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Neutronics assessment of different quench tank location options in IFMIF-DONES

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The quench tank (QT) location in the test cell is an open issue for IFMIF-DONES (International Fusion Material Irradiation Facility- DEMO Oriented NEutron Source) design. Neutronics assessments have been carried out on two QT location options. A parametric study shows that the neutron streaming has a quasi-linear function of the void thickness in the lithium chute. Activation calculations at key locations of QT system indicate that the contact dose rate is higher than the hands-on dose limit in the whole maintenance period. In addition, shutdown dose in the LFR partially exceeds 100 μSv/hr after 1-day shutdown. Therefore, hands-on maintenances are not allowed for the QT maintenance in both QT location options.

Keywords: IFMIF, DONES, MCNP, Quench Tank, shutdown dose, hands-on maintenance

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1. Introduction

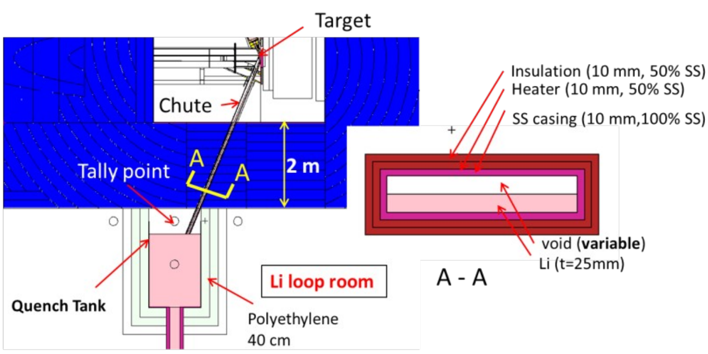
IFMIF-DONES (International Fusion Material Irradiation Facility- DEMO Oriented NEutron Source) [1, 2] is an IFMIF-based plant with a simplified design in order to reduce the time scale and budget of IFMIF. It consists of only one of the accelerator (40 MeV and 125 mA) in IFMIF design, and irradiates only the High Flux Test Module (HFTM). The main design, however, is inherited from the so-call IFMIF Engineering Validation and Engineering Design Activities (EVEDA) phase [1].

Quench Tank (QT) is a container for buffering the high-speed lithium flow from the Target Assembly (TA). The location of the QT is an open issue in IFMIF/EVEDA and has been assessed in [3]. At this design point, the QT is located below the TC floor connected to TA with a 3.5 m long channel (chute). Neutron from the target streaming through the void space of the chute is the main issue for the QT due to the neutron activation. In addition, this long chute is not preferable in several aspects, thus a new design is recently proposed to embed the QT in the TC floor [4]. As a goal, hands-on maintenance in lithium facility room (LFR) should be achievable after shutdown of the facility for a certain time, e.g. 1 day. In this work, neutronics analyses have been conducted for assessing these two QT location options.

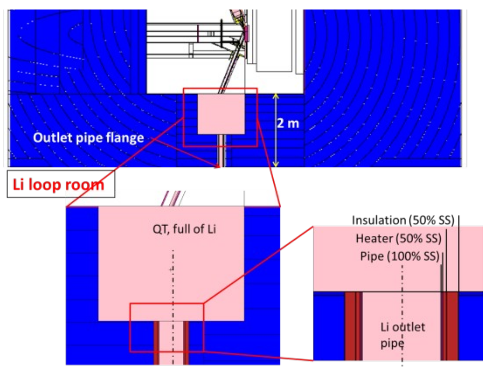
2. Computation methodology

The McDeLicious-11 code [5], which is an extension of the MCNP5-1.6 Monte Carlo code with the capability to simulate the deuterium-lithium neutron source, was employed in the particle transport calculation of IFMIF-DONES. Neutron cross-section library FENDL-3, Starter Library, Release 4 (FENDL-3/SLIB4) [6] was adopted. Activation calculations were performed with the inventory code FISPACT-2007 [7] together with the activation cross-section library EAF-2007 [8]. The shutdown dose rate calculations were performed using the rigorous 2-step method. This method combines the particle transport and inventory calculation in a sequence that first the beam-on neutron flux is calculated using the McDeLicious-11 code, and then transferred to the FISPACT code for the beam-off decay gamma source calculation, at the end the source is used for gamma transport calculations using the MCNP code. This complicated calculation process was achieved using the R2Smesh-2.1 [9] code system developed at KIT.

The neutronics model is based on the IFMIF/EVEDA reference TC model called “mdl69” [10], updating it to adapt to the design of IFMIF-DONES. In this model, the medium flux test module and low flux test module behind the HFTM in the beam direction are removed. One beam is switch off, while the beam-duct is remained. The neutronics models are shown in Fig. 1, respectively for two QT location options. In Option-1, the QT has inner diameter of 1.2 m, height of 1.7 m and lithium height 1.2 m, and is placed in the LFR below the TC floor. The QT is made of stainless steel (SS), and is surrounded by 0.4 m of polyethylene as the neutron shielding material. The chute has a rectangular cross-section. The thickness of lithium and void space inside the chute is respectively 25 mm. Because the streaming neutron significantly elevates the activation of the QT, effort has been devoted to evaluate the feasibility of reducing this void thickness in fluid dynamics studies [4]. In this work, a parametric study has been carried out to evaluate the decrease of neutron flux by reducing this void thickness void thickness from 25 mm to 10 mm with an interval of 5 mm. In the following texts these cases are briefed as Case-25 to Case-10. In Option-2, the QT is embedded in the TC floor as shown in Fig. 1(b). Because the QT activation Option-2 is not concerned in this analysis, only the lithium inside the QT is modeled for representing the QT, while the QT structure is not taken into account.



(a) QT located in the LFR below the TC floor (Option-1)



(b) QT embedded in TC floor (Option-2)

Fig. 1. MCNP geometry of IFMIF-DONES TC with different QT locations.

The MCNP mesh tally was used to obtain the neutron and gamma flux and dose during operation and shutdown. The beam-on neutron flux was calculated at the lower TC with a resolution of 10 × 20 × 10 cm^3 in X, Y, Z coordinates respectively. For calculating the beam-on neutron flux for shutdown dose calculation, a fine mesh tally with a resolution of 2 × 2 × 2 cm^3 was used to obtain the integral flux, and a coarse mesh with a resolution of 4 × 20 × 20 cm^3 was used for achieving good statistics of spatial-dependent neutron spectra. The flux spectra are calculated in the VITAMIN-J+ group structure (211 groups), which covering neutron energy from thermal to 55 MeV.

3. Results and discussions

3.1 Parametric study of the void thickness

Neutron flux has been calculated in the Option-1 with different void-thickness in the chute, as shown in Fig. 2. Among these cases, the Case-25 is considered as the reference case, the Case-10 has the minimum allowable void thickness from lithium flow point of view, and Case-15 is a conservative case taking other possible void space in the chute into account. The neutron streaming along the chute can be clearly observed from Fig.2. It results in a strong flux gradient around the chute and a high flux level inside the QT. It seems that reducing the void-thickness has remarkable effect in reducing the neutron flux inside/around the QT. However, the flux remains above 10^7 n/cm^2/s in the QT of Case-15, which is still very high. Cell-based tally has been used to obtain the flux at a tally point shown in Fig.1(a) inside the QT, and a quasi-linear relation is found between the void thickness and neutron flux at this position, as shown in Fig. 3. Comparing with the Case-25, the flux at this point decreases ~50% in Case-15. Accordingly, the activation of the QT will be reduced also ~50% assuming no significant difference in the neutron flux spectrum. In the following calculation, Case-15 is used as representative case of Option-1 for activation and shutdown dose analysis.

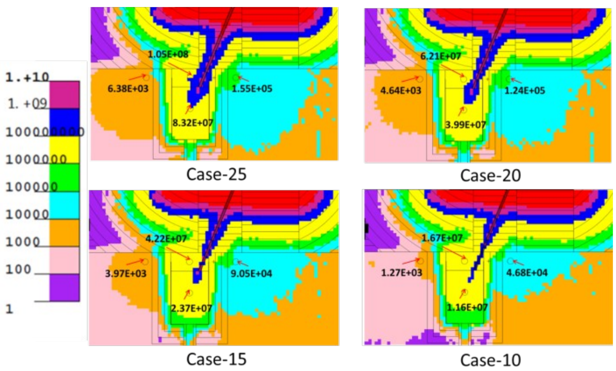


Fig. 2. Neutron flux (n/cm^2/s) (vertical cuts at the target center) with different void-thickness in the chute.

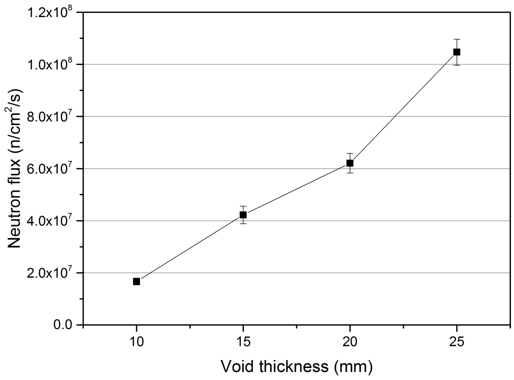


Fig. 3. Change of neutron flux at the tally point shown in Fig.1(a) along with void thickness of the chute.

3.2 Activation and shutdown dose analysis

IFMIF-DONES is scheduled with 20-days maintenances in 1-year operation period, and hands-on maintenances are planned in the LFR after 1-day shutdown. In Option-1, the chute has to be disconnected with the QT and token out from inside of the TC. Similarly for Option-2, the lithium outlet flange indicated in Fig.1(b) has to be disconnected from downstream pipes in order to take the QT out from the TC for maintenance. To evaluate the contact dose at these positions, activation calculations have been performed using the FISPACT code. The activation of QT in Option-1 has been calculated choosing the upper part which has stronger neutron flux. Stainless steel SS316L was used with 10 ppm, 500ppm, 1000ppm, and 100ppm of B, Co, Nb and Ta impurities, respectively. The evolution of contact dose rate at the QT in Option-1 is shown in Fig.4, choosing the Case-15 for study. A similar evaluation is carried out and shown in Fig.4 for the outlet flange in Option-2. After 345-days operation and 1-day cooling, the contact dose rate of QT in Option-1 is 348 µSv/hr, and that of flange in Option-2 is 1124 µSv/hr. The dose level decreases rather slow after 1-day of cooling. The nuclides contributing the major amount of dose are ^{56}Mn($T_{1/2}$=2.6 hours), ^{182}Ta($T_{1/2}$=114 days) and ^{60}Co($T_{1/2}$=5.27 years). Considering <10 µSv/hr as the criteria [11], the hands-on maintenance is not possible to be achieved within the maintenance period, i.e. 20 days.

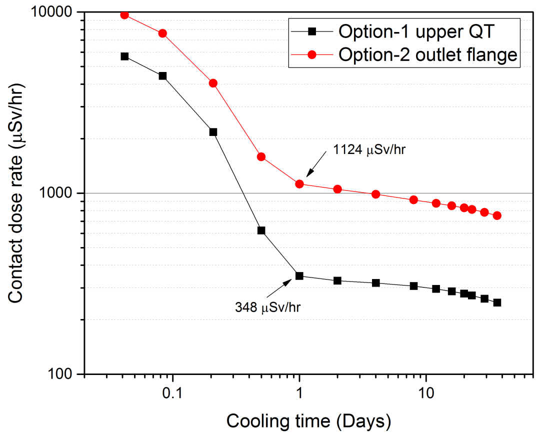


Fig. 4. Evolution of the contact dose rate at the concerned.

The dose rate after 1-day shutdown has been calculated for the two options to evaluate the dose in the LFR. The mesh for neutron flux tally covers the 0.5 m of the heavy concrete wall inside the TC where is highly activated. Also, additional meshes have covered the QT, the chute in Option-1, and the outlet pipe in Option-2. The calculated fluxes on meshes are used in the R2SMesh code for calculating the gamma source distribution. The highly activated in-TC components such as TA and HFTM are required to be removed from the TC to the access cell right above. In addition, lithium is required to be drained out from the QT and also the chute. For these purposes, these components and materials have been set as void in the material detection phase of the R2SMesh calculation process. Due to the huge number of points, the gamma source was separated into three parts. The dose rate results on the same mesh are summed up at the end after three gamma transport calculations using these gamma sources.

The dose rate in Option-1 is shown in Fig.5. The dose inside the QT is ~1000 μSv/hr, and outside the QT is above 100 μSv/hr. The activated components contributing major amount of dose in the LFR are the chute, the QT and also the concrete above the QT. The chute is highly activated and requires remote handling for access. The neutron shielding material polyethylene functions partially as gamma shielding, while the gamma shielding can be further improved by adding heavy material layer, e.g. lead, outside the QT. The dose rate in Option-2 is given in Fig.6. Due to large opening in the outlet pipe when lithium is drained, ~10^4 μSv/hr of dose below the pipe is typically strong. Additional shielding blocks can be placed below the outlet pipe in order to reduce the dose in the LFR, while remote handling is still required for opening the outlet pipe flange. To sum up, it is concluded that hands-on maintenances are not allowed in the LFR after 1-day shutdown, and remote handling is require for accessing the two important locations in the QT maintenance procedure.

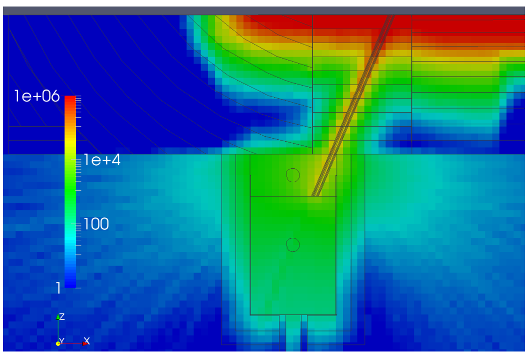


Fig. 5. shutdown dose rate (μSv/hr) for Option-1 at the lower TC after 1-day shutdown.

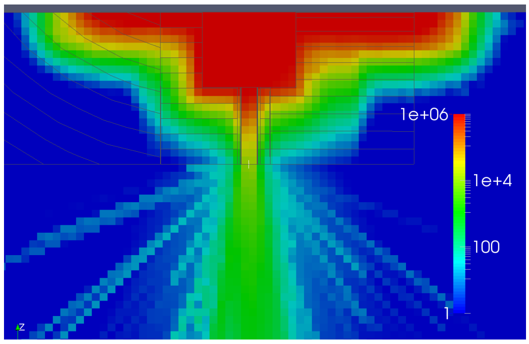


Fig. 6. shutdown dose rate (μSv/hr) for Option-2 at the lower TC.

4. Conclusions and discussions

A neutronics assessment has been carried to evaluate two QT location options in the IFMIF-DONES TC design. For Option-1, a parametric study shows that the neutron streaming has a quasi-linear function of the void thickness in the lithium chute. Activation calculations at key locations of QT system indicate that the contact dose rate is higher than the hands-on dose limit in the whole maintenance period. In addition, shutdown dose in the LFR partially exceeds 100 μSv/hr after 1-day shutdown. Therefore, hands-on maintenances are not allowed for the LFR, and remote handling is required for the QT maintenance.

There is some possible means to reduce the doses by introducing additional shielding to both options. However, a suitable design scheme has to be worked out in the future for reducing the neutron streaming in straight pipe/chute. In this way the hands-on maintenance in LFR can be realistically achieved.

Acknowledgments

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