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Neutronic analyses for EU DEMO upper limiter

Aljaž Čufar[1], Maria Lorena Richiusa[2,3], Dieter Leichtle[4]

[1] Reactor Physics Department, Jožef Stefan Institute, Jamova cesta 39, SI-1000 Ljubljana, Slovenia
[2] Department of Engineering Science, Oxford Thermofluids Institute, University of Oxford, Oxford, OX2 0ES, UK
[3] UKAEA-CCFE, Culham Science Centre, Abingdon, Oxon, OX14 3DB, UK
[4] Karlsruhe Institute of Technology, D-76344 Eggenstein-Leopoldshafen, Karlsruhe, Germany

Introduction

- Limiters play a crucial role in the operation of DEMO
- Upper limiter integration was done in several steps (**Talk: M. L. Richiusa et al – P6A4, Thursday afternoon**)
- Simplistic models used in initial analyses
  - Radial dependence of the nuclear loads ("1D") – to investigate the general behavior and determine suitable cooling channel density
  - Effect of different shielding mixtures on the deposited nuclear loads
  - Effect of different shielding mixtures on the neutron/gamma shielding performance
- Detailed models based on initial results used in more detailed analyses
  - More detailed modelling, but still simplistic, i.e. cooling channels not explicitly modelled
  - Detailed 3D maps of the nuclear loads – to study local behavior
  - Design of the cooling solution was optimized based on these results (**Poster: A. Froio et al – PS3-3, Thursday**)
- This work is part of ISFNT paper: M. L. Richiusa et al, The Integrated Engineering Design Concept of the Upper Limiter within the EU-DEMO LIMITER System

Conclusions

- Simple model for initial investigations, detailed model to determine local behavior
- No problems found with shielding performance
- Detailed 3D maps of nuclear heating, DPA, and He production
- Integral and peak values of nuclear loads informed future design directions

1. Tolls used

- SuperMC [1] for CAD to MCNP geometry conversion
- MCNP5 v1.60 [2] and JEFF 3.3 [3] nuclear data for analyses

2. Simple limiter model

- Initial simulations carried out using simple model
  - 3 plasma facing layers
  - Shielding block (homogenized water-Eurofer mix)
- Shield block (SB) configurations – homogenized
  - Box design – Eurofer box with water filling
  - Plate design – Eurofer plates cooled by water channels
- Analysis of radial dependence of nuclear heating
- HCPB and WCLL tritium breeding blanket (TBB)

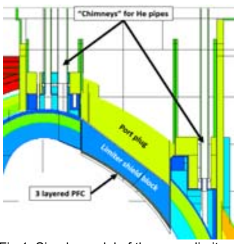


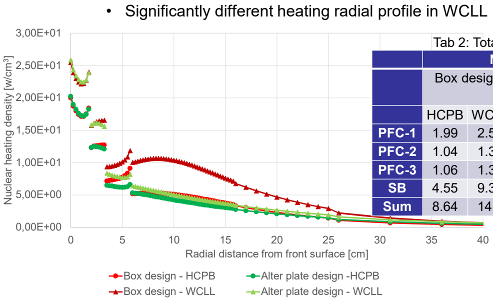
Fig 1: Simple model of the upper limiter

Tab 1: Material composition of analyzed cases for the simple limiter design

	Box design	Plate design	Alt. plate design
PFC-1	Tungsten (100 vol%)		
PFC-2 – tube layer	Tungsten (39.5 vol%), CuCrZr (17.0 vol%), oxygen free Cu (13.5 vol%), water (30 vol%)		
PFC-3 – bottom layer	Eurofer (39.5 vol%), tungsten (21.0 vol%), void (39.5 vol%)		
Shielding block	Eurofer (53 vol%), water (47 vol%, at 0.92 g/cm³)	Eurofer (87.5 vol%), water (7.4 vol% at 0.92 g/cm³), void (5.1 vol%)	Eurofer (87.5 vol%), water (7.4 vol% at 0.7 g/cm³), void (5.1 vol%)

3. Analyses using simple limiter model

- Total nuclear heating of each layer
- Radial dependence of nuclear heating
- For different SB configurations and TBB concepts
  - Minor differences in deposited energy for HCPB
  - Significantly different heating radial profile in WCLL



Tab 2: Total nuclear heating per layer

	Nuclear heating [MW]					
	Box design		Plate design		Alternative plate design	
	HCPB	WCLL	HCPB	WCLL	HCPB	WCLL
PFC-1	1.99	2.57	2.00	2.56	2.00	2.60
PFC-2	1.04	1.34	1.02	1.32	1.02	1.32
PFC-3	1.06	1.38	0.88	1.11	0.87	1.09
SB	4.55	9.35	4.47	5.77	4.35	5.54
Sum	8.64	14.6	8.37	10.8	8.24	10.5

Fig 2: Radial dependence of the nuclear heating for different analyzed cases using simple upper limiter model

4. Detailed model of upper limiter

- More realistic geometry
- 3 plasma facing layers + attachment layer
- Shielding block still homogenized – based on plate design

Tab 3: Material composition of layers for the detailed limiter design.

Layer	Material composition
PFC-1 (20 mm)	Tungsten (100%)
PFC-2 – layer with cooling pipes (17 mm)	Cu (11.70 vol%), CuCrZr (14.81 vol%), water (26.33 vol%, at 0.935 g/cm³), tungsten (47.17 vol%)
PFC-3 (3 mm)	Tungsten (100%)
PFC attachment layer (23 mm)	Eurofer (21 vol%), void (79 vol%)
Shielding block	Eurofer (92.85 vol%), water (5.28 vol% at 0.7 g/cm³), alumina (1.87 vol%)

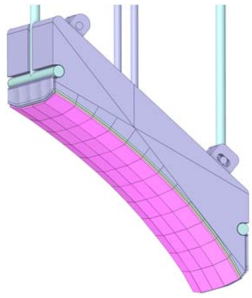


Fig 3: Detailed model of the upper limiter

5. Analyses using a detailed model

- Nuclear loads of interest
  - Nuclear heating in limiter (total per component and mesh based)
  - DPA, He production in limiter
  - Peak nuclear heating in TFC: 6 W/m³ (limit 50 W/m³) – good shielding properties
  - DPA in vacuum vessel (VV): 0.2 DPA / 6 FPY (limit 2.75 DPA) – VV is far from the limiter

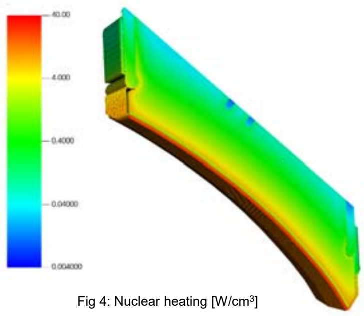


Fig 4: Nuclear heating [W/cm³]

Tab 4: Total nuclear heating per component

Layer	Nuclear heating
PFC-1	2.35 MW
PFC-2	1.46 MW
PFC-3	0.376 MW
PFC attachment layer	0.171 MW
Shielding block	5.18 MW
PFC cooling pipes (outside of PFC)	29.2 kW
PFC cooling liquid (outside of PFC)	34.4 kW
Sum	9.60 MW

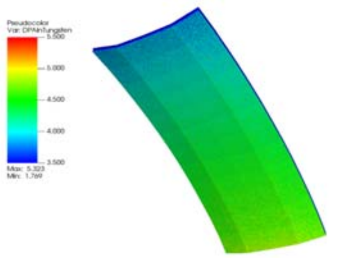


Fig 5: Neutron induced damage in tungsten [DPA/FPY]

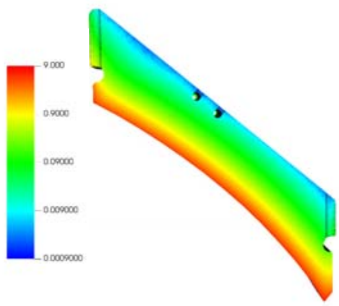


Fig 6: Neutron induced damage in Eurofer [DPA/FPY]

6. Further work

- Upper limiter as a reference for other limiters
- Initial work already done on
  - Outboard midplane limiter (OML)
  - Outboard lower limiter (OLL)

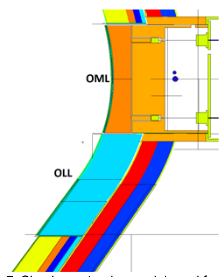


Fig 7: Simple neutronics model used for initial OML and OLL analyses.

References

[1] Y. Wu, FDS Team, CAD-based interface programs for fusion neutron transport simulation, Fusion Engineering and Design 84 (2009), 1987-1992.
[2] F. Brown et al, Verification of MCNP5-1.60, LA-UR-10-05611, Los Alamos National Laboratory (2010).
[3] JEFF 3.3: https://www.oecd-nea.org/dbdata/jeff/jeff33/

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