Shielding analysis of Transmutation Experimental Facility

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Abstract. The Japan Atomic Energy Agency is planning to construct the Transmutation Experimental Facility (TEF) to promote research, development, and demonstration of elemental technologies for accelerator-driven systems (ADSs). At ADS Target Test Facility (TEF-T), 250-kW H⁻ beams accelerated by the 400-MeV LINAC will be derived to a lead-bismuth eutectic target. Toward the construction of TEF, a shielding analysis is carried out for the whole structure of the TEF-T in detail. The analysis for the beam tunnel shows that backward neutrons produced from the LBE target have large impact on the radiation dose in the TEF beam tunnel. This paper presents the analytical results for components such as target station, hot cell and beam tunnel, and the shielding structure of the whole TEF.

1. Introduction
To promote research, development, and demonstration of elemental technologies for accelerator-driven systems (ADS), the Japan Atomic Energy Agency (JAEA) is planning to construct Transmutation Experimental Facility (TEF) at J-PARC. At ADS Target Test Facility (TEF-T), 250-kW H⁻ beams accelerated by the 400-MeV LINAC will be derived to a lead-bismuth eutectic (LBE) target for the material examinations aimed for the ADS. The TEF-T will operate as a spallation neutron source especially for research and development of semiconductor by using high-energy neutrons. For the license of this facility, the shielding design is important because unnecessary shield drastically increases the cost of construction.

In this study, shielding analysis was carried out for the whole structure of the TEF in detail toward the construction. Shielding design including the target station, beam tunnel, hot cell to maintain the LBE target and beam dumps for beam commissioning were also determined. This paper presents the results of the shielding analysis for these components and the shielding structure of the whole TEF.

2. Calculation conditions
The shielding analysis was conducted based on the design criteria shown in Table 1. In this table, for example, calculated dose values at a boundary between radiation shield and controlled area (CA) must be lower than 25 μSv/h. Here, the dose rate was calculated using the Monte-Carlo transport code system PHITS [1], where INCL4.6 [2] and GEM [3] were employed for simulation of intranuclear cascade and de-excitation processes, respectively. For neutron and photon transport below 20 MeV, the Japanese Evaluated Nuclear Data Library JENDL-4.0 [4] was adopted. For conservative estimation, the Tesch formula [5] was also used in determining the thickness of concrete shield.
Figure 1 illustrates a birds-eye view of the TEF-T facility. The 250-kW negative hydrogen (H⁻) beams accelerated by the 400-MeV LINAC are transported through a joint section between LINAC and the TEF beam tunnel, and injected to the LBE target (15 cm in diameter × 100 cm in depth) installed at the center of the target station. In the beam tunnel, totally two beam dumps are installed for beam commissioning according to the intended use.

Table 1. Design criteria used in this analysis.

| Areas                                | Laws and regulations                  | Effective dose rate          |
|--------------------------------------|---------------------------------------|------------------------------|
| Boundary of JAEA-Tokai site          | < 250 μSv/3 months (whole JAEA)       | < 0.11 μSv/h[^1]             |
|                                      | < 50 μSv/3 months (whole J-PARC)[^4]  | (whole JAEA)                 |
| Non-controlled area in JAEA-Tokai site | < 20 μSv/week                         | < 0.5 μSv/h[^2]              |
| Controlled area where rad-workers can enter without special permission | < 1 mSv/week                         | < 25 μSv/h[^2]               |
| Criterion of soil activation[^3]     | < 5 mSv/h                             | (< 11 mSv/h)                 |

[^1] The 3 months correspond to 2184 hours (=91 days = 365/4 days) / According to a note of radiation safety division of Science and Technology Agency on Oct 23, 2000.
[^2] The 3 months correspond to 5000 hours (1/4 of annual actual working hours, 2000 hours) and the 1 week corresponds to 40 hours.
[^3] The criterion on the soil activation is set to an average of each facility but allows 11 mSv/h as a maximum local value.
[^4] About 10 Sv/year for Transmutation Experimental Facility.

3. Results

3.1. Target station
To reduce radiation dose due to the intense spallation neutrons produced from the LBE target, the LBE target is surrounded with thick iron and concrete shields. As shown in Figure 2, at least a 3-m-thick
iron and 2-m-thick concrete shield is required to satisfy the criterion of “< 25 µSv/h” at the boundary of CA. By this analytical result, the structure of target station was determined as illustrated in Figure 3.

3.2. **Hot cell**
The irradiated LBE target including its vessel is moved to a hot cell and utilized for various examinations. Figure 4 shows dose rate distributions in the hot cell and radiation shield of concrete and shielding glass. From these results, it was found that a 1.5-m concrete shield or 1-m shielding glass is required to satisfy the criterion at the boundary of CA.

![Figure 2. Dose rate distribution in radiation shield of the target station.](image2)

![Figure 3. Vertical cross-section of the target station.](image3)

![Figure 4. Dose rate distributions in the hot cell and radiation shield. (left panel: ordinary concrete, right panel: shielding glass).](image4)

3.3. **Beam tunnel**
The thickness of the concrete wall, floor, and ceiling in the beam tunnel is determined with the Tesch line-loss formula, where beam loss was assumed to be 0.1 W/m. In addition to the results of Tesch line-loss formula, contributions of backstreaming neutrons from the LBE target and spallation neutrons produced from the beam dump to the dose rate were taken into account. Figure 5 shows a contour map of a contribution of backstreaming neutrons to the dose rate distribution in the beam tunnel. As indicated in this figure, it was revealed that backward neutrons dominate the radiation dose.
in the beam tunnel. To ensure the dose rate lower than the criterion at the boundary of CA, a maze structure was employed for the passage for carrying in/out equipment and a concrete wall dedicated for shielding the backstreaming neutrons was installed.

![Contour map of dose rate distributions in the beam tunnel.](image)

**Figure 5.** Contour map of dose rate distributions in the beam tunnel. Red dashed line represents a boundary of CA (< 25 µSv/h).

4. Conclusion

The detailed shielding structures including the target station, hot cell, beam tunnel and the beam dumps have been determined by the PHITS code based on the INCL4.6 and GEM models. The analysis for the beam tunnel has shown that the backward neutrons produced from the LBE target have a large impact on the radiation dose in the beam tunnel. This indicates that the prediction accuracy of the spallation models, i.e. INCL4.6/GEM, for the backward neutrons is important for the shielding design of the TEF-T beam tunnel. Future work, therefore, will pay attention to validation of spallation models especially for the prediction accuracy of backward neutrons.

References

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