Tritium Production in Activated IFMIF-DONES HFTM

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INTRODUCTION

International fusion materials irradiation facility - DEMO oriented neutron source (IFMIF-DONES) is a planned facility dedicated for nuclear fusion relevant material qualification. Facility employs deuteron beam and lithium target based accelerator for high energy neutron production. Neutron energies correspond to the energy of neutrons produced via deuterium tritium fusion reaction. Irradiated samples will provide better understanding of material activation and degradation under nuclear fusion reactor conditions. **High flux test module (HFTM)** is a structure where specimen stacks with sample capsules are located. During IFMIF-DONES operation the specimen stacks will be irradiated by neutrons resulting in strong activation, more so supporting structures will be affected as well. Activation assessment of HFTM helps to ensure the safe operation and decommissioning of IFMIF-DONES, as heat and ionizing radiation produced from activation products impacts the design limitations, handling and waste management of the irradiated structures.

MAIN OBJECTIVE OF THIS WORK

Objective of this work is to estimate the tritium production and activation characteristics for IFMIF-DONES high flux test module expected after 345 days of operation.

METHODOLOGY AND MODEL DESCRIPTIONS

Model of High Flux Test Module

HFTM is a complex structure designed to withstand the high neutron and heat fluxes. For the analysis HFTM were divided into two component groups: i) container and support structures, ii) Specimen structures. Later comprises the components that are more or less directly exposed to the neutron beam. It includes specimen stacks with sample capsules. Container and support group consists of container, attachment adapter, helium feed pipes, lower attachment adapter, support trusses, upper attachment adapter. All container and support structure parts are made of 316L(N) stainless steel. As for specimen stacks, it consists of closer, grid, capsule sleeve. All these parts are made from EUROFER steel. There is also natural sodium filling for heat conduction. Dummy samples (also referred as specimens) are made from EUROFER (75%) and sodium (25%) composite. Specimen Bin is made from EUROFER, AISI 321, MgO, NiCr 80/20, and INNOBRAZE ML 442 alloy with respective percentage shares of 73.26, 10.76, 8.04, 2.3 and 5.64 %. Top reflector is made of 316L(N) stainless steel.

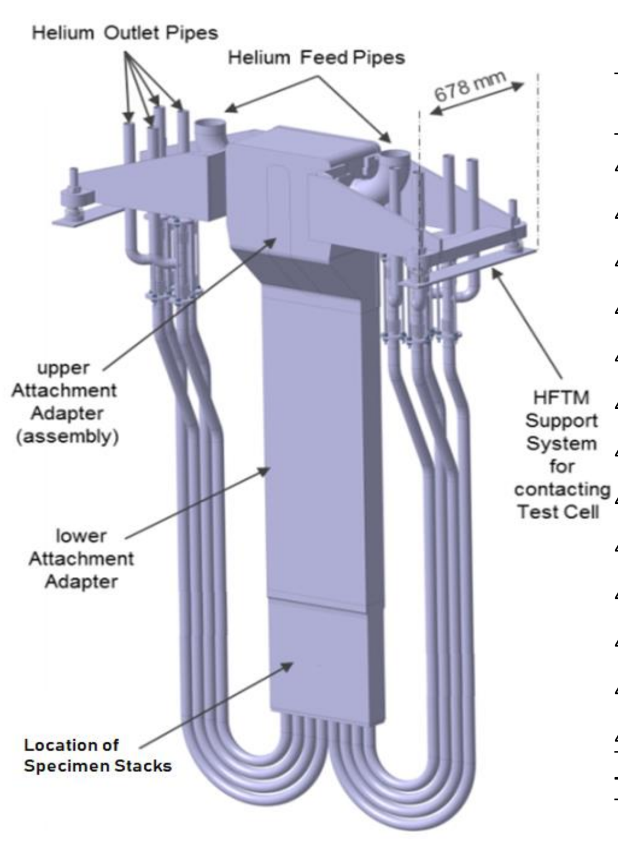

***Fig 1.** MCNP model of IFMIS-DONES HFTM*

Table 1. *HFTM model description*

PBS index	Segment	Number of Cells	Volume, cc	Mass, kg	Material
4.3.1.	**Container**	795	5769.54	45.75	SS316LN(N)
4.3.1.	**Top Reflector**	192	4436.68	35.18	SS316LN(N)
4.3.2.	**Lower Attachment Adapter**	58	13623.28	108.03	SS316LN(N)
4.3.2.	**Upper Attachment Adapter**	147	11936.48	94.66	SS316LN(N)
4.3.3.	**Attachment Adapter Pipe**	6	769.44	6.10	SS316LN(N)
4.3.4.	**Container Pipe**	386	13009.99	103.17	SS316LN(N)
4.3.5.	**Support Trusses**	190	19281.19	152.90	SS316LN(N)
4.3.6.	**Closer**	224	32.05	0.25	EUROFER
4.3.6.	**Capsule Sleeve**	256	314.85	7.93	EUROFER
4.3.6.	**Gas Grid**	32	20.15	0.16	EUROFER
4.3.6.	**Na Filling**	384	110.82	0.10	Sodium
4.3.6.	**Specimen Bin**	1248	1008.05	2.38	EUROFER+other alloys
4.3.6.	**Specimen**	33	1689.98	10.35	EUROFER+Sodium
Total		**3951**	**72002.49**	**566.98**	

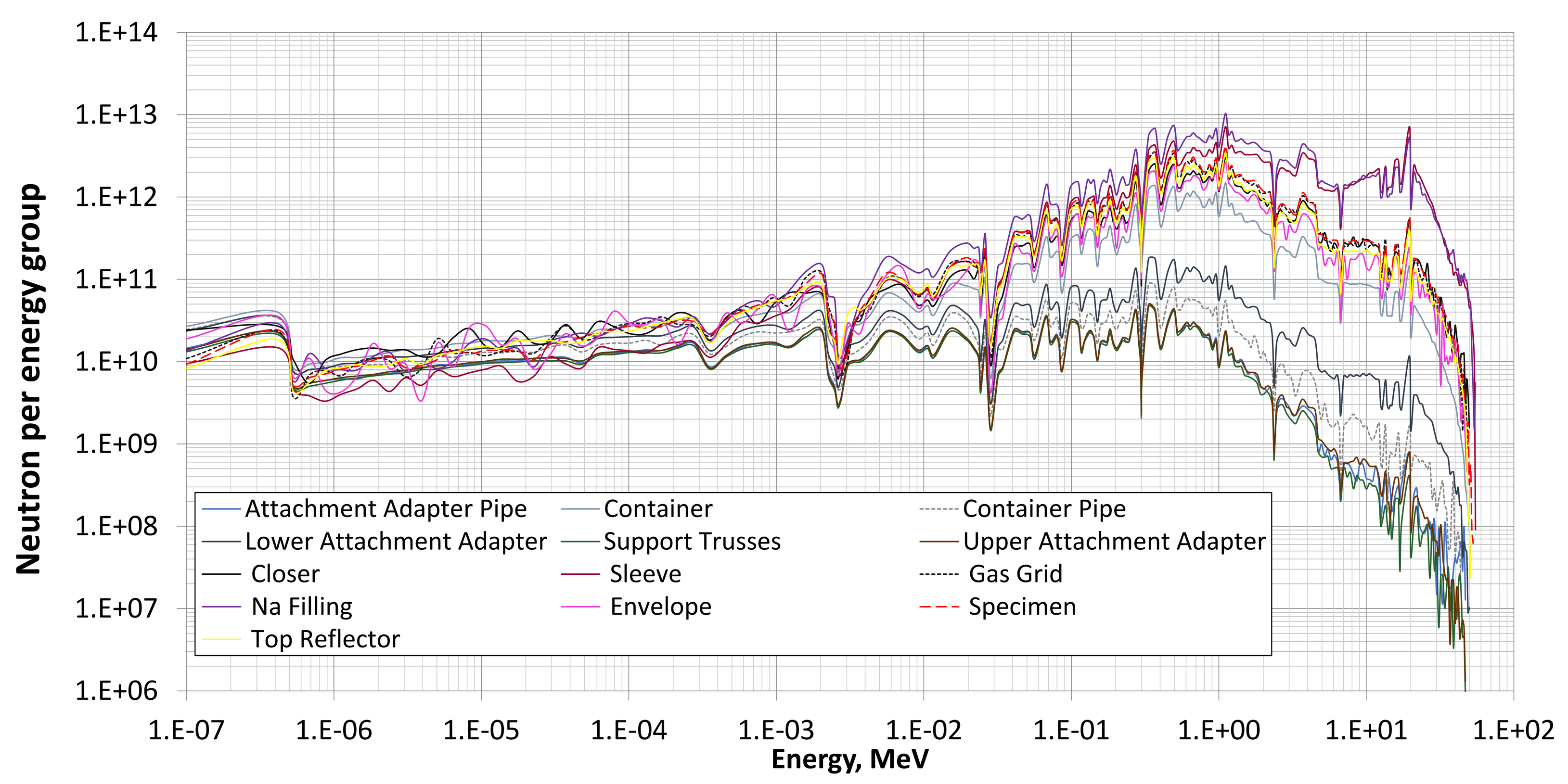

***Fig 2.** Averaged neutron spectra for HFTM segments.*

Computational methods and operation scenario

Neutron fluxes and energy distributions were calculated for group of cells representing certain components of HFTM. Complete calculation was performed by means of **MCNP6+McDeliciuous-17** with **The Joint Evaluated Fission and Fusion Nuclear Data Library (JEFF-3.3**) nuclear data library. The statistical error of Monte Carlo calculation was less than 10% with 1e+08 particles histories for energy groups ranging from 1 KeV to 55 MeV. The error for lower energy groups was higher and might require additional assessment.

Activation and transmutation calculations were performed with **FISPACT-II** inventory code. Average normalized neutron spectra for structural components were used in **FISPACT-II** calculations. **EAF-2010** nuclear data library was used for reactions and reaction cross-sections together with **GEFY 6.1** decay and fission yield data. Continuous operation scenario was considered lasting for 345 day.

CALCULATION RESULTS AND ANALYSES

In HFTM, atoms of sodium are much more likely to be displaced (partly due to higher neutron flux at its localization and partly due to lower lattice displacement energies) compared to structural steels with annual DPA equal to ~15. Sodium also exhibits highest specific decay heat, activity and contact dose rates, while among investigated steels most active material after the end of irradiation is EUROFER-73 at the sleeve localization. In most cases heat is mainly produced by gamma radiation (from 60 % to 95%) with remaining fraction belonging to beta particles. This is valid for shutdown period up to 10 years as later beta particles from tritium decay are the main contributors to the decay heat. There is also exception for sodium where beta particles from F 20 decay process constitute up to 62% of total decay heat within first few seconds at the end of irradiation.

At the end of the irradiation tritium contributes up to ~0.04% to the total value of activity with a tendency for fraction to increase with longer shutdown periods. The highest total activity and tritium inventory in container structure belongs to container component followed by lower attachment adapter and container pipes. As for specimen stack, the highest total activity and tritium inventory belongs to specimen sleeve.

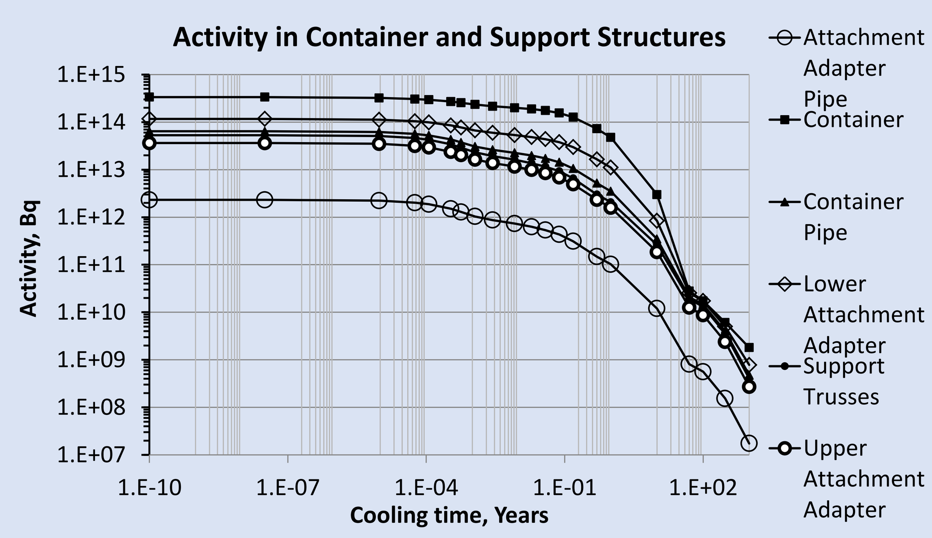

***Fig 3.** Total activity in container and support structures*

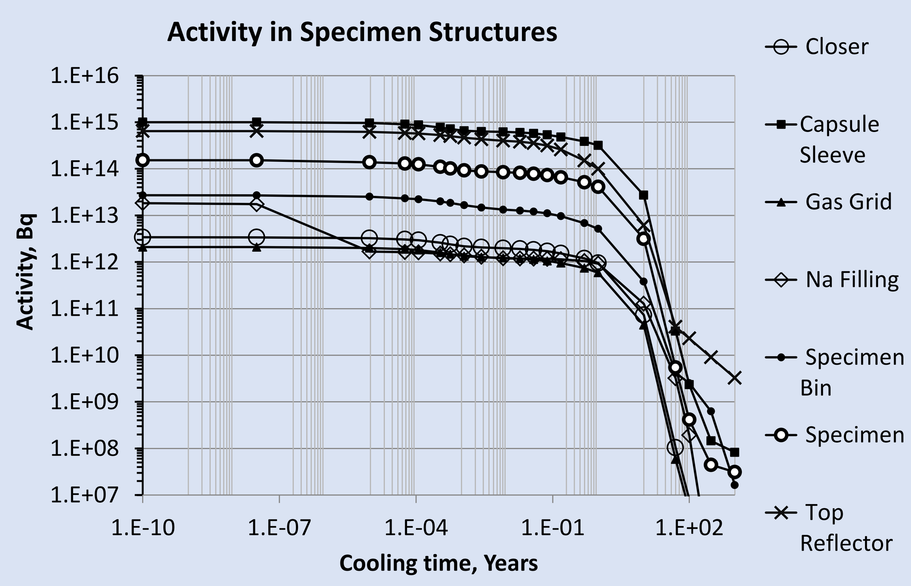

***Fig 4.** Total activity in specimen structures*

Table 2. HFTM decay heat after 1 hour of cooling.

Segment	Total Decay heat (W)	(%)	Beta (W)	(%)	Gamma (W)	(%)
Attachment Adapter Pipe	3.89E-01	0.14	1.20E-01	0.18	2.69E-01	0.12
Container	3.71E+01	13.02	7.07E+00	10.33	3.01E+01	13.86
Container Pipe	1.04E+01	3.65	3.10E+00	4.53	7.31E+00	3.37
Lower Attachment Adapter	1.62E+01	5.68	4.27E+00	6.23	1.19E+01	5.50
Support Trusses	9.00E+00	3.15	2.80E+00	4.09	6.20E+00	2.86
Upper Attachment Adapter	6.06E+00	2.13	1.86E+00	2.72	4.20E+00	1.94
Closer	4.39E-01	0.15	1.18E-01	0.17	3.21E-01	0.15
Capsule Sleeve	1.14E+02	40.08	3.13E+01	45.77	8.30E+01	38.28
Gas Grid	2.74E-01	0.10	7.31E-02	0.11	2.01E-01	0.09
Na Filling	6.77E-01	0.24	6.59E-02	0.10	6.11E-01	0.28
Specimen Bin	3.25E+00	1.14	7.47E-01	1.09	2.51E+00	1.16
Specimen	1.92E+01	6.73	5.03E+00	7.35	1.42E+01	6.54
Top Reflector	6.79E+01	23.80	1.19E+01	17.34	5.60E+01	25.84
Total	2.85E+02		6.85E+01		2.17E+02	

IFMIF-DONES HFTM Activation

- **Total Activity** **2,46 PBq**
- **Activity of Tritium** **0,9 TBq**
- **Major Radionuclides** **Mn 56 – 0.6 PBq** **Fe 55 - 0.5 PBq** **Cr 51 - 0.34 PBq**

**after the end of irradiation*

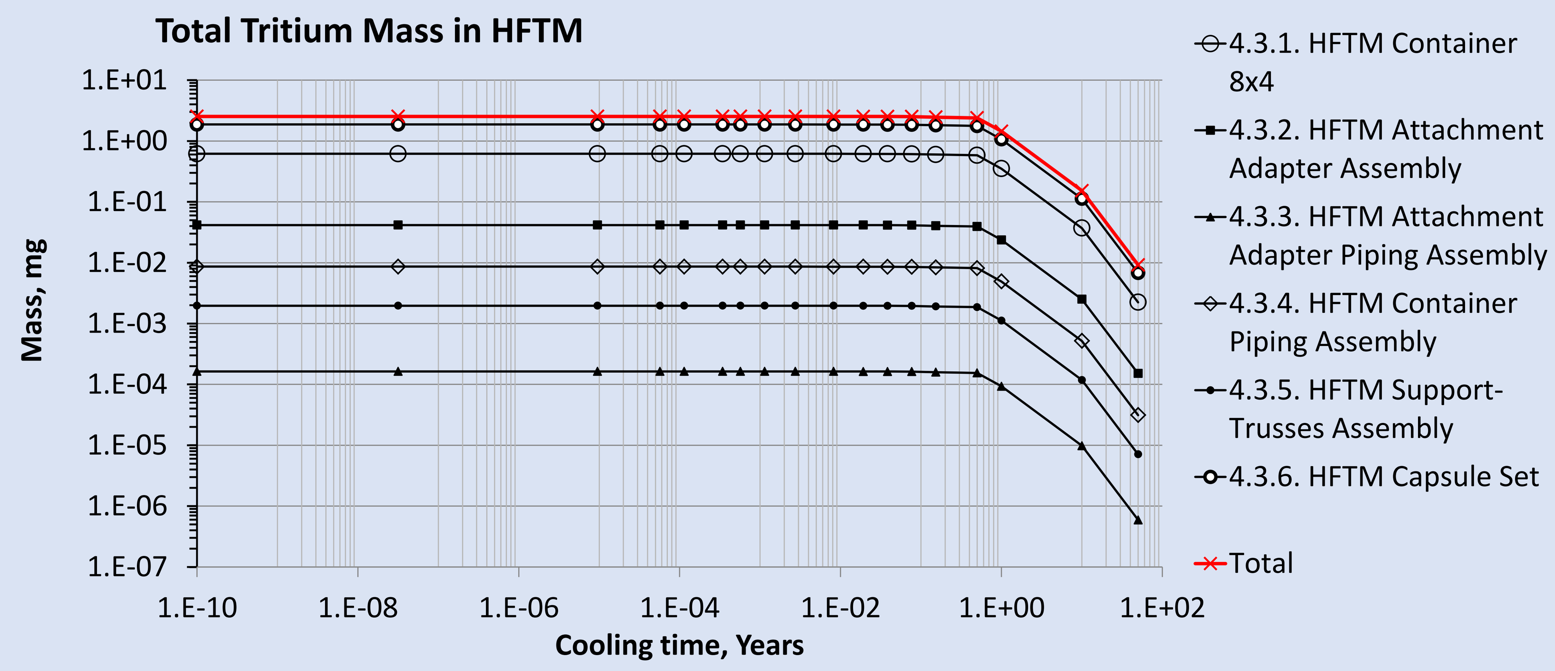

***Fig 5.** Total tritium mass in HFTM*

Tritium production

IFMIF-DONES HFTM was analyzed in terms of material activation after preceding 345 days lasting neutron irradiation.

- **In sodium, tritium is mainly produced from Na 23 (n,t) reaction, while in the investigated steels Fe 56 (n,Xt) reactions are the most common.**
- **Tritium inside the HFTM is being produced in all investigated materials in relatively low amounts (up to 1E-07 appm/sec).**
- **After one year of operation ~2.5 mg of tritium is being produced in whole HFTM structure.**

ACKNOWLEDGEMENT

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