EUROfusion

OVERVIEW OF THE R&D OF MATERIALS INTENDED FOR DEMO AND DONES AT LITHUANIAN ENERGY

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Outline

- **Eu DEMO**
  - Model Analysis
  - Irradiation Scenario
  - Materials
  - Example of results
- **DEMO Oriented Neutron Source (DONES)**
  - Model
  - Methodology, computational model and source
  - Results examples

EU DEMO: Model

For Vacuum vessel calculations was used 2015 DEMO baseline model

Activation analysis were performed with 2 kinds blanket configurations:

- HCPB()
- WCLL ()

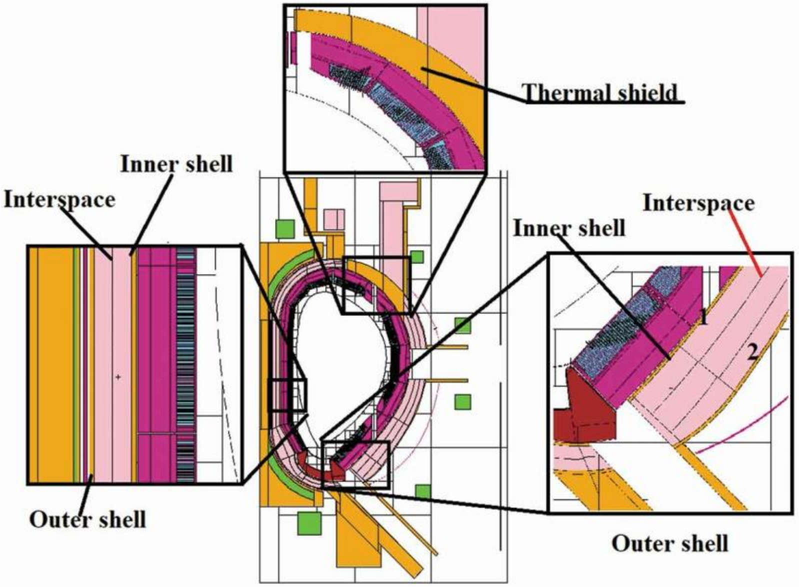


Figure 1 MCNP model of DEMO VV

Using MCNP6 with JEFF 3.2 nuclear data library was calculated neutron flux

Nuclide inventory calculations were performed with Fispact-II code and TENDL-2017 nuclear data library

Figure 2 EU DEMO MCNP model with HCPB (left) and WCLL (right) blanket concept

Model

For Divertor calculations was used 11.25 degree toroidal sector from the full DEMO1 2017 model

Activation analysis were performed with 2 kinds blanket configurations:

- HCPB (provided by Sara, HCPBlayer-DIV19_MCNPmodel_ENEA_18112020.txt)
- WCLL (provided by Sara WCLLlayer-DIV19_MCNPmodel_ENEA_25052020.txt)

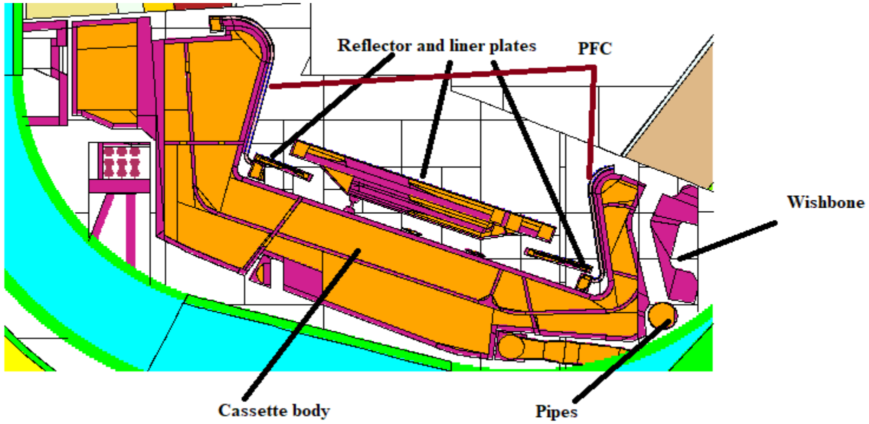


Figure 3 DEMO divertor generic neutronic model

Figure 4 EU DEMO MCNP model with HCPB (left) and WCLL (right) blanket concept

Using MCNP6 with JEFF 3.2 nuclear data library was calculated neutron flux for 1835 divertor cells

Nuclide inventory calculations were performed with Fispact-II code and TENDL-2017 nuclear data library

Irradiation Scenario

⇒ **1st DEMO operation phase:**
- ⇒ Continuous operation over 5.2 years (CY) with 10 days at 30% of the nominal fusion power followed by
- ⇒ 10 days pulsed operation with 48 pulses:
  - ⇒ 4 hours at full power
  - ⇒ 1h dwell time in between.

⇒ **2st DEMO operation phase:**
- ⇒ Continuous operation over 14.8 years (CY) with 10 days at 30% of the nominal fusion power followed by
- ⇒ 10 days pulsed operation with 48 pulses:
  - ⇒ 4 hours at full power
  - ⇒ 1h dwell time in between.

- Decay times for the calculation of the activity inventories and the decay heat:
  0 s, 1 s, 5 min, 30 min, 1 hr, 3 hr, 5 hr, 10 hr, 1 day, 3 days, 1 week, 2 weeks, 4 weeks, 8 weeks, 6 months, 1 year, 10 years, 50 years, 100 years and 1000 years.

Materials

Table 1 Vacuum Vessel Material Composition (wt%)

316L(N)-IG+ Water		316L(N)-IG	
elements		elements	
Fe	58.745	FE	63.684
C	0.028	C	0.03
Mn	1.845	MN	2
Si	0.461	SI	0.5
P	0.023	P	0.025
S	0.009	S	0.01
Cr	16.604	CR	18
Ni	11.531	NI	12.5
Mo	2.491	MO	2.7
N	0.074	N	0.08
B	0.001	B	0.001
Cu	0.277	CU	0.3
Co	0.046	CO	0.05
Nb	0.009	NB	0.01
Ti	0.092	TI	0.1
Ta	0.009	TA	0.01
H	0.868		
O	6.887		

Table 2 Divertor components material Composition (wt%)

Euroofer		Tungsten		(W, H20, CuCrZr)		Inconel		Ti alloy		Water	
element		element		element		element		element		element	
Fe	88.698	Al	0.0015	W	81.9957	C	0.08	Ti	88.0075	H	11.2
B	0.002	C	0.003	CR	0.1138	Mn	0.35	Al	6.75	O	88.8
C	0.11	Ca	0.0005	ZR	0.0164	Si	0.35	V	4.5		
N	0.03	Co	0.001	O	2.5215	P	0.015	Fe	0.4		
O	0.01	Cr	0.002	CO	0.0091	Cr	0.015	O	0.28		
Al	0.01	Cu	0.001	SI	0.0017	Nb	19	H	0.0125		
Si	0.05	Fe	0.003	CU	15.0245	Ta	5.125	N	0.05		
P	0.005	H	0.0005	H	0.3172	Co	5.175				
S	0.005	K	0.001			Mo	1				
Ti	0.02	Mg	0.0005			Fe	3.05				
V	0.2	Mn	0.0005			Al	11.634				
Cr	9	Mo	0.01			Ti	0.5				
Mn	0.4	N	0.0005			Ni	0.9				
Co	0.01	Na	0.001			B	52.5				
Ni	0.01	Nb	0.001			Cu	0.006				
Cu	0.01	Ni	0.0005								
Nb	0.005	O	0.002								
Mo	0.005	P	0.002								
Ta	0.12	Pb	0.0005								
W	1.1	S	0.0005								
As	0.05	Si	0.002								
Sn	0.05	Ta	0.002								
Sb	0.05	Ti	0.0005								
Zr	0.05	Zr	0.0005								
		W	99.9595								
		Ag	0.001								
		As	0.0005								
		Ba	0.0005								
		Cd	0.0005								
		Zn	0.0005								

Example of results I (Neutron flux)

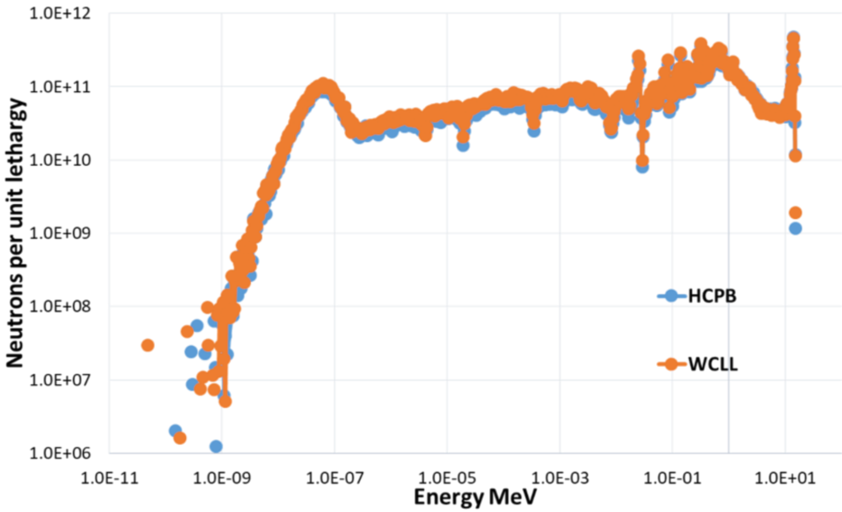


Figure 5 Neutron spectra in WCLL and HCPB at the bottom of the divertor. Material Eurofer

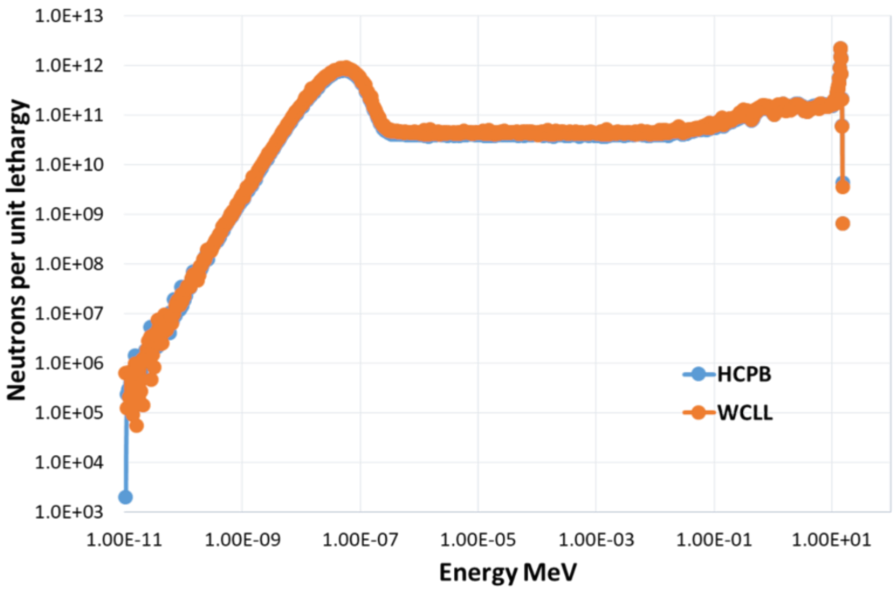


Figure 6 Neutron spectra in WCLL and HCPB bottom of the divertor. Material: water

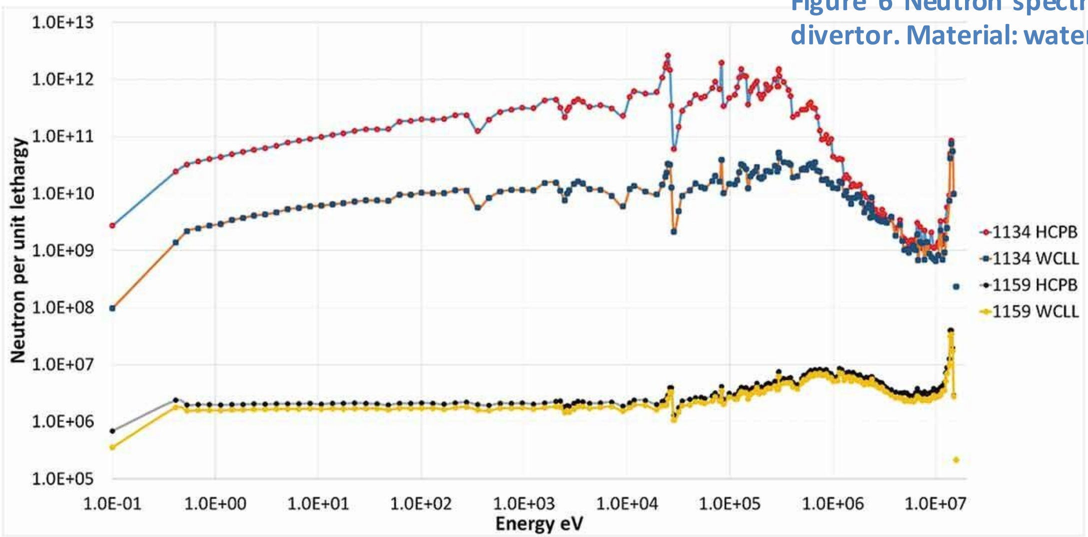


Figure 7 Neutron spectrum examples in EU DEMO Vacum vessel. 1123 represents 316L(N)-IG material and 1159 - 316L(N)-IG+water

Example of results I (Nuclide inventory)

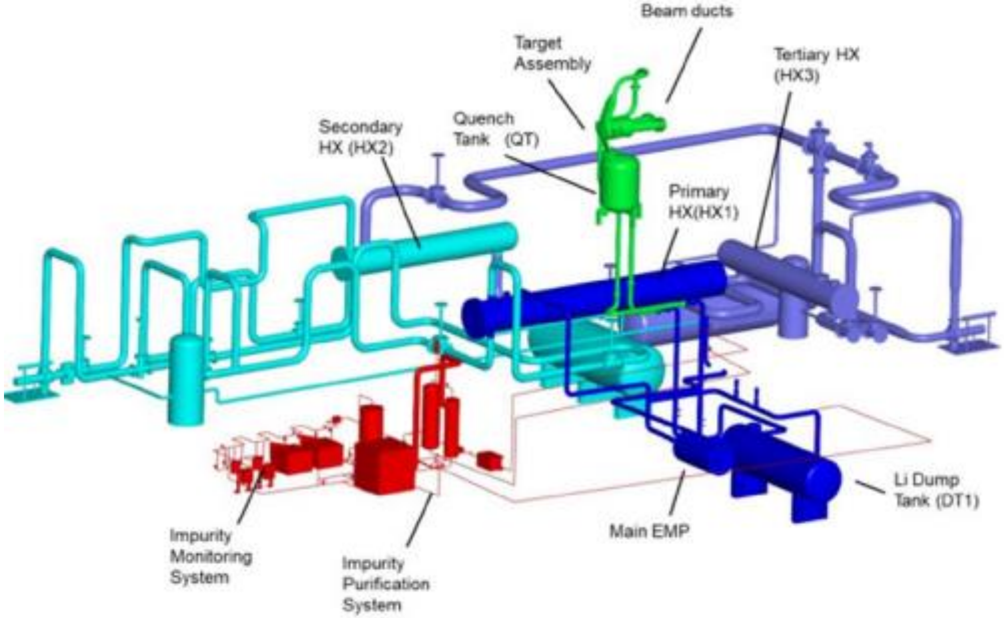
Table 3 Summary data for investigated layers with principle nuclide identified

Name of zone	Material	Activity [Bq]					Decay heat [kW]					Princ. Radionuclide				
		1 s	1 month	1 year	10 years	100 years	1 s	1 month	1 year	10 years	100 years	1 s	1 month	1 year	10 years	100 years
HCPB																
Pipes	Eurofer	2.45E+17	7.19E+16	4.12E+16	4.01E+15	5.91E+11	4.70E+01	2.42E+00	6.50E-01	5.95E-02	5.29E-06	Mn56	Fe55	Fe55	Fe55	others
	Water	1.52E+16	2.28E+12	2.27E+12	2.22E+12	2.13E+12	1.76E+01	1.66E-04	1.66E-04	1.64E-04	1.61E-04	N16	C14	C14	C14	C14
Plates	Eurofer	4.22E+18	1.31E+18	7.98E+17	7.70E+16	8.47E+12	8.12E+02	3.84E+01	1.13E+01	8.55E-01	7.96E-05	Mn56	Fe55	Fe55	Fe55	others
	Water	1.35E+17	1.26E+13	1.26E+13	1.21E+13	1.13E+13	1.57E+02	9.16E-05	9.15E-05	9.10E-05	8.94E-05	N16	C14	C14	C14	C14
	Tungsten	2.38E+18	2.79E+17	2.09E+16	1.54E+13	7.46E+10	2.26E+02	5.75E+00	4.20E-01	4.73E-03	4.24E-06	W187	W185	W185	W185	others
Wishbone	Ti alloy	5.14E+14	2.15E+13	3.12E+12	5.00E+10	1.03E+09	2.02E-01	4.48E-03	2.97E-04	5.62E-08	8.01E-09	V52	Sc48	Sc48	Ca45	others
	Inconel pin	1.02E+15	4.95E+14	9.43E+13	9.65E+12	4.05E+11	1.54E-01	1.11E-01	2.30E-02	3.22E-03	3.86E-06	Ta182	Ta182	Ta182	Co60	others
PFC	Eurofer (support)	1.33E+17	5.17E+16	3.32E+16	3.16E+15	1.98E+11	2.73E+01	1.59E+00	4.67E-01	2.30E-02	2.59E-06	Mn56	Fe55	Fe55	Fe55	others
	Tungsten (I - III layer)	3.40E+18	5.82E+17	4.23E+16	3.03E+13	1.47E+11	2.93E+02	1.18E+01	8.33E-01	8.92E-03	8.81E-06	W187	W185	W185	W185	others
	W + CuCrZr+ Water (II layer)	4.01E+18	4.96E+17	3.75E+16	1.01E+15	1.54E+14	3.98E+02	1.11E+01	1.64E+00	2.97E-01	4.31E-04	W187	W185	W185	W185	others
Cassette body	Eurofer	2.53E+18	7.73E+17	4.39E+17	4.23E+16	6.09E+12	4.93E+02	2.96E+01	7.60E+00	6.32E-01	5.75E-05	Mn56	Fe55	Fe55	Fe55	others
	Water	8.04E+16	2.41E+13	2.41E+13	2.37E+13	2.28E+13	9.40E+01	1.84E-04	1.84E-04	1.84E-04	1.81E-04	N16	C14	C14	C14	C14
WCLL																
Pipes	Eurofer	3.03E+17	8.31E+16	4.64E+16	4.56E+15	7.74E+11	5.69E+01	2.80E+00	7.31E-01	7.97E-02	6.94E-06	Mn56	Fe55	Fe55	Fe55	others
	Water	1.49E+16	3.09E+12	3.08E+12	3.01E+12	2.89E+12	1.74E+01	2.33E-05	2.33E-05	2.33E-05	2.29E-05	N16	C14	C14	C14	C14
Plates	Eurofer	5.07E+18	1.46E+18	8.70E+17	8.47E+16	1.08E+13	9.55E+02	4.29E+01	1.24E+01	1.14E+00	1.02E-04	Mn56	Fe55	Fe55	Fe55	others
	Water	1.34E+17	1.74E+13	1.73E+13	1.66E+13	1.55E+13	1.57E+02	1.26E-04	1.26E-04	1.25E-04	1.23E-04	N16	C14	C14	C14	C14
	Tungsten	2.94E+18	3.00E+17	2.18E+16	1.72E+13	7.97E+10	2.89E+02	6.21E+00	4.45E-01	5.57E-03	4.52E-06	W187	W185	W185	W185	others
Wishbone	Ti alloy	6.52E+14	1.76E+13	2.68E+12	5.19E+10	1.42E+09	2.59E-01	3.55E-03	2.37E-04	6.01E-08	1.12E-08	V52	Sc48	Sc48	Ca45	others
	Inconel pin	1.19E+15	5.88E+14	1.12E+14	1.19E+13	5.40E+11	1.84E-01	1.36E-01	2.88E-02	4.13E-03	4.62E-06	Ta182	Ta182	Ta182	Co60	others
PFC	Eurofer (support)	1.43E+17	5.37E+16	3.40E+16	3.25E+15	2.32E+11	2.88E+01	1.72E+00	4.82E-01	2.70E-02	3.11E-06	Mn56	Fe55	Fe55	Fe55	others
	Tungsten (I - III layer)	3.98E+18	6.30E+17	4.43E+16	3.22E+13	1.54E+11	3.54E+02	1.29E+01	8.92E-01	9.81E-03	9.43E-06	W187	W185	W185	W185	others
	W + CuCrZr+ Water (II layer)	4.75E+18	5.54E+17	4.01E+16	1.02E+15	1.50E+14	4.72E+02	1.25E+01	1.73E+00	3.03E-01	4.21E-04	W187	W185	W185	W185	others
Cassette body	Eurofer	3.05E+18	8.85E+17	4.89E+17	4.76E+16	7.78E+12	5.84E+02	3.44E+01	8.54E+00	8.22E-01	7.36E-05	Mn56	Fe55	Fe55	Fe55	others
	Water	7.95E+16	3.21E+13	3.20E+13	3.14E+13	3.03E+13	9.29E+01	2.44E-04	2.44E-04	2.43E-04	2.40E-04	N16	C14	C14	C14	C14

Table 4 Summarizing data for investigated layers with principle nuclides identified

	Activity					Decay Heat					Princ. Radionuclides				
	1 second	1 month	1 year	100 years	1000 years	1 second	1 month	1 year	100 years	1000 years	1 second	1 month	1 year	100 years	1000 years
HCPB	PBq					MW									
Inner shell	4.10E+03	6.20E+02	3.00E+02	1.10E+01	2.70E-01	1.10E+00	4.00E-02	2.90E-02	3.00E-05	9.20E-07	^{56}Mn	$^{55}Fe/^{60}Co$	$^{55}Fe/^{60}Co$	others	others
Interspace	2.20E+04	3.70E+03	1.70E+03	7.50E+01	1.70E+00	6.50E+00	1.60E-01	1.20E-01	2.10E-04	4.70E-06	^{56}Mn	$^{55}Fe/^{60}Co$	$^{55}Fe/^{60}Co$	others	others
Outer shell	2.50E+01	4.60E+00	2.20E+00	6.50E-02	1.60E-03	6.70E-03	2.60E-04	1.70E-04	1.80E-07	4.90E-09	^{56}Mn	$^{55}Fe/^{60}Co$	$^{55}Fe/^{60}Co$	others	others
WCLL															
Inner shell	7.50E+02	1.40E+02	6.80E+01	1.90E+00	4.70E-02	2.10E-01	8.40E-03	5.40E-03	5.30E-06	1.50E-07	^{56}Mn	$^{55}Fe/^{60}Co$	$^{55}Fe/^{60}Co$	others	others
Interspace	2.40E+03	4.10E+02	1.90E+02	7.70E+00	1.80E-01	6.80E-01	1.80E-02	1.30E-02	2.20E-05	4.90E-07	^{56}Mn	$^{55}Fe/^{60}Co$	$^{55}Fe/^{60}Co$	others	others
Outer shell	1.40E+01	3.00E+00	1.50E+00	3.30E-02	8.70E-04	3.60E-03	1.60E-04	9.10E-05	9.30E-08	2.70E-09	^{56}Mn	$^{55}Fe/^{60}Co$	$^{55}Fe/^{60}Co$	others	others

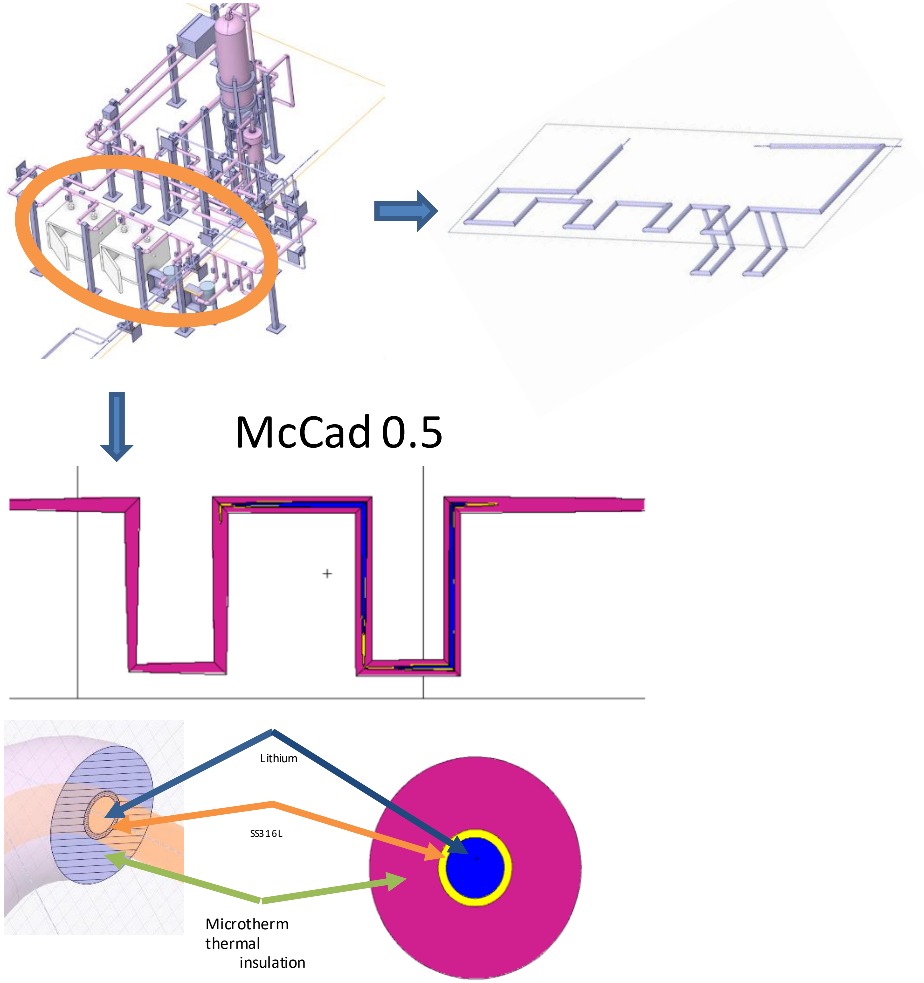
DONES:



- The Demo-Oriented NEutron Source (DONES) is an irradiation facility for testing candidate materials for DEMO reactor and future fusion power plants

DONES: MODELS

Li Sampling Cell pipes



Total 0.008877148 m^3 volume of Li

Figure 8. CAD and MCNP model Li sampling cell

❖Li Dump Tank

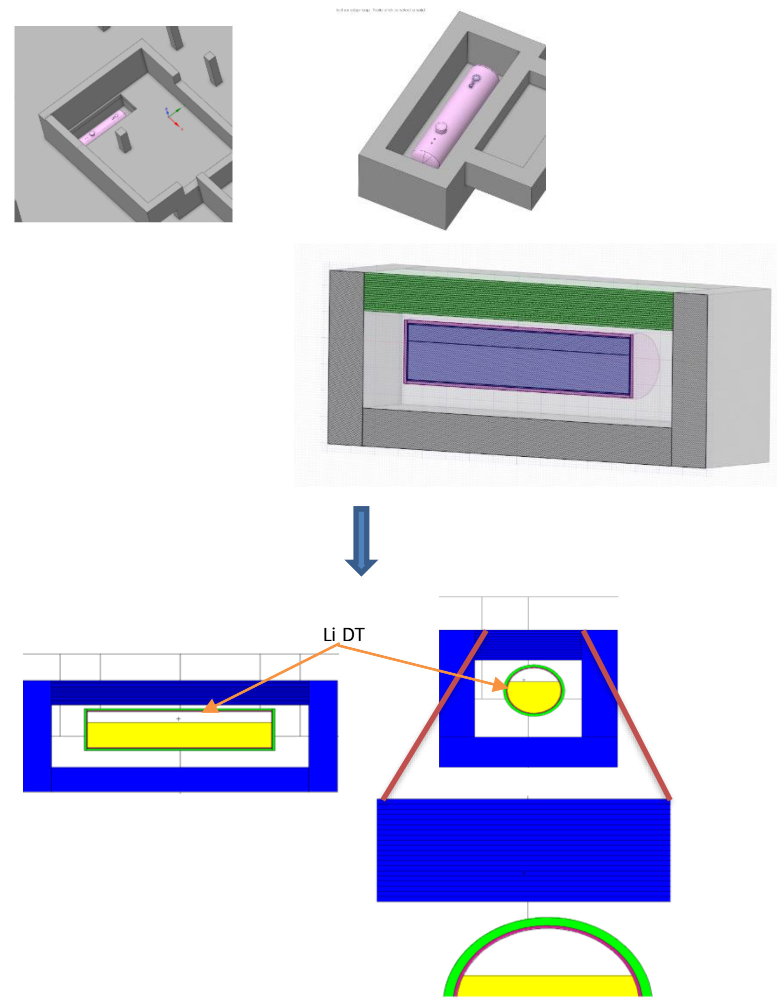
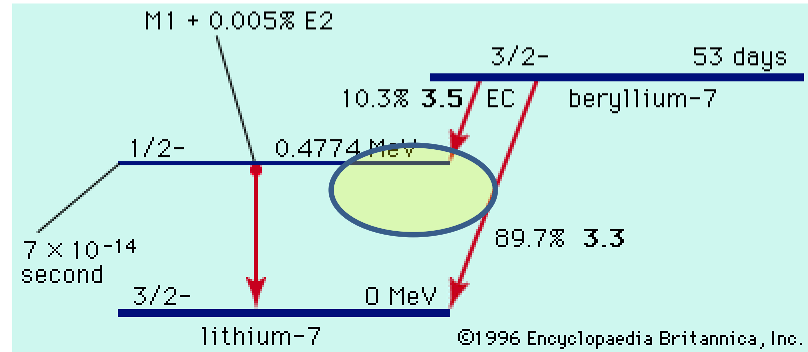


Figure 9. CAD and MCNP model Li Dump Tank

Methodology, computational model and source

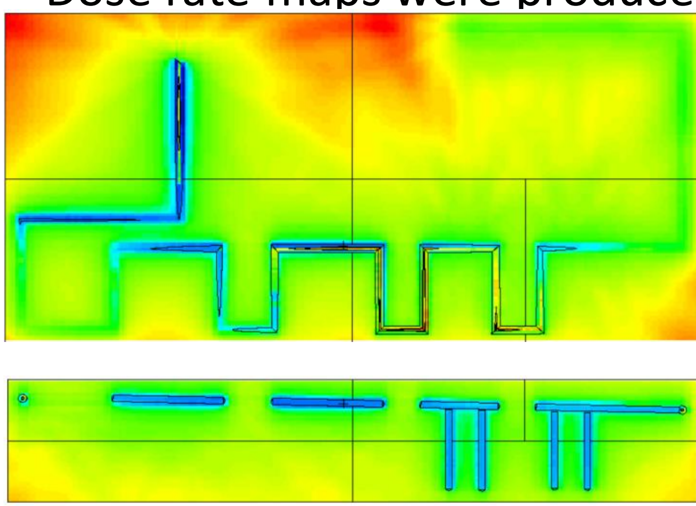
- Gamma radiation source in Li pipes loop from Be-7 – 0.4774 MeV and ACPs

	CL	LiHX	TotLi	Tot
55Fe	49.853475	38.808611	10.402984	99.065062
54Mn	0.000000	0.000000	10.271263	10.271263
51Cr	0.077783	0.060550	0.000804	0.139273
57Co	0.483109	0.376078	0.183213	1.042399
60Co	0.879025	0.684280	0.177950	1.741254



- Gamma transport calculations, dose rate and gamma flux were performed by means of particle transport code MCNP.

- Dose rate maps were produced using ADVANTG WW.



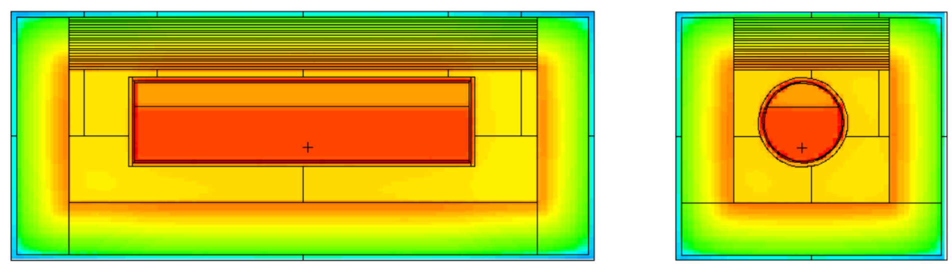
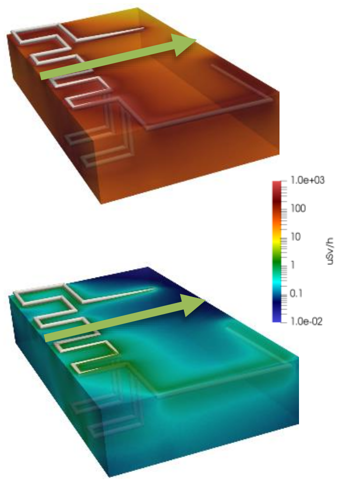
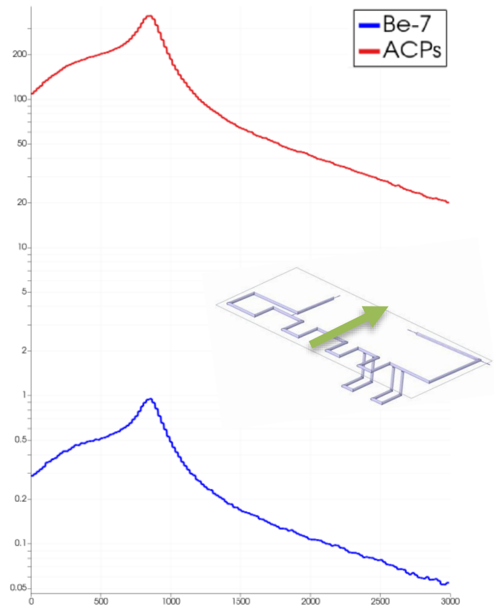


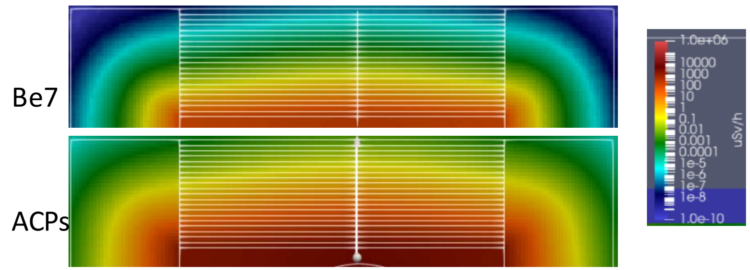
Figure 10. Weight windows generated with ADVANTG for Li Sampling Cell pipes and Dump Tank

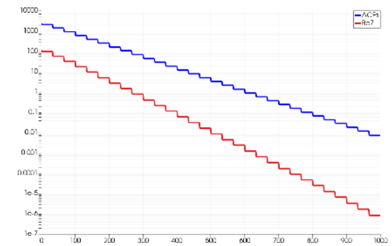
Results examples



Test run results 1e+9 nps
Statistics are sufficient

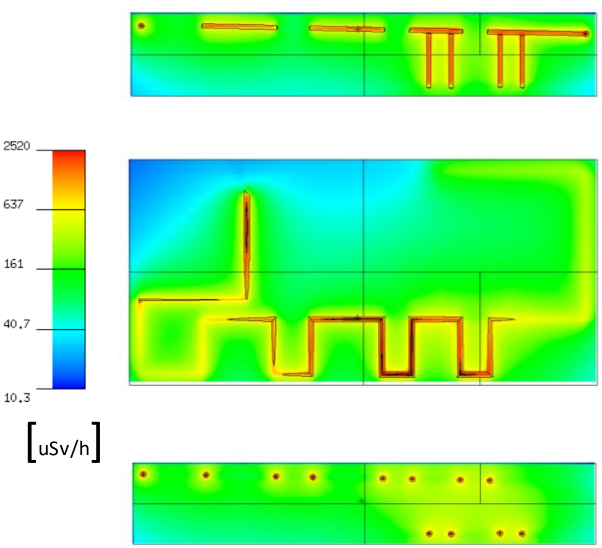


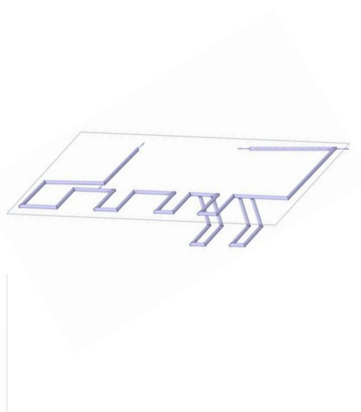


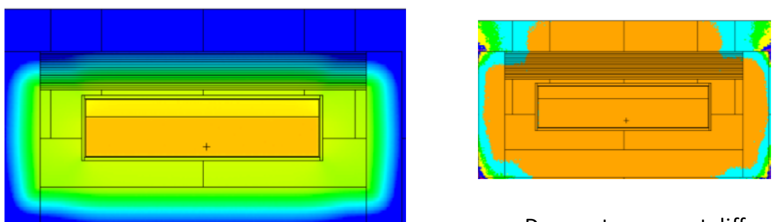


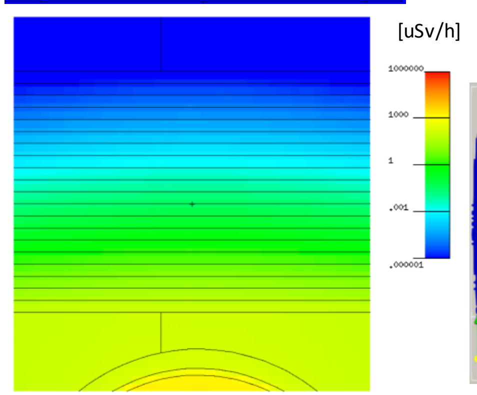
~3 microSv/h

20 cm of shielding fo Be7
50 cm of shielding for ACPs

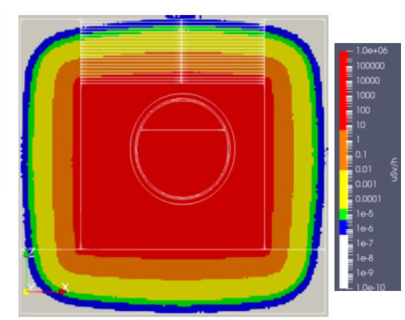








Dose rate maps at different
cross-sections for Be-7 case.



Articles for more information

- Breidokaitė S. , Stankūnas G. . Neutron Flux in EU DEMO Divertor Cassette Body Using HCPB and WCLL Breeding Blanket Models In: *Journal of Fusion Energy.* New York: Springer, 2022, Vol. 41, 41, p. 1-6. ISSN 0164-0313 , eISSN 1572-9591.
- Breidokaitė S. , Eade T., Berry T., Stankūnas G. , Tidikas A. . Activation analysis and evaluation of the radionuclide inventories, decay heat for European DEMO divertor components In: *Applied Radiation and Isotopes* . Oxford: Elsevier, 2022, Vol. 187, 110314, p. 729-741. Scopus . ISSN 0969-8043, eISSN 1872-9800.
- Breidokaitė S. , Stankūnas G. . Activities in Divertor Reflector and Linear Plates Using WCLL and HCPB Breeding Blanket Concepts In: *Energies.* Basel: MDPI, 2021, Vol. 14, 8305, p. 1-16. ISSN 1996-1073.
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- Tidikas A. , Stankūnas G. . Activation analysis of the European DEMO divertor with respect to the different breeding blanket segmentation In: *Fusion Engineering and Design* . Lausanne: Elsevier, 2020, Vol. 161, 112012, p. 1-6. ISSN 0920-3796, eISSN 1873-7196.

- Stankūnas G., Tidikas A.. Application of ADVANTG Code for the SDDR Calculations on IFMIF-DONES Target Assembly and HFTM In: *IEEE TRANSACTIONS ON NUCLEAR SCIENCE.* Piscataway: IEEE, 2022, Vol. 69, No. 6, p. 1225-1228. ISSN 0018-9499.
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Thank you for your attention