

Assessment of the Be-7 radiation dose in the IFMIF-DONES lithium loop

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Introduction

- IFMIF-DONES, is an accelerator based neutron irradiation facility which aims at providing the irradiation data for the construction of a DEMO fusion power plant. It is a deuterium-lithium (d-Li) neutron source driven by a deuteron accelerator (40 MeV and 125 mA) striking at the liquid Li target, and produces neutrons through stripping reactions.
- The radioactive isotope Be-7 is produced in the d-Li reaction. The deposition of Be-7 in the Li pipes, lead to high gamma doses, and raises a safety concern during maintenance. Therefore, a reliable assessment of the Be-7 dose in the Li loop is required.

Be-7 inventory

- Half-life 53.1 days; gamma energy 477 keV; Main pathways Li-6 (d, n) Be-7, Li-7 (d,2n) Be-7
- The Be-7 production rate is estimated in [1], which is 0.75 g/year calculated for IFMIF-DONES. the Be-7 inventory (production + decay) at 1 fpy (full power year, 345 days for IFMIF-DONES) is about 0.15 g.
- Recent re-evaluation [2] of the Be-7 production cross-section shows that the nuclear data in [1] provides reasonable estimation over other libraries, e.g. TENDL2017, FENDL3.1d, etc.

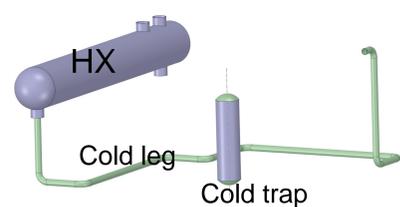
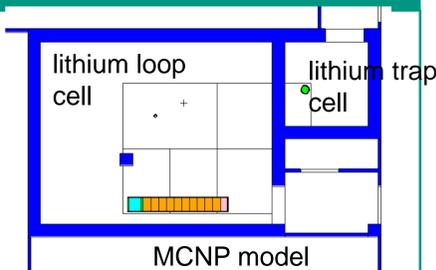
time	Be-7 activity
1 h	99.95%
10 h	99.46%
1 day	98.71%
2 days	97.43%
4 days	94.93%
10 days	87.79%
20 days	77.07%

[1] Simakov, S. P., Fischer, U., & Von Möllendorff, U. (2004). Assessment of the 3 H and 7 Be generation in the IFMIF lithium loop. *Journal of Nuclear Materials*, 329, 213–217.

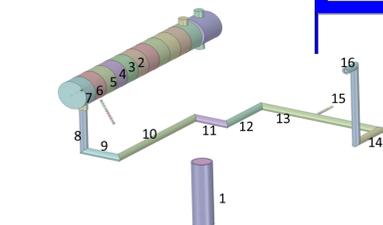
[2] Simakov, S., Fischer, U., & Konobeyev, A. (2020). Status and benchmarking of the deuteron induced Tritium and Beryllium-7 production cross sections in Lithium. <https://doi.org/10.5445/IR/1000120615>

Geometry and source modeling

- The lithium loop model was simplified by considering only the heat exchanger (HX), cold leg and cold trap, where the Be-7 is deposited.
- Model converted using McCad, then integrated in to the main building model
- Source regions are subdivided into 16 segments associated with the Be-7 activities on each segment, calculated Be-7 deposition analyses.



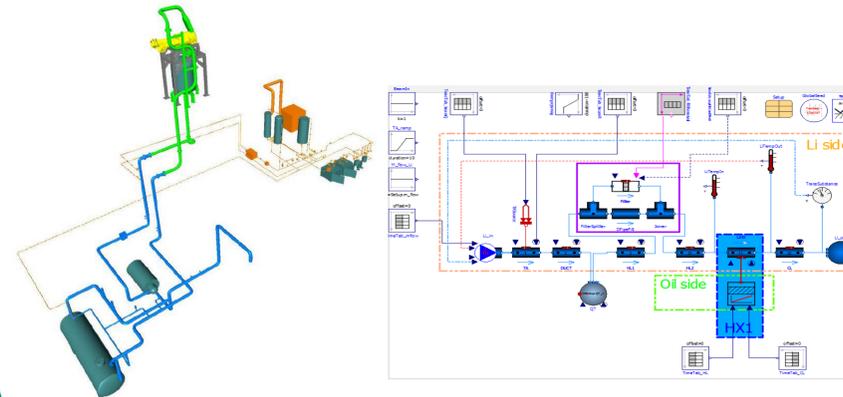
Neutron CAD model of the lithium loop



Source region of the lithium loop (16 segments)

Be-7 deposition simulation

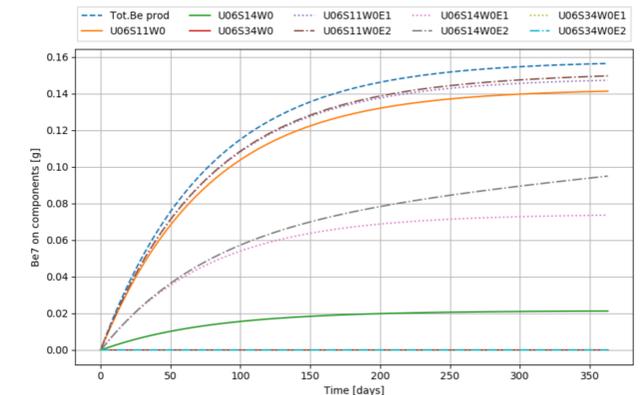
- Simulation with openModelica with Be-7 production rate of 0.75g/fpy, the mass transfer simulations have been performed with a parametric studies
 - 4x Cold leg temperature: 250, 275, 290, 300 °C
 - 3x ICS mass flow: 0.5%, 1.0%, 1.5%
 - 4x Cold leg mass transfer coefficients (MTC): 3.2E-4, 3.6E-4, 3.8E-4, 4.0E-4
 - 4x Trap efficiency: 100%, 60%, 40%, 0%
- The effect of the increased loop temperature (tested on 250, 275,290 and 300 degC) is significant, a theoretical total removal can be achieved, with some increased mass flow over ICS (eg. 1%).



DONES Lithium loop

Simulation model of lithium loop in openModelica

Naming convention
U06S11W0E1 — Optional Filter study: without - trap eff.1 - 100%, 2 - constant 60%, 3 - start on 60% and linearly decreases to 40% over the irradiation period, 4- 0%
Nitrogen content: 1 - 10wppm, 2 - 30 wppm
Cold leg temperature [degC]: 1 - 250, 2 - 275, 3 - 290, 4 - 300
Mass flow ratio of ICS: 1 - 0.5%, 2 - 1%, 3 - 1.5%
Model ID

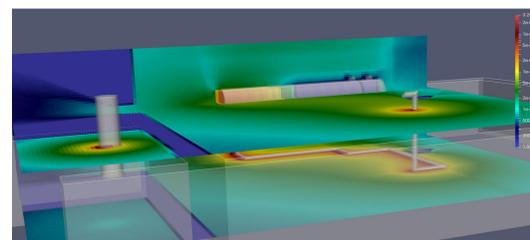


Simulation results of Be-7 deposition in the primary loop during operation

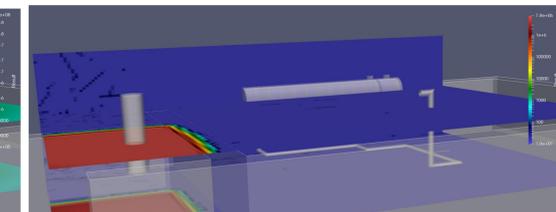
Gamma dose simulation

- Simulations of all the cases were done using batch run of MCNP6 code with photon library mcplib04. Results are tallied with mesh tallies and sphere tallies, and converted to the effective dose ($\mu\text{Sv/h}$).
- The dose map of three typical cases are shown, which the cases U06S11W1F1 as reference parameter, U06S14W1F2 with 300 °C cold leg temperature, and U06S14W1F4 with 0% cold trap efficiency.
- Without removing the Be-7 to the cold trap, the dose level in the lithium loop cell will reach several Sv/h. Therefore, 300 °C is considered a good operation temperature for the cold leg.

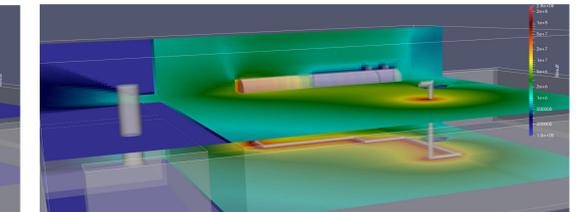
	Cold Leg Temp.	Hot Leg Temp.	ICS mass flow [%]	MTC CL	MTC HX	Trap eff. [%]
U06S11W1E2	250	274	0.5	0.000328	8.29E-06	60
U06S14W1E3	300	324	1	0.000323781	300	40
U06S14W1E4	300	324	1	0.000396	9.12E-06	0



U06S11W1F2: HX1: 18.2% deposition, Cold leg: 74.0%, Cold trap: 7.7%



U06S14W1F3: Cold trap: 100%



U06S14W1F4: HX1: 6.1% deposition, Cold leg: 93.9%, Cold trap: 0%

Gamma dose ($\mu\text{Sv/h}$) at 345 days operation, 0 second after shutdown

Summary

- The Be-7 deposition and radiation dose has been assessed through multi-physics simulations, including Be-7 mass transfer simulation and gamma transport simulation. A parametric study has been done with in total 192 cases.
- The Be-7 results very strong radiation in the lithium loop cell. With 300 °C operation temperature, Be-7 can be confined in the lithium trap cell. The HX and cold leg need additional shielding in case of cold trap is not in duty.