B2 - 1

Sensitometric Properties in Heavy Ion Radiography

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Introduction

Recently the heavy ion has been applied not only to the radiotherapy but also the radiography for its advantageous physical characteristics, for example a specific ionization curve with Bragg peak and a superior contrast resolution compared with a conventional radiography in the falling edge of Bragg peak[1]. Especially the heavy ion radiography is considered to be potentially useful for the quality assurance of the heavy ion therapy since the proton radiography is applied to a tool of the quality control in the proton therapy in practice[2] Therefor it is very important to estimate the characteristic curve, which is one of the factors characterized the image quality of heavy ion radiograph, and make fundamental properties of it clear.

In this study, we discussed the sensitometric properties in the heavy ion radiography using the intensity scale method with the industrial enveloped film which is often used in the heavy ion radiography.

Materials and methods

The experimental arrangement is shown in Fig.1. The 400MeV Carbon ion beam of Heavy Ion Medical Accelerator in Chiba at National Institute Radiological Sciences was used throughout this work. To obtain characteristic curves for each steps, a polyester step wedge of 0.4mm increments with 10 steps, each size of which is 1cm×10cm and the industrial enveloped films (X-TL) was placed in the center of the beam and the thickness of range shifter was adjusted to 184.1mm so that the step wedge should be at a position of the falling edge of Bragg peak. The intensity of irradiation was varied from 500 to 50000 beam monitor counts.

Exposed films were processed by the film processor (CEPROS 30 Fuji Medical Systems) under the condition of 45 s processing at 35.0 °C. Optical densities were measured by the specular densitometer with 10μm×1000μm aperture (PDM-5 Konica Medical) 9 times for

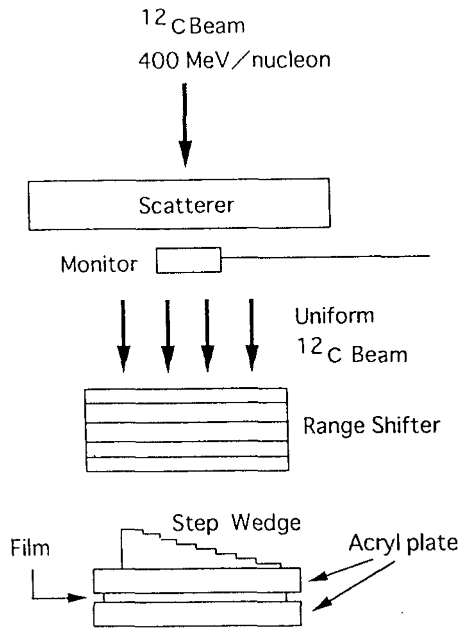

Fig.1. Layout of experimental arrangemennt.

each steps and the average of them was used to analysis.

Results and discussion

Characteristic curves and their gradient curves obtained at each steps is shown in fig.2 and fig.3 respectively. From fig.3, it is seen that the gradient curves depend on the thickness of step wedge. To manifest this dependence, the relation between the thickness of step wedge and the optical density corresponding the maximum values of gradient is shown in fig.4. In our previous work[1], we reported that the optical density dose not show a peak as is found in the specific ionization curve of heavy ion beam and is almost constant in the region that the number of heavy ions is invariant and start decreasing at in the region that the number of heavy ions decreases. This means that the optical density approximately depends only on the number of heavy ions incident upon emulsion but not on their energy. X-TL film used in the experiment is a double emulsion film and the number of heavy ions in the falling edge of Bragg peak varies extremely. Therefor the dependence of the gradient curves on thickness of wedge may be caused by the ratio of the number of hits on a front emulsion to that on a back one, g.

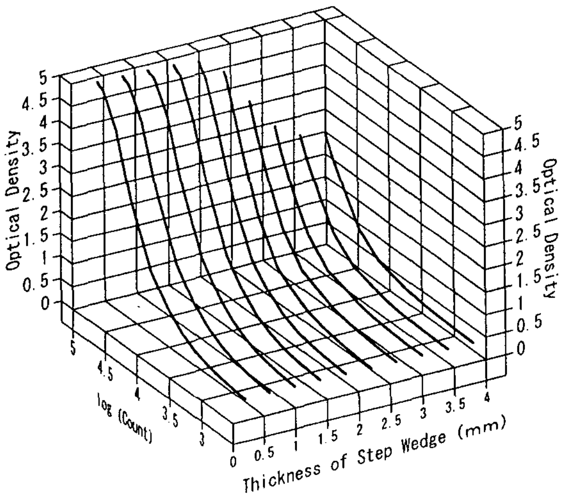

Fig.2. Characteristic curves at each steps.

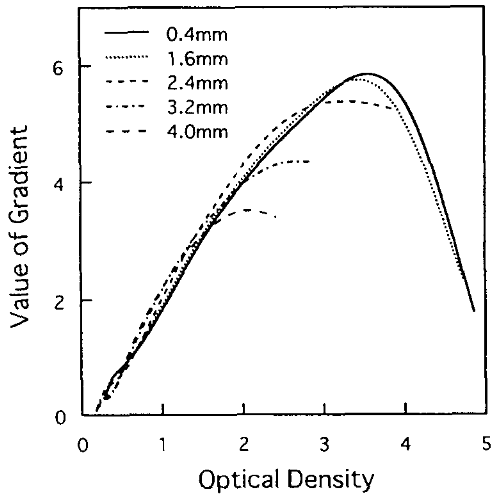

Fig.3. Gradient curves at each steps.

To concrete above consideration, experimental results are qualitatively analyzed based on m hits model of emulsion which is composed of identical grains, each requiring m (m = 1 for heavy ions) quantum hits for developability. In this model, the optical density D is given by [3]

$$D = \frac{1}{2} D_{max} \left\{ 2 - \sum_{j=0}^{m-1} \frac{1}{j!} \left\{ (\sigma X)^j e^{-\sigma X} + (\sigma g X)^j e^{-\sigma g X} \right\} \right\} + D_{base}, \qquad (1)$$

where D_{max} and D_{base} represent the maximum density obtainable in the emulsion and the density of the film base respectively and X is the number of heavy ions incident on a front emulsion per unit area and σ is the average cross section for quantum hits on a film grain. Then the condition for the maximum values of gradient G is expressed as

$$\frac{dG}{d(\log_{10} X)} = \frac{d^2 D}{d(\log_{10} X)^2} = 0 \quad (2)$$

From eq. (1), eq. (2) is the follow;

$$(1 - R)e^{-R} + g(1 - gR)e^{-gR} = 0 \ , \quad (3)$$

where $R = \sigma X$. The theoretical relation between relative value of net density and g under above condition is shown in fig.5. Since the value of g decrease as the thickness of wedge increasing, the theoretical result maintains the experimental one. The modulation transfer function (MTF) depends on the residual range[1] and therefor MTF measured by using a double emulsion film may be not necessarily accurate, such as an asymmetric screen-film system[4].

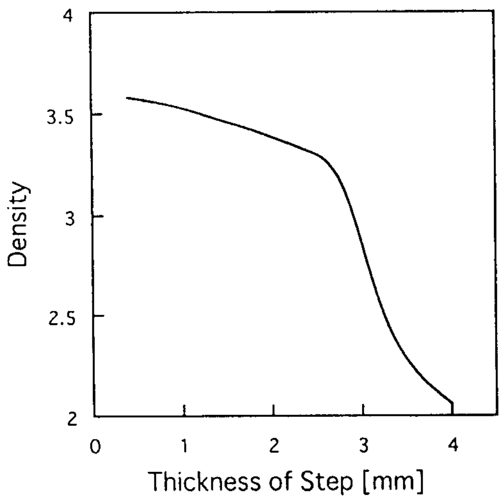

Fig.4. Relation between thickness of step wedge and density.

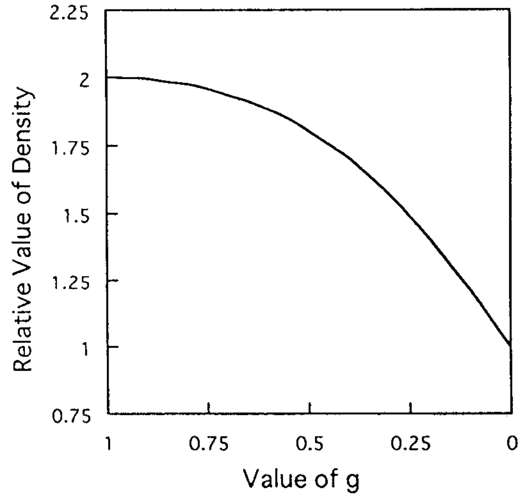

Fig.5. Relation between value of g and relative value of density.

Conclusions

Characteristic curves using double emulsion films varies by the thickness of object and its behavior is supported by the theoretical result based on m hits model. As the result, a use of a double emulsion film does not lead to the accurate characteristic curve so that a single emulsion film should be used for the accurate measurement of characteristic curves and MTF.

Reference

1) Inada T., Nishimura K., Satoh H., et.al. : Heavy ion radiography, Jpn. J. Med. Phys. 1996 ;16(3) 217-225.

2) Schneider U., Pedroni E. : Proton radiograph as a tool for quality control in proton therapy, Med. Phys. 1995; 22(4) : 353-363

3) Carl J. Vyborny H and D curves of screen-film systems: factors affecting their dependence on x-ray energy Med. Phys. 1979; 6(1) : 39-44
4) R.V. Metter : Describing the signal-transfer characteristics of asymmetrical radiographic screen-film systems, Med. Phys. 1992; 19(1) : 53-58