MEDICAL X-RAY DOSE ESTIMATION PROGRAM
Progress Report
for Period Ending February 28, 1973

J. W. Poston
G. G. Warner

MASTER

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HEALTH PHYSICS DIVISION

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INTRODUCTION

The Health Physics Division at the Oak Ridge National Laboratory has undertaken a study to determine the feasibility of obtaining absorbed doses to internal organs from external sources of x-ray beams in the energy range 20 - 150 keV. The study was initiated as a result of an interagency agreement between the U. S. Atomic Energy Commission and the Food and Drug Administration. A previous report described the progress of the study from March 1 through August 31, 1972.¹ This report summarizes the progress from September 1, 1972 through February 28, 1973.

SCOPE OF THE WORK

The primary objective of this work is the calculation of average absorbed dose in several critical internal organs per unit of surface radiation exposure for normally incident external x-ray beams in the energy range 20 - 150 keV. Organs of primary interest are the ovaries, testes, thyroid, lens of the eye, and the red bone marrow. These calculations make use of Monte Carlo techniques which trace energy deposition

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**Mathematics Division.

histories of photons incident on the phantom. Energy depositions are recorded in a mathematical representation of an anthropomorphic phantom containing 23 internal organs, skin, and a skeleton containing both red and yellow bone marrow (see Figure 1). Details of the phantom and the techniques employed in this study have been reported previously²⁻⁵. Briefly, the phantom is comprised of essentially three regions: (1) a skeletal region, including bone, bone marrow, and other organic constituents; (2) a lung region; and (3) the remainder of the phantom. These regions are composed primarily of hydrogen, carbon, nitrogen, and oxygen. In the skeleton additional elements amount to about 18% of the total mass, with calcium and phosphorus accounting for most of this amount. In the lungs the composition is somewhat different from that of other soft tissues in the remainder of the phantom. The densities of the skeletal region (bone plus marrow), lungs, and the remainder of the phantom are approximately 1.5, 0.3, and 1.0 gm/cm³, respectively. The region outside the phantom is considered to be a void. Regarding the absorbed dose in the bone marrow, it is assumed that the bone and the bone marrow are mixed homogeneously in the skeleton of the phantom.

PROGRESS TO DATE

Calculations of absorbed dose to selected internal organs due to external photon beams were continued during this reporting period. Each calculation was made for a 4 cm x 4 cm collimated beam of parallel monoenergetic photons impinging on the front surface of the phantom. Beam locations were selected, on the right side of the phantom only, according to the grid network described in the previous report.¹ Photon energies of

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ANTERIOR VIEW OF THE PRINCIPAL ORGANS IN THE HEAD AND TRUNK OF THE PHANTOM

Figure 1. The Adult Human Phantom

30, 55, and 80 keV were used in these calculations. Figure 2 gives a schematic representation of a typical calculation. The absorbed dose per unit exposure was calculated for the organs of primary interest for each beam location.

The total number of grid locations (calculations) for each photon energy was: 55 keV - 120, 30 keV - 95, and 80 keV - 104. Absorbed dose per unit exposure to selected organs for each of these sets of calculations is given in appendices A, B, and C respectively.

The completion of these calculations and the subsequent analysis of the data have demonstrated the feasibility of this approach for providing estimates of dose due to x-ray beams. Results of each calculation were transmitted to the Bureau of Radiological Health in the form of conventional computer printout sheets as well as on magnetic tape. Further analysis is proceeding at the Bureau.

Several facets of the computer code were considered to require revision in order to provide a calculational geometry which is more realistic. These changes which were completed in anticipation of further calculations are described below.

The location of the testes in the phantom and the shape of the legs are two features of the phantom which were not very realistic. The phantom was originally designed for use with internally deposited emitters and the effect on the calculated dose of these geometries was not thought to be large. A detailed view of the new legs and male genitalia of the phantom is shown in Figure 3. Another feature which fits this same category is the shape of the head of the phantom. During this period, modifications in the phantom geometry which had been designed previously were incorporated

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Figure 2. General Arrangement for Typical Monoenergetic Photon Calculation

Figure 3. Legs and Male Genitalia of Phantom

into the existing Monte Carlo code. The new phantom geometry is shown in Figure 4. As can be seen in this figure, the modifications include the separation of the legs of the phantom, a region containing the testes, and a rounded region for the cranium or top of the head. These modifications resulted in a slight change in the total weight of the phantom. The phantom employed in the original set of calculations had a total weight of 70,024 gms whereas the new phantom weight is 69,880 gms.

The change in the shape of the head necessitated also the relocation of the lens of the eye region. A schematic diagram of the new region (in the Y-Z plane, $X=0$) is shown in Figure 5. The Z-coordinates of the lens region are now $Z = 81.5$ to $Z = 85.5$ whereas the Z-coordinates of the "old" region were $Z = 86$ and $Z = 90$. Table I presents data for three monoenergetic, 4×4 cm beams located over the thyroid gland. The number of collisions in the eye regions is increased due to the reduction in distance between the thyroid gland and the eye regions.

One of the primary changes in the code which was specified during the first phase of this research was a change in the elemental composition of the thyroid gland. The initial composition of the gland was assumed to be that of tissue² and did not include the element iodine. In the early calculations a second thyroid gland was added which contained in its composition an amount of iodine increased over that of standard tissue. Included in this 20-gm organ were 10 mg of iodine. A subroutine was added to calculate the absorbed dose for the "iodated" thyroid for each interaction in the standard thyroid. This approach, employed in the initial series of calculations, has been changed so that now there is only a single thyroid gland in the geometry, the elemental composition of which includes 10 mg of iodine.

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Figure 4. The Adult Human Phantom

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Figure 5. Schematic Diagram of Head of Phantom Showing Lens of Eye Region, Y-Z Plane at X=0

TABLE I. DOSE TO LENSES FROM A MONOENERGETIC
BEAM OF PHOTONS LOCATED DIRECTLY
OVER THE THYROID GLAND

Energy (keV)	NEW REGIONS*			OLD REGIONS**		
	Dose (Rad/R)	C. of Var. (%)	No. of Collisions	Dose (Rad/R)	C. of Var. (%)	No. of Collisions
30	3.36 -7	43.1	22	3.04 -8	95.3	4
55	6.35 -6	18.2	90	1.17 -6	38.5	26
80	1.13 -5	14.5	99	3.94 -6	28.8	37

* z coordinates for this region are 81.5 to 85.5

**z coordinates for this region are 86 to 90

During this period further efforts have been expended to reduce the running time and thus the cost of each calculation. These efforts have resulted in an optimization of the code and have reduced the running time by a factor of more than two. In the initial calculations a portion of the code which is used in calculating absorbed doses in 101 volume elements was deleted thereby reducing the running time by nearly 25 percent. However, this reduction was accompanied by the loss of the depth dose data. It is recommended that the "volume element" portion of the code be reestablished since the overall running time with the new optimization would still be significantly less than with the original code.

SUMMARY

During this reporting period over 400 individual calculations have been completed for 4 x 4 cm beams of monoenergetic photons of 30, 55, and 80 keV. These data in the form of computer printouts and on magnetic tape have been transmitted to the Bureau of Radiological Health. In addition, the phantom geometry has been modified to include a rounded head, the separated legs, a more realistic location for the testes, the relocation of the eye regions, and the resolution of the "two-thyroid" problem. Optimization of the computer code has resulted in the further reduction in running time by more than a factor of two.

ACKNOWLEDGMENTS

The assistance of J. P. Hickey in the preparation of the figures and tables reported herein is gratefully acknowledged.

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4. G. G. Warner and A. M. Craig, Jr., *ALGAM, A Computer Program for Estimating Internal Dose from Gamma-Ray Sources in a Man Phantom*, ORNL-TM-2250 (June 10, 1968).
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APPENDICES

Presented here are the results for all the calculations performed with the phantom geometry as reported in reference one. Appendix A presents results for 55 keV beams, appendix B for 30 keV beams, and appendix C for 80 keV beams.

Appendix A will be used to illustrate the use of the enclosed figures and tables. Figure A-1 is a plan view of the phantom used in the calculations. The grid network described in the first progress report can be seen on the right side of the phantom. The number in each block is the run number and corresponds to the point of incidence of the beam for that calculation. By selecting a beam location the calculated absorbed dose to the organs of interest can be obtained by looking up the run number (given in the square) in the table of results. Presented in the table are the coefficient of variation for the thyroid gland, ovaries, testes, lens of the eye, and red bone marrow. These values represent the absorbed dose due to direct and/or scattered radiation delivered to the particular organ by a beam of photons located in the designated position.

APPENDIX A

Summary of Calculated Absorbed Dose per Unit Exposure for 55 keV Photon Beams.

				1	
			31	2	115
	60	32	3	116	
			33	4	
			34	5	
			35	6	117
		61	36	7	118
106	84	62	37	8	
		85	63	38	9
		86	64	39	10
		87	65	40	11
		88	66	41	12
		89	67	42	13
		90	68	43	14
		91	69	44	15
		92	70	45	16
		93	71	46	17
		94	72	47	18
107	95	73	48	19	
108	96	74	49	20	119
109	97	75	50	21	120
110	98	76	51	22	
111	99	77	52	23	
112	100	78	53	24	
113	101	79	54	25	
114	102	80	55	26	
		103	81	56	27
		104	82	57	28
		105	83	58	29
			59	30	

Fig. A-1

Appendix A: Summary of calculated absorbed dose to organs of interest

Energy - 55 keV
Anterior-posterior exposure
4 x 4 cm beam

Note: 6.6 - 5 read as 6.6×10^{-5} rad/R

Run number	Thyroid		Ovaries		Testes		Lens of eye		Red bone marrow	
	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)
1	6.6-5	100	0	0	0	0	7.8-3	8.7	4.5-3	1.5
2	9.0-5	90	0	0	0	0	1.5-1	2.3	5.6-3	1.0
3	8.4-4	35	0	0	0	0	1.4-1	2.3	6.1-3	0.9
4	4.7-3	13	0	0	0	0	9.8-3	7.5	7.8-3	0.7
5	3.4-2	6.2	0	0	0	0	1.4-3	27	7.3-3	1.0
6	5.2-1	1.8	0	0	0	0	5.0-4	45	5.9-3	1.3
7	4.3-1	1.9	0	0	0	0	2.8-4	58	5.8-3	1.4
8	2.8-2	6.9	0	0	0	0	5.7-5	58	7.8-3	1.1
9	8.4-3	12	0	0	0	0	3.5-5	100	8.1-3	1.0
10	3.0-3	21	0	0	0	0	1.1-5	100	7.7-3	1.1
11	7.0-4	31	0	0	0	0	0	0	8.3-3	1.0
12	5.5-4	46	0	0	0	0	0	0	7.5-3	1.1
13	1.6-4	62	4.8-5	100	0	0	0	0	8.2-3	1.0
14	0	0	0	0	7.6-6	100	0	0	7.8-3	1.1
15	0	0	3.1-4	72	0	0	0	0	8.1-3	1.2
16	0	0	7.9-4	46	5.2-8	100	0	0	9.7-3	1.5
17	3.8-7	100	2.6-3	26	8.3-7	89	0	0	1.0-2	1.6
18	0	0	4.3-3	23	1.7-4	47	0	0	1.0-2	1.6
19	0	0	8.4-3	15	2.4-4	61	0	0	9.2-3	1.6
20	0	0	2.1-2	10	7.1-4	28	0	0	7.6-3	1.8
21	0	0	2.3-2	10	1.3-3	19	0	0	6.2-3	1.9
22	0	0	1.3-2	13	4.6-3	10	0	0	4.2-3	2.1
23	0	0	9.2-3	16	1.5-2	7.1	0	0	3.3-3	2.4
24	0	0	2.8-3	27	4.4-2	4.1	0	0	2.4-3	2.7
25	0	0	7.1-4	97	3.0-1	1.7	0	0	1.6-3	3.1
26	0	0	1.1-3	46	7.1-2	3.3	0	0	9.4-4	3.3
27	0	0	2.2-4	97	1.7-2	6.2	0	0	7.0-4	3.1
28	0	0	2.4-6	100	5.9-3	10	0	0	5.2-4	2.2
29	0	0	5.8-6	100	2.4-3	16	0	0	4.4-4	2.1
30	0	0	0	0	6.8-4	24	0	0	3.2-4	2.5
31	8.1-5	98	0	0	0	0	1.7-1	2.1	9.1-3	0.9
32	6.7-4	33	0	0	0	0	1.9-1	2.1	8.3-3	0.8
33	4.5-3	15	0	0	0	0	7.6-3	8.2	1.0-2	0.7
34	2.2-2	7.8	0	0	0	0	8.3-4	34	5.7-3	1.2
35	6.2-2	4.7	0	0	0	0	5.2-4	43	3.6-3	1.6
36	6.2-2	4.7	0	0	0	0	2.2-4	60	5.2-3	1.3
37	1.9-2	8.7	0	0	0	0	1.3-4	65	6.4-3	1.1
38	6.6-3	15	0	0	0	0	1.2-4	51	5.9-3	1.0
39	2.0-3	21	0	0	0	0	9.5-5	63	5.4-3	1.1
40	7.3-4	33	0	0	0	0	0	0	6.2-3	1.0
41	4.0-4	38	0	0	0	0	0	0	5.4-3	1.1
42	1.9-4	68	0	0	0	0	2.4-5	85	6.0-3	1.1
43	2.7-5	98	1.6-4	69	0	0	0	0	5.4-3	1.2
44	1.4-4	76	5.2-4	58	7.3-8	100	0	0	5.3-3	1.3
45	4.9-7	90	5.4-4	68	2.9-7	95	0	0	4.9-3	1.7
46	0	0	1.2-3	35	3.4-5	73	0	0	4.6-3	2.1
47	0	0	5.4-3	24	1.2-4	53	0	0	5.3-3	2.0
48	2.0-4	100	1.2-2	13	2.8-4	41	0	0	7.1-3	1.8
49	0	0	3.5-2	9.2	6.3-4	30	0	0	8.8-3	1.6
50	0	0	6.8-2	6.7	1.6-3	19	0	0	7.3-3	1.7
51	0	0	1.5-2	13	4.0-3	12	0	0	5.2-3	2.0

Appendix A (continued)

Run number	Thyroid		Ovaries		Testes		Lens of eye		Red bone marrow	
	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)
52	0	0	6.4-3	19	1.1-2	8.2	0	0	4.2-3	2.2
53	0	0	3.4-3	24	3.2-2	4.8	0	0	3.2-3	2.4
54	0	0	9.8-4	38	7.6-2	3.2	0	0	2.0-3	2.7
55	0	0	1.3-5	78	3.8-2	4.3	0	0	1.2-3	2.8
56	0	0	1.5-8	100	1.4-2	6.9	0	0	9.4-4	2.3
57	0	0	9.0-5	100	4.6-3	12	0	0	8.4-4	1.9
58	0	0	0	0	1.2-3	19	0	0	8.1-4	1.4
59	0	0	0	0	5.8-4	31	0	0	6.0-4	1.5
60	1.6-4	77	0	0	0	0	5.5-3	9.9	4.7-3	1.5
61	7.2-3	13	0	0	0	0	2.3-4	46	6.1-3	1.4
62	6.8-3	12	0	0	0	0	2.0-5	71	7.3-3	1.0
63	1.9-3	26	0	0	0	0	8.7-5	69	5.7-3	1.0
64	1.3-3	28	0	0	0	0	4.9-5	73	5.1-3	1.1
65	1.9-4	73	0	0	0	0	0	0	6.1-3	1.0
66	1.4-4	64	0	0	0	0	0	0	4.8-3	1.1
67	7.7-5	66	0	0	6.9-5	78	0	0	5.5-3	1.0
68	1.4-6	95	0	0	0	0	0	0	4.8-3	1.2
69	5.3-5	100	6.6-6	76	0	0	0	0	4.5-3	1.3
70	0	0	9.2-5	83	0	0	0	0	3.5-3	1.8
71	0	0	1.7-3	32	2.3-5	88	0	0	3.0-3	2.5
72	0	0	2.8-3	25	8.0-5	59	0	0	4.1-3	2.2
73	0	0	8.4-3	16	4.0-4	39	0	0	8.7-3	1.6
74	0	0	3.3-2	10	3.4-4	36	0	0	1.3-2	1.4
75	0	0	7.3-2	6.4	1.2-3	21	0	0	1.2-2	1.4
76	0	0	1.4-2	13	2.2-3	15	0	0	1.1-2	1.4
77	0	0	5.6-3	19	5.2-3	10	0	0	1.0-2	1.5
78	0	0	1.2-3	32	1.1-2	7.4	0	0	8.1-3	1.6
79	0	0	3.0-4	66	1.3-2	6.7	0	0	3.7-3	1.7
80	0	0	0	0	1.1-2	7.6	0	0	2.7-3	1.3
81	0	0	0	0	5.1-3	11	0	0	2.5-3	0.9
82	0	0	0	0	2.5-3	14	0	0	2.4-3	0.7
83	0	0	0	0	8.7-4	24	0	0	2.5-3	0.7
84	3.0-3	22	0	0	0	0	5.5-4	30	7.4-3	1.0
85	1.8-3	24	0	0	0	0	5.9-5	99	6.6-3	1.0
86	5.2-4	39	0	0	0	0	1.0-5	60	6.2-3	1.0
87	5.6-4	41	0	0	0	0	0	0	3.5-3	1.8
88	1.6-4	69	0	0	0	0	1.4-5	95	5.2-3	1.1
89	2.5-5	76	7.1-5	100	0	0	0	0	5.1-3	1.1
90	2.1-6	100	0	0	0	0	0	0	4.5-3	1.1
91	3.4-5	100	1.9-4	81	0	0	0	0	4.2-3	1.2
92	2.7-6	100	2.6-4	97	0	0	0	0	2.8-3	1.8
93	0	0	1.0-3	39	1.1-6	100	0	0	1.9-3	2.8
94	0	0	2.4-3	32	2.7-5	71	0	0	3.2-3	2.5
95	0	0	5.3-3	21	4.2-5	74	0	0	1.0-2	1.5
96	0	0	8.7-3	17	4.3-4	37	0	0	1.6-2	1.2
97	0	0	1.3-2	13	7.4-4	28	0	0	1.7-2	1.2
98	0	0	6.6-3	17	1.1-3	27	0	0	1.7-2	1.2
99	0	0	3.7-3	24	2.7-3	15	0	0	1.6-2	1.2
100	0	0	1.7-3	39	3.4-3	13	0	0	1.4-2	1.3
101	0	0	6.7-4	42	4.1-3	13	0	0	4.0-3	1.7
102	0	0	2.4-4	80	2.6-3	14	0	0	2.3-3	1.4
103	0	0	2.5-4	87	1.7-3	18	0	0	1.8-3	1.1
104	0	0	0	0	7.4-4	21	0	0	1.4-3	1.0
105	0	0	0	0	2.2-4	39	0	0	1.1-3	1.2
106	6.5-4	33	0	0	0	0	3.8-4	37	7.3-3	0.9

Appendix A (continued)

Run number	Thyroid		Ovaries		Testes		Lens of eye		Red bone marrow	
	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)
107	0	0	2.3-3	37	5.1-5	51	0	0	3.3-3	2.5
108	0	0	4.0-3	24	1.2-4	45	0	0	4.5-3	2.2
109	0	0	2.9-3	35	3.4-4	52	0	0	5.3-3	2.0
110	0	0	3.7-3	23	4.9-4	34	0	0	4.9-3	2.1
111	0	0	9.5-4	40	1.0-3	26	0	0	4.6-3	2.1
112	0	0	9.1-4	39	8.6-4	25	0	0	3.5-3	2.4
113	0	0	1.2-4	67	1.3-3	20	0	0	1.9-3	3.0
114	0	0	7.2-5	83	7.1-4	27	0	0	8.7-4	3.5
115	3.0-4	58	0	0	0	0	1.7-1	2.2	9.1-3	0.9
116	5.3-4	41	0	0	0	0	1.8-1	2.1	8.4-3	0.8
117	7.1-2	4.6	0	0	0	0	5.6-4	30	3.8-3	1.6
118	6.3-2	4.8	0	0	0	0	3.0-4	41	5.4-3	1.3
119	0	0	3.3-2	8.9	1.7-4	38	0	0	8.9-3	1.6
120	0	0	7.3-2	6.3	1.7-3	16	0	0	7.4-3	1.7

APPENDIX B

Summary of Calculated Absorbed Dose per Unit Exposure for 30
keV Photon Beams.

ORNL - DWG 73-1447

Fig. B-1

Appendix B: Summary of calculated absorbed dose to organs of interest

Energy - 30 keV

Anterior-posterior exposure

4 x 4 cm beam

Note: 2.8 - 5 read as 2.8×10^{-5} rad/R

Run number	Thyroid		Ovaries		Testes		Lens of eye		Red bone marrow	
	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)
1	0	0	0	0	0	0	1.4-3	13	9.6-4	1.8
2	0	0	0	0	0	0	8.3-2	2.2	1.1-3	0.8
3	2.8-5	100	0	0	0	0	8.0-2	2.3	1.6-3	0.5
4	5.9-4	25	0	0	0	0	4.4-4	20	1.6-3	0.4
5	7.7-3	7.2	0	0	0	0	5.9-5	78	7.0-4	1.3
6	3.0-1	1.5	0	0	0	0	1.2-6	79	4.3-4	2.8
7	2.6-1	1.7	0	0	0	0	2.9-6	100	4.6-4	2.7
8	5.0-3	8.2	0	0	0	0	1.3-8	100	2.2-3	1.0
9	8.0-4	22	0	0	0	0	0	0	2.5-3	0.9
10	2.0-4	39	0	0	0	0	0	0	1.8-3	1.1
11	9.5-6	94	0	0	0	0	5.3-9	100	2.7-3	0.8
12	8.6-7	97	0	0	0	0	0	0	1.8-3	1.0
13	0	0	0	0	0	0	0	0	2.4-3	0.9
14	0	0	0	0	0	0	0	0	2.1-3	1.0
15	0	0	0	0	0	0	0	0	2.2-3	1.0
16	0	0	1.6-7	100	0	0	0	0	1.4-3	1.7
17	0	0	2.4-6	68	0	0	0	0	6.7-4	3.5
18	0	0	5.7-5	79	2.8-8	100	0	0	6.5-4	3.6
19	0	0	6.1-4	29	0	0	0	0	4.9-4	4.0
20	0	0	2.0-3	19	4.6-6	68	0	0	3.2-4	4.7
21	0	0	3.0-3	17	1.7-5	53	0	0	2.3-4	5.2
22	0	0	7.6-4	26	1.3-4	30	0	0	1.1-4	5.9
23	0	0	3.5-4	28	1.3-3	11	0	0	9.4-5	6.5
24	0	0	7.1-5	41	9.4-3	4.8	0	0	6.6-5	7.5
25	0	0	1.9-6	79	1.1-1	2.0	0	0	3.9-5	8.5
26	0	0	6.0-5	100	1.8-2	4.1	0	0	2.5-5	7.1
27	0	0	0	0	1.9-3	9.3	0	0	2.1-5	4.0
28	0	0	0	0	2.5-4	22	0	0	2.3-5	3.3
29	0	0	0	0	3.7-5	49	0	0	2.3-5	3.0
30	0	0	0	0	0	0	1.2-3	14	5.1-4	2.3
31	0	0	0	0	0	0	9.7-2	2.1	2.2-3	1.0
32	0	0	0	0	0	0	9.8-2	2.1	2.0-3	0.5
33	3.7-4	30	0	0	0	0	2.4-4	28	1.7-3	0.6
34	3.8-3	9.6	0	0	0	0	6.6-5	52	5.8-4	1.5
35	2.4-2	4.4	0	0	0	0	1.5-5	72	2.5-4	2.7
36	2.4-2	4.5	0	0	0	0	1.4-5	68	1.9-3	1.5
37	2.7-3	12	0	0	0	0	0	0	2.8-3	0.9
38	4.7-4	26	0	0	0	0	0	0	2.3-3	0.9
39	4.1-5	52	0	0	0	0	0	0	1.7-3	1.0
40	2.0-5	66	0	0	0	0	0	0	2.5-3	0.8
41	0	0	0	0	0	0	0	0	1.7-3	1.0
42	0	0	0	0	0	0	0	0	2.3-3	0.9
43	0	0	0	0	0	0	0	0	1.9-3	1.0
44	1.1-6	100	1.1-7	100	0	0	0	0	1.9-3	1.0
45	0	0	0	0	0	0	0	0	9.8-4	1.5
46	0	0	1.2-4	88	0	0	0	0	1.8-4	4.7
47	0	0	2.5-4	54	0	0	0	0	1.8-4	4.7
48	0	0	1.2-3	27	0	0	0	0	3.3-4	4.3
49	0	0	6.4-3	13	0	0	0	0	4.5-4	3.9
50	0	0	1.9-2	8.9	1.7-5	7.3	0	0	3.3-4	4.2
51	0	0	1.8-3	19	1.3-4	28	0	0	2.1-4	4.4

Appendix B (continued)

Run number	Thyroid		Ovaries		Testes		Lens of eye		Red bone marrow	
	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)
52	0	0	1.9-4	46	9.9-4	13	0	0	1.8-4	4.8
53	0	0	2.6-5	54	5.2-3	6.4	0	0	1.4-4	5.3
54	0	0	0	0	2.1-2	4.0	0	0	7.6-5	5.5
55	0	0	1.9-6	95	7.1-3	5.6	0	0	5.0-5	3.7
56	0	0	0	0	1.5-3	11	0	0	5.7-5	2.3
57	0	0	0	0	4.0-4	18	0	0	7.7-5	2.0
58	3.3-4	23	0	0	0	0	1.6-5	98	3.4-3	0.9
59	1.9-4	38	0	0	0	0	0	0	2.3-3	0.8
60	1.3-5	46	0	0	0	0	0	0	1.7-3	1.0
61	9.4-6	77	0	0	0	0	0	0	2.6-3	0.8
62	1.3-5	100	0	0	0	0	0	0	1.8-3	1.0
63	0	0	0	0	0	0	0	0	2.4-3	0.8
64	0	0	0	0	0	0	0	0	1.9-3	0.9
65	0	0	0	0	0	0	0	0	1.8-3	1.0
66	0	0	0	0	0	0	0	0	9.0-4	1.5
67	0	0	1.7-5	65	0	0	0	0	9.4-5	5.8
68	0	0	1.9-4	47	0	0	0	0	1.6-4	4.9
69	0	0	9.5-4	24	6.5-5	74	0	0	7.9-4	3.0
70	0	0	6.7-3	14	7.4-6	95	0	0	1.4-3	2.3
71	0	0	1.9-2	9.1	3.4-5	60	0	0	1.3-3	2.3
72	0	0	1.9-3	24	6.7-5	36	0	0	1.2-3	2.4
73	0	0	5.5-4	36	4.9-4	20	0	0	1.2-3	2.4
74	0	0	8.2-5	79	1.3-3	13	0	0	9.9-4	2.7
75	0	0	2.7-5	94	1.7-3	11	0	0	3.8-4	1.9
76	0	0	3.3-5	100	1.3-3	12	0	0	3.5-4	1.1
77	0	0	0	0	4.0-4	21	0	0	4.0-4	0.9
78	0	0	0	0	1.1-4	29	0	0	4.5-4	0.9
79	3.2-5	58	0	0	0	0	8.6-7	100	2.3-3	0.9
80	2.0-6	100	0	0	0	0	0	0	1.9-3	1.0
81	3.6-9	100	0	0	0	0	0	0	2.7-3	0.8
82	1.2-5	100	0	0	0	0	0	0	1.8-3	1.0
83	6.6-9	100	0	0	0	0	0	0	2.2-3	0.9
84	6.1-8	71	0	0	0	0	0	0	1.8-3	1.0
85	0	0	0	0	0	0	0	0	1.8-3	1.0
86	0	0	1.6-7	100	0	0	0	0	8.7-4	1.5
87	0	0	7.8-6	93	0	0	0	0	6.3-5	6.4
88	0	0	5.1-6	56	0	0	0	0	1.6-4	4.9
89	0	0	4.6-4	45	0	0	0	0	1.7-3	2.2
90	0	0	1.6-3	24	0	0	0	0	3.1-3	1.6
91	0	0	1.4-3	21	3.9-6	70	0	0	3.2-3	1.6
92	0	0	4.6-4	37	2.4-5	47	0	0	3.2-3	1.6
93	0	0	1.0-4	63	1.4-4	33	0	0	3.1-3	1.6
94	0	0	1.9-5	85	2.0-4	32	0	0	2.9-3	1.7
95	0	0	3.0-7	98	1.6-4	27	0	0	4.9-4	1.8

APPENDIX C

Summary of Calculated Absorbed Dose per Unit Exposure for 80 keV
Photon Beams.

ORNL-DWG 73-1448

80 keV, A-P
4 x 4 cm BEAM

Fig. C-1

Appendix C: Summary of calculated absorbed dose of organs of interest

Energy - 80 keV
 Anterior-posterior exposure
 4 x 4 cm beam
 Note: 1.1 - 4 read as 1.1×10^{-4} rad/R

Run number	Thyroid		Ovaries		Testes		Lens of eye		Red bone marrow	
	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)
1	1.1-4	100	0	0	0	0	8.7-3	9.6	4.5-3	1.5
2	1.4-3	28	0	0	0	0	1.6-1	2.6	5.8-3	1.1
3	2.6-3	24	0	0	0	0	1.5-1	2.6	6.8-3	1.0
4	7.9-3	13	0	0	0	0	1.5-2	6.9	9.5-3	0.8
5	4.1-2	6.3	0	0	3.5-5	100	4.4-3	12	1.0-2	1.0
6	5.3-1	2.0	0	0	0	0	1.3-3	21	8.1-3	1.3
7	4.7-1	2.1	0	0	0	0	7.1-4	36	7.7-3	1.3
8	3.2-2	7.7	0	0	0	0	3.1-4	53	9.1-3	1.1
9	9.6-3	11	0	0	0	0	3.1-4	54	9.3-3	1.1
10	5.5-3	17	0	0	0	0	1.3-4	76	9.2-3	1.1
11	1.6-3	23	2.9-4	100	0	0	2.5-5	100	9.4-3	1.1
12	5.1-4	48	0	0	0	0	0	0	9.1-3	1.1
13	3.0-4	63	0	0	0	0	0	0	9.4-3	1.1
14	1.9-4	72	2.1-4	79	6.4-6	79	0	0	9.5-3	1.2
15	1.1-4	84	6.4-4	49	4.8-8	100	0	0	9.6-3	1.3
16	0	0	2.9-3	30	3.7-5	96	0	0	1.2-2	1.4
17	0	0	2.5-3	32	2.1-4	73	0	0	1.3-2	1.5
18	4.5-7	100	5.7-3	22	2.5-4	41	0	0	1.4-2	1.5
19	0	0	1.4-2	14	4.6-4	33	0	0	1.3-2	1.5
20	0	0	2.2-2	11	1.5-3	22	0	0	1.1-2	1.6
21	0	0	2.8-2	11	3.1-3	15	0	0	8.6-3	1.7
22	0	0	2.1-2	12	7.2-3	10	0	0	6.2-3	2.0
23	0	0	6.5-3	20	1.7-2	6.9	0	0	4.9-3	2.2
24	4.7-6	100	4.6-3	21	5.8-2	4.0	0	0	3.7-3	2.4
25	0	0	2.4-3	32	3.7-1	1.7	0	0	2.5-3	2.8
26	0	0	1.7-3	41	8.2-2	3.5	0	0	1.9-3	2.9
27	0	0	5.2-4	50	2.2-2	6.3	0	0	1.2-3	2.9
28	0	0	3.7-4	62	8.9-3	9.9	0	0	9.9-4	2.8
29	5.1-7	100	0	0	0	0	7.2-3	11	2.6-3	2.0
30	1.0-3	41	0	0	0	0	1.9-1	2.4	8.7-3	1.0
31	1.6-3	27	0	0	0	0	2.0-1	2.3	9.0-3	0.9
32	6.7-3	14	0	0	0	0	1.1-2	7.7	1.2-2	0.8
33	2.0-2	9.0	0	0	0	0	2.2-3	17	7.8-3	1.2
34	6.2-2	5.3	0	0	0	0	9.5-4	27	5.0-3	1.5
35	6.4-2	5.4	0	0	0	0	6.1-4	29	6.0-3	1.4
36	2.4-3	8.2	0	0	0	0	1.9-4	48	6.7-3	1.2
37	7.5-3	14	0	0	0	0	7.1-5	100	6.5-3	1.2
38	3.8-3	19	0	0	0	0	1.4-4	62	6.1-3	1.2
39	9.3-4	40	0	0	0	0	0	0	6.7-3	1.1
40	6.2-4	43	0	0	0	0	1.7-6	100	6.0-3	1.3
41	3.1-4	49	5.2-7	100	0	0	0	0	6.4-3	1.2
42	4.2-5	100	2.9-4	60	0	0	0	0	6.2-3	1.3
43	4.7-5	78	5.4-4	45	0	0	0	0	6.4-3	1.5
44	6.3-5	100	1.2-3	45	4.1-5	71	0	0	6.7-3	1.7
45	0	0	3.8-3	26	1.5-4	56	0	0	6.9-3	1.9
46	0	0	7.3-3	22	2.8-5	97	0	0	8.1-3	1.8
47	0	0	1.7-2	13	6.2-4	28	0	0	9.9-3	1.6
48	1.6-3	100	4.8-2	9.0	1.9-3	21	0	0	1.2-2	1.5
49	0	0	1.0-1	6.6	3.1-3	16	0	0	9.7-3	1.7
50	0	0	2.6-2	12	5.9-3	11	0	0	7.2-3	1.8
51	0	0	8.4-3	18	1.5-2	7.8	0	0	5.9-3	2.0

Appendix C (continued)

Run number	Thyroid		Ovaries		Testes		Lens of eye		Red bone marrow	
	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)	Dose (rads/R)	C. of var. (%)
52	0	0	4.1-3	28	3.5-2	5.0	0	0	4.5-3	2.3
53	0	0	2.3-3	32	8.6-2	3.4	0	0	3.2-3	2.5
54	0	0	9.0-4	68	4.5-2	4.5	0	0	2.1-3	2.7
55	0	0	5.0-4	69	1.7-2	6.8	0	0	1.5-3	2.4
56	0	0	1.6-6	84	5.7-3	11	0	0	1.3-3	2.1
57	8.4-3	14	0	0	0	0	6.6-4	31	5.3-3	1.5
58	9.4-3	12	0	0	0	0	7.0-4	34	7.0-3	1.1
59	4.9-3	17	0	0	0	0	1.8-4	57	5.7-3	1.2
60	1.6-3	26	0	0	0	0	1.1-4	100	5.2-3	1.3
61	5.5-4	44	0	0	0	0	5.4-5	72	5.8-3	1.2
62	7.4-4	47	0	0	0	0	0	0	4.9-3	1.4
63	2.2-4	62	2.9-6	100	8.1-7	100	0	0	5.3-3	1.3
64	8.2-7	82	4.0-4	100	0	0	0	0	5.1-3	1.4
65	3.8-5	98	4.9-4	53	3.5-5	100	0	0	5.1-3	1.5
66	6.7-5	100	1.7-3	39	3.1-5	83	0	0	4.7-3	1.9
67	0	0	2.4-3	30	9.7-8	84	0	0	4.6-3	2.2
68	0	0	6.2-3	21	2.6-4	42	0	0	6.2-3	2.0
69	5.3-5	100	1.5-2	15	6.0-4	76	0	0	1.1-2	1.6
70	0	0	4.0-2	10	1.0-3	27	0	0	1.5-2	1.4
71	0	0	7.9-2	7.0	1.7-3	22	0	0	1.4-2	1.4
72	0	0	1.9-2	13	3.5-3	14	0	0	1.3-2	1.4
73	0	0	8.2-3	17	1.1-2	8.9	0	0	1.1-2	1.5
74	0	0	3.9-3	23	1.5-2	7.4	0	0	9.2-3	1.7
75	0	0	2.8-3	36	2.1-2	6.5	0	0	5.0-3	1.7
76	0	0	6.8-4	44	1.7-2	6.8	0	0	3.6-3	1.5
77	0	0	1.2-5	100	9.3-3	9.3	0	0	3.1-3	1.1
78	0	0	0	0	3.8-3	14	0	0	2.9-3	0.9
79	3.4-3	21	3.7-5	100	0	0	5.9-4	31	7.0-3	1.1
80	2.9-3	21	0	0	0	0	5.2-4	35	6.6-3	1.1
81	1.4-3	30	0	0	0	0	1.3-4	73	6.4-3	1.2
82	5.2-4	41	1.3-4	100	0	0	8.5-5	97	6.8-3	1.1
83	1.1-4	78	0	0	0	0	4.6-5	89	5.0-3	1.3
84	4.5-4	58	8.0-5	100	2.3-6	100	7.7-5	100	4.9-3	1.3
85	9.5-5	75	2.1-4	96	0	0	0	0	4.6-3	1.4
86	1.4-6	100	7.8-4	60	0	0	0	0	4.4-3	1.5
87	7.6-6	100	8.9-4	56	0	0	0	0	3.5-3	2.1
88	1.0-8	100	1.8-3	38	5.5-3	79	0	0	3.0-3	2.7
89	0	0	4.6-3	23	2.3-4	42	0	0	4.4-3	2.4
90	0	0	6.8-3	20	3.2-4	43	0	0	1.1-2	1.6
91	0	0	1.4-2	15	4.9-4	30	0	0	1.7-2	1.3
92	0	0	1.3-2	13	8.4-4	28	0	0	1.8-2	1.2
93	0	0	1.2-2	18	2.4-3	16	0	0	1.7-2	1.2
94	0	0	7.3-3	18	3.8-3	12	0	0	1.7-2	1.3
95	0	0	3.4-3	30	5.5-3	12	0	0	1.4-2	1.3
96	0	0	1.5-3	45	6.0-3	12	0	0	5.3-3	1.7
97	0	0	1.3-4	63	4.5-3	12	0	0	3.1-3	1.7
98	0	0	3.2-4	66	2.5-3	16	0	0	2.2-3	1.6
99	0	0	1.2-3	44	1.2-4	50	0	0	4.2-3	2.5
100	0	0	4.2-3	22	3.2-4	43	0	0	5.4-3	2.2
101	0	0	5.3-3	21	6.4-4	38	0	0	5.9-3	2.1
102	0	0	3.2-3	28	7.6-4	27	0	0	6.0-3	2.1
103	0	0	3.1-3	30	1.8-3	23	0	0	5.4-3	2.2
104	0	0	1.3-3	48	1.7-3	22	0	0	4.1-3	2.4

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