RADIOLOGICAL SAFETY ASSESSMENTS FOR FUSION NEUTRON SOURCE IN ENGINEERING DESIGN ACTIVITIES UNDER IFMIF/EVEDA PROJECT

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International Fusion Materials Irradiation Facility (IFMIF)-like fusion neutron source (FNS) produces fusion-like neutrons by injecting 125 mA/40 MeV deuteron beam into a liquid lithium target in order to elucidate fusion neutron irradiation effects on DEMO reactor materials. Under the IFMIF/Engineering Validation and Engineering Design Activities (EVEDA) project, the present study identified released amounts of tritium (T) and beryllium-7 (Be-7) from a FNS facility under steady-state operation/accidental cases and assessed public doses due to the released nuclides.

1. INTRODUCTION

EU and JA are conducting the design activities for their own IFMIF-like FNSs, namely IFMIF/DONES and A-FNS, respectively, based on the achievements of the IFMIF/EVEDA project. The project is being performed as international collaboration between EU and Japan in the Broader Approach (BA) Agreement in order to develop common technologies for IFMIF-like FNSs. The project includes development of prototype accelerator LIPAc, engineering design activities for FNS, and R&D activities for Lithium Target Facility. The engineering design activity performed by JA, started in 2020, is divided into five tasks: (1) T migration estimation, (2) erosion/deposition modelling in the lithium loops, (3) accident analysis in safety, (4) study on the optimization of the Li-Oil heat exchanger, and (5) use of LIPAc as testing facility. The tasks（1)–(4) are to be completed in Mar. 2025 and only the last one continues until Jan. 2028. Since radionuclides are inevitably produced in an FNS facility, one of the crucial issues in the engineering design activities is the implementation of radiological safety measures. This paper presents the results of tasks (1)–(3) that aim to evaluate the production (Section 2) and migration (Section 2 and 3) amounts of the radioactive products and impacts on the worker (Section 2) and public (Section 4).

2. ACTIVATION CALCULATION AND TRANSFER MODELLING IN THE LIQUID LI LOOP

Various radio nuclides are produced in the liquid Li loop by reactions of deuterons and neutrons with Li, impurities in Li, and structural materials of the loop. Although the major radionuclides, T and Be-7, which are mainly produced by D-Li reaction, are evaluated so far, other nuclides have not been studied extensively due to lack of experimental knowledge. Initially, we calculated produced amounts of nuclides with the inventory code FISPACT-II [1] with the impurity concentrations in Li measured with the Li samples obtained from the EVEDA Li test loop (ELTL) after the 3850-h validation operation. Then, in order to obtain deposition amounts of the nuclides on Li loop components, we constructed a transfer model of the radioactive products through the loop. It should be noted T migration was extensively investigated in the next section. This model identified the dominant nuclides and their radioactivity in each Li-loop component for the first time. In addition, effective doses due to deposited nuclides were assessed as one of the A-FNS engineering design activities. This revealed feasibilities of hands-on maintenance for the components such as heat exchanger (HX) and electromagnetic pump, contributing to developing maintenance strategies of these components [2].

3. TRITIUM MIGRATION ESTIMATION

Quantitative evaluation of radioactive material migrations in a facility is essential especially for T as movable one. T migration amounts from the loop to other systems were calculated with considering permeations through structural materials, precipitations, evaporations, and so on [3]. This calculation indicates that most T trapped in cold trap (CT) or hydrogen trap (HT) while others migrate outside the loop under steady-state operation. Furthermore, the release amounts from the facility through a stack were calculated with an updated T migration model (Fig. 1). These calculations found that the water vapor removal ratios of 1%, which was defined in the previous IFMIF design, was insufficient to reduce the T risk. In addition, T release amounts when air in-leakage into the loop, Li leakage out of the loop, and failures of Detritiation System (DS) were estimated as incidental/accidental scenarios. These results can be utilized as design requirements for DS, as well as are essential input data in assessments for the public impact described in the following section.

4. ASSESSMENT FOR THE PUBLIC DOSES

For assessing radiological impacts on the public when nuclides are released from an FNS facility, an atmospheric dispersion calculation code was newly developed [4]. This code calculates advection/diffusion of nuclides such as T (HT and HTO) and Be-7 with Gaussian Puff model. In this study, the developed code was evaluated by benchmarking with the existing codes under various meteorological conditions. In order to elucidate the public impacts when releases of T or Be-7 under steady-state and accidental cases, accidental scenario was postulated in addition to the scenarios described in the above. Since most T is trapped in CT or HT whereas Be-7 in CT and HX, releases of these trapped T and Be-7 are the highest source term emission, although those accidents are basically prevented and mitigated with multiple defence layers. For example, released T and Be-7 from components (first boundaries) due to initiating events such as Li fire are treated by DS and aerosol filtering system (AFS), respectively. In the present activity, Li fire events with and without working DS and AFS were calculated under most severe meteorological conditions selected for each of T and Be-7. Under the steady-state operation, the public doses are less than the criteria in normal operation defined in the previous IFMIF design (10 μSv). The effective doses in case of accidents at HX, CT, or HT while DS and AFS are in operation are less than the public dose limit defined by ICRP60 (1 mSv), as shown in Fig. 2. The maximum effective dose due to T appears around 400 m from the release point since it diffuses from the release heigh of 10 m to the ground. On the other hand, deposited Be-7 on the ground due to precipitation contributes to the effective doses as gamma source, which causes maximum peak near the release point. The effective doses in case of accidents at HX, CT, or HT without DS and AFS are beyond the public dose limit. These results indicate the potential radiological risks in the FNS facility can be reasonably reduced by preventing multiple failures, although their probabilities and mitigation measures have to be further investigated.

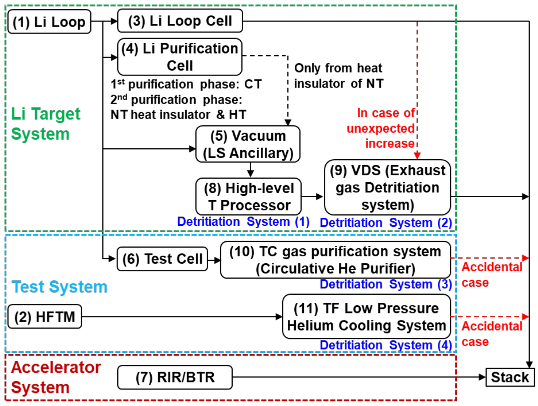

Figure 1 T migration model in IFMIF-like FNS facility.

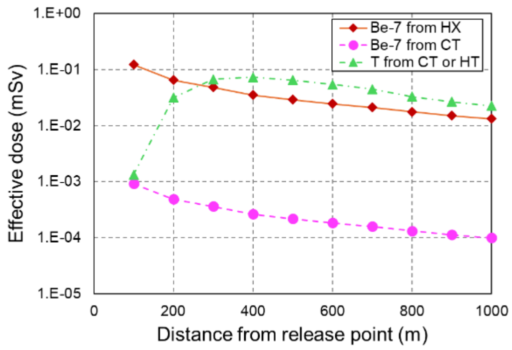

Figure 2 Effective doses in the public due to released tritium (T) and Be-7 in case of accidents at HX, CT, or HT with DS and AFS in operation under most severe meteorological conditions (wind speed of 1 m/s, atmospheric stability class F, and no precipitation for T and precipitation rate of 5 mm/h for Be-7) at release height of 10 m.

5. CONCLUSION

The engineering design activities mainly focused on the assessments for the impacts of the radioactive products such as T and Be-7 have been performed by JA under the IFMIF/EVEDA project. The achievements of the activities will advance the FNS design especially for the liquid Li target system, DS, and safety system, as well as contribute to the radiological safety assessments and safety design development in FNS.

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