Activation measurement of copper by ^{238}U irradiation

A. Akashio,[*1] K. Tanaka,[*1] N. Shigyo,[*1,*2] and K. Sugihara[*1,*2,*3]

γ-ray residual radiation dose around the copper beam dump of BigRIPS, where the highest radiation dose rate is expected at RIBF, is occasionally estimated by Monte-Carlo radiation transport code such as PHITS.[1)] However, there are no measured data for the activation caused by uranium beam and the accuracy of the calculation remains unknown. Therefore, 345 MeV/nucleon uranium beams were irradiated on a stack of copper sheets, which is the material of the beam dump, to measure the produced radioisotopes and compare them with the PHITS calculation.[1)]

Ten 1 mm thick copper sheets were stacked. A 10 mm thick copper plate was applied as the radiation sample. After the irradiation of the uranium beam, γ rays were measured with a germanium detector to identify the nuclide and quantity of the produced radioisotopes. To consider long-lived radiation from the beam dump, the γ rays were measured nine months after the irradiation. Figure 1 shows the depth dependence of the observed radioactive nuclei. The depth was reduced from the copper sheet number. The amount of the radioisotopes was evaluated from the individual measurements of the copper sheets. The range of 345 MeV/nucleon uranium-238 beam in copper was approximately 3.3 mm. Manganese-54, cobalt-56, -57, -58, and cobalt-60 were observed at all the copper sheets. Therefore, the isotopes of manganese and cobalt in the range 1–3 mm were produced through a reaction between the uranium and copper nuclei. The isotopes deeper than 4 mm were produced by a nuclear reaction of secondary neutrons with copper nuclei. Further, the secondary neutron was produced from the reaction with uranium beam and copper. Consequently, osmium-185, hafnium-175, zirconium-97, and ruthenium-103 were observed in the depth range of 4–6 mm. As nuclei of mass number of approximately 180 are heavier than typical fission fragments of uranium which mass are approximately 140, osmium and hafnium are supposed to be produced by projectile fragmentation of uranium beam. Zirconium and ruthenium, with approximate mass number of 100, are typical nuclides from in-flight fission of uranium beam. The range of produced nuclei in copper was longer than the 3.3 mm range of uranium beam because their atomic number are smaller than that of uranium. Moreover, the nuclei produced by fission were not observed at 7 mm depth and beyond.

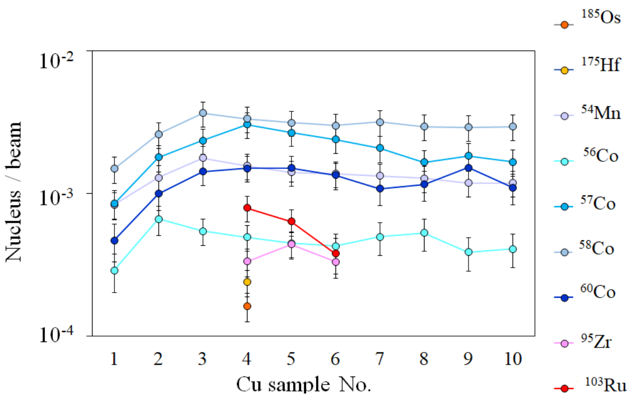

Fig. 1. Depth dependence of the observed radioactive nuclei in the copper sheets. The depth was converted from the number of the sheets.

The measured activity of nuclei was compared with the calculation by PHITS. Figure 2 shows the activity ratio of the calculated to measured value.

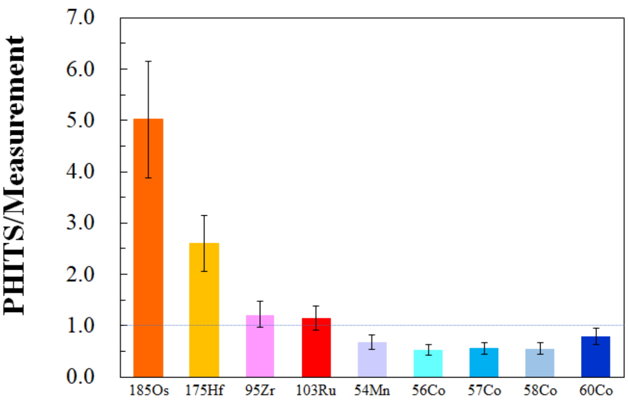

Fig. 2. Ratio of nuclei calculated evaluation by PHITS to measured values.

The calculated activation rate of copper by the secondary neutron was approximately 50% of measured value. The calculated production rate of projectile-fragmentation nuclides of osmium-185 and hafnium-175 were several times higher than measured values. However, the ratios of the fission nuclei zirconium-97, and rutheniu-103 were approximately identical to the measured values.

Consequently, the benchmark of activation for 345 MeV/nucleon uranium-beam irradiation on copper material was obtained. The PHITS evaluation was consistent the measured values within a factor of several.

*1 RIKEN Nishina Center
*2 Department of Applied Quantum Physics and Nuclear Engineering, Kyushu University
*3 High Energy Accelerator Research Organization (KEK)

Reference

1) T. Sato *et al.*, J. Nucl. Sci. Tech. **55**, 684 (2018).