# **EVALUATION OF A FLUORESCENT SCREEN WITH A CCD SYSTEM** FOR OUALITY ASSURANCE IN HEAVY-ION BEAM SCANNING IRRADIATION SYSTEM

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## Abstract

Two-dimensional dosimetry system was developed for quality assurance (QA) of therapeutic scanned ion beams at HIMAC. This system consists of a fluorescent screen and a charge coupled device (CCD) camera. To evaluate the performance of this system, we carried out a few experiments for OA procedures. The verification of this system was also carried out by comparing the film dosimetry. As a result, we confirmed that this system could be used as the system for QA procedures of therapeutic scanned ion beams.

#### **INTRODUCTION**

Heavy-ion beams such as carbon-ion beams have attracted growing interest for cancer treatment due to their high dose localization and high biological effect at the Bragg peak. To make the best use of these characteristics and provide flexible dose delivery, three-dimensional (3D) pencil beam scanning [1-3] is an ideal irradiation technique. At the Heavy Ion Medical Accelerator in Chiba (HIMAC), it has been utilized for treatment since 2011 [4]. In a dynamic delivery system using the 3D scanning system, it requires additional quality assurance (QA) procedures to ensure a consistent and safe dose prescription, as compared with broad-beam delivery system. Since the accuracy and quality of the planned dose for the treatment depends on the accurate deposition of individually weighted pencil beams, any change of scanned beams will result in a significant impact on the irradiation dose. Thus, the OA procedures and tool for making refined measurements for the verification of the position and size of pencil beams must be developed. For this purpose, a few types of QA tool have been developed, such as an ionization chamber array and a radiographic film. These systems allow an efficient check of the absorbed dose in the treatment field at many points and perform a direct comparison with the planned dose at these points. However, the spatial resolution of the ionization chamber array is not so high. Although radiographic film is a very useful tool due to its high spatial resolution and suit for the measurement of the integral dose, overall data processing with the system is time consuming. Instead of these systems, we developed a quick verification system using a fluorescent screen with a charge coupled device (CCD) camera, which we called the QA-SCN [5], originally proposed by Boon et al [6, 7].

In this paper, the results of the OA measurements obtained by using the QA-SCN are described. The performance of the QA-SCN is evaluated from the viewpoints of utility as the system for OA procedures of therapeutic scanned ion beams. The verification of the OA-SCN was also carried out by comparing the film dosimetry.

#### **MATERIALS AND METHODS**

The technical details of the OA-SCN system, e.g., design of the QA-SCN, the control system and the off-line image processing, was reported previously [5]. A simplified explanation only is given here.



Figure 1: Schematic of the QA-SCN system layout.

The QA-SCN system was used to verify the 2D irradiation field deduced from the relative fluence on the isocenter without the water phantom. Figure 1 shows a schematic layout of the QA-SCN system. The QA-SCN consists of a fluorescent intensifying screen (Type HG-M2, Gd<sub>2</sub>O<sub>2</sub>S:Tb, Fujifilm Corp., Japan), a CCD camera (Type BU-41L, 1360×1024 pixels, Bitran Corp., Japan), a mirror, camera controllers and a dark box to protect against surrounding light. The CCD camera allows the measurements of 2D light output with a large dynamic range and low thermal noise, due to a decrease of the operating temperature of the CCD by a cooling unit. The QA-SCN is set at the isocenter. The distribution of fluorescent light is reflected by the mirror, located at 45  $\ge$ degrees relative to beam axis, and is observed by the CCD camera, which was installed at 90 degrees relative  $\gtrsim$ to the beam axis to reduce the background from the  $\odot$ radiation. The distance between the fluorescent screen

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and the mirror is 505 mm, and the distance between the mirror and the CCD camera is 535 mm. The viewing field and the aperture of the dark box covered an irradiation field of  $250 \times 250$  mm<sup>2</sup>, which corresponded to the specification of the irradiation system. Also, to verify the performance of the QA-SCN, the film was attached on the QA-SCN and irradiated with similar irradiation patterns.

After the irradiation, all of the detected images are transferred to data server at once, and the image processing is started. First, the background data are subtracted from the original image. To suppress the spike noises, the median filter is applied to the image after subtraction. Simultaneously, the pixel spacing is converted to the actual spacing as millimeters. To reduce the variations of output caused by lens vignetting and a difference in thickness of the screen, the flat field correction is applied. Figure 2 shows the profile of uniform irradiation field with and without these corrections. The overall level of the response is not affected by these corrections.



Figure 2: Profiles of irradiation field by a scanned ion beam with and without each correction. The dashed line shows the profile without correction. The dotted line shows the profile with background correction only. The continuous line shows the profile with background correction, median filter. The triangle shows the profile with background correction, median filter and flat field correction.

## **RESULTS AND DISCCUSION**

Several types of QA inspections must be performed to check the beam position, 2D intensity modulation and the effect of hysteresis for therapeutic scanned ion beams. The scanned beam position is directly affects the delivered dose distribution. Thus, we confirmed the accuracy of the position for scanned beam by using spot irradiation. Typical results of spot irradiation measured by the QA-SCN are shown in Fig. 3. Figure 4 shows differences between the measured and prescribed positions for three different irradiation fields,  $\pm 120$ ,  $\pm 80$ ,  $\pm 40$  mm. The results show the accuracy of  $\pm 0.3$  mm at 1-sigma. To verify the energy dependence of the scanned beam position, the measurement was also carried out by using the spot irradiation. As shown in Fig. 5, differences between the measured and prescribed positions for three different energies obtained by using small irradiation field ISBN 978-3-95450-119-9

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are within 0.2 mm at 1-sigma.



Figure 3: The results of spot irradiation measured by the QA-SCN.



Figure 4: Differences between the measured and prescribed positions for three different irradiation fields,  $\pm 120, \pm 80, \pm 40$  mm.



Figure 5: Differences between the measured and prescribed positions for three different energies, 430, 290, 140 MeV/n.

To verify the uniformity of the 2D irradiation field, we measured the uniform irradiation. Figure 6 shows results of 2D uniformity measurement. The upper and right-hand

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figures in Fig. 6 show the results for a typical one-dimensional distributions selected form the 2D irradiation measurements at both the horizontal and vertical irradiation lines for the treatment room F. The fluctuations of the uniform irradiation were small, 2% at the standard deviation. To check the spacing of each spot, we also fitted the uniform irradiation field measured by QA-SCN with multi Gaussian functions. The beam size and position, which are the parameter of the Gaussian function, were deduced from the measurements obtained by spot irradiation. Figure 7 shows the measured and fitting profiles of uniform irradiation field for three different irradiation fields. In any fields, we confirmed the spot spacing determined by fitting is within less than 0.1 mm of the prescribed position.

The performance of the QA-SCN was also verified by comparing the film dosimetry. To check the propriety of the beam position, we compared the results of spot irradiation measured by the QA-SCN and the film dosimetry in Fig. 8. In both measurements, differences between the measured and prescribed positions are within 0.2 mm at 1-sigma.



Figure 6: Result of 2D uniformity measurement obtained by using large uniform irradiation.



Figure 7: Fitting results of three different uniform irradiation fields using multi Gaussian functions.

As shown in Fig. 9, the differences between the uniformity of 2D irradiation by using the QA-SCN and the film were less than 1.2%. From these results, we confirmed measurements by the QA-SCN were good agreement with the film dosimetry.

Overall verification of the scanned beam can be realized by checking the 2D delivery with intensity modulation [8]. The checking irradiation pattern introduced by Flanz [8] was employed and measured by the QA-SCN. As shown in Fig. 10, the 2D irradiation with the intensity modulation was successfully performed. The measured distribution was good agreement with the expected one, i.e. 1.5% at 1-sigma.



Figure 8: Differences between the measured and prescribed positions obtained by using small spot irradiation field. The rhombus shows differences obtained by the QA-SCN. The square shows differences obtained by the film.



Figure 9: Result of 2D uniformity measurement obtained by using middle uniform irradiation. The continuous line shows the profile measured by using the QA-SCN. The dotted line shows the profile measured by using the film.

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Figure 10: Measured distribution in 2D intensity modulation. The dotted line shows the prediction.

### CONCLUSIONS

We evaluated a fluorescent screen and a CCD camera system, so-called the QA-SCN, used as useful tool for quality assurance of therapeutic scanned ion beams. Several types of QA inspections such as the accuracy of the scanned beam position, the uniformity of the 2D irradiation field, the verification of the spacing at each spot and the check of intensity modulation in 2D delivery, can be measured by using the QA-SCN accurately. Compared with the result of the QA-SCN and the film, in both measurements, the accuracy of the beam position was within 0.2 mm. The differences between the QA-SCN and the film by using 2D uniform irradiation were less than 1.2%. As a result, we confirmed that the QA-SCN could be used as a useful tool for QA procedures of therapeutic scanned ion beam.

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