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《Original》 Gamma-ray Dose Measurements in a Human Phantom Using Thermoluminescent Dosimeter

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Abstract

A human phantom of polyethylene has been designed and sculptured for studying the effective radiation safety control. The phantom has the approximate size of the Korean adult and was sliced into thirty-five transverse slabs, 2.5 cm thick.

The relative dose at the specified position was determined from the exposure that a TLD badge worn on the surface of the phantom body received from external γ-ray. The variation of the exposure as a function of depth in the phantom was measured for uncollimated γ-ray using TLD rods, and also isodose curves were obtained for the anatomical cross-section of the critical organs of the body.

To simulate radiation exposure condition in the nuclear facility, measurements were made for given angles of incident γ-ray. The front to back attenuation factor for human phantom of thickness 20 cm was 0.439 for Cs^{137} γ-ray which is in reasonable agreement with the published data.

요 약

방사선 안전관리의 효과적인 연구를 위해 유사인체 모형을 설계, 제작하였다. 이 모형의 치수는 한국인의 체격과 근사하게 맞추었으며 두께 2.5 cm인 포리에칠렌판 35매로 구성되었다.

유사인체모형의 표면에 착용한 열형광 선량계(Disc type TLD)로써 외부 γ-방사선에 의한 신체특정부위의 피폭선량을 측정하였으며, 아울러 깊이에 따른 흡수선량에 대해서 열형광 선량계(micro rod type TLD)로써 측정하여 결정장기 부위의 각단면에 대한 등가선량선을 얻었다.

선량측정은 방사선 작업자의 작업환경조건에 유사하도록 유사인체 모형에 대해 배치하고 여러 입사방향에 대해서 실시 하였다. 그 결과 Cs-137, γ-방사선에 대하여 두께 20 cm인 유사인체 모형에서의 감쇄는 0.439 였으며 이는 보고된 자료들과 잘 일치하였다.

1. Introduction

Personnel monitoring is particularly recommended in the radiation environment where it is necessary to renew the awareness of radiation harzards among the radiation workers. In radiological protection the maximum permissible doses recommended by the I. C. R. P.[1] are for specific critical organs of the body. Since the dose to an organ of the body cannot be measured directly, it is common to measure the exposure received from external radiation by a dosimeter worn on the front surface of the trunk. For the practical purpose, personnel dosimeter has to measure not only the exposure to the body but also absorbed dose of the critical organs in the case of need. An information obtained would also be imporatant in the event of a serious over-exposure, and for studies of population genetic and somatic hazards.

By making simplified assumptions about the radiation fields to which a men was exposed, Farr[2] has attempted the interpretation of ionization chamber readings in terms of organ dose, and Adams[3] has been able to estimate an upper limits to absorbed dose received by an internal organ of the body from the personnel film badge records. The uncertainties of personnel dosimeter used to measure surface exposure or the lack of depth dose distribution data for required γ-ray energy, have led to experimental studies using a human body phantom.[4] Although depth dose distribution of γ-ray for human tissue has been measured in many laboratories, there are many divergencies in applying this information to conditions more usually met with in radiation protection, because the data were commonly based on the purpose of radiation therapy.

In the present work a human phantom have been designed and sculptured, which has the approximate size of the Korean adult. The measurements of the variation of absorbed dose with depth and relative dose at specified body position have been made using a TLD, and trunk phantom which were irradiated at given incident directions of γ-ray. A more detailed description of this work is given in KAERI annual report.[5]

Table 1. Dimension of physique

Item	Present human phantom (cm)	Average for Korean (cm)[7]
Head	58	55
Neck	36	34.7
Shoulder	40	36.8
Chest	86.5	86
Abdomen	78	73
Pelvis	86	84
Sitting height	85.5	—

2. Experimental

1) Construction of Human Phantom

A human phantom has been designed and made of high density polyethylene equivalent to human tissue in atomic number. The human phantom has consisted of whole body but excluded of arms and legs, which is transected at 2.5 cm intervals for insertion of dosimeter or film.[6] The phantom contains ten transverse slab in the head and neck, five in the shoulder, and twenty in the trunk portion so it has approximately the full-sizes of the Korean adult based on the body scale reported by Sung.[7] Since his data are insufficient for woman's dimensions, living conditions and not classfied into urban and rural, etc., in the present work the phantom was slightly modified to the average-man corresponding to complete body 166 cm tall for Korean adults,

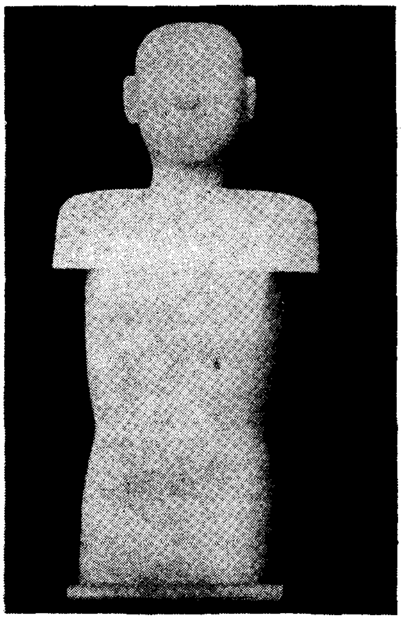

Fig. 1. Anterior views of homogeneous human phantom

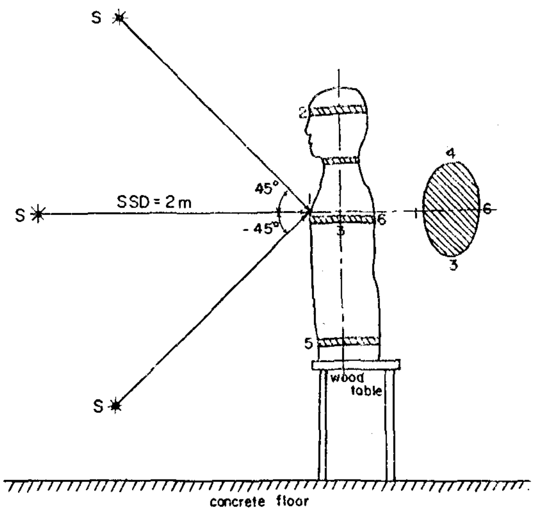

Fig. 2. Experimetal arrangement with human phantom

Dimensions of each body portion are shown in Table 1, but the phantom is a similar one rather than real physique for Korean adults. Anterior view of homogeneous human phantom is shown in Fig. 1. All cross section planes of the phantom are drilled in a gird array with 2.5 cm×2.5 cm spacing and hole dimensions are 1.2 mm in diameter and 6.2 mm in depth for installation of TLD or glass dosimeter rod. On the one hand, as the ovaries are located at a distance of 10 cm from the front surface and a distance of 11 cm from the back surface of the human body referred to report by Jones[8] the size of phantom prepared approximates to the human body and the measuring position covers the positions of the critical organs. The fundamental basis of phantom dosimetry is fully dicussed in the earlier publication.[9]

2) Experimental Procedure

a) Dosimeters

The relative dose at the specified position was measured with personnel badge system consisting of LiF-teflon dosimeter and TLD Reader (model 7100, Teledyne, USA). The TLD badge [10,11] was designed to utilize three LiF-teflon disc dosimeter. The response of each disc has been modified by filter in such a way that the thermoluminescence signals approximate directly the dose to the basal layer of the skin, the gonads, and the blood forming bone marrow over a wide range of energies. Disc type LiF-teflon dosimeter contains 30 mg of LiF-7 phosphor and the dimensions are 12.7 mm dia. ×0.4 mm thick. Also the variation[12] of exposure with depth in the human phantom was measured by LiF microdosimeters with the dimension of 1 mm dia. ×6 mm long. The most valuable feature of LiF dosimeter is its low energy dependence, *i.e.* the ratio of the response to 40 KeV and 1 MeV photons is only≒1.3,[13] and dose rate dependence of this dosimeter was reported to be negligible at least up to 2 × 10^8 rad/sec.[14,15] The range of measurable dose is about 1 mR to 10^5R,

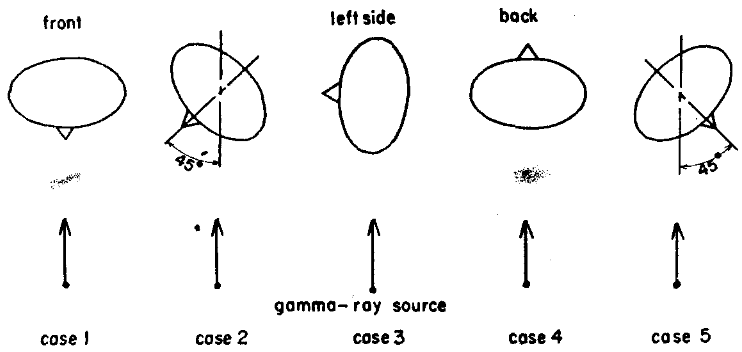

Fig. 3. An arrangement for determination of relative dose of human phantom site

Table 2. Relative dose to body sites

Case \ Site	Incident angle	Orbital region	Left axillary	Right axillary	Pelvis region	Meta-thorax
Case 1	45°	1.230	0.891	0.892	0.757	0.475
	0°	0.968	0.881	0.887	0.980	0.439
	−45°	0.846	0.932	0.920	1.319	0.374
Case 2	45°	1.155	0.945	0.498	0.822	0.521
	0°	0.993	1.050	0.348	0.911	0.420
	−45°	0.806	1.056	0.386	1.280	0.380
Case 3	45°	1.118	0.985	0.401	0.515	0.993
	0°	0.950	1.140	0.424	0.892	0.989
	−45°	0.910	1.264	0.353	1.438	0.892
Case 4	45°	1.441	2.042	2.148	0.714	2.321
	0°	0.891	2.100	2.000	1.095	2.230
	−45°	0.850	2.560	2.581	1.586	2.612
Case 5	45°	1.235	0.456	0.830	0.750	0.357
	0°	0.940	0.530	1.094	1.094	0.476
	−45°	0.886	0.496	1.106	1.310	0.510

Figures are normalized to the dose of thorax position

b) Irradiation

Irradiations were carried out with the Cs^{137} γ-ray source. Although the response of dosimeter was varied with the γ-ray energy from Ra^{226}, Cs^{137}, and Co^{60} respectively, the difference in response was within the limits of experimental errors. Therefore, Cs^{137} source was selected for a typical γ-ray source in this work. Since the attenuations of radiation in the medium are dependent on the initial energy of incident γ-ray, 75 KeV, 205 KeV, and 1.25 MeV irradinations were made using a X-ray machine (SHT, 250M, type 2, Shimadzu, Japan) and Co^{60} γ-ray source for the comparision of energy dependence. These sources were calibra ted with an ionization chamber of which the

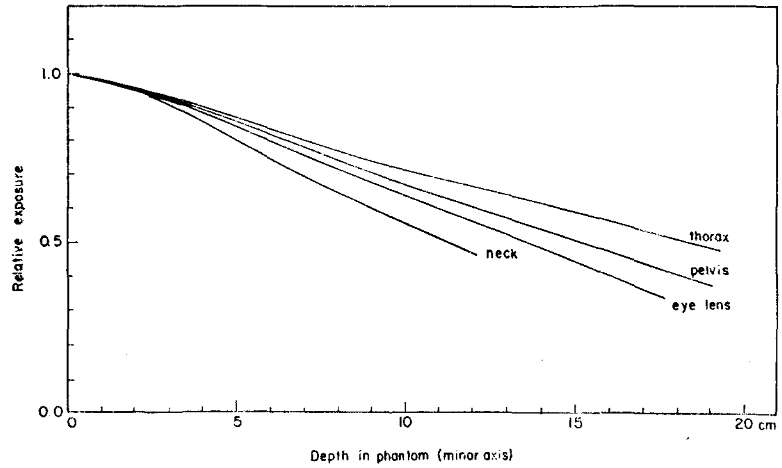

Fig. 4. Relative depth dose curves for uncollimated Cs^{137} γ-ray

accuracy is known to be $\pm 5\%$.

c) Experimental Arrangement

The absorbed dose of a particular tissue is determined by biological consideration, but it also depends on the type and direction angle of incident radiation to the body. To determine the critical organ dose which is significant in the radiation protectional point of view, a careful consideration in irradiation was made. As shown in Fig. 2 the human phantom was arranged on the wooden table which is 60 cm height above the ground level, thus the scattering contribution from the floor was eliminated, and a simulation of radiation exposure condition was made for the worker. Irradiations were made at a distance of 2 meters or more from uncollimeted γ-ray source so that the radiation field was a broad beam condition.

In order to measure the surface dose at the specified position, TLD badges were attached to the left middle-trunk, eyes, center of the back trunk, pelvis region and two lateral positions at the middle-trunk level. As shown in Fig. 3, five directions of incident γ-ray to the body are selected and the absorbed dose in various irradiation conditions is evaluated from the experimental data in terms of current.

3. Results and Discussion

1) Relative Dose to Body Positions

As has been mentioned previously, TLD badges attached on the given position of human phantom were exposed to uncollimated γ-ray source with fifteen directions of incidence. The exposure of the each position was normalized to that of middle-trunk position where personnel dosimeter is usually worn. The results are summarized in Table 2 and it shows the relative dose obtained by the TLD badge as a function of the position of the dosimeter with respect to the angle of γ-ray incidence. The variations of response of the detector are caused by the scattering effects and difference in absorptivity at the human body or by the directional dependence of the personnel dosimeters. The second column in Table 2 shows a vertical angle of incident γ-ray to the standing positions of radiation workers. For example, the gonadal dose estimated from the TLD badge worn on the upper part of the phantom's trunk was 75.7% in upper incidence,

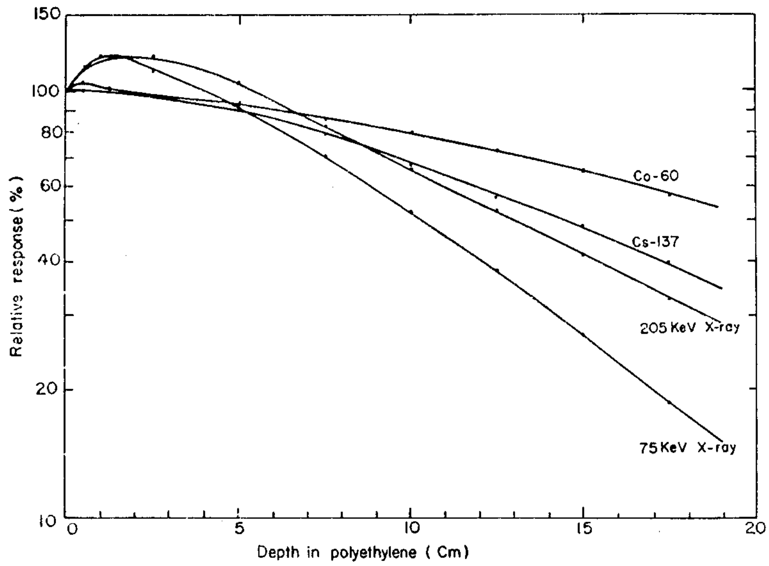

Fig. 5. Depth dose curves for human phantom normalized to surface

98.0% in normal incidence and 131.9% in lower incidence.

These results indicate that direction of incident photons makes a significant contribution to the gonadal dose, and suggest that the correction factors must be used in evaluation of exposure of the critical sites from personnel dosimeter readings. In the case of normal incidence, a calculational dose considering the γ-ray attenuation in polyethylene and inverse square law correction was 0.43 to an anterior surface dose of unity. This result agrees with the experimental value in less than 2%. When the γ-rays are entering from the back of human phantom, trunk dose of posterior surface obtained by the personnel dosimeter will be 2.32 times as much as the dose of anterior trunk. However, the deviation in the present work was about 30%, because the two TLD badge and γ-ray source were not in a straight line. In the case of the back and side incidence of γ-ray to the phantom to the reproducibility was not satisfied. Although the back incidence is not usual situation for radiation worker, this correction often plays very important roles for dose estimations.

2) Depth Dose Distribution

To estimate the critical organ dose from personnel dosimeter reading, absorbed dose distributions inside the human phantom were measured using lithium fluoride TLD rods. Among almost all the thermoluminescent substances generally used, LiF is the most satisfactory detecting medium[16] with respect to soft tissue because its effective atomic number is similar to that of the human tissues. From this, it may be aid that the TL reading will be directly proportional to the absorbed dose in the phantom.

The depth dose distribution was measured for only front-normal incident radiation against phantom. In order to measure the absorbed dose, four transverse planes corresponding to the eye, neck, thorax and pelvis region were chosen. The results of depth dose, measured for the minor axis of the human phantom and

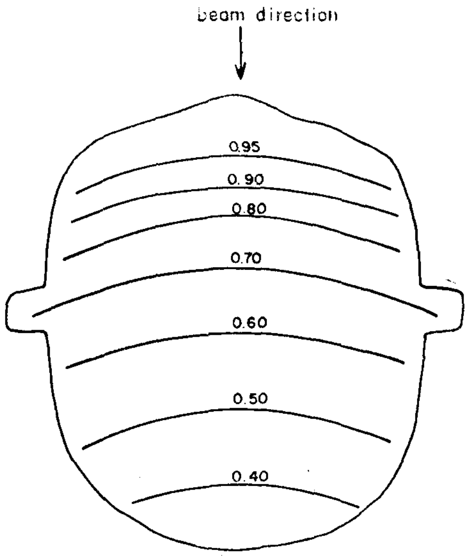

Fig. 6-1. Depth dose distributions relative to surface dose in an orbital region ($\theta=0°$)

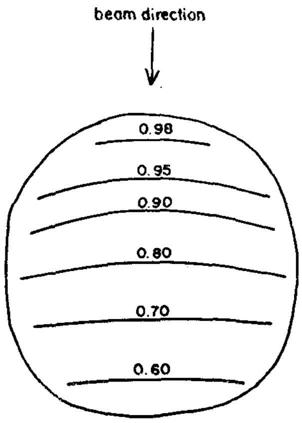

Fig. 6-2. Depth dose distributions relative to surface dose in a neck ($\theta=0°$)

normalized to unity against the surface exposure, are presented graphically in Fig. 4. No absolute calibration of the LiF rods was performed, since only relative dose measurements were ultimately required. As shown in Fig. 4, when depth dose curves in a given plane are compared with each other, it coincided with that obtained near the surface but with increasing depth it showed a divergency of about 20%. Because of rugged surface of the human phantom or geometrical arrangements of source and detector, attenuation of absorbed dose was not ideal form with somewhat unusual sharps.

To compare the above results with parallel irradiation to the transverse section of the human phantom and also to review the distribution of absorbed dose due to the different radiation energy, dose distribution in the polyethylene was measured using Co^{60} γ-ray, 205 KeV and 75 KeV X-ray.

The results are normalized against the surface dose and is shown in Fig. 5. The peak absorption dose takes place at various depths [17,18] from the phantom surface. The front to back attenuation factor for the phantom of thickness 19.7 cm varied from 0.52 to 0.14 for the energies from 1.25 MeV down to 75 KeV.

The data obtained were also presented as the isodose curves in those planes of the phantom selected for investigation. Each curve represented a percentage of the exposure at the surface of each plane as shown in Fig. 6. The relative doses at central part of the planes are higher than those at the edges as expected in homogeneous phantom. The patterns are similar in general, but there are some discrepances in dose distributions. These may partly be due to a difference in the incident angle of photons to each planes.

4. Conclusions

The results obtained by a single dosimeter in the position where the personnel badge is usually attached may be used to estimate the absorbed dose in various organs and positions of the body. The directions and energies of the incident γ-ray to the person must be known in order to derive the exact absorbed dose from the experimental data.

The absorbed dose, D, in any organ may

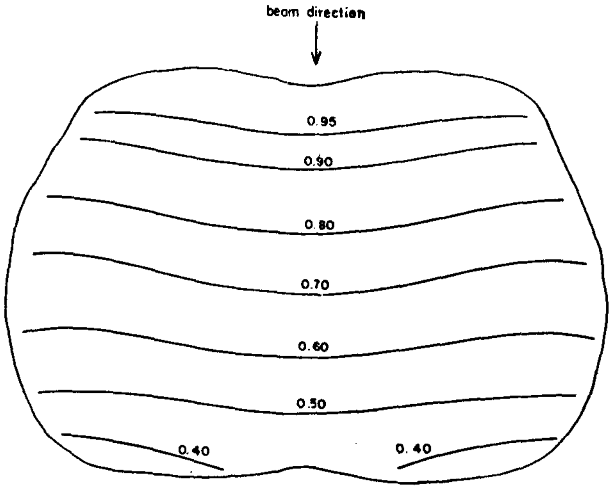

Fig. 6-3. Depth dose distributions relative to surface dose in a thorax ($\theta=0°$)

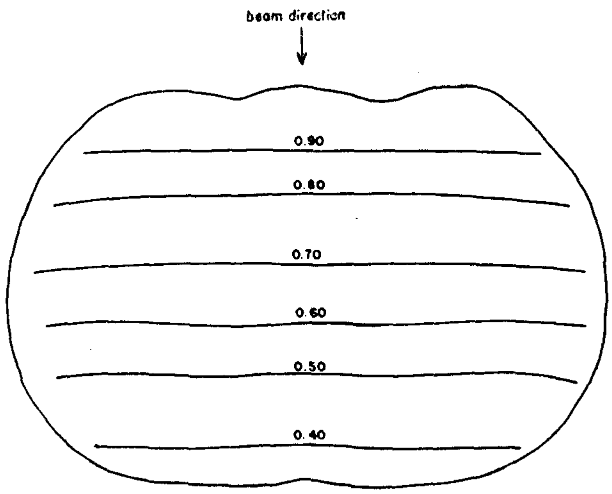

Fig. 6-4. Depth dose distributions relative to surface dose in a pelvis region ($\theta=0°$)

be expressed in terms of the incident exposure, E, in the following way:

$$D=C_i \cdot d_i \cdot E$$

where d_i is the depth correction factor of any organs position referred to Fig. 6, and C_i is the rad/roentgen conversion factor[19] which depends upon the atomic compositions of the tissue and upon the energy of the photons entering the phantom.

The method by which organ doses are estimated involves two steps. Firstly, the personnel dosimeters must evaluate the exposure to the radiation workers and the energy as well as the direction of the incident radiations. Secondly, applying the data to the relative dose of the body position and depth dose distributions of γ-ray in tissue, the absorbed organ dose may be calculated by a prior knowledge of the effective depth and weight of the organs considered. With TLD badges personnel exposure can be determined with the acceptable accuracy, and the largest uncertainty was found to be caused from the orientation during exposure. Further inter-comparison measurements and phantom studies will serve to evaluate the possibility of critical dosimetry based on a single dosimeter.

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