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CURRENT STATUS OF DEMO ACTIVATED WASTE STUDIES

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Abstract

Previous studies of the European Demonstration fusion reactor concept (DEMO) have shown that the expected amounts of radioactive waste at end of life (EOL) are of the order of 10^4 tonnes. These studies also suggested that comparable amounts of waste will be classified as low level waste (LLW) and intermediate level waste (ILW) 100 years after DEMO EOL. Since these studies were performed, updated models for the DEMO reactor have been developed. To assess the waste expectations from these models new assessments have been performed. These continue to suggest that approximately 10^4 tonnes of radioactive waste can be expected 100 years post EOL. A significant contribution to the ILW produced arises from activated in-vessel Eurofer steel. Long lived activity from ^{14}C causes most Eurofer to be unable to meet UK LLW requirements for over 1000 years after EOL. It has been suggested that amount of activated Carbon present in steels can be reduced via a decarburization process. This has been shown to work for non-active samples, reducing the carbon content to 1 weight part per million. Modelling the effect of such a process showed that the amount of ILW mass could be significantly reduced, but will remain approximately 10^4 tonnes on the desired decommissioning time scales (approximately 100 years post EOL).

1 INTRODUCTION

The waste expectations of the European Demonstration fusion reactor concept (DEMO) have been studied for a number of years [1, 2, 3]. These studies showed that DEMO models are expected to produce on the order of 10^4 tonnes of radioactive waste. It has been hoped that 100 years after DEMO end of life (EOL) all or most of activated material from DEMO can be disposed of as low level waste (LLW). These previous studies have shown that the expected masses of material classified as LLW and intermediate level waste (ILW) are comparable 100 years after DEMO EOL.

Since these studies were performed, updated models for the DEMO reactor have been developed. As such the waste expectations need to be re-evaluated, this is the subject of this work. The geometries for these models have been updated to include more detailed blanket designs and the bioshield since the previous waste assessments. Two blanket concepts have been used in this study: the Helium cooled Pebble Bed (HCPB) (heterogeneous blankets) and the water cooled Lithium-Lead (WCLL) (both homogeneous blankets) designs.

2 WASTE ASSESSMENT METHODOLOGY

The methodology used in this work matches that of the previous work [1, 2, 3]. Monte-Carlo neutron transport calculations were performed on the DEMO design geometry to determine neutron flux spectra. These are then used in high fidelity inventory simulations to find the expected activation and transmutation of each material in each geometry cell. The activation calculations used an irradiation schedule approximating DEMO's assumed operation including maintenance periods.

The neutron transport was performed using MCNPv6.2 [4, 5], with the JEFF 3.3 [6] nuclear data library, and the inventory simulations used FISPACT-II [7], with TENDL2017 cross section data [8] and UK decay2012 decay data. Each of the resultant inventories is assessed according to relevant waste criteria. This work, like those previously, has used the UK LLW criteria and the possibility of an inventory being non-active waste (NAW) assessed based on its IAEA clearance index. These criteria are stated in table 1.

All inventories have their waste criteria assessed from EOL to 1000 years later. The work includes replacement blankets and divertors; replacement component inventories were allowed to cool for any remaining operational time before assessment. An example activation profile of WCLL-blanket Eurofer (a reduced activation steel) is shown in figure 1.

Table 1: Waste Criteria used in this work. The activity limits are that of the UK.

Class	Criteria
ILW	α-Activity $\geq$ 4 MBq/kg, $\beta+\gamma$-Activity $\geq$ 12 MBq/kg
LLW	α-Activity $<$ 4 MBq/kg, $\beta+\gamma$-Activity $<$ 12 MBq/kg
NAW	IAEA Clearence Index $<$ 1

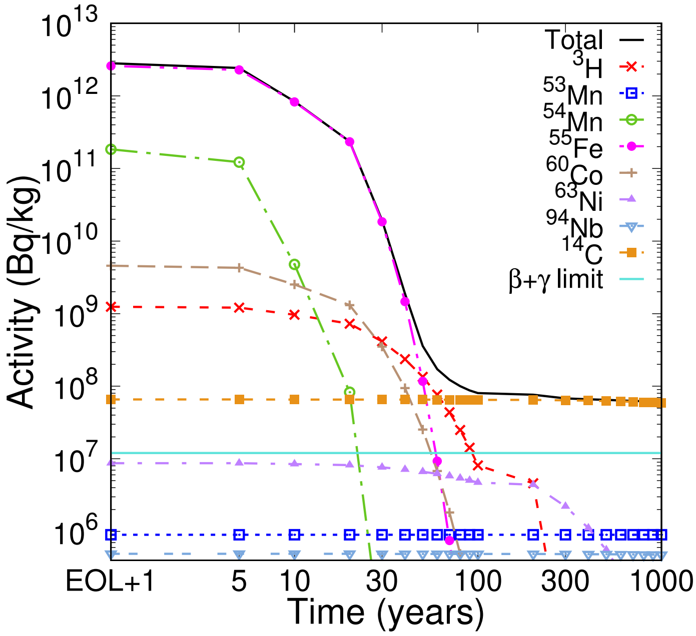

Figure 1: Figure showing the expected activation profile of Eurofer steel under DEMO WCLL irradiation conditions. The nuclide contributions plotted are only from the nuclides which provide a significant contribution to overall activity on the time-scale plotted .

3 WASTE ASSESSMENT

The results of the current assessments suggest that the waste performance of the DEMO reactor remains comparable to previous work. The waste mass evolution of the current DEMO models are shown in figure 2. In both blanket models studied the majority of reactor material is expected to require disposal as radioactive waste, with 1-2$\times 10^4$ tonnes being classified as ILW, possibly needing geological disposal, 100 years after EOL. The WCLL model has greater total mass due to the Pb content of the LiPb breeder material. The water content of the WCLL blanket moderated the neutron flux, resulting in low activation in the vessel. This is the cause of larger amounts of NAW in the WCLL model.

The moderating effect of the the WCLL blankets is clear when time-to-LLW is studied on a cell-by-cell basis. Figure 3 shows slices through the DEMO torus for the WCLL and HCPB models, where the cells have been colour coded by the time required for that cell to meet LLW criteria. The HCBP model (left panel) shows that the inner layers of the vacuum vessel have been activated sufficiently to required over 1000 years to meet LLW limits. The same cells when the WCLL blankets are used (right panel) mostly require shorter time scales, typically around 300 years. In these figure the blankets have not been coloured due to the complexities these geometries.

A significant proportion of the ILW mass from DEMO arises from activated structural components in the blankets. Current plans use Eurofer steel which is expected to produce long lived activation products. Figure 1 shows that these can include ^{14}C, ^{53}Mn and ^{94}Nb, the presence of which can cause difficulties when attempting to achieve LLW waste criteria. The divertor, a mostly Eurofer component, is expected to require over 1000 years for the majority of its mass to be LLW (see figure 3).

4 POSSIBLE MITIGATION STRATEGIES

4.1 **Decarburisation**

The expected activation profile from DEMO Eurofer shown in 1 reveals that ^{14}C as the major cause of failing to meet the UK LLW limit. It has been suggested that the Carbon content of activated steels could be reduced to 1 weight part per million via a so called decarburisation process [9]. The process, where Oxygen is blown across the surface of molten steel to create CO which is eventually captured as solid $CaCO_3$, has been used as part of steel manufacturing to reduce carbon content to as little as 1 weight part per million. The affect of such a technique has been applied to the Eurofer inventories and their waste classification reassessed. The resulting DEMO ILW mass evolution, as well as the estimated $CaCO_3$ ILW,

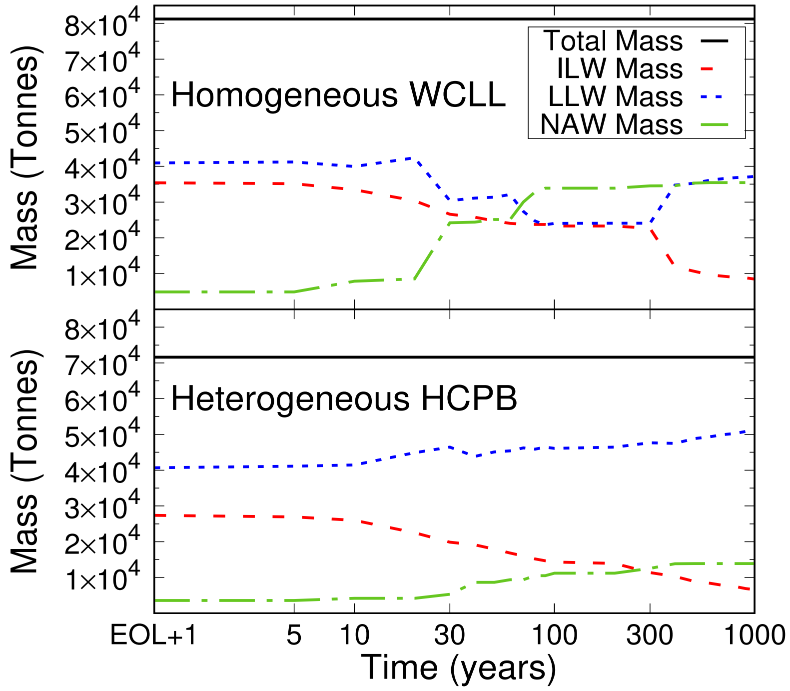

Figure 2: Figure showing the expected ILW, LLW and NAW masses from each of the DEMO models studied for time after reactor EOL. While the HCPB model produces a greater proportion of LLW, the WCLL models produce more NAW. Both blanket concepts produce comparable proportions of ILW. .

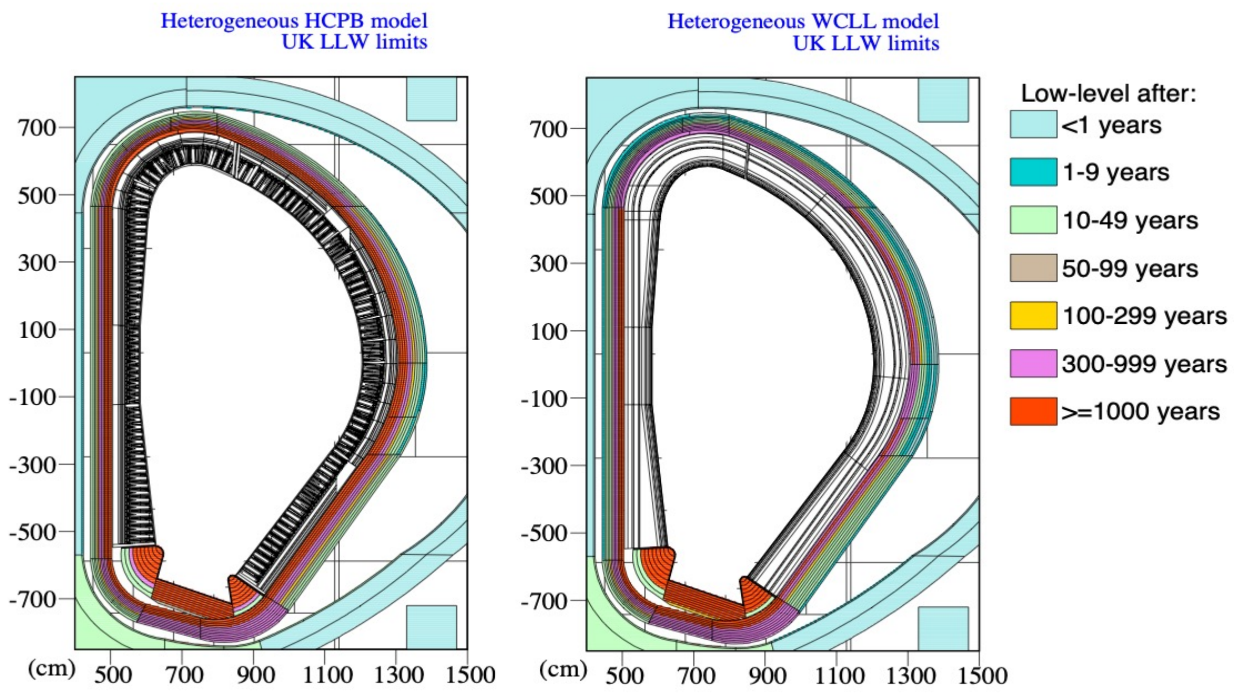

Figure 3: Figure showing the DEMO geometry where the cells hav been colour coded by the time required to meet LLW criteria. The blankets are not coloured due to the complexity of there geometry. .

are shown in figure 4.

Including decarburisation can improve the expected waste evolution of DEMO Eurofer, but some secondary ILW $CaCO_3$ should be expected. The decarburisation doesn't take effect until ^{14}C is a significant contributor to total activity, approximately 50 years post EOL, at which point the expected ILW mass is reduced but not removed entirely. The remaining ILW is material which is unaffected by decarburisation. While the reduction in ILW mass is not on the scale of orders of magnitude, decarburisation does reduce the expected times required to be LLW. Figure 5 shows the divertor geometry from figure 3, but colour coded based on the post decarburisation waste classifications. While several cells still require over 300 years to be LLW the results are an improvement over the 1000 years expected previously.

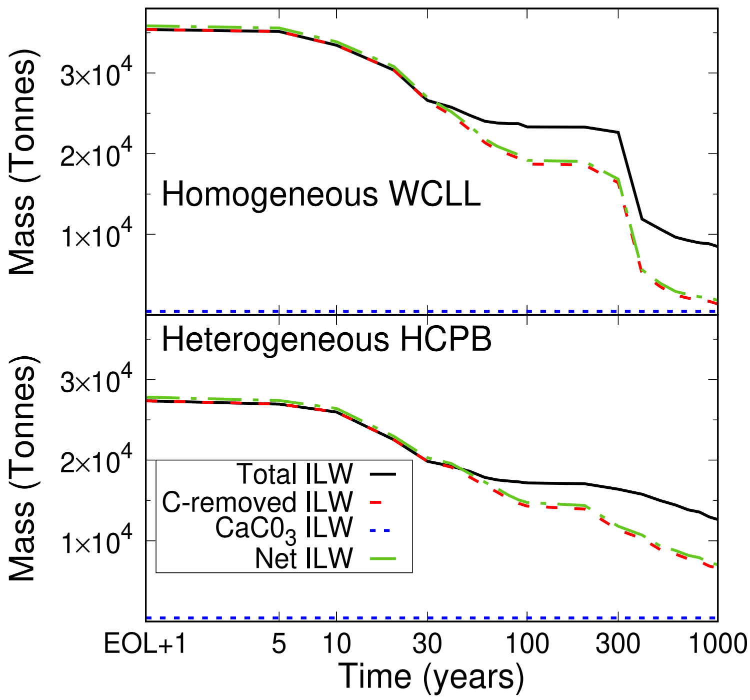

Figure 4: Figure showing the level of ILW expected form each of the DEMO models before and after decarburization has been approximated. The amount of expected $CaCO_3$ appears constant as the same amount of Carbon is removed at each time step. .

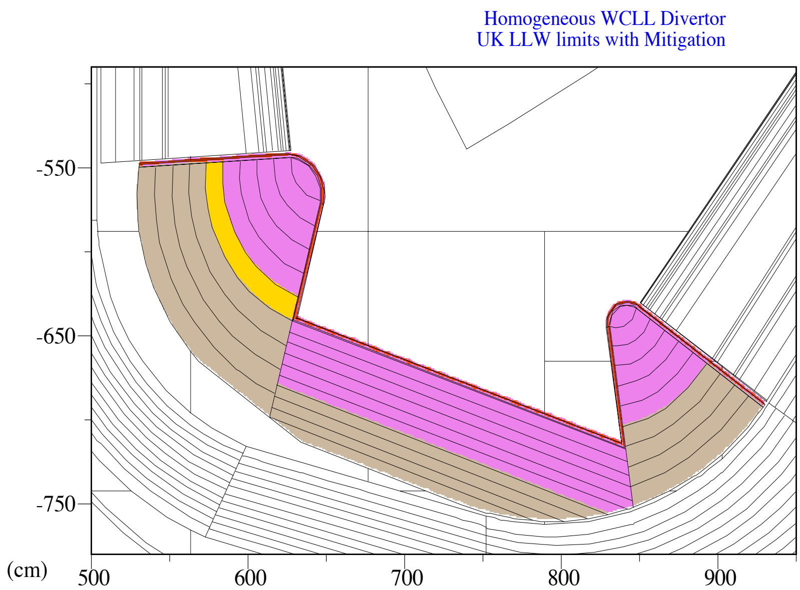

Figure 5: Figure showing the time to LLW required for divertor cells after decarburisation. The colour coding is the same as in figure 3 .

While this technique has the potential to improve the waste disposal prospects of in-vessel fusion steels, there are still a number of issues that must be resolved before it could be adopted as a DEMO waste mitigation strategy. These include proper assessment of the secondary waste burden from $CaCO_3$ (what is presented here is estimate) and whether it can be safely applied to large volumes of activated steel (it has only previously been tested on non-active material).

4.2 Impurity reduction

Many long-lived activation products are produced from impurities in material compositions. In Eurofer ^{94}Nb is produced via neutron capture reactions on Nb impurities. The reduction of these impurities during Eurofer manufacture may also improve waste performance. Unfortunately the global activity limits used by UK criteria mean a reduction in ^{94}Nb would not improve waste classification, as ^{94}Nb is dwarfed by other activity sources, see figure 1. Nb reduction can have an effect when individual nuclide limits are applied, such as those in different waste management systems. For example the French LLW system [10, 11], which is based on individual nuclide activities, allows 9.2×10^7 Bq/kg of ^{14}C and 1.2×10^5 Bq/kg of ^{94}Nb. Comparing these to the activities shown in figure 1 reveals that these criteria may make decarburisation unnecessary, but Nb impurity reduction could provide a significant improvement in long term waste classification. The possibility of applying waste mitigation techniques, such as decarburisation or Nb reduction, need be considered in the context of the regulations DEMO wastes will be subject to.

5 CONCLUSION

The expected levels of radioactive waste are an ongoing issue for the DEMO reactor concept. The continued development of the DEMO models does not appear to have significantly altered the outlook with approximately 10^4 tonnes of material requiring disposal, a significant proportion of this ILW, 100 years after end of life. The application of waste mitigation techniques appears capable of lowering the amount of ILW but the resultant expected total ILW mass is of the same order of magnitude as the unmitigated ILW mass. The effectiveness of the mitigation strategies discussed here is dependant on the criteria the active material is subject to. In the case of Eurofer: decarburisation will lower long lived total activity, so is effective where global activity limits are used, whereas impurity reduction will be more effective when specific nuclide limits are applied. As the exact regulations DEMO wastes will be subject to during decommissioning are not known which mitigation strategies will be the most effective is not certain. It should be noted that any waste mitigation techniques applied after EOL will produce secondary active wastes which need to be included in complete reactor waste assessments.

ACKNOWLEDGEMENTS

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