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다목적 방사선 조사장치 개발 및 선량분포특성

(The Development of a Multi-Purpose Irradiator and the Characteristic of Dose Distribution)

李東勳*, 池永勳*, 李東漢*, 金潤鐘**, 洪勝弘**

(Dong Hoon Lee, Young Hoon Ji, Dong Han Lee, Yoon Jong Kim, and Seung Hong Hong)

요 약

다목적 방사선 조사장치의 설계, 제작 및 성능검사에 대해 기술하였다. 세슘-137을 사용한 다목적 방사선조사장치는 생물학에서 저선량 방사선에 대한 영향연구, 혹은 TLD(Thermo Luminescent dosimeter)의 교정을 위해 사용되어진다. 본 조사장치는 방사선 동위원소를 안전한곳에 저장하고 있다가 방사선조사시에만 조사실로 180도 회전하여 설정된 시간만큼 시료에 방사선 조사가 이루어 진 후, 사용이 끝나면 다시 차폐된 저장위치로 복귀하게된다. 제어시스템은 PLC 기반으로 구축하여 저선량율 조사장치의 시제품을 제작하였으며, 또한 컴퓨터를 통해 방사선 조사장치의 제어 및 세부 동작 상태 등을 실시간 검색, 원격제어 및 관리 할 수 있는 종합 관리 프로그램을 개발하였다. 조사실 내부 구성은 시료의 종류에 따라 최대 20RPM까지 다양하게 회전하면서 균일 조사될 수 있도록 조사실 및 챔버를 설계 제작하였으며, 조사실내 넣을 수 있는 조사체 최대 용량은 4.5리터이다. 조사실내의 방사선량의 분포도는 가프크로믹 필름을 사용하여 측정한 결과 2Ci 범위내에서 세슘-137의 경우 공기중에서 0.13cGy/min이었고 일반 물질과 등가인 물에서는 0.11cGy/min로 나타났으며, 오차는 약 ±7%의 한도내에서 균일한 분포를 보였다. 또한 실제 누설선량은 조사실 밖 표면에서 최대 0.35mR/hr이였으며 1m 떨어진곳에서는 최대 0.03mR/hr로 허용치 이내였다.

Abstract

The design, construction and performance test of a convenient multi-purpose irradiator is described. A multi-purpose irradiator using Cesium-137 has been developed for studies of low dose radiation effects in biology and for calibration of Thermo Luminescent dosimeter(TLD). During the operation, three rods of radioactive material which are 10cm in length revolve 180 degrees and irradiate biological samples, or TLD, and return to their shielded position, after the programmed time. A programmable Logic Controller(PLC) controls the sequence of operation, interlock, motor rotation and safety system. The rotation speed of biological samples can vary up to 20 RPM. A real time monitoring system was also incorporated to check and control the operation status of the irradiator. The capacity of the irradiation chamber was 4.5 liters. The isodose distribution at arbitrary vertical planes was measured by using film dosimetry. The dose-rate was 0.13 cGy/min in air and 0.11 cGy/min in water equivalent material in the case of Cesium-137. Range

* 正會員, 原子力醫學原 放射線影響硏究室

(Radiation Effect Lab., Korea Institute of Radiological & Medical Sciences)

** 正會員, 仁荷大學校 電子工學科

(Dept. of Electronic Eng., Inha University)

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of activity was 2 Ci. The homogeneity of dose distribution in the chamber was ±7%. The actual radiation level on the surface was within permissible levels. The irradiator had a maximum 0.35 mR/min radiation leakage on its surface.

Keyword : Irradiator, dose-rate, PLC, Cesium-137, Dose distribution

I. INTRODUCTION

There are so many studies using low dose in the fields of biology and medical science. So, the men engaged in those fields demand the irradiator can dose the experimental material precisely. Also that irradiator need to prevent radiation from leakage when the machine is under the operating because of using radio isotopes. Therefore the irradiator that is satisfied above mentioned demands is developed in this study.

There are several kinds of irradiators using radio isotopes. One is an irradiator for treatment of cancer patients and the others are for radiation effects research, experimentation and health side effects. One of the treatment machines using radio isotopes is a remote afterloading system. An afterloading system which transfers sources into cancerous tissue directly is also a part of primary radiation treatments. There has been a considerable increase in this form of cancer treatment because of accurate high dose-rates and low radiation side effects. Also, there are lots of irradiators for research to expose alpha, beta and gamma ray delivery from low dose to high dose[1-4]. The biological effects of low dose-rate radiation exposure are of importance to both radiation cancer therapy and radiation protection. A number of studies have shown that low doses of ionizing radiation can produce a stimulatory effect and induce adaptive responses to the harmful effects of a subsequent high-dose radiation exposure[5-6]. A self-contained gamma ray irradiator has been developed for studies of low dose radiation effects and also for calibration of TLD. It is a versatile gamma ray irradiator because source rods can be exchanged easily. So, irradiators for medium dose-rate can be created by replacing the low dose-rate source with a medium dose-rate source. It is particularly well suited for irradiating blood components, small animals, as well as other biological samples for radiation effects study. It is also possible to apply it in the field of agriculture for improving seeds by irradiation and for increasing shelf life in food. This irradiator can be also used as a standard radiation source for TLD calibration. This system has to be equipped with uniform dose distribution in the chamber and a large enough space for irradiating experimental animals easily and safely. The shielding and safety systems incorporated in the unit are designed to protect people from harmful amounts of radiation.

The design, construction and dose distribution in a convenient multi-purpose gamma irradiator that can change sources to Cesium-137, Iridium-192, Cobalt-60 and so on is described.

A irradiator stop functioning because it dose the experimental material using the radio isotopes that decay according as time goes. That time, the existing irradiators are done away. But the irradiator that is developed through this study can not only stock the source safely but also change the isotope source with source cassette.

II. Methods

<Fig. 1> shows the system configured with an input part, output part, control part and monitoring part. The input part was made up of several kinds of switches and a digital timer which controlled the irradiation time. The output part consisted of lamps to display the state of the irradiator, a motor to rotate samples and a cylinder to rotate the source

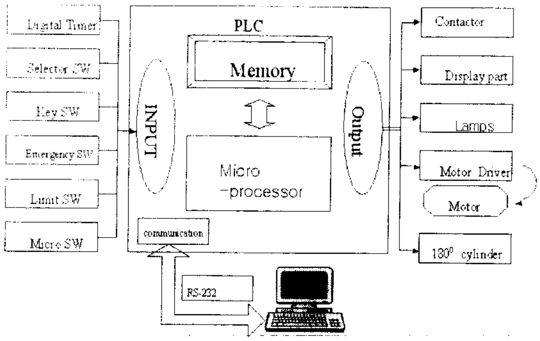

그림 1. 시스템 구성도
Fig. 1. System diagram.

180 degrees. The control part controlled all parts and communicated to the computer for the operation states and emergency states. The PLC controlled the sequence of operation, interlocks, motor rotation and safety systems. PLC could communicate with the computer using the RS-232C method. The real time monitoring system was also implemented to check and control the operation status of the irradiator. The rotation speed of the biological sample varied up to 20 RPM in order to irradiate uniformly by changing the potentiometer on the control panel.

1. Design of chamber

The housing of radioactive sources was designed like <Fig. 2>. Sealed sources were made up of three rods that contained five Cesium-137 sources about 20 mCi, 1-5 cGy dose-rate. Three rods which were 10 cm long were located equidistant with respect to the center of the chamber. The source housing also was curved to focus the irradiation to the center. Therefore, objects like biological samples could be uniformly exposed by sources without regard to position in the chamber. Also, a shield block was constructed with 7cm of lead(Pb) to prevent radioactivity from sources escaping. The whole source activity was 2 Ci in the case of Cesium-137. The change of source was very simple and convenient because the source rods could be separated and replaced easily. The radioactive sources were located in safe areas when the irradiator was not operating. Next, the whole source

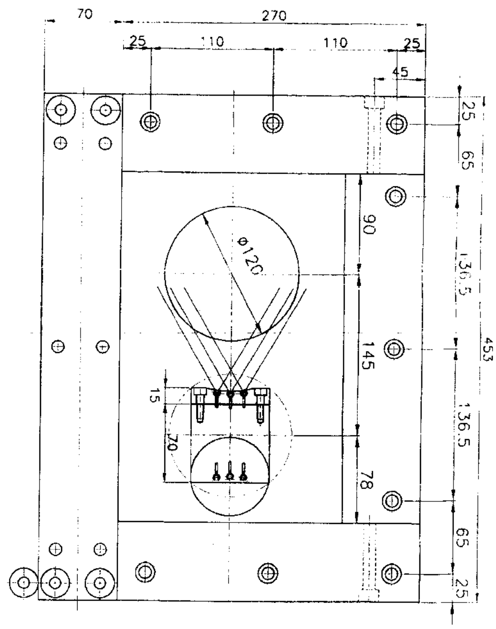

그림 2. 선원보관실 및 조사실 설계도
Fig. 2. The design of source housing and chamber.

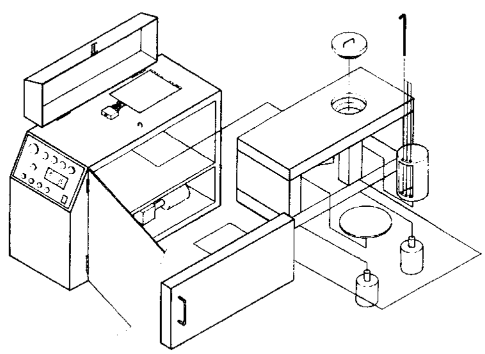

그림 3. 방사선조사장치 개요도
Fig. 3. Schematic diagram of the irradiator.

housing rotated 180 degrees and irradiated the samples with gamma radiation at the start of the process. The capacity of the irradiation chamber is 4.5 liters. <Fig. 3> shows schematic diagram of the irradiator.

2. Control system and operation sequence

The Control system is controlled by PLC. The PLC has digital I/O modules, analog I/O modules and RS-232C module for communication with monitoring system. An operator or user can control the irradiator by pushing buttons, by setting the

그림 4. 방사선조사장치 외관
Fig. 4. Photograph of the irradiator.

그림 5. 시스템 모니터링 화면
Fig. 5. Main Monitoring screen.

potentiometer for rotation speed of the samples and by setting the timer on the control panel. <Fig. 4> shows a photograph of the irradiator. The adjustable speed of the canister is from 0 to 20 RPM. The irradiating dose can be controlled by a digital timer from a second to several hours. The rotary operation of the source by an electric-pneumatic system using an air pump prevents radiation leakage from the source because the radioactive source automatically returns to a safe area from an active area when accidents occur, like a shutdown of the main power supply or opening the door while operating.

3. Monitoring program

The radioactive sources are useful for research and treatment of cancer, but they are very dangerous materials if exposed to the operator. Therefore, this system requires strong safety protocols. The monitoring program helps the operator to control the system in many ways. An operator can remotely control and view the status of the procedure during normal and emergency operation. If there is an error, the system informs the operator and provides a solution. <Fig. 5> is main screen of the monitoring and control unit. The irradiator system is operated not only by the manual control panel, but also remotely by using a mouse. The icons on the monitor are very similar to the control panel in the real irradiator system. In addition, the monitoring program tells the present system state and informs the operator about the next operation in the sequence with text messages and sounds. When an emergency state occurs, the system operates to prevent the radioactive source from being exposed automatically and simultaneously instructs the operator.

Ⅲ. Results

1. The absolute dose-rate and dose distribution

The absolute dose-rate in the chamber was measured with a PTW No.192 0.6cc ion chamber and PTW Unidos 10005 electrometer which had already been calibrated with a Cobalt-60 source before measurement. This dose-rate was measured in air and also in water. The absolute dose-rate in air was measured at the center of effective space in the chamber for 1 minute. The absolute dose-rate in water was also measured. The absolute dose-rate in air was 0.13 cGy/min and in water was 0.11 cGy/min

A gafcromic film 8.5 by 12.5 cm^2 was used for measuring the dose distribution at the center of the chamber. Because the position of the ion chamber which had been measured for absolute dose-rate was matched with the interval of film density, dose distribution according to position in the chamber could be calculated. The canister motor was rotated at 5 RPM for 150 minutes to irradiate material 20

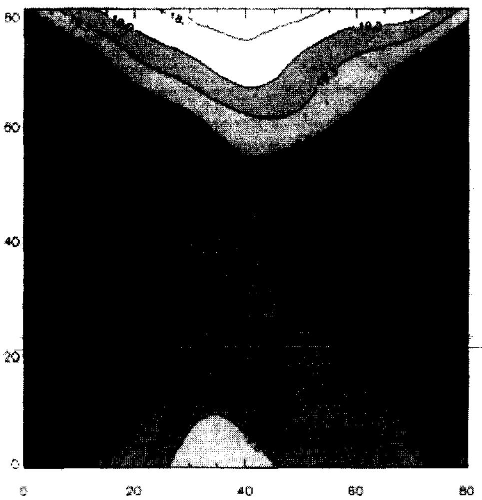

그림 6. 조사실내 방사선량 분포도
Fig. 6. Dose distribution.

cGy in air at the same position to produce the same absolute dose-rate. A film densitometer read the density at 1 cm intervals in the chamber 8 by 8 cm^2. <Fig. 6> shows the dose distribution at 1mm intervals after processing with the method of two dimension interpolation. The measuring unit is cGy in the figure.

The Dose distribution has a good homogeneity with a ± 7 % error ratio, when compared to other irradiators.

Also, The Radiation leakage from the irradiator surface was within 0.35 mR/hr and 1m away it was within 0.03 mR/hr.

2. Specification and Performance verification with TLD

<Table 1 > shows the specifications and characteristics developed in our laboratory

Several experiments have been conducted to investigate gamma ray irradiator characteristics, such as response to radiation, time, as well as linearity and reproducibility of the irradiator. The dependence of the output dose was examined by exposing the radiation detector, TLD UD-802AT from the Cesium-137 irradiator. Exposure time was 5 minutes. The number of TLD for experiments was twenty-six. The TLD detector showed excellent linearity and

표 1. 방사선조사기 사양
Table 1. Specifications of irradiator.

Items	Specifications
Source	^{137}Cs(15ea)
Range activity	2 Ci
Dose-rate in air	0.13 cGy/min
Dose-rate in water	0.11 cGy/min
Homogeneity of dose distribution	<±7%
Radiation level at surface	<0.35 mR/hr
Radiation level at 1m away	<0.03 mR/hr
Control & monitoring	Digital timer & PLC
Housing	Source Rotation(180°)
Irradiation chamber	4.5liter
Weight	900Kg
Power	220V/60Hz
Canister RPM	Max. 20rpm

표 2. TLD를 이용한 조사실내 성능검사
Table 2. Performance test with TLD.

	Dose(mSv)	Min(mSv)	Max(mSv)	Error ratio(%)
TLD1	6.65	6.63	6.68	0.3
TLD2	6.18	6.08	6.37	2.16
TLD3	5.45	5.41	5.50	0.74
TLD4	5.55	5.51	5.61	0.77

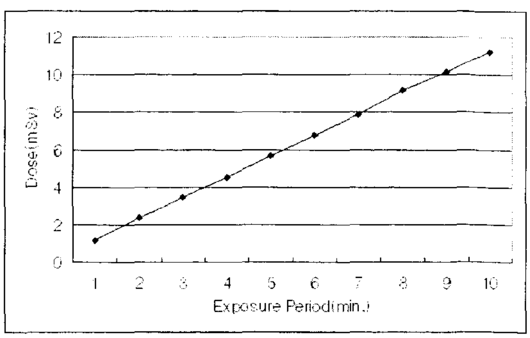

그림 7. 세슘-137에 대한 조사실내 선형성검사
Fig. 7. Linearity curve of a irradiator using Cesium-137.

reliability. Results are presented in <Table 2> and <Fig. 7> There are dose differences among TLD1 and

TLD4 in <Table 1> because of inherent TLD errors.

The error ratio was within 2.16%. The total dose deviation with TLD was ±10%. The results showed good reliability and homogeneity, the same as results using an ion chamber detector.

Ⅳ. DISCUSSION AND CONCLUSION

This irradiator was very well suited to investigate the biological effects of low dose radiation. The capacity of the irradiation chamber was 4.5 liters. The dose-rate was 0.13 cGy/min in air and 0.11 cGy/min in water equivalent material. The range of activity was about 2 Ci. The homogeneity of dose distribution in the chamber was ±7%. The actual radiation level on the surface was within permissible level. The PLC controls the sequence of operation, interlock, motor rotation and safety system. The rotation speed of biological samples could vary up to 20 RPM. The real time monitoring system was also incorporated to check and control the operation status of the irradiator. The irradiator has a maximum of 0.35 mR/min radiation leakage on its surface.

We plan to use the irradiator with uniform gamma rays on biological cells, blood and experimental animals to study radiation effects for low and medium dose radiation. In addition, we can also use the irradiator for TLD calibration.

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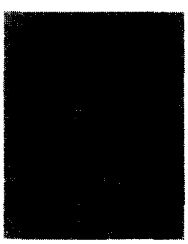
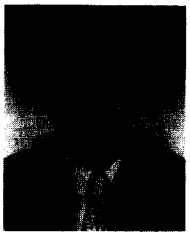


李 東 勳(正會員)

received the B.S., M.S. and Ph.D. degrees in electronic engineering from Inha University, Inchon, Korea. He has worked for the application of accelerators. He was involved to produce Radioisotopes and neutron therapy with cyclotron MC50 and also worked for the Dept. of Radiation Oncology. Now, His interesting fields are Radiation detector, Digital Radiography and medical accelerator application fields

池 永 勳(正會員)

received the B.S. and M.S. degrees in physics from Hanyang University, Seoul, Korea. He has worked for medical physics. He is now the korean association for radiation protection, editor and korean society of medical physics, secretary.



李 東 漢(正會員)
received the B.S. and M.S. degrees in physics from Kyungpook University, Kyungpook, Korea. He has worked for medical physics. He is now Korea Cancer Center Hospital, senior engineer and medical physicist.

金 潤 鐘(正會員)
received the B.S. and M.S. degrees in electronic engineering from Inha University, Inchon, Korea, in 1997 and 1999, respectively. He is now a Ph.D. candidate for electronic engineering, in Inha University. From 1997 to 2002, he worked as a biological system engineer in Korea Cancer Center Hospital. His research interests include Digital Radiography, Computer Vision and Bio-signal Processing.

洪 勝 弘(正會員)
received the B.S. degree in electronics from Inha University, Korea in 1964 and the M.S. degrees in 1966. He received the Ph.D. degree in biomedical engineering from University of Tokyo, Japan in 1975. He was a member of the Faculty of Kwangwoon University, Korea, during the 1969-1978 academic year. In 1978, he joined the Inha University, where he is now a Processor in the Department of Electronic Engineering. He was President of the Institute of Electronics Engineers of Korea in 1994, a chairman of the IEEE Seoul Section during the 1996-1997 and a chairman of the IEEE Korea Council during the 1998-1999.