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A Preliminary Assessment of Radiation and Air Activation for the Neutron Science Facility in RAON

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1. Introduction

The Neutron Science Facility (NSF) in Korea heavy-ion accelerator (RAON) will be constructed to measure the fast neutron cross-section which is useful for the development of innovative nuclear power plants and the advanced accelerator-driven system. The NSF consists of three rooms such as the target room, TOF hall and DAQ room. In the target room, the carbon (C) and lithium (Li) targets are placed for the generation of the white and mono-energetic neutrons, respectively. Some detector will be located at TOF hall to measure fast neutron cross-section by Time-of-Flight (TOF) method. The works will stay in the DAQ room during an operation for about 1 month. In order to test the characteristics of the detector, the workers are also possible to access the TOF hall after a shutdown [1]. Therefore, the shielding analysis of the NSF is required to meet the above purpose.

In view of this, we performed the calculation of the shielding concrete thickness required for a target room by using MCNPX code [2] with a neutron source obtained from Institute for Basic Science (IBS). In addition, the dose distribution and air activation for the entire space in NSF were evaluated using MCNPX and SP-FISPACT 2010 codes [3].

2. Methods and Results

2.1 Neutron Source

The white neutron source produced from the C(d,n) reaction is more conservative than the mono-energetic neutron source from Li(p,n) reaction in the shielding analysis because deuteron has the neutron. The neutron source in the C(d,n) reaction was obtained from IBS.

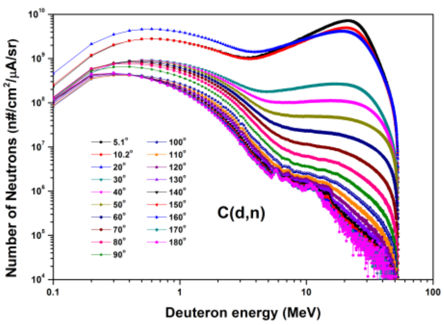

Fig. 1. Neutron spectrum calculated by McDeC code.

They performed the calculation of neutron source by using the MeDeC code with a deuteron energy of 53 MeV as the energy groups of 530 and linear scale. The used beam current is 2.3 μA. A cylindrical carbon target with a thickness of 0.7 cm and a diameter of 15 cm was used in the calculation. Fig. 1 shows the neutron spectrum for angular distribution as a function of deuteron energy. The angular distribution was divided into 5 degree intervals up to 10 solid angle in the forward direction, and the other direction is 10 degree intervals.

2.2 Calculation

The concrete thickness required for radiation shielding in the target room at NSF was estimated using the given neutron source. The neutron source is placed on a point area to the x- and y-axes as shown in Fig. 2, and is located at 1.5 and 3.5 m from the bottom and the ceiling, respectively. The thickness of the concrete wall was set at 10 cm intervals from 10 to 400 cm in the forward direction, and other direction was placed up to 300 cm. The dose rate for concrete wall was evaluated by F2 tally per concrete thickness of 10 cm, where the dose conversion factor of ICRP-74 was used for the dose calculation. The dose limits for workers and the public were applied to 5 and 0.25 μSv/hr in consideration of a safety margin (50%). The well-known variance reduction method was used to determine the accurate concrete thickness.

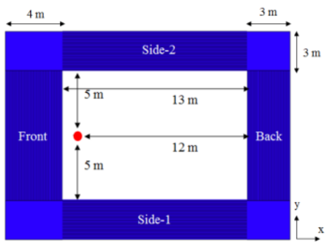

Fig. 2. Schematic of the neutron source position and concrete structures (top view).

The dose distribution to the entire space in NSF (horizontal 94 m, vertical 33 m) was evaluated with dose map size of 0.1 m × 1 m × 1 m. The collimator with a length of 4 m and with a radius of 2 cm was installed in the target room to the TOF hall. The NSF inside was set to an empty space without air. The calculation of dose distribution was done using TMESH tally and the weight window method was applied.

The assessment of air activation was performed for the target room and TOF hall in the NSF. The energy distribution of neutron was evaluated for VITAMIN-J 175 energy group using the E4 option in the MCNPX. The energy distribution in high energy region applied the physical model, and the produced radionuclides were recorded by a HISTP option. The used code for the assessment of air activation is SP-FISPACT 2010. After a shutdown, the air activation was evaluated for the cooling time of 1 h, 1 d, 7 d, 30 d, and 1 y. In the calculation of air activation, we assumed to be closed inside the facility during the operation. The preset results are compared with air concentration and release limits.

2.3 Results

The dose rate attenuation according to the thickness of concrete walls at all directions was determined using the MCNPX code. It can be seen from Fig. 3 that the concrete thickness to shield the radiation based on the workers limit were needed to 280, 170, 170, 170, and 170 cm for front, back, side-1, side-2 and ceiling, respectively. On the other hand, the concrete thickness for the public limit is 340, 210, 220, 220, and 220 cm in each direction. The relative error of the present result is less than 8%.

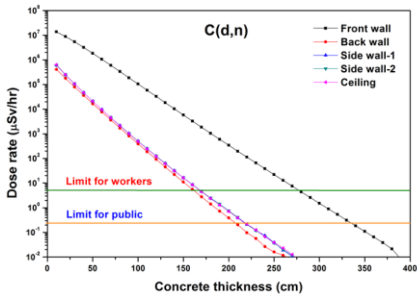

Fig. 3. Dose rate attenuation for the concrete thickness in the $^{nat}C(d,n)$ reaction with a deuteron energy of 53 MeV.

The dose distribution to the entire space in NSF is shown in Fig. 4. Neutron beam dump material was randomly considered as a combination of iron (20 cm) and concrete (100 cm) through the dose rate assessment. Form dose distribution, it was found that the concrete thickness of the target room is suitable for the shielding in all directions. In addition, it can be seen from Fig. 4 that neutrons go through the collimator and it is scattered to outside wall in TOF hall. The dose rate behind outside wall from beam dump was satisfied with public limit. However, the dose rate for the beam line was evaluated to be 58 mSv/hr. Some shielding material is required to satisfy the dose rate limit.

The total radioactivity for the target room and TOF hall after a shutdown is 3.06E-01 and 1.33E-05 Bq/cm^3, respectively. Fig. 5 shows the radioactivity of radio-nuclides for target room and TOF hall as a function of the cooling time. The total radioactivity was shown to decrease more than 10 times in the target room and TOF hall after a cooling time of 1 day. The H-3, C-14, S-35, Cl-38, Cl-39, Ar-37, A-41, and I-125 nuclides are the main radionuclides that affect the total radioactivity. It was compared with air concentration and release limits. In the target room, C-14 and Cl-39 are the excess of release limits as 8.31E-04 and 3.02E-03 Bq/cm^3. Ar-41 is the excess of air concentration limits as 1.79E-01 Bq/cm^3. However, in case of the TOF hall, all radionuclides did not exceed the limits.

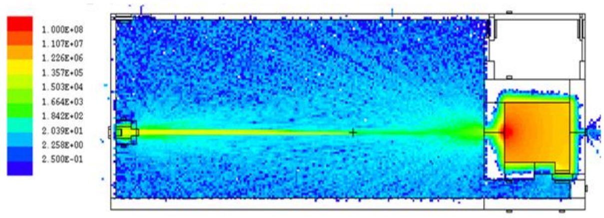

Fig. 4. Dose distribution to the entire space in NSF.

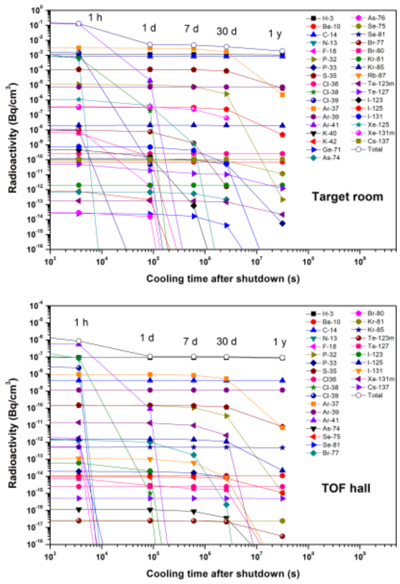

Fig. 5. The radioactivity of radionuclides for target room and TOF hall as a function of the cooling time.

3. Conclusions

We have performed the shielding calculation with the neutron source produced from the C(d,n) reactions. The concrete thickness was evaluated for all directions of the target room, and it was confirmed by performing the calculation of dose distribution to the entire space. However, the dose rate for the beam line was high. The radioactivity of radionuclides at TOF hall do not exceeded the air concentration and release limits.

REFERENCES

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