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The Estimation of Organ Dose from Inhaled Radionuclides

N. Adams and J.A. Reissland

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NRPB-R51

THE ESTIMATION OF ORGAN DOSES FROM INHALED RADIONUCLIDES

by

N Adams and J A Reissland

ABSTRACT

A procedure is described for the calculation of the integrated doses received by body organs in specified time periods following the inhalation of a radionuclide. This procedure takes account of the contributions from radioactive daughters produced after inhalation and in principle may be extended to any number of generations of a decay chain. In practice, it is usually adequate to consider only the two most significant generations and to make simple approximations for the contributions from any others.

Doses to eight body organs have been calculated for 65 radionuclides, assuming that one curie of each is inhaled in the form of 1 μm AMAD aerosol, and for times following inhalation ranging from 1 day to 50 years.

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Foreword

In calculating the dose per unit intake, the authors of this report have drawn freely from the dosimetric models and retention equations currently under discussion in Committee 2 of the International Commission on Radiological Protection. One of the authors (N Adams) has contributed to the work of this committee during the last three years as a member of the Secretariat. The authors wish to acknowledge that they have used material from the work of the Committee and they would like to thank its chairman and secretary, Drs J Vennart and G W Dolphin, who have given their approval for the publication of these data. However, the reader is warned that the models and the parameters used (those in tables C, D, E and the bone classes in table F) have not been finally approved by Committee 2 and some changes may be made.

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1. INTRODUCTION

This report describes a method which may be adopted to estimate the radiation doses received by various body organs in given time periods following the inhalation of a radionuclide. Use has been made of the lung model of the ICRP Task Group on Lung Dynamics[1] and of the GI tract model of Eve[2] to describe the transport of the inhaled material from the region of deposition and through the organs of interest. As the radioactive material progresses through the body, organs are irradiated both from transformations occurring in the organ itself and from those occurring in surrounding organs. Irradiated organs are called target organs and those in which transformations occur are called source organs.

There are three main steps necessary to estimate the doses to any organ due to a given nuclide in a given period of time.

(i) The computation of the number of nuclear transformations of the inhaled radionuclide in each of the source organs, ie, those through which the radioactive material passes. A similar computation is necessary for any radioactive daughters formed after inhalation of the parent nuclide.

(ii) The preparation of matrices (one for each radionuclide involved, parent and daughters) whose elements are the doses received by the target organs per transformation in the source organs.

(iii) The combination of (i) and (ii) to obtain the total dose to each target organ from the inhaled parent and any daughter radionuclides.

Doses to the thyroid, red bone marrow, endosteal cells, lower large intestine, lungs, liver, ovaries and testes are tabulated for periods of 1, 7, 30, 60 and 365 days and 10, 20, 30, 40 and 50 years following the inhalation of 1 curie of each radionuclide. The depositions in the different lung regions (nasopharyngeal, tracheobronchial and pulmonary) depend on particle size. The lung as a target and source organ includes the tracheobronchial region, pulmonary region, the pulmonary lymph nodes but not the nasopharyngeal region. The doses quoted are for particles of 1 μm AMAD (Activity Median Aerodynamic Diameter).

2. STEP (i) - TRANSFORMATIONS IN SOURCE ORGANS

A linear compartment model was employed to describe the progression of inhaled material through the lung and thence either into the GI tract or, via a transfer compartment with a half life of six hours (analogous to the blood), to body organs. Uptake to the transfer compartment from the small intestine was also represented. Transfers between compartments are all described by first order differential equations with constant coefficients, as discussed by Skrable *et al*[3]. A series of linear chains was involved, extending from a single compartment up to seven

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compartments, and these are fully described by the equations

$$\dot{q}_1(t) = I_1(t) - \lambda_1 q_1(t) \quad \text{.....(1)}$$

$$\dot{q}_i(t) = I_i(t) + \lambda_{i-1,i}\, q_{i-1}(t) - \lambda_i q_i(t) \quad \text{.....(2)}$$

$$i = 2 \text{ to } n$$

where $q_i(t)$ is the total amount of activity in compartment i at time t; $I_i(t)$ is the rate of intake of activity from outside the system into compartment i at time t; $\lambda_{i-1,i}$ is the rate constant for transfer of material from compartment i-1 to compartment i; λ_i is the rate constant for the decrease of active material in compartment i, including that through radioactive decay.

If we choose t = 0 to be the time of inhalation, $I_i(0) = 0$ and $q_i(0) = 0$ for $i \geqslant 2$, $q_1(0)$ is then the activity deposited at t = 0 in the first compartment following the inhalation of 1 Ci. Thus we may solve equations (1) and use the results in equation (2), successively generating solutions for all $q_i(t)$. These may be integrated over the required time period T to give the number of transformations. The general solution is:

all λ_i different:

$$U_i(T) = \prod_{k=1}^{i-1} \lambda_{k,k+1} \left\{ \sum_{k=1}^{i} \frac{(1 - e^{-\lambda_k T})}{\lambda_k \prod_{\substack{p=1 \\ p \neq k}}^{i} (\lambda_p - \lambda_k)} \right\} \quad \text{.....(3)}$$

$\lambda_1 = \lambda_2$

$$U_i(T) = \prod_{k=1}^{i=1} \lambda_{k,k+1} \left\{ \frac{1}{\lambda_1 \prod_{k=3}^{i} (\lambda_k - \lambda_1)} \left[- Te^{-\lambda_1 T} + (1 - e^{-\lambda_1 T}) \left(\frac{1}{\lambda_1} - \sum_{k=3}^{i} \frac{1}{\lambda_k - \lambda_1} \right) \right] + \sum_{k=3}^{i} \frac{1 - e^{-\lambda_k T}}{\lambda_k (\lambda_k - \lambda_1)^2} \frac{1}{\prod_{\substack{l=3 \\ l \neq k}} (\lambda_l - \lambda_k)} \right\} \quad \text{.....(4)}$$

with similar expressions if any other pair of λ_i are equal.

The compartments used to represent the lung are those of the ICRP Task Group on Lung Dynamics[1] (see Figure 1). The amended values of the parameters of this model given in ICRP Publication 19[4] and reproduced in Table A were used. The classification of elements in the solubility classes D, W or Y and the values adopted for the fractions to represent material absorbed from the small intestine into the transfer compartment constitute the best available knowledge at this time for material in oxide form.

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The model of the GI tract is shown in Figure 2 together with the parameters (Table B) as proposed by Eve[2] and by ICRP[5].

Figure 3 shows the linear chains for all the parent metabolic paths. The numerical values for the λs may be found from Table A using

$$\lambda_{i,i+1} = \frac{\ln 2}{T}$$

where T is taken from the appropriate class (D, W or Y) and compartment (a to j).

$$\lambda_i = \lambda_{i,i+1} + \lambda_R$$

where λ_R is the radioactive decay constant of the relevant nuclide. λ_{ST}, λ_{SI}, λ_{ULI} and λ_{LLI} are given in Table B and λ_{Tr} is taken as 2.77 days^{-1} except for strontium and barium (see Table C). The values of λ_{ORG} were obtained for each element by representing retention as an exponential or sum of exponentials and taking the current best available estimates for the amplitudes and half times of the exponentials. As yet there are no established values for these retention parameters but it is anticipated that ICRP Committee 2 will be publishing recommendations in the near future. Tables C and D show the values of the retention parameters for each element which have been used in our calculations.

For the alkaline earths, the ICRP Publication 20[6] tabulates retention values for soft tissue and bone as a function of time after intake to blood. These have been fitted by three or four exponential terms. For these elements the coefficient for the transfer compartment was modified to improve the representation of the retention during the first day or so after intake to the blood.

The transformations of radioactive daughters were computed similarly but for each linear chain of n compartments for a parent, n chains with n + 1 compartments were summed for each daughter. The metabolic parameters were taken to be the same as those of the parent (except that when the daughters were isotopes of iodine their proper metablic parameters were used) but the radioactive decay constant appropriate for the daughter was used. An example of a set of linear chains for a daughter is given in Figure 4. This shows the first chain (corresponding to the parent chain in which the first transfer is from the NP region to the transfer compartment via route 'a') for a radioactive daughter with decay constant λ_R being formed in the compartments of the chain. The total number of the transformations in each compartment is the sum of the contributions from the three chains. Each of the parent chains of Figure 3 (ie, 6 for class D, 8 for class W and 9 for class Y) has a series of such chains to be summed if the daughter is radioactive.

Extension of the method for the first daughter leads from a parent chain with n compartments through a daughter with n chains of n + 1 compartments to a granddaughter with n(n + 1) chains each with n + 2 compartments. Thus a three

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compartment parent chain leads to 12 five-compartments for the grand-daughter and a six compartment parent chain to 42 eight-compartments in calculations involving a grand-daughter. The rapid escalation in the number of chains which need to be considered as the number of generations increases prompted the approximation of the longer radioactive decay schemes by reducing them to two generations. The chief means by which this was achieved was by treating the transformation of a nuclide as being simultaneous with the transformation of its daughter if its half life was an order of magnitude greater than that of its daughter. This assumption does not affect the ultimate dose received and only slightly accelerates its accumulation. Daughter nuclides with half lives longer than 10^5 years are treated as being stable.

3. STEP (ii) - DOSE TO TARGET ORGAN DUE TO TRANSFORMATIONS IN SOURCE ORGAN

The elements of the matrices which convert the number of transformations in the source organs to the doses to target organs include contributions from both non-penetrating radiation (ie, α- and β- particles) and from penetrating radiation (ie, photons). These contributions were estimated for the inhaled nuclides and for any radioactive daughters as follows.

3.1 Non-penetrating radiation

For all source organs except bone the initial kinetic energy of non-penetrating radiations (α and β) emitted during transformations is assumed to be completely absorbed within the source organ (ie, the source and target organs coincide) and the contribution to the matrix element is taken to be the average dose to the whole source organ per transformation.

When bone is the source organ non-penetrating radiation deposits energy in two radiosensitive tissues, red bone marrow and endosteal cells, which are treated as separate target organs. The spatial distribution of transformations in mineral bone determines the fraction of the initial kinetic energy which is absorbed in each of these organs (see Table E).

Two alternative distributions of transformations in bone are assumed from nuclides which are concentrated in bone, uniform volume concentration throughout mineral bone, which is labelled class V (for volume), and uniform superficial concentration on endosteal surfaces of bone, which is labelled class S (for superficial).

The allocation to classes S or V (see Table F) of nuclides which are concentrated in bone is largely, but not entirely, determined by the half lives of the nuclides. For example, nuclides with short half lives are unlikely to diffuse appreciably into bone before physical decay and therefore class S is appropriate. Long lived nuclides are not necessarily in class V because some, such as the actinides (eg, plutonium-239), appear to remain near bone surfaces, perhaps as a

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consequence of a special bone remodelling process, and are regarded as class S. However, all isotopes of the alkaline earths with half lives greater than 15 days are allocated to class V.

Table E shows the values used for the fraction of the emitted energy absorbed in red bone marrow and endosteal cells for α- and β- emissions from surface and volume distributions of transformations. These values are taken from an as yet unpublished analysis of bone dosimetry. It is implicitly assumed in this analysis that for V class nuclides there are 4 times as many transformations in cortical bone as in trabecular bone (ie, in proportion to their masses) but for S class nuclides the same number of transformations occur in cortical and trabecular bone which have equal endosteal surface areas.

3.2 Penetrating radiation

Only a fraction of the initial energy of penetrating radiation (photons) emitted by transformations in any source organ is deposited in that organ and further fractions are deposited in every other organ. For all target organs except endosteal cells the values of these fractions per gram of target organ are given in ICRP Publication 23[5] for monoenergetic photons with energies from 0.01 to 4.0 MeV. These fractions were used to derive the contributions to the matrix elements, ie, the average doses in the target organs. The contributions to the matrix elements representing dose to endosteal cells from photons were taken to be the average photon doses in the whole skeleton.

3.3 General

For many of the radionuclides considered in this report, values of both the non-penetrating and penetrating components of the elements of the matrix (but expressed in rem per μCi day) have been published by Snyder *et al*[7] and these have been employed where appropriate. The special procedures which are described above when the target organ is red bone marrow or endosteal cells were, however, adopted for those radionuclides which are concentrated in bone.

4. STEP (iii) - DOSES TO ORGANS

The doses to organs were derived by multiplying the matrices produced by steps i and ii. The results are given in Table G which shows the accumulated doses to eight organs at various times following inhalation of a curie of each radionuclide. Doses to the thyroid were only specifically calculated for isotopes of iodine whether these were inhaled nuclides or their daughters and for technetium. For inhaled nuclides for which thyroid doses are not calculated the thyroid dose has been approximated by the dose to the ovaries, which may also be employed as an approximation to the average dose to the whole body and consequently for the breast dose.

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5. COMMENTS

The organ doses per inhaled curie which are given in Table G are intended for use for radiological protection purposes. This work employed the best data available at the time of the calculations. Since the data are subject to continual revision, particularly the metabolic retention and transfer values, it is inevitable that later calculations will produce some modifications to these results. The biological data will be monitored and, when appropriate, revisions to these dose calculations will be issued.

The values in Table G have been compared with those given by the US Nuclear Regulatory Commission[8], although it did not include all the nuclides and body organs considered in this report. The comparison tests the computations as a whole, including the combined consequences of the metabolic parameters and the transformations-to-dose matrices employed by both reports. Reasonable agreement was found for most nuclides, though minor differences were common in doses to red bone marrow and endosteal cells and are attributed to the use of different bone dosimetry models. In cases where there was some considerable discrepancy, our calculations were carefully checked and special attention given to the input data; most of the differences were traced to different assumptions such as lung class or body distribution parameters. The remaining discrepancies are not resolvable from the published information but have been checked on the basis of self-consistency with the doses in other organs or in other nuclides. The data in Table G are believed to be internally self-consistent and the ones most appropriate for current use.

6. ACKNOWLEDGEMENTS

The work described in this report was carried out under contract from HSE (Nuclear Installations Inspectorate).

We are also grateful to Mr. B W Hunt (NRPB) for valuable assistance with computations.

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Region	Pathway	Class					
		D		W		Y	
		T	F	T	F	T	F
N - P (D_{N-P} = 0.30)	a	0.01	0.5	0.01	0.1	0.01	0.01
	b	0.01	0.5	0.40	0.9	0.40	0.99
T - B (D_{T-B} = 0.08)	c	0.01	0.95	0.01	0.5	0.01	0.01
	d	0.2	0.05	0.2	0.5	0.2	0.99
P (D_P = 0.25)	e	0.5	0.8	50	0.15	500	0.05
	f			1.0	0.4	1.0	0.4
	g			50	0.4	500	0.4
	h	0.5	0.2	50	0.05	500	0.15
L		0.5	1.0	50	1.0	1000	0.9
		-	0.0	-	0.0	∞	0.1

Table A. Parameters for lung clearance model

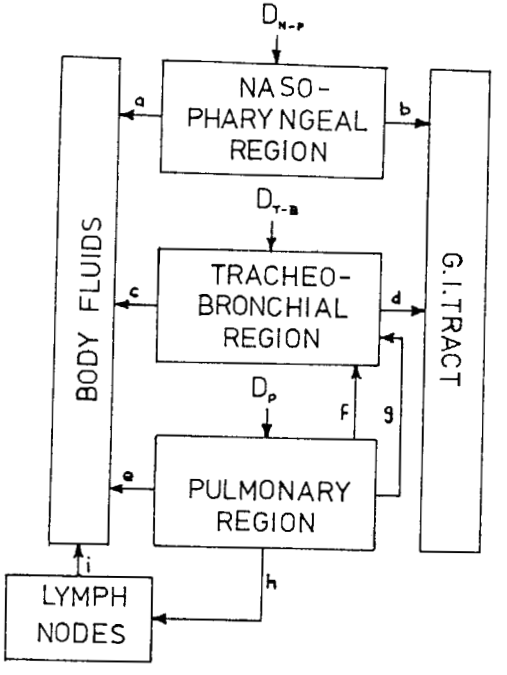

Figure 1. Lung clearance model

Clearance model employed with the values for the removal half-times (T) and compartmental fractions (F) for each class (D, W and Y). The regional depositions D_{N-P}, D_{T-B} and D_P are for an aerosol with AMAD = 1 μm. Half-times in the table are given in reciprocal days.

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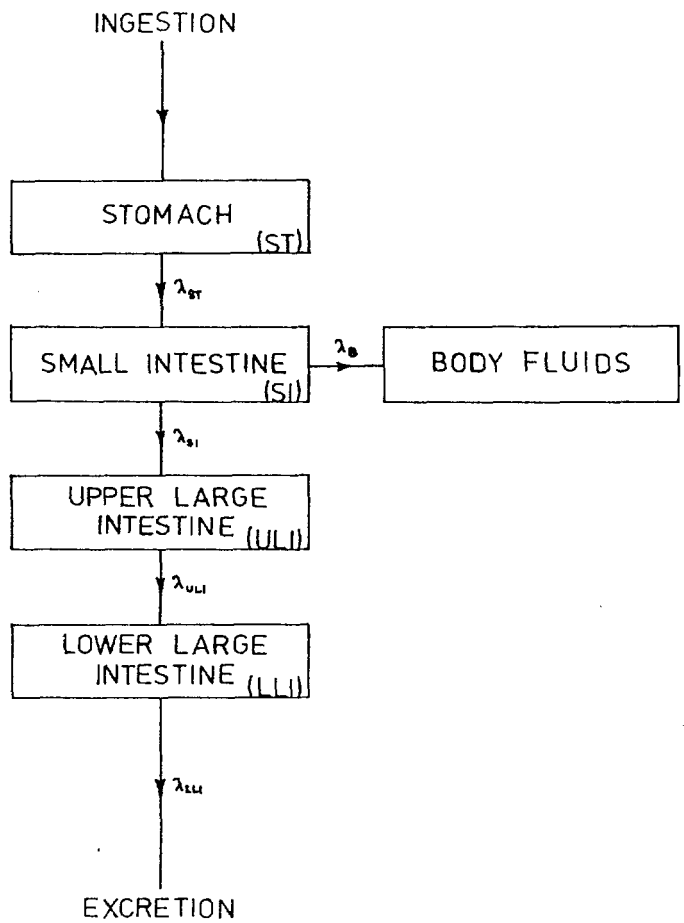

Figure 2. Gastrointestinal tract model

Section of GI tract	Mass of contents (g)	Mean residence time (days)	λ days^{-1}
Stomach (ST)	250	1/24	24
Small intestine (SI)	400	4/24	6
Upper large intestine (ULI)	220	13/24	1.8
Lower large intestine (LLI)	135	24/24	1

Table B. Parameters for gastrointestinal tract model

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FIGURE 3. (Linear Chains For Parent Radionuclides)

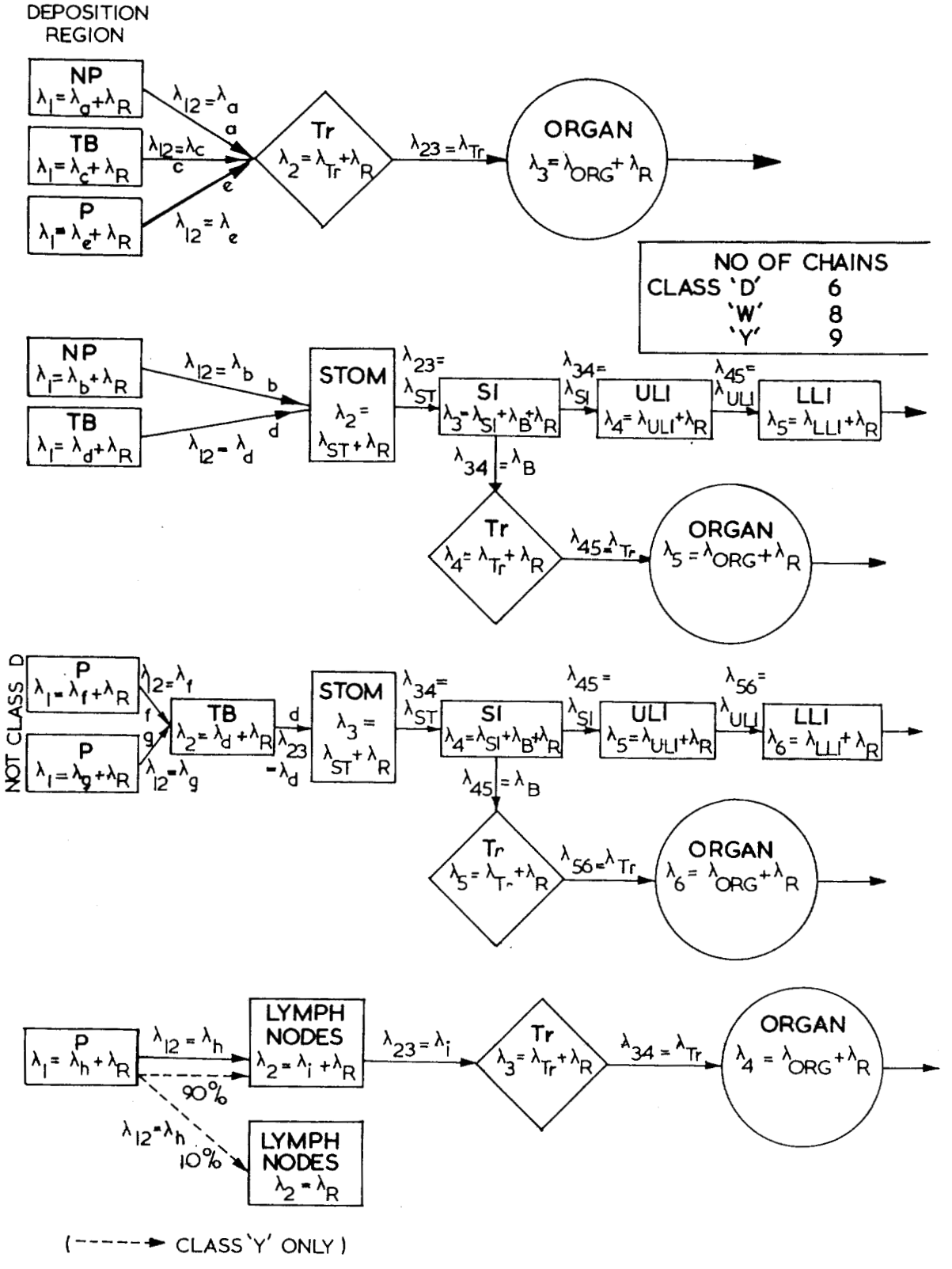

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FIGURE 4. (Example of Linear Chains for a Daughter Radionuclide Corresponding to the First Chain of Figure 3 i.e. Beginning with Transfer 'a'.

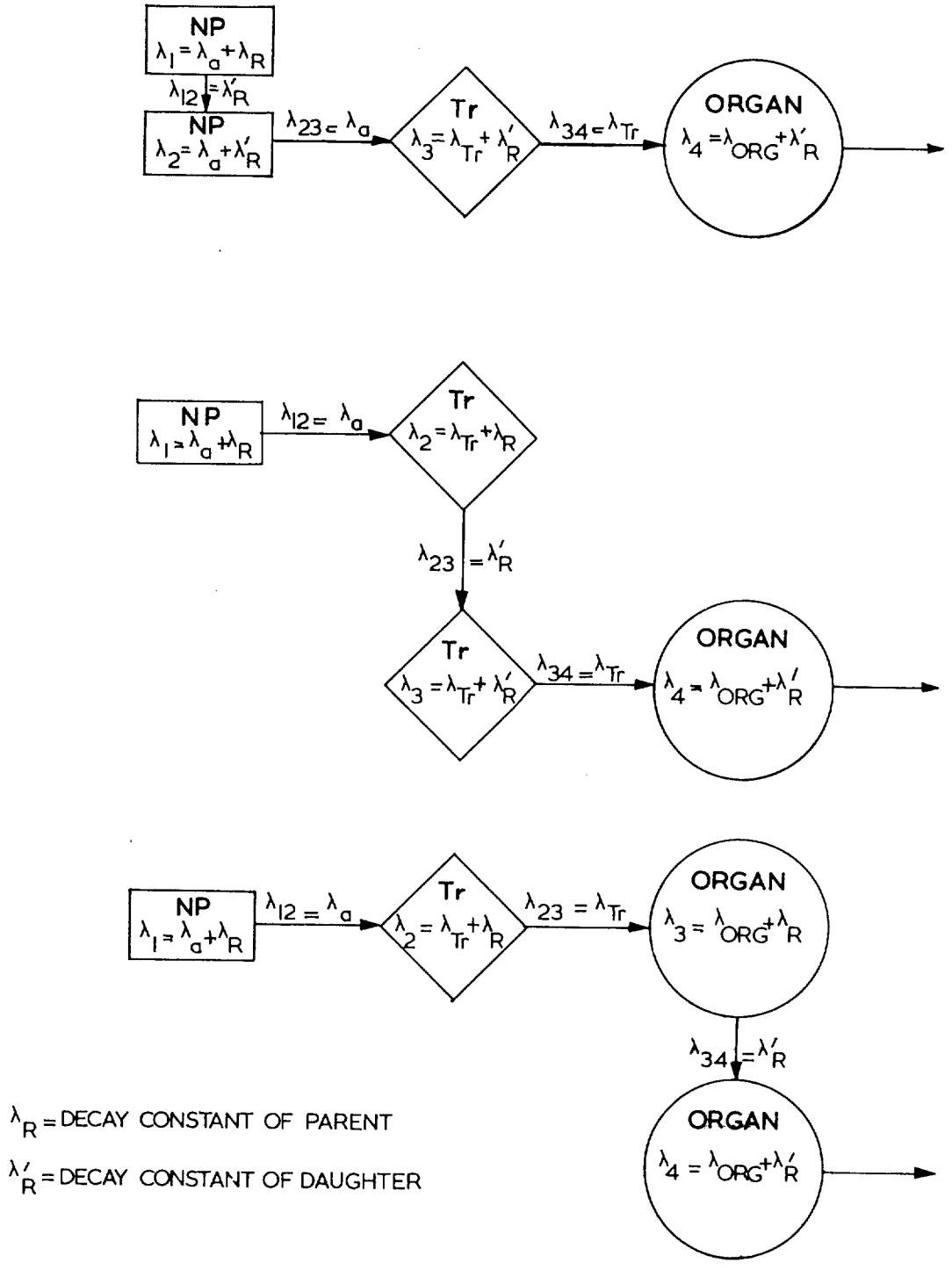

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Table C - Fraction Transferred to Source Tissue

Element	Bone	Liver	Kidneys	Spleen	Testes	Muscle	Thyroid	Ovaries	Rest of Body
Sodium	0.2								0.8
Rubidium	0.2								0.8
Strontium *	0.28								0.72+
Yttrium	0.5	0.15							0.1
Zirconium	0.45								0.55
Niobium	0.71		0.018	0.01	0.002				0.26
Molybdenum	0.21					0.09			0.7
Technetium			0.04				0.02		0.94
Ruthenium		0.05	0.05						0.9
Rhodium		0.05	0.05						0.9
Antimony		0.2							0.8
Tellurium	0.04	0.11	0.07			0.19			0.59
Iodine							0.3		
Caesium									1.0
Barium *	0.105								0.63
Lanthanum, Cerium, Praseodyminum, Neodymium		0.7		0.04					0.26
Promethium	0.45	0.45							0.1
Neptunium, Plutonium, Americium, Curium	0.45	0.45			.00035			.00011	

* The rate constant for the transfer compartment (λ_{Tr}) is taken as 100 days^{-1}.

\+ λ_{Tr} = 1.155 day^{-1}

All other λ_{Tr} = 2.77 days^{-1}

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Table D - Retention Parameters

Element	A_1	T_1 days	A_2	T_2 days	A_3	T_3 days	A_4	T_4 days
Sodium	0.49	8.5	0.51	135	0.00027	445		
Rubidium	1.0	60						
Strontium) Bone	0.43	4	0.36	1400	0.21	9000		
) Rest	0.69	0.6	0.42	5	0.097	100	0.007	900
Yttrium	1.0	8000						
Zirconium) Bone	1.0	∞						
) Rest	0.91	7	0.09	∞				
Niobium	0.5	6	0.5	200				
Molybdenum	0.85	1	0.15	50				
Technetium	0.76	1.6	0.19	3.7	0.043	22		
Ruthenium	0.15	0.3	0.35	8.0	0.3	35	0.2	1000
Rhodium	0.15	0.3	0.35	8.0	0.3	35	0.2	1000
Antimony	0.7	20						
Tellurium) Bone	1.0	2500						
) Rest	0.5	0.8	0.5	18				
Iodine	1.0	120						
Caesium	0.1	2	0.9	110				
Barium) Bone	0.57	3	0.29	1100	0.14	5500		
) Rest	0.79	0.6	0.13	3.5	0.08	140		
Lanthanum) Cerium) Praseodyminum) Neodymium)	1.0	3750						
Promethium	1.0	8000						
Neptunium) Bone	1.0	100 years						
Plutonium) Liver	1.0	40 years						
Americium) Gonads	1.0	∞						
Curium)								

Where the retention R(t) is given by

$$R(t) = A_1 e^{-0.693t/T_1} + A_2 e^{-0.693t/T_2} + A_3 e^{-0.693t/T_3} + A_4 e^{-.693t/T_4}$$

Table E

Fraction of non-penetrating radiation energy from transformations in mineral bone that is absorbed in red bone marrow and endosteal cells

Target Organ \ Radiation Energy Class	α any Surface	β any Volume	β $\bar{E} > 0.4$ MeV Surface	β $\bar{E} < 0.4$ MeV Surface
Red Bone Marrow	0.25	0.20	0.25	0.25
Endosteal Cells	0.25	0.02	0.02	0.25

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Table F - Index of Included Nuclides

Element	Lung Class	Mass No.	Bone Class
Sodium	D	24	
Rubidium	D	86	
		88	
		89	
Strontium	D	89	V
		90	V
		91	S
		92	S
Yttrium	Y	90	S
		91	V
		93	S
Zirconium	Y	95	S
		97	S
Niobium	Y	95	S
		97	S
Molybdenum	Y	99	S
Technetium	W	99m	
Ruthenium	Y	103	
		105	
		106	
Rhodium	Y	105	
Antimony	W	125	
		127	
		128	
		129	
		130m	
		130	
		131	
Tellurium	W	127m	S
		127	S
		129m	S
		129	S
		131m	S
		132	S
		133m	S

Element	Lung Class	Mass No.	Bone Class
Iodine	D	131	
		132	
		133	
		134	
		135	
Caesium	D	134	
		136	
		137	
		138	
Barium	D	139	S
		140	S
Lanthanum	Y	140	
		141	
		142	
Cerium	Y	141	S
		143	
		144	
Praseodymium	Y	143	
		145	
Neodymium	Y	147	
Promethium	Y	147	V
		149	S
Neptunium	Y	239	S
Plutonium	Y	238	S
		239	S
		240	S
		241	S
Americium	W	242	S
Curium	W	242	S
		244	S

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DOSE IN RADS PER CURIE INHALED — SIZE 1.00M — ORGAN: THYROID

NUCLIDE \ TIME:	1 D	7 D	30 D	60 D	1 Y	10 Y	20 Y	30 Y	40 Y	50 Y
NA-24	2.5(2)	4.9(2)	4.9(2)							
RB-86	1.3(2)	1.5(3)	4.2(3)	5.2(3)	5.5(3)	5.5(3)				
88	2.9(-1)	2.9(-1)								
89	1.9(-1)	4.3(-1)	1.1(0)	1.6(0)	2.0(0)	2.0(0)				
SR-89	1.1(2)	5.0(2)	9.5(2)	1.2(3)	1.5(3)	1.5(3)				
90	5.9(1)	5.7(2)	1.6(3)	2.4(3)	5.7(3)	8.0(3)	8.1(3)	8.1(3)		
91	1.5(2)	1.9(2)	1.9(2)	1.9(2)						
92	7.3(1)	7.5(1)	7.5(1)							
Y-90	1.2(-1)	6.3(-1)	7.8(-1)	7.8(-1)						
91	6.2(-1)	5.5(0)	8.8(0)	1.2(1)	2.2(1)	2.3(1)	2.3(1)			
93	3.8(0)	7.7(0)	7.7(0)							
ZR-95	1.1(2)	1.0(3)	1.1(3)	1.3(3)	1.7(3)	1.7(3)				
97	1.8(2)	5.3(2)	5.3(2)							
NB-95	1.1(2)	9.8(2)	1.1(3)	1.1(3)	1.2(3)	1.2(3)				
97	5.7(-1)	5.7(-1)								
MO-99	3.9(1)	2.6(2)	2.6(2)							
TC-99M	2.6(1)	3.2(1)	3.2(1)							
RU-103	7.0(1)	6.1(2)	7.0(2)	7.5(2)	8.1(2)	8.1(2)				
105	1.2(1)	2.0(1)	2.0(1)							
106	3.5(1)	3.6(2)	6.5(2)	9.0(2)	2.3(3)	4.1(3)	4.1(3)			
RH-105	1.0(1)	4.7(1)	4.8(1)							
SB-125	5.2(1)	5.1(2)	8.3(2)	1.1(3)	1.4(3)	1.4(3)				
127	9.8(1)	7.0(2)	7.8(2)	7.8(2)						
128	1.1(2)	1.9(2)	1.9(2)							
129	3.3(0)	3.8(0)	4.2(0)	4.4(0)	4.4(0)	4.4(0)				
130M	1.3(0)	1.3(0)								
130	1.7(-1)	1.7(-1)								
131	8.6(1)	8.8(2)	1.9(3)	2.0(3)	2.0(3)					
TE-127M	1.3(1)	1.5(2)	3.8(2)	5.1(2)	6.4(2)	6.4(2)				
127	3.8(0)	5.4(0)	5.4(0)							
129M	3.8(1)	3.3(2)	7.1(2)	8.7(2)	9.4(2)	9.4(2)				
129	3.5(-1)	3.5(-1)								
131M	1.1(3)	4.3(4)	1.1(5)	1.2(5)	1.2(5)					
132	7.0(4)	1.8(5)	2.0(5)	2.0(5)						
133M	1.1(3)	4.0(3)	4.0(3)							
I-131	4.3(4)	4.4(5)	9.3(5)	1.0(6)	1.0(6)					
132	5.3(3)	5.4(3)								
133	5.8(4)	1.6(5)	1.6(5)							
134	9.3(2)	9.3(2)								
135	2.4(4)	3.0(4)	3.0(4)							
CS-134	1.7(2)	2.0(3)	8.0(3)	1.4(4)	3.6(4)	3.9(4)	3.9(4)			
136	2.0(2)	2.0(3)	5.0(3)	5.9(3)	6.1(3)	6.1(3)				
137	1.0(2)	1.2(3)	5.1(3)	9.2(3)	2.5(4)	2.7(4)	2.7(4)			
138	5.3(0)	5.3(0)								
BA-139	6.5(0)	6.5(0)								
140	1.1(2)	6.3(2)	1.1(3)	1.2(3)	1.3(3)					
LA-140	2.4(2)	1.2(3)	1.2(3)							
141	1.3(-1)	7.1(-1)	7.6(-1)	7.8(-1)	8.1(-1)	8.1(-1)				
142	3.3(0)	3.3(0)								
CE-141	1.5(1)	1.3(2)	1.4(2)	1.4(2)	1.5(2)	1.5(2)				
143	4.0(1)	1.8(2)	1.8(2)							
144	9.0(0)	8.2(1)	1.1(2)	1.5(2)	5.3(2)	1.3(3)	1.3(3)			
PR-143	1.5(-1)	1.4(0)	3.8(0)	4.8(0)	5.1(0)	5.1(0)				
145	3.2(-2)	3.7(-2)	3.7(-2)							
ND-147	2.5(1)	2.1(2)	2.2(2)	2.2(2)	2.2(2)					
PM-147	1.3(-2)	1.3(-1)	6.2(-1)	1.3(0)	1.1(1)	1.3(2)	1.4(2)	1.4(2)		
149	1.7(0)	9.9(0)	1.0(1)	1.0(1)						
NP-239 B	1.4(-1)	6.9(-1)	8.1(-1)	8.1(-1)						
239 A	3.0(-7)	1.2(-5)	8.4(-5)	1.9(-4)	1.9(-3)	7.8(-2)	2.0(-1)	3.3(-1)	4.6(-1)	5.9(-1)
PU-238	7.1(0)	7.3(1)	3.4(2)	7.4(2)	7.4(3)	2.9(5)	7.4(5)	1.2(6)	1.6(6)	1.9(6)
239	6.6(0)	6.9(1)	3.2(2)	6.9(2)	6.9(3)	2.9(5)	7.6(5)	1.2(6)	1.7(6)	2.2(6)
240	6.6(0)	6.9(1)	3.2(2)	6.9(2)	6.9(3)	2.9(5)	7.6(5)	1.2(6)	1.7(6)	2.2(6)
241 B	6.8(-3)	7.1(-2)	3.3(-1)	7.1(-1)	7.0(0)	2.2(2)	4.4(2)	5.8(2)	6.6(2)	7.1(2)
241 A	1.9(-5)	1.2(-3)	2.3(-2)	1.0(-1)	6.7(0)	2.5(3)	1.1(4)	2.2(4)	3.5(4)	4.8(4)
AM-241	1.3(2)	1.4(3)	6.5(3)	1.4(4)	1.1(5)	1.2(6)	2.5(6)	3.7(6)	4.8(6)	6.0(6)
CM-242	1.4(2)	1.5(3)	6.8(3)	1.4(4)	6.1(4)	8.5(4)	9.1(4)	9.6(4)	1.0(5)	1.1(5)
244	1.4(2)	1.4(3)	6.9(3)	1.5(4)	1.2(5)	1.1(6)	1.8(6)	2.3(6)	2.7(6)	2.9(6)

Table G

Doses to Organs

1015023

DOSE IN RADS PER CURIE INHALED SIZE 1.0UM ORGAN: RED BONE MARROW

NUCLIDE	TIME: 1 D	7 D	30 D	60 D	1 Y	10 Y	20 Y	30 Y	40 Y	50 Y
NA-24	3.7(2)	6.7(2)	6.7(2)							
SR-88	3.1(2)	3.5(3)	1.0(4)	1.3(4)	1.3(4)	1.3(4)				
89	1.4(0)	1.4(0)								
89	1.0(0)	1.6(0)	3.3(0)	4.5(0)	5.5(0)	5.5(0)				
SR-89	2.8(2)	3.6(3)	1.2(4)	1.8(4)	3.2(4)	3.2(4)				
90	1.7(2)	5.1(3)	2.5(4)	5.0(4)	2.8(5)	1.6(6)	2.3(6)	2.6(6)	2.7(6)	2.8(6)
91	1.6(2)	2.6(2)	3.2(2)	3.7(2)	4.9(2)	4.9(2)				
92	8.6(1)	9.2(1)	9.2(1)							
Y-90	6.3(0)	3.3(1)	4.1(1)	4.1(1)						
91	4.1(0)	4.0(1)	1.6(2)	2.9(2)	6.9(2)	7.1(2)	7.1(2)			
93	6.6(0)	9.4(0)	9.4(0)							
ZR-95	6.1(1)	4.0(2)	1.0(3)	1.8(3)	4.5(3)	4.6(3)	4.6(3)			
97	1.2(2)	2.4(2)	2.4(2)							
NB-95	6.2(1)	3.8(2)	8.0(2)	1.1(3)	1.5(3)	1.5(3)				
97	3.3(0)	3.3(0)								
MO-99	2.9(1)	1.4(2)	1.5(2)	1.5(2)						
TC-99M	5.6(0)	6.2(0)	6.2(0)							
RU-103	4.1(1)	2.6(2)	5.6(2)	7.9(2)	1.1(3)	1.1(3)				
105	1.5(1)	1.8(1)	1.8(1)							
106	2.2(1)	2.1(2)	6.2(2)	1.0(3)	3.4(3)	5.8(3)	5.8(3)			
RH-105	6.3(0)	2.0(1)	2.0(1)							
SB-125	3.9(1)	3.0(2)	8.4(2)	1.3(3)	2.0(3)	2.0(3)				
127	7.7(1)	4.2(2)	5.4(2)	5.4(2)						
128	1.1(2)	1.4(2)	1.4(2)							
129	4.0(0)	4.5(0)	4.9(0)	5.1(0)	5.1(0)	5.1(0)				
130M	8.8(0)	8.8(0)								
130	1.7(-1)	1.7(-1)								
131	9.4(-1)	1.0(0)	1.1(0)	1.2(0)						
TE-127M	1.8(1)	2.3(2)	8.3(2)	1.4(3)	3.6(3)	3.9(3)	3.9(3)			
127	5.5(0)	8.0(0)	8.0(0)							
129M	4.8(1)	4.6(2)	1.4(3)	2.0(3)	2.6(3)	2.6(3)				
129	7.5(-1)	7.5(-1)								
131M	1.2(2)	3.4(2)	3.6(2)	3.6(2)						
132	5.7(2)	1.5(3)	1.7(3)	1.7(3)						
133M	4.2(0)	5.0(0)	5.0(0)							
I-131	1.9(1)	7.0(1)	1.2(2)	1.3(2)	1.3(2)					
132	1.6(1)	1.6(1)								
133	1.9(1)	3.0(1)	3.0(1)							
134	6.8(0)	6.8(0)								
135	2.7(1)	2.8(1)	2.8(1)							
CS-134	2.1(2)	2.1(3)	8.3(3)	1.5(4)	3.8(4)	4.0(4)	4.0(4)			
136	2.6(2)	2.2(3)	5.5(3)	6.5(3)	6.7(3)	6.7(3)				
137	1.2(2)	1.3(3)	5.2(3)	9.4(3)	2.6(4)	2.8(4)	2.8(4)			
138	5.3(0)	5.3(0)								
BA-139	9.1(0)	9.1(0)								
140	1.3(2)	1.6(3)	3.8(3)	4.4(3)	4.6(3)	4.6(3)				
LA-140	1.4(2)	4.2(2)	4.3(2)	4.3(2)						
141	1.6(-1)	4.7(-1)	8.3(-1)	1.1(0)	1.4(0)	1.4(0)				
142	1.3(1)	1.3(1)								
CE-141	1.2(1)	7.3(1)	1.5(2)	2.0(2)	2.5(2)	2.5(2)				
143	2.6(1)	7.5(1)	7.6(1)	7.6(1)						
144	6.3(0)	4.3(1)	1.2(2)	2.1(2)	9.0(2)	1.8(3)	1.8(3)			
PR-143	1.5(-1)	1.4(0)	3.8(0)	4.8(0)	5.1(0)	5.1(0)				
145	7.6(0)	8.7(0)	8.7(0)							
ND-147	1.8(1)	1.0(2)	1.6(2)	1.8(2)	1.8(2)	1.8(2)				
PM-147	4.9(-1)	5.1(0)	2.4(1)	5.1(1)	4.4(2)	4.9(3)	5.5(3)	5.5(3)		
149	3.9(0)	1.8(1)	2.0(1)	2.0(1)						
NP-239 B	1.1(0)	5.6(0)	6.5(0)	6.6(0)						
239 S	2.2(-6)	9.1(-5)	6.4(-4)	1.4(-3)	1.4(-2)	5.7(-1)	1.4(0)	2.3(0)	3.1(0)	3.8(0)
PU-238	5.3(1)	5.5(2)	2.6(3)	5.5(3)	5.5(4)	2.2(6)	5.2(6)	8.0(6)	1.0(7)	1.2(7)
239	4.9(1)	5.1(2)	2.4(3)	5.2(3)	5.2(4)	2.1(6)	5.4(6)	8.5(6)	1.1(7)	1.4(7)
240	5.0(1)	5.1(2)	2.4(3)	5.2(3)	5.2(4)	2.1(6)	5.4(6)	8.5(6)	1.2(7)	1.4(7)
241 B	5.1(-2)	5.3(-1)	2.5(0)	5.3(0)	5.2(1)	1.6(3)	3.2(3)	4.0(3)	4.5(3)	4.8(3)
241 S	1.4(-4)	8.9(-3)	1.7(-1)	7.6(-1)	5.0(1)	1.8(4)	7.5(4)	1.5(5)	2.3(5)	3.0(5)
AM-241	9.7(2)	1.0(4)	4.9(4)	1.1(5)	8.4(5)	8.9(6)	1.7(7)	2.5(7)	3.2(7)	3.8(7)
CM-242	1.1(3)	1.1(4)	5.1(4)	1.0(5)	4.5(5)	6.3(5)	6.7(5)	7.1(5)	7.3(5)	7.6(5)
244	1.0(3)	1.1(4)	5.2(4)	1.1(5)	8.7(5)	7.9(6)	1.3(7)	1.5(7)	1.8(7)	1.9(7)

1015024

DOSE IN RADS PER CURIE INHALED SIZE 1.00UM ORGAN: ENDOSTEAL CELLS

NUCLIDE \ TIME:	1 D	7 D	30 D	60 D	1 Y	10 Y	20 Y	30 Y	40 Y	50 Y
NA-24	3.5(2)	6.5(2)	6.5(2)							
RB-86	3.5(2)	4.1(3)	1.2(4)	1.5(4)	1.5(4)	1.5(4)				
88	1.2(0)	1.2(0)								
89	8.7(-1)	1.6(0)	3.5(0)	4.3(0)	6.0(0)	6.0(0)				
SR-89	2.3(2)	3.6(3)	1.2(4)	1.8(4)	3.2(4)	3.2(4)				
90	1.7(2)	5.1(3)	2.5(4)	5.0(4)	2.8(5)	1.6(6)	2.3(6)	2.5(6)	2.7(6)	2.8(6)
91	1.5(2)	2.4(2)	3.0(2)	3.6(2)	4.7(2)	4.8(2)				
92	1.2(2)	1.3(2)	1.3(2)							
Y-90	6.3(0)	3.3(1)	4.1(1)	4.1(1)						
91	4.9(0)	4.9(1)	2.0(2)	3.6(2)	8.6(2)	8.6(2)	8.8(2)			
93	5.7(0)	8.0(0)	8.0(0)							
ZR-95	4.0(1)	2.4(2)	7.5(2)	1.4(3)	3.6(3)	3.7(3)	3.7(3)			
97	8.8(1)	1.6(2)	1.6(2)							
NB-95	4.1(1)	2.3(2)	5.8(2)	8.3(2)	1.1(3)	1.1(3)				
97	2.7(0)	2.7(0)								
MO-99	2.1(1)	9.5(1)	1.1(2)	1.1(2)						
TC-99M	4.5(0)	5.0(0)	5.0(0)							
RU-103	2.7(1)	1.6(2)	4.1(2)	6.0(2)	8.5(2)	8.5(2)				
105	1.1(1)	1.3(1)	1.3(1)							
106	1.7(1)	1.7(2)	5.4(2)	9.1(2)	3.1(3)	5.3(3)	5.3(3)			
RH-105	4.3(0)	1.2(1)	1.3(1)							
SB-125	2.8(1)	2.2(2)	6.8(2)	1.0(3)	1.6(3)	1.6(3)				
127	5.8(1)	3.2(2)	4.2(2)	4.2(2)						
128	8.1(1)	1.0(2)	1.0(2)							
129	3.7(0)	4.1(0)	4.5(0)	4.7(0)	4.7(0)	4.7(0)				
130M	7.0(0)	7.0(0)								
130	1.5(-1)	1.5(-1)								
131	7.6(-1)	8.5(-1)	9.5(-1)	9.6(-1)	9.6(-1)					
TE-127M	1.7(1)	2.2(2)	8.1(2)	1.4(3)	3.6(3)	3. 3)	3.9(3)			
127	5.4(0)	7.9(0)	7.9(0)							
129M	4.5(1)	4.4(2)	1.3(3)	1.9(3)	2.6(3)	2.6(3)				
129	6.9(-1)	6.9(-1)								
131M	8.8(1)	2.4(2)	2.6(2)	2.6(2)						
132	5.4(2)	1.5(3)	1.8(3)	1.8(3)						
133M	3.4(0)	4.0(0)	4.0(0)							
I-131	1.5(1)	6.0(1)	1.1(2)	1.2(2)	1.2(2)					
132	1.3(1)	1.3(1)								
133	1.6(1)	2.4(1)	2.5(1)							
134	5.4(0)	5.4(0)								
135	2.1(1)	2.3(1)	2.3(1)							
CS-134	1.9(2)	1.5(3)	7.7(3)	1.4(4)	3.5(4)	3.7(4)	3.7(4)			
136	2.3(2)	2.0(3)	5.0(3)	5.9(3)	6.1(3)	6.1(3)				
137	1.1(2)	1.2(3)	5.0(3)	9.0(3)	2.4(4)	2.7(4)	2.7(4)			
138	5.3(0)	5.3(0)								
BA-139	9.1(0)	9.1(0)								
140	7.0(2)	7.1(3)	1.5(4)	1.8(4)	1.9(4)	1.9(4)				
LA-140	8.9(1)	2.4(2)	2.5(2)	2.5(2)						
141	1.4(-1)	3.0(-1)	5.9(-1)	8.0(-1)	1.0(0)	1.0(0)				
142	1.0(1)	1.0(1)								
CE-141	7.3(0)	4.0(1)	9.6(1)	1.4(2)	1.8(2)	1.8(2)				
143	1.7(1)	4.1(1)	4.2(1)	4.2(1)						
144	4.2(0)	2.7(1)	8.9(1)	1.7(2)	7.9(2)	1.6(3)	1.6(3)			
PR-143	1.5(-1)	1.4(0)	3.8(0)	4.8(0)	5.1(0)	5.1(0)				
145	7.6(0)	8.7(0)	8.7(0)							
ND-147	1.1(1)	5.7(1)	1.0(2)	1.1(2)	1.2(2)	1.2(2)				
PM-147	6.1(-1)	6.4(0)	3.0(1)	6.3(1)	5.4(2)	6.1(3)	6.9(3)	6.9(3)		
149	3.8(1)	1.8(2)	2.0(2)	2.0(2)						
NP-239 B	1.3(1)	6.7(1)	7.8(1)	7.8(1)						
239 A	2.8(-5)	1.1(-3)	8.0(-3)	1.8(-2)	1.8(-1)	7.1(0)	1.8(1)	2.9(1)	3.8(1)	4.8(1)
PU-238	6.6(2)	6.9(3)	3.2(4)	6.9(4)	6.9(5)	2.7(7)	6.6(7)	1.0(8)	1.3(8)	1.6(8)
239	6.2(2)	6.4(3)	3.0(4)	6.5(4)	6.5(5)	2.6(7)	6.7(7)	1.1(8)	1.4(8)	1.8(8)
240	6.2(2)	6.4(3)	3.0(4)	6.5(4)	6.5(5)	2.6(7)	6.7(7)	1.1(8)	1.4(8)	1.8(8)
241 B	6.4(-1)	6.7(0)	3.1(1)	6.7(1)	6.5(2)	2.0(4)	3.9(4)	5.1(4)	5.7(4)	6.0(4)
241 A	1.8(-3)	1.1(-1)	2.2(0)	9.5(0)	6.3(2)	2.3(5)	9.4(5)	1.8(6)	2.8(6)	3.8(6)
AM-241	1.2(4)	1.3(5)	6.1(5)	1.3(6)	1.1(7)	1.1(8)	2.2(8)	3.1(8)	4.0(8)	4.8(8)
CM-242	1.4(4)	1.4(5)	6.4(5)	1.3(6)	5.7(6)	7.9(6)	8.4(6)	8.8(6)	9.2(6)	9.5(6)
244	1.3(4)	1.3(5)	6.5(5)	1.4(6)	1.1(7)	9.8(7)	1.6(8)	2.0(8)	2.3(8)	2.4(8)

1015025

DOSE IN RADS PER CURIE INHALED SIZE 1.0UM ORGAN: LOWER LARGE INTESTINE

NUCLIDE \ TIME:	1 D	7 D	30 D	60 D	1 Y	10 Y	20 Y	30 Y	40 Y	50 Y
NA-24	4.1(2)	7.3(2)	7.3(2)							
RB-86	4.6(2)	2.4(3)	5.1(3)	6.2(3)	6.5(3)	6.5(3)				
88	4.0(-1)	4.0(-1)								
89	6.6(-1)	1.0(0)	1.7(0)	2.1(0)	2.6(0)	2.6(0)				
SR-89	3.6(3)	1.2(4)	1.2(4)	1.3(4)	1.3(4)					
90	2.1(3)	1.1(4)	1.2(4)	1.3(4)	1.6(4)	1.8(4)	1.8(4)			
91	1.7(3)	2.4(3)	2.4(3)							
92	1.2(3)	1.2(3)	1.2(3)							
Y-90	7.4(3)	4.6(4)	4.6(4)							
91	5.8(3)	5.2(4)	5.4(4)	5.4(4)	5.4(4)	5.4(4)				
93	3.6(3)	7.7(3)	7.7(3)							
ZR-95	1.5(3)	1.3(4)	1.4(4)	1.4(4)	1.4(4)	1.4(4)				
97	6.4(3)	2.0(4)	2.0(4)							
NB-95	7.6(2)	6.7(3)	6.9(3)	6.9(3)	7.0(3)	7.0(3)				
97	7.3(0)	7.3(0)								
MO-99	3.3(3)	2.1(4)	2.1(4)							
TC-99M	3.6(0)	4.5(0)	4.5(0)							
RU-103	1.2(3)	1.0(4)	1.0(4)							
105	4.8(2)	1.1(3)	1.1(3)							
106	1.3(4)	1.2(5)	1.2(5)	1.3(5)	1.3(5)	1.4(5)	1.4(5)			
RH-105	1.0(3)	5.0(3)	5.0(3)							
SB-125	8.7(2)	8.2(3)	9.1(3)	9.8(3)	1.1(4)	1.1(4)				
127	3.7(3)	2.7(4)	2.7(4)							
128	1.1(3)	2.0(3)	2.0(3)							
129	4.1(2)	5.2(2)	5.2(2)							
130M	2.0(0)	2.0(0)								
130	6.5(-1)	6.5(-1)								
131	9.6(-1)	1.3(0)	1.3(0)							
TE-127M	1.6(3)	1.8(4)	2.0(4)	2.1(4)	2.2(4)	2.2(4)				
127	4.3(2)	8.4(2)	8.4(2)							
129M	4.1(3)	3.7(4)	3.9(4)	4.0(4)	4.1(4)	4.1(4)				
129	5.1(0)	5.1(0)								
131M	2.3(3)	1.0(4)	1.0(4)							
132	1.2(3)	6.0(3)	6.2(3)	6.2(3)						
133M	1.2(1)	2.3(1)	2.3(1)							
I-131	1.0(2)	2.7(2)	2.7(2)							
132	1.4(1)	1.4(1)								
133	1.4(2)	2.3(2)	2.3(2)							
134	2.3(0)	2.3(0)								
135	6.2(1)	7.1(1)	7.1(1)							
CS-134	3.3(2)	2.7(3)	1.0(4)	1.8(4)	4.4(4)	4.7(4)	4.7(4)			
136	3.4(2)	2.7(3)	6.6(3)	7.7(3)	8.0(3)	8.0(3)				
137	2.5(2)	1.8(3)	6.0(3)	1.1(4)	2.8(4)	3.1(4)	3.1(4)			
138	6.0(0)	6.0(0)								
BA-139	5.3(1)	5.3(1)								
140	2.4(3)	8.3(3)	8.8(3)	9.0(3)	9.0(3)					
LA-140	4.7(3)	2.4(4)	2.4(4)							
141	5.7(2)	7.2(2)	7.2(2)							
142	3.8(1)	3.8(1)								
CE-141	1.7(3)	1.5(4)	1.5(4)							
143	3.0(3)	1.5(4)	1.5(4)							
144	1.3(4)	1.2(5)	1.2(5)	1.2(5)	1.2(5)	1.3(5)				
PR-143	2.9(3)	2.5(4)	2.5(4)							
145	9.9(2)	1.4(3)	1.4(3)							
ND-147	2.6(3)	2.1(4)	2.2(4)							
PM-147	6.0(2)	5.5(3)	5.6(3)	5.6(3)	6.0(3)	6.3(3)	6.3(3)			
149	2.9(3)	1.7(4)	1.7(4)							
NP-239 B	1.0(3)	6.0(3)	6.0(3)							
239 A	2.6(-5)	5.9(-4)	6.1(-4)	6.2(-4)	7.1(-4)	8.6(-4)	8.6(-4)			
PU-238	5.4(2)	5.0(3)	5.1(3)	5.1(3)	5.5(3)	6.1(3)	6.1(3)			
239	5.1(2)	4.7(3)	4.8(3)	4.8(3)	5.1(3)	5.7(3)	5.7(3)			
240	5.1(2)	4.7(3)	4.8(3)	4.8(3)	5.1(3)	5.7(3)	5.7(3)			
241 B	5.3(1)	4.8(2)	4.9(2)	5.0(2)	5.3(2)	5.8(2)	5.8(2)			
241 A	1.8(-3)	5.3(-2)	5.9(-2)	6.7(-2)	3.6(-1)	3.0(0)	3.1(0)	3.1(0)		
AM-241	4.4(2)	4.3(3)	4.7(3)	4.9(3)	5.4(3)	5.4(3)				
CM-242	4.8(2)	4.8(3)	5.1(3)	5.4(3)	5.7(3)	5.7(3)				
244	4.6(2)	4.6(3)	4.9(3)	5.2(3)	5.7(3)	5.7(3)				

1015026

DOSE IN RADS PER CURIE INHALED SIZE 1.0UM ORGAN: LUNGS

NUCLIDE \ TIME:	1 D	7 D	30 D	60 D	1 Y	10 Y	20 Y	30 Y	40 Y	50 Y
NA-24	3.9(3)	4.5(3)	4.5(3)							
RB-86	5.3(3)	8.8(3)	1.1(4)	1.3(4)	1.3(4)					
88	5.2(2)	5.2(2)								
89	2.2(2)	2.2(2)								
SR-89	4.5(3)	6.8(3)	7.3(3)	7.5(3)	7.8(3)	7.6(3)				
90	2.3(3)	4.6(3)	5.7(3)	6.5(3)	9.8(3)	1.2(4)	1.2(4)			
91	3.4(3)	3.6(3)	3.6(3)							
92	2.6(3)	2.7(3)								
Y-90	1.1(4)	3.0(4)	3.4(4)	3.4(4)						
91	7.8(3)	3.7(4)	1.2(5)	2.0(5)	3.6(5)	3.7(5)				
93	8.1(3)	9.6(3)	9.6(3)							
ZR-95	2.0(3)	9.7(3)	3.5(4)	6.4(4)	1.5(5)	1.5(5)				
97	1.1(4)	1.6(4)	1.6(4)							
NB-95	1.0(3)	4.8(3)	1.5(4)	2.2(4)	3.1(4)	3.1(4)				
97	5.8(2)	5.8(2)								
MO-99	4.9(3)	1.4(4)	1.6(4)	1.6(4)						
TC-99M	1.1(2)	1.2(2)	1.2(2)							
RU-103	1.6(3)	7.6(3)	2.4(4)	3.7(4)	5.4(4)	5.4(4)				
105	1.8(3)	2.1(3)	2.1(3)							
106	1.9(4)	9.1(4)	3.3(5)	6.2(5)	2.5(6)	3.9(6)	3.9(6)			
RH-105	1.7(3)	3.5(3)	3.6(3)	3.6(3)						
SB-125	1.6(3)	8.1(3)	2.7(4)	4.5(4)	8.3(4)	6.4(4)	6.4(4)			
127	7.1(3)	2.4(4)	3.1(4)	3.1(4)						
128	3.4(3)	3.9(3)	3.9(3)							
129	2.7(3)	2.7(3)	2.8(3)	2.8(3)						
130M	7.3(2)	7.3(2)								
130	6.2(2)	6.2(2)								
131	5.5(2)	5.5(2)								
TE-127M	2.5(3)	1.7(4)	5.6(4)	8.7(4)	1.3(5)	1.3(5)				
127	1.4(3)	1.6(3)	1.6(3)							
129M	7.3(3)	3.5(4)	9.6(4)	1.3(5)	1.5(5)	1.5(5)				
129	5.5(2)	5.5(2)								
131M	5.0(3)	1.1(4)	1.2(4)	1.2(4)						
132	1.9(3)	5.4(3)	6.4(3)	6.4(3)						
133M	1.1(3)	1.2(3)	1.2(3)							
I-131	1.6(3)	2.3(3)	2.3(3)	2.3(3)						
132	9.5(2)	9.5(2)								
133	2.9(3)	3.4(3)	3.4(3)							
134	5.4(2)	5.4(2)								
135	1.6(3)	1.7(3)								
CS-134	2.0(3)	4.6(3)	1.0(4)	1.7(4)	3.8(4)	4.0(4)	4.0(4)			
136	2.0(3)	4.4(3)	7.4(3)	8.3(3)	8.5(3)	8.5(3)				
137	2.3(3)	4.3(3)	9.1(3)	1.2(4)	2.8(4)	3.0(4)	3.0(4)			
138	5.5(2)	5.5(2)								
BA-139	9.2(2)	9.2(2)								
140	2.5(3)	3.8(3)	4.3(3)	4.4(3)	4.4(3)					
LA-140	7.1(3)	1.6(4)	1.6(4)	1.6(4)						
141	3.3(3)	3.3(3)	3.4(3)	3.5(3)	3.6(3)	3.6(3)				
142	1.5(3)	1.5(3)								
CE-141	2.3(3)	1.0(4)	3.1(4)	4.6(4)	6.2(4)	6.2(4)				
143	4.7(3)	1.0(4)	1.3(4)	1.4(4)	1.4(4)					
144	1.7(4)	8.2(4)	3.0(5)	5.6(5)	2.1(6)	2.9(6)	2.9(6)			
PR-143	4.0(3)	1.7(4)	3.9(4)	4.7(4)	4.9(4)	4.9(4)				
145	3.3(3)	3.5(3)	3.5(3)							
ND-147	3.5(3)	1.5(4)	3.1(4)	3.6(4)	3.8(4)	4.0(4)	4.0(4)			
PM-147	8.1(2)	3.9(3)	1.5(4)	2.8(4)	1.3(5)	2.8(5)	2.9(5)			
149	4.3(3)	1.1(4)	1.2(4)	1.2(4)						
NP-239 B	1.5(3)	3.8(3)	4.2(3)	4.2(3)						
239 A	2.3(-3)	4.7(-2)	2.8(-1)	5.9(-1)	3.2(0)	1.1(1)	1.3(1)	1.4(1)	1.5(1)	1.6(1)
PU-238	7.3(4)	3.5(5)	1.3(6)	2.6(6)	1.3(7)	4.5(7)	5.0(7)	5.3(7)	5.6(7)	5.8(7)
239	6.8(4)	3.3(5)	1.2(6)	2.4(6)	1.2(7)	4.3(7)	4.9(7)	5.2(7)	5.6(7)	6.0(7)
240	6.8(4)	3.3(5)	1.2(6)	2.4(6)	1.2(7)	4.3(7)	4.9(7)	5.2(7)	5.6(7)	6.0(7)
241 B	7.1(1)	3.4(2)	1.3(3)	2.5(3)	1.2(4)	3.9(4)	4.1(4)	4.2(4)	4.3(4)	4.3(4)
241 A	1.5(-1)	4.9(0)	8.3(1)	3.2(2)	9.6(3)	1.8(5)	2.8(5)	3.6(5)	4.6(5)	5.6(5)
AM-241	7.0(4)	3.4(5)	1.1(6)	1.9(6)	3.4(6)	3.4(6)				
CM-242	7.8(4)	3.7(5)	1.2(6)	1.9(6)	2.9(6)	2.9(6)				
244	7.4(4)	3.6(5)	1.2(6)	1.9(6)	3.5(6)	3.6(6)				

1015027

DOSE IN RADS PER CURIE INHALED SIZE 1.0UM ORGAN: LIVER

NUCLIDE	TIME: 1 D	7 D	30 D	60 D	1 Y	10 Y	20 Y	30 Y	40 Y	50 Y
NA-24	3.3(2)	5.4(2)	5.4(2)							
RB-86	1.3(2)	1.5(3)	4.2(3)	5.3(3)	5.6(3)	5.6(3)				
88	1.4(0)	1.4(0)								
89	1.6(0)	1.8(0)	2.5(0)	3.0(0)	3.4(0)	3.4(0)				
SR-89	1.1(2)	5.0(2)	9.5(2)	1.2(3)	1.5(3)	1.5(3)				
90	5.9(1)	5.7(2)	1.6(3)	2.4(3)	5.7(3)	8.0(3)	8.1(3)	8.1(3)		
91	1.5(2)	1.8(2)	1.9(2)	1.9(2)						
92	8.3(1)	8.4(1)	8.4(1)							
Y-90	6.3(0)	3.3(1)	4.1(1)	4.1(1)						
91	5.1(0)	5.0(1)	2.0(2)	3.6(2)	8.6(2)	8.9(2)	8.9(2)			
92	7.8(0)	1.0(1)	1.0(1)							
ZR-95	7.9(1)	4.1(2)	1.5(3)	2.9(3)	7.6(3)	7.8(3)	7.8(3)			
97	1.5(2)	2.3(2)	2.3(2)							
NB-95	8.1(1)	3.9(2)	1.1(3)	1.7(3)	2.3(3)	2.3(3)				
97	6.2(0)	6.2(0)								
MO-99	2.7(1)	9.7(1)	1.1(2)	1.1(2)						
TC-99M	6.4(0)	7.0(0)	7.0(0)							
RU-103	5.5(1)	2.8(2)	8.5(2)	1.3(3)	1.9(3)	1.9(3)				
105	2.5(1)	2.8(1)	2.8(1)							
106	3.5(1)	3.5(2)	1.2(3)	2.1(3)	7.0(3)	1.2(4)	1.2(4)			
RH-105	8.4(0)	2.2(1)	2.3(1)	2.3(1)						
SB-125	8.9(1)	8.6(2)	3.0(3)	4.5(3)	6.9(3)	6.9(3)				
127	2.4(2)	1.6(3)	2.2(3)	2.3(3)						
128	2.3(2)	2.9(2)	2.9(2)							
129	2.7(1)	3.1(1)	3.5(1)	3.6(1)	3.6(1)	3.6(1)				
130M	1.7(1)	1.7(1)								
130	8.5(-1)	8.5(-1)								
131	2.2(0)	2.2(0)	2.2(0)							
TE-127M	3.7(1)	4.2(2)	1.2(3)	1.7(3)	2.1(3)	2.1(3)				
127	1.3(1)	1.8(1)	1.8(1)							
129M	1.0(2)	9.7(2)	2.2(3)	2.7(3)	3.0(3)	3.0(3)				
129	1.6(0)	1.6(0)								
131M	1.8(2)	4.3(2)	4.6(2)	4.6(2)						
132	6.0(2)	1.6(3)	1.8(3)	1.8(3)						
133M	7.8(0)	8.8(0)	8.8(0)							
I-131	2.5(1)	4.2(1)	5.1(1)	5.2(1)	5.2(1)					
132	2.9(1)	2.9(1)								
133	2.8(1)	3.4(1)	3.4(1)							
134	1.3(1)	1.3(1)								
135	4.2(1)	4.4(1)	4.4(1)							
CS-134	2.7(2)	2.3(3)	9.0(3)	1.6(4)	4.0(4)	4.3(4)	4.3(4)			
136	3.3(2)	2.4(3)	6.0(3)	7.0(3)	7.2(3)	7.2(3)				
137	1.4(2)	1.3(3)	5.4(3)	9.8(3)	2.6(4)	2.9(4)	2.9(4)			
138	5.3(0)	5.3(0)								
BA-139	6.5(0)	6.5(0)								
140	9.2(1)	4.8(2)	9.2(2)	1.0(3)	1.1(3)					
LA-140	2.2(2)	5.6(2)	5.9(2)	5.9(2)						
141	6.1(0)	6.9(0)	8.6(0)	9.9(0)	1.2(1)	1.2(1)				
142	2.6(1)	2.6(1)								
CE-141	1.9(1)	1.3(2)	4.6(2)	7.2(2)	1.1(3)	1.1(3)				
143	4.7(1)	1.2(2)	1.6(2)	1.7(2)	1.8(2)					
144	7.0(1)	7.1(2)	3.2(3)	6.6(3)	4.2(4)	1.1(5)	1.1(5)			
PR-143	1.5(1)	1.4(2)	3.9(2)	4.8(2)	5.1(2)	5.1(2)				
145	5.1(0)	5.9(0)	5.9(0)							
ND-147	3.1(1)	2.0(2)	4.7(2)	5.5(2)	5.9(2)	6.9(2)	9.2(2)	9.2(2)		
PM-147	2.0(0)	2.1(1)	9.7(1)	2.1(2)	1.8(3)	2.0(4)	2.2(4)	2.3(4)		
149	1.1(1)	5.0(1)	5.8(1)	5.8(1)						
NP-239 B	3.8(0)	2.0(1)	2.3(1)	2.3(1)						
239 A	7.3(-6)	3.0(-4)	2.1(-3)	4.7(-3)	4.7(-2)	1.8(0)	4.4(0)	6.7(0)	8.6(0)	1.0(1)
PU-238	1.8(2)	1.8(3)	8.6(3)	1.8(4)	1.8(5)	6.9(6)	1.6(7)	2.3(7)	2.9(7)	3.4(7)
239	1.6(2)	1.7(3)	8.0(3)	1.7(4)	1.7(5)	6.8(6)	1.6(7)	2.5(7)	3.2(7)	3.8(7)
240	1.7(2)	1.7(3)	8.1(3)	1.7(4)	1.7(5)	6.8(6)	1.7(7)	2.5(7)	3.2(7)	3.8(7)
241 B	1.7(-1)	1.8(0)	9.3(0)	1.8(1)	1.7(2)	5.2(3)	9.8(3)	1.2(4)	1.3(4)	1.4(4)
241 A	4.7(-4)	2.9(-2)	5.8(-1)	2.5(0)	1.7(2)	5.8(4)	2.3(5)	4.2(5)	6.1(5)	7.8(5)
AM-241	3.2(3)	3.4(4)	1.6(5)	3.5(5)	2.8(6)	2.8(7)	5.2(7)	7.1(7)	8.9(7)	1.0(8)
CM-242	3.6(3)	3.7(4)	1.7(5)	3.4(5)	1.5(6)	2.1(6)	2.2(6)	2.3(6)	2.3(6)	2.4(6)
244	3.4(3)	3.6(4)	1.7(5)	3.7(5)	2.9(6)	2.5(7)	3.9(7)	4.7(7)	5.2(7)	5.5(7)

1015028

DOSE IN RADS PER CURIE INHALED SIZE 1.0UM ORGAN: OVARIES

NUCLIDE	TIME: 1 D	7 D	30 D	60 D	1 Y	10 Y	20 Y	30 Y	40 Y	50 Y
NA-24	2.5(2)	4.9(2)	4.9(2)							
RB-86	1.3(2)	1.5(3)	4.2(3)	5.2(3)	5.5(3)	5.5(3)				
88	2.9(-1)	2.9(-1)								
89	1.9(-1)	4.3(-1)	1.1(0)	1.6(0)	2.0(0)	2.0(0)				
SR-89	1.1(2)	5.0(2)	9.5(2)	1.2(3)	1.5(3)	1.5(3)				
90	5.3(1)	5.7(2)	1.6(3)	2.4(3)	5.7(3)	8.0(3)	8.1(3)	8.1(3)		
91	1.5(2)	1.9(2)	1.9(2)	1.9(2)						
92	7.3(1)	7.5(1)	7.5(1)							
Y-90	1.2(-1)	6.3(-1)	7.8(-1)	7.8(-1)						
91	6.2(-1)	5.5(0)	8.8(0)	1.2(1)	2.2(1)	2.3(1)	2.3(1)			
93	3.8(0)	7.7(0)	7.7(0)							
ZR-95	1.1(2)	1.0(3)	1.1(3)	1.3(3)	1.7(3)	1.7(3)				
97	1.8(2)	5.3(2)	5.3(2)							
NB-95	1.1(2)	9.8(2)	1.1(3)	1.1(3)	1.2(3)	1.2(3)				
97	5.7(-1)	5.7(-1)								
MO-99	3.9(1)	2.6(2)	2.6(2)							
TC-99M	1.7(0)	2.0(0)	2.0(0)							
RU-103	7.0(1)	6.1(2)	7.0(2)	7.5(2)	8.1(2)	8.1(2)				
105	1.2(1)	2.0(1)	2.0(1)							
106	3.5(1)	3.6(2)	6.5(2)	9.0(2)	2.3(3)	4.1(3)	4.1(3)			
RH-105	1.0(1)	4.7(1)	4.8(1)							
SB-125	5.2(1)	5.1(2)	8.3(2)	1.1(3)	1.4(3)	1.4(3)				
127	9.8(1)	7.0(2)	7.8(2)	7.8(2)						
128	1.1(2)	1.9(2)	1.9(2)							
129	3.3(0)	3.8(0)	4.2(0)	4.4(0)	4.4(0)	4.4(0)				
130M	1.3(0)	1.3(0)								
130	1.7(-1)	1.7(-1)								
131	1.9(-1)	2.0(-1)	2.0(-1)							
TE-127M	1.3(1)	1.5(2)	3.8(2)	5.1(2)	6.4(2)	6.4(2)				
127	3.8(0)	5.4(0)	5.4(0)							
129M	3.8(1)	3.3(2)	7.1(2)	8.7(2)	9.4(2)	9.4(2)				
129	3.5(-1)	3.5(-1)								
131M	1.3(2)	5.2(2)	5.3(2)							
132	5.5(2)	1.5(3)	1.7(3)	1.7(3)						
133M	9.9(-1)	1.3(0)	1.3(0)							
I-131	4.5(0)	1.1(1)	1.2(1)	1.2(1)						
132	2.8(0)	2.8(0)								
133	4.7(0)	6.9(0)	6.9(0)							
134	1.0(0)	1.0(0)								
135	6.3(0)	6.9(0)	6.9(0)							
CS-134	1.7(2)	2.0(3)	8.0(3)	1.4(4)	3.6(4)	3.9(4)	3.9(4)			
136	2.0(2)	2.0(3)	5.0(3)	5.9(3)	6.1(3)	6.1(3)				
137	1.0(2)	1.2(3)	5.1(3)	9.2(3)	2.5(4)	2.7(4)	2.7(4)			
138	(0)	5.3(0)								
BA-139	6.[0)	6.5(0)								
140	1.1(2)	6.3(2)	1.1(3)	1.2(3)	1.3(3)					
LA-140	2.4(2)	1.2(3)	1.2(3)							
141	1.3(-1)	7.1(-1)	7.6(-1)	7.8(-1)	8.1(-1)	8.1(-1)				
142	3.3(0)	3.3(0)								
CE-141	1.5(1)	1.3(2)	1.4(2)	1.4(2)	1.5(2)	1.5(2)				
143	4.0(1)	1.8(2)	1.8(2)							
144	9.0(0)	8.2(1)	1.1(2)	1.5(2)	5.3(2)	1.3(3)	1.3(3)			
PR-143	1.5(-1)	1.4(0)	3.8(0)	4.8(0)	5.1(0)	5.1(0)				
145	3.2(-2)	3.7(-2)	3.7(-2)							
ND-147	2.5(1)	2.1(2)	2.2(2)	2.2(2)	2.2(2)					
PM-147	1.3(-2)	1.3(-1)	6.2(-1)	1.3(0)	1.1(1)	1.3(2)	1.4(2)	1.4(2)		
149	1.7(0)	9.9(0)	1.0(1)	1.0(1)						
NP-239 B	1.4(-1)	6.9(-1)	8.1(-1)	8.1(-1)						
239 A	3.0(-7)	1.2(-5)	8.4(-5)	1.9(-4)	1.9(-3)	7.8(-2)	2.0(-1)	3.3(-1)	4.6(-1)	5.9(-1)
PU-238	7.1(0)	7.3(1)	3.4(2)	7.4(2)	7.4(3)	2.9(5)	7.4(5)	1.2(6)	1.6(6)	1.9(6)
239	6.6(0)	6.9(1)	3.2(2)	6.9(2)	6.9(3)	2.9(5)	7.6(5)	1.2(6)	1.7(6)	2.2(6)
240	6.6(0)	6.9(1)	3.2(2)	6.9(2)	6.9(3)	2.9(5)	7.6(5)	1.2(6)	1.7(6)	2.2(6)
241 B	6.8(-3)	7.1(-2)	3.3(-1)	7.1(-1)	7.0(0)	2.2(2)	4.4(2)	5.8(2)	6.6(2)	7.1(2)
241 A	1.9(-5)	1.2(-3)	2.3(-2)	1.0(-1)	6.7(0)	2.5(3)	1.1(4)	2.2(4)	3.5(4)	4.8(4)
AM-241	1.3(2)	1.4(3)	6.5(3)	1.4(4)	1.1(5)	1.2(6)	2.5(6)	3.7(6)	4.8(6)	6.0(6)
CM-242	1.4(2)	1.5(3)	6.8(3)	1.4(4)	6.1(4)	8.5(4)	9.1(4)	9.6(4)	1.0(5)	1.1(5)
244	1.4(2)	1.4(3)	6.9(3)	1.5(4)	1.2(5)	1.1(6)	1.8(6)	2.3(6)	2.7(6)	2.9(6)

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DOSE IN RADS PER CURIE INHALED SIZE 1.0UM ORGAN: TESTES

NUCLIDE	TIME: 1 D	7 D	30 D	60 D	1 Y	10 Y	20 Y	30 Y	40 Y	50 Y
NA-24	1.9(2)	3.8(2)	3.8(2)							
RB-86	1.3(2)	1.5(3)	4.2(3)	5.3(3)	5.6(3)	5.6(3)				
88	2.0(-1)	2.0(-1)								
89	9.3(-2)	3.3(-1)	1.0(0)	1.5(0)	1.9(0)	1.9(0)				
SR-89	1.1(2)	5.0(2)	9.5(2)	1.2(3)	1.5(3)	1.5(3)				
90	5.9(1)	5.7(2)	1.6(3)	2.4(3)	5.7(3)	8.0(3)	8.1(3)	8.1(3)		
91	1.1(2)	1.4(2)	1.4(2)	1.5(2)						
92	6.4(1)	6.5(1)	6.5(1)							
Y-90	1.2(-1)	6.3(-1)	7.8(-1)	7.8(-1)						
91	1.4(-1)	1.4(0)	4.3(0)	7.4(0)	1.7(1)	1.7(1)	1.7(1)			
93	5.2(-1)	9.9(-1)	9.9(-1)							
ZR-95	1.3(1)	1.2(2)	1.5(2)	1.8(2)	2.9(2)	2.9(2)	2.9(2)			
97	2.2(1)	6.2(1)	6.2(1)							
NB-95	1.4(1)	1.2(2)	1.6(2)	1.8(2)	2.1(2)	2.1(2)				
97	1.5(-1)	1.5(-1)								
MO-99	4.6(0)	2.9(1)	3.0(1)	3.0(1)						
TC-99M	9.1(-1)	1.1(0)	1.1(0)							
RU-103	1.1(1)	1.2(2)	2.1(2)	2.6(2)	3.2(2)	3.2(2)				
105	1.8(0)	3.0(0)	3.0(0)							
106	9.7(0)	1.4(2)	4.1(2)	6.5(2)	2.0(3)	3.6(3)	3.6(3)			
RH-105	1.6(0)	8.0(0)	8.1(0)	8.1(0)						
SB-125	1.4(1)	1.6(2)	4.5(2)	6.4(2)	9.0(2)	9.0(2)				
127	3.2(1)	2.6(2)	3.3(2)	3.3(2)						
128	2.7(1)	4.3(1)	4.3(1)							
129	2.7(0)	3.1(0)	3.5(0)	3.6(0)	3.7(0)	3.7(0)				
130M	4.0(-1)	4.0(-1)								
130	7.3(-2)	7.3(-2)								
131	1.0(-1)	1.1(-1)								
TE-127M	1.0(1)	1.2(2)	3.5(2)	4.8(2)	6.0(2)	6.1(2)				
127	3.6(0)	5.2(0)	5.2(0)							
129M	2.9(1)	2.5(2)	6.2(2)	7.7(2)	8.4(2)	8.4(2)				
129	3.2(-1)	3.2(-1)								
131M	4.0(1)	1.4(2)	1.4(2)							
132	5.6(2)	1.5(3)	1.7(3)	1.7(3)						
133M	4.6(-1)	4.9(-1)	4.9(-1)							
I-131	5.7(-1)	1.3(0)	1.5(0)	1.5(0)						
132	4.8(-1)	4.8(-1)								
133	6.7(-1)	9.8(-1)	9.8(-1)							
134	2.0(-1)	2.0(-1)								
135	1.1(0)	1.2(0)	1.2(0)							
CS-134	1.8(2)	2.2(3)	9.1(3)	1.6(4)	4.1(4)	4.4(4)	4.4(4)			
136	2.0(2)	2.1(3)	5.6(3)	6.6(3)	6.8(3)	6.8(3)				
137	1.0(2)	1.3(3)	5.5(3)	9.9(3)	2.7(4)	2.9(4)	2.9(4)			
138	5.3(0)	5.3(0)								
BA-139	6.5(0)	6.5(0)								
140	7.8(1)	4.7(2)	9.0(2)	1.0(3)	1.0(3)					
LA-140	2.8(1)	1.3(2)	1.3(2)							
141	6.6(-2)	1.3(-1)	1.4(-1)	1.5(-1)	1.7(-1)	1.7(-1)				
142	7.1(-1)	7.1(-1)								
CE-141	1.4(0)	1.3(1)	1.6(1)	1.8(1)	2.1(1)	2.1(1)				
143	4.1(0)	1.9(1)	1.9(1)							
144	1.5(0)	1.4(1)	4.0(1)	7.3(1)	4.3(2)	1.1(3)	1.1(3)			
PR-143	1.5(-1)	1.4(0)	3.6(0)	4.8(0)	5.1(0)	5.1(0)				
145	3.2(-2)	3.7(-2)	3.7(-2)							
ND-147	2.7(0)	2.2(1)	2.5(1)	2.5(1)	2.6(1)	2.9(1)	2.9(1)			
PM-147	1.3(-2)	1.3(-1)	6.2(-1)	1.3(0)	1.1(1)	1.3(2)	1.4(2)	1.4(2)		
149	2.4(-1)	1.3(0)	1.4(0)	1.4(0)						
NP-239 B	1.4(-1)	6.9(-1)	8.1(-1)	8.1(-1)						
239 A	3.0(-7)	1.2(-5)	8.4(-5)	1.9(-4)	1.9(-3)	7.8(-2)	2.0(-1)	3.3(-1)	4.6(-1)	5.9(-1)
PU-238	7.1(0)	7.3(1)	3.4(2)	7.4(2)	7.4(3)	2.9(5)	7.4(5)	1.2(6)	1.6(6)	1.9(6)
239	6.6(0)	6.9(1)	3.2(2)	6.9(2)	6.9(3)	2.9(5)	7.6(5)	1.2(6)	1.7(6)	2.2(6)
240	6.6(0)	6.9(1)	3.2(2)	6.9(2)	6.9(3)	2.9(5)	7.6(5)	1.2(6)	1.7(6)	2.2(6)
241 B	6.8(-3)	7.1(-2)	3.3(-1)	7.1(-1)	7.0(0)	2.2(2)	4.4(2)	5.8(2)	6.6(2)	7.1(2)
241 A	1.9(-5)	1.2(-3)	2.3(-2)	1.0(-1)	6.7(0)	2.5(3)	1.1(4)	2.2(4)	3.5(4)	4.8(4)
AM-241	1.3(2)	1.4(3)	6.5(3)	1.4(4)	1.1(5)	1.2(6)	2.5(6)	3.7(6)	4.5(6)	5.3(6)
CM-242	1.4(2)	1.5(3)	6.8(3)	1.4(4)	6.1(4)	8.5(4)	9.1(4)	9.6(4)	1.0(5)	1.1(5)
244	1.4(2)	1.4(3)	6.9(3)	1.5(4)	1.2(5)	1.1(6)	1.8(6)	2.3(6)	2.7(6)	2.9(6)

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