Projectile Dependency of Radioactivities of Spallation Products Induced in Copper

Hiroshi Yashima
Department of Quantum Science and Energy Engineering, Tohoku University,
Aoba01, Aramaki, Aobaku, Sendai 980-8578,Japan
e-mail:yashima@cyric.tohoku.ac.jp
Hiroshi Sugita, Takashi Nakamura, Tomoyuki Shiomi
Department of Quantum Science and Energy Engineering, Tohoku University,
Aoba, Aramaki, Aobaku, Sendai 980-8578,Japan
Yoshitomo Uwamino, Sachiko Ito
Institute of Physical and Chemical Research, Hirosawa, Wako, Saitama 351-01, Japan
Akifumi Fukumura
National Institute of Radiological Sciences, 4-9-1, Anagawa, Inage-ku
Chiba-shi, Chiba, 263-8555, Japan

The reaction cross sections of spallation products in a Cu target by 230MeV/nucleon Ne,C,He,p and 100MeV/nucleon Ne,C ions were obtained. Irradiation experiments were performed at HIMAC (Heavy Ion Medical Accelerator in Chiba), National Institute of Radiological Sciences. Gamma-ray spectra from activation samples were measured with a HPGe detector. From the gamma-ray spectra, we obtained the variation of reaction cross sections of Cl-38, Cr-49, Mn-55, Cu-60, Cu-61 and Co-62m in Cu sample with Cu target thickness and mass-yield distribution of nuclides in Cu sample on the surface of Cu target. The results showed that the dependence of the cross sections to the projectile mass varies with the mass number difference between Cu and produced nuclide

1. Introduction

Recently the high-energy and high-intensity accelerators have increasingly been used for nuclear physics, solid-state physics, radiotherapy, material damage study, and so on. Safety design consideration for the accelerator facilities requires reaction cross section data for high-energy ions to estimate the radioactivities induced in the accelerator components and in the shielding materials. We therefore irradiated 230MeV/nucleon Ne,C,He,p and 100MeV/nucleon Ne,C ions onto a Cu target, and investigated the projectile dependency of induced radioactivities of spallation products.

2. Experiment and Analysis

Irradiation experiments were performed at HIMAC (Heavy Ion Medical Accelerator in Chiba), National Institute of Radiological Sciences. A schematic view of the experimental set-up is shown in Fig.1. The Cu target was composed of a stack of 100mm×100mm×5mm Cu plates, and C, Al, Cr, Fe, Ni, Cu, Pb samples were inserted between the Cu plates. The thickness of Cu target is longer than the flight path of the projectile beam. Table1 shows the flight path of the projectile beam calculated by the SPAR code [1]. After irradiation, we measured the gamma-ray spectra from samples with a HPGe detector. Fig.2 shows a schematic view of the gamma-ray detection system. The reaction rates of radionuclides produced in samples which were identified from the gamma-ray spectra and the decay curves were estimated after being corrected for the peak efficiency of the HPGe detector and the coincidence-summing effect.

3. Results and Discussions

From the reaction rates, we obtained the reaction cross sections of Cl-38, Cr-49, Mn-56 Cu-60, Cu-61 and Co-62m in a Cu target by 230 MeV/nucleon Ne,C,He,p and 100MeV/nucleon Ne,C ions and mass-yield distribution of nuclides in Cu sample at surface of Cu target.

Fig.3 shows the variation of reaction cross sections of Cl-38 produced in the Cu sample with Cu target thickness. Target thickness is expressed as the unit of the flight path. In Fig.3, the reaction cross sections of Cl-38 are almost constant down to the beam flight path and rapidly decrease beyond it in the case of C and Ne ion (230,100MeV/nucleon) irradiations, while it gradually decreases with target thickness in the case of 230MeV/nucleon He ion. Since the mass number difference between Cu and Cl-38 is large, Cl-38 is produced dominantly by a primary projectile beam.

Fig.4 shows the variation of reaction cross sections of Cr-49 produced in the Cu sample with Cu target thickness. In Fig.4, the reaction cross sections of Cr-49 increase down to the beam flight path and decrease beyond it in the case of C and Ne ion (230,100MeV/nucleon) irradiations while it is almost constant down to the beam flight path and rapidly decrease beyond it in the case of 230MeV/nucleon He ion and it monotonously decreases with target thickness in the case of 230MeV/nucleon p ion. Since the mass number of Cr-49 becomes closer to Cu than that of Cl-38, the fraction of Cr-49 produced by secondary particles increases.

Figs.5 to 8 show the variation of reaction cross sections of Mn-56,Cu-60,Cu-61,Co-62m produced in the Cu sample with Cu target thickness, respectively. In these figures, the reaction cross sections of these nuclides show the similar tendency as that of Cr-49 although the cross section increase with the target thickness is much higher for spallation products of lighter mass.

Fig.9 shows the mass-yield distribution of nuclides in Cu sample on the surface of Cu target. The cross section is normalized to the cross section for 230MeV/u Ne ions. Table2 shows the cross section ratio of nuclides normalized to the cross section for 230MeV/u p ions. In Fig.9 and Table2, the projectile dependency of the cross section is small in the nuclide of which the mass number is closer to Cu while it becomes larger with the lower mass nuclides.

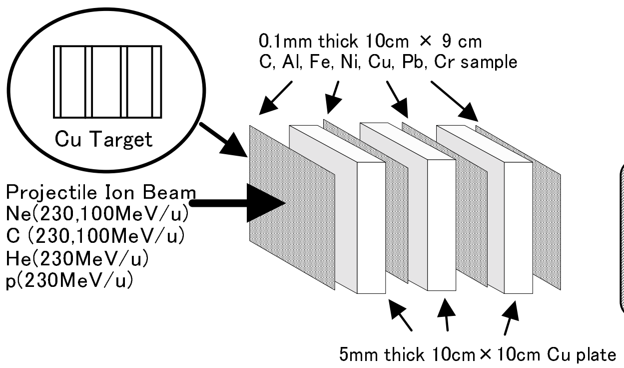

Fig.1 Schematic view of the experimental geometry.

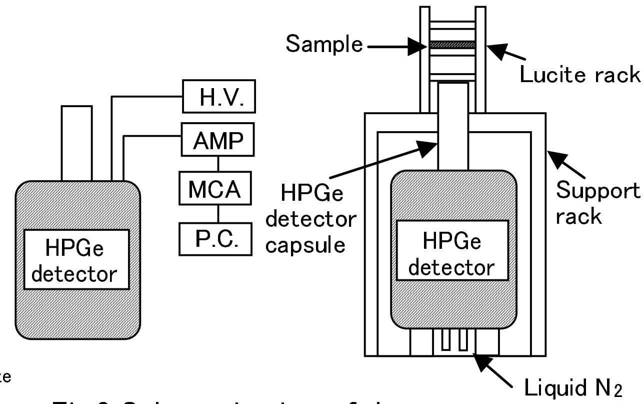

Fig.2 Schematic view of the gamma-ray detection system

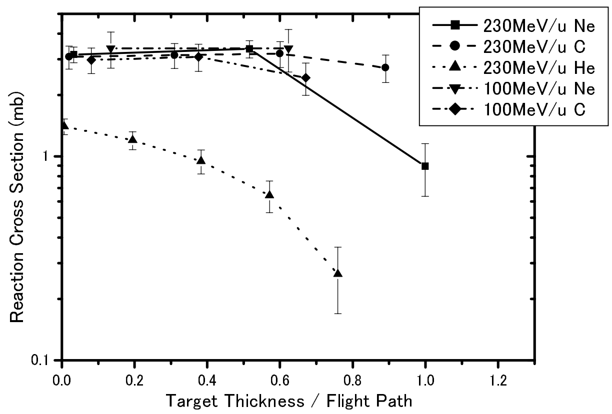

Fig.3 Reaction cross section of Cl-38 in Copper

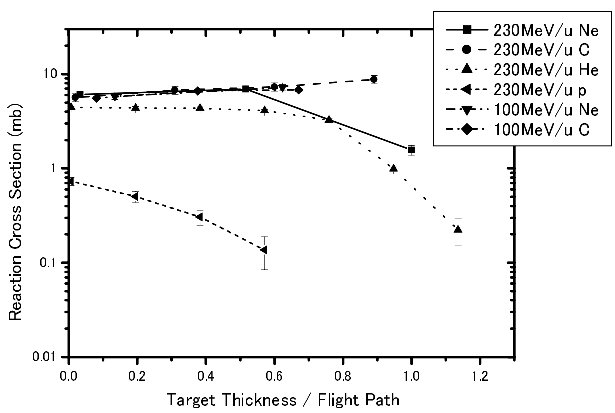

Fig.4 Reaction cross section of Cr-49 in Copper

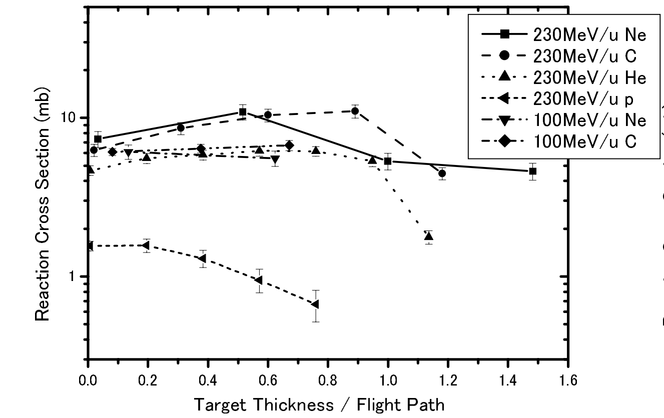

Fig.5 Reaction cross section of Mn-56 in Copper

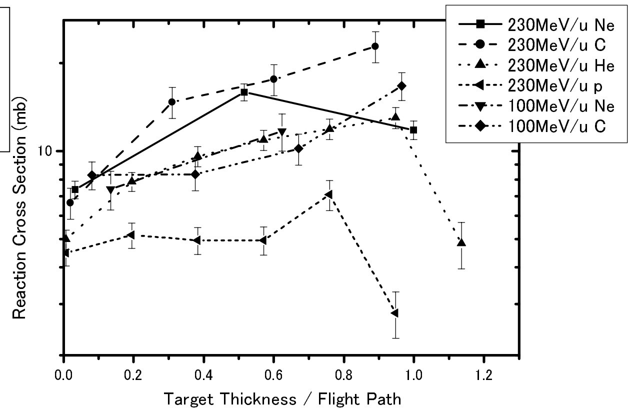

Fig.6 Reaction cross section of Cu-60 in Copper

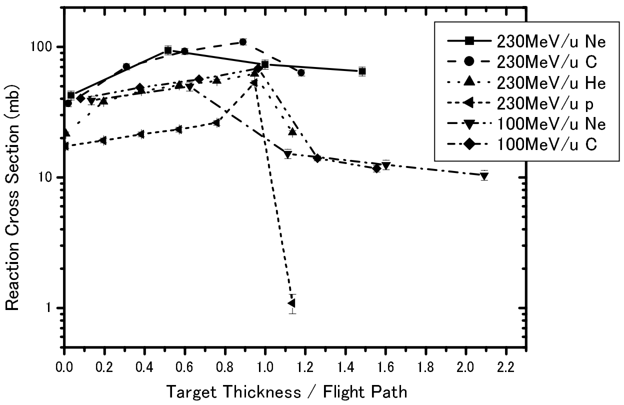

Fig.7 Reaction cross section of Cu-61 in Copper

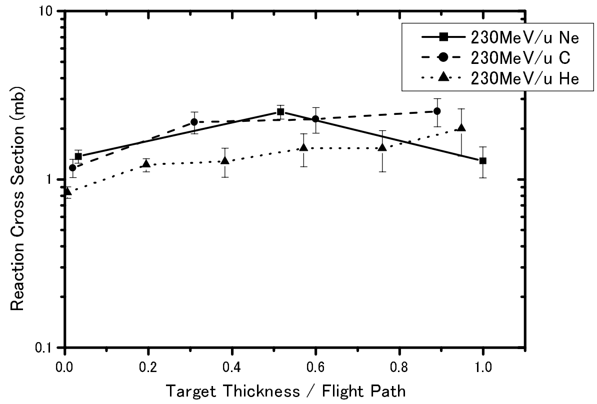

Fig.8 Reaction cross section of Co-62m in Copper

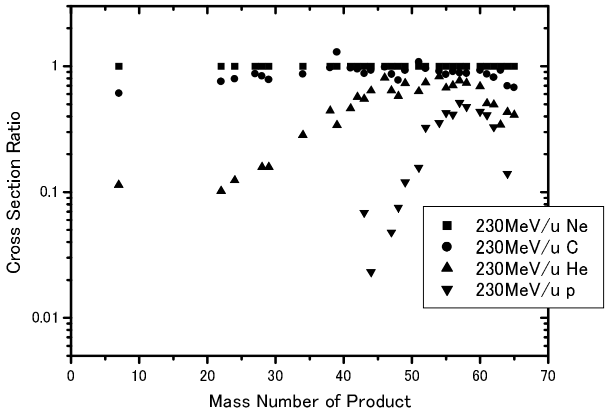

Fig.9 Mass-yield distribution in Copper

Table1 The flight path of the projectile beam

Projectile Ion	Flight Path[mm]
230MeV/u Ne	11.0
230MeV/u C	18.2
230MeV/u He	54.7
230MeV/u p	54.7
100MeV/u Ne	2.7
100MeV/u C	4.4

Table2 Cross Section Ratio in Copper (projectile energy 230MeV/u)

Product	Ne	C	He	p
Sc-43	7.0	6.1	3.8	1
Sc-44	36.5	54.7	26.1	1
Sc-44m	50.1	44.0	29.2	1
Sc-47	20.9	18.1	13.4	1
Cr-48	13.3	10.3	7.7	1
Cr-49	8.3	7.7	6.1	1
Cr-51	6.4	6.9	4.0	1
Mn-52m	3.1	3.0	2.3	1
Fe-52	3.0	2.8	2.0	1
Mn-54	2.8	2.6	2.3	1
Co-55	2.3	2.0	1.6	1
Mn-56	4.7	4.0	3.0	1
Co-56	1.8	1.7	1.4	1
Co-57	1.9	1.7	1.5	1
Ni-57	2.0	1.7	1.3	1
Co-58	2.1	1.8	1.5	1
Co-60	2.7	2.5	1.9	1
Cu-60	1.6	1.5	1.1	1
Cu-61	2.4	2.1	1.2	1
Zn-62	1.9	1.5	0.8	1
Cu-64	7.2	5.0	3.1	1

4.Conclusion

We performed the irradiation experiments by 230MeV/nucleon Ne,C,He,p and 100MeV/nucleon ions, and obtained the variation of reaction cross sections of nuclides produced in Cu sample with Cu target thickness and mass-yield distribution of nuclides in Cu sample on the surface of Cu target. It was found that these cross sections have two tendencies. When the mass number difference between Cu and produced nuclide is small, the fraction of nuclides produced by secondary particle is large. The reaction cross section is almost equal for Ne and C ions but smaller for He and p ions. The more the projectile mass number of ion and energy increases, the more the reaction cross section increases toward the inner part of Cu target. When the mass number difference between Cu and produced nuclide is large, where the threshold energy is high, and nuclide is almost produced by a primary projectile beam. The cross section difference between Ne,C and He,p becomes larger in the lower mass nuclides. We are now analyzing the induced radioactivities produced in other samples.

References

[1] T. Nakane, Nucl. Phys., A491, 130 (1989).