Beam preparation for fee-based utilization of a 70-MeV/A Kr-beam

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In October 2014, RIKEN provided a 70 MeV/A Kr beam from the RIKEN Ring Cyclotron (RRC) to private companies as the first fee-based utilization.[1] Since the customers required irradiations in an atmosphere with a uniform flux distribution over a large area and specified linear energy transfer (LET), we developed the following system at the E5A beam line and successfully delivered desired beams to the customers.

The uniform beam-flux distribution was achieved with wobbler magnets and a scatterer foil. A pair of 60-Hz wobbler magnets deflected the beam from the RRC vertically and horizontally so that the beam center traced a circle. At about 68 cm downstream, the beam passed through a scatterer (48-μm thick Au foil), where multiple scattering brought about a lateral velocity distribution. At about 392 cm downstream from the scatterer, the beam passed to the atmosphere through an 8-cm diameter and 75-μm thick polyimide (Kapton) vacuum-separation window.

In the atmosphere part of the beam path, we used an energy degrader and several detectors to control the LET and measure the beam characteristics. Figure 1 shows the configuration. After the window, there were an ionization chamber (IC: Applied Engineering Inc., AE-1341S) and a 0.5-mm thick plastic scintillator for measuring the total beam intensity. The IC had a 5-cm diameter window that determined the beam size downstream. An adjustable energy degrader (Wood-Bell Co. Ltd.) followed to control the LET, where the beam energy was adjusted by inserting up to eight Al foils with 8-cm diameter and thicknesses of 12.8, 23.8, 48.6, 100.2, 100.8, 196.4, 486.0, and 975.4 μm. We can insert any combination of the foils by using a remote-control pneumatic system to set the LET almost continuously. After the degrader, two sets of $\Delta E + E$ Si-detector stacks were mounted on a motor-driven linear slider; the detectors can be not only placed at the center of the beam path but also horizontally moved across the beam for measuring the beam-flux distribution. The customer samples were placed at about 10 cm downstream from the Si detectors.

Beam scanning with the Si detectors revealed that the beam flux was uniform within ±1.8 % over a diameter of about 35 mm. Another measurement with a GAFCHROMIC-film irradiation showed that the local deviation of the dose was within ±5 %.

For the beam-intensity measurements, the scintillator counted the ions from nearly-zero intensity to about 2.5×10^5 ions/s and the IC was available from 400 to 2.5×10^6 ions/s.

We adjusted and verified the LET at the sample in the following way: Increasing the thicknesses of the degrader foils, we measured the beam energy by using the Si detectors until the beam was totally stopped. Then we compared the thickness-energy relation to SRIM calculations[2] and obtained the stopping power in the sample as a function of the degrader thickness, with a correction for the energy loss in the atmosphere between the Si detector and the sample. We considered the stopping power as the LET.

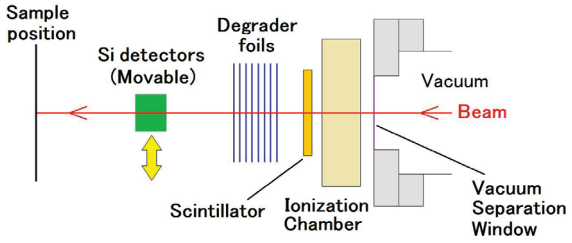

Fig. 1. Setup of Kr-beam irradiation after the window.

Figure 2 shows the relation between the LETs of ^{40}Ar, ^{84}Kr, and ^{132}Xe ions at the surface of Si and their ranges in the material. The 70-MeV/A ^{84}Kr beam from the RRC has the maximum energy of 43 MeV/A at the irradiation position, which corresponds to an LET between 13.2 and 40.9 MeV/(mg/cm^2); the solid line in Fig. 2 indicates this region. In addition, if we use 95-MeV/A ^{40}Ar and 26-MeV/A ^{132}Xe beams accelerated by the RRC, an LET from 2.3 to 69 MeV/(mg/cm^2) is available at the same beam line.

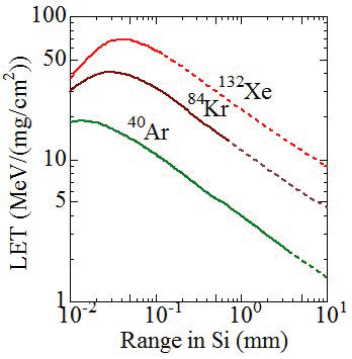

Fig. 2. LETs of ^{40}Ar, ^{84}Kr, and ^{132}Xe ions at the surface of Si as functions of their ranges. The solid lines correspond to the ions accelerated by the RRC and extracted to the atmosphere.

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References

1) A. Yoshida et al.: In this report.
2) J. F. Ziegler: http://www.srim.org.