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INHALATION DOSE CONVERSION FACTORS FOR VARIOUS RADIONUCLIDES ASSOCIATED WITH LIQUID METAL FAST BREEDER REACTORS

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TABLE OF CONTENTS

Introduction	1
Metabolic Model	1
Figure 1	2
Model Concepts and Parameters	4
Table 1	6
Table 2	7
Table 3	9
Table 4	10
Table 5	11
Table 6	13
Table 7	15
Table 8	16
Table 9	19
Table 10	22
Time Integrated Organ Deposited Activity	24
Dose Conversion Factors	24
Table 11	25 - 47
Table 12	50
Table 13	51
Table 14	52
Table 15 - 24	53 - 66
References	67
Appendix	A1 - A51

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ABSTRACT

This report presents 1) values of the parameters needed in the estimation of internal radiation doses from inhalation of radioactive aerosols resulting from hypothetical liquid metal fast breeder reactor accidents, 2) the values of the time integrated organ deposited radioactivity per unit of radioactivity inhaled ($\mu\text{Ci-days/Ci}$ inhaled) based on a metabolic model that incorporates the respiratory tract model adopted by the International Commission on Radiological Protection Task Group on Lung Dynamics and 3) the values of the dose conversion factors (F-factors) in rem per curie inhaled for various important LMFBR radionuclides.

INHALATION DOSE CONVERSION FACTORS FOR VARIOUS RADIONUCLIDES ASSOCIATED WITH LIQUID METAL FAST BREEDER REACTORS

J. D. Thomas and J. G. ...

I. INTRODUCTION

An assessment of radiological consequences of a release of radioactive aerosols into the atmosphere as a result of a hypothetical liquid metal fast breeder reactor (LMFBR) accident requires estimates of the radiological environment at various distances from the point of release followed by estimates of potential internal and external radiation exposures to people at these distances. Our present studies are concentrated on inhalation dose assessment parameters. A discussion of lung deposition and clearance models showing the advantages of the Task Group Lung Model⁽¹⁾ and the need for a standardization of values of parameters such as particle size distribution and chemical nature of the radionuclides was recently reported.⁽²⁾ The estimation of organ doses following inhalation of radionuclides requires in addition values of the organ mass, fractional organ uptake, clearance rates, effective energies of the emitted radiations, tidal volume and respiratory rate.

It is the purpose of this report to present 1) the values of the parameters needed in the estimation of internal radiation doses from inhalation of radioactive aerosols resulting from hypothetical LMFBR accidents 2) the values of the time integrated organ deposited activity per unit of activity inhaled and 3) the values of the dose conversion factors (F-factors) in rem per curie inhaled.

II. METABOLIC MODEL

The model of the respiratory tract adopted by the Task Group on Lung Dynamics^(1,3) can be incorporated into a metabolic model showing the pathways to organs via the blood. This metabolic model forms the basis for the calculation of organ doses from inhalation of radionuclides. A schematic diagram of the model is presented in Figure 1.

Figure 1

Figure 1 Dynamic Deposition and Metabolic Model of Inhaled Radionuclides. Modified from Task Group on Lung Dynamics, ICRP (1,3)

The respiratory portion of the model is divided into three major regions, the nasopharyngeal (NP), the tracheobronchial (TB), and the pulmonary (P). In addition to the respiratory regions, three other closely associated compartments are defined; the gastrointestinal (GI) tract, systemic blood and pulmonary lymph. The general metabolic model includes additional compartments (organs and tissues) into which material is transported from the respiratory tract, lymphatic system and GI tract via the blood. Deposition which varies with the aerodynamic properties of the aerosol, is described by D_3 , D_4 and D_5 for the NP, TB, and P regions, respectively. These parameters are expressed as percentages of the total amount inhaled (D_1).

The letters "a" through "j" indicate the translocation pathways associated with clearance of the various subcompartments (the fraction translocated by each pathway is presented in Section III). The fraction transferred from the GI tract to the blood is denoted by f_1 and the fractions transferred from the blood to the various organs are denoted by f'_2 . All parameters shown in Figure 1 in addition to other parameters needed in calculation of time integrated radioactivity and organ doses are discussed in Section III.

III. MODEL CONCEPTS AND PARAMETERS

The concepts and parameters considered in the model and discussed below are (a) age of the exposed individual, (b) selection of organs and organ masses, (c) determination of dose equivalent in rem, (d) selection of more important radio-nuclides, (e) clearance class of each nuclide according to three degrees of lung retention (avid, moderate, or minimal), (f) lung clearance rates, (g) lung deposition efficiencies as a function of particle size, (h) tidal volume and respiratory rate, (i) gastrointestinal tract transit times, (j) effective energy and decay schemes, (k) organ retention as a function of time and (l) radioactive chains.

a. Age Considerations

Calculation of organ doses in children of ages up to 15 years need special attention with regard to organ masses and physiological factors. Dose corrections for differences in organ masses can be made, but not for differences in physiological factors since these factors are not available. The consideration of internal dose calculations for children is of particular concern in radiological assessment in large mixed population zones, but not in the occupational zone within site boundaries; therefore, values of the parameters for adult man only will be used here.

b. Selection of Organs and Organ Masses

Organs and their masses for which dose or dose equivalent is estimated were selected on the basis of the report by Snyder, et.al.⁽⁴⁾ The organs selected are listed in Table 1. These values are based on a "phantom" consisting of idealized "mathematical" models for the total body and organs and are in close agreement with those listed in International Commission on Radiological Protection (ICRP) publication "Reference Man".⁽⁵⁾ The lung mass value of 1000 gms is to be used for gamma rays and 540 gms (blood free lung) for alpha particles.

c. Dose Equivalent in Rem

The calculation of dose equivalent in rem is based on a quality factor Q which is a term used to modify values of absorbed dose so that irradiation due to all ionizing radiations may be expressed on a common scale. $Q = 1$ for all photons and for electrons of either sign; $Q = 10$

for neutrons above 10 kev in energy (spontaneous fission); $Q = 10$ for alpha particles; $Q = 20$ for recoil nuclei. A distribution factor $N = 5$ is used for all high Linear Energy Transfer (LET) radiations of bone to correct for the non-uniform deposition of the radionuclide. A special factor of .01 is used for alpha particles and for fission fragments irradiating the gastrointestinal tract with the source in the contents of the tract since experiments have shown that these particles fail to penetrate the intestinal mucosa an appreciable extent. For recoil nuclei produced in the contents of the tract the factor is taken as zero while for neutrons the factor is taken as unity.

d. Selection of Radionuclides

A list of the more important radionuclide contributors to the organ doses associated with hypothetical fast breeder reactor accidents is shown in Table 2. This list includes fission products, actinides, and neutron activation products that may be important under certain accident conditions. The fission products, actinides and some of the activation products were chosen on the basis of a hazard ranking scheme involving expected inventory, rem per curie inhaled, and guidelines doses for critical organs.⁽⁶⁾ Radionuclides in the hazard ranking list that contribute about 99.5% of the internal hazard are included as well as the radionuclides H-3, Mn-52m, Mn-52, Mn-56, Fe-55, Co-57, and Zn-72, for which data for hazard ranking were not available.

TABLE 1 SELECTED ORGANS FOR DOSE CALCULATIONS

<u>Organ</u>	<u>Mass (grams)*</u>
Adrenals	15.5
Bladder	45.13 wall; 200 contents
Kidneys	284.2
Liver	1809
Lungs	999.2
Respiratory Lymph Nodes	15
Other Tissue	48,480 (28,000 suggested for muscle; 12,500 g for separable adipose tissue)
Ovaries	8.268
Pancreas	60.27
Skeleton	10,470
Cortical Bone	4,000
Cancellous Bone	1,000
Red Marrow	1,500
Yellow Marrow	1,500
Skin	2,833
Spleen	173.6
Testes	37.08
Thyroid	19.63
Total Body	68,880
Uterus	65.4
Gastrointestinal Tract	
Stomach	150 wall; 246.9 contents
Small intestine-contents	1044 wall plus contents
Upper large intestine	109.2 wall; 220 contents
Lower large intestine	160.1 wall; 136.8 contents

*Based on a mathematical anthropomorphic phantom. (4)

TABLE 2 CONDENSED LIST OF IMPORTANT RADIONUCLIDES FOR INHALATION
DOSE ASSESSMENT OF HYPOTHETICAL LMFBR ACCIDENTS†

Atomic Number	Element	Mass Number	Atomic Number	Element	Mass Numbers
1	H*	3**	53	I	131**
25	Mn*	52**	53	I	133**
25	Mn*	52M**	53	I	135
25	Mn*	56	55	Cs	137**
26	Fe*	55**	56	Ba	140
27	Co*	57**	58	Ce	141
27	Co	58**	58	Ce	144
27	Co	60**	59	Pr	143
30	Zn*	72	94	Pu	238
38	Sr	89	94	Pu	239
38	Sr	90**	94	Pu	240
39	Y	91	94	Pu	241
40	Zr	95	95	Am	241
41	Nb	95	96	Cm	242
44	Ru	103	96	Cm	243
44,	Ru	106	96	Cm	244
52	Te	132			

† Values of rem/ μ Ci - day for source and target organs for each radionuclide listed with the exception of Zn-72 have been published in ORNL-5000 (Parts I, II, & III)⁽⁴⁾

* Radionuclides were selected on the basis of those required to deliver 99.5% of the dose as determined in G.E. Quarterly Report GEAP-14034-5,1975⁽⁶⁾ with the exception of those marked with a single asterik which are expected nuclides for which insufficient information was available for inclusion in dose contribution calculations

** Decay schemes and energies of the emitted rays or particles of the radionuclides marked with a double asterik are found in MIRD Pamphlet No. 10.⁽⁷⁾ All others can be obtained from Table of Isotopes, Lederer et.al.⁽⁸⁾

e. Assignment of Clearance Classes

The assignment of clearance classes as defined for the Task Group Lung Model⁽¹⁾ and designated as Class Y, W, or D according to three degrees of lung retention (avid, moderate or minimal) for the more important nuclides is shown in Table 3. It was assumed that, except for iodine, oxides of these nuclides are formed in hypothetical liquid metal fast breeder reactor accidents.* The clearance classes were then determined as outlined by Morrow, et.al.⁽¹⁾ with the exception of niobium, strontium, barium, cesium and zirconium which were recently revised.⁽⁹⁾

f. Lung Clearance Parameter Values

Table 4 shows the most recent modification of values for biological half-lives and regional fractions applicable to the TGLM and currently accepted by Committee 2 of the ICRP.⁽³⁾ The path ways noted in the table are those shown in Figure 1.

g. Lung Deposition Parameter Values

Deposition efficiencies shown in Table 5 were estimated from data of the Task Group on Lung Dynamics⁽¹⁾ as a function of the activity median aerodynamic diameter (AMAD). An assignment of one or two values for the AMAD would simplify the dose calculations, but this has not been possible to date.

h. Tidal Volume and Respiratory Rate

Deposition of particles in the three regions of the respiratory tract (nasopharyngeal, tracheobronchial, and pulmonary) varies with tidal volume and respiration rate which in turn vary with the degree of activity of the individual; however, a reasonable assumption has been made that, for LMFBR accidents, deposition values be based on respiration during moderate activity (tidal volume of 1450 ml at a respiration rate of 15 per minute).

* Alkali and alkaline earth oxides are probably converted to carbonates in air and in the respiratory tract.

TABLE 3

ASSIGNMENT OF CLEARANCE CLASSES TO THE MORE IMPORTANT
EXPECTED NUCLIDES IN HYPOTHETICAL LMFBR ACCIDENTS

<u>Nuclide</u>	<u>Clearance Class</u>
H	D
Mn	W
Fe	W
Co	W
Zn	Y
Ga	W
Rb	D
Sr	D
Y	Y
Zr	Y
Nb	Y
Ru	Y
Rh	Y
Te	W
I	D
Cs	D
Ba	D
La	Y
Ce	W
Pr	Y
Pu	Y
Am	Y
Cm	Y

Table 4

Constants for Use with TUM Clearance Model

Region	Pathway*	Clearance Classes					
		f**	(D) λ (sec ⁻¹)	f	(W) λ (sec ⁻¹)	f	(Y) λ (sec ⁻¹)
N-P	(a)	0.5	8.023 E-04	0.1	8.023 E-04	0.01	8.023 E-04
	(b)	0.5	8.023 E-04	0.9	8.914 E-06	0.99	2.006 E-05
T-B	(c)	0.95	8.023 E-04	0.5	8.023 E-04	0.01	8.023 E-04
	(d)	0.05	4.011 E-05	0.5	4.011 E-05	0.99	4.0113 E-05
P	(e)	0.8	1.605 E-05	0.15	1.605 E-07	0.05	1.605 E-08
	(f)	--	--	0.4	8.023 E-06	0.4	8.023 E-06
	(g)	--	--	0.4	1.605 E-07	0.4	1.605 E-08
	(h)	0.2	1.605 E-05	0.05	1.605 E-07	0.15	1.605 E-08
L	(i)	1.0	1.605 E-05	1.0	1.605 E-07	0.9	8.023 E-09

* Pathways are shown in Figure 1.

** f represents the fraction that follows the specific pathway listed.

TABLE 5
Deposition of Dust Particles in the Respiratory
Tract as a Function of Particle Diameter

(Tidal Volume = 1450 ml; Respiratory rate = 15 per minute)

Mass Median Diameter (Micron)	Deposition Fraction		
	D ₃ N-P Region	D ₄ T-B Region*	D ₅ P Region
0.01			0.75
0.05			0.60
0.10	0.01	0.08	0.50
0.20	0.05	0.08	0.45
0.50	0.15	0.08	0.30
1.0	0.30	0.08	0.25
2.0	0.50	0.08	0.20
5.0	0.75	0.08	0.15
10.0	0.90	0.08	0.095

*Deposition in the Tracheobronchial compartment can be approximated by considering it constant for particles between 0.1 and 10.0 microns. (1)

i. Gastrointestinal Tract Transit Times

Calculations of doses to the gastrointestinal tract require estimates of the values for the mean transit time through portions of the tract. At least three different sets of values have been published as shown in Table 6. The most recent revision is that by Eve⁽¹⁰⁾ and is currently recommended for use in radiological assessment of hypothetical LMFBR accidents.

The integrated activity in the four portions of the GI tract can be calculated from the total input to the G.I. system and the mean residence times given in Table 6. The calculation for the small intestine involves the removal rate due to absorption in the blood. If the material is assumed to be absorbed at a constant rate (λ_a) and if f_1 is the fraction of material entering the small intestine (SI) that is absorbed into the blood then the following expressions apply

$$1 - f_1 = e^{-\lambda_a T_{SI}}$$

$$\lambda_a = \frac{1}{T_{SI}} \ln \frac{1}{1 - f_1}$$

Where:

$1 - f_1$ = the fraction of material leaving the SI and passing through the remainder of the GI tract

λ_a = absorption rate constant for a given element

T_{SI} = residence time in the SI

In these expressions f_1 must be less than 1. For elements to which investigators have assigned a value of 1, the value of f_1 is set to 0.95.

j. Effective Energy and Decay Schemes

It is recommended that revised decay schemes and energy values published by the Medical Internal Radiation Dose Committee⁽⁷⁾ be used where applicable, and for those radionuclides not included in Reference 7, decay schemes and energy values published by Lederer et.al.⁽⁸⁾ be used.

Table 6

Mean Transit Times Through Portions of GI Tract

Portion of GI Tract	Transit Times (Hour)		
	Eve(10)	Hayes(11)	ICRP(12)
Stomach (S)	1	1	1
Small Intestine (SI)	4	4	4
Upper Large Intestine (ULI)	13	13	8
Lower Large Intestine (LLI)	24	31	18

k. Organ Retention Parameter Values

Revised retention models for a number of stable elements (Table 7) have been reported by Snyder, et.al.⁽⁹⁾ for systemic organs. Application of these to radionuclides are recommended upon proper correction for radio-active decay. For the elements H, Mn, Fe, Zn, Ga, not considered in Reference 10, it is tentatively recommended the exponential retention models, biological half-lives, f_2' (fraction of material in blood that reaches organ of interest), and f_1 (fraction of material in G.I. tract that reaches the blood) published in ICRP Publication 2⁽¹²⁾ be used. These are reproduced here in Table 8.

A summary of revised retention models reported by Snyder, et.al.⁽⁹⁾ is presented below.

Actinides - ($f_1 = 3 \times 10^{-5}$ for plutonium and $f_1 = 10^{-3}$ for other actinides)

The retention in organs of the activity entering blood at t days following the intake is given by

$$R_{\text{bone}}(t) = .45 e^{-\frac{.693}{36500}t} \quad (3)$$

$$R_{\text{liver}}(t) = .45 e^{-\frac{.693}{14600}t} \quad (4)$$

$$R_{\text{kidneys}}(t) = 0.01 e^{-\frac{.693}{14600}t} \quad (5)$$

$$R_{\text{testes}}(t) = 0.0001 e^{-\frac{.693}{36500}t} \quad (6)$$

$$R_{\text{ovaries}}(t) = 0.00001 e^{-\frac{.693}{36500}t} \quad (7)$$

$$R_{\text{other tissues}}(t) = 0.05 e^{-\frac{.693}{36500}t} \quad (8)$$

Table 7

List of Stable Elements with Revised Retention Models

Sr	Ba
Y	La
Zr	Ce
Nb	Pr
Mo	Nd
Ru	Pm
Rh	Pu
Sb	Np
Te	Am
I	Cm
Cs	
Co	

Table 8

Elements of Condensed List That Are Not Included in The List
Of Revised Retention Models (WASH 1400)⁹ and Parameter Values
Taken From ICRP Publication 2¹²

Element	Organ of Reference	Biological Elimination Half-Time(days)	Fraction From GI Tract to Blood(f_1)	Fraction From Blood to Organ of Ref. (f'_2)
H	Total Body	12	1.0	1.0
Mn	Total Body *	17	0.1	0.68
	Pancreas	5.7		0.03
	Liver	25		0.24
	Kidneys	6.8		0.05
Fe	Total Body *	800	0.1	0.75
	Spleen	600		0.02
	Liver	554		0.13
	Bone	1680		0.10
Zn	Total Body *	933	0.1	0.128
	Bone	1300		0.15
	Kidneys	149		0.04
	Muscle	1959		0.3
	Liver	91		0.35
	Pancreas	25		0.03
	Testes	270		0.0009
	Ovaries	107		0.0004
Ga	Total Body *	6	10^{-3}	0.42
	Liver	4.8		0.25
	Bone	12		0.30
	Spleen	6		0.01
	Kidneys	9		0.02

* Total body values for f'_2 are listed in ICRP Pub. 2⁽¹²⁾ as equal to 1.0.
the values assigned in this report were obtained by subtracting the total
fraction deposited in other tissues from 1.0.

Cerium, Praseodymium, Neodymium, and Promethium ($f_1 = 10^{-4}$)

$$R(t) = Ae^{-.693t/5000} \quad (9)$$

where A has values of 0.5, 0.4, 0.025, 0.05 respectively for liver, bone, kidneys, and other tissues.

Cesium ($f_1 = 0.95$)

$$R_{\text{total body}}(t) = 0.13 e^{-.693t/1.4} + 0.87 e^{-.693t/135} \quad (10)$$

Cobalt ($f_1 = 0.05$)

$$R(t) = 0.5 e^{-0.693t/.5} + 0.3 e^{-0.693t/6} + 0.1 e^{-0.693t/60} + 0.1 e^{-0.693t/800} \quad (11)$$

$$R_{\text{total body}} = .95 R(t) \quad (12)$$

Additional liver retention = $0.05R(t)$

Iodine ($f_1 = 0.95$)

$$R_{\text{(thyroid)}}(t) = -0.328 e^{-0.693t/0.243} + 0.016 e^{-0.693t/11.3} + 0.312 e^{-0.693t/117} \quad (13)$$

$$R_{\text{total body}}(t) = 0.997 e^{-0.693t/0.243} - 0.04873 e^{-0.693t/11.3} + 0.0514 e^{-0.693t/117} \quad (14)$$

For Daughter X_e produced in thyroid and total body (half time = 2 hr)

$$R_{\text{total body}}(t) = R_{\text{thyroid}}(t) = e^{-0.693 t/0.0833} \quad (15)$$

Rubidium ($f_1 = 0.95$)

$$R_{\text{total body}}(t) = 0.1 e^{-0.693t/4} + 0.9 e^{-0.693t/95} \quad (16)$$

Ruthenium and Rhodium ($f_1 = 0.04$)

Ruthenium

$$R_{\text{total body}}(t) = 0.15 e^{-2t} + 0.4 e^{-0.07t} + 0.25 e^{-0.012t} + 0.2 e^{-0.0004t} \quad (17)$$

Rhodium

$$R(t) = 0.67 e^{-0.693t/3} + 0.33 e^{-0.693t/200} \quad (18)$$

Tellurium ($f_1 = 0.25$)

$$R_{\text{total body}}(t) = 0.32 e^{-0.693t/9.2} \quad (19)$$

$$R_{\text{liver}}(t) = 0.055 e^{-0.693t/10.2} \quad (20)$$

$$R_{\text{muscle}}(t) = 0.10 e^{-0.693t/17.7} \quad (21)$$

$$R_{\text{kidneys}}(t) = 0.034 e^{-0.693t/23} \quad (22)$$

$$R_{\text{bone}}(t) = 0.02 e^{-0.693t/8000} \quad (23)$$

Strontium-Yttrium and Barium-Lanthanum

Strontium ($f_1 = 0.2$)

Barium ($f_1 = 0.1$)

Snyder, et.al.⁽⁹⁾ has adopted the model of Marshall, et.al.⁽¹³⁾ for the adult and has tabulated microcurie-days of Sr-89, Sr-90, Sr-91 and Ba-140 accumulated in cancellous bone, cortical bone and soft tissues following intake of 1 microcurie of each nuclide to blood. It is recommended that these values, reproduced here in Table 9 be adopted.

Microcurie-Days Accumulated in Cancellous Bone, in Cortical Bone
and in Soft Tissues Following Intake of 1 μ Ci of the
Indicated Radionuclide to Blood*

Time (days)	Body Tissues	^{89}Sr	^{90}Sr	^{91}Sr	^{140}Ba
2	canc. bone	0.151	0.153	0.0291	0.0745
	cort. bone	0.161	0.164	0.0311	0.0817
	soft tissue	1.18	1.20	0.410	0.614
7	canc. bone	0.609	0.636	0.0313	0.202
	cort. bone	0.666	0.697	0.0334	0.227
	soft tissue	2.23	2.30	0.416	0.907
30	canc. bone	1.97	2.31	0.0313	0.401
	cort. bone	2.30	2.71	0.0334	0.479
	soft tissue	4.09	4.53	0.416	1.37
60	canc. bone	3.09	4.20		0.467
	cort. bone	3.70	5.08		0.565
	soft tissue	5.21	6.45		1.49
180	canc. bone	5.17	12.8		0.487
	cort. bone	6.34	16.0		0.591
	soft tissue	6.37	10.6		1.51
15	canc. bone	5.57	24.1		
	cort. bone	6.86	30.9		
	soft tissue	6.47	13.1		
1825	canc. bone	5.60	82.7		
	cort. bone	6.91	120.0		
	soft tissue	6.47	17.1		
3650	canc. bone		119.0		
	cort. bone		197.0		
	soft tissue		17.9		
7300	canc. bone		147.0		
	cort. bone		292.0		
	soft tissue		18.2		
10,950	canc. bone		153.0		
	cort. bone		331.0		
	soft tissue		18.3		
14,600	canc. bone		157.0		
	cort. bone		376.0		
	soft tissue		18.3		
18,250	canc. bone		158.0		
	cort. bone		394.0		
	soft tissue		18.3		

* The entries indicated for a given time t represent the μ Ci-days accumulated for the period 0 to t days. Blank spaces indicate the data are the same as the last entry in the column.

Yttrium and Lanthanum ($f_1 = .0001$)

Yttrium($f_2' = 0.50$ for bone, 0.15 for liver, 0.1 for all other tissues)

Deposition of Yttrium in bone is considered to be partitioned equally between cancellous and cortical bone.

Retention of Yttrium is assumed to follow a single exponential with a biological half-time of 8000 days in all these tissues.

Lanthanum ($f_2' = 0.40$ for bone, 0.4 for liver, 0.05 for kidney, 0.10 for other soft tissue) $T_{eff} = 1.68$ days

Zirconium-Niobium

Zirconium ($f_1 = 2 \times 10^{-3}$)

$$\text{General Retention } R(t) = 0.5 e^{-0.693t/7} + 0.5 e^{-0.693t/8000} \quad (24)$$

$$R_{\text{bone}}(t) = 0.90 (0.5 e^{-0.693t/8000}) \quad (25)$$

$$R_{\text{soft tissues}}(t) = 0.10 (0.5 e^{-0.643t/8000}) + 0.5 e^{-0.693t/7} \quad (26)$$

Niobium ($f_1 = 0.01$)

$$\text{General Retention } R(t) = 0.5 e^{-0.693t/6} + 0.5 e^{-0.693t/200} \quad (27)$$

$$R_{\text{uniform all tissue}}(t) = 0.5 e^{-0.693t/6} \quad (28)$$

$$R_{\text{bone}}(t) = .357 e^{-0.693t/200} \quad (29)$$

$$R_{\text{kidney}}(t) = 0.855 \times 10^{-2} e^{-0.693t/200} \quad (30)$$

$$R_{\text{spleen}}(t) = 0.500 \times 10^{-2} e^{-0.693t/200} \quad (31)$$

$$R_{\text{testes}}(t) = 0.128 \times 10^{-2} e^{-0.693t/200} \quad (32)$$

$$R_{\text{other tissues}}(t) = 0.128 e^{-0.693t/200} \quad (33)$$

1. Radioactive Chains

Generally, very little information is available concerning the retention of daughter radionuclides in the organs where they are produced, or concerning their transfer to other organs. In most cases the assumption is made, as suggested by Snyder et.al.,⁽¹⁰⁾ that the daughter will be retained in the organ where it is produced and will have the same retention function as it would have if it had been freshly deposited. Exceptions to this assumption, summarized from reference 10, are noted in Table 10 for the tabulation of chains encountered in the condensed list of LMFBR radionuclides.

Table 10

Treatment of Radioactive Daughters in Chains of the
LMFBR Radionuclides

Chain	Treatment of Daughters
$\text{Sr}^{90} \rightarrow \text{Y}^{90} \rightarrow \text{Zr}^{90}$	<p>Y produced in an organ is retained as if inhaled originally</p> <p>Y produced in the lungs is assigned the clearance class W and a value 0.0001 for f_1</p>
$\text{Y}^{95} \rightarrow \text{Zr}^{95} \rightarrow \text{Nb}^{95} \rightarrow \text{Mo}^{95}$	<p>Zr produced in the lungs or GI tract is assigned the clearance class Y and a value of 0.002 for f_1</p> <p>Zr produced in an organ is retained as if inhaled originally</p> <p>Nb produced in an organ retained as if inhaled originally</p> <p>Nb produced in the lungs or GI tract is assigned clearance class Y and a value of 0.01 for f_1</p>
$\text{Ru}^{103} \rightarrow \text{Rh}^{103} \rightarrow \text{Pd}^{103}$ $\text{Ru}^{106} \rightarrow \text{Rh}^{106} \rightarrow \text{Pd}^{106}$	<p>Parent-Daughter in equilibrium in all tissues except lungs and GI tract where the standard model is used and a value of 0.04 is assigned for f_1 for Ru and Rh</p>
$\text{Te}^{132} \rightarrow \text{I}^{132} \rightarrow \text{Xe}^{132}$	<p>Iodine produced in the lungs, stomach and contents of the small intestine goes entirely to the blood and then follows regular course. 95% of I produced in the contents of the upper large intestine and the lower large intestine goes to the blood and then follows regular course. Iodine produced in any of the systemic organs is assumed to reach the blood and then follows regular course.</p> <p>It has been assumed that Iodine leaves the systemic organs rapidly and a clearance constant (λ) of $3.30 \times 10^{-5} \text{ sec}^{-1}$ has been assigned to facilitate computation of the time integrated activity in thyroid and total body upon leaving the blood.</p>

$I^{133} \rightarrow Xe^{133} \rightarrow Cs^{133}$	Xe produced in the lungs is assigned clearance class D, and that portion that reaches the blood goes to the total body and is assigned a biological half time of 2 hrs.
$I^{135} \rightarrow Xe^{135} \rightarrow Cs^{135}$	<p>Xe produced in lung and GI tract is assigned a value of 0.95 for f_1</p> <p>Xe produced in the thyroid and total body is assigned a biological half-time of 2 hours and the following retention expression</p> $R(t) = (e^{-0.693t/.0833}) e^{-\lambda_r t}$
$Cs^{137} \rightarrow Ba^{137m} \rightarrow Ba^{137}$	Parent-Daughter in equilibrium in tissues and metabolize as Cs. Essentially the same integrated activity is assigned for Ba^{137m} as for Cs^{137} .
$Ba^{140} \rightarrow La^{140} \rightarrow Ce^{140}$	La produced in the lungs is assigned clearance class W and a value of 0.0001 for f_1 . When produced in an organ of the body it is assumed to be retained as though it had just entered from the blood.
$Ce^{144} \rightarrow Pr^{144} \rightarrow Nd^{144}$	Ce and Pr have the same metabolic behavior. Pr produced in the lungs is treated as if inhaled. Pr produced in the GI tract is assigned a value of 0.0001 for f_1 .
$Pu^{241} \rightarrow Am^{241} \rightarrow Np^{237}$	Pu, Am, Cm have the same metabolic models.
$Cm^{242} \rightarrow Pu^{238} \rightarrow U^{234}$	Pu produced in lungs and GI tract is assigned a value of 3×10^{-5} for f_1 .
$Cm^{243} \rightarrow Pu^{239} \rightarrow U^{235}$	Cm and Am produced in the lungs and GI tract are assigned a value of 0.001 for f_1 .
$Cm^{244} \rightarrow Pu^{240} \rightarrow U^{236}$	
$Zn^{72} \rightarrow Ga^{72} \rightarrow Ge^{72}$	<p>Ga produced in the lungs or GI tract is assigned clearance class W and a value of 0.001 for f_1. When produced in an organ of the body it is retained as though it had just entered from the blood.</p> <p>Ga produced in the muscle, pancreas, testes, and ovaries is assumed to have a biological half time of 6 days.</p>

IV TIME INTEGRATED ORGAN DEPOSITED ACTIVITY

The calculation of time integrated activity per unit activity inhaled ($\mu\text{Ci-days/Ci}$ inhaled) for the radionuclides shown in Table 2 was accomplished by use of a computer code described in the Appendix. The metabolic model shown in Figure 1, and the values of the essential parameters and retention models presented in Section III above are used in the calculations. The calculations were carried out for four particle sizes (AMAD of 0.1μ , 0.2μ , 0.5μ and 1.0μ) Table 11 presents the values of the time integrated activity commitment in $\mu\text{Ci-days/Ci}$ inhaled that will accrue in 70 years based on the assumptions presented in this report.

V DOSE CONVERSION FACTORS

Radiological consequences from inhaled radionuclides are usually determined from organ dose commitments calculated from the amount of radionuclides inhaled in radioactivity units such as curies and published dose conversion factors (F-factors) in units of rem per curie inhaled. Published F-factors are based on the old lung model recommended by Committee 2 of ICRP⁽¹²⁾, the disadvantages of which were discussed previously.⁽²⁾ Dose conversion factors based on the new lung model recommended by the ICRP Task Group on Lung Dynamics⁽¹⁾ and on revised organ retention models have not been published although extensive tables of rem per $\mu\text{Ci-day}$ deposited in a large number of organs have been reported for a large number of radionuclides by Snyder et.al.⁽⁴⁾ The purpose of this section is to present a tabulation of dose conversion factors calculated on the basis of the metabolic model which incorporates the Task Group Lung Model (Figure 1) and organ retention models, some of which were recently revised⁽⁹⁾, presented in sections II and III.

TABLE 11
Time Integrated Activity For A 70 Year Exposure Period
Following Inhalation of Aerosols of Various Mass Median
Aerodynamic Diameters

ORGAN*	MICROCURIE DAYS PER CURIE Pu238 INHALED			
	<u>0.1μm</u>	<u>0.2μm</u>	<u>0.5μm</u>	<u>1.0μm</u>
N-P	5.71 E+3**	2.86 E+4	8.56 E+4	1.71 E+5
T-B	2.29 E+4	2.29 E+4	2.29 E+4	2.29 E+4
Pul	2.13 E+8	1.92 E+8	1.28 E+8	1.07 E+8
Pul Lymph Node	1.03 E+8	9.30 E+7	6.20 E+7	5.17 E+7
Stomach	2.03 E+4	2.03 E+4	1.95 E+4	2.40 E+4
SI	8.11 E+4	8.10 E+4	7.77 E+4	9.58 E+4
ULI	2.63 E+5	2.63 E+5	2.52 E+5	3.11 E+5
LLI	4.86 E+5	4.86 E+5	4.66 E+5	5.75 E+5
Blood	1.13 E+3	1.02 E+3	6.95 E+2	6.01 E+2
Bone	6.70 E+8	6.07 E+8	4.15 E+8	3.59 E+8
Liver	5.12 E+8	4.64 E+8	3.17 E+8	2.74 E+8
Kidneys	1.14 E+7	1.03 E+7	7.04 E+6	6.10 E+6
Testes	1.49 E+5	1.35 E+5	9.22 E+4	7.98 E+4
Ovaries	1.49 E+4	1.35 E+4	9.22 E+3	7.98 E+3
Other Tissues	7.44 E+7	6.74 E+7	4.61 E+7	3.99 E+7

* N-P is used to denote naso-pharyngeal region of the respiratory tract, T-B the tracheobronchial region, and Pul the pulmonary region. SI is used to denote the small intestine, ULI the upper large intestine and LLI the lower large intestine.

** 5.71 E+3 means 5.71×10^3 .

TABLE 11 CONTINUED

Microcurie Days Per Curie Pu239 Inhaled

<u>ORGAN</u>	<u>0.1μm</u>	<u>0.2μm</u>	<u>0.5μm</u>	<u>1.0μm</u>
N-P	5.71 E+3	2.86 E+4	8.57 E+4	1.71 E+5
T-B	2.29 E+4	2.29 E+4	2.29 E+4	2.29 E+4
Pul	2.16 E+8	1.95 E+8	1.30 E+8	1.08 E+8
Pul Lymph Node	1.08 E+8	9.74 E+7	6.49 E+7	5.41 E+7
Stomach	2.04 E+4	2.04 E+4	1.95 E+4	2.41 E+4
SI	8.16 E+4	8.15 E+4	7.80 E+4	9.61 E+4
ULI	2.65 E+5	2.65 E+5	2.53 E+5	3.12 E+5
LLI	4.89 E+5	4.89 E+5	4.68 E+5	5.76 E+5
Blood	1.17 E+3	1.06 E+3	7.21 E+2	6.23 E+2
Bone	8.70 E+8	7.88 E+8	5.38 E+8	4.66 E+8
Liver	6.47 E+8	5.86 E+8	4.00 E+8	3.46 E+8
Kidney	1.44 E+7	1.30 E+7	8.89 E+6	7.69 E+6
Testes	1.93 E+5	1.75 E+5	1.20 E+5	1.04 E+5
Ovaries	1.93 E+4	1.75 E+4	1.20 E+4	1.04 E+4
Other Tissues	9.67 E+7	8.75 E+7	5.98 E+7	5.18 E+7

TABLE 11 CONTINUED

Microcurie Days Per Curie Pu240 Inhaled

<u>ORGAN</u>	<u>0.1μm</u>	<u>0.2μm</u>	<u>0.5μm</u>	<u>1.0μm</u>
N-P	5.71 E+3	2.86 E+4	8.57 E+4	1.71 E+5
T-B	2.29 E+4	2.29 E+4	2.29 E+4	2.29 E+4
Pul	2.16 E+8	1.95 E+8	1.30 E+8	1.08 E+8
Pul Lymph Node	1.08 E+8	9.73 E+7	6.49 E+7	5.41 E+7
Stomach	2.04 E+4	2.04 E+4	1.95 E+4	2.41 E+4
SI	8.16 E+4	8.15 E+4	7.80 E+4	9.61 E+4
ULI	2.65 E+5	2.65 E+5	2.53 E+5	3.12 E+5
LLI	4.89 E+5	4.89 E+5	4.68 E+5	5.76 E+5
Blood	1.17 E+3	1.06 E+3	7.21 E+2	6.23 E+2
Bone	8.67 E+8	7.85 E+8	5.36 E+8	4.64 E+8
Liver	6.45 E+8	5.84 E+8	3.99 E+8	3.45 E+8
Kidney	1.43 E+7	1.30 E+7	8.86 E+6	7.67 E+6
Testes	1.93 E+5	1.74 E+5	1.19 E+5	1.03 E+5
Ovaries	1.93 E+4	1.74 E+4	1.19 E+4	1.03 E+4
Other Tissues	9.63 E+7	8.72 E+7	5.96 E+7	5.16 E+7

TABLE 11 CONTINUED

Microcurie Days Per Curie Pu241 Inhaled

ORGAN	0.1 μ m		0.2 μ m		0.5 μ m		1.0 μ m	
	<u>Pu241</u>	<u>Am241</u>	<u>Pu241</u>	<u>Am241</u>	<u>Pu241</u>	<u>Am241</u>	<u>Pu241</u>	<u>Am241</u>
N-P	5.71 E+3	1.37 E-2	2.86 E+4	6.83 E-2	8.57 E+4	2.05 E-1	1.71 E+5	4.10 E-1
T-B	2.29 E+4	2.73 E-2	2.29 E+4	2.73 E-2	2.29 E+4	2.73 E-2	2.29 E+4	2.73 E-2
Pul	1.96 E+8	5.84 E+5	2.35 E+8	5.25 E+5	1.18 E+5	3.50 E+5	9.80 E+7	2.92 E+5
Pul Lymph Node	8.09 E+7	7.71 E+5	7.28 E+7	6.94 E+5	4.87 E+7	4.63 E+5	4.04 E+7	3.86 E+5
Stomach	1.96 E+4	2.26 E+1	1.97 E+4	2.03 E+1	1.91 E+4	1.36 E+1	2.37 E+4	1.13 E+1
SI	7.84 E+4	9.02 E+1	7.86 E+4	8.12 E+1	7.61 E+4	5.42 E+1	9.45 E+4	4.53 E+1
ULI	2.55 E+5	2.93 E+2	2.55 E+5	2.64 E+2	2.47 E+5	1.77 E+2	3.07 E+5	1.48 E+2
LLI	4.70 E+5	5.44 E+2	4.72 E+5	4.90 E+2	4.56 E+5	3.28 E+2	5.67 E+5	2.75 E+2
Blood	9.21 E+2	6.97 E00	8.35 E+2	6.28 E00	5.73 E+2	4.18 E00	4.99 E+2	3.49 E00
Bone	2.13 E+8	1.79 E+7	1.93 E+8	1.62 E+7	1.32 E+8	1.11 E+7	1.15 E+8	9.55 E+6
Liver	1.83 E+8	1.27 E+7	1.66 E+8	1.15 E+7	1.14 E+8	7.83 E+6	9.94 E+7	6.75 E+6
Kidney	4.07 E+6	2.82 E+5	3.69 E+6	2.55 E+5	2.53 E+6	1.74 E+5	2.21 E+6	1.50 E+5
Testes	4.73 E+4	3.98 E+3	4.29 E+4	3.60 E+3	2.94 E+4	2.46 E+3	2.57 E+4	2.12 E+3
Ovaries	4.73 E+3	3.98 E+2	4.29 E+3	3.60 E+2	2.94 E+3	2.45 E+2	2.57 E+3	2.12 E+2
Other Tissues	2.37 E+7	1.99 E+6	2.14 E+7	1.80 E+6	1.47 E+7	1.23 E+6	1.28 E+7	1.06 E+6

TABLE 11 CONTINUED

Microcurie Days Per Curie Am241 Inhaled

<u>ORGAN</u>	<u>0.1μm</u>	<u>0.2μm</u>	<u>0.5μm</u>	<u>1.0μm</u>
N-P	5.71 E+3	2.86 E+4	8.57 E+4	1.71 E+5
T-B	2.29 E+4	2.29 E+4	2.29 E+4	2.29 E+4
Pul	2.16 E+8	1.94 E+8	1.30 E+8	1.08 E+8
Pul Lymph Node	1.07 E+8	9.65 E+7	6.43 E+7	5.36 E+7
Stomach	2.04 E+4	2.04 E+4	1.95 E+4	2.41 E+4
SI	8.14 E+4	8.13 E+4	7.79 E+4	9.60 E+4
ULI	2.64 E+5	2.64 E+5	2.53 E+5	3 12 E+5
LLI	4.88 E+5	4.88 E+5	4.67 E+5	5.76 E+5
Blood	1.16 E+3	1.05 E+3	7.21 E+2	6.25 E+2
Bone	8.30 E+8	7.52 E+8	5.15 E+8	4.47 E+8
Liver	6.21 E+8	5.62 E+8	3.85 E+8	3.34 E+8
Kidney	1.38 E+7	1.25 E+7	8.55 E+6	7.42 E+6
Testes	1.84 E+5	1.67 E+5	1.14 E+5	9.93 E+4
Ovaries	1.84 E+4	1.67 E+4	1.14 E+4	9.93 E+3
Other Tissues	9.22 E+7	8.35 E+7	5.72 E+7	4.97 E+7

TABLE 11 CONTINUED

Microcurie Days Per Curie Cm242 Inhaled

ORGAN	0.1 μ m		0.2 μ m		0.5 μ m		1.0 μ m	
	<u>Cm242</u>	<u>Pu238</u>	<u>Cm242</u>	<u>Pu238</u>	<u>Cm242</u>	<u>Pu238</u>	<u>Cm242</u>	<u>Pu238</u>
N-P	5.70 E+3	7.02 E-2	2.85 E+4	3.51 E+1	8.55 E+4	1.05 E00	1.71 E+5	2.10 E00
T-B	2.28 E+4	1.41 E-1	2.29 E+4	1.41 E-1	2.28 E+4	1.41 E-1	2.28 E+4	1.41 E-1
Pul	5.29 E+7	7.97 E+5	4.76 E+7	7.17 E+5	3.17 E+7	4.78 E+5	2.64 E+7	3.98 E+5
Pul Lymph Node	3.64 E+6	4.95 E+6	3.27 E+6	4.46 E+5	2.18 E+6	2.97 E+5	1.82 E+6	2.48 E+5
Stomach	1.41 E+4	3.11 E+1	1.47 E+4	2.80 E+1	1.57 E+4	1.87 E+1	2.08 E+4	1.57 E+1
SI	5.60 E+4	1.24 E+2	5.84 E+4	1.12 E+2	6.25 E+4	7.50 E+1	8.31 E+4	6.30 E+1
ULI	1.81 E+5	4.05 E+2	1.89 E+5	3.66 E+2	2.03 E+5	2.46 E+2	2.69 E+5	2.08 E+2
LLI	3.34 E+5	7.56 E+2	3.48 E+5	6.83 E+2	3.73 E+5	4.62 E+2	4.95 E+5	3.94 E+2
Blood	1.14 E+2	5.04 E00	1.09 E+2	4.54 E00	9.06 E+1	3.02 E00	9.95 E+1	2.52 E00
Bone	1.02 E+6	3.33 E+6	9.73 E+5	3.02 E+6	8.12 E+5	2.07 E+6	8.91 E+5	1.80 E+6
Liver	1.01 E+6	2.55 E+6	9.67 E+5	2.31 E+6	8.07 E+5	1.58 E+6	8.86 E+5	1.37 E+6
Kidney	2.25 E+4	5.66 E+4	2.15 E+4	5.12 E+4	1.79 E+4	3.51 E+4	1.97 E+4	3.05 E+4
Testes	2.27 E+2	7.41 E+2	2.16 E+2	6.71 E+2	1.81 E+2	4.60 E+2	1.98 E+2	3.99 E+2
Ovaries	2.27 E+1	7.41 E+1	2.16 E+1	6.71 E+1	1.81 E+1	4.60 E+1	1.98 E+1	3.99 E+1
Other Tissues	1.13 E+5	3.70 E+5	1.08 E+5	3.35 E+5	9.02 E+4	2.30 E+5	9.90 E+4	2.00 E+5

TABLE 11 CONTINUED

Microcurie Days Per Curie Cm243 Inhaled

<u>ORGAN</u>	<u>0.1μm</u>		<u>0.2μm</u>		<u>0.5μm</u>		<u>1.0μm</u>	
	<u>Cm243</u>	<u>Pu239</u>	<u>Cm243</u>	<u>Pu239</u>	<u>Cm243</u>	<u>Pu239</u>	<u>Cm243</u>	<u>Pu239</u>
N-P	5.71 E+3	2.57 E-4	2.86 E+4	1.28 E-3	8.57 E+4	3.85 E-3	1.71 E+5	7.71 E-3
T-B	2.29 E+4	5.14 E-4	2.29 E+4	5.14 E-4	2.29 E+4	5.14 E-4	2.29 E+4	5.14 E-4
Pul	2.07 E+8	1.17 E+4	1.87 E+8	1.05 E+4	1.25 E+8	6.99 E+3	1.04 E+8	5.83 E+3
Pul Lymph Node	9.56 E+7	1.66 E+4	8.60 E+7	1.49 E+4	5.73 E+7	9.94 E+3	4.78 E+7	8.29 E+3
Stomach	2.01 E+4	4.51 E-1	2.01 E+4	4.06 E-1	1.93 E+4	2.71 E-1	2.39 E+4	2.26 E-1
SI	8.01 E+4	1.80 E00	8.02 E+4	1.62 E00	7.71 E+4	1.08 E00	9.53 E+4	9.05 E-1
ULI	2.60 E+5	5.87 E00	2.60 E+5	5.28 E00	2.50 E+5	3.53 E00	3.10 E+5	2.95 E00
LLI	4.81 E+5	1.09 E+1	4.81 E+5	9.79 E00	4.62 E+5	6.55 E00	5.72 E+5	5.50 E00
Blood	1.06 E+3	1.49 E-1	9.60 E+2	1.34 E-1	6.58 E+2	8.91 E-2	5.73 E+2	7.43 E-2
Bone	4.45 E+8	5.63 E+5	4.03 E+8	5.09 E+5	2.77 E+8	3.48 E+5	2.41 E+8	3.01 E+5
Liver	3.55 E+8	3.86 E+5	3.22 E+8	3.50 E+5	2.21 E+8	2.39 E+5	1.92 E+8	2.06 E+5
Kidney	7.90 E+6	8.59 E+3	7.16 E+6	7.77 E+3	4.91 E+6	5.31 E+3	4.27 E+6	4.59 E+3
Testes	9.89 E+4	1.25 E+2	8.96 E+4	1.13 E+2	6.15 E+4	7.74 E+1	5.35 E+4	6.70 E+1
Ovaries	9.89 E+3	1.25 E+1	8.96 E+3	1.13 E+1	6.15 E+3	7.74 E00	5.35 E+3	6.70 E00
Other Tissues	4.94 E+7	6.25 E+4	4.48 E+7	5.66 E+4	3.07 E+7	3.87 E+4	2.67 E+7	3.35 E+4

TABLE 11 CONTINUED

Microcurie Days Per Curie Cm244 Inhaled

ORGAN	0.1 μ m		0.2 μ m		0.5 μ m		1.0 μ m	
	<u>Cm244</u>	<u>Pu240</u>	<u>Cm244</u>	<u>Pu240</u>	<u>Cm244</u>	<u>Pu240</u>	<u>Cm244</u>	<u>Pu240</u>
N-P	5.71 E+3	9.48 E-4	2.86 E+4	4.74 E-3	8.57 E+4	1.42 E-2	1.71 E+5	2.84 E-2
T-B	2.29 E+4	1.90 E-3	2.29 E+4	1.90 E-3	2.29 E+4	1.90 E-3	2.29 E+4	1.90 E-3
Pul	2.02 E+8	4.18 E+4	1.81 E+8	3.76 E+4	1.21 E+8	2.51 E+4	1.01 E+8	2.09 E+4
Pul Lymph Node	8.76 E+7	5.72 E+4	7.88 E+7	5.15 E+4	5.25 E+7	3.43 E+4	4.38 E+7	2.86 E+4
Stomach	1.99 E+4	1.62 E00	1.99 E+4	1.46 E00	1.92 E+4	9.71 E-1	2.38 E+4	8.11 E-1
SI	7.92 E+4	6.46 E00	7.93 E+4	5.81 E00	7.65 E+4	3.88 E00	9.48 E+4	3.24 E00
ULI	2.57 E+5	2.10 E+1	2.58 E+5	1.89 E+1	2.49 E+5	1.26 E+1	3.08 E+5	1.06 E+1
LLI	4.75 E+5	3.89 E+1	4.76 E+5	3.51 E+1	4.59 E+5	2.35 E+1	5.69 E+5	1.97 E+1
Blood	9.88 E+2	5.15 E-1	8.95 E+2	4.63 E-1	6.15 E+2	3.09 E-1	5.37 E+2	2.51 E-1
Bone	2.96 E+8	1.60 E+6	2.69 E+8	1.45 E+6	1.85 E+8	9.90 E+5	1.61 E+8	8.57 E+5
Liver	2.47 E+8	1.12 E+6	2.24 E+8	1.01 E+6	1.54 E+8	6.90 E+5	1.34 E+8	5.96 E+5
Kidney	5.49 E+6	2.48 E+4	4.98 E+6	2.24 E+4	3.42 E+6	1.53 E+4	2.99 E+6	1.32 E+4
Testes	6.59 E+4	3.55 E+2	5.97 E+4	3.22 E+2	4.10 E+4	2.20 E+2	3.58 E+4	1.90 E+2
Ovaries	6.59 E+3	3.55 E+1	5.97 E+3	3.22 E+1	4.10 E+3	2.20 E+1	3.58 E+3	1.90 E+1
Other Tissues	3.29 E+7	1.78 E+5	2.99 E+7	1.61 E+5	2.05 E+7	1.10 E+5	1.79 E+7	9.52 E+4

TABLE 11 CONTINUED

Microcurie Days Per Curie H-3 Inhaled				
<u>ORGAN</u>	<u>0.1μm</u>	<u>0.2μm</u>	<u>0.5μm</u>	<u>1.0μm</u>
N-P	1.44 E+2	7.21 E+2	2.16 E+3	4.33 E+3
T-B	2.25 E+3	2.25 E+3	2.25 E+3	2.25 E+3
Pul	4.69 E+5	3.24 E+5	2.16 E+5	1.80 E+5
Pul Lymph Node	1.80 E+5	6.49 E+4	4.33 E+4	3.61 E+4
Stomach	3.76 E+2	1.21 E+3	3.30 E+3	6.44 E+3
SI	1.50 E+3	4.83 E+3	1.32 E+4	2.57 E+4
Blood	8.56 E+3	6.71 E+3	6.13 E+3	7.29 E+3
Total Body	1.28 E+7	1.00 E+7	9.16 E+6	1.09 E+7

TABLE 11 CONTINUED

Microcurie Days Per Curie Mn-52 Inhaled

<u>ORGAN</u>	<u>0.1μm</u>	<u>0.2μm</u>	<u>0.5μm</u>	<u>1.0μm</u>
N-P	1.01 E+4	5.04 E+4	8.40 E+4	3.02 E+5
T-B	1.17 E+4	1.17 E+4	1.17 E+4	1.17 E+4
Pul	2.44 E+6	2.19 E+6	1.46 E+6	1.22 E+6
Pul Lymph Node	1.85 E+4	1.66 E+4	1.11 E+4	9.24 E+3
Stomach	9.83 E+3	1.03 E+4	9.04 E+3	1.53 E+4
SI	3.84 E+4	4.04 E+4	3.53 E+4	5.95 E+4
ULI	1.05 E+5	1.11 E+5	9.68 E+4	1.63 E+5
LLI	1.73 E+5	1.82 E+5	1.59 E+5	2.68 E+5
Blood	8.30 E+2	8.81 E+2	9.34 E+2	1.27 E+3
Liver	1.14 E+5	1.21 E+5	1.28 E+5	1.74 E+5
Kidney	1.59 E+4	1.69 E+4	1.79 E+4	2.43 E+4
Pancreas	8.79 E+3	9.33 E+3	9.89 E+3	1.34 E+4
Total Body	2.98 E+5	3.16 E+5	3.35 E+5	4.54 E+5

TABLE 11 CONTINUED

Microcurie Days Per Curie Mn52M Inhaled

<u>ORGAN</u>	<u>0.1μm</u>	<u>0.2μm</u>	<u>0.5μm</u>	<u>1.0μm</u>
N-P	1.99 E+2	9.93 E+2	1.71 E+3	5.96 E+3
T-B	1.14 E+3	1.14 E+3	1.14 E+3	1.14 E+3
Pul	1.07 E+4	9.59 E+3	6.40 E+3	5.33 E+3
Pul Lymph Node	1.59 E-1	1.43 E-1	9.56 E-2	7.97 E-2
Stomach	8.37 E+1	8.77 E+1	8.19 E+1	1.23 E+2
SI	3.80 E+1	3.99 E+1	3.72 E+1	5.57 E+1
ULI	4.24 E00	4.44 E00	4.15 E00	6.21 E00
LLI	1.64 E-1	1.72 E-1	1.61 E-1	2.41 E-1
Blood	1.85 E+2	2.03 E+2	2.47 E+2	3.15 E+2
Liver	8.24 E+1	9.00 E+1	1.10 E+2	1.40 E+2
Kidney	1.71 E+1	1.87 E+1	2.29 E+1	2.91 E+1
Pancreas	1.02 E+1	1.12 E+1	1.37 E+1	1.75 E+1
Total Body	2.32 E+2	2.55 E+2	3.12 E+2	3.96 E+2

TABLE 11 CONTINUED

Microcurie Days Per Curie Mn-56 Inhaled

<u>ORGAN</u>	<u>0.1μm</u>	<u>0.2μm</u>	<u>0.5μm</u>	<u>1.0μm</u>
N-P	1.26 E+3	6.31 E+3	1.06 E+4	3.78 E+4
T-B	4.57 E+3	4.57 E+3	4.57 E+3	4.57 E+3
Pul	7.45 E+4	6.71 E+4	4.47 E+4	3.73 E+4
Pul Lymph Node	8.32 E00	7.49 E00	4.99 E00	4.16 E00
Stomach	1.15 E+3	1.21 E+3	1.12 E+3	1.74 E+3
SI	2.21 E+3	2.32 E+3	2.15 E+3	3.34 E+3
ULI	1.44 E+3	1.51 E+3	1.40 E+3	2.18 E+3
LLI	3.56 E+2	3.76 E+2	3.47 E+2	5.40 E+2
Blood	4.20 E+2	4.60 E+2	5.57 E+2	7.12 E+2
Liver	1.35 E+3	1.47 E+3	1.79 E+3	2.28 E+3
Kidney	2.77 E+2	3.04 E+2	3.68 E+2	4.70 E+2
Pancreas	1.66 E+2	1.82 E+2	2.20 E+2	2.81 E+2
Total Body	3.81 E+3	4.17 E+3	5.05 E+3	6.46 E+3

TABLE 11 CONTINUED

Microcurie Days Per Curie Co-57 Inhaled

<u>ORGAN</u>	<u>0.1μm</u>	<u>0.2μm</u>	<u>0.5μm</u>	<u>1.0μm</u>
N-P	1.16 E+4	5.82 E+4	9.71 E+4	3.49 E+5
T-B	1.21 E+4	1.21 E+4	1.21 E+4	1.21 E+4
Pul	1.86 E+7	1.67 E+7	1.11 E+7	9.28 E+6
Pul Lymph Node	1.29 E+6	1.16 E+6	7.71 E+5	6.43 E+5
Stomach	1.74 E+4	1.74 E+4	1.40 E+4	2.06 E+4
SI	6.95 E+4	6.93 E+4	5.59 E+4	8.21 E+4
ULI	2.14 E+5	2.14 E+5	1.72 E+5	2.53 E+5
LLI	3.95 E+5	3.74 E+5	3.18 E+5	4.67 E+5
Blood	1.65 E+3	1.61 E+3	1.39 E+3	1.56 E+3
Liver	4.27 E+5	4.14 E+5	3.60 E+5	4.04 E+5
Total Body	5.32 E+6	5.17 E+5	4.49 E+6	5.03 E+6

TABLE 11 CONTINUED

Microcurie Days Per Curie Co-58 Inhaled

<u>ORGAN</u>	<u>0.1μm</u>	<u>0.2μm</u>	<u>0.5μm</u>	<u>1.0μm</u>
N-P	1.15 E+4	5.77 E+4	9.62 E+4	3.46 E+5
T-B	1.21 E+4	1.21 E+4	1.21 E+4	1.21 E+4
Pul	1.30 E+7	1.17 E+7	7.79 E+6	6.49 E+6
Pul Lymph Node	6.21 E+5	5.59 E+5	3.73 E+5	3.10 E+5
Stomach	1.52 E+4	1.53 E+4	1.26 E+4	1.94 E+4
SI	6.04 E+4	6.11 E+4	5.03 E+4	7.71 E+4
ULI	1.86 E+5	1.88 E+5	1.55 E+5	2.37 E+5
LLI	3.40 E+5	3.43 E+5	2.83 E+5	4.33 E+5
Blood	1.29 E+3	1.28 E+3	1.18 E+3	1.38 E+3
Liver	1.44 E+5	1.42 E+5	1.31 E+5	1.54 E+5
Total Body	1.79 E+6	1.77 E+6	1.63 E+6	1.91 E+6

TABLE 11 CONTINUED

Microcurie Days Per Curie Co-60 Inhaled

<u>ORGAN</u>	<u>0.1μm</u>	<u>0.2μm</u>	<u>0.5μm</u>	<u>1.0μm</u>
N-P	1.17 E+4	5.84 E+4	9.73 E+4	3.50 E+5
T-B	1.21 E+4	1.21 E+4	1.21 E+4	1.21 E+4
Pul	2.14 E+7	1.92 E+7	1.28 E+7	1.07 E+7
Pul Lymph Node	1.71 E+6	1.54 E+6	1.03 E+6	8.56 E+5
Stomach	1.85 E+4	1.84 E+4	1.47 E+4	2.12 E+4
SI	7.39 E+4	7.34 E+4	5.86 E+4	8.45 E+4
ULI	2.28 E+5	2.27 E+5	1.81 E+5	2.61 E+5
LLI	4.22 E+5	4.18 E+5	3.34 E+5	4.82 E+5
Blood	1.85 E+3	1.78 E+3	1.51 E+3	1.66 E+3
Liver	1.13 E+6	1.09 E+6	9.23 E+5	1.02 E+6
Total Body	1.41 E+7	1.36 E+7	1.15 E+7	1.27 E+7

DRAFT

TABLE 11 CONTINUED

Microcurie Days Per Curie Tel32 Inhaled

ORGAN	0.1 μ m		0.2 μ m		0.5 μ m		1.0 μ m	
	Tel32	I 132	Tel32	I 132	Tel32	I 132	Tel32	I 132
N-P	1.44 E+2	1.36 E+1	7.19 E+2	6.79 E+1	2.16 E+3	2.04 E+2	4.31 E+3	4.08 E+2
T-B	2.18 E+3	1.47 E+3	2.18 E+3	1.47 E+3	2.18 E+3	1.47 E+3	2.18 E+3	1.47 E+3
Pul	4.06 E+5	3.41 E+5	2.81 E+5	2.36 E+5	1.87 E+5	1.57 E+5	1.56 E+5	1.31 E+5
Pul Lymph Node	1.35 E+5	1.14 E+5	4.87 E+4	4.09 E+4	3.25 E+4	2.73 E+4	2.71 E+4	2.27 E+4
Stomach	3.63 E+2	8.41 E+1	1.19 E+3	2.76 E+2	3.25 E+3	7.55 E+2	6.35 E+3	1.47 E+3
SI	1.40 E+3	9.15 E+2	4.57 E+3	3.00 E+3	1.25 E+4	8.21 E+3	2.44 E+4	1.60 E+4
ULI	3.05 E+3	2.43 E+3	1.00 E+4	7.96 E+3	2.74 E+4	2.18 E+4	5.34 E+4	4.25 E+4
LLI	4.64 E+3	4.10 E+3	1.52 E+4	1.35 E+4	4.16 E+4	3.68 E+4	8.13 E+4	7.19 E+4
Blood	7.13 E+3	3.40 E+4	5.62 E+3	2.60 E+4	4.88 E+3	2.28 E+4	5.46 E+3	2.59 E+4
Bone	5.77 E+4	4.14 E+4	4.55 E+4	3.27 E+4	3.95 E+4	2.83 E+4	4.42 E+4	3.17 E+4
Liver	1.20 E+5	8.63 E+4	9.50 E+4	6.81 E+4	8.24 E+4	5.91 E+4	9.22 E+4	6.62 E+4
Kidney	8.60 E+4	6.17 E+4	6.78 E+4	6.87 E+4	5.88 E+4	4.22 E+4	6.59 E+4	4.72 E+4
Total Body	6.82 E+5	7.76 E+5	5.39 E+5	6.06 E+5	4.67 E+5	5.27 E+5	5.23 E+5	5.94 E+5
Muscle	2.44 E+5	1.75 E+5	1.92 E+5	1.38 E+5	1.67 E+5	1.20 E+5	1.87 E+5	1.34 E+5
Thyroid		3.69 E+4		2.83 E+4		2.47 E+4		2.81 E+4

2h

TABLE 11 CONTINUED

Microcurie Days Per Curie I 131 Inhaled

<u>ORGAN</u>	<u>0.1μm</u>	<u>0.2μm</u>	<u>0.5μm</u>	<u>1.0μm</u>
N-P	1.44 E+2	7.20 E+2	2.16 E+3	4.32 E+3
T-B	2.22 E+3	2.22 E+3	2.22 E+3	2.22 E+3
Pul	4.41 E+5	3.06 E+5	2.04 E+5	1.70 E+5
Pul Lymph Node	1.60 E+5	5.75 E+4	3.84 E+4	3.20 E+4
Stomach	3.70 E+2	1.20 E+3	3.28 E+3	6.40 E+3
SI	1.46 E+3	4.73 E+3	1.29 E+4	2.52 E+4
ULI	2.26 E+2	7.33 E+2	2.00 E+3	3.90 E+3
LLI	3.84 E+2	1.25 E+3	3.40 E+3	6.64 E+3
Thyroid	2.31 E+6	1.83 E+6	1.69 E+6	2.02 E+6
Total Body	3.86 E+5	3.06 E+5	2.83 E+5	3.38 E+5

TABLE 11 CONTINUED

Microcurie Days Per Curie I133 Inhaled

ORGAN	0.1 μ m		0.2 μ m		0.5 μ m		1.0 μ m	
	<u>I133</u>	<u>Xe133</u>	<u>I133</u>	<u>Xe133</u>	<u>I133</u>	<u>Xe133</u>	<u>I133</u>	<u>Xe133</u>
N-P	1.43 E+2	2.68 E-1	7.13 E+2	1.34 E00	2.14 E+3	4.02 E00	4.27 E+3	8.03 E00
T-B	2.02 E+3	3.61 E+1	2.02 E+3	3.61 E+1	2.02 E+3	3.61 E+1	2.02 E+3	3.61 E+1
Pul	2.98 E+5	2.57 E+4	2.06 E+5	1.78 E+4	1.38 E+5	1.18 E+4	1.15 E+5	9.87 E+3
Pul Lymph Node	7.30 E+4	1.53 E+4	2.63 E+4	5.51 E+3	1.75 E+4	3.67 E+3	1.46 E+4	3.06 E+3
Stomach	3.32 E+2	7.09 E00	1.13 E+3	1.30 E+1	3.13 E+3	2.77 E+1	6.13 E+3	4.97 E+1
SI	1.17 E+3	5.26 E+1	3.99 E+3	1.35 E+2	1.10 E+4	3.43 E+2	2.16 E+4	6.54 E+2
ULI	1.33 E+2	1.67 E+1	4.53 E+2	5.04 E+1	1.25 E+3	1.35 E+2	2.45 E+3	2.61 E+2
LLI	1.37 E+2	4.31 E+1	4.67 E+2	1.36 E+2	1.29 E+3	3.69 E+2	2.53 E+3	7.18 E+2
Blood	5.08 E+3	5.11 E+2	4.45 E+3	3.34 E+2	4.47 E+3	2.43 E+2	5.67 E+3	2.32 E+2
Total Body	1.23 E+5	3.01 E+2	1.08 E+5	2.15 E+2	1.08 E+5	1.76 E+2	1.38 E+5	1.90 E+2
Thyroid	1.40 E+5	9.16 E+1	1.23 E+5	8.03 E+1	1.23 E+5	8.05 E+1	1.57 E+5	1.02 E+2

TABLE 11 CONTINUED

Microcurie Days Per Curie I-135 Inhaled

ORGAN	0.1 μ m		0.2 μ m		0.5 μ m		1.0 μ m	
	<u>I 135</u>	<u>Xe135</u>	<u>I 135</u>	<u>Xe135</u>	<u>I 135</u>	<u>Xe135</u>	<u>I 135</u>	<u>Xe135</u>
N-P	1.39 E+2	3.45 E00	6.96 E+2	1.73 E+1	2.08 E+3	5.18 E+1	4.18 E+3	1.04 E+2
T-B	1.73 E+3	2.53 E+2	1.73 E+3	2.53 E+2	1.73 E+3	2.53 E+2	1.73 E+3	2.53 E+2
Pul	1.68 E+5	9.39 E+4	1.16 E+5	6.50 E+4	7.74 E+4	4.33 E+4	6.45 E+4	3.61 E+4
Pul Lymph Node	2.31 E+4	2.88 E+4	8.31 E+3	1.04 E+4	5.54 E+3	6.92 E+3	4.62 E+3	5.76 E+3
Stomach	2.71 E+2	5.38 E+1	1.00 E+3	1.23 E+2	2.83 E+3	2.94 E+2	5.57 E+3	5.52 E+2
SI	7.63 E+2	3.39 E+2	2.82 E+3	1.02 E+3	7.97 E+3	2.72 E+3	1.57 E+4	5.27 E+3
ULI	5.28 E+1	5.40 E+1	1.95 E+2	1.80 E+2	5.51 E+2	4.95 E+2	1.09 E+3	9.68 E+2
LLI	2.79 E+1	5.39 E+1	1.03 E+2	1.86 E+2	2.92 E+2	5.17 E+2	5.75 E+2	1.01 E+3
Blood	2.90 E+3	1.46 E+3	2.86 E+3	1.13 E+3	3.21 E+3	9.35 E+2	4.34 E+3	1.03 E+3
Total Body	4.72 E+4	1.04 E+3	4.65 E+4	8.92 E+2	5.21 E+4	8.57 E+2	7.06 E+4	1.06 E+3
Thyroid	1.75 E+4	1.53 E+2	1.73 E+4	1.51 E+2	1.94 E+4	1.69 E+2	2.62 E+4	2.30 E+2

TABLE 11 CONTINUED

Microcurie Days Per Curie Cs137 Inhaled

<u>ORGAN</u>	<u>0.1μm</u>		<u>0.2μm</u>		<u>0.5μm</u>		<u>1.0μm</u>	
	<u>Cs137</u>	<u>Ba137</u>	<u>Cs137</u>	<u>Ba137</u>	<u>Cs137</u>	<u>Ba137</u>	<u>Cs137</u>	<u>Ba137</u>
N-P	1.44 E+2	1.22 E+2	7.21 E+2	6.11 E+2	2.16 E+3	1.83 E+3	4.33 E+3	3.66 E+3
T-B	2.25 E+3	2.07 E+3	2.25 E+3	2.07 E+3	2.25 E+3	2.23 E+3	2.25 E+3	2.23 E+3
Pul	4.69 E+5	4.67 E+5	3.25 E+5	3.23 E+5	2.16 E+5	2.16 E+5	1.80 E+5	1.80 E+5
Pul Lymph Node	1.80 E+5	1.80 E+5	6.49 E+4	6.49 E+4	4.33 E+4	4.33 E+4	3.61 E+4	3.61 E+4
Stomach	3.76 E+2	3.74 E+2	1.21 E+3	1.20 E+3	3.30 E+3	3.27 E+3	6.44 E+3	6.38 E+3
SI	1.50 E+3	1.50 E+3	4.83 E+3	4.83 E+3	1.32 E+4	1.32 E+4	2.57 E+4	2.57 E+4
ULI	2.43 E+2	2.63 E+2	7.85 E+2	8.49 E+2	2.14 E+3	2.31 E+3	4.17 E+3	4.51 E+3
LLI	4.50 E+2	4.50 E+2	1.45 E+3	1.45 E+3	3.95 E+3	3.95 E+3	7.69 E+3	7.70 E+3
Blood	8.56 E+3	1.04 E+4	6.70 E+3	8.10 E+3	6.09 E+3	7.22 E+3	7.20 E+3	8.39 E+3
Total Body	1.24 E+8	1.24 E+8	9.70 E+7	9.70 E+7	8.82 E+7	8.82 E+7	1.04 E+8	1.04 E+8

TABLE 11 CONTINUED

Microcurie Days Per Curie Ce-141 Inhaled

<u>ORGAN</u>	<u>0.1μm</u>	<u>0.2μm</u>	<u>0.5μm</u>	<u>1.0μm</u>
N-P	1.14 E+4	5.69 E+4	9.50 E+4	3.41 E+5
T-B	1.20 E+4	1.20 E+4	1.20 E+4	1.20 E+4
Pul	8.89 E+6	8.00 E+6	5.33 E+6	4.44 E+6
Pul Lymph Node	2.85 E+5	2.57 E+5	1.71 E+5	1.43 E+5
Stomach	1.35 E+4	1.38 E+4	1.16 E+4	1.83 E+4
SI	5.35 E+4	5.47 E+4	4.60 E+4	7.29 E+4
ULI	1.72 E+5	1.76 E+5	1.48 E+5	2.34 E+5
LLI	3.11 E+5	3.18 E+5	2.67 E+5	4.24 E+5
Blood	8.66 E+2	8.73 E+2	8.71 E+2	1.01 E+3
Bone	1.42 E+6	1.43 E+6	1.42 E+6	1.64 E+6
Liver	1.77 E+6	1.78 E+6	1.78 E+6	2.06 E+6
Kidney	8.85 E+4	8.92 E+4	8.90 E+4	1.03 E+5
Total Body	1.77 E+5	1.78 E+5	1.78 E+5	2.06 E+5

TABLE 11 CONTINUED

Microcurie Days Per Curie Ce-144 Inhaled

ORGAN	0.1 μ m		0.2 μ m		0.5 μ m		1.0 μ m	
	<u>Ce144</u>	<u>Pr144</u>	<u>Ce144</u>	<u>Pr144</u>	<u>Ce144</u>	<u>Pr144</u>	<u>Ce144</u>	<u>Pr144</u>
N-P	1.17 E+4	1.13 E+4	5.82 E+4	5.66 E+4	9.73 E+4	9.44 E+4	3.50 E+5	3.40 E+5
T-B	1.21 E+4	1.12 E+4	1.21 E+4	1.12 E+4	1.21 E+4	1.12 E+4	1.21 E+4	1.12 E+4
Pul	1.87 E+7	1.87 E+7	1.68 E+7	1.68 E+7	1.12 E+7	1.12 E+7	9.34 E+6	9.34 E+6
Pul Lymph Node	1.30 E+6	1.30 E+6	1.17 E+6	1.17 E+6	7.83 E+5	7.83 E+5	6.52 E+5	6.52 E+5
Stomach	1.75 E+4	1.57 E+4	1.74 E+4	1.64 E+4	1.41 E+4	1.40 E+4	2.06 E+4	2.35 E+4
SI	6.97 E+4	6.90 E+4	6.95 E+4	6.91 E+4	5.60 E+4	5.60 E+4	8.23 E+4	8.33 E+4
ULI	2.26 E+5	2.26 E+5	2.26 E+5	2.26 E+5	1.82 E+5	1.82 E+5	2.67 E+5	2.67 E+5
LLI	4.17 E+5	4.17 E+5	4.16 E+5	4.16 E+6	3.35 E+5	3.35 E+5	4.92 E+5	4.92 E+5
Blood	1.42 E+3	7.56 E+2	1.37 E+3	7.44 E+2	1.21 E+3	6.92 E+2	1.28 E+3	7.67 E+2
Bone	1.91 E+7	1.91 E+7	1.84 E+7	1.84 E+7	1.62 E+7	1.62 E+7	1.72 E+7	1.72 E+7
Liver	2.39 E+7	2.39 E+7	2.31 E+7	2.31 E+7	2.02 E+7	2.02 E+7	2.15 E+7	2.15 E+7
Kidney	1.19 E+6	1.19 E+6	1.15 E+6	1.15 E+6	1.01 E+6	1.01 E+6	1.08 E+6	1.08 E+6
Total Body	2.39 E+6	2.39 E+6	2.31 E+6	2.31 E+6	2.02 E+6	2.02 E+6	2.15 E+6	2.15 E+6

TABLE 11 CONTINUED

Microcurie Days Per Curie Pr-143 Inhaled

<u>ORGAN</u>	<u>0.1μm</u>	<u>0.2μm</u>	<u>0.5μm</u>	<u>1.0μm</u>
N-P	5.55 E+3	2.78 E+4	8.33 E+4	1.67 E+5
T-B	2.25 E+4	2.25 E+4	2.25 E+4	2.25 E+4
Pul	6.09 E+6	5.48 E+6	3.65 E+6	3.04 E+6
Pul Lymph Node	3.96 E+4	3.57 E+4	2.38 E+4	1.98 E+4
Stomach	1.17 E+4	1.25 E+4	1.41 E+4	1.93 E+4
SI	4.61 E+4	4.93 E+4	5.57 E+4	7.63 E+4
ULI	1.46 E+5	1.56 E+5	1.76 E+5	2.41 E+5
LLI	2.57 E+5	2.74 E+5	3.10 E+5	4.25 E+5
Blood	1.88 E+1	2.27 E+1	3.18 E+1	4.85 E+1
Bone	1.29 E+4	1.56 E+4	2.19 E+4	3.33 E+4
Liver	1.61 E+4	1.94 E+4	2.73 E+4	4.16 E+4
Kidney	8.07 E+2	9.72 E+2	1.37 E+3	2.08 E+3
Total Body	1.61 E+3	1.94 E+3	2.73 E+3	4.16 E+3

The values of the time integrated radioactivity for Pu238, Pu239, Pu240, Pu241, Am241, Cm242, Cm243, and Cm244 were used to calculate dose conversion factors (F-factors) in rem per Ci inhaled using the following expressions:

For all tissues except GI tract,

$$\text{F-factor (rem/Ci inhaled)} = \frac{51.2}{m} \text{ Eeff U} \quad (34)$$

For GI tract,

$$\text{F-factor (rem/Ci inhaled)} = 1/2 \frac{51.2}{m_s} \text{ Eeff U} \quad (35)$$

Where

m = mass of the organ (g)

m_s = mass of the contents in the regions of the GI tract (stomach, small intestine (SI), upper large intestine (ULI), and lower large intestine (LLI)) (g)

Eeff = the effective energy per disintegration for the radionuclide in the organ MeV/dis

U = the time integrated activity deposited in the organ over a 70 year period ($\mu\text{Ci-days}$ per Ci inhaled)

and the value $51.2 = 3.7 \times 10^4 \frac{(\text{dis/sec})}{\mu \text{ Ci}} 1.6 \times 10^{-6} \frac{(\text{ergs})}{\text{MeV}} \times$

$$10^{-2} \frac{\text{rads}}{\text{erg/g}} 8.64 \times 10^4 (\text{sec/day})$$

The factor of 1/2 is included in the case of the GI tract because the dose to the walls of the GI system is about 1/2 the dose to the contents.⁽¹²⁾ The effective energies of the activities used in the calculations were those reported in ICRP Publication 2⁽¹²⁾ and are tabulated in Table 12. For α emitters a factor of 0.01 is used for GI tract since according to ICRP - Pub. 2⁽¹²⁾, experiments have shown α particles fail to penetrate the intestinal mucosa an appreciable extent.

The values of the organ masses and the GI tract contents used in the calculations are shown in Table 1.

The values for the F-factors obtained are shown in Tables 13 through 21. The dose conversion factors are largest for the 0.1 μm diameter particles for all radionuclides listed and all organs except the GI tract for which the

F-factor is essentially constant for 0.1, 0.2 and 0.5 μm diameter particles and is largest for a 1.0 μm diameter particle. The dose conversion factors for all organs except the GI tract decrease by a factor of about 2 as the median diameter increases from 0.1 to 1.0 μm for all radionuclides except Cm^{242} which exhibits a decrease by a factor of less than 2 for all organs except the lungs.

TABLE 12

Effective Energies of Actinides (MeV/dis)

Actinides	Bone	Liver	Lungs	Kidneys	Lymph	Ovaries	Testes	Other Tissues	Stomach	Small Intest.	Upper Large Intest.	Lower Large Intest.
Pu-238	284	57	57	57	57	57	57	57	0.57	0.57	0.57	0.57
Pu-239	266	53	53	53	53	53	53	53	0.53	0.53	0.53	0.53
Pu-240	266	53	53	53	53	53	53	53	0.53	0.53	0.53	0.53
Pu-241	0.048	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013
Pu-242	250	51	51	51	51	51	51	51	0.51	0.51	0.51	0.51
Am-241	283	57	57	57	57	57	57	57	0.57	0.57	0.57	0.57
Cm-242	315	63	63	63	63	63	63	63	0.63	0.63	0.63	0.63
Cm-243	299	60	60	60	60	60	60	60	0.60	0.60	0.60	0.60
Cm-244	299	60	60	60	60	60	60	60	0.60	0.60	0.60	0.60

TABLE 13

F-factors For Various Particle Sizes of Inhaled Pu-238

F-factors (rem/Ci inhaled)

Organ	Mass Median Aerodynamic Diameter (μm)			
	0.1	0.2	0.5	1.0
Bone	1.95×10^9	1.77×10^9	1.21×10^9	1.04×10^9
Liver	8.26×10^8	7.48×10^8	5.11×10^8	4.42×10^8
Lung	1.15×10^9	1.04×10^9	6.92×10^8	5.78×10^8
Pul. Lymph	2.00×10^{10}	1.81×10^{10}	1.21×10^{10}	1.01×10^{10}
Kidneys	1.17×10^8	1.06×10^8	7.23×10^7	6.26×10^7
Stomach	1.20×10^3	1.20×10^3	1.15×10^3	1.42×10^3
SI	1.13×10^3	1.13×10^3	1.09×10^3	1.34×10^3
ULI	1.74×10^4	1.74×10^4	1.67×10^4	2.06×10^4
LLI	5.18×10^4	5.18×10^4	4.96×10^4	6.12×10^4
Testes	1.17×10^7	1.06×10^7	7.26×10^6	6.28×10^6
Ovaries	5.26×10^6	4.77×10^6	3.25×10^6	2.82×10^6
Other Tissue	4.48×10^6	4.06×10^6	2.77×10^6	2.40×10^6

TABLE 14

F-factors For Various Particle Sizes of Inhaled Pu-239
F-factors (rem/Ci inhaled)

Organ	Mass Median Aerodynamic Diameter (μm)			
	0.1	0.2	0.5	1.0
Bone	2.37×10^9	2.30×10^9	1.47×10^9	1.27×10^9
Liver	9.70×10^8	8.77×10^8	6.0×10^8	5.19×10^8
Lung	1.09×10^9	9.80×10^8	6.53×10^8	5.43×10^8
Pul Lymph	1.95×10^{10}	1.76×10^{10}	1.17×10^{10}	9.79×10^9
Kidneys	1.38×10^8	1.24×10^8	8.48×10^7	7.33×10^7
Stomach	1.12×10^3	1.12×10^3	1.07×10^3	1.32×10^3
SI	1.06×10^3	1.06×10^3	1.01×10^3	1.25×10^3
ULI	1.63×10^4	1.63×10^4	1.56×10^4	1.92×10^4
LLI	4.84×10^4	4.84×10^4	4.63×10^4	5.70×10^4
Testes	1.41×10^7	1.28×10^7	8.71×10^6	7.54×10^6
Ovaries	6.33×10^6	5.74×10^6	3.91×10^6	3.38×10^6
Other Tissues	5.41×10^6	4.89×10^6	3.34×10^6	2.90×10^6

TABLE 15
F-factors For Various Particle Sizes of Inhaled Pu-240
F-factors (rem/Ci inhaled)

Organ	Mass Median Aerodynamic Diameter (μm)			
	0.1	0.2	0.5	1.0
Bone	2.36×10^9	2.14×10^9	1.46×10^9	1.26×10^9
Liver	9.67×10^8	8.76×10^8	5.98×10^8	5.17×10^8
Lung	1.09×10^9	9.80×10^8	6.53×10^8	5.43×10^8
Pul Lymph	1.95×10^{10}	1.76×10^{10}	1.17×10^{10}	9.79×10^9
Kidneys	1.37×10^8	1.24×10^8	8.46×10^7	7.32×10^7
Stomach	1.12×10^3	1.12×10^3	1.07×10^3	1.32×10^3
SI	1.06×10^3	1.06×10^3	1.01×10^3	1.25×10^3
ULI	1.63×10^4	1.63×10^4	1.56×10^4	1.92×10^4
LLI	4.84×10^4	4.84×10^4	4.63×10^4	5.70×10^4
Testes	1.41×10^7	1.27×10^7	8.71×10^6	7.54×10^6
Ovaries	6.01×10^6	5.71×10^6	3.91×10^6	3.38×10^6
Other Tissues	5.39×10^6	4.88×10^6	3.34×10^6	2.89×10^6

TABLE 16

F-factors For Various Particle Sizes of Inhaled Pu-241
F-factors (rem/Ci inhaled)

Organ	Mass Median Aerodynamic Diameter (μm)			
	0.1	.2	.5	1.0
Bone	5.2×10^7	4.71×10^7	3.22×10^7	2.78×10^7
Liver	2.1×10^7	1.86×10^7	1.27×10^7	1.1×10^7
Lung	3.40×10^6	3.12×10^6	2.04×10^6	1.70×10^6
Pul Lymph	1.53×10^8	1.38×10^8	9.22×10^7	7.69×10^7
Kidneys	2.96×10^6	2.62×10^6	1.79×10^6	1.55×10^6
Stomach	2.79×10^1	2.78×10^1	2.65×10^1	3.27×10^1
SI	2.63×10^1	2.63×10^1	2.50×10^1	3.09×10^1
ULI	4.05×10^2	4.03×10^2	3.85×10^2	4.73×10^2
LLI	1.20×10^3	1.2×10^3	1.14×10^3	1.41×10^3
Testes	3.14×10^5	2.84×10^5	1.94×10^5	1.67×10^5
Ovaries	1.40×10^5	1.27×10^5	8.67×10^4	7.50×10^4
Other Tissue	1.2×10^5	1.09×10^5	7.42×10^4	6.40×10^4

TABLE 17

F-factors For Various Particle Sizes of Inhaled Pu-242
F-factors (rem/Ci inhaled)

Organ	Mass Median Aerodynamic Diameter (μ m)			
	0.1	0.2	0.5	1.0
Bone	2.23×10^9	2.02×10^9	1.38×10^9	1.19×10^9
Liver	9.34×10^8	8.46×10^8	5.77×10^8	4.99×10^8
Lungs	1.04×10^9	9.43×10^8	6.29×10^8	5.22×10^8
Pul Lymph	1.88×10^{10}	1.70×10^{10}	1.13×10^{10}	9.42×10^9
Kidneys	1.32×10^8	1.19×10^8	8.17×10^7	7.07×10^7
Stomach	1.08×10^3	1.08×10^3	1.03×10^3	1.27×10^3
SI	1.02×10^3	1.02×10^3	9.75×10^2	1.20×10^3
ULI	1.57×10^4	1.57×10^4	1.50×10^4	1.85×10^4
LLI	4.66×10^4	4.66×10^4	4.66×10^4	5.49×10^4
Testes	1.36×10^7	1.23×10^7	8.45×10^6	7.32×10^6
Ovaries	6.10×10^6	5.53×10^6	3.79×10^6	3.28×10^6
Other Tissue	5.21×10^6	4.71×10^6	3.22×10^6	2.79×10^6

TABLE 18

F-factors For Various Particle Sizes of Inhaled Am-241
 F-factors (rem/ Ci inhaled)

Organ	Mass Median Aerodynamic Diameter (μ m)			
	0.1	0.2	0.5	1.0
Bone	2.41×10^9	2.18×10^9	1.49×10^9	1.30×10^9
Liver	1.00×10^9	9.07×10^8	6.21×10^8	5.39×10^8
Lungs	1.17×10^9	1.05×10^9	7.02×10^8	5.84×10^8
Pul Lymph	2.08×10^{10}	1.88×10^{10}	1.25×10^{10}	1.04×10^{10}
Kidneys	1.42×10^8	1.28×10^8	8.78×10^7	7.62×10^7
Stomach	1.21×10^3	1.21×10^3	1.15×10^3	1.42×10^3
SI	1.14×10^3	1.14×10^3	1.09×10^3	1.34×10^3
ULI	1.75×10^4	1.75×10^4	1.68×10^4	2.07×10^4
LLI	5.20×10^4	5.2×10^4	4.97×10^4	6.13×10^4
Testes	1.45×10^7	1.30×10^7	8.97×10^6	7.82×10^6
Ovaries	6.49×10^6	5.89×10^6	4.02×10^6	3.51×10^6
Other Tissue	5.55×10^6	5.03×10^6	3.44×10^6	2.99×10^6

TABLE 19

F-factors For Various Particle Sizes of Inhaled Cm-242
F-factors (rem/Ci inhaled)

Organ	Mass Median Aerodynamic Diameter (μm)			
	0.1	0.2	0.5	1.0
Bone	1.30×10^7	1.19×10^7	8.64×10^6	8.11×10^6
Liver	5.91×10^6	5.45×10^6	3.99×10^6	3.79×10^6
Lungs	3.20×10^8	2.84×10^8	1.92×10^8	1.60×10^8
Kidneys	8.37×10^5	7.70×10^5	5.64×10^5	5.36×10^5
Pul Lymph	1.75×10^9	7.90×10^8	5.27×10^8	4.40×10^8
Testes	7.81×10^4	7.16×10^4	5.19×10^4	4.86×10^4
Ovaries	3.50×10^4	3.21×10^4	2.33×10^4	2.18×10^4
Other Tissue	2.98×10^4	2.74×10^4	1.98×10^4	1.86×10^4
Stomach	9.21×10^2	9.60×10^2	1.03×10^3	1.36×10^3
SI	8.67×10^2	9.02×10^2	9.65×10^2	1.28×10^3
ULI	1.33×10^4	1.39×10^4	1.49×10^4	1.97×10^4
LLI	3.93×10^4	4.10×10^4	4.41×10^4	5.83×10^4

TABLE 20

F-factors For Various Particle Sizes of Inhaled Cm-243
 F-factors (rem/Ci Cm-243 inhaled)

Organ	Mass Median Aerodynamic Diameter (μm)			
	0.1	0.2	0.5	1.0
Bone	1.36×10^9	1.24×10^9	8.49×10^8	7.38×10^8
Liver	6.03×10^8	5.47×10^8	3.75×10^8	3.26×10^8
Lungs	1.18×10^9	1.06×10^9	7.11×10^8	5.92×10^8
Kidneys	8.55×10^7	7.75×10^7	5.20×10^7	4.62×10^7
Pul Lymph	1.96×10^{10}	1.76×10^{10}	1.17×10^{10}	9.79×10^9
Testes	8.20×10^6	7.44×10^6	5.10×10^6	4.43×10^6
Ovaries	3.68×10^6	3.33×10^6	2.29×10^6	2.00×10^6
Other Tissue	3.13×10^6	2.84×10^6	1.95×10^6	1.69×10^6
Stomach	1.25×10^3	1.25×10^3	1.20×10^3	1.49×10^3
SI	1.18×10^3	1.18×10^3	1.13×10^3	1.40×10^3
ULI	1.82×10^4	1.82×10^4	1.75×10^4	2.16×10^4
LLI	5.39×10^4	5.39×10^4	5.18×10^4	6.41×10^4

TABLE 21

F-factors For Various Particle Sizes of Inhaled Cm-244
F-factors (rem/Ci inhaled)

Organ	Mass Median Aerodynamic Diameter (μm)			
	0.1	0.2	0.5	1.0
Bone	9.11×10^8	8.28×10^8	5.66×10^8	4.93×10^8
Liver	4.21×10^8	3.82×10^8	2.61×10^8	2.28×10^8
Lungs	1.15×10^9	1.03×10^9	6.88×10^8	5.74×10^8
Kidneys	5.96×10^7	5.40×10^7	3.71×10^7	3.24×10^7
Pul Lymph	1.80×10^{10}	1.61×10^{10}	1.08×10^{10}	8.97×10^9
Testes	5.49×10^6	4.97×10^6	3.41×10^6	2.98×10^6
Ovaries	2.46×10^6	2.22×10^6	1.53×10^6	1.34×10^6
Other Tissue	2.09×10^6	1.89×10^6	1.31×10^6	1.13×10^6
Stomach	1.24×10^3	1.24×10^3	1.19×10^3	1.48×10^3
SI	1.17×10^3	1.17×10^3	1.13×10^3	1.39×10^3
ULI	1.79×10^4	1.80×10^4	1.74×10^4	2.15×10^4
LLI	5.33×10^4	5.34×10^4	5.15×10^4	6.38×10^4

The dose conversion factors for the rest of the radionuclides listed in Table 2 were obtained by taking the values of $\mu\text{Ci-days per curie}$ inhaled shown in Table 11 of Section IV and multiplying by appropriate values of rem per $\mu\text{Ci-day}$ tabulated by Snyder et.al.⁽⁴⁾ which include the contribution to the organ dose due to crossfire radiation (radiation from the radionuclide deposited in neighboring organs). Table 22 shows examples of the dose conversion factors for various source and target organs and Table 23 shows an example of F-factors summed over the source organs for various particle sizes of inhaled aerosol. Only F-factors for particles of $0.1 \mu\text{m}$ mass median aerodynamic diameter are presented in Table 24 for various radionuclides.

1131 F-factors* (rem/Ci inhaled) For Source and Target Organs
For a 0.1 μ m Mass Median Aerodynamic Diameter

TARGET ORGANS	SOURCE ORGANS								Total For Targets
	Lungs	Pul Lymph Node	Stomach Cont	SI+ Cont	ULI Cont	LLI Cont	Thyroid	T. Body	
Adrenals	7.27 E+1	2.64 E+1	5.55 E-2	1.36 E-1	1.49 E-2	1.24 E-2	2.86 E+1	1.08 E+2	2.36 E+2
Blad Wall	1.94 E00	7.02 E-1	9.03 E-2	2.98 E-1	3.05 E-2	1.55 E-1	1.17 E00	1.01 E+2	1.05 E+2
GI(S Wall)	5.51 E+1	2.00 E+1	8.58 E00	3.46 E-1	5.58 E-2	4.61 E-2	1.45 E+1	1.02 E+2	2.00 E+2
GI(SI + Cont)	7.36 E00	2.67 E00	6.51 E-2	2.10 E+1	2.51 E-1	2.36 E-1	1.91 E00	1.06 E+2	1.39 E+2
GI(ULI Wall)	9.66 E00	3.50 E00	8.44 E-2	2.28 E00	5.69 E00	1.09 E-1	1.92 E00	1.03 E+2	1.26 E+2
GI(LLI Wall)	2.76 E00	1.00 E00	3.20 E-2	6.80 E-1	4.59 E-2	1.53 E+1	1.91 E00	1.03 E+2	1.25 E+2
Kidneys	2.90 E+1	1.05 E+1	8.44 E-2	3.07 E-1	4.16 E-2	2.30 E-2	7.48 E00	9.96 E+1	1.47 E+2
Liver	7.19 E+1	2.61 E+1	5.00 E-2	1.80 E-1	3.84 E-2	8.33 E-3	2.25 E+1	9.84 E+1	2.20 E+2
Lungs	4.76 E+3	1.73 E+3	4.44 E-2	2.96 E-2	4.81 E-3	2.54 E-3	1.59 E+2	9.30 E+1	6.74 E+3
Pul Lymph Node	4.76 E+3	1.05 E+5	4.44 E-2	2.96 E-2	4.81 E-3	2.54 E-3	1.59 E+2	9.30 E+1	1.10 E+5
Muscle	3.95 E+1	1.43 E+1	3.50 E-2	1.52 E-1	2.25 E-2	4.38 E-2	2.11 E+2	9.11 E+1	3.56 E+2
Ovaries	4.20 E00	1.52 E00	1.28 E-2	9.40 E-1	1.83 E-1	4.57 E-1	2.26 E00	9.96 E+1	1.09 E+2
Pancreas	7.89 E+1	2.86 E+1	4.40 E-1	2.03 E-1	3.14 E-2	1.88 E-2	1.32 E+1	1.04 E+2	2.25 E+2
Bone	3.19 E+1	1.16 E+1	1.64 E-2	8.61 E-2	1.21 E-2	2.97 E-2	1.23 E+2	9.50 E+1	2.62 E+2
R Marrow	4.04 E+1	1.47 E+1	2.87 E-2	2.77 E-1	3.71 E-2	8.99 E-2	1.36 E+2	1.00 E+2	2.92 E+2
Y Marrow	3.34 E+1	1.21 E+1	2.28 E-2	1.20 E-1	1.73 E-2	3.66 E-2	6.49 E+1	9.23 E+1	2.03 E+2
TE CL **	3.19 E+1	1.16 E+1	1.64 E-2	8.61 E-2	1.21 E-2	2.97 E-2	1.23 E+2	9.50 E+1	2.62 E+2
Skin	1.91 E+1	6.94 E00	1.35 E-2	4.95 E-2	7.84 E-3	1.46 E-2	1.31 E+2	7.64 E+1	2.34 E+2
Spleen	6.57 E+1	2.38 E+1	2.42 E-1	1.53 E-1	1.98 E-2	2.27 E-2	2.00 E+1	1.00 E+2	2.10 E+2
Testes	6.00 E-1	2.18 E-1	1.19 E-3	3.59 E-2	6.67 E-3	5.26 E-2	4.00 E-1	9.46 E+1	9.59 E+1
Thymus	1.14 E+2	4.13 E+1	6.59 E-3	1.25 E-2	2.14 E-3	1.31 E-3	6.75 E+2	1.03 E+2	9.33 E+2
Thyroid	3.15 E+1	1.14 E+1	3.50 E-3	3.31 E-3	5.51 E-4	3.82 E-4	1.21 E+6	8.96 E+1	1.21 E+6
Uterus	2.90 E00	1.05 E00	2.16 E-2	8.80 E-1	6.98 E-2	1.60 E-1	2.13 E00	1.04 E+2	1.11 E+2
Total Body	1.05 E+2	3.81 E+1	5.98 E-2	3.58 E-1	4.43 E-2	8.14 E-2	5.24 E+2	9.15 E+1	7.59 E+2

* Based on the product of our values of time integrated activity (μ Ci-days/Ci inhaled) and the values of rem/ μ Ci-day published in ORNL 5000⁴.

** Total endosteal cells.

TABLE 23

F-factors (rem/Ci inhaled) For I131 Summed Over All
Source Organs For Aerosols of Various Particle Sizes

Target Organs	Particle Mass Median Aerodynamic Diameter (m)			
	0.1	0.2	0.5	1.0
Adrenals	2.36 E+2	1.69 E+2	1.42 E+2	1.57 E+2
Blad Wall	1.05 E+2	8.44 E+1	8.10 E+1	1.00 E+2
GI(S Wall)	2.00 E+2	1.67 E+2	1.96 E+2	2.83 E+2
GI(SI + Cont)	1.39 E+2	1.61 E+2	2.74 E+2	4.69 E+2
GI(ULI Wall)	1.26 E+2	1.18 E+2	1.54 E+2	2.37 E+2
GI(LLI Wall)	1.25 E+2	8.84 E+1	2.20 E+2	3.71 E+2
Kidneys	1.47 E+2	1.10 E+2	9.84 E+1	1.15 E+2
Liver	2.20 E+2	1.56 E+2	1.31 E+2	1.44 E+2
Lungs	6.74 E+3	4.12 E+3	2.80 E+3	2.40 E+3
Pul Lymph Node	1.10 E+5	4.12 E+4	2.76 E+4	2.31 E+4
Muscle	3.56 E+2	2.73 E+2	2.45 E+2	2.87 E+2
Ovaries	1.09 E+2	8.94 E+1	9.10 E+1	1.19 E+2
Pancreas	2.25 E+2	1.60 E+2	1.35 E+2	1.51 E+2
Bone	2.62 E+2	1.99 E+2	1.79 E+2	2.08 E+2
R Marrow	2.92 E+2	2.22 E+2	1.99 E+2	2.33 E+2
Y Marrow	2.03 E+2	1.53 E+2	1.35 E+2	1.56 E+2
TE CL	2.62 E+2	1.99 E+2	1.79 E+2	2.08 E+2
Skin	2.34 E+2	1.81 E+2	1.63 E+2	1.92 E+2
Spleen	2.10 E+2	1.51 E+2	1.28 E+2	1.39 E+2
Testes	9.59 E+1	7.61 E+1	7.09 E+1	8.51 E+1
Thymus	9.33 E+2	7.11 E+2	6.32 E+2	7.33 E+2
Thyroid	1.21 E+6	9.59 E+5	8.85 E+5	1.06 E+6
Uterus	1.11 E+2	9.02 E+1	8.94 E+1	1.14 E+2
Total Body	7.59 E+2	5.76 E+2	5.13 E+2	5.96 E+2

TABLE 24

F-factors (rem/Ci inhaled) for Particles of 0.1 μ m Mass Median
Aerodynamic Diameter For Various Radionuclides

Target Organs	H3	Mn52m	Mn52	Mn56	Fe55	Co57	Co58
Adrenals	5.32 E+1	1.01 E+1	4.19 E+3	4.72 E+1		1.62 E+3	6.27 E+3
Blad Wall	5.32 E+1	8.38 E-1	1.25 E+3	9.46 E00		3.95 E+2	1.22 E+3
GI(S Wall)	5.34 E+1	2.00 E+1	4.06 E+3	1.63 E+2		1.26 E+3	5.34 E+3
GI(SI+Cont)	5.36 E+1	5.08 E00	3.59 E+3	1.55 E+2		7.45 E+2	2.80 E+3
GI(ULI Wall)	5.31 E+1	3.37 E00	5.49 E+3	1.85 E+2		1.22 E+3	4.14 E+3
GI(LLI Wall)	5.31 E+1	8.91 E-1	8.31 E+3	7.36 E+1		1.99 E+3	6.18 E+3
Kidneys	5.31 E+1	1.60 E+1	3.29 E+3	7.24 E+1		7.40 E+2	3.14 E+3
Liver	5.31 E+1	1.40 E+1	5.80 E+3	9.48 E+1		2.89 E+3	1.01 E+4
Lungs	1.90 E+2	6.79 E+2	3.02 E+4	3.50 E+3		2.97 E+4	5.86 E+4
Pul Lymph Node	3.56 E+3	6.79 E+2	3.45 E+4	3.52 E+3		9.69 E+4	1.29 E+5
Muscle	5.31 E+1	6.10 E00	2.52 E+3	3.27 E+1		8.88 E+2	3.70 E+3
Ovaries	5.31 E+1	1.29 E00	2.94 E+3	1.88 E+1		6.03 E+2	2.21 E+3
Pancreas	5.31 E+1	1.89 E+1	5.78 E+3	1.39 E+2		1.59 E+3	6.45 E+3
Bone	5.31 E+1	4.50 E00	1.85 E+3	2.48 E+1		1.10 E+3	3.89 E+3
R Marrow	5.31 E+1	5.70 E00	2.59 E+3	3.21 E+1		1.41 E+3	3.66 E+3
Y Marrow	5.31 E+1	4.67 E00	1.96 E+3	2.62 E+1		1.12 E+3	2.96 E+3
TECL	5.31 E+1	4.50 E00	1.85 E+3	2.49 E+1		1.11 E+3	2.84 E+3
Skin	5.31 E+1	3.34 E00	1.35 E+3	1.87 E+1		4.28 E+2	1.98 E+3
Spleen	5.31 E+1	9.11 E00	3.64 E+3	5.23 E+1		1.40 E+3	5.67 E+3
Testes	5.31 E+1	5.25 E-1	5.89 E+2	5.79 E00		2.52 E+2	7.89 E+3
Thymus	5.31 E+1	1.77 E00	6.20 E+3	8.52 E+1		2.36 E+3	9.45 E+3
Thyroid	5.31 E+1	4.91 E00	1.95 E+3	2.77 E+1		6.53 E+2	3.51 E+3
Uterus	5.31 E+1	1.39 E00	1.69 E+3	1.55 E+1		4.97 E+2	1.48 E+3
Total Body	5.31 E+1	1.56 E+1	2.93 E+3	8.45 E+1		1.34 E+3	4.34 E+3

TABLE 24 CONTINUED

Target Organs	Co60	Zn72	Sr89	Y91	Zr95	Nb95
Adrenals	3.69 E+4					
Blad Wall	1.44 E+4					
GI(S Wall)	2.99 E+4					
GI (SI + Cont)	1.98 E+4					
GI (ULI Wall)	2.38 E+4					
GI (LLI Wall)	2.95 E+4					
Kidneys	2.25 E+4					
Liver	6.53 E+4					
Lungs	2.53 E+5					
Pul Lumph Node	7.99 E+5					
Muscle	2.24 E+4					
Ovaries	1.65 E+4					
Pancreas	3.36 E+4					
Bone	1.85 E+4					
R Marrow	2.24 E+4					
Y Marrow	1.84 E+4					
TECL	1.85 E+4					
Skin	1.38 E+4					
Spleen	2.94 E+4					
Testes	1.13 E+4					
Thymus	5.06 E+4					
Thyroid	2.03 E+4					
Uterus	1.64 E+4					
Total Body	2.53 E+4					

TABLE 24 CONTINUED

Target Organs	Ru103	Ru106	Tel32	I131	I133*	I135**
Adrenals			1.77 E+3	2.36 E+2	1.58 E+2	1.41 E+2
Blad Wall			1.07 E+3	1.05 E+2	6.41 E+1	4.19 E+1
GI (S Wall)			1.42 E+3	2.00 E+2	1.48 E+2	1.46 E+2
GI (SI+Cont)			1.23 E+3	1.39 E+2	1.08 E+2	8.16 E+1
GI (ULI Wall)			1.41 E+3	1.26 E+2	8.64 E+1	6.68 E+1
GI (LLI Wall)			1.66 E+3	1.25 E+2	7.90 E+1	4.95 E+1
Kidneys			7.43 E+3	1.47 E+2	1.01 E+2	8.57 E+1
Liver			3.23 E+3	2.20 E+2	1.52 E+2	1.49 E+2
Lungs			1.82 E+4	6.74 E+3	8.64 E+3	6.45 E+3
Pul Lymph Node			2.54 E+5	1.10 E+5	1.17 E+5	6.74 E+4
Muscle			1.38 E+3	3.56 E+2	1.17 E+2	1.01 E+2
Ovaries			1.04 E+3	1.09 E+2	6.50 E+1	4.60 E+1
Pancreas			1.61 E+3	2.25 E+2	1.62 E+2	1.50 E+2
Bone			1.45 E+3	2.62 E+2	1.04 E+2	8.10 E+1
R-Marrow			1.32 E+3	2.92 E+2	1.17 E+2	9.61 E+1
Y-Marrow			1.15 E+3	2.03 E+2	1.00 E+2	8.01 E+1
TECL			1.33 E+3	2.62 E+2	1.04 E+2	8.10 E+1
Skin			8.47 E+2	2.34 E+2	8.72 E+1	6.45 E+1
Spleen			1.47 E+3	2.10 E+2	1.41 E+2	1.31 E+2
Testes			9.71 E+2	9.59 E+1	6.16 E+1	3.56 E+1
Thymus			1.79 E+3	9.33 E+2	2.61 E+2	2.57 E+2
Thyroid			5.46 E+4	1.21 E+6	1.54 E+5	1.98 E+4
Uterus			1.15 E+3	1.11 E+2	6.55 E+1	4.96 E+1
Total Body			1.61 E+3	7.59 E+2	2.84 E+2	1.66 E+2

* Xel33 daughter contribution was obtained from MIRD Pamphlet 10⁽⁷⁾ except for respiratory lymph node which was calculated using an effective energy of 0.14 MeV and equation 34.

**Xel35 daughter contribution calculated from equations 34 and 35. The effective energy used for lymph and thyroid was 0.33 MeV, 0.5 MeV was used for total body and 0.40 MeV for all other source organs.

TABLE 24 CONTINUED

Target Organs	Cs137	Ba140	Ce141	Ce144	Pr143
Adrenals			5.53 E+2	4.74 E+3	3.70 E-1
Blad Wall			8.54 E+1	2.50 E+3	3.70 E-1
GI(S Wall)			6.15 E+2	5.31 E+3	3.77 E+2
GI(SI+Cont)			8.16 E+2	8.71 E+3	9.27 E+2
GI(ULI Wall)			3.71 E+3	3.77 E+4	5.34 E+3
GI(LLI Wall)			1.04 E+4	1.06 E+5	1.53 E+4
Kidneys			2.86 E+3	2.61 E+5	4.23 E+1
Liver			9.69 E+3	8.97 E+5	1.44 E+2
Lungs			8.23 E+4	1.34 E+6	9.86 E+4
Pul Lymph Node			2.45 E+5	1.74 E+6	1.40 E+5
Muscle			2.76 E+2	2.98 E+3	3.70 E-1
Ovaries			1.98 E+2	2.69 E+3	3.70 E-1
Pancreas			5.37 E+2	3.83 E+3	3.70 E-1
Bone			2.87 E+3	2.60 E+5	4.19 E+1
R Marrow			5.09 E+2	2.34 E+4	1.51 E00
Y Marrow			4.09 E+2	3.57 E+3	3.70 E-1
TECL			1.85 E+3	1.58 E+5	2.71 E+1
Skin			2.57 E+2	2.66 E+3	3.70 E-1
Spleen			4.10 E+2	3.11 E+3	3.70 E-1
Testes			5.00 E+1	2.48 E+3	3.70 E-1
Thymus			6.52 E+2	3.30 E+3	3.70 E-1
Thyroid			1.65 E+2	2.62 E+3	3.70 E-1
Uterus			1.16 E+2	2.58 E+3	3.70 E-1
Total Body,			1.93 E+3	6.49 E+4	3.70 E-1

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APPENDIX

CONVOLX - A COMPUTER PROGRAM TO ESTIMATE EXPOSURE OF THE BODY ORGANS TO INHALED RADIONUCLIDES

The calculation of the time integrated inventory of a particular nuclide and its daughter products in the various organs of the human body is accomplished by the use of the computer program CONVOLX. Its computations proceed from formulas derived from basic principles, and empirical inputs from Section III of the text. Numerical integration schemes are used to solve the governing equations.

The conservation of mass is expressed by the following equation

$$\frac{dI}{dt} = (\text{Rate coming in}) - (\text{Rate going out})$$

or:

$$\frac{dI(t)}{dt} = f(t) - \lambda I(t) \quad (\text{A-1})$$

where:

λ is the rate of decrease of the inventory, (fraction per second)

$I(t)$ is the inventory at time t , (atoms)

$f(t)$ is the rate of inventory increase at time t , (atoms/second)

Equation (1) has the following solution:

$$I(t) = I(0) e^{-\lambda t} + \int_0^t f(\tau) e^{-\lambda(t-\tau)} d\tau \quad (\text{A-2})$$

The integration of $I(t)$ over time yields exposure, ie.

$$E(t) = \int_0^t I(\tau) d\tau \quad (\text{A-3})$$

Equations (A-2) and (A-3) are solved numerically in CONVOLX for each organ of the body and for each isotope and its daughters. The empirical inputs are the values of $I(0)$ and λ 's for the various organs.

The solution of equation (A-2) is obtained in the following manner.

$$I(t) = I(0)e^{-\lambda t} + \int_0^t f(\tau) e^{-\lambda(t-\tau)} d\tau$$

$$I(t + \Delta t) = I(0) e^{-\lambda t} e^{-\lambda \Delta t} + \int_0^{t+\Delta t} f(\tau) e^{-\lambda(t+\Delta t-\tau)} d\tau$$

$$I(t+\Delta t) = \left[I(0)e^{-\lambda t} + \int_0^t f(\tau) e^{-\lambda(t-\tau)} d\tau \right] e^{-\lambda \Delta t} + \int_t^{t+\Delta t} f(\tau) e^{-\lambda(t+\Delta t-\tau)} d\tau$$

With a change of variable in the last term and a substitution, $\tau' = \tau - t$,

$$I(t + \Delta t) = I(t) e^{-\lambda \Delta t} + \int_0^{\Delta t} f(\tau) e^{-\lambda(\Delta t-\tau')} d\tau'$$

Letting $f(\tau) = A\tau^2 + B\tau + C$

and $\Delta t = 2h$

The coefficients A, B, and C may be solved from the following conditions

$$S_0 = f(0)$$

$$S_1 = f(h)$$

$$S_2 = f(2h)$$

The coefficients are shown below

$$C = S_0$$

$$B = \frac{4S_1 - 3S_0 - S_2}{2h}$$

$$A = \frac{S_0 - 2S_1 + S_2}{2h^2}$$

Evaluation of the integral $(A\tau^2 + B\tau + C)e^{-\lambda(2h-\tau)} d\tau$

Use of the following

$$I_A = Ae^{-2\lambda h} \int_0^{2h} \tau^2 e^{\lambda \tau} d\tau$$

$$I_B = Be^{-2\lambda h} \int_0^{2h} \tau e^{\lambda \tau} d\tau$$

$$I_C = Ce^{-2\lambda h} \int_0^{2h} e^{\lambda \tau} d\tau$$

gives

$$I = I_A + I_B + I_C$$

Closed form solution and substitutions yield:

$$I = S_0 \left[-\frac{1}{2\lambda h^2} + \frac{1}{h^2 \lambda^3} + e^{-2\lambda h} \left(-\frac{1}{h^2 \lambda^3} - \frac{3}{2h\lambda^2} - \frac{1}{\lambda} \right) \right] +$$

$$S_1 \left[\frac{2}{h\lambda^2} - \frac{2}{h^2 \lambda^3} + e^{-2\lambda h} \left(\frac{2}{h^2 \lambda^3} + \frac{2}{h\lambda^2} \right) \right] +$$

$$S_2 \left[\frac{1}{\lambda} - \frac{3}{2h\lambda^2} + \frac{1}{h^2 \lambda^3} + e^{-2\lambda h} \left(-\frac{1}{h^2 \lambda^3} - \frac{1}{2h\lambda^2} \right) \right]$$

Letting $2\lambda h = U$, the solution becomes:

$$I = \frac{1}{\lambda U^2} \left(c_1 S_0 + c_2 S_1 + c_3 S_2 \right)$$

Where:

$$c_1 = 4 - U - e^{-U} (U^2 + 3U + 4)$$

$$c_2 = U - 2 + e^{-U} (U + 2)$$

$$c_3 = U^2 - 3U + 4 - e^{-U} (U + 4)$$

For values of $U < 0.01$ accuracy can be enhanced by the following calculation of C_1 , C_2 , and C_3

$$C_1 = \frac{U^3}{6} \left(1 - U + \frac{9U^2}{20} - \frac{4U^3}{30} + \frac{5U^4}{168} - \frac{3U^5}{560} \right)$$

$$C_2 = \frac{U^3}{6} \left(1 - \frac{U}{2} + \frac{3U^2}{20} - \frac{U^3}{30} + \frac{U^4}{168} - \frac{U^5}{1120} \right)$$

$$C_3 = \frac{U^3}{6} \left(1 - \frac{U^2}{20} + \frac{U^3}{60} - \frac{3U^4}{840} + \frac{U^5}{1680} \right)$$

For the calculation of the integral when the time points are not equidistant (i.e. at a timestep doubling calculation), the value of S_1 must be adjusted as illustrated in the following sketch.

The figure shows the movement of S_1 to S_1^o for the calculation at $t = a + 3h$, and the movement of S_1^o to S_2' for the calculation at $t = a + 5h$, where

$S_1^o = \frac{9S_1 + 2S_2 - 2S_0}{8}$, is the representation of the move to the mid-point of the interval $(a, a + 3h)$.

The effective decay used in the solution for the time dependent inventory is organ k is given by

$$\lambda_k = \lambda_R + \sum_{i=1}^n \lambda_{k,i}$$

where:

n is the number of organs

λ_R is the physical constant decay of the isotope

$\lambda_{k,i}$ is the biological clearance constant for the pathway from organ k to organ i

The calculation of the source function $f(\tau)$ is as follows:

$$f(\tau) = I(\tau)_p \lambda_p + \sum_{i=1}^n I(\tau)_i \lambda_{i,k}$$

where;

λ_p is the physical decay constant of the parent isotope

$I(\tau)_p$ is the inventory of the parent isotope

$\lambda_{i,k}$ is the biological clearance constant for the pathway from organ i to organ k

$I(\tau)_i$ is the inventory in organ i

FLOW
CHART OF
CONVOLX

The starting values of $I(0)$ come from the table of deposition fractions for the different particle sizes (table 5 in the text), and the clearance fractions come from the TGLM clearance model (table 4 in the text). The product of these two fractions for their respective respiratory tract regions determine the starting values of $I(0)$, resulting in the inhalation of a unit fraction of mass (atoms, curies, etc.). Table (A-1) shows the starting values used in the analysis. The starting values for the remainder of the organs and the outside are zero.

INPUT VARIABLES AND DESCRIPTION

FS(I,J,K)	is the fraction rate by which material moves from organ (J) to organ (I), $I = 1, 30$, $J = 1, 30$ and $K = 1, 4$
	I and J are organ indices K is compound class index
ISTY (I)	is the index of the compound class, $I = 2, 6$
RLAMB (I)	is the fraction rate by which material decays to another nuclide, $I = 2, 6$
NAME (I, J)	is the 4H hollerith word in which the names of the organs are stored by pairs, $I = 1, 30$ and $J = 1, 2$
NOMT (I, J)	is the 4H hollerith word in which the names of the compound classes are stored by pairs, $I = 1, 4$, $J = 1, 2$
QB (I, 0)	is the fraction of material in Organ (I) at time = 0, $I = 1, 30$

TABLE A-1

STARTING FRACTIONS BASED ON THE TGLM CLEARANCE MODEL
AND DEPOSITION FRACTIONS AS A FUNCTION OF PARTICLE SIZE

0.10 MICRON

ORGAN	CLEARANCE CLASS		
	D	W	Y
N-P _a	.005	.001	.0001
N-P _b	.005	.009	.0099
T-B _c	.076	.040	.0008
T-B _d	.004	.040	.0792
P _e	.400	.075	.025
P _f	-	.200	.200
P _g	-	.200	.200
P _h	.250	.025	.075

TABLE A-1 (Continued)

STARTING FRACTIONS BASED ON THE TGLM CLEARANCE MODEL
AND DEPOSITION FRACTIONS AS A FUNCTION OF PARTICLE SIZE

0.20 MICRON

ORGAN	CLEARANCE CLASS		
	D	W	Y
N-P _a	.025	.005	.0005
N-P _b	.025	.045	.0495
T-B _c	.076	.040	.0008
T-B _d	.004	.040	.0792
P _e	.360	.0675	.0225
P _f	-	.180	.180
P _g	-	.180	.180
P _h	.090	.0225	.0675

TABLE A-1 (Continued)

STARTING FRACTIONS BASED ON THE TGLM CLEARANCE MODEL
AND DEPOSITION FRACTIONS AS A FUNCTION OF PARTICLE SIZE

0.50 MICRON

ORGAN	CLEARANCE CLASS		
	D	W	Y
N-P _a	.075	.015	.0015
N-P _b	.075	.075	.1485
T-B _c	.076	.040	.0008
T-B _d	.004	.040	.0792
P _e	.240	.045	.015
P _f	-	.120	.120
P _g	-	.120	.120
P _h	.06	.015	.045

TABLE A-1 (Continued)

STARTING FRACTIONS BASED ON THE TGLM CLEARANCE MODEL
AND DEPOSITION FRACTIONS AS A FUNCTION OF PARTICLE SIZE

1.00 MICRON

ORGAN	CLEARANCE CLASS		
	D	W	Y
N-P _a	.15	.030	.003
N-P _b	.15	.270	.297
T-B _c	.076	.040	.0008
T-B _d	.004	.040	.0792
P _e	.200	.0375	.0125
P _f	-	.100	.100
P _g	-	.100	.100
P _h	.050	.0125	.0375

SAMPLE CASE WITH PLOTS

Pu-241 ----- Am-241

Pu-241 is Y class

Am-241 is Y1 class *

Particle Size 1.0 micron

Sex Female

* Y1 class is the same as Y class except for the value of F_1

Preparation of Input

Pu and Am are considered members of clearance class Y, and Pu has the starting values from Table A-1 for the 1.0 micron size particle.

The retention in organs of the activity entering the blood at t days following the intake is given by

$$R_{\text{bone}}(t) = .45 e^{-\frac{.693}{36500}t}$$

$$R_{\text{liver}}(t) = .45 e^{-\frac{.693}{14600}t}$$

$$R_{\text{kidneys}}(t) = 0.01 e^{-\frac{.693}{14600}t}$$

$$R_{\text{testes}}(t) = 0.0001 e^{-\frac{.693}{36500}t}$$

$$R_{\text{ovaries}}(t) = 0.00001 e^{-\frac{.693}{36500}t}$$

$$R_{\text{other tissues}}(t) = 0.05 e^{-\frac{.693}{36500}t}$$

Pu, Am Cm have the same metabolic models Pu produced in lungs and GI tract is assigned a value of 3×10^{-5} for f_1

Cm and Am produced in the lungs and GI tract are assigned a value of 0.001 for f_1

ISTY (2) = 3

ISTY (3) = 1

RLAMB (2) = 1.69 E-9

RLAMB (3) = 4.80 E-11

QB (I,0) is as follows for I = 1, 8

1	3.00	E-3
2	2.97	E-3
3	8.00	E-4
4	7.92	E-2
5	1.25	E-2
6	1.00	E-1
7	1.00	E-1
8	3.75	E-2

Name (I, J) is Defined as Follows

I	J =	1	2
1		N-P	LUNG
2		N-P	LUNG
3		T-B	LUNG
4		T-B	LUNG
5		PUL	LUNG
6		PUL	LUNG
7		PUL	LUNG
8		PUL	LUNG
9		LYMP	H
10		STOM	ACH
11		S I	NTES
12		UL I	NTES
13		LL I	NTES
14		BLOO	D
15		BONE	
16		LIVE	R
17		KIDN	EY
18		TEST	ES
19		OVAR	IES
20		OTHE	R
30		OUTS	IDE

NOMT (I,J) is defined as follows

1	CLAS	S Y1
3	CLAS	S Y

The values of FS (I, J, K) are chosen by the following procedure. Since Pu and Am are identical except for the value F_1 , FS (I, J, 1) and FS (I, J, 3) are the same for all I and J except for FS (12, 11, K) and FS (14, 11, K) K = 1 or 3. FS (I, J, K) for I = 1, 14, J = 1, 14 follow from the TGLM clearance model and the GI transit times of volume I, except as follows

$$\begin{aligned} \text{FS (12, 11, 1)} &= (1-F_1) \lambda_{si} = 6.94 \text{ E-5} \\ \text{FS (14, 11, 1)} &= F_1 \lambda_{si} = 6.94 \text{ E-8} \\ \text{FS (12, 11, 3)} &= (1-F'_1) \lambda_{si} = 6.94 \text{ E-5} \\ \text{FS (14, 11, 3)} &= F'_1 \lambda'_{si} = 2.08 \text{ E-9} \end{aligned}$$

where $F_1 = 1.00 \text{ E-3}$ for Am-241

$F'_1 = 3.00 \text{ E-5}$ for Pu-241

λ_{si} is the biological clearance constant for the small intestine

The values of the FS (I, J, K) for J = 14 and I = 15, 30, K = 1 or 3 come from the constant in the retention formulas divided by 10^3 . The choice of the FS (I, J, K) values for J = 30 and I = 15, 30, K = 1 or 3 come from the time constant in the exponent or the retention formulas, converted to units of seconds.

THE FOLLOWING PAGES ARE PROGRAM OUTPUT

PAGES A19 AND A20 ARE THE INPUT EDIT

PAGE A21 IS THE OUTPUT EDIT

PAGE A22 THROUGH A44 ARE THE INVENTORY-TIME MAPS
OF Pu-241 AND Am-241 IN EACH OF THE BODY'S
ORGANS FROM THESE PICTURES ISOTOPE MOVEMENT
CAN BE TRACED .

RATES IN FRACTION PER SECOND

FROM N-P LUNG TO BLOOD	IS	8.0230E-04 FOR TYPE CLASS Y1
FROM N-P LUNG TO STOMACH	IS	2.0060E-05 FOR TYPE CLASS Y1
FROM T-B LUNG TO BLOOD	IS	8.0230E-04 FOR TYPE CLASS Y1
FROM T-B LUNG TO STOMACH	IS	4.0113E-05 FOR TYPE CLASS Y1
FROM PUL LUNG TO BLOOD	IS	1.6050E-08 FOR TYPE CLASS Y1
FROM PUL LUNG TO STOMACH	IS	8.0230E-06 FOR TYPE CLASS Y1
FROM PUL LUNG TO STOMACH	IS	1.6050E-08 FOR TYPE CLASS Y1
FROM PUL LUNG TO LYMPH	IS	1.6050E-08 FOR TYPE CLASS Y1
FROM LYMPH TO BLOOD	IS	8.0230E-09 FOR TYPE CLASS Y1
FROM STOMACH TO S INTES	IS	2.7700E-04 FOR TYPE CLASS Y1
FROM S INTES TO UL INTES	IS	6.9400E-05 FOR TYPE CLASS Y1
FROM S INTES TO BLOOD	IS	6.9400E-08 FOR TYPE CLASS Y1
FROM UL INTES TO LL INTES	IS	2.1370E-05 FOR TYPE CLASS Y1
FROM LL INTES TO OUTSIDE	IS	1.1570E-05 FOR TYPE CLASS Y1
FROM BLOOD TO BONE	IS	4.5000E-04 FOR TYPE CLASS Y1
FROM BLOOD TO LIVER	IS	4.5000E-04 FOR TYPE CLASS Y1
FROM BLOOD TO KIDNEY	IS	1.0000E-05 FOR TYPE CLASS Y1
FROM BLOOD TO TESTES	IS	1.0000E-07 FOR TYPE CLASS Y1
FROM BLOOD TO OTHER	IS	5.0000E-05 FOR TYPE CLASS Y1
FROM BLOOD TO OUTSIDE	IS	3.9900E-05 FOR TYPE CLASS Y1
FROM BONE TO OUTSIDE	IS	2.1970E-10 FOR TYPE CLASS Y1
FROM LIVER TO OUTSIDE	IS	5.4940E-10 FOR TYPE CLASS Y1
FROM KIDNEY TO OUTSIDE	IS	5.4940E-10 FOR TYPE CLASS Y1
FROM TESTES TO OUTSIDE	IS	2.1970E-10 FOR TYPE CLASS Y1
FROM OVARIES TO OUTSIDE	IS	2.1970E-10 FOR TYPE CLASS Y1
FROM OTHER TO OUTSIDE	IS	2.1970E-10 FOR TYPE CLASS Y1

FROM N-P LUNG TO BLOOD	IS	8.0230E-04 FOR TYPE CLASS Y
FROM N-P LUNG TO STOMACH	IS	2.0060E-05 FOR TYPE CLASS Y
FROM T-B LUNG TO BLOOD	IS	8.0230E-04 FOR TYPE CLASS Y
FROM T-B LUNG TO STOMACH	IS	4.0113E-05 FOR TYPE CLASS Y
FROM PUL LUNG TO BLOOD	IS	1.6050E-08 FOR TYPE CLASS Y
FROM PUL LUNG TO STOMACH	IS	8.0230E-06 FOR TYPE CLASS Y
FROM PUL LUNG TO STOMACH	IS	1.6050E-08 FOR TYPE CLASS Y
FROM PUL LUNG TO LYMPH	IS	1.6050E-08 FOR TYPE CLASS Y
FROM LYMPH TO BLOOD	IS	8.0230E-09 FOR TYPE CLASS Y
FROM STOMACH TO S INTES	IS	2.7700E-04 FOR TYPE CLASS Y
FROM S INTES TO UL INTES	IS	6.9400E-05 FOR TYPE CLASS Y
FROM S INTES TO BLOOD	IS	2.0800E-09 FOR TYPE CLASS Y
FROM UL INTES TO LL INTES	IS	2.1370E-05 FOR TYPE CLASS Y
FROM LL INTES TO OUTSIDE	IS	1.1570E-05 FOR TYPE CLASS Y
FROM BLOOD TO BONE	IS	4.5000E-04 FOR TYPE CLASS Y
FROM BLOOD TO LIVER	IS	4.5000E-04 FOR TYPE CLASS Y
FROM BLOOD TO KIDNEY	IS	1.0000E-05 FOR TYPE CLASS Y
FROM BLOOD TO TESTES	IS	1.0000E-07 FOR TYPE CLASS Y
FROM BLOOD TO OTHER	IS	5.0000E-05 FOR TYPE CLASS Y
FROM BLOOD TO OUTSIDE	IS	3.9900E-05 FOR TYPE CLASS Y
FROM BONE TO OUTSIDE	IS	2.1970E-10 FOR TYPE CLASS Y
FROM LIVER TO OUTSIDE	IS	5.4940E-10 FOR TYPE CLASS Y
FROM KIDNEY TO OUTSIDE	IS	5.4940E-10 FOR TYPE CLASS Y
FROM TESTES TO OUTSIDE	IS	2.1970E-10 FOR TYPE CLASS Y
FROM OVARTES TO OUTSIDE	IS	2.1970E-10 FOR TYPE CLASS Y
FROM OTHER TO OUTSIDE	IS	2.1970E-10 FOR TYPE CLASS Y

MICRO CURIE DAYS PER CURIE INHALED
 CLASS Y
 1.6900E-09

CLASS Y1
 1.8000E-11

N-P LUNG	1.4427E+00	8.6313E-08
N-P LUNG	5.7119E+03	1.3667E-02
T-B LUNG	1.1544E+01	6.9051E-07
T-B LUNG	2.2652E+04	2.7346E-02
PUL LUNG	1.6312E+07	4.8637E+04
PUL LUNG	2.8048E+05	1.7259E+00
PUL LUNG	1.3049E+08	3.8910E+05
PUL LUNG	4.8935E+07	1.4591E+05
LYMPH	8.0661E+07	7.7106E+05
STOMACH	1.9639E+04	2.2603E+01
S INTES	7.8383E+04	9.0182E+01
UL INTES	2.5455E+05	2.9344E+02
LL INTES	4.7006E+05	5.4394E+02
BLOOD	9.2113E+02	6.9731E+00
BONE	2.1290E+08	1.7918E+07
LIVER	1.8030E+08	1.2697E+07
KIDNEY	4.0733E+06	2.8215E+05
TESTES	4.7312E+04	3.9819E+03
OVARIES	0.	0.
OTHER	2.3656E+07	1.9909E+06

Pu-241 NASOPHARYNX

Pu-241 TRACHEOBRONCHIAL

DRAFT

Pu-241 PULMONARY

URAT-1

Pu-241 LYMPH

Pu-241 STOMACH

DRAFT

Pu-241 SMALL INTESTINE

DRAFT

Pu-241, UPPER LARGE INTESTINE

DRAFT

Pu-241 LOWER LARGE INTESTINE

DRAFT

Pu-241 BLOOD

DRAFT

Pu-241 BONE

DRAFT

Pu-241 LIVER

DRAFT

Pu-241 KIDNEY

DRAFT

Am-241 NASOPHARYNX

Am-241 TRACHEOBRONCHIAL

DRAFT

Am-241 PULMONARY

DRAFT

Am-241 LYMPH

DRAFT

Am-241 STOMACH

DRAFT

Am-241 SMALL INTESTINE

DRAFT

Am-241 UPPER LARGE INTESTINE

A 40

DRAFT

Am-241 LOWER LARGE INTESTINE

DRAFT

Am-241 BONE

DRAFT

Am-241 LIVER

DRAFT

Am-241 KIDNEY

DRAFT

DRAFT

PROGRAM LISTING

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PROGRAM CONVOLA(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE69)
LEVEL 2,FS,QA,QM
COMMON /LARC/ FS(30,30,4),QA(30,1000),QB(30,1000)
DIMENSION NAME(30,2),T(1000),XIAM(30),SUMS(30),NOM1(4,2)
DIMENSION EB(30,6),US1(30,6),US2(30,6),RLAMB(6),ISTY(6)
DIMENSION SUB(5)
DIMENSION QUTOT(1000)
DATA ISTY/4, 2, 4*4/
DATA RLAMB/ 6*1.0E-25/
DATA ((FS(I,J,1),I=1,30),J=1,30)/
113*0.0, 8.023E-4, 16*0.0, 9*0.0, 8.023E-4, 20*0.0,
113*0.0, 8.023E-4, 16*0.0, 9*0.0, 4.011E-5, 20*0.0,
113*0.0, 1.605E-5, 16*0.0, 60*0.0,
16*0.0, 1.605E-5, 21*0.0, 13*0.0, 1.605E-5, 16*0.0,
110*0.0, 2.77E-4, 19*0.0,
111*0.0, 3.472E-6, 0.0, 6.597E-5, 16*0.0,
112*0.0, 2.137E-5, 17*0.0,
129*0.0, 1.157E-5,
114*0.0, .45E-3, .45E-3, .01E-3, .0001E-3, .00001E-3, .05E-3, 10*0.0,
129*0.0, 2.197E-10,
129*0.0, 5.494E-10,
129*0.0, 5.494E-10,
129*0.0, 2.197E-10,
129*0.0, 2.197E-10,
129*0.0, 2.197E-10,
1 300*0.0/
DATA ((FS(I,J,2),I=1,30),J=1,30)/
113*0.0, 8.023E-4, 16*0.0, 9*0.0, 8.914E-6, 20*0.0,
113*0.0, 8.023E-4, 16*0.0, 9*0.0, 4.011E-5, 20*0.0,
113*0.0, 1.605E-7, 16*0.0, 9*0.0, 8.023E-6, 20*0.0,
1 9*0.0, 1.605E-7, 20*0.0, 8*0.0, 1.605E-7, 21*0.0,
113*0.0, 1.605E-7, 16*0.0,
110*0.0, 2.77E-4, 19*0.0,
111*0.0, 3.472E-6, 0.0, 6.597E-5, 16*0.0,
112*0.0, 2.137E-5, 17*0.0,
129*0.0, 1.157E-5,
114*0.0, .45E-3, .45E-3, .01E-3, .0001E-3, .00001E-3, .05E-3, 10*0.0,
129*0.0, 2.197E-10,
129*0.0, 5.494E-10,
129*0.0, 5.494E-10,
129*0.0, 2.197E-10,
129*0.0, 2.197E-10,
129*0.0, 2.197E-10,
1 300*0.0/
DATA ((FS(I,J,3),I=1,30),J=1,30)/
113*0.0, 8.023E-4, 16*0.0, 9*0.0, 2.006E-5, 20*0.0,
113*0.0, 8.023E-4, 16*0.0, 9*0.0, 4.011E-5, 20*0.0,
113*0.0, 1.605E-8, 16*0.0, 9*0.0, 8.023E-6, 20*0.0,
1 9*0.0, 1.605E-8, 20*0.0, 8*0.0, 1.605E-8, 21*0.0,
113*0.0, 8.023E-9, 16*0.0,
110*0.0, 2.77E-4, 19*0.0,
111*0.0, 3.472E-6, 0.0, 6.597E-5, 16*0.0,
112*0.0, 2.137E-5, 17*0.0,
129*0.0, 1.157E-5,
114*0.0, .45E-3, .45E-3, .01E-3, .0001E-3, .00001E-3, .05E-3, 10*0.0,
129*0.0, 2.197E-10,
129*0.0, 5.494E-10,

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129*0.0, 5.494E-10,
129*0.0, 2.197E-10,
129*0.0, 2.197E-10,
129*0.0, 2.197E-10,
1 300*0.0/
DATA ((FS(I,J,4),I=1,30),J=1,30)/
113*0.0, 8.023E-4, 16*0.0, 9*0.0, 8.023E-4, 20*0.0,
113*0.0, 8.023E-4, 16*0.0, 9*0.0, 4.011E-5, 20*0.0,
113*0.0, 1.605E-5, 16*0.0, 60*0.0,
16*0.0, 1.605E-5, 21*0.0, 13*0.0, 1.605E-5, 16*0.0,
110*0.0, 2.77E-4, 19*0.0,
111*0.0, 3.472E-6, 0.0, 6.597E-5, 16*0.0,
112*0.0, 2.137E-5, 17*0.0,
129*0.0, 1.157E-5,
114*0.0, .45E-3, .45E-3, .01E-3, .0001E-3, .00001E-3, .05E-3, 10*0.0,
129*0.0, 2.197E-10,
129*0.0, 5.494E-10,
129*0.0, 5.494E-10,
129*0.0, 2.197E-10,
129*0.0, 2.197E-10,
129*0.0, 2.197E-10,
1 300*0.0/
DATA((NAME(K,L),L=1,2),K=1,30)/
1 4HN-P, 4HLUNG, 4HN-P, 4HLUNG, 4HT-B, 4HLUNG, 4HT-B, 4HLUNG,
1 4HPUL, 4HLUNG, 4HPUL, 4HLUNG, 4HPUL, 4HLUNG, 4HPUL, 4HLUNG,
1 4HLYMP, 4HH, 4HSTOM, 4HACH, 4HS I, 4HNIES, 4HUL I, 4HNIES,
1 4HLL I, 4HNIES, 4HBL00, 4HD, 4HBONE, 4H, 4HLIVE, 4HR,
1 4HAI0N, 4HEY, 4HTEST, 4HES, 4HOVAR, 4HIES, 4HOTH, 4HR,
1 4HUSC, 4HIE, 4HSPL, 4HEN, 4HPANC, 4HREAS, 4HTHYR, 4H0ID,
1 4H, 4H, 4H, 4H, 4H, 4H, 4H, 4H, 4H, 4H,
1 4H, 4H, 4H0UTS, 4HIDE /
DATA((NUMT(K,L),L=1,2),K=1,4)/
1 4HCLAS, 4HS 01, 4HCLAS, 4HS W, 4HCLAS, 4HS Y, 4HCLAS, 4HS D /
DUM=2H
KEY=0
NSJDP=1000
C INITIAL SAVE SOURCES
DO 203 IST=1,5
SIB(IST)=0.0
DO 204 K=1,30
US1(K,IST)=0.0
US2(K,IST)=0.0
204 CONTINUE
203 CONTINUE
C INITIAL INVENTORY IN ORGAN K
DO 200 K = 1,30
DO 202 IT=1,1000
WHOT(IT)=0.0
I(IT)=0.0
WA(K,IT) = 0.0
WB(K,IT) = 0.0
202 CONTINUE
DO 201 IST=1,5
EB(K,IST)=0.0
201 CONTINUE
200 CONTINUE
C FIX ISDIOPE

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QB(1,1)=.008E+20
QB(2,1)=.072E+20
QB(3,1)=.040E+20
QB(4,1)=.040E+20
QB(5,1)=.063E+20
QB(6,1)=.168E+20
QB(7,1)=.168E+20
QB(8,1)=.021E+20
RLAMB(2)=9.17E-6
RLAMB(3)=1.51E-6
ISTY(2)=4
ISTY(3)=1
NAME(15,1)= 4HNEG
NAME(15,2)= 4HTHYR
NAME(16,1)= 4HTHYR
NAME(16,2)= 4HODD
NAME(17,1)= 4HTHYR
NAME(17,2)= 4HODD
NAME(18,1)= 4HTOT
NAME(18,2)= 4H3OD
NAME(19,1)= 4HNEG
NAME(19,2)= 4HT.B.
NAME(20,1)= 4HTOT
NAME(20,2)= 4H3OD
FS(15,14,1)=0.0
FS(16,14,1)=0.0
FS(17,14,1)=0.0
FS(18,14,1)=0.0
FS(19,14,1)=0.0
FS(20,14,1)=0.0
FS(30,15,1)=0.0
FS(30,16,1)=0.0
FS(30,17,1)=0.0
FS(30,18,1)=2.311E-3
FS(30,19,1)=0.0
FS(30,20,1)=0.0
FS(15,14,4)= 0.328E-3
FS(16,14,4)= 0.016E-3
FS(17,14,4)= 0.312E-3
FS(18,14,4)= 0.097E-3
FS(19,14,4)= 0.04873E-3
FS(20,14,4)= 0.0514E-3
FS(30,15,4)= 3.301E-5
FS(30,16,4)= 7.098E-7
FS(30,17,4)= 6.855E-8
FS(30,18,4)= 3.301E-5
FS(30,19,4)= 7.098E-7
FS(30,20,4)= 6.855E-8
QB(1,1)= 0.005
QB(2,1)= 0.005
QB(3,1)= 0.076
QB(4,1)= 0.004
QB(5,1)= 0.400
QB(6,1)= 0.0
QB(7,1)= 0.0
QB(8,1)= 0.250
QB(1,1)= 0.025

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```

QB(2,1)= 0.025
QB(3,1)= 0.076
QB(4,1)= 0.004
QB(5,1)= 0.360
QB(6,1)= 0.0
QB(7,1)= 0.0
QB(8,1)= 0.090
QB(1,1)= 0.075
QB(2,1)= 0.075
QB(3,1)= 0.076
QB(4,1)= 0.004
QB(5,1)= 0.240
QB(6,1)= 0.0
QB(7,1)= 0.0
QB(8,1)= 0.060
QB(1,1)= 0.150
QB(2,1)= 0.150
QB(3,1)= 0.076
QB(4,1)= 0.004
QB(5,1)= 0.200
QB(6,1)= 0.0
QB(7,1)= 0.0
QB(8,1)= 0.050
C      INPUT PRINT OUT
      WRITE(5,253)((1,QB(I,1)),I=1,30)
253  FORMAT(1H1,/,/,5(3X,3HQB(,12,5H, 1)=,1PE13.4)/,/,)
      WRITE(5,252)
252  FORMAT(1H1,40H          RATES IN FRACTION PER SECOND          ,/,)
      DO 250 I=1,4
      DO 250 J=1,30
      DO 250 K=1,30
      IF(FS(K,J,I) .LT. 1.E-20) GO TO 250
      WRITE(5,251)NAME(J,1),NAME(J,2),NAME(K,1),NAME(K,2),FS(K,J,I),
1  NUMT(J,1),NUMT(J,2)
251  FORMAT(10X,5HFROM ,2A4,4H TO ,2A4,4H IS ,1PE13.4,10H FOR TYPE ,
1  2A4/)
250  CONTINUE
      DO 500 IST=2,6
      FSA=RLAMB(IST-1)
      FSB=RLAMB(IST)
      ISTYP=ISFY(IST)
C      CONSIDER DECAY OF ORGAN K CONSTANT
      DO 120 K = 1,30
      XLAM(K) = FSB
      DO 130 J = 1,30
      XLAM(K) = XLAM(K) + FS(I,K,ISTYP)
130  CONTINUE
120  CONTINUE
C      CONSIDER TIME DEPENDENT INVENTORIES
      DT=2.0
      NCOUNT=0
      DO 300 II = 2,1000
      NCOUNT=NCOUNT+1
      IF(NCOUNT .EQ. 41)DT=DT*2.0
      IF(NCOUNT .EQ. 41)NCOUNT=1
      IF(IST .EQ. 2) T(II)=T(II-1)+DT
      IF(KEY .EQ. 1) GO TO 260

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      IF (T(IT) .GT. 2.2E+9) NSTOP=IT
      IF (T(IT) .GT. 2.2E+9) KEY=1
260  CONTINUE
C    CONSIDER INVENTORY ORGAN K AT TIME(IT)
      DO 100 K=1,30
C    CONSIDER SOURCES TO ORGAN K AT TIME(IT)
      SUMS(K) = FSA * QA(K,IT)
      DO 110 I = 1,30
      SUMS(K) = SUMS(K) + FS(K,I,ISTYP) * QB(1,IT)
110  CONTINUE
      IF (K .EQ. 10) SIB(IST)=SIB(IST)+SUMS(K)*DI
      IF (IT.EQ.2) OS1(K,IST) = SUMS(K)
      IF (IT.EQ.2) OS2(K,IST) = SUMS(K)
C    SOLVE CONVOLUTION INTEGRAL FOR TIME(IT)
      U=(T(IT)-T(IT-2))*XLAM(K)
      S2 = U*U
      S3 = S2*U
      S4=S3 * U
      S5= S4 * U
      EX = EXP(-U)
50  IF (U.GT.0.0100) GO TO 42
      AA=1.0-S2/20.0+S3/60.0 -3./840.*S4 + S5/1680.
      BB = 1.0 - U/2.0 + 0.15 * S2 - S3/30.0 + S4/168. - S5/1120.
      CC = 1.0 - U + 0.45 * S2 - 2./15. *S3+ 5./168.*S4 - 3./560.*S5
      DD = 6.0/U
      GO TO 30
42  AA = 4.0 - 3.0 * U + S2 - (4.0+U) * EX
      BB = (2.0+U) * EX - 2.0+U
      CC = 4.0 - U - (4.0+3.0*U+S2) * EX
      DD = S2
30  IF (IT .EQ. 2) GO TO 71
      OS2P=OS2(K,IST)
      IF (MCOINT.EQ.1) OS2(K,IST)=(9.*OS2(K,IST)+SUMS(K)-2.*OS1(K,IST))/8.
      QB(K,IT)= QB(K,IT-2) * EX + (SUMS(K) * AA+
1  4.0 * OS2(K,IST) * BB + OS1(K,IST) * CC)/DD/XLAM(K)
      OS2(K,IST)=OS2P
      GO TO 70
71  EX=EXP(XLAM(K)*(T(IT-1)-T(IT)))
      QB(K,IT)=QB(K,IT-1)*EX+SUMS(K)*(1.-EX)/XLAM(K)
70  CONTINUE
C    RESAVE OLD SOURCES
      OS1(K,IST) = OS2(K,IST)
      OS2(K,IST) = SUMS(K)
      QB101(11)=QB101(11)+QB(K,11)
100  CONTINUE
300  CONTINUE
C    COMPUTE EXPOSURE TO ORGAN K
C
      DO 401 K = 1,30
      SUM3=0.0
      DO 400 IF=2,NSTOP
      SUM3=SUM3+(QB(K,IF)+QB(K,IF-1))*(T(IF)-T(IF-1))/2.
400  CONTINUE
      FB(K,IST) = FB(K,IST) + SUM3
401  CONTINUE
      IF (IST .GE. 5) GO TO 512
      WRITE(69)T

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512 CONTINUE
  DO 510 K=1,30
    LLL=ISTY(IST)
    WRITE(69)NAME(K,1),NAME(K,2),DUM,NUMT(LLL,1),NUMT(LLL,2)
    WRITE(69)(QB(K,I),I=1,1000)
510 CONTINUE
  DO 501 K=1,30
    DO 502 I=1,1000
      QA(K,I)=QB(K,I)
      QB(K,I)=0.0
502 CONTINUE
501 CONTINUE
500 CONTINUE
  L2=ISTY(2)
  L3=ISTY(3)
  L4=ISTY(4)
  L5=ISTY(5)
  L6=ISTY(6)
  DO 600 I=3,1000
    QBTOT(I)=QBTOT(2)-QBTOT(I)
600 CONTINUE
  DO 601 IST=2,6
    DO 601 K=1,30
      EH(K,IST)= EH(K,IST)/.0864*RLAMB(IST)/RLAMB(2)
601 CONTINUE
  WRITE(6,710)(QBTOT(I),I=2,1000,2)
710 FORMAT(1H1,/,10(1PE13.4))
  WRITE(6,702)NUMT(L2,1),NUMT(L2,2),NUMT(L3,1),NUMT(L3,2),NUMT(L4,1),
    1,NUMT(L4,2),NUMT(L5,1),NUMT(L5,2),NUMT(L6,1),NUMT(L6,2),RLAMB( 2),
    1RLAMB( 3),RLAMB( 4),RLAMB( 5),RLAMB( 6)
702 FORMAT(1H1, 87H MICRO CURIE DAYS PER CURIE INHALED BY C
    1UMPARTMENT AND TYPE WITH DECAY RATES,/,23X, 5(6X,2A4.6X)/,20X,5(7X
    1,1PE13.4)/)
  WRITE(6,701)(NAME(K,1),NAME(K,2),(EH(K,IST),IST=2,6)),K=1,30)
701 FORMAT(30(12X,2A4,5(7X,1PE13.4)/))
  WRITE(6,703)NUMT(L2,1),NUMT(L2,2),SIB(2),NUMT(L3,1),NUMT(L3,2),
    1SIB(3),NUMT(L4,1),NUMT(L4,2),SIB(4),NUMT(L5,1),NUMT(L5,2),SIB(5),
    1 NUMT(L6,1),NUMT(L6,2),SIB(6)
703 FORMAT(1H1,////////,5(20X,17H101AL INTEGRATED ,2A4,16H SOURCE TO BL
    1000,5X,1PE13.4,6H ATOMS,///) )
99999 STOP
      END

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