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Application of an imaging plate to dose distribution measurement of clinical proton beams

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1. Introduction

The imaging plate (IP) has been widely used to measure the two-dimensional distribution of incident radiations since it has a high sensitivity, a wide dynamic range and a high position resolution. In our facility, the technique has been applied to the dose distribution measurement of clinical proton beams. Some fundamental characteristics have been investigated for quantitive dose evaluation: linearity of PSL intensity, fading characteristics, the lot dependence, the stopping power dependence and the tolerance of IP to radiation damage[1,2].

2. Experimental

Proton irradiation was carried out at the horizontal beam line of Proton Medical Research Center (PMRC), University of Tsukuba. In this beam line, approximately mono-energetic 250 MeV protons are delivered from the KEK 500 MeV booster synchrotron with the aid of a carbon energy-degrader and a momentum analyzing system. Delivered proton beams have a sharply-bunched time structure; each pulse consists of about 2 - 4 x 10^9 protons with a duration time of 50 ns in fwhm.

Firstly, the incident protons were scattered by a 3 mm-thick lead plate (referred as "first scatterer") to obtain laterally uniform spatial distribution. Between the first scatterer and a patient bed, some beam shaping devices and beam monitors were inserted, if necessary : i.e. a binary range shifter, a ridge filter, a field collimator and a secondary-emission chamber (SEC) monitor. A thimble ionization chamber (TIC), JARP C110, 0.2 ml, was used to measure protons; the reading was evaluated as "proton dose to water" with a correction of recombination effect. The sensitivity of the TIC had been calibrated in a ^{60}Co γ-ray standard field in advance.

The IP used in the present work was BAS-III 2025 (Fuji Film Co., Ltd.). Before each irradiation, latent images were erased off. During irradiation, each plate was kept inside a black thin vinyl bag. The scanner used was BAS2000-II (Fuji Film Co., Ltd.) with fixed scanning parameters of "Latitude" = 4, "Sensitivity" = 400 and "Resolution" = 200 μm. The upper limit of measurable PSL intensity in this setting is 10^5 PSL/mm^2. This is maximum one for BAS2000-II operation.

3. Results and Discussion

3.1 Linearity of PSL intensity to proton dose

Photo-stimulated luminescence intensity was measured for various proton dose from 0.003 Gy (1 pulse) to 0.240 Gy (75 pulses). A ridge filter was used to form a 70 mm iso-dose region in depth, "spread-out Bragg peak (SOBP)". An IP was placed in the SOBP. Stored images were readout 90 minutes after the termination of each irradiation. As shown in Fig.1, the PSL intensity is proportional to proton dose up to 0.148 Gy at least. At 0.224 and 0.24 Gy, readout PSL intensity reaches the upper limit of scanner range, 10^5 PSL/mm^2. It seems that the upper limit of measurable dose is controlled by the scanner range in this measurement.

3.2 Fading characteristics

Fading characteristics up to 200 minutes after irradiation were measured for various proton dose to water, 0.0108 ~ 0.132 Gy, under some temperature conditions, 22 ~ 26 °C. In this measurement, 7 ~ 10 sheets of IPs were stacked each other and inserted into the SOBP region; the influence of such stack configuration was carefully examined and found to be negligible for the present purpose. Protons were irradiated to those IPs simultaneously and each IP was readout after a certain duration to obtain the PSL intensity. This procedure was repeated and eight fading curves were evaluated. Those curves were normalized by the PSL intensity per proton dose at the termination of irradiation (t = 0 min.), I_0 (PSL/mm^2/Gy), and plotted in Fig.2. Before the normalization by I_0, a systematic difference of IP sensitivity was observed between two lot-groups in those fading curves. In Fig.2, all experimental data can be fitted well by a combination of two exponential curves with different time constants. A result of data fitting with two exponential decay functions gives the following equation:

$$I / I_0 = 0.25 \exp(-\ln 2 \times t / 15.5) + 0.75 \exp(-\ln 2 \times t / 3400).$$

This fading curve (I/I_0) consists of two components with half-lives of 15.5 minutes (25 %) and 3400 minutes (75 %).

3.3 Proton stopping power dependence

A Bragg curve was measured with IPs by changing a binary range shifter. The proton dose to water was measured by the TIC which was put just in front of the IP. The SEC was used as a reference monitor in order to compensate the slight beam-intensity fluctuation during irradiation.

Figure 3 shows the obtained data with different detectors, IP and TIC, as a function of the thickness of the range shifter. Each curve is normalized so that their plateaus come to the same level. As indicated in the figure, there is notable disagreement between the two curves beyond the peak position of Bragg curve. It should be kept in mind that the shapes of both Bragg curves are slightly distorted from the real dose distribution at the proximal region. This may be due to a scattering effect by the insertion of range-shifting material and use of thick dosimeters.

In Fig.3, the ratios of PSL intensity to proton dose measured by TIC are also plotted. That is normalized at the range-shifter thickness of 55 mm. From 0 to 190 mm, the ratio is kept almost constant. On the other hand, more than 190 mm, it decreases with approaching the distal edge.

3.4 Tolerance of IP to radiation damage

An unused IP was excessively irradiated as a spot by the 250 MeV proton beam. After latent images were adequately erased off, low dose protons were irradiated to the IP and the variation of PSL signals was measured as a function of the proton fluence which had been previously irradiated in excess. "Relative PSL intensity", which is defined as the ratio of the readout PSL signal to expected one for non-irradiated IP, is plotted as a function of proton fluence (Fig.4). From this figure, it can be seen that there is no notable deterioration of PSL signals up to 5 x 10^{12} protons/cm^2. More than this fluence, the PSL intensities start to decrease as the increase of fluence.This fluence corresponds to about 3000 Gy as proton dose to water.

4. Summary

The upper limit of measurable proton dose by an IP system is almost controlled by the readout range of scanner used. When stored images are readout 90 minutes after irradiation, reasonable linear response of an IP to proton dose to water is ascertained up to about 0.15 Gy. Fading curves are neither so sensitive to a small change of room temperature (22 - 26 °C) nor to a certain variation of proton dose (0.0108 - 0.132 Gy). As far as the measurements repeated in the present work are concerned, reproducibility of the PSL intensity seems to be fairly good if both the fading characteristics and the lot-dependence of the sensitivity of each IP are taken into account with caution. Stopping power dependence of IP response must be considered very carefully for the quantitative evaluation of dose profiles. Up to 5 x 10^{12} protons/cm^2, there was no notable deterioration of PSL signals. Less than this fluence, the influence of radiation damage is practically negligible.

References

[1] Y. Hayakawa et al., Nucl. Instr. and Meth., A 378 (1996) 627.
[2] A. Nohtomi et al., Nucl. Instr. and Meth., A424 (1999) 569

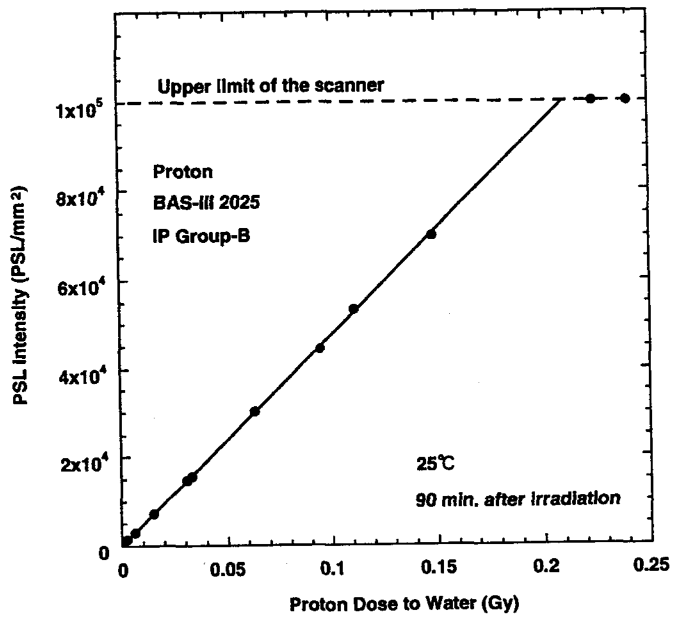

Fig.1 Linearity of PSL intensity to proton dose to water measured in an SOBP.

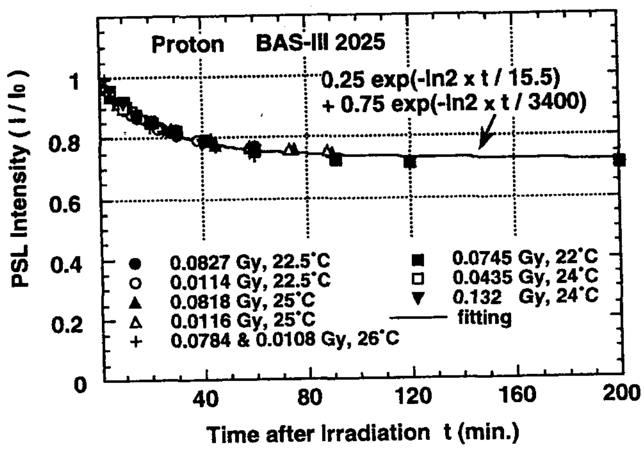

Fig.2 Normalized fading curves of PSL intensity.

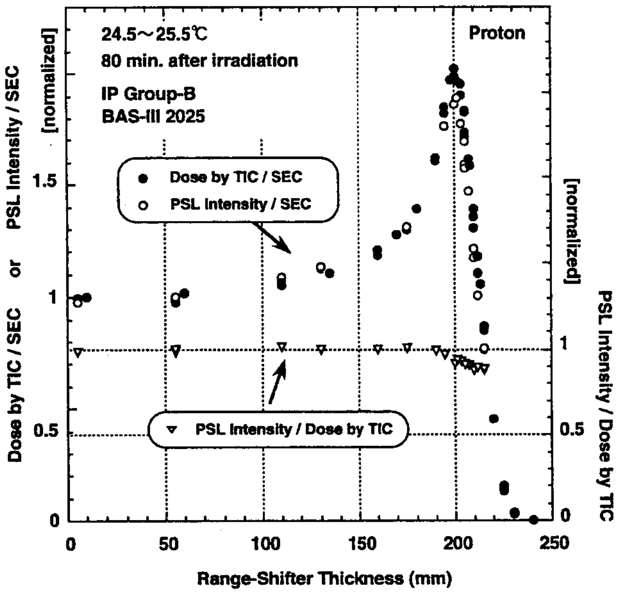

Fig.3 Bragg curves obtained by the TIC and IPs. The ratios of IP signals relative to the dose measured by TIC are also plotted.

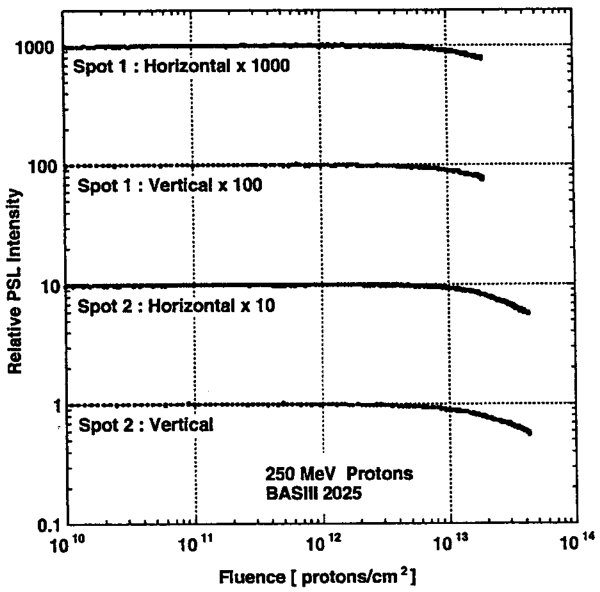

Fig.4 Relative PSL intensity as a function of proton fluence.