Journal of NUCLEAR SCIENCE and TECHNOLOGY, Supplement 4, p. 318–321 (March 2004)

# Development of Multi-Channel Dosimeter System for Measurement of Dose Distribution in Therapeutic Photon Beams

Jhin Kee KIM[1, 3*], Bu Gil KIM[2], Jung Soo KIM[1,3], Hyeong Cheol KWON[1,3], Jung Hong KIM[4], Jung Ku KANG[5]
Young Kee OH[6], Kyo Chul SHIN[7], Jeung Kee KIM[8], Ki Hwan KIM[9], Dong Hyeok JEONG[10]
[1]*Research Institute of Clinical Medicine, Chonbuk National University, Jeonju,*
[2]*Biomedical Engineering, Chonbuk National University, Jeonju,*
[3]*Radiation Oncology, Chonbuk National University Hospital, Jeonju,*
[4] *Physics, Chonbuk National University, Jeonju,* [5]*Radiation Oncology, Chonju Jesus Hospital, Jeonju,*
[6]*Biomedical Engineering, Yeungnam University, Taegu,* [7]*Radiation Oncology, Dankook University Hospital, Cheonan,*
[8]*Radiation Oncology, Dong-A University Hospital, Pusan,*[9]*Radiation Oncology, Chungnam University Hospital, Taejon,*
[10]*Radiation Oncology, Wonkwang Univ. Hospital, Iksan, Korea*

We investigated the characteristics of the multi-channel dosimeter (MCD) system for dose distribution by the moving wedge in clinical photon beams. Also we developed an electrometer for the multi-channel dosimeter system for radiation therapy. In dynamic field irradiation, the virtual wedge technique and its fraction methods are available through the computer-controlled asymmetric independent collimator. The modified MCD system consists of an electrometer, a solid detector and an array phantom. The MCD is used for the point dose measurement and the field size scanning. Thus, we evaluated the dosimetric characteristics of the virtual wedge and the conventional fixed wedge by the radiation field analyzer (RFA). In our analysis for the 6 and 10 MV photon beams, the maximum dose in the virtual-wedge and the fixed-wedge factors varied from 1.2 % to 1.6 % for square collimator setting ranging from 10 to 20 cm, respectively. We constructed the modified MCD system with the developed electrometer for radiation therapy to improve on the analytical expressions describing the dose distributions for the virtual wedge and the wedge fraction method in 6 and 10 MV clinical photon beams.

***KEYWORDS: Variable-type wedge filter, wedge angle, multi-channel detector system***

## I. Introduction

The main target of radiotherapy is to increase the cure rate by medicating plenty dose in focused region to be treated. And the final purpose is to minimize the dose for normal tissue and the side effect occurred during treatment. Recently, the intensity modulated radio-therapy (IMRT) method and 3D conformal therapy have been developed to achieve these purposes.[1,2] These treatment methods are to make irradiation field along the shape of focused region from several directions and to medicate radiation dose for each direction. When we use this 3D conformal radiation therapy, we need to regulate the dose distribution according to shapes of irradiation surface and tumor, in which we can partially apply methods to use dose compensator or control dose of radiation and multi-leaf collimator or beam intensity modulated method. Another special compensator can be applied to give a change in isodose distribution of radiation path being situated. The commercial compensator of wedge form could be used as a special compensation device. During irradiation we used the special cover with and without such commercialized general wedge. In addition, we could change the some special compensation effect and the isodose distribution by controlling the irradiation time. In order to apply such effect, the techniques controlling the operating time of asymmetry collimator through computer have been used.[3-5)]

Among these techniques, the virtual wedge filter technique gives theoretically a change of the isodose distribution curve by asymmetry collimator. Since the radiation dose distribution in tissue is different from those of the fixed wedge, there is no decreasing phenomenon of dose, and the scattered dose becomes less. Also, it is reported for the virtual wedge to be more useful than the existing fixed wedge to make a relative direct wedge angle regardless of depth.[6-8)] We have developed an auxiliary device for such elaborated radiation therapy method, in which the exact radiation dose should be irradiated in tumor region in radiotherapy. The dose measurement method was repeatedly to measure the dose for specific position by the single measuring device. Therefore, the bulky measurement for all irradiation field sizes should be accompanied to get the dose information in irradiation field. There were overloads of machine by long-use, manpower and energy waste. And the radiation dosimetry was quite difficult in use of additional device such a variable-type wedge filter for therapeutic photon beams. [9,10)]

Because of the above problems and necessity of alternative method, we needed researches for the dynamic field and the MCD system. Variable-type wedge filter is a tool being attached to medical linear accelerator. We wanted to improve the dosimeter for wedge filter and to supplement the fixed wedge filter function, and wished

*Corresponding author, Tel. 82-63-250-1184, Fax. 82-63-250-1192, E-mail: kmjnki@chol.com

to accumulate some basic data for development of domestic instruments instead of the foreign expensive equipments. Therefore, we developed partially the MCD, in which the devices were modified applicable to dynamic wedge method.

## Ⅱ. Materials and Methods.

### 1. Specific property of dosimetry system

Diode detector, ion ionization chamber and thermoluminescence dosimeter (TLD) are being used to measure the radiation dose reaching in tumor volume in a phantom or in human body. In the ionization chamber, we measured by using electrometer the accumulated electric charge generated by the irradiated radiation. It was converted to the radiation dose by means of calibration factor such as temperature and atmospheric pressure. Since the semiconductor detector has usually small volume size with higher space resolution, and better radiation sensitivity than those of ionization chamber, and thus it is commonly used for the dosimetry of photon and electron beams.[11-13]

Since the measurement of dose distribution of buildup region should have high space resolution, we wanted to obtain repeatability for measurement by using a suitable semiconductor detector (Scanditronix p-Si detector, Sweden). Our external diode detectors was available for photon beams as follows: detector material is p-type Silicon, chip thickness of 0.05 mm, effective detection point of 1.5 mm, axial directional dependence within 2%, maximum deviation from linearity in the dose range 0.1 to 0.6 mGy within 1% dose per pulse, sensitivity variation with temperature 0.4% per degree centigrade.

We have used the reference ionization chamber (PTW-W30004, 0.6 ml, PTW, Germany) as standard dosimeter for the absorbed dose verification.

### 2. Composed detector system and signal transaction

For the dose detector system with multi-channels, the basic amplification circuit of detector output has been used by taking an advantage of the multiplex basic technology. First, we amplified the output of detector, and converted the detected data to eight-bit analog digital (A-D) converter, and applied the data processing program for eight channels, so that the simultaneous measurement could be available selectively. Because of very small detector output, after multiplying 100 times by using current-voltage amplification, we changed the small current to voltage. Basically, it is current-voltage conversion circuit, in which the current flowing into the input terminal of reversal amplification passes through the feedback resistance. Since we needed a high resistor with good stability, we put a potentiometer into the feedback loop to obtain the high amplification rate, and could make a high equivalent resistor. Because the drift current is also magnified together, we used the low-drift OP amplifier (OP-AMP). Resistance value of voltage dividing circuit must be selected carefully since its error is smaller than that of the feedback resistance. Since an OP-AMP must use small input bias current, the field effect transistor OP-AMP (3528BM of Barbrown Co., Ltd) are used, and the offset voltage quantity by bias current could be collected by making a non-reversal input. The A-D converter with a ADC0809 (National semiconductor Co.) was used, which is combined with a multiplex of 8 channels in input department. A data processing program of the system was developed using Delphi language, and the module controlling printer port was made with an assembler. The data of system were collected by printer port of computer. After selecting channel, we latched and inflicted conversion-opening signal of A-D converter. The end of A-D converter was done by inputting A-D converter output of 3 state buffer outputs by detecting the end-of-channel (EOC) signal of A-D converter. We made the data processing program to select each channel separatively, and analyzed the radiation dose, the dose rate, the percent-depth-dose (PDD) and so on, which are used commonly in radiation therapy. Also, we could store the measurement data into text file, and used it as beam data in treatment plan computer.

### 3. Measurement of dose distribution for wedge field

The depth dose distribution for 6 and 10 MV photon beams was measured and compared with each other by using standard measurement system (PTW-UNIDOS-W30004, PTW, Germany) in medical linear accelerator. We constructed the prototype system consisted of the multi-channel dosimeter system and p-Si semi-conductor detector (with sensitive volume of 0.25 ml, effective measurement point of 0.54 mm), and manufactured the auxiliary device with a flat style phantom for applying to the commercialized scanning system (RFA-7, Sweden). The scanning system used in measurement is consisted of a 3-D water phantom (with size of 51x51x51㎝$^3$), a dosimetry regulator and a remote-control system for positioning the detector.

We measured the depth dose distribution for standard field size about each photon beams, and measured the beam flatness to beam axis in 1.5, 5, 10, 20 cm depths. We also calculated the wedge angles from the beam flatness for variable-type wedge filter in 10 ㎝ depth, and compared them with the fixed-wedge angles.

## Ⅲ. Results and Discussion

For the measurement in the radiation dose distribution of cancer therapy by 6 and 10 MV photon beams, and for administration of the various treatment methods, we investigated the direction and mobility of instrumentation system, the beam flatness and the adaptability of dose distribution measurement by the signal process of multi-channel A/D conversion method. We amplified the output of detector, and converted the detected data into the digital data by 8-bit analog-digital converter (ADC8017), and applied data processing program for eight channels so that the simultaneous measurement is available selectively for data processing. In order to apply the multi-channel dosimeter system to adaptability of administration application for radiation therapy system, we manufactured, as shown in **Figs.1,2**, an adapter for the applicable detector arrangement in RFA 3-D phantom and the flat-type 2-D phantom, which are used in measurement. A dependence on direction of our semiconductor detector EDD-5 (Scanditronix, Commercial, Hi-pSi) with six channels was within 3%, 4% for axis and for direction of 45° tilt angle, respectively. The detector impedance was more than 350 MΩ in 0 V. The measurement data was reproduced within 2.1%, as shown in **Fig.3**, which indicate the dose profiles and the beam flatness for 6 MV medical photon beam. It was calculated in the difference between measured data of standard reference chamber and measured data of multi-channel detector.

Among these techniques, the virtual wedge filter technique gives theoretically a change of the isodose distribution curve by asymmetry collimator. Since the radiation dose distribution in tissue is different from those with the fixed wedge filters, there is no decreasing phenomenon of dose, and the scattered dose become less. Also, the virtual wedge is more useful than the existing fixed wedge to make a wedge angle regardless of depth, as indicated in **Figs**.4, and **Table 1**.

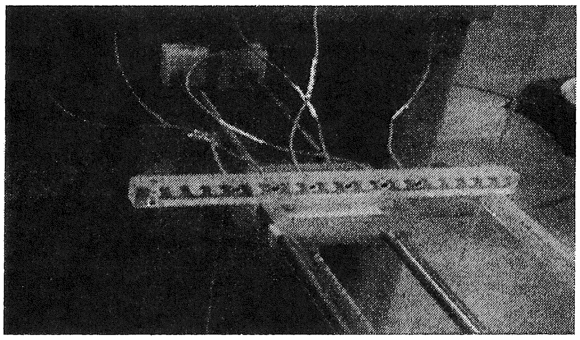

**Fig. 1.** QA Tools - Array adapter for scanning system

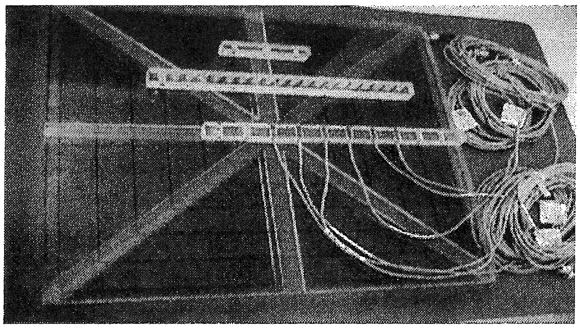

**Fig. 2.** QA Tools - Plate adapter for dose measurement

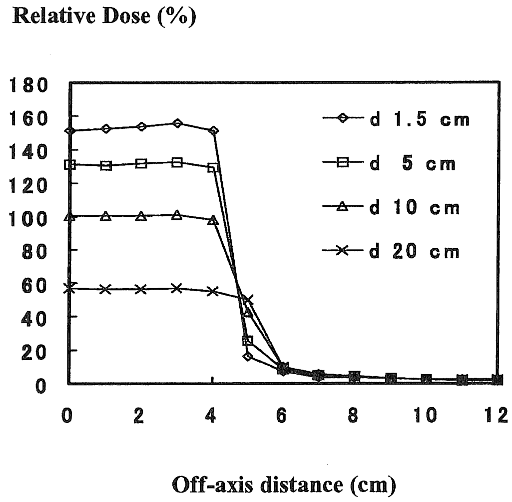


**Fig. 3.** Measured beam profile for 6 MV photon beam in field size 10x10 $cm^2$.

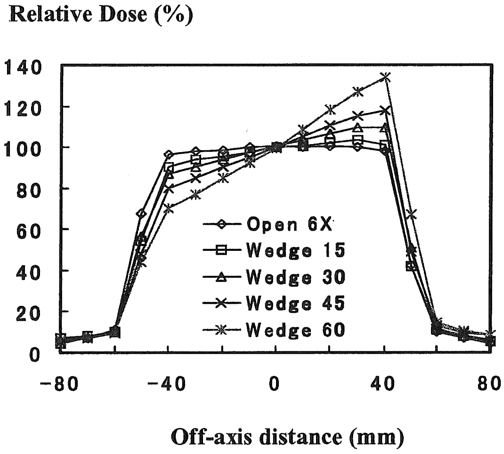


**Fig. 4.** Measured beam profile for 6 MV photon beam in wedge field size 10x10 $cm^2$.

It is necessary to define correctly the tumor region in human body for patient's radiotherapy, and to maximize the cure effect by means of exact amount of radiation dose at the planed region, and also to minimize the side effect by minimizing the radiation dose that is irradiated in normal region. In this case, the isodose distribution in therapy region is much deficient, because of the radiation diminution and the absorption property by the inhomogeneous body structure, the indeterminate form of tumor shape and limit of radiotherapy method. Actually, the randomicity of radiation dose distribution in tumor occurred by these causes is now permitted within 5% change. Except the above elements, an uncertainty of the radiation dose is increased by inaccuracy of radiation output of radiotherapy equipment, limit of data, dose measurement error and the dose calculation error. By these errors, the radiation dose that is irradiated in tumor in radiation treatment is permitted within 3% error from tumor dose.

**Table 1.** A comparison of virtual wedge angle measured at 100 cm SAD, depth 10 cm.

| Virtual Wedge Angle | 6 MV | 10 MV |
|---|---|---|
| 15 ° | 15.80 ° | 15.88 ° |
| 30 ° | 30.03 ° | 29.63 ° |
| 45 ° | 45.03 ° | 44.80 ° |
| 60 ° | 61.20 ° | 62.21 ° |

The program to minimize these errors is applied in each hospital unit, and also the quality assurance (QA) programs that enforce administration locally and nationally or internationally to confirm almost impossible systematic error within hospital have been developed by the International Atomic Energy Agency (IAEA) and several institutions, and been applied. However, these QA programs put an essential point in systematic error that can produce in irradiation to patient. There is danger that the excess or insufficient radiation dose is irradiated by output fluctuation or miscontrol of radiotherapy equipments, which can be happen in actual treatment.

To confirm occurring possibility of the various predictable errors and to irradiate the exact dose, we need the correct dosimetry and the QA administration with treatment method. Therefore, the maximum field size at radiation treatment is usually 40 x 40 $cm^2$.

We need to expand the number of channels of detector system to 64 channels in order to improve accuracy of dosimetry including all radiation field sizes which is used in the actual patient treatment by multi-channel dosimetry system. If one wants to use our multi-channel dosimeter system as the common measuring instrument, he should use the confidence amplification circuit to low drift by using the precision parts and through a circuit improvement, and to low noise in the amplification part of detector output to improve accuracy
of measuring instrument. The detector arrangement for measurement of the dynamic wedge method should be done by 1 ㎝ within. Our scanning measurement is available by 0.5 ㎝ within using by moving adapter.

In this research, we constructed an administration system about radiation therapy, dosimetry system of variable-type wedge filter, multi-channel dosimetry system, detector-signal amplification technology and data processing algorithm, which are considered to contribute to the radiometry equipment and the radiation QA research, and hereafter, our research is assumed to be applied to development of peripheral devices for radiation therapy.

## Ⅳ. Conclusions

Since the change of dose distribution is occurred by asymmetry collimator, there is no decreasing phenomenon in the internal radiation dose distribution, unlike with the fixed wedge filter. These results are considered to be very useful in applying to the irradiation methods for the relative linear wedge angle, other various wedge angles, method of mixing the fraction, and so on.

According to the arbitrary special shielding effect to be wanted, we could give the change of radiation dose distribution with and without the universal fixed wedge during irradiation and by regulating the irradiation time and by control of the operation time for asymmetry collimator.

To apply these effects, we investigated the dose distribution and the wedge angles through the measuring system composed of variable-type wedge filter. So we developed partially MCD, and devices are modified to be applicable to dynamic wedge method.

**References**


1) Convery DJ, Rosenbloom ME., "The generation of intensity-modulated fields for conformal radiotherapy by dynamic collimation," Phys. Med. Biol., 37, 1359 (1992).
2) Khan FM, Potish RA. Treatment Planning in Radiation Oncology. Williams & Wilkins, 187 (1998)
3) Klein EE, Low DA, Meigooni A., Purdy JA., "Dosimetry and clinical implementation of dynamic wedge," Int. J. Radiat. Oncol. Biol. Phys., 31, 583 (1995).
4) Lydon JM. Rykers KL., "Beam profiles in the nonwedged direction for dynamic wedges," Phys. Med. Biol., 41, 1217 (1996).
5) Leavitt DD, Martin M, Moeller JH, Lee WL., "Dynamic wedge field techniques computer controlled collimator motion and dose delivery," Med. Phys., 17, 87 (1990).
6) Leavitt DD, Larsson L., "Evaluation of a diode detector array for measurement of dynamic wedge dose distribution," Med. Phys., 20, 381 (1993).
7) Zwicker RD, Shahabi S, Wu A, Sternick ES., "Effective wedge angles for 6MV wedges from medical linear accelerators," Med. Phys., 12, 347 (1985).
8) Williamson JF, Khan FM, Sharma SC., "Film dosimetry of megavoltage photons beams-A practical method of isodensity to isodese curve conversion, Med. Phys., 8, 94 (1981)
9) Kijewski PK, Chin LM, Bjarngard BE., "Wedge-shaped dose distributions by computer-controlled collimator motion," Med. Phys., 5, 426 (1987).
10) Cross P, Joseph DJ, Cant J, Cooper SG, Denham JW., "Tangential breast irradiation: simple improvements," Int. J. Radiat. Oncol. Biol. Phys., 23, 433 (1992).
11) Grusell, E. Rikner, G., "Evaluation of temperature effects in p-type silicon detectors," Phys. Med. Biol., 31, 527 (1986).
12) Rikner, G., Grusell, E., "General specifications for silicon semiconductors for use in radiation dosimetry," Phys. Med. Biol., 32, 1109 (1987).
13) Slessinger ED, Gerber RL, Harms WB, Klein EE, Purdy JA., "Independent collimator dosimetry for a dual photon energy linear accelerator," Int. J. Radiat. Oncol. Biol. Phys., 27, 681 (1993).