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The proton-beam has been known as an useful radiation source for treatment of cancer since it has a well-defined range and the characteristic sharp Bragg peak. Radiobiological experiments with proton-beam of energy higher than 100 MeV have been extensively reported in literatures.[1,2] However, the radiobiological data for protons of lower energy are very limited. Before applying biological samples for irradiation, the proton beam must be uniform with a given intensity over at least 100 cm^2 of irradiation field. Further high accuracy in dose measurement at varying depth of tissue is also an essential prerequisite. We describe here a method to control proton-beam (Ep maximum of 40 MeV) generated by Tohoku University cyclotron for radiobiological experiment and the resultant beam characteristics is presented.

Experimental Setup:

Proton-beam directly emerged in air from the transport pipe though 25 m Ti foil showed a large variability of the intensity within the irradiation field. In order to achieve the required homogeneity, the protons (Ep = 40 MeV) emerging from the pipe were focused onto a quartz plate (1 mm thick) and the beam profile was measured by X-ray film (Kodak X-Omat V) at 150 cm apart from the focus in air. The result is shown in Fig. 1. The relative photographic density as a function of the distance from the center shows a Gaussian distribution perpendicular to the beam axis. The result was unchanged when the density was converted to R with a reference of ^{60}Co gamma-rays. The final experimental setup is shown in Fig. 2 where protons were focused in the pipe onto a quartz plate and the beam emerging from the scatterer of quartz was further transported in a distance of 4.3 m, then extracted out into air through Mylar foil (1.38 g/cm^3) of 200 μm thickness (beam diameter of 20 cm). A plastic scintillator was placed beside the disconnected portion of the transport pipes to measure only proton-induced photons as shown in Fig. 2. Dose measurements were performed using a specially built parallel plate ionization chamber with ionization volume of 0.1 ml. The plates are made of Lucite with a thin graphite coating. The collected charge with a collecting potential of 200 V was measured with a vibrating reed electrometer (Takeda Riken Co., LTD, TR84). A motor-drived stepwedge of Lucite (1.20 g/cm^3) was placed 20 cm from the beam exit and in front of the parallel plate ionization chamber.

Result:

The Bragg curves obtained from 38 MeV protons are shown in Fig. 3 and the peak was located at Lucite thickness of 1.17 g/cm^2 with the quartz scatterer of 1 mm thickness and at 1.02 g/cm^2 with the scatterer of 1.4 mm thickness. The ratio of the intensity at Bragg peak to plateau was about 5.7 which was identical to those measured by others.[3,4] The beam profile in film density at the beam exit indicates that the dose distribution was uniform within 10 % over the beam diameter of 20 cm. In order to correct the variation of dose rate due to the fluctuation of beam current during irradiation, a plastic scintillator for monitoring the number of proton-induced photons was confirmed useful since the number of photons/sec was linearly related to the ionization current measured by the ionization chamber as shown in Fig. 4.

These findings indicate that the proton-beam thus obtained is useful for biological irradiation with a sample of less than 10 mm thickness. The dose rate calculated from the ionization current was in the order of magnitude of 1 R/sec at a beam current of 1 nA which was further reduced to 10 % with the beam chopper.

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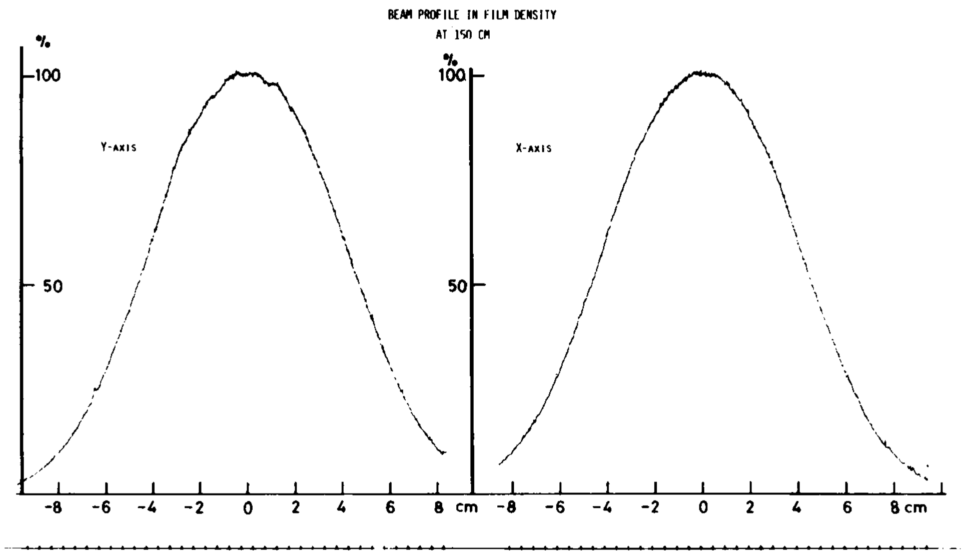

Fig. 1. Beam profile in film density at 150 cm apart from the focus in air as a function of the distance from the center.

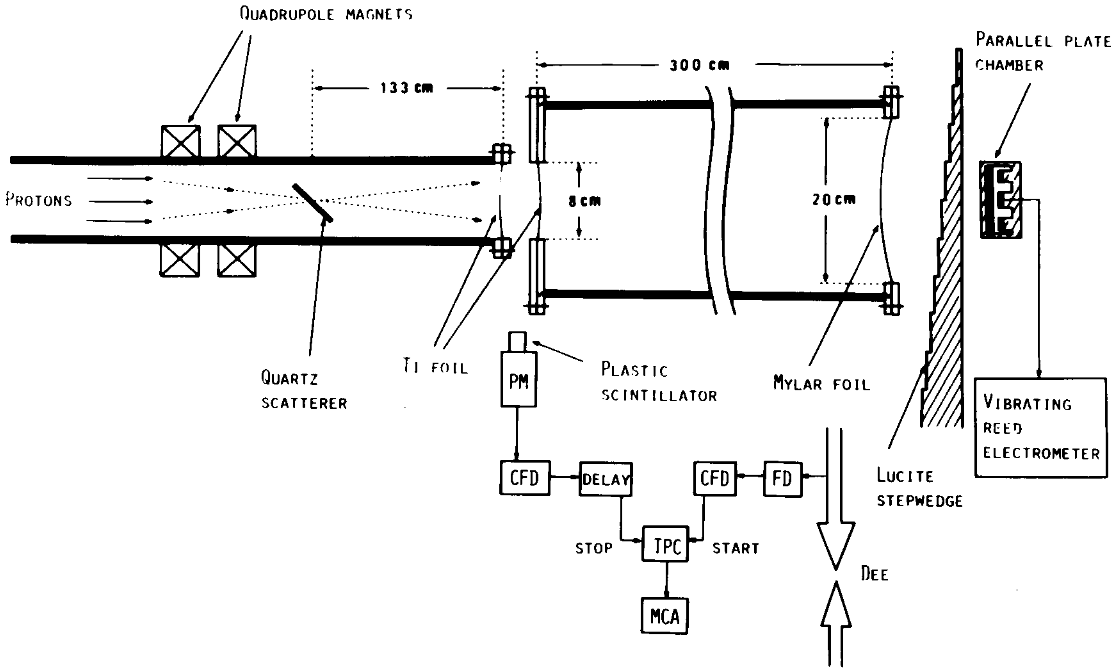

Fig. 2. Experimental setup. PM; photomultiplier, CFD; constant fraction discriminator, FD; frequency divider, TPC; time to pulse converter, MCA; multi-channel analyzer.

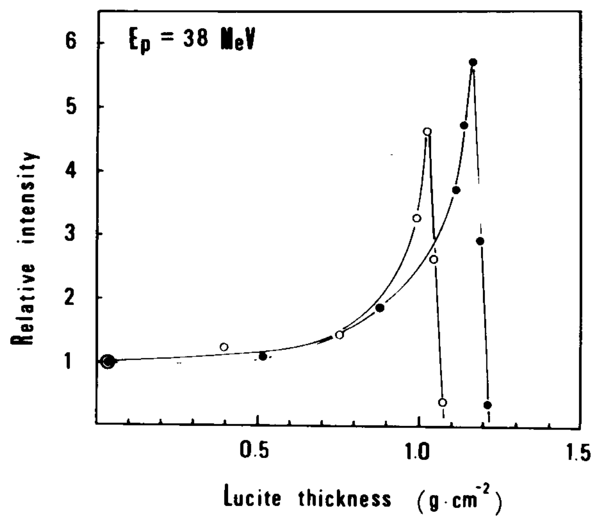

Fig. 3. Bragg curves of 38 MeV protons. Open circle for scatterer of 1.4 mm thickness and closed circle for that of 1.0 mm.

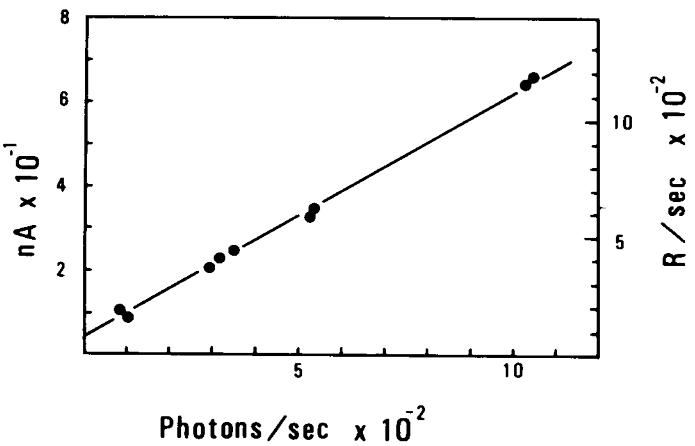

Fig. 4. Beam intensity as a funciton of the number of proton-induced photons.