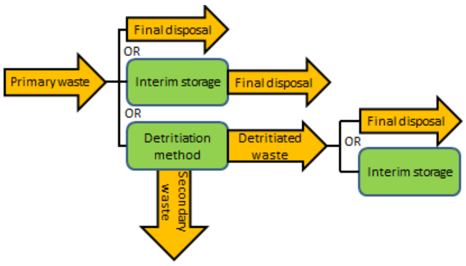

Fig. 2. Management strategies available in TWIT

The final repositories currently available in TWIT correspond to French disposal sites, CIRES for Very Low Level Waste and CSA for Short-Lived Low and Intermediate Level Waste, and disposal site in the UK for Low Level Waste. In addition to these existing disposal sites, the user can define his or her acceptance limits.

4.2.1.2 Parameters

Detritiation factors used for the case study are shown in Table 1.

Table 1. Parameters used for the case study

Technique	Detritiation factor
Interim storage	16.8
Detritiation via Thermal treatment	100

4.2.1.3 Results given by TWIT

For the case study, TWIT has identified the following management strategies for both waste scenarios:

1) 3 consecutive interim storage periods
2) 2 consecutive thermal treatments, considering the same efficiency for both treatments. This assumption could appear to be too optimistic and the detritiation factor may differ for the second treatment. This should be confirmed by a real process.
3) 1 thermal treatment followed by interim storage

4.2.2 Conclusion

The main purpose of TWIT is to identify different management strategies for tritiated waste that would results in final disposal of the waste. Because most of the parameters can be easily changed, the user can immediately see the impact of these changes and thus identify the crucial parameters of each management strategy.

TWIT takes into account only technical parameters in order to identify management strategies that should be further analysed and compared against non-technical parameters.

4.3 Step 2 – Comparative analysis

After identification of the 3 suitable options by TWIT, these options were scored by a panel of 6 experts from different fields related to tritiated waste management against various assessment criteria in the following categories: Environment, Safety, Technical feasibility.

Each of the selected criteria has a number of assessment criteria with the same weighting factor (see Table 2). However, the final distribution among the criteria was used: 40% to the environment, 30% to the safety, and 30% to the technical feasibility. The maximum score for all three criteria was fixed at 100.

Table 2. Criteria chosen for comparative analysis

Criterion	Parameter	Scoring criteria
Environment	Global releases per year	Amount of released tritium
	Public acceptance	Nuisance felt by the public
	Waste volumes for disposal	Waste volume reduction factor
	Secondary waste management	Availability of disposal route
Safety	Public exposure	Increase of exposure
	Occupational exposure	Level of exposure
	Tritium incident management	Availability of detritiation devices
Technical feasibility	Process reliability	Time before availability
	Process complexity	Technical maturity
	Process efficiency	Volume and activity reduction

4.3.1 Results of the analysis

The results of the comparative analysis are shown in Figure 3. The scoring shown in this figure corresponds to the following:

- For the environmental criterion, the scoring was higher for the thermal treatment due to the reduction

of the long-term stewardship burden compared to the interim storage solution which will last longer. Thermal treatment also provides a reduction of the releases.
- From the safety point of view, the thermal treatment process uses glove-boxes that may offer a confinement for the packages in case of a tritium incident (on site response).
- From a technical point of view, there is a balance between the complexity of the process, which is higher for the thermal treatment, and the process efficiency, which is lower for the interim storage. As a result, this criterion does not differentiate the two solutions.

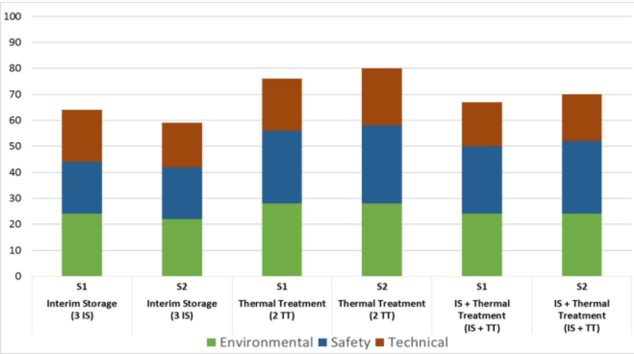

Fig. 3. Comparative analysis - results

Considering the input parameters, the second step of the analysis lead to the following conclusions:

Tritium Activity:
- The interim storage solution is suitable for lowly tritiated waste.
- Thermal treatment can handle higher levels of tritium in the waste as the detritiation factor is higher and waste can be re-processed.

Secondary waste:
- Interim storage does not generate secondary waste.
- Thermal treatment is more interesting if it is combined with a water detritiation system to deal with tritiated water produced.

Sustainability:
- Interim storage allows us to take advantage of a new BAT not available at the time of production of the waste. However, it represents a mid-term stewardship burden.
- Thermal treatment offers the possibility to close the loop of the tritium fuel cycle by tritium recovery.

4.4 Step 3 – Economical assessment

The third step of the methodology results in identification of the BAT by performing an economical assessment. The several options are economically feasible and the ongoing study is to refine the strategy in order to identify the most cost-effective one. The following costs are taken into account for this assessment:

- Design and construction cost
- Maintenance, refurbishment and modifications
- Operational cost
- Transport to the disposal site and disposal cost
- Tritium recovery (cost and profit)
- Secondary waste management
- Dismantling of the process

5. Conclusion

Tritiated waste management concerns are linked to the fact that tritium is very mobile. In order to secure safe management of this type of waste, specific analyses are required for each category.

The first two steps of identifying the BAT have been described in this article and applied on two different cases of purely tritiated waste made from stainless steel. The first step aims to identify all relevant management strategies for tritiated waste. This comprises many calculations and therefore CEA decided to develop a software tool for identification of management strategies resulting in acceptance of the waste in final repositories. The tool allows waste management experts to easily compare different waste management strategies. However, the results given by this tool need to be further analysed, for example by comparative analysis, which is the main aim of the second step of the methodology.

The comparative analysis took into account different assessment criteria related to environment, safety and technical feasibility and compared the management strategies identified by TWIT against these criteria. The results of the comparative analysis show that detritiation of purely tritiated metallic waste made from stainless steel appears to be very attractive, allowing a significant decrease of interim storage duration. The third step, resulting in identification of the BAT, based on economical assessment is ongoing.

The methodology using TWIT, to simplify identification of all suitable management strategies, represents a great opportunity for such an important decision-making process as selection of waste management strategy that may last for decades and ensures the effective management and control of radioactive waste is achieved, taking into account all relevant parameters and issues.

Acknowledgments

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