

APPENDIX A

**GENMOD INTERNAL DOSIMETRY
COMPUTER CODE**

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The computer code GENMOD is employed for evaluation of bioassay measurement data and computation of internal dose equivalent. The code implements standard biokinetic models of the ICRP to describe the fate of radionuclides taken into the body. Dose factors are applied to cumulative activities in source organs to compute dose equivalent to target organs and effective dose equivalent. The code is described in detail by Johnson and Carver (1981) and Dunford and Johnson (1988). The following subsections provide a summary description of the biokinetic models and dose computation methods employed by GENMOD as implemented by the Hanford Internal Dosimetry Program.

GENMOD BIODYNAMIC MODELS

The GENMOD internal dosimetry code employs the ICRP's Task Group on Lung Dynamics Model (TGLD 1966) for the respiratory tract and the Eve-Dolphin model for transport of material through the gastrointestinal (GI) tract (Eve 1966). A general systemic compartment model describes the uptake and transport of most elements. Exceptions are iodine and alkaline earths that are described by specific models. In addition, a modification of the general model permits evaluation of systemic excretion of plutonium using the empirically derived excretion function of Jones (1985). The models are diagrammed in Figures A.1 through A.5 (from Dunford and Johnson 1988) and are described in the following subsections.

Respiratory Tract Model

The respiratory tract model (Figure A.1) of the TGLD is employed as described by Dunford and Johnson (1988). A special inhalation class is described in the plutonium section for highly nontransportable compounds. Default model parameters for this "super Y" class as well as for classes D, W, and Y are provided in Table A.1.

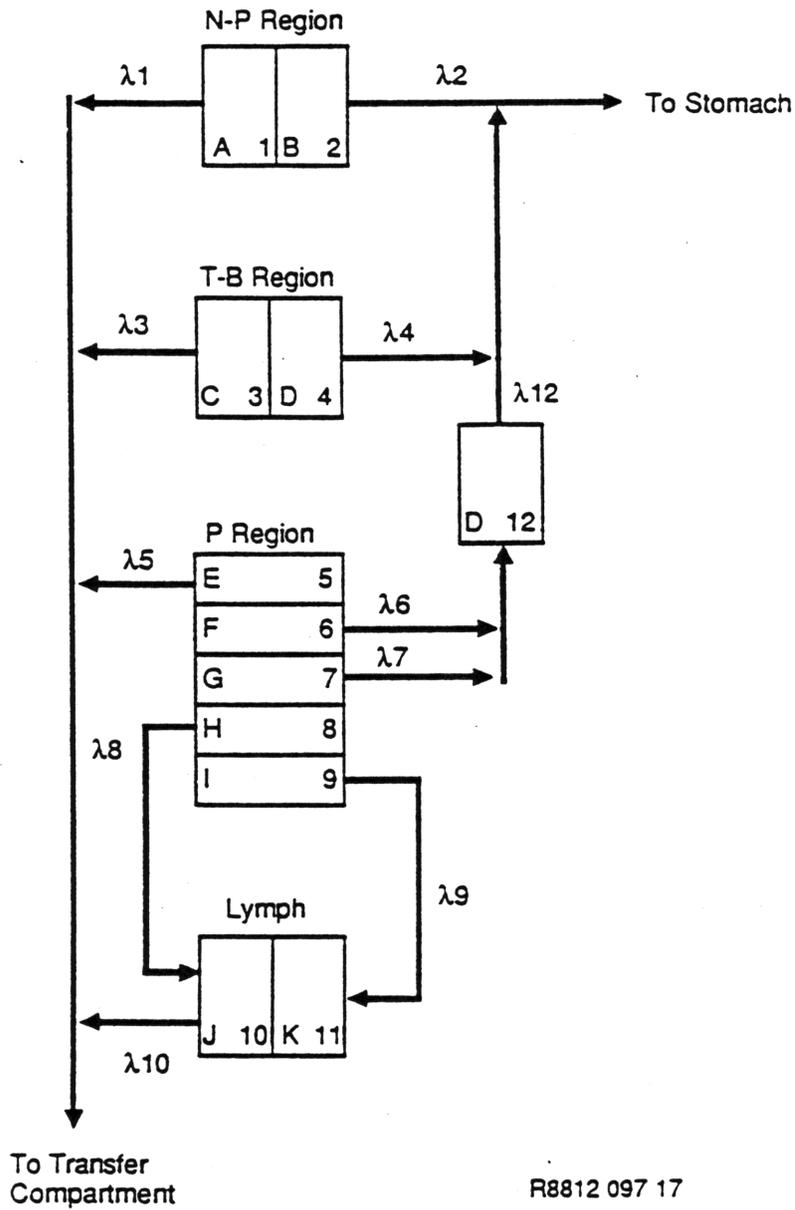


FIGURE A.1. GENMOD Lung Model (Compartments A through H to ICRP 30 Notation.)

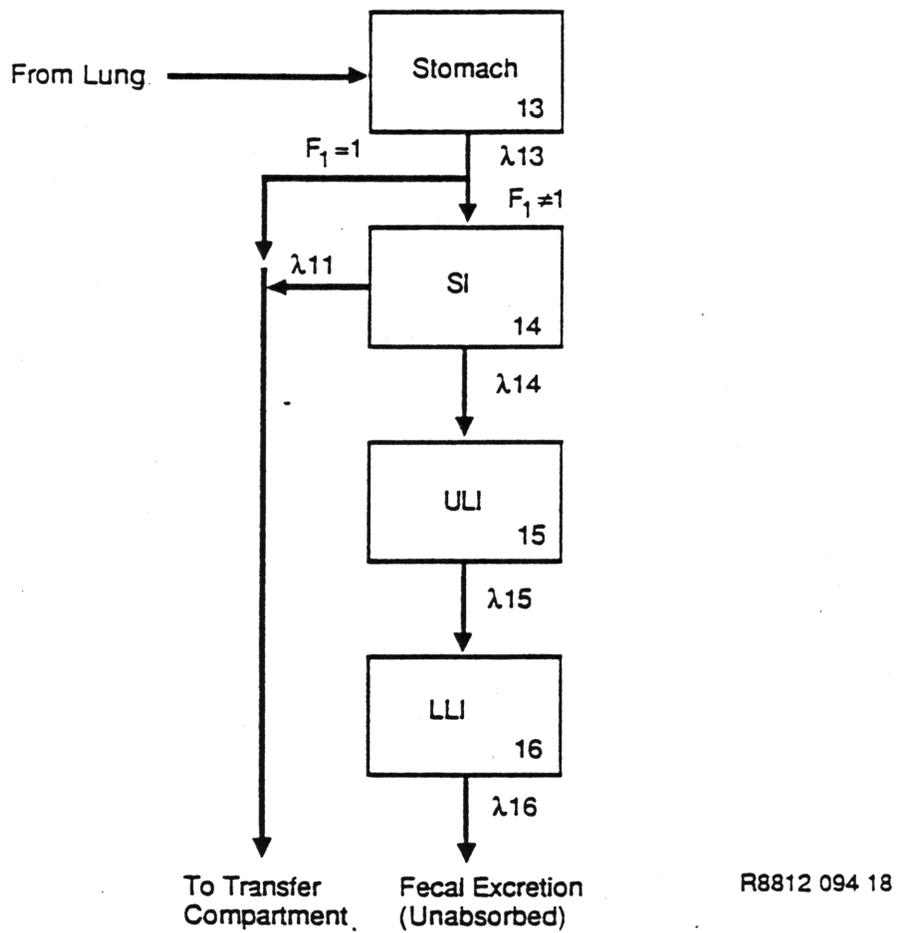
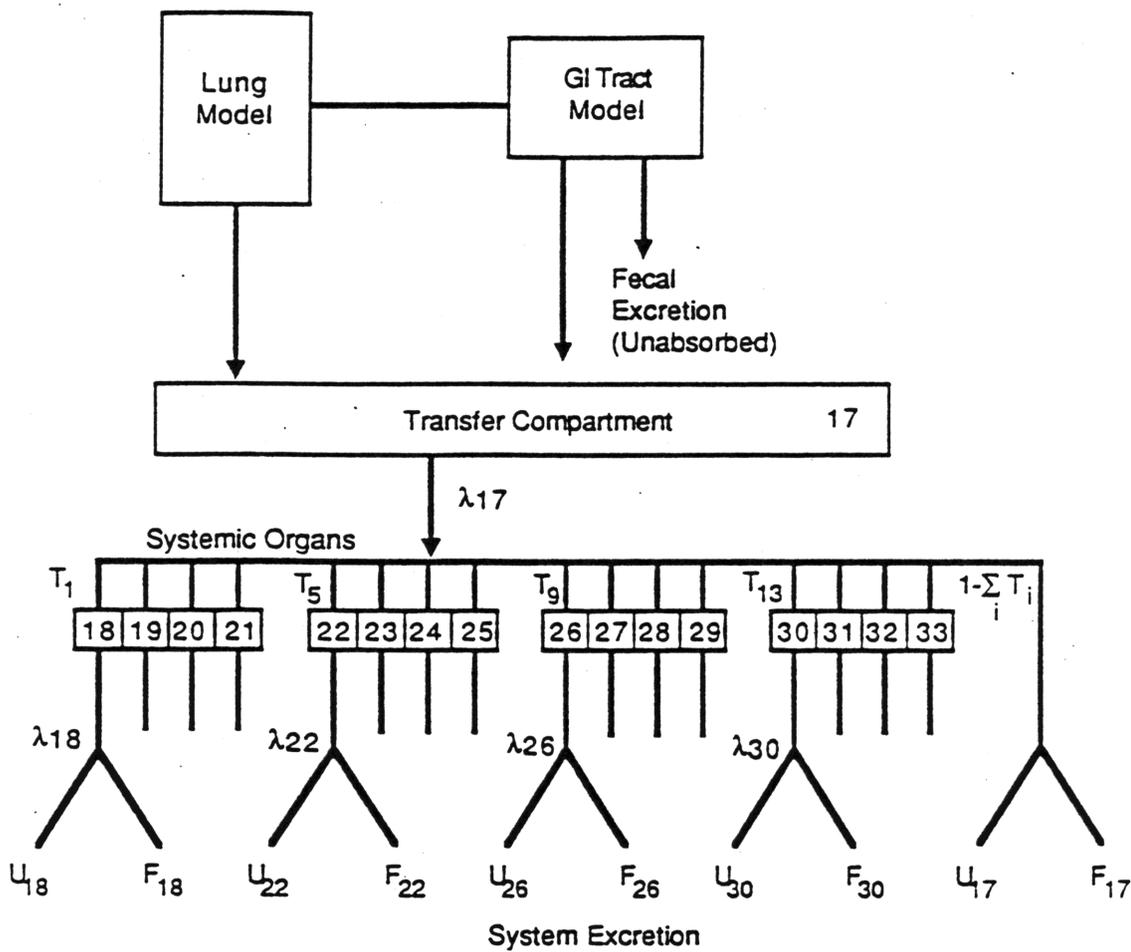
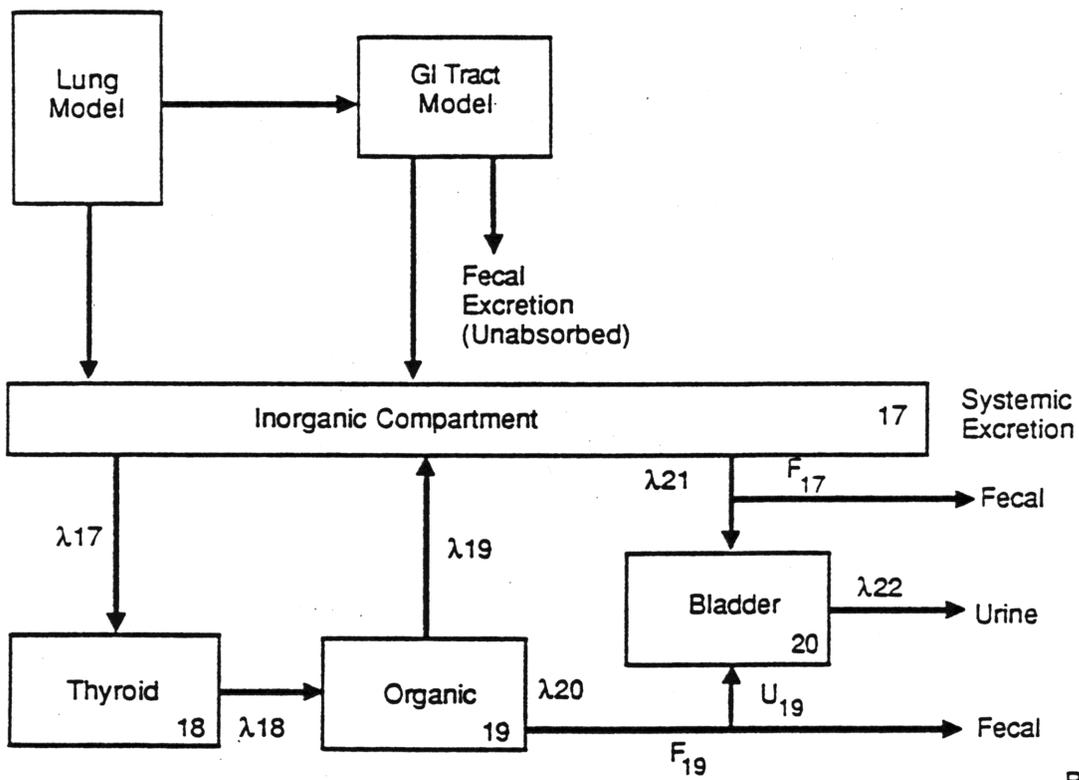


FIGURE A.2. GENMOD GI Tract Model



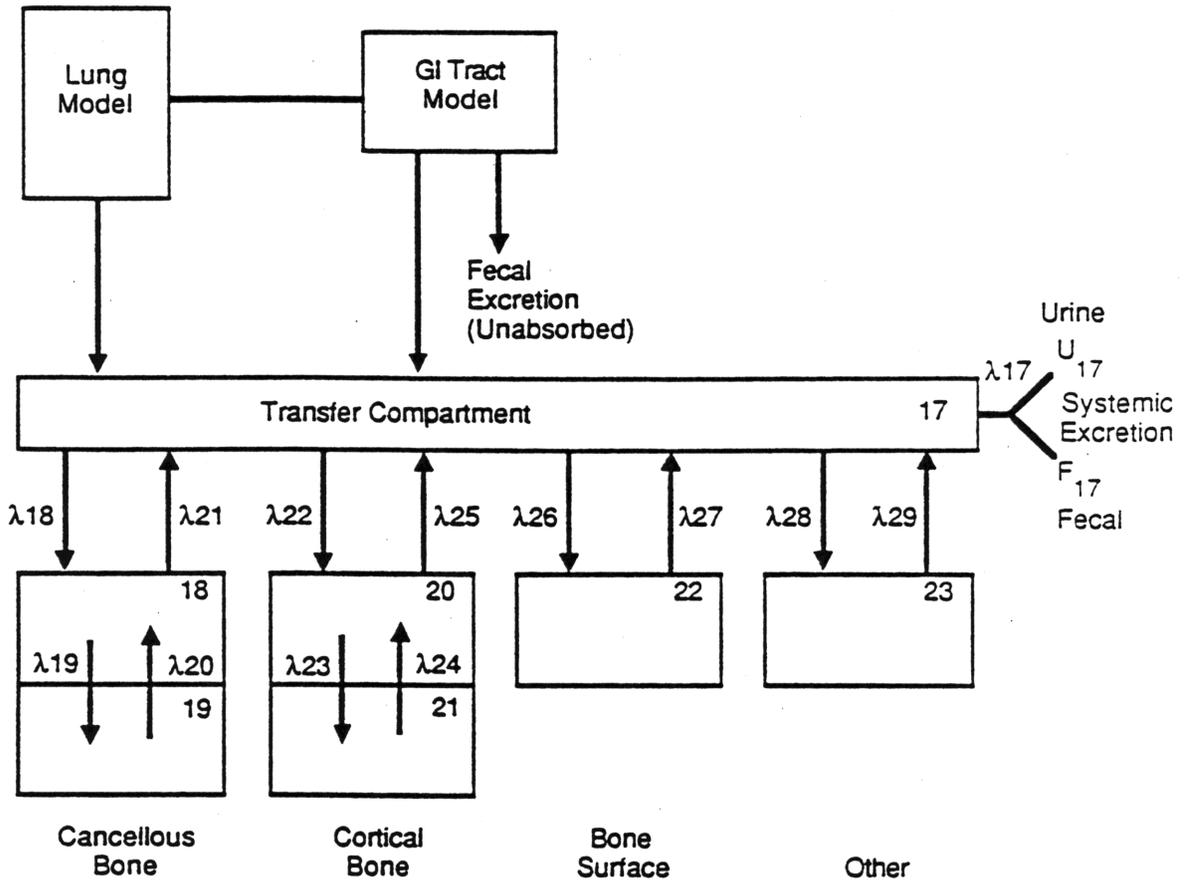
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FIGURE A.3. GENMOD General Model



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FIGURE A.4. GENMOD Iodine Model



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FIGURE A.5. GENMOD Alkaline Earth Model

TABLE A.1. GENMOD Parameters - Respiratory Tract Model

Model Parameter ^(a)	Input Name	Inhalation Class			
		D	W	Y	Super Y
Regional Deposition Fraction					
N-P ^(b) Region	ZNP	-----	0.30 ^(c)	-----	-----
T-B ^(d) Region	ZTB	-----	0.08 ^(c)	-----	-----
P ^(e) Region	ZP	-----	0.25 ^(c)	-----	-----
Compartment Fraction					
A	Amount(1)	0.5	0.1	0.01	0.01
B	Amount(2)	0.5	0.9	0.99	0.99
C	Amount(3)	0.95	0.5	0.01	0.01
D	Amount(4)	0.05	0.5	0.99	0.99
E	Amount(5)	0.8	0.15	0.05	0.05
F	Amount(6)	0.0	0.4	0.4	0.4
G	Amount(7)	0.0	0.4	0.4	0.4
H	Amount(8)	0.2	0.05	0.135	0.135
I	Amount(9)	0.0	0.0	0.015	0.015
J	Amount(10)	--	--	--	--
K	Amount(11)	--	--	--	--
D'	Amount(12)	0.0	0.0	0.0	0.0
Removal Rate (day ⁻¹)					
λ_1	Lung rate(1)	69.3	69.3	69.3	6.93E-5
λ_2	Lung rate(2)	69.3	1.73	1.73	1.73
λ_3	Lung rate(3)	69.3	69.3	69.3	6.93E-5
λ_4	Lung rate(4)	3.47	3.47	3.47	3.47
λ_5	Lung rate(5)	1.39	1.39E-2	1.39E-3	6.93E-5
λ_6	Lung rate(6)	--	0.693	0.693	0.693
λ_7	Lung rate(7)	--	1.39E-2	1.39E-3	1.39E-3
λ_8	Lung rate(8)	1.39	1.39E-2	1.39E-3	1.39E-3
λ_9	Lung rate(9)	--	--	1.39E-3	1.39E-3
λ_{10}	Lung rate(10)	1.39	1.39E-2	6.95E-4	6.93E-5
λ_{12}	Lung rate(12)	λ_4	λ_4	λ_4	λ_4

- (a) Refer to Figure A.1.
 (b) N-P = nasal-passage.
 (c) Particle size: 1- μ m AMAD.
 (d) T-B = tracheal-bronchial.
 (e) P = pulmonary.

Gastrointestinal Tract Model

The GI tract model (Figure A.2) documented by Eve (1966) is employed as described by Dunford and Johnson (1988). Table A.2 lists the parameters used by GENMOD to describe the fate of material entering the GI tract.

TABLE A.2. GENMOD Parameters - GI Tract Model

<u>Model Parameter (a)</u>	<u>Name</u>	<u>Value, day⁻¹</u>
Removal Rate		
Stomach	Lung rate(13)	24
SI ^(b)	Lung rate(14)	6
	Lung rate(11)	0[If $F_1 = 1$], $LR(14) * (F_1/1-F_1)$ [If $F_1 \neq 1$]
ULI ^(c)	Lung rate(15)	1.8
LLI ^(c)	Lung rate(16)	1.0

and the F_1 value is:

<u>Element</u>	<u>Inhalation Class</u>			<u>Ingestion</u>	
	<u>D</u>	<u>W</u>	<u>Y (e)</u>	<u>Soluble</u>	<u>Insoluble</u>
Manganese	0.1	0.1	--	0.1	--
Cobalt	0.8	0.05	0.05	0.3	0.05
Iron		0.1	0.1	--	0.1--
Cesium	1.0	--	--	1.0	--
Iodine	1.0	--	--	1.0	--
Europium	--	0.001	0.001	0.001	--
Uranium	0.05	0.05	0.002	0.05	0.002
Strontium	0.3	--	0.01	0.3	0.01
Americium	--	0.001	--	0.001	0.0005
Plutonium	--	0.0001	0.00001	0.001	0.0001

- (a) Refer to Figure A.2.
- (b) SI = small intestine.
- (c) ULI = upper large intestine.
- (d) LLI = lower large intestine.
- (e) Also for super Y.

Systemic Compartment Model

The general model (Figure A.3), iodine model (Figure A.4), and alkaline earth model (Figure A.5) employed by GENMOD are described by Dunford and Johnson (1988). However, several changes in the parameters used by the models have been made as follows:

- The radioiodine model parameters were modified to provide an effective biological half-life for the thyroid of 120 days as recommended by the ICRP (1979).
- The general model parameters for plutonium were modified to reflect the uptake distribution and retention values recommended in ICRP 48 (1987).
- The ICRP 48 uptake-excretion pathways were eliminated and the pseudo-uptake retention function for plutonium described by Skrabble (1987) was added to incorporate the plutonium uptake excretion function of Jones (1985).

Tables A.3 through A.5 provide systemic compartment values for the general model, the iodine model, and the alkaline earth model, respectively.

GENMOD DOSE EQUIVALENT COMPUTATIONS

GENMOD is a dosimetry code that is based on ICRP 30; however, there are some differences in the way that dose equivalent computations are performed, as discussed in the following subsections.

Organ Dose Equivalent

GENMOD calculates organ dose equivalents due to activity deposited in source organs. Source organs may include the lung, pulmonary lymphatics, stomach contents, small intestine (SI), upper large intestine (ULI), lower large intestine (LLI), and specific sites of systemic deposition listed in ICRP 30 for the element. For material distributed uniformly throughout the body (i.e., if a site of deposition in ICRP 30 is given as "all other organs and tissues"), the source organ is considered to be the total body. Target organs include all source organs (except that the pulmonary lymph is considered to be part of the lung for dose calculation purposes) plus bone marrow if bone surfaces are a source tissue, and both bone marrow and bone

TABLE A.3. GENMOD Parameters - General Systemic Organ Model

Element	Organ	Compartment Number (i)	Systemic Organ Compartments			Transfer Rate Constant, day ⁻¹ [TCOUT] (d)
			Deposition Fraction [TCOMP(i)] (a)	Compartment Half-life, day [RT(i + 7)] (b)	Excretion Fraction Urine/Feces [ORGUEX/ORGFEEX] (c)	
Manganese	Bone	1	0.35	40	NA(e)	2.77
	Liver	5	0.1	4		
	Other	6	0.15	40		
Iron	Other	9	0.2	4		2.77
		10	0.2	40		
	Liver	1	0.08	2000	NA(e)	
Cobalt	Spleen	5	0.013	2000		1.39
	Other	9	0.907	2000		
	Liver	1	0.03	6	NA(e)	
Cesium	Other	2	0.01	60		2.77
		3	0.01	800		
		5	0.27	6		
		6	0.09	60		
		7	0.09	800		
		1	0.1	2		
		2	0.9	110		
Europium	Bone	1	0.4	3500	NA(e)	2.77
	Kidney	5	0.06	10		
	Liver	9	0.4	3500		

TABLE A.3. (contd)

Element	Organ	Compartment Number (i)	Systemic Organ Compartments						
			Deposition Fraction [TCOMP(i)] (a)	Compartment Half-life, ϕ_{day} [RT(i + 7)] (b)	Excretion Fraction Urine/Feces [ORGUEX/ORGFEEX] (c)	Transfer Compartment Rate Constant [TCOUT] (d)			
Uranium	Bone	1	0.2	20	1.0/0.0	2.77			
		2	0.023	5000					
	Kidney	5	0.12	6					
		6	0.00052	1500					
	Other	9	0.12	6					
		10	0.00052	1500					
	Plutonium	Bone	1	0.5			18250	0/0	2.77
			5	0.3			7300	0/0	
		Liver	9	0.00035			1.0E+6	0/0	
			13	0.0085			1.24	1/1	
Gonads		14	0.00541	15.7	1/1				
		15	0.0225	182	1/1				
Pseudo comp. (f)	16	0.5	2.44E4	1/1					

- (a) Shown as Ti in Figure A.3.
- (b) Shown as l(i + 7) in Figure A.3.
- (c) Shown as U(i + 7) and F(i + 7) in Figure A.3.
- (d) Shown as l₁₇ in Figure A.3.
- (e) NA - not applicable.
- (f) Pseudo compartment devised as a way to include Jones' empirically derived excretion function in model. To do so required setting the excretion from specified organ compartments to 0.0, and from pseudo compartments to 1.0.

TABLE A.4. GENMOD Parameters - Iodine Model

<u>Model Parameter (a)</u>	<u>Input Name</u>	<u>Parameter Value</u>
λ_{17}	TCOMP(1)	0.87 day ⁻¹
λ_{18}	TCOMP(9)	0.00866 day ⁻¹
λ_{19}	ORGUEX(26)	0.052 day ⁻¹
λ_{20}	TCOMP(5)	0.0058 day ⁻¹
λ_{21}	TCOUT	1.9 day ⁻¹
λ_{22}	ORGUEX(22)	7.5 day ⁻¹
U ₁₇	UEX	1.0
U ₁₉	RT(22)	0.9
F ₁₇	FEX	0.0
F ₁₉	RT(26)	0.1

(a) Refer to Figure A.4.

if bone volume is a source. If "other tissues" is listed as a source organ, then it is also considered to be a target organ.

Doses to target organs are calculated in the same way as in ICRP 30 with the following exception. The dose equivalent to "other tissues" does not include crossfire from activity deposited in other organs nor does it contribute to the dose received by other organs. That is, the dose equivalent to "other tissues" is solely due to self-irradiation. Source-to-target dose factors are listed by Snyder et al. (1974) and Dunning, Pleasant, and Killough (1977). Dose factors for activity deposited in "other tissues" are listed under "T-Body" in these publications.

TABLE A.5. GENMOD Parameters - Alkaline Earth Model

<u>Model Parameter (a)</u>	<u>Input Name</u>	<u>Parameter Value</u>
l_{17}	TCOUT	3.44
l_{18}	TCOMP(1)	0.378
l_{19}	TCOMP(2)	0.00725
l_{20}	RT(18)	0.00479
l_{21}	RT(19)	0.00105
l_{22}	TCOMP(5)	0.516
l_{23}	TCOMP(6)	0.00136
l_{24}	RT(22)	0.00214
l_{25}	RT(23)	0.000149
l_{26}	TCOMP(9)	2.66
l_{27}	RT(26)	0.403
l_{28}	TCOMP(13)	17.6
l_{29}	RT(30)	1.29
U_{17}	UEX	0.8
F_{17}	FEX	0.2

(a) Refer to Figure A.5.

(b) Units are inverse days except UEX and FEX are unitless.

Effective Dose Equivalent^(a)

The total stochastic risk incurred from the irradiation of body tissues following intakes of radionuclides is considered to be proportional to the effective dose equivalent. The effective dose equivalent is defined in DOE 5480.11 (1988) as:

$$H_E = \sum_T w_T H_T \text{ (rem)} \quad (\text{A.1})$$

where H_T is the dose equivalent for an organ or tissue T from all internal sources and w_T is a weighting factor representing the ratio of the risk arising from irradiation of tissue T to the total risk when the whole body is irradiated uniformly.

The weighting factors (w_T) are defined in DOE 5480.11 (1988) as:

<u>Organ or Tissue</u>	<u>Weighting Factor</u>
Gonads	0.25
Breasts	0.15
Red bone marrow	0.12
Lungs	0.12
Thyroid	0.03
Bone surfaces	0.03
Remainder	0.30

In the above table, "remainder" means the five other organs with the highest dose and the weighting factor for each such organ is 0.06. Organs considered in the "remainder" category include the following:

-
- (a) The effective dose equivalent, as defined in DOE 5480.11 (1988), includes contributions from internally deposited radionuclides and from external exposure to radioactive material and/or radiation-generating devices. This guide addresses the assessment of dose from internally deposited radionuclides and thus the term "effective dose equivalent" when used here refers to the internal component only.

Muscle	Stomach wall	Kidneys
Liver	Small intestine wall	Pancreas
Spleen	Upper large intestine wall	Uterus
Thymus	Lower large intestine wall	Adrenals
Bladder wall		

According to DOE 5480.11 (1988), the skin, lens of the eyes, and extremities are specifically excluded from the list of organs to be considered in the calculation of effective dose equivalent from internally deposited radionuclides.

The GENMOD approach to the computation of effective dose equivalent differs from the ICRP 30 method by summing the effective dose equivalent contributions from activity in source organs rather than by summing the weighted target organ dose equivalents.

Another difference is the way that activity deposited uniformly throughout the body is handled, as described in the following summary of the GENMOD procedure.

1. Source organs are identified. The source organs always include the lung, pulmonary lymphatics, stomach contents, SI contents, ULI contents, and the LLI contents. The organs identified as systemic deposition sites in the metabolic model are also included. If the model predicts that a portion of the uptake will be deposited throughout the body, then the source organ for this deposition is identified as the total body.
2. A factor that converts the activity in a source organ to effective dose equivalent is computed for each of the identified source organs. These factors, called S-prime factors (Johnson, Stewart, and Carver 1979), are calculated as follows:

$$S_S' = \sum_T w_T S_{ST} \quad (A.2)$$

where S_S' is the sum of the weighted dose equivalents to target organs T from activity deposited in source organs S. The S_{ST} factors are SEE(T-S) values converted into units of dose equivalent per unit cumulated activity (Sv/Bq-day). The weighting factors are as given previously. Thus, each S_S' factor is based on the sum of the contributions to each of the six "risk organs" and the five highest remaining organs. This procedure is applied to the calculation of S_S' values for all source organs except for the

source "total body." In this case, the calculation is performed by considering self-irradiation only, and by applying a weighting factor of 1.0.

3. The effective dose equivalent, H_E , is computed by summing the effective dose equivalent contributions from each source organ as follows:

$$H_E = \sum_T S_S' Z Q_S(t)dt \quad (A.3)$$

where $R Q_S(t)dt$ is the cumulated activity in source organ S over the time period of interest.

The ICRP and GENMOD approaches to the calculation of effective dose equivalent show excellent agreement when activity is essentially all deposited in a few primary sites such as for plutonium, uranium, and strontium. Agreement is also very good for radionuclides that distribute uniformly throughout the body; however, in these cases the effective dose equivalents computed by GENMOD generally exceed those computed using the ICRP procedure. As example comparisons, the committed effective dose equivalent calculated by GENMOD and ICRP 30 are in perfect agreement for inhalation of class D ^{106}Ru ; however, the GENMOD-computed dose exceeds the ICRP 30 dose by 3% for inhaled, class D ^{137}Cs and by 16% for class W ^{60}Co . The differences are attributed to the application of the 10% rule in ICRP 30 to eliminate some target organs from the effective dose equivalent computation, and to GENMOD's use of a weighting factor of 1.0 for activity deposited in "other organs and tissues of the body."

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