Measurement of residual radioactivity in copper exposed to high energy heavy ion beam

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The residual radioactivities produced by high energy heavy ions have been measured using the heavy ion beams of the Heavy Ion Medical Accelerator (HIMAC) at National Institute of Radiological Sciences. The spatial distribution of residual radioactivities in 3.5cm, 5.5cm and 10cm thick copper targets of 10cm×10cm size bombarded by 290MeV/u, 400MeV/u-^{12}C ion beams and 400MeV/u-^{20}Ne ion beam, respectively, were obtained by measuring the gamma-ray activities of 0.5mm thick copper foil inserted in the target with a high purity Ge detector after about 1hour to 6 hours irradiation.

1. Introduction

In radiation safety design of high energy and high intensity accelerator, the evaluation of residual radioactivities of accelerator and shielding materials is very important for protection of radiation workers, especially during maintenance work. The radioactivities of air, coolant water and soil are also important for protection of natural environment and nearly inhabitants. The residual radioactivities are produced by accelerating charged particles and secondary neutrons. Those by charged particles are a main source in accelerator materials exposed to a beam. Nevertheless, there exist very few experimental data of residual radioactivities produced by high energy heavy ions and the accurate estimation method has not been established yet. Several experimental studies on the reaction between carbon ion beam and copper target have been reported at projectile energies of 15 to 90MeV/u [1-3]. In this study, we performed irradiation experiments of copper target using the 290MeV/u and 400MeV/u ^{12}C ions and 400MeV/u ^{20}Ne ion beams of the Heavy Ion Medical Accelerator in Chiba (HIMAC) at National Institute of Radiological Sciences.

2. Materials and Methods

Irradiation was performed with 290 and 400MeV/u-^{12}C ion beams , and 400MeV/u-^{20}Ne ion beam delivered from HIMAC. Figure 1 shows an assembly of the natural copper target of 10cm×10cm size and 0.5cm thickness which has total thickness of copper target of 3.5cm, 5.5cm and 10cm to stop the projectile heavy ion beams, 290 and 400MeV/u-^{12}C ion beam and 400MeV/u-^{20}Ne ion beam, respectively. Additional copper activation foils of 10cm×10cm and 0.5mm thickness were inserted at every 5mm to 20mm interval in the copper target to measure the spatial distribution of residual radioactivities in the copper target.

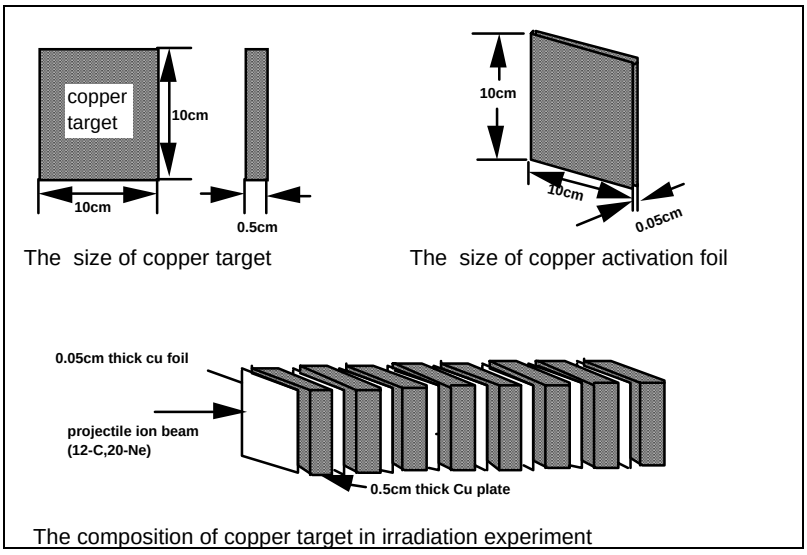

Fig.1 : Schematic view of copper target assembly used for irradiation experiment

The size of projectile beam is about 1cm in diameter and the beam perpendicularly bombarded the target. The irradiation condition and the activation foils used in the experiment are listed in Table1. During irradiation experiment， the beam intensities were measured with an transmission-type ionization chamber .

Table1 Projectile beam and activation foil used for irradiation experiment

Projectile heavy ion beam	Integrated beam intensity	Irradiation time	Activation foil
290MeV/u ^{12}C	1.949×10^{-7} C	1 hour	^{nat}Cu
400MeV/u ^{12}C	2.006×10^{-7} C	1 hour	^{nat}Cu
400MeV/u ^{20}Ne	2.666×10^{-7} C	1 hour	^{nat}Cu
400MeV/u ^{12}C	8.186×10^{-6} C	6 hour	^{27}Al, ^{nat}Fe, ^{nat}Cu, SUS

The gamma rays from residual radioactivities in copper foil inserted in the copper target were

measured by the high purity Ge detector by coupling with the 4096 multi-channel analyzer. The measuring time of copper foils was between 60min and 5hours, and the cooling time was between 6min and 5days from beam off, considering the half lives of residual radioactive nuclides.
From the measured gamma-ray spectra , we identified a number of radionuclides and the reaction rate of residual nuclei were obtained from the peak counts after corrected with the peak efficiency of Ge detector

3. Results and Discussion

From the irradiation experiments, we identified the residual nuclei of these activation foils and obtained the spatial distribution of their reaction rates in the copper target. Table2 gives the measured residual nuclides in copper activation foil. The number of identified radionuclides is 14, 17 , 20 and 38, the mass number of residual nuclides is between 27(^{27}Mg) and 61(^{61}Cu) for 290MeV/u ^{12}C ion bombardment during 1hour irradiation time, 24(^{24}Na) and 61(^{61}Cu) for 400MeV/u ^{12}C ion bombardment during 1hour irradiation time, 27(^{27}Al) and 63(^{63}Zn) for 400MeV/u ^{20}Ne ion bombardment during 1hour irradiation time, 7(^{7}Be) and 63(^{63}Zn) and for 400MeV/u ^{12}C ion bombardment during 6 hours irradiation time, respectively.

Table 2 Residual nuclides measured in the copper activation foil

Projectile heavy ion beam	Residual nuclides in copper activation foil
290MeV/u ^{12}C ion-^{nat}Cu	^{27}Mg, ^{29}Al, ^{34m}Cl, ^{38}Cl, ^{39}Cl, ^{41}Ar, ^{44}Sc, ^{49}Cr, ^{56}Mn, ^{53}Fe, ^{61}Co, ^{62m}Co, ^{60}Cu, ^{61}Cu (14)
400MeV/u ^{12}C ion-^{nat}Cu	^{24}Na, ^{29}Al, ^{34m}Cl, ^{38}Cl, ^{39}Cl, ^{40}Cl, ^{41}Ar, ^{43}Sc, ^{44}Sc, ^{49}Cr, ^{52m}Mn, ^{56}Mn, ^{53}Fe, ^{61}Co, ^{62m}Co, ^{60}Cu, ^{61}Cu (17)
400MeV/u ^{20}Ne ion-^{nat}Cu	^{24}Na, ^{29}Al, ^{38}Cl, ^{40}Cl, ^{41}Ar, ^{43}Sc, ^{44}Sc, ^{44m}Sc, ^{49}Cr, ^{52}Mn, ^{52m}Mn, ^{56}Mn, ^{53}Fe, ^{61}Co, ^{62m}Co, ^{60}Cu, ^{61}Cu, ^{56}Ni, ^{65}Ni, ^{63}Zn (20)
400MeV/u ^{12}C ion-^{nat}Cu	^{7}Be, ^{24}Na, ^{28}Mg, ^{29}Al, ^{34m}Cl, ^{38}Cl, ^{39}Cl, ^{41}Ar, ^{42}K, ^{43}K, ^{44}K, ^{43}Sc, ^{44m}Sc, ^{44}Sc, ^{46}Sc, ^{47}Sc, ^{48}Sc, ^{48}V, ^{49}Cr, ^{51}Cr, ^{52}Mn, ^{54}Mn, ^{56}Mn, ^{52}Fe, ^{59}Fe, ^{55}Co, ^{56}Co, ^{57}Co, ^{58}Co, ^{61}Co, ^{62m}Co, ^{60}Cu, ^{61}Cu, ^{56}Ni, ^{57}Ni, ^{65}Ni, ^{62}Zn, ^{63}Zn (38)

Figures 2 to 5 show the spatial distributions of ^{61}Cu, ^{56}Mn, ^{44}Sc and ^{38}Cl in the copper target for 290 and 400MeV/u ^{12}C ion and 400MeV/u ^{20}Ne ion bombardments.
Figures 2 and 3 show the spatial distributions of ^{61}Cu and ^{56}Mn in the copper target for 290 and 400MeV/u ^{12}C ion and 400MeV/u ^{20}Ne ion bombardments. These figures indicate that the

spatial distributions of activation rates of ^{61}Cu and ^{56}Mn which are close to the target nucleus of natural Cu (^{63}Cu and ^{65}Cu) increase with penetrating the copper target, while on the other hand, the spatial distributions of ^{44}Sc and ^{38}Cl which have much smaller atomic number and mass number than natural Cu have a constant distribution in the copper target and steeply decrease at the point of energy range of the incident beam (2.5cm for 290MeV/nucleon ^{12}C , 4.0cm for 400MeV/u- ^{12}C and 2.5cm for 400MeV/u-^{20}Ne). It is also clear from Figs.2 to 5 that the spatial distributions of ^{61}Cu, ^{56}Mn, ^{44}Sc and ^{38}Cl which were produced by the 290 and 400MeV/u-^{12}C ions give similar activation rate curves with depth each other and steeply decrease at the stopping range of an incident beam, especially for ^{44}Sc and ^{38}Cl activation rates. We can find that the ^{61}Cu and ^{56}Mn spatial distributions extend in the copper target beyond the energy range of an incident beam, especially for 400MeV/u-^{12}C and ^{20}Ne ion incidences. This may be explained from the phenomenological fact that the ^{61}Cu and ^{56}Mn isotopes were mainly produced through ^{nat}Cu (n,xn) and (p,px) reactions by the secondary fragment particles, such as protons and neutrons, produced by ^{12}C interaction with copper, in addition to that by the direct reactions of an incident beam. On the other hand, ^{44}Sc and ^{38}Cl isotope productions have rather high threshold energy and were mainly produced by the direct reactions of ^{12}C and ^{20}Ne ion beams with copper target.

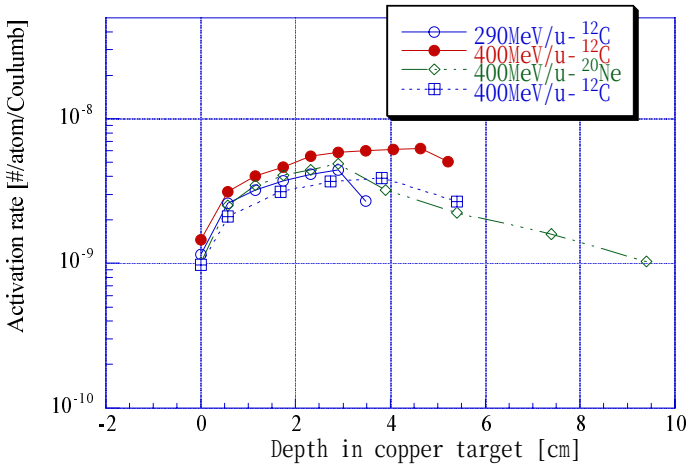

Fig.2 Spatial distribution of ^{61}Cu activation rate in the copper target

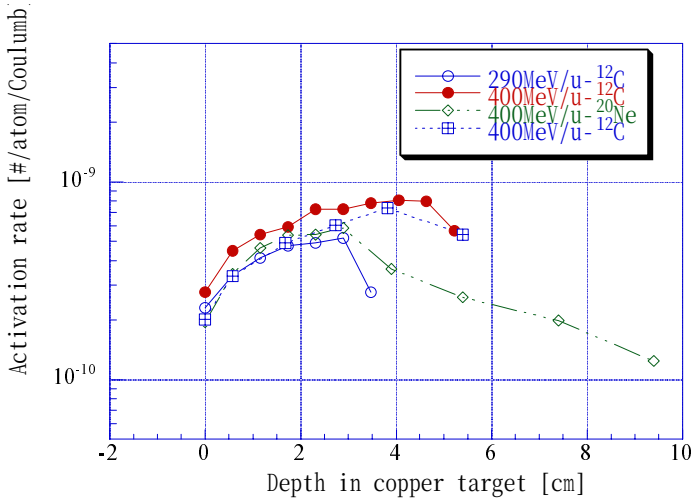

Fig.3 Spatial distribution of ^{56}Mn activation rate in the copper target

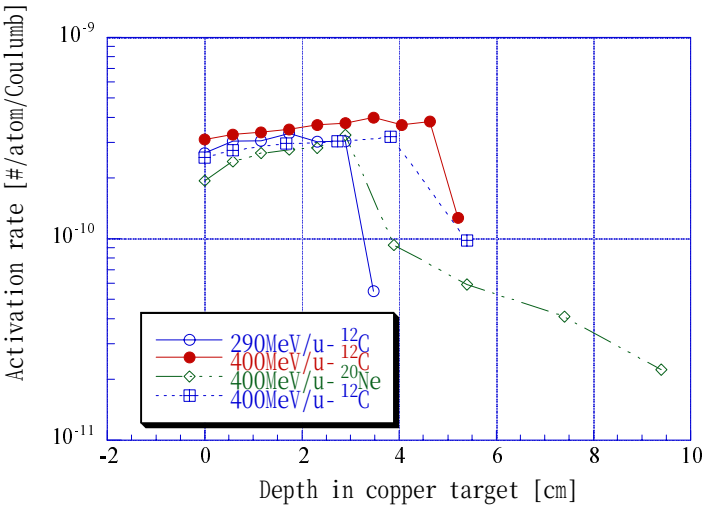

Fig.4 Spatial distribution of ^{44}Sc activation rate in the copper target

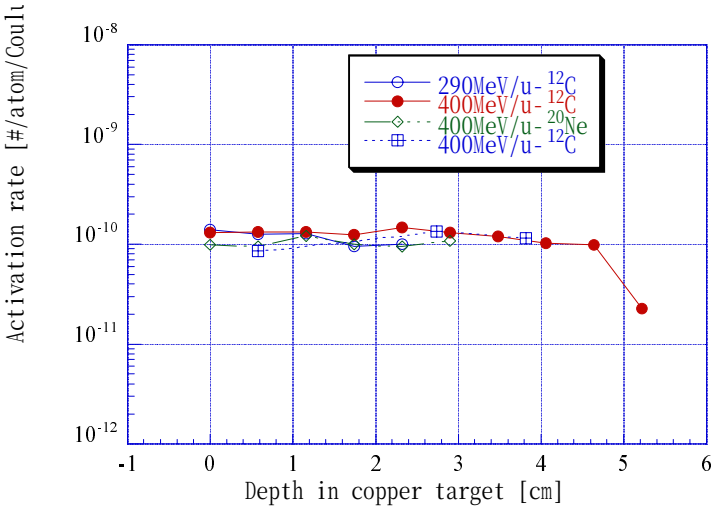

Fig.5 Spatial distribution of ^{38}Cl activation rate in the copper target

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