ABSORBED DOSE TO SELECTED INTERNAL ORGANS FROM TYPICAL DIAGNOSTIC EXPOSURES *

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Estimates of dose to internal organs from exposure to diagnostic x-ray beams are usually based on measurements of the entrance and exit dose and/or the use of depth dose curves for homogeneous media. This paper presents the results of a series of Monte Carlo calculations which mock-up typical diagnostic x-ray procedures. Results are presented for 22 internal organs as well as red and yellow bone marrow for two typical procedures. The calculations employ measured x-ray spectra from 45 kVp, 1-mm Al to 105 kVp, 2-mm Al and are for a field size of 14" x 17". In addition, depth dose profiles in various sections of the heterogeneous phantom are presented for each x-ray beam.

Introduction

It is well established that x-rays, particularly medical and dental x-rays, contribute the largest exposure to the population of any man-made source of ionizing radiation. The fundamental objective of the medical use of radiation is to obtain optimum diagnostic information with minimum exposure to the patient, and the radiological personnel concerned, and the general public. However, the problems posed when one attempts to estimate the doses received by various organs of the body from a medical exposure are among the most difficult problems the radiological physicist must face. The geometrical complexities and inhomogeneities of the body and the various organs make experimental simulation of the human body extremely difficult and usually unsatisfactory.

Monte Carlo techniques currently in use on high-speed digital computers have greatly facilitated the solution of these complex problems. These techniques have gained wide use in the field of radiation protection because the method allows one to perform an experiment by use of the computer. Many experimental arrangements and physical parameters, which can be described mathematically, can be operated on by the computer to produce the desired results.

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A Monte-Carlo-type computer program has been developed at the Oak Ridge National Laboratory, which can be used to estimate dose due to external photon beams typical of those employed in x-ray diagnosis.

Description of the Study

Two diagnostic x-ray procedures were simulated on a computer for these studies. Eight computer runs consisted of a set of exposures each of which simulated a chest x-ray and eight runs consisted of a set of exposures each of which simulated a G. I. x-ray.

The target for these studies was an anthropomorphic phantom, which may be considered to be two coexistent phantoms. One is that of an adult human body and some of its internality. It has been variously described [1,2,3,4,5] and in its present form represents a worthwhile target for these studies. It contains 23 internal organs including gonads, lungs, and four parts of the G. I. tract; it has ten skeletal parts with provisions for red and yellow marrows; and there is skin and there is tissue which includes muscle. The bone marrow and the bone are mixed homogeneously in the skeleton of this phantom.

The other phantom is called a geometric phantom. Whereas, in toto, it has the same outer dimensions and the same mass and composition of the human phantom, it is divided into dose regions by cutting planes and curves. For example, the trunk of the phantom has five layers, is divided into five concentric cylinders, and is cut by four vertical cross planes. This results in 85 subregions in which depth dose may be determined.

Both phantoms are heterogeneous by virtue of their composition which consists of 3 distinct media: tissue, lung, and bone with their concomitant densities and attenuation and absorption properties.

Each of the 16 exposures consisted of a collimated 36 cm x 44 cm (14 x 17 in) beam of 120,000 parallel photons incident on the posterior (P-A) of each phantom. In these calculations the source input was a set of eight measured x-ray energy spectra due to Epp and Weiss[6] at the Sloan-Kettering Institute for Cancer Research in New York City. The spectra range from 45 kVp, 1-mm Al filtration to 105 kVp, 2-mm Al filtration. The energy of each photon was determined from a normalized distribution of relative photon fluences per unit energy interval between 10 keV and 102 keV. Monte Carlo methods were used to follow the transport of each photon through the phantoms, determining the scattering angles, absorption sites, etc., and permitting the estimates of absorbed dose in units of absorbed dose per unit incident exposure (rad/R). The absorbed dose was calculated in the internal organs of the adult human phantom as well as in the volume elements of the geometric phantom.

Depth dose distributions in the trunk for the simulated chest x-ray exposures are presented in Figure 1. These data are for 36 x 44 cm beams incident on the posterior of the phantom. Illustrated are the effects on dose of the reduction in average energy of the beams and the attenuation of the beams as they pass through the phantom. For the high energy beam, the dose from the back to front drops off by a factor of 10. For the low energy beam, it is reduced by a factor of about 130. The average dose in the first 2 cm of tissue for the 105 kVp beam is 1.7 times higher than for the 45 kVp beam. Near the exit surface the dose for the 105 kVp is 23 times higher than that for the 45 kVp beam. Data for the simulated G. I. exposure are similar in magnitude and ratio negating the necessity to discuss these results in detail.

Often the radiologist uses the dose at 5 cm depth as an indicator of the average dose to the red bone marrow. Table I presents such a comparison of the data derived from the simulated chest exposures. The last column of the table is the ratio of the red bone marrow dose to the 5 cm depth dose and shows that the indicator mentioned above might lead to a 40% error.

Figure 2 shows dose to selected organs for a simulated chest x-ray as a function of average beam energy. There appears to be three pairs of curves. The pair with the highest dose represents organs definitely within the beam. The next highest pair, the upper large intestine and the thyroid gland, represents organs outside but near the edge of the beam. The last pair represents organs definitely outside the beam.

Lowering the beam location to a position which simulates a G. I. exposure caused a 50% increase in the dose from the low energy beam and a 20% increase in dose from the high energy beam to the red bone marrow. This result is due to the exposure of the pelvis which contains about 32% of the red bone marrow and was outside the beam during the simulated chest exposure. The dose to other organs, such as the uterus and the upper and lower large intestine, was increased by at least a factor of three at this lower exposure.

This study represents only a beginning in that it demonstrates the versatility of Monte Carlo techniques in the simulation of diagnostic procedures. The computer programs used allow various source descriptions, such as point sources located at various source to skin distances, divergent beams, etc. In addition, the beam size, shape, and angle of incidence on the phantom may be specified.

References

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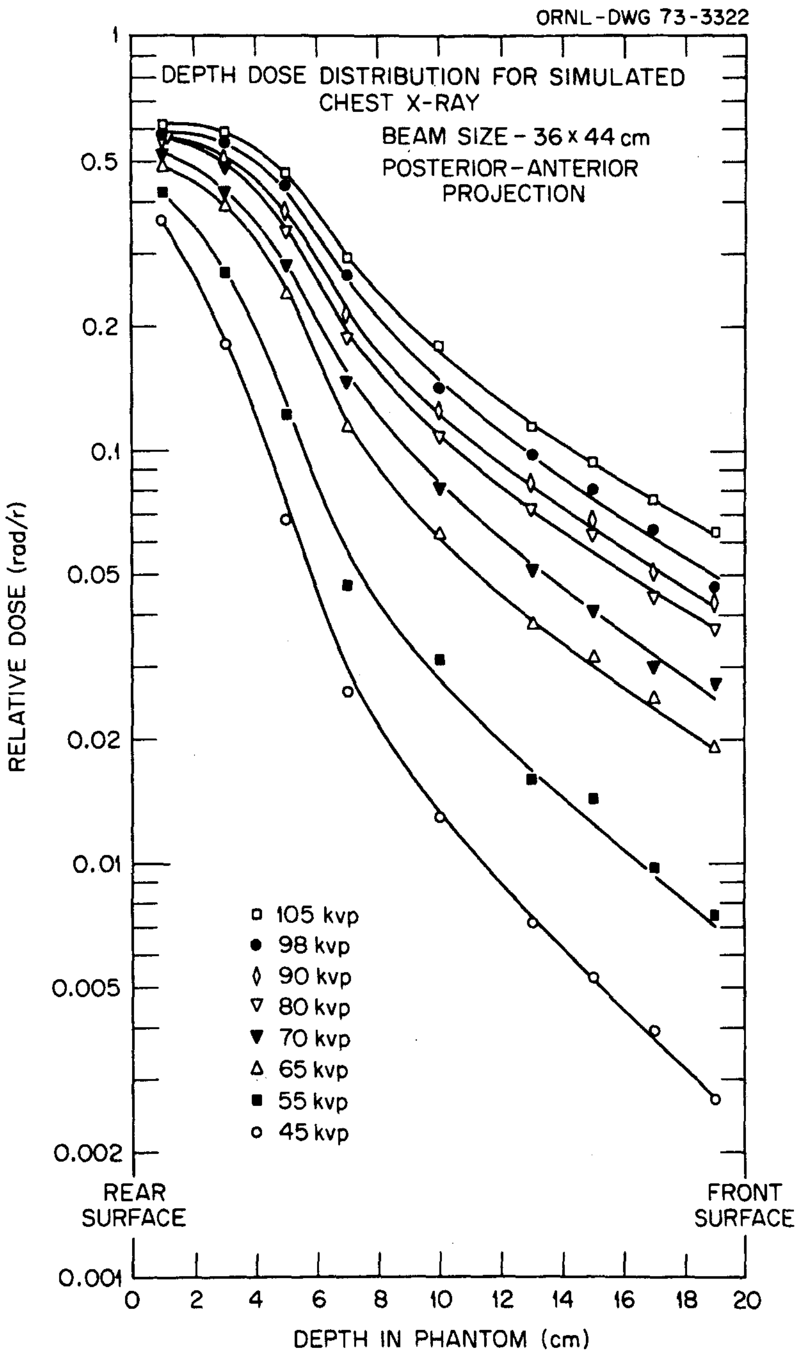
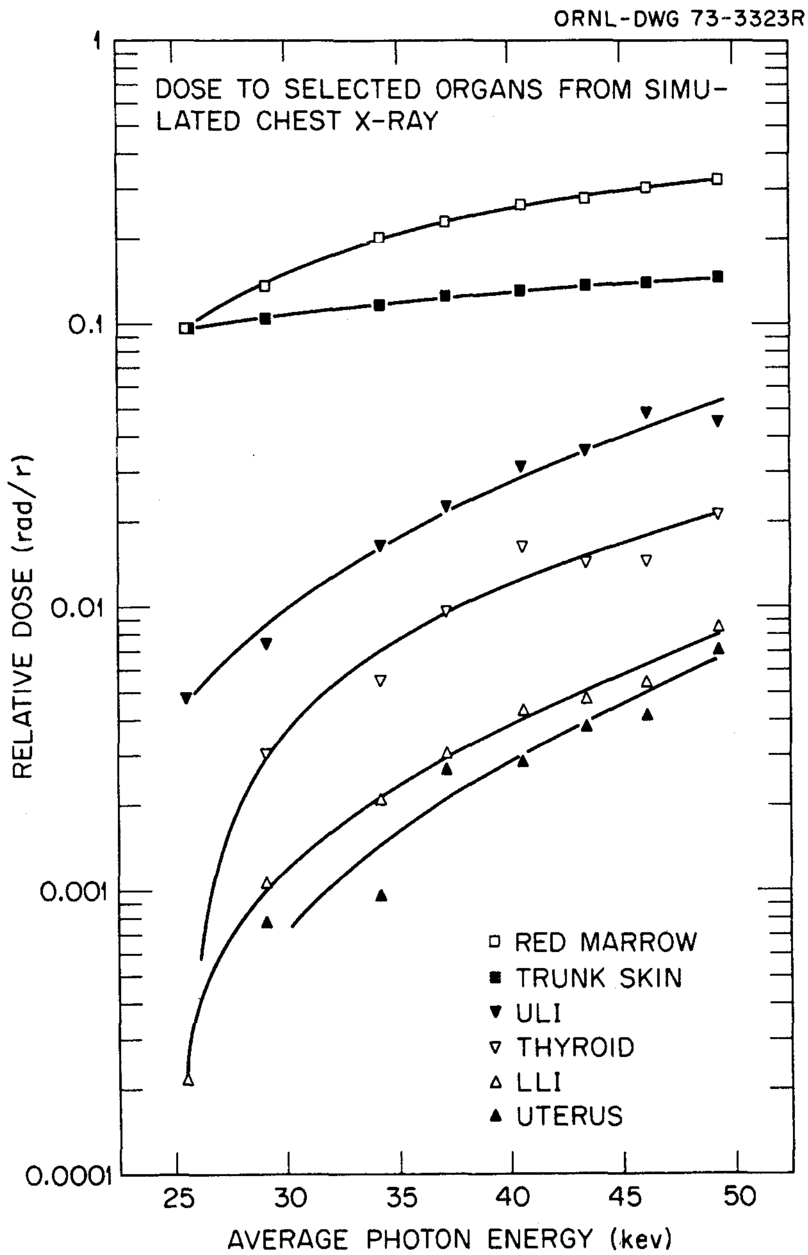
TABLE I. Comparison of Average Absorbed Dose at 5 cm Depth to Average Absorbed Dose to Red Bone Marrow

Avg. Beam Energy (keV)	Avg. Dose at 5 cm Depth in the Beam (rad/R)	Dose to Red Bone Marrow (rad/R)	Ratio
25.5	0.164	0.242	1.48
29.1	0.303	0.343	1.13
34.2	0.564	0.503	0.892
37.1	0.707	0.573	0.810
40.6	0.836	0.657	0.786
43.4	0.944	0.696	0.737
46.1	1.08	0.754	0.698
49.3	1.18	0.805	0.682


ORNL-DWG 73-3322
DEPTH DOSE DISTRIBUTION FOR SIMULATED
CHEST X-RAY
BEAM SIZE - 36 x 44 cm
POSTERIOR-ANTERIOR
PROJECTION
RELATIVE DOSE (rad/r)
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
105 kvp
98 kvp
90 kvp
80 kvp
70 kvp
65 kvp
55 kvp
45 kvp
REAR
SURFACE
FRONT
SURFACE
0
2
4
6
8
10
12
14
16
18
20
DEPTH IN PHANTOM (cm)


ORNL-DWG 73-3323R
DOSE TO SELECTED ORGANS FROM SIMULATED CHEST X-RAY
RELATIVE DOSE (rad/r)
1
0.1
0.01
0.001
0.0001
25
30
35
40
45
50
AVERAGE PHOTON ENERGY (kev)
RED MARROW
TRUNK SKIN
ULI
THYROID
LLI
UTERUS