Current status of DEMO activated waste studies

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INTRODUCTION

- Previous work [1,2,3] has shown that the expected levels of intermediate level waste (ILW) from DEMO can be of the order of 10^4 tonnes 100 years after reactor end of life (EOL).
- Since these calculations were published the DEMO models have undergone further development and possible waste mitigation approaches have been explored. The impact of this on expected wastes is presented.

1. BACKGROUND

ACTIVATED WASTE FROM FUSION

- Burning fusion plasmas produce a large flux of neutrons which impinge upon the surrounding reactor structure causing material damage and activation.
- Many activation products are sufficiently long lived that after EOL many reactor components will require disposal as radioactive waste.
- It is hoped that most, if not all, fusion wastes can be classed a low-level waste (LLW) 100 years after EOL.

CLASSIFYING RADIOACTIVE WASTE

- Different national radioactive waste management organizations have different waste criteria.
- This work uses the UK LLW classification scheme and the IAEA clearance index for non-active wastes (NAW):
  - ILW: α-activity ≥ 4 MBq kg^{-1} and ($\beta+\gamma$)-activity ≥ 12 MBq kg^{-1}
  - LLW: α-activity < 4 MBq kg^{-1} and ($\beta+\gamma$)-activity < 12 MBq kg^{-1}
  - NAW: IAEA clearance index > 1

2. WASTE ASSESMENT METHODOLOGY

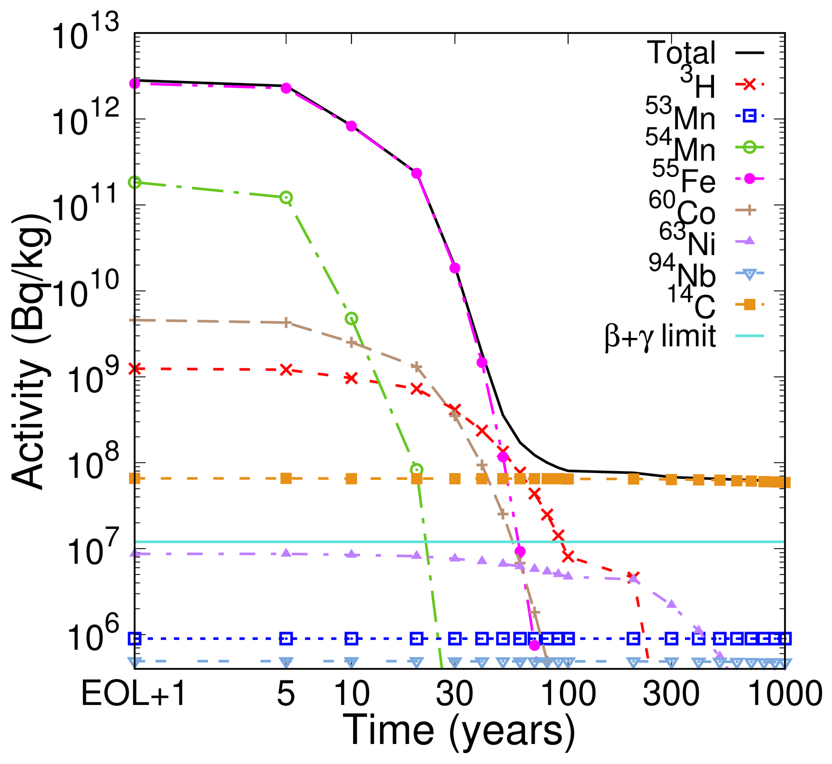


Figure 1: The expected activation profile of Eurofer steel under DEMO irradiation conditions. The nuclides plotted are those which provide a significant contribution to total activity.

- The methodology used in this work is the same as previous DEMO waste assessments [1,2,3]:
  1. Neutron transport calculations (MCNPv6.2 [4,5] with JEFF3.3 [6]) determine the neutron flux spectrum in each cell.
  2. Activation calculations are then performed (FISPACT-II [7] with TENDL2017 [8] and UK decay2012) for each material within each cell. The resulting inventories are classified with the UK waste criteria.
- Two heterogeneous DEMO models were studied in this work:
  1. Water cooled lithium-lead (WCLL)
  2. Helium cooled pebble bed (HCPB)
- Reactor components were irradiated for their expected lifetimes, accounting for replacement blankets and divertors.

3. WASTE ASSESSMENT

WCLL:

- At 100 years most of the mass is NAW, but between 2-3×10^4 tonnes remains ILW.
- The increased total mass of the WCLL model is a result of the Pb content and most ILW is in-vessel material.
- The water content of the blankets moderates the neutron spectrum, resulting in lower activation of the vessel.

HCPB:

- The LLW mass is always dominant, despite this the expected ILW mass at 100 years is on the order of 10^4 tonnes.
- Near blanket vessel region can require over 1000 years to be LLW.
- The HCPB model produces less NAW than the WCLL equivalent.

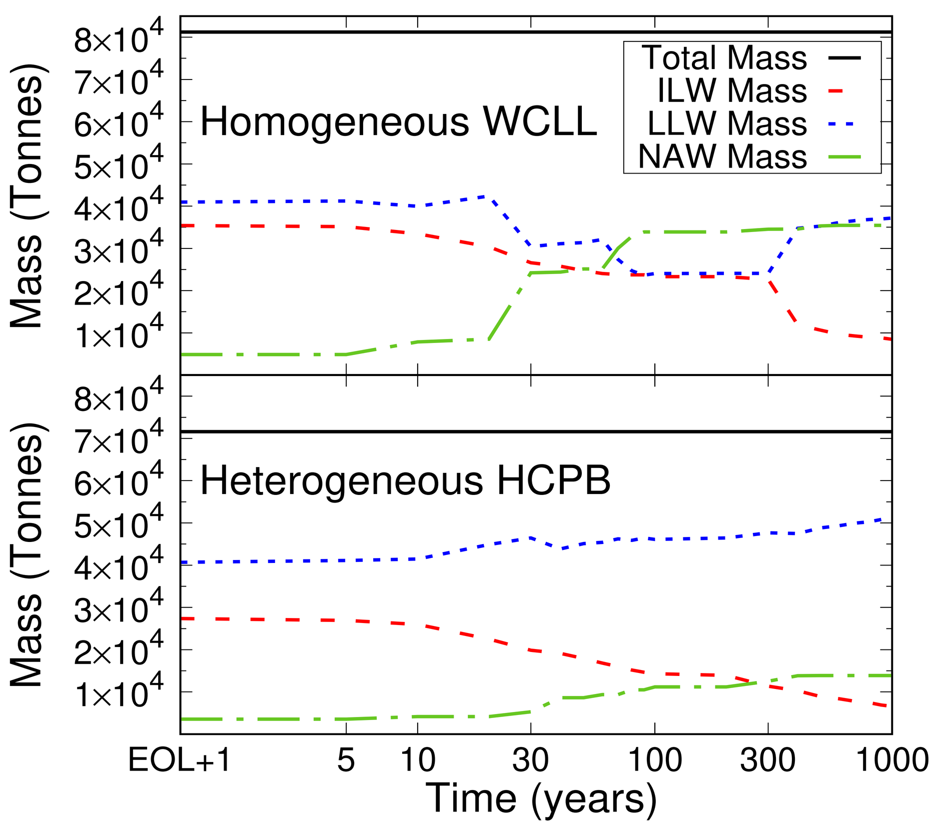


Figure 2: The expected ILW, LLW and NAW masses from each of the DEMO models studied for time after reactor EOL. The results shown include all reactor materials and replacements

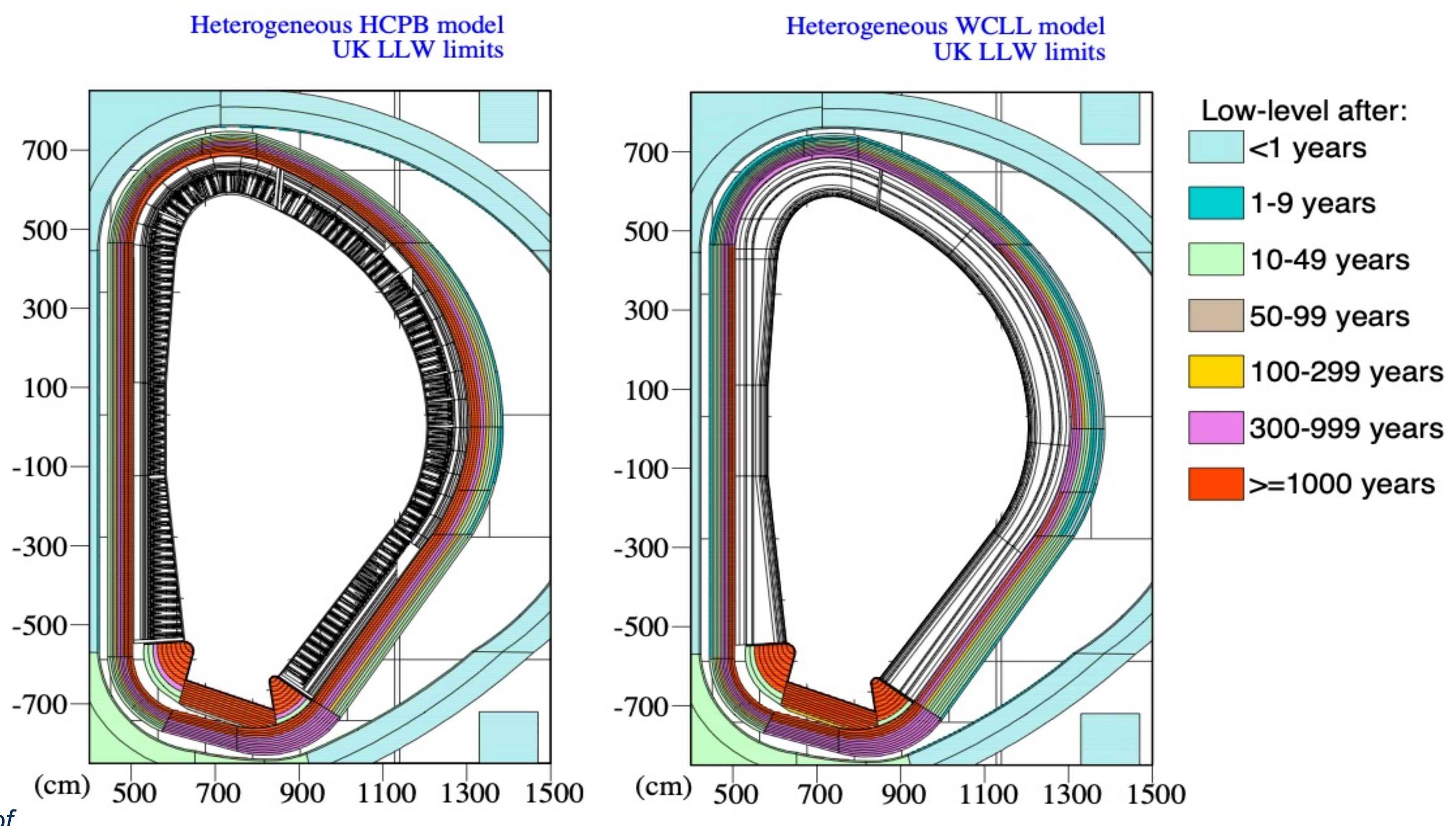
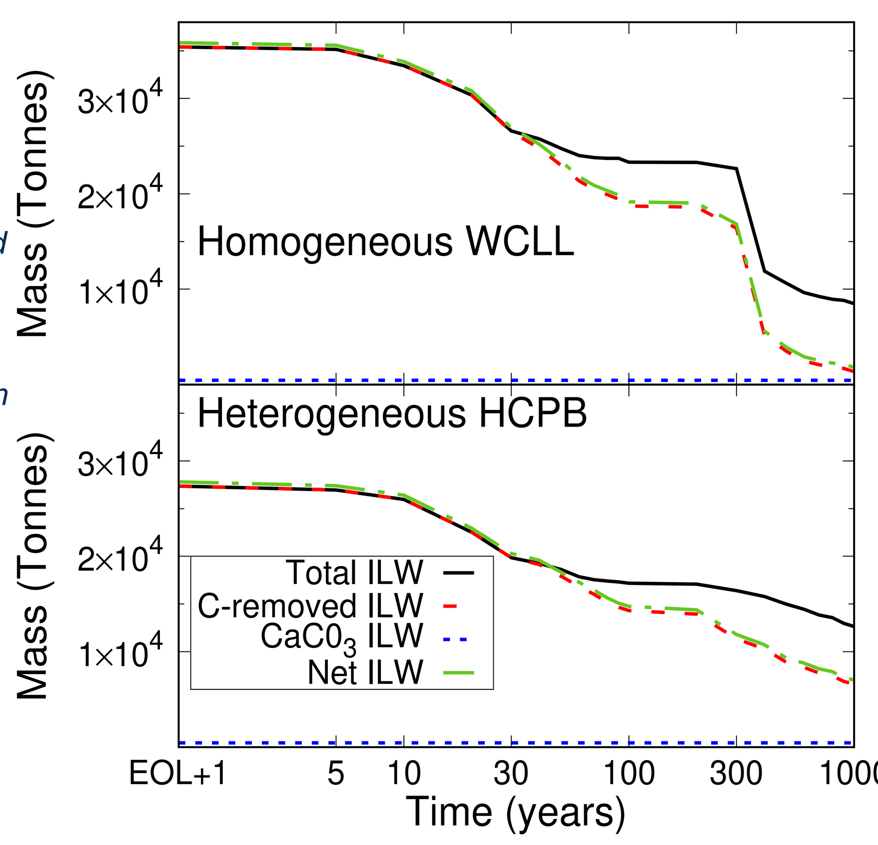


Figure 3: Time to LLW colour map of the WCLL and HCPB geometries. The blankets are not coloured but are included in other figures.

4. POSSIBLE MITIGATION STRATEGY

Figure 4: ILW mass expected from each of the DEMO models after decarburisation has been approximated.



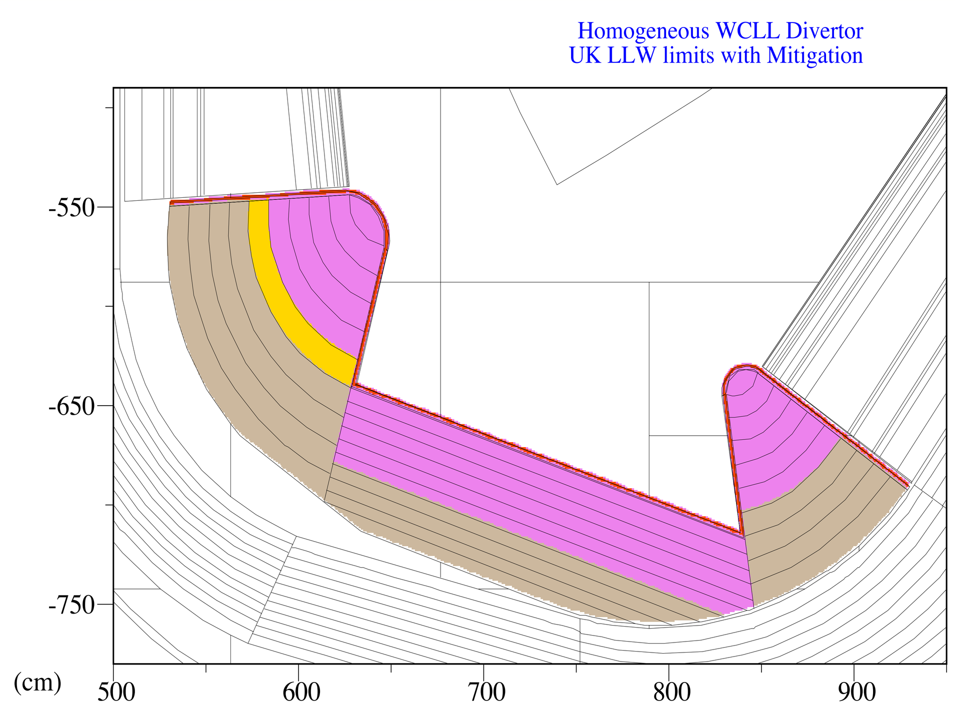


Figure 5: Time to LLW colour map of the WCLL divertor after decarburisation has been approximated. Uses the same key as figure 3.

- Long lived activity in Eurofer, the reduced activation steel used in the blankets, is dominated by ^{14}C (see figure 1).
- Industrial processes exist to remove excess C from steels during manufacturing, decarburisation. It has been suggested [9] that such processes (which result in C captured in $CaCO_3$) could be used on active steels to reduce ^{14}C activity prior to disposal.
- Decarburisation has been approximated by assuming that the carbon content of Eurofer inventories can be reduced to 1 wppm.
- Performing decarburization does decrease the expected ILW mass but not significantly 100-years post EOL. Highly active Eurofer can still require 300 years to meet LLW criteria.
- The $CaCO_3$ is expected to be secondary ILW, but is expected to be produced in relatively small quantities

CONCLUSION

- Fusion reactors will produce a significant amount of material which will require disposal as radioactive waste. It should become expected that some fusion waste will require ILW disposal even 100 years post EOL.
- Levels of ILW could possibly be reduced via waste mitigation techniques. However, such technologies have not currently been shown to be applicable to large volumes of active material. The calculations here assume 100% efficiency so should be considered a "best-case" scenario.
- Different LLW criteria may change the effectiveness of a waste mitigation strategy. For example, Under French criteria decarburization would not be necessary as ^{94}Nb activity would cause ILW classification not ^{14}C. Nb content of Eurofer could be lowered during manufacturing.

REFERENCES

[1] M. R. Gilbert *et.al* , "Activation, decay heat, and waste classification studies of the European DEMO concept", *Nucl. Fus.*, vol. **57**,p. 046015, 2017.

[2] M. R. Gilbert *et.al* , "Waste assessment of European DEMO fusion reactor designs", *Fus. Eng. Des.*, vol. **136**, pp. 42-48, 2018.

[3] M. R. Gilbert *et.al* , "Waste implications from minor impurities in European DEMO materials", *Nucl. Fus.,* 2019.

[4] C. J. Werner *et.al* , "MCNP6.2 Release Notes", Tech. Rep. report LA-UR-18-20808, Los Alamos National Laboratory, 2018.

[5] C. J. Werner *et.al* , "MCNP Users Manual Code Version 6.2", Tech. Rep. report LA-UR-17-29981, Los Alamos National Laboratory, 2017.

[6] A.J.M Plompen, *et al.* "The joint evaluated fission and fusion nuclear data library, JEFF-3.3", *Eur. Phys. J. A* **56,** 181 (2020)

[7] J. -Ch. Sublet *et.al* , "FISPACT-II: An advanced simulation system for activation, transmutation and material modelling", *Nucl. Data Sheets*, vol. **139**, pp. 77-137, 2017.

[8] A. J. Koning, D. Rochman, and J. -Ch. Sublet. "TENDL-2017". Release Date: December 30, 2017. Available from *https://tendl.web.psi.ch/tendl_2017/tendl2017.html.*

[9] L. Di Pace *et.al* , "Feasibility studies of DEMO potential waste recycling by proven existing industrial-scale processes", *Fus. Eng. Des*, vol. **146**, pp. 107-110, 2019.SI:SOFT-30.

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