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Calculation of *Dangerous Values* for Radionuclides Considered by the IAEA Code of Conduct

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ABSTRACT

The D-value or *dangerous quantity* system was designed by the International Commission for Radiological Protection for the determination of source protection categories that can be used to reduce the likelihood of accidents, the consequences of which could result in harm to individuals or costly or expensive cleanup. The process includes multiple scenarios for exposure and two different approaches to the evaluation of detriment. This document provides an example calculation using ^{137}Cs to walk through the complex process of determining its D-value in the hopes of making the process easily understandable.

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NOMENCLATURE

Abbreviation	Definition
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
LET	Linear energy transfer
RBE	Relative biological effectiveness

1. INTRODUCTION

Radioactive sources, including sealed and unsealed sources, are used around the world for a variety of purposes and they incorporate a wide range of radionuclides and amounts of radioactive material. High activity sources, if not managed safely and securely, can cause severe deterministic effects to individuals in a short period of time. Accidents involving radioactive sources have occurred, some with serious—even lethal—consequences. The 1990s in particular saw a growing concern over radioactive materials and devices falling out of regulatory control and being used for malicious purposes [1]. Following an assessment of the major findings of the International Conference on the Safety of Radiation Sources and Security of Radioactive Materials, held in Dijon, France in 1998 [2], and in aftermath of 9/11, IAEA undertook a number of tasks to improve safety and security of radioactive sources around the world.

The first task was to categorize radioactive sources, "that could be relevant to decisions in both a retrospective application to bring sources under control and in a prospective sense to guide the application of the regulatory infrastructure [3]." The early development of a categorization scheme was three such categories based on amounts of radioactivity as used in particular applications. As a measure for identifying the quantity and type of radioactive material in terms of their potential to cause harm to human health, an operational definition of a dangerous source was needed [4]. The operational definition of a *dangerous source*, also known as *D-value*, is the quantity of radioactive material which, if uncontrolled, could lead to the death of an exposed individual or decrease that person's quality of life. The complete methodology for determination of D-values is found in the IAEA's *Dangerous Quantities of Radioactive Material (D-Values)*, referred to here by its' document number, EPR-D-Values 2006 [5].

D-values are calculated using two approaches which are known in the scientific community as the *expert* and *risk* approaches. Within these approaches, D-values are derived for non-dispersed (D_1-values) and for dispersed (D_2-values) radionuclides that may be important in the event of a nuclear or radiological emergency. The D_1-value accounts for two external exposure scenarios of the non-dispersed material and the D_2-value considers exposures that may result from the dispersion of the material. The recommended D-value for a radionuclide is established to be the most limiting (i.e., lowest value) of the two D_1 and D_2 values.

This report provides a detailed description of the approaches used to establish the D-values by demonstrating the D value calculation for ^{137}Cs. The report further evaluates and compares the recommended D-value of ^{137}Cs with that of other radionuclides.

All figures, equations, and tables in this document are extracted from EPR-D-Values-2006 [5]. As such, there will be no further citations in the text unless they refer to other documents.

2. SCENARIOS

2.1. Introduction to Scenarios

This section discusses various scenarios that were taken into consideration while calculating the D-value using both *expert* and *risk* approaches. As stated in Section 1, the exposure scenarios are classified into two groups: non-dispersed and dispersed. The non-dispersed radioactive material refers to an unshielded and encapsulated radioactive source, leading to only external exposure scenarios. Dispersed radioactive material refers to disruption of sealed radioactive source resulting from leakage or other forms of dismantlement that can spread throughout the environment leading to both external and internal exposure scenarios.

2.2. Non-dispersed Scenarios

In determining the D_1-value for non-dispersed material, two hypothetical scenarios are considered. In both these scenarios the radioactive material is encapsulated and unshielded. The D_1-values are evaluated using both *risk* and *expert* approaches.

2.2.1. Scenario I: Pocket

The *Pocket* scenario assumes a person carrying an unshielded source in the pocket. The scenario calculates the amount of unshielded radioactive material which, if adjacent to the human body, would be considered dangerous as a source of local external exposure. Considering that is unreasonable to carry a mass of greater than or equal to 500 grams (g) in the pocket, the mass limit for *Pocket* scenario calculation was established as 500 g.

2.2.2. Scenario II: Room

Analysis of the *Room* scenario provides the amount of material that would be considered dangerous if such a source was left unshielded in the same room as the person for an extended period of time. The following assumptions were made in establishing the D_1-value for the *Room* scenario exposure pathway:

- The source is unshielded and encapsulated.
- The person was exposed over a period of 100 hours at a distance of 1 meter from the source.
- The mass limit is established as 1×10^6.
- The dose rate is 10 mGy/h.

2.3. Dispersed Scenarios

The methodology used for calculating the D_2-value includes the following four scenarios of exposure to dispersed radioactive material. Independent calculations for D_2 were simultaneously performed using both the *risk* and *expert* approaches.

2.3.1. Scenario III: Inhalation

Scenario III is the *Inhalation* scenario, which assumes internal exposure from inhalation of airborne material dispersed as a result of a fire or explosion. The calculations determine the amount of radioactive material that, if inhaled, can lead to permanent injury or death. Parameters include:

- The inhalation intake fraction, IF_H, defined as the amount of the respirable fraction assumed to be inhaled by the individual during an emergency, is assumed to be 1×10^{-3}.
- The person was assumed to be in a 300 m^3 room for 0.5 hour.
- The respirable intake fraction, F_{III}, which is the product of respirable release fraction of the initial activity, RRF, and the inhalation intake fraction, IF_H, is assumed to be 1×10^{-4}.
- The mass limit was set as 1×10^6 g.

2.3.2. Scenario IV: Ingestion

Scenario IV, also referred to as the *Ingestion* scenario, assumes an inadvertent ingestion of radioactive material through handling of leaking radioactive source material and through consumption of radioactive-material contaminated water. The D_2-value for this scenario was estimated using the following assumptions:

- The radioactive material is 100% soluble in water.
- The radioactive material is thoroughly mixed in 1×10^{-6} l of water.
- The individual drinks 2 liters (L) of contaminated water for a continuous five day period.
- The ingestion intake fraction, F_{IV} is 1×10^{-5}, is used for both inadvertent ingestion and ingestion of contaminated water.
- The mass limit was set as 1×10^{-6} g.

2.3.3. Scenario V: Contamination

Scenario V, referred to as the *Contamination* scenario, is used to determine the amount of dispersible radioactive material due to contact irradiation of a local area of the skin that would be considered detrimental. Scenario V assumes the following:

- A fraction 1×10^{-2}, (F_V) of the radioactive material leaks from a source and uniformly contaminates a surface over an area of 1 m^2.
- Surface contamination leads to skin contamination at 10% of the surface value.
- Skin is exposed for 5 hours.
- The maximum thickness of uncontrolled contamination of the hand is assumed to be 0.1 $\mathrm{g/cm}^2$.
- The mass limit of dispersible material was set as 1×10^6 g.

2.3.4. Scenario VI: Immersion

Scenario VI, referred to as the *Immersion* scenario, determines the amount of radioactive noble gas that, if dispersed in a room, would be considered dangerous as a result of external exposure. Scenario VI assumes the following:

- The dilution of the gas due to air exchange is negated.
- The gas is uniformly dispersed in a 300 m^3 room.
- The person is exposed for 0.5 hours.
- The mass limit for dispersible material is set to 1×10^6 g.

3. THE APPROACHES

EPR-D-Values-2006 uses two different approaches, termed as *expert* and *risk* approaches, to calculate D-values. This section presents a detailed description of the algorithms used in the two approaches.

In the sections that follow, parameters with both superscripts and subscripts are provided. Superscripts are either E representing the *expert* approach or R representing the *risk* approach. Arabic numeral subscripts 1 and 2 represent non-dispersed scenarios and dispersed scenarios respectively. Roman numeral subscripts I through VI represent the specific scenarios as indicated. For example, the ${}^{E}D_1$ value is the activity of a radionuclide in a source, derived using the *expert* (E) approach, that if uncontrolled but not dispersed might result in an emergency that could reasonably be expected to cause severe deterministic effects and where I represents the scenario category— 1 for non-dispersed and 2 for dispersed.

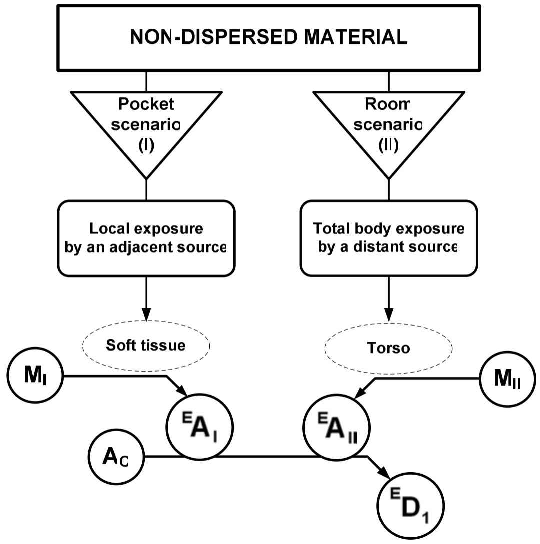

Figure 3-1 Visual representation of the *expert* approach calculation of D_1.

3.1. The *Expert* Approach

The *expert* approach for calculating the D-values was based on existing guidance, professional judgment and readily available data. This approach uses the term reference level to allude to the dose at which severe deterministic effects could occur. It uses the thoracic region of the respiratory tract as recommended by ICRP-66 as the target organ for the inhalation scenario and the basal membrane of skin as the target organ for the pocket scenario D-value calculations [6].

3.1.1. $^{E}D_1$ Calculation

The algorithm to calculate the $^{E}D_1$-value is visually represented in Figure 3-1. It includes the two non-dispersed external exposure scenarios that involve local exposure from an adjacent source and a total body exposure from a distant source. This section demonstrates $^{E}D_1$-value calculations for both the ^{137}Cs *Pocket* and *Room* external exposure scenarios.

I, Pocket Scenario

The initial activity $^{E}A_{1,I}$, (Bq), which as per the *expert* approach, can cause severe deterministic effects in soft tissue for the Pocket scenario is given by:

$$^{E}A_{1,I} = \frac{1}{T_I * DF_{1,I}^{L+H}} RD_1^{L+H} \tag{1}$$

where:

Table 3-1 Parameters for scenarios used in developing D-values (EPR-D-Values Table 11).

Scenario		Parameter		
	Title	Symbol	Value	Definition
I	"Pocket"	T_I	3.6×10^4 s	Duration of exposure
		M_I	5×10^2 g	Mass Limit
II	"Room"	T_{II}	3.6×10^5 s	Duration of exposure
		M_{II}	1×10^6 g	Mass Limit
III	"Inhalation"	F_{III}	1×10^{-4}	Respirable Intake Fraction
		M_{III}	1×10^6 g	Mass Limit
IV	"Ingestion"	F_{IV}	1×10^{-5}	Ingestion intake fraction
		M_{IV}	1×10^6 g	Mass Limit
V	"Skin Contamination"	F_V	1×10^{-2}	Fraction of material dispersed
		S_V	1×10^4 cm^2	Area of contaminated surface
		R_V	1×10^{-1}	Ratio of skin to surface contamination
		T_V	1.8×10^4 s	Duration of exposure
		M_V	1×10^6 g	Mass Limit
VI	"Immersion"	F_{VI}	1	Fraction of material released into room
		V_{VI}	3×10^2 m^3	Volume of room
		T_{VI}	1.8×10^3 s	Duration of exposure
		M_{VI}	1×10^6 g	Mass Limit

T_I = is the duration of exposure for Scenario I and is given in Table 3-1.

$DF_{1,I}^{L+H}$ = the dose conversion factor for absorbed dose in soft tissue according to the pocket scenario, (Gy/(Bq-s)). For high LET, this factor is given in table 3-2 and for low LET it is numerically equal to the relative biological effectiveness (RBE)-weighted dose rate conversion factor $AF_{1,I}$ in Table 3-3.

$RD_1^{L+H} =$ = reference level of absorbed dose for the onset of severe deterministic health effects in soft tissue (Gy), and is given in Table 3-4.

The appropriate parameters for the pocket scenario with exposure to ^{137}Cs-137 are:

- $T_1 = 3.6 \times 10^4$ s

Table 3-2 Absorbed dose rate conversion factors for soft tissue and bone marrow for high LET (neutron) emitters (EPR-D-Values Table 13).

Radionuclide	Adjacent Source	Distance Source
	Soft tissue	Red marrow
	$\mathrm{DF}_{1,I}^{L+H}$	$\mathrm{DF}_{2,II}^{L+H}$
	(Gy/(Bq*s))	(Gy/(Bq*s))
Cf-252	3.0 E-14	3.0 E-17
^{239}Pu/^{9}Be	5.0 E-16	5.0 E-19
^{241}Am/^{9}Be	5.0 E-16	5.0 E-19

Table 3-3 RBE-weighted dose rate conversion factors for external exposure from low-LET emitters (EPR-D-Values Table 15) [5].

Radionuclides	Adjacent source	Distance source
	Soft tissue	Red marrow
	$AF_{1,I}$	$AF_{2,II}$
	((Gy-Eq)/ (Bq*s))	((Gy-Eq)/ (Bq*s))
^{137}Cs	5.9E-15	9.6E-18

Table 3-4 Reference levels used in the *expert* approach for the onset of severe deterministic effects from external exposure (EPR-D-Values Table 5).

Exposure pathway	Effect	Critical organ or tissue	Reference Level	
			Value (Gy)	Symbol
Soft tissue exposure to adjacent source	Necrosis of soft tissue	Soft tissue (Tissue 1)	25	RD_1^{L+H}
Contact exposure to surface contamination	Moist desquamation	Basal membrane of skin (Tissue 6E)	25	RD_{6E}^{L+H}
Total body exposure to a distant source or immersions	[any severe deterministic effect]	Torso (Tissue 7)	1	RD_7^{L+H}

- $DF_{1,I}^{L+H} = 5.9 \times 10^{-15} \ \frac{\text{Gy}}{(\text{Bq*s})}$
- $RD_1^{L+H} = 25$ Gy

Substituting these values into Equation 1 results in:

$$^{E}A_{1,I} = \frac{1}{(3.6 \times 10^{4}\ \text{s})(5.9 \times 10^{-15}\ \text{Gy/Bq*s})} (25\ \text{Gy})$$

$$^{E}A_{1,I} = 1.177 \times 10^{11}\ \text{Bq}$$

The mass (M) of ^{137}Cs with activity $^{E}A_{1,I}$ (g) is determined as follows:

$$M = \frac{^{E}A_{1,I}}{SA(\text{Bq/g})} = \frac{1.777 \times 10^{11}\ \text{Bq}}{3.22 \times 10^{12}\ \text{Bq/g}} = 0.3655\, g \tag{2}$$

where:

SA = *specific activity* of the radionuclide, radioactivity per unit mass.

At this point, the mass limit, M_I is considered:

$$^{E}A_{I} = \begin{cases} ^{E}A_{1,I} \ if\, M \leq M_{I} \\ \text{Unlimited, if } M > M_{I} \end{cases} \tag{3}$$

where:

M_I	=	mass limit for Scenario I and is given by table 3-1 as 500 g.

Since $M_I > M$

$$\boxed{^{E}A_{I} =^{E} A_{1,I} = 1.177 \times 10^{11} \ \text{Bq}}$$

II, Room Scenario

In accordance with scenario II, the initial activity in Bq that can cause severe deterministic health effects in the torso is given by:

$$^{E}A_{7,II} = \frac{1}{T_{II} * DF_{2,II}^{L+H}} RD_{7}^{L+H} \tag{4}$$

where:

T_{II}	=	duration of exposure for Scenario II, (s), given in Table 3-1,
DF_{7}^{L+H}	=	absorbed dose conversion factor for external exposure of the red marrow from a source 1 m from the body, (Gy/(Bq*s)). For high LET it is given in Table 3-2 and for low LET it is numerically equal to the RBE-weighted dose rate conversion factor $AF_{2,II}$ in Table 3-3, and
RD_{7}^{L+H}	=	reference level of absorbed dose for the onset of severe deterministic health effects in the torso from external exposure, (Gy), and is given in Table 3-4.

The values for the room scenario are:

- $T_{II} = 3.6 \times 10^{5}$ s
- $DF_{2,II}^{L+H} = 9.6 \times 10^{-18}$ Gy/(Bq * s)
- $RD_{7}^{L+H} = 1$ Gy

Substituting these values, the initial activity (Bq) of ^{137}Cs is calculated as follows:

$$^{E}A_{7,II} = \frac{1}{(3.6 \times 10^{5} \text{ s})(9.6 \times 10^{-18})(\text{Gy/Bq*s})} (1 \text{ Gy})$$

$$^{E}A_{7,II} = 2.8935 \times 10^{11} \text{ Bq}$$

The mass (M) of ^{137}Cs with activity $^{E}A_{7,II}$ (g) is calculated as follows:

$$M = \frac{^{E}A_{7,II}}{SA \text{ Bq/g}} = \frac{2.8935 \times 10^{11} \text{ Bq}}{3.22 \times 10^{12} \text{ Bq/g}} = 0.08986 \text{ g} \tag{5}$$

As with the pocket scenario, the mass limit is considered:

$$^{E}A_{II} = \begin{cases} ^{E}A_{7,II} \; if\, M \leq M_{II} \\ \text{Unlimited, if} M > M_{II} \end{cases} \tag{6}$$

where:

M_{II}	=	mass limit for scenario II (g) and is given by Table 3-1 as 1×10^{6}

Since $M_{II} > M$,

$$\boxed{^{E}A_{II} =^{E} A_{7,II} = 2.8935 \times 10^{11} \text{ Bq}}$$

Final $^{E}D_1$-Value

EPR-D-Values-2006 evaluates a criticality activity limit (A_c) for all radionuclides to ensure criticality is not a concern. As ^{137}Cs emits no neutrons and, therefore, criticality hazard is not a concern, this report assumes A_c as unlimited. Table A-6 lists the criticality limit converted to activity, A_c for radionuclides with an atomic number greater than 87.

Therefore, the $^{E}D_1$-value is established as the minimum value of the three activities $^{E}A_I$, $^{E}A_{II}$, and $^{E}A_c$ rounded down to one digit, and is given by:

$$\boxed{^{E}D_1 = \min\{^{E}A_I, ^{E}A_{II}, ^{E}A_C\} = {}^{E}A_I = 1 \times 10^{11} \text{ Bq} = 1 \times 10^{-1} \text{ TBq}}$$

3.1.2. $^{E}D_2$ Calculation

The $^{E}D_2$-value is the activity of a radionuclide in a source, derived using *expert* approach, that, if uncontrolled and dispersed, might result in an emergency that could reasonably be expected to cause severe deterministic effects.

In calculating the $^{E}D_2$ for dispersed material, the four scenarios of *Inhalation*, *Ingestion*, *Contamination*, and *Immersion* are considered. A visual representation of the method used to calculate the D_2-value is presented in Figure 3-2.

III, Inhalation scenario

In accordance with the *Inhalation* scenario, exposure of the red marrow (Tissue 2), thoracic region of the respiratory tract (Tissue 3E), and thyroid (Tissue 5) were considered. The initial activities of the three tissues, which, according to the *expert* approach can cause severe deterministic health effects, are presented as follows:

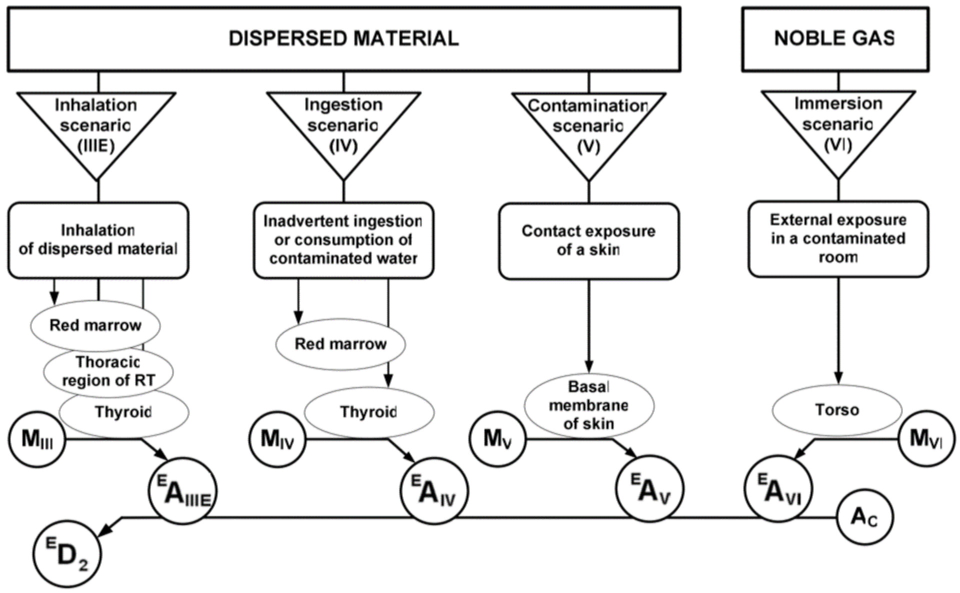

Figure 3-2 Visual representation of the *expert* Approach calculation of D_{II}

$$^{E}A_{2,IIIE} = \frac{1}{F_{III} * DF^{L+H}_{2,IIIE}(\Delta)} RD^{L+H}_{2}(\Delta) \tag{7}$$

$$^{E}A_{3E,IIIE} = \frac{1}{F_{III} * DF^{R}_{3E,IIIE}(\Delta)} RD^{R}_{3E}(\Delta) \tag{8}$$

$$^{E}A_{5E,IIIE} = \frac{1}{F_{III} * DF^{L}_{5E,IIIE}(\Delta)} RD^{L}_{5}(\Delta) \tag{9}$$

where:

F_{III}	=	respirable intake fraction, as found in Table 3-1.
DF	=	committed absorbed dose conversion factors for the respective internal exposure tissues 2, 3E, and 5 which are obtained from Table 3-5. The complete table from EPR-D-Values 2006 report is provided in Appendix A.
RD	=	reference level of the committed absorbed doses for internal exposure in tissues 2, 3E, and 5, respectively, for the onset of severe deterministic health effects, and is given in Table 3-6

On substituting the values from the above tables, the initial activity for the different tissues from internal exposure in accordance with the Scenario III is calculated as:

$$^{E}A_{2,IIIE} = \frac{1}{(1\times 10^{-4})(6.5\times 10^{-11}\ \text{Gy/Bq*s})}(1\,\text{Gy}) = 1.54\times 10^{14}\ \text{Bq}$$

Table 3-5 Inhalation committed absorbed dose and contamination absorbed dose conversion factors (EPR-D-Values Table 16).

Radionuclide	Inhalation			Contamination
	Red marrow	Respiratory tract Low LET	Respiratory tract High LET	Basal membrane of the skin
	$DF^{L+H}_{2,IIIE}$ (Δ)	$DF^{L}_{3E,IIIE}$ (Δ)	$DF^{HS}_{3E,IIIE}$ (Δ)	$DF^{L}_{6E,V}$
	(Gy/Bq)	(Gy/Bq)	(Gy/Bq)	(Gy/(Bq*s/cm^2))
^{137}Cs	6.5E-11	2.9E-09	NG	4.4E-10

Table 3-6 Reference levels used in the *expert* approach for the onset of severe deterministic effects from internal exposure (EPR-D-Values Table 6).

Exposure pathway	Effect	Organ or tissue	Characteristics of the radioactive material	Reference Level		
				Value (Gy)	Δ (d)	Symbol
Inhalation or ingestion	Haemato-poietic syndrome	Red marrow (Tissue 2)	Any radionuclide	1	2	RD^{L+H}_{2} (Δ)
Inhalation	Pneumonitis	Thoracic region of the respiratory tract (Tissue 3E)	Type S long-lived emitter of high LET radiation	25	365	RD^{HS}_{3E}(Δ)
			Type S long-lived emitter of ^{90}Sr (i.e. ^{90}Sr TiO_3)	40	365	RD^{LS}_{3E}(Δ)
			Other emitters of low LET radiation	6	2	RD^{L}_{5}(Δ)
Inhalation or ingestion	Hypo-thyroidism	Thyroid (Tissue 5)	Thyroid-seeking radionuclides	1	2	RD^{L+H}_{2}(Δ)

$$^{E}A_{3E,IIIE} = \frac{1}{(1\times10^{-4})(2.9\times10^{-9}\ \text{Gy/Bq*s})}(6\,\text{Gy}) = 2.07\times10^{13}\ \text{Bq}$$

$$^{E}A_{5E,IIIE} : N/A \text{ for this scenario}$$

Continuing with the minimum activity value, $^{E}A_{3E,III}$, the mass (M) of ^{137}Cs is calculated as follows:

$$M = \frac{^{E}A_{3E,IIIE}}{SA\,\text{Bq/g}} = \frac{2.069\times10^{13}\,\text{Bq}}{3.22\times10^{12}\,\text{Bq/g}} = 6.425\,\text{g} \tag{10}$$

Given that the mass limit (M_{III}) for the *Inhalation* scenario was established as 1×10^{6} g (obtained from Table 3-1, then $M_{III} > M$ and:

$$\boxed{^{E}A_{IIIE} = min\{^{E}A_{2,IIIE},^{E}A_{3E,IIIE},^{E}A_{5,IIIE}] = 2.07\times10^{13}\ \text{Bq}}$$

IV, Ingestion Scenario

Given that the absorbed dose conversion factors for the colon, red marrow, and thyroid per unit intake by ingestion are generally of the same order of magnitude as for inhalation, it can be inferred that the initial activity resulting from inhalation intake fraction of 10^{-4} of material dispersed (see Table 3-1 would be less than that calculated assuming an ingestion intake fraction of 10^{-5}. The expert analyst for EPR-D-Values 2006 did not perform the *Ingestion* calculations.

> As discussed in Appendix II, the expert did not explicitly consider ingestion since the inhalation scenario should be controlling in the case of intake. Furthermore, it was recognized that the threshold doses for onset of severe deterministic effects in the bone marrow and lung following inhalation would be considerably higher than those for the brief external exposure given in Table 7. However, based on an examination of studies available at the time (when *expert* approach calculations were being done), for low LET emitters, the intake associated with the action levels for the lung given in Table 7 (6 Gy in 2 days) were found to deliver a dose rate that was a reasonable limiting case for estimating the intake that was considered life threatening [5].

It can be deduced that the calculation of $^{E}D_{II}$-value for ^{137}Cs *Ingestion* scenario is below a significant threat threshold than the ^{137}Cs inhalation scenario and therefore the *Ingestion* scenario calculation is omitted and will not be further considered in this section.

V, Skin Contamination Scenario

The initial activity $^{E}A_{6E,V}$ (Bq) that according to the *expert* approach can cause severe deterministic health effects in Tissue 6E (basal membrane of the skin) in accordance with Scenario V is given below:

$$^{E}A_{6E,V} = \frac{S_V}{F_V * R_V * T_V * DF^{L}_{6E,V}} RD^{L+H}_{6E} \tag{11}$$

where:

S_V	=	area of the primary contaminated surface for scenario V given in Table 3-1,
F_V	=	fraction of material dispersed for scenario V given in Table 3-1,
R_V	=	ratio of skin to surface contamination for scenario V given in Table 3-1,
T_V	=	duration of exposure for scenario V given in Table 3-1,
$DF^{L}_{6E,V}$	=	absorbed dose conversion factor for contact exposure of the basal membrane of the skin given in Table 3-5, and
RD^{L+H}_{6E}	=	reference level of absorbed dose to the basal membrane of the skin for the onset of severe deterministic health effects given in Table 3-4.

On substituting the values, the initial activity for the *Contamination* scenario is calculated as follows:

$$^{E}A_{6E,V} = \frac{1\times10^{4}\ \text{cm}^2}{(1\times10^{-2})(1\times10^{-1})(1.8\times10^{4}\ \text{s})(4.4\times10^{-10}\ \text{Gy/(Bq*s/cm}^2))}(25\,\text{Gy})$$

$$^{E}A_{6E,V} = 3.16\times10^{13}\,\text{Bq}$$

The mass (M) of ^{137}Cs with activity $^{E}A_{6E,V}$ (g) is calculated as follows:

$$M = \frac{^{E}A_{6E,V}}{SA\,\text{Bq/g}} = \frac{3.16\times10^{13}\,\text{Bq}}{3.22\times10^{12}\,\text{Bq/g}} = 9.80\,\text{g} \tag{12}$$

The M_V value from Table 3-1 is 1×10^{6} g and $M_V > M$. Therefore,

$$\boxed{^{E}A_V = 3.16\times10^{13}\ \text{Bq}}$$

VI, Immersion Scenario

Dispersion of a radioactive source containing radioactive noble gas can lead to external exposure of the whole body from immersion in a local cloud. Since ^{137}Cs is not a noble gas, the *Immersion* scenario or Scenario VI does not apply and shall be omitted from the D-value calculations.

Final $^{E}D_2$-Value

The dose from criticality was considered in the final determination of $^{E}D_1$. EPR-D-Values 2006 also considers it here as a consideration for $^{E}D_2$. Since the likelihood of a criticality event from dispersed material, except for dispersed material dissolved in water, but the values in Table A-6 make no considerations for this fact. Therefore, the same values are used for both $^{E}D_1$ and $^{E}D_2$, making this a questionable practice.

To continue, criticality activity limit (A_C) for ^{137}Cs is assumed to be unlimited (Table A-6).

The $^{E}D_{II}$-value for ^{137}Cs is established as the minimum value of the three activities $^{E}A_{III}$, $^{E}A_V$, and $^{E}A_C$, and is given by:

$$\boxed{^{E}D_{II} = min\{^{E}A_{IIIE}, ^{E}A_V, ^{E}A_C\} = {}^{E}A_{IIIE} = 2.069 \times 10^{13} \text{ Bq}}$$

3.1.3. Final ^{E}D Value Determination

The ^{E}D-value obtained by means of *expert* approach is given by taking the limiting value of the ^{E}D$_I$ and ^{E}D$_{II}$-values, as shown below:

$$^{E}D_I = 1 \times 10^{-1} \text{ TBq}$$

$$^{E}D_{II} = 2.069 \times 10^{1} \text{ TBq}$$

$$^{E}D = min\{^{E}D_I, ^{E}D_{II}\} = ^{E}D_I = 1 \times 10^{-1} \text{ TBq} \tag{13}$$

$$\boxed{^{E}D = 1 \times 10^{-1} \text{ TBq}}$$

3.2. The *Risk* Approach

The *risk* approach used for calculating D-values is based on quantitative evaluation of the risk of developing severe deterministic effects. In the *risk* approach, the level of dose at which severe deterministic effects could occur is referred to as the threshold level. This level was estimated to be the dose at which the effect would be expected to occur in 5% of those exposed. This section demonstrates the D-value calculations for ^{137}Cs by independently solving for dispersed ($^{R}D_1$) and non-dispersed ($^{R}D_2$) scenarios using the *risk* approach.

For the *risk* approach, the IAEA adopts the concept of RBE[1]-weighted dose to describe deterministic effects that are described by clinical effects as recommended by the ICRP [7]. Units for this quantity are Gray-equivalent (Gy-Eq).

[1]RBE stands for *relative biological effectiveness* and refers to effects that manifest at a greater severity than expected by absorbed dose alone.

3.2.1. $^{R}D_1$ Calculation

$^{R}D_1$ is referred to as the D-value from two *non-dispersed scenarios*. The exposure schemes for determining $^{R}D_1$-value is visually represented in Figure 3-3.

The initial activity $^{R}A_{1,I}$, (Bq), which according to *risk* approach can cause severe deterministic health effects in Tissue 1 (soft tissue) is given in the equation below.

$$^{R}A_{1,I} = \frac{1}{T_I * AF_{1,I}} TD_1 \qquad (14)$$

where:

TD_I	=	threshold level of the RBE-weighted dose for the onset of severe deterministic effects in soft tissue, (Gy-Eq) given in Table 3-7.
$^{R}AF_{1,I}$	=	conversion factor for the RBE-weighted dose rate in soft tissue according to the pocket scenario, ((Gy-Eq)/(Bq*s)), and is given in Table 3-3. For reference, this is provided once more, with the full table available in Appendix A.
T_I	=	duration of exposure for Scenario I and is given in Table 3-1.

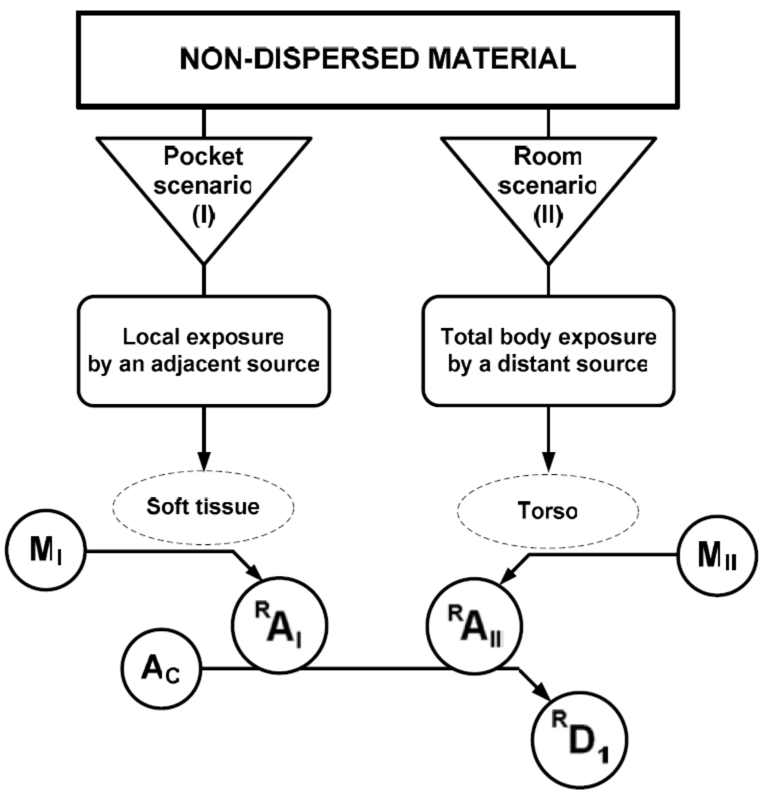

Figure 3-3 Visual representation of the *Risk* Approach calculation of D_I.

The scenarios used in the *risk* approach are the same as those in the *expert* approach. For more detail, see Section 3.1.

Table 3-7 Threshold levels of RBE-weighted dose from external exposure (EPR-D-Values Table 8).

Exposure	Effect	Organ or tissue	Threshold level	
			Value (Gy-Eq)	Symbol
Local exposure from an adjacent source	Necrosis of soft tissue	Soft tissue (Tissue 1)	25	TD_1
Contact exposure from surface contamination	Moist desquamation	Derma of skin (Tissue 6R)	10	TD_{6R}
Total body exposure from a distant source or immersion	[Composite of several tissues]	Torso (Tissue 7)	1	TD_7

I, Pocket Scenario

Substituting values:

$$T_1 = 3.6 \times 10^4\,\mathrm{s}$$

$$AF_{1,I} = 5.9 \times 10^{-15}\,\frac{\text{Gy-Eq}}{(\text{Bq*s})}$$

$$TD_1 = 25\,\text{Gy-Eq}$$

The initial activity, ${}^{R}A_{1,I}$ (Bq), for ^{137}Cs is calculated as follows:

$${}^{R}A_{1,I} = \frac{1}{(3.6 \times 10^4 s) * (5.9 \times 10^{-15})(\text{Gy-Eq/Bq*s})}(25\,\text{Gy-Eq})$$

$${}^{E}A_{1,I} = 1.177 \times 10^{11}\,\mathrm{Bq}$$

The Mass (M) of ^{137}Cs with activity ${}^{R}A_{1,I}$ is calculated as follows:

$$M = \frac{{}^{R}A_{1,I}}{SA\mathrm{Bq/g}} = \frac{1.777 \times 10^{11}\ \mathrm{Bq}}{3.22 \times 10^{12}\,\mathrm{Bq/g}} = 0.3655\,\mathrm{g} \tag{15}$$

As with the *expert* approach, the mass limit is then considered:

Table 3-8 RBE-weighted dose rate conversion factors for soft tissue and bone marrow for high LET (neutron) emitters (EPR-D-Values Table 14).

Neutron source	Origin of neutrons	Soft tissue			Red marrow		
		$AF^{L}_{1,I}$	$AF^{H}_{1,I}$	$AF_{1,I}$	$AF^{L}_{2,II}$	$AF^{H}_{2,II}$	$AF_{2,II}$
		((Gy-Eq)/ (Bq*s))	((Gy-Eq)/ (Bq*s))	((Gy-Eq)/ (Bq*s))	((Gy-Eq)/ (Bq*s))	((Gy-Eq)/ (Bq*s))	((Gy-Eq)/ (Bq*s))
^{248}Cm	SF	1.2E-14	1.4E-13	1.5E-13	2.1E-17	2.4E-16	2.6E-16
^{250}Cf	SF	1.1E-16	1.5E-15	1.6E-15	1.8E-19	2.4E-18	2.6E-18
^{252}Cf	SF	4.5E-15	6.0E-14	6.4E-14	7.5E-18	1.0E-16	1.1E-16
^{254}Cf	SF	1.6E-13	2.1E-12	2.3E-12	2.7E-16	3.5E-15	3.8E-15
^{239}Pu/^{9}Be	(α,n)	9.0E-18	4.0E-17	4.9E-17	1.5E-20	6.7E-20	8.2E-20
^{241}Am/^{9}Be	(α,n)	8.9E-17^{c}	5.0E-17	1.4E-16	9.4E-20^{c}	8.4E-20	1.8E-19

$$^{R}A_{I} = \begin{cases} ^{R}A_{1,I} \; if\, M \leq M_{I} \\ Unlimited \; if\, M > M_{I} \end{cases} \tag{16}$$

where:

M = mass of ^{137}Cs with activity $^{R}A_{1,I}$ (g) and
M_I = mass limit for Scenario I (g) and is given by table 3-1.

Since the mass limit M_I = 500 g, $M_I > M$ and

$$\boxed{^{R}A_{1,I} = 1.177 \times 10^{11}\,\mathrm{Bq}}$$

II, Room Scenario

Scenario II assumes irradiation of torso to have resulted from an exposure to a source at about 1 m from the body surface. The exposure to the red bone marrow was used to approximate the dose to all the organs in the torso. The initial activity $^{R}A_{7,II}$, (Bq), of ^{137}Cs which according to the *risk* approach can cause severe deterministic health effects in Tissue 7 (torso) as per Scenario II is given below:

$$^{R}A_{7,II} = \frac{1}{T_{II} * AF_{2,II}} TD_{7} \tag{17}$$

where:

TD_7 = threshold level of the RBE-weighted dose for the onset of severe deterministic health effects in the torso, (Gy-Eq), and is given in Table 3-7, and
$AF_{2,II}$ = RBE-weighted dose rate conversion factor for external exposure of the red marrow to a source at a distance of 1 m, ((Gy-Eq)/(Bq*s)), and is given in Tables 3-8 and 3-3.

T_{II}, the duration of exposure for Scenario II, (s), is given in Table 3-1.

Substituting table values into Equation 17:

$$T_{II} = 3.6 \times 10^5\,\text{s}$$

$$TD_7 = 9.6 \times 10^{-18}\,(\text{Gy-Eq}/(\text{Bq} * \text{s}))$$

$$AF_{2,II} = 1\,\text{Gy-Eq}$$

The initial activity, ${}^{R}A_{7,II}$ (Bq), for ^{137}Cs is calculated as follows:

$$^{R}A_{7,II} = \frac{1}{(3.6 \times 10^5\ \text{s}) * (9.6 \times 10^{-18}\ \text{Gy-Eq/Bq*s})}(1\,\text{Gy-Eq})$$

$$^{R}A_{7,II} = 2.8935 \times 10^{11}\,\text{Bq}$$

The Mass (M) of ^{137}Cs with activity ${}^{R}A_{7,II}$ is calculated as follows:

$$M = \frac{^{R}A_{7,II}}{SA\ \text{Bq/g}} = \frac{2.8935 \times 10^{11}\,\text{Bq}}{3.22 \times 10^{12}\,\text{Bq/g}} = 0.08986\,g \tag{18}$$

Since M_{II} is 1×10^6, $M_{II} > M$ and

$$\boxed{^{R}A_{II} = ^{R}A_{7,II} = 2.8935 \times 10^{11}\ \text{Bq}}$$

Final ${}^{R}D_1$ Value

Based on the Table A-6, presented in Appendix A, the criticality activity limit (A_C) for ^{137}Cs is assumed to be unlimited. Therefore, the ${}^{R}D_I$-value for ^{137}Cs is established as the minimum value of the three activities ${}^{R}A_I$, ${}^{R}A_{II}$, and ${}^{E}A_C$, and is given by

$$\boxed{^{R}D_1 = min\{^{R}A_I, ^{R}A_{II}, ^{R}A_C\} = {}^{R}A_I\ = 1.17 \times 10^{-1}\,\text{TBq}}$$

3.2.2. ${}^{R}D_2$ Calculation

The ${}^{R}D_2$-value is the activity of a radionuclide in a source that if dispersed and uncontrolled may result in severe deterministic health effects. In reference to the *risk* approach, the calculations of ${}^{R}D_2$-value include those four *dispersed* scenarios described in Section 2. The flowchart outlined in Figure 3-4 provides a visual representation of *risk* approach based D_2 calculation.

III, Inhalation Scenario

In the *risk* approach, scenario III (Inhalation), considers exposure of the red marrow (Tissue 2), the alveolar-interstitial (AI) region of the respiratory tract (Tissue 3R), the colon (Tissue 4) and the thyroid (Tissue 5), caused by inhalation of airborne radioactive material.

cause severe deterministic health effects in Tissue (T) of red marrow, AI region of respiratory tract, the colon and thyroid is given as follows:

$$ {}^{R}A_{T,IIIR} = \frac{1}{F_{III} * AF_{T,IIIR}(\Delta)} TD_T(\Delta) \tag{19} $$

where:

F_{III}	=	respirable intake fraction for Scenario III, as seen in Table 3-1,
$AF_{T,IIIR}(\Delta)$	=	committed RBE-weighted dose conversion factor for internal exposure of tissue T (in this case, 2, 3R, 4, or 5) due to inhalation intake, and is given in Table 3-10, and
$TD_{T(\Delta)}$	=	threshold level of the committed RBE-weighted dose in tissue from internal exposure, for the onset of severe deterministic health effects (Gy-Eq), and is given in Table 3-9.

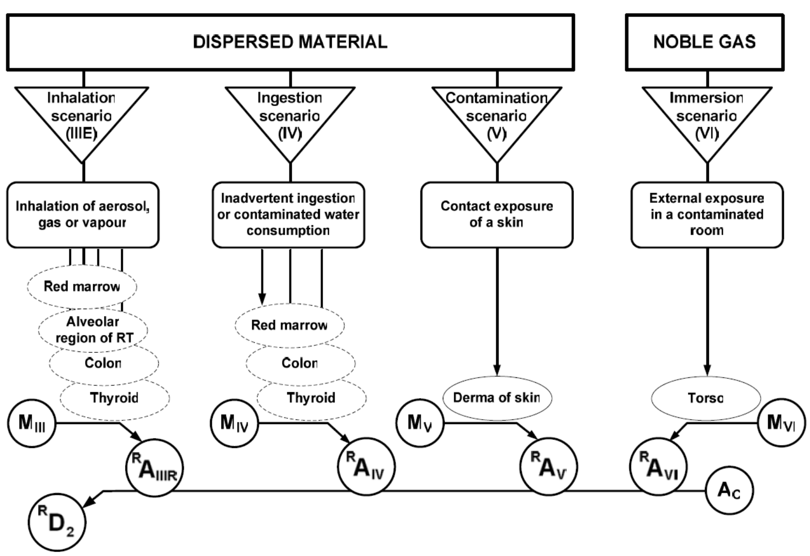

Figure 3-4 Visual representation of the *Risk* Approach calculation of D_{II}.

The initial activity ${}^{R}A_{III}$ (Bq), that according to the *risk* approach can

Table 3-9 Threshold levels of committed RBE-weighted dose from internal exposure (EPR-D-Values Table 9).

Exposure pathway	Effect	Target organ or tissue	Threshold level		
			Value (Gy-Eq)	Δ (d)	Symbol
Inhalation and ingestion	Haematopoietic syndrome	Red marrow (Tissue 2)	0.2	30	$TD_2(\Delta)$
			2		
Inhalation	Pneumonitis	Alveolar-interstitial region of respiratory tract (Tissue 3R)	30	30	$TD_{3R}(\Delta)$
Inhalation and ingestion	Gastrointestinal syndrome	Colon (Tissue 4)	20	30	$TD_4\Delta$
Inhalation and ingestion	Hypothyroidism	Thyroid (Tissue 5)	2	365[g]	$TD_5(\Delta)$

Table 3-10 Inhalation committed RBE-weighted dose conversion factors (EPR-D-Values Table 18). The full table can be found in the appendix (Table A-3).

Radionuclide[a]	Inhalation			
	Red marrow	AI Region	Colon	Thyroid
	$AF_{2,IIIR}$ (Δ)	$AF_{3R,IIIR}$ (Δ)	$AF_{4,IIIR}$ (Δ)	$AF_{5,IIIR}$ (Δ)
	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)
^{137}Cs	7.9E-10	7.6E-10	9.7E-10	NA

After value substitution, the Inhalation scenario initial activity calculations are given as below:

$$^{R}A_{2,IIIR} = \frac{1}{(1\times10^{-4})(7.9\times10^{-10}\text{ Gy-Eq/Bq})}(2\,\text{Gy-Eq}) = 2.532\times10^{13}\text{ Bq}$$

$$^{R}A_{3,IIIR} = \frac{1}{(1\times10^{-4})(7.6\times10^{-10}\text{ Gy-Eq/Bq})}(30\,\text{Gy-Eq}) = 3.947\times10^{14}\text{Bq}$$

$$^{R}A_{4,IIIR} = \frac{1}{(1\times10^{-4})(9.7\times10^{-10}\text{ Gy-Eq/Bq})}(20\,\text{Gy-Eq}) = 2.062\times10^{14}Bq$$

$^{R}A_{5,IIIR}$ (thyroid) is not applicable for this scenario.

M is the mass of ^{137}Cs with an activity of $^{R}A_{2,IIIR}$ for the *Inhalation* scenario and is calculated as below:

$$M = \frac{^{R}A_{2,IIIR}}{SA\text{ Bq/g}} = \frac{2.532\times10^{13}\,\text{Bq}}{3.22\times10^{12}\,\text{Bq/g}} = 7.863\,\text{g} \qquad (20)$$

The mass limit from Table 3-1 is 1×10^{6}. Therefore, $M_{III} > M$ and:

$$\boxed{^{R}A_{IIIR} = min\{^{R}A_{2,IIIR},^{R}A_{3,IIIR},^{R}A_{4,IIIR},^{R}A_{5,IIIR}] = 2.53\times10^{13}\text{ Bq}}$$

IV, Ingestion Scenario

Scenario IV considers exposure of the red marrow (Tissue 2), colon (Tissue 4), and thyroid (Tissue 5) by ingestion of dispersed radioactive material. The initial activity $^{R}A_{T,IV}$, (Bq), that as per *risk* approach can cause severe deterministic effects in tissue (T) is given by:

$$^{R}A_{T,IV} = \frac{1}{F_{IV} * AF_{T,IV}(\Delta)}TD_{T}(\Delta) \qquad (21)$$

For T = 2,4, and 5

where:

F_{IV}	=	ingestion intake fraction for scenario IV, and is given in Table 3-1.
$AF_{T,IV}(\Delta)$	=	committed RBE-weighted dose conversion factor for internal exposure of tissue T (2, 4, or 5) due to ingestion intake, given in Table 3-11, and
$TD_{T}(\Delta)$	=	threshold level of the committed RBE-weighted dose from internal exposure to tissue T and is given in Table 3-9.

Substituting table values into Equation 19, the initial activity for scenario III is determined:

Table 3-11 Inhalation committed RBE-weighted dose and contamination RBE-weighted dose conversion factors (EPR-D-Values Table 19). The complete table is presented in Appendix A (Table A-4).

Radionuclides	Inhalation			Contamination
	Red marrow	Colon	Thyroid	Derma of skin
	$AF_{2,IV}$ (Δ)	$AF_{4,IV}$ (Δ)	$AF_{5,IV}$ (Δ)	$AF_{6R,V}$
	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/(s*Bq/cm^2))
^{137}Cs	2.3E-09	2.9E-09	NA	1.4E-10

$$^{R}A_{2,IV} = \frac{1}{(1\times10^{-5})(2.9\times10^{-9}\text{Gy-Eq/Bq})}(2\,\text{Gy-Eq}) = 8.7\times10^{13}\,\text{Bq}$$

$$^{R}A_{4,IV} = \frac{1}{(1\times10^{-5})(2.9\times10^{-9}\ \text{Gy-Eq/Bq})}(20\,\text{Gy-Eq}) = 6.9\times10^{14}\,\text{Bq}$$

$^{R}A_{5,IV}$, dose to the thyroid is not applicable for this scenario since the thyroid is not a target organ for Cs.

M is the mass of ^{137}Cs with an activity of $^{R}A_{2,IV}$ for the ingestion scenario and is calculated as below:

$$M = \frac{^{R}A_{2,IV}}{SA\,\text{Bq/g}} = \frac{8.7\times10^{13}\,\text{Bq}}{3.22\times10^{12}\,\text{Bq/g}} = 27.01\,\text{g} \tag{22}$$

M_V, obtained from Table 3-1, is 1×10^{6} g; therefore $M_V > M$ and:

$$\boxed{^{R}A_{2,IV} = 8.7\times10^{13}\ \text{Bq}}$$

V, Skin contamination scenario

Scenario V or the *Contamination* scenario, assumes that the skin became contaminated due to a leaking source. The *risk* approach uses derma of the skin (300-500 µm under the surface) for the purposes of estimating severe deterministic effects. The initial activity $^{R}A_{6R,V}$, which according to the *risk* approach can cause severe deterministic health effects in Tissue 6R (derma of the skin) is given by:

$$^{R}A_{T,IV} = \frac{S_V}{F_V * R_V * T_V * AF_{6R,V}} TD_{6R} \tag{23}$$

where:

S_V	=	area of the primary contaminated surface for Scenario V, (cm^2), and is given in Table 3-1,
F_V	=	fraction of the radioactive material dispersed for Scenario V, and is given in Table 3-1,
R_V	=	ratio of skin to surface contamination for Scenario V, and is given in Table 3-1,
T_V	=	duration of exposure for Scenario V and is given in Table 3-1.
$AF_{6R,V}$	=	RBE-weighted dose rate conversion factor for contact exposure of the derma of the skin due to surface contamination, and is given in Table 3-11, and
TD_{6R}	=	threshold level of the RBE-weighted dose in the derma for the onset of severe deterministic health effects and is given in Table 3-7,

Using these values, the initial activity in the Contamination scenario can be solved for as follows:

$$^{R}A_{6R,V} = \frac{1\times10^{14}\ \text{cm}^2}{(1\times10^{-2})(1\times10^{-1})(1.8\times10^{4}\ \text{(Gy-Eq)/(s Bq/cm}^2))}(10\,\text{Gy-Eq}) \tag{24}$$

$$^{R}A_{6R,V} = 5.556\times10^{13}\,Bq \tag{25}$$

The M is the mass of ^{137}Cs with an activity of $^{R}A_{6R,V}$ for the contamination scenario and is calculated as below:

$$M = \frac{^{R}A_{6R,V}}{SA} = \frac{5.556\times10^{13}\,\text{Bq}}{3.22\times10^{12}\,\text{Bq/g}} = 17.26\,\text{g} \tag{26}$$

The mass limit M is shown in Table 3-1 to be $M_V = 1\times10^{6}$ g. Since $M_V > M$,

$$\boxed{^{R}A_{V} = ^{R}A_{6R,V} = 5.556\times10^{13}\ \text{Bq}}$$

VI, Immersion scenario

With the immersion scenario only pertaining to noble gases, this scenario does not apply to ^{137}Cs, and can therefore shall be omitted from the D-value consideration.

3.2.3. Final $^{R}D_2$ Value

The criticality activity limit (A_C) for ^{137}Cs is assumed to be unlimited. The $^{R}D_{II}$-value for ^{137}Cs is established as the smallest of the four activities $^{R}A_{IIIR}$, $^{R}A_{IV}$, $^{R}A_{V}$ and $^{R}A_{C}$, and is given by

$$\boxed{^{R}D_2 = min\{^{R}A_{IIIR}, ^{R}A_{IV}, ^{R}A_{V}, ^{R}A_{C}\} = ^{R}A_{IIIR} = 2.532\times10^{13}\,\text{Bq}}$$

In the preceding two subsections, the ${}^{R}\mathrm{D}_{I}$ and ${}^{R}\mathrm{D}_{II}$-values were calculated and displayed below.

$$^{R}D_{1} = 1 \times 10^{-1}\,\mathrm{TBq}$$

$$^{R}D_{2} = 2.532 \times 10^{1}\,\mathrm{TBq}$$

For ^{137}Cs,the ${}^{R}D$-value is the more limiting of the ${}^{R}\mathrm{D}_{1}$ and ${}^{R}\mathrm{D}_{2}$-values and was determined to be $1 \times 10^{-}1$ TBq.

$$^{R}D = min\{^{R}D_{1},^{R}D_{2}\} =^{R} D_{1} = 1 \times 10^{-1}\,\mathrm{TBq}$$

$$\boxed{^{R}D = 1 \times 10^{-1}\ \mathrm{TBq}}$$

3.3. Summary of *Expert* and *Risk* Approach Results.

Table 3-12 shows the individual results for each scenario under both *expert* and *risk* approaches. For both approaches, the D_1-value is limited by the *Pocket* scenario. Also, for both approaches, the D_2-value is limited by the *Inhalation* scenario. In both cases the tissue limiting the *Inhalation* scenario is the thoracic respiratory tract. The Scenario I values for both approaches is the same 0.118 TBq; therefore, the D-value is 0.1 TBq.

Table 3-12 Initial activity amounts (TBq) for both *expert* and *risk* approaches (NE refers to the scenario not being evaluated).

Scenario or D_N	Approach *Expert*	*Risk*
I	0.118	0.118
II	0.289	0.289
D_1	0.118	0.118
III	20.7	25.3
IV	N/E	87.0
V	31.6	55.6
VI	N/E	N/E
D_1	20.7	25.3
D	0.1	0.1

$$\boxed{D = 0.1\ \ \mathrm{TBq}}$$

4. D-VALUES AND LIMITING SCENARIOS FOR RADIONUCLIDES CONSIDERED IN THE IAEA CODE OF CONDUCT

The following table displays the D-values for and limiting scenarios for radionuclides explicitly called out in the IAEA Code of Conduct [1]. Those listed with an (R) designation were limited by the *risk* approach and the others by the *expert* approach. Note that the pocket scenario is limiting for the nine β/γemitters and inhalation for the six alpha emitters. For the pure β-emitting $^{90}Sr/^{90}Y$, inhalation is also limiting ostensibly because the radiation in question is not penetrating.

Table 4-1 D-values and associated limiting scenarios for radionuclides explicitly provided in the IAEA Code of Conduct [1]. RT refers to human respiratory tract.

	Category 1			Limiting Scenario
	1000xD (TBq)	D-Value	Limiting D	
^{241}Am	60	0.06	D_2	Inhalation (R), Thoracic RT
$^{241}Am/Be$	60	0.06	D_2	Inhalation (R), Thoracic RT, ^{241}Am only
^{252}Cf	20	0.02	D_1	Pocket
^{244}Cm	50	0.05	D_2	Inhalation (R), Thoracic RT
^{60}Co	30	0.03	D_1	Pocket
^{137}Cs	100	0.1	D_1	Pocket
^{153}Gd	1000	1	D_1	Pocket
^{192}Ir	80	0.08	D_1	Pocket
^{147}Pm	40000	40	D_2	Inhalation (R), Thoracic RT
^{238}Pu	60	0.06	D_2	Inhalation (R), Thoracic RT
$^{239}Pu/Be$	60	0.06	D_2	Inhalation (R), Thoracic RT, ^{239}Pu only
^{226}Ra	40	0.04	D_1	Pocket
^{75}Se-75	200	0.2	D_1	Pocket
$^{90}Sr/^{90}Y$	1000	1	D_1	Inhalation (R), Thoracic RT, ^{90}Sr only
^{170}Tm	20000	20	D_1	Pocket
^{169}Yb	300	0.3	D_1	Pocket

Many of the D-values differ simply due to the nature of their individual unique radioactive properties. Radionuclides with shorter half-lives or greater-energy radiations will accordingly have lower

Table 4-2 Limiting scenarios summary (EPR-D-Values Table 23).

Limited by developing severe deterministic effects in the organ or tissue:	Scenario					
	I	II	IIIR	IV	V	VI
Soft tissue	266					
Red marrow			27	1		0
AI region of respiratory tract			32			
Colon			0	0		
Thyroid			6	0		
Derma of skin					8	
Torso		5				
Limited by criticality	9					
Unlimited	15					
Total	369					

D-values. Also, alpha-emitting radionuclides tend to have much lower D_2 than D_1-values due to the complete absorption of typically 3–5 MeV of kinetic energy within the target tissue. There are two neutron sources represented, ^{241}Am/Be and ^{239}Pu/Be. In both cases, the dose rate from the neutron emission is inconsequential when compared to either the internal or external dose from the alpha and gamma emissions [8]. This is because the neutron-producing reactions are only a small fraction of the decays of either ^{241}Am or ^{239}Pu [9].

The design of the D-value system applies well to the safety theme of radioactive sources, especially when compared to accidents that have actually occurred. However, application to a security mission may be less appropriate, because physical and chemical properties do matter when considering dispersion of material. Table 4-2 below shows the limiting scenarios and tissues for 369 different radionuclides considered. Note that for D_1, 266 radionuclides are limited by the pocket scenario, the overwhelming limiting scenario, whereas five are limiting for room. The room scenario may be a more logical consideration for use for harm from an adversary.

5. SUMMARY

In this report, the process of calculating D-values was shown in depth and demonstrated through an example calculation of ^{137}Cs. The results were then compared to the D-values calculated for other radionuclides.

In Section 1, it was explained that the calculation can be accomplished using two different approaches, which are typically referred to as the *expert* and *risk* approaches within the scientific community. Within these two approaches, two D-values are calculated using similar equations, with the first D-value (displayed as D_1) taking into account two scenarios of exposure where the material is not dispersed, and with the second D-value (displayed as D_2) accounting for four different scenarios of exposure in which the material is dispersed. The actual D-value is the lowest of these two values (D_1 and D_2).

In Section 2, each of the six scenarios were provided in order to explain the assumptions made during the calculation of D-values. These scenarios are divided into two categories: Non-dispersed and dispersed. The first category, non-dispersed, contains two scenarios, *Pocket* and *Room*, which refer to situations in which an individual is exposed to unshielded but undispersed radioactive material located either in their pocket or within the room itself. The second category, dispersed, contains four scenarios, which are *Inhalation*, *Ingestion*, *Contamination*, and *Immersion*. In these situations, an individual is exposed to unshielded and dispersed radioactive material through either making contact with a contaminated surface or having the material enter the human body through those pathways. It should be noted that the *Immersion* scenario only applies to noble gases, and as a result, is often inapplicable to many calculations.

Section 3 introduced the two approaches, *expert* and *risk*, and briefly gave a description of the difference in calculation. This largely comes down to the fact that, in the *xpert* approach, the basal membrane of the skin is used and the reference dose level is the dose which does not affect exposed persons, whereas in the *risk* approach, the derma of the skin is used and the threshold dose level is the dose which only produces effects in 5% of the exposed persons.

Following the introduction and description of each respective approach, there followed a demonstration of the D-value calculation using the aforementioned approaches. This was accomplished by using the values for ^{137}Cs, provided by established standard values from the IAEA.

In Section 4, the D-values from both approaches and constituent scenario results provided. Values for those radionuclides explicitly provided in the IAEA Code of Conduct with limiting pathways were provided along with a discussion on the propriety of those pathways for adversarial use of such radiological sources.

REFERENCES

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APPENDIX A. NON-REDACTED TABLES

Below are the non-redacted tables of which portions are contained in this document. Footnotes are not included; the reader is directed to EPR-D-Values 2006 for that information.

Table A-1 RBE-weighted dose rate conversion factors for external exposure from low-LET emitters (EPR-D-Values 2006 Table 15).

Radionuclides[a]	Adjacent source	Distant source
	Soft tissue	Red marrow
	$AF_{1,I}$	$AF_{2,II}$
	((Gy-Eq)/ (Bq*s))	((Gy-Eq)/ (Bq*s))
H-3	7.6E-27	2.9E-29
Be-7	5.2E-16	8.3E-19
Be-10	2.4E-18	3.6E-21
C-11	1.1E-14	1.8E-17
C-14	1.6E-20	1.8E-23
N-13	1.1E-14	1.8E-17
F-18	1.1E-14	1.8E-17
Na-22	2.2E-14	3.7E-17
Na-24	3.6E-14	6.3E-17
Mg-28	3.0E-14	5.1E-17
Al-26	2.6E-14	4.3E-17
Si-31	5.2E-17	8.2E-20
Si-32+	5.2E-17	8.3E-20
P-32	5.2E-17	8.3E-20
P-33	9.3E-20	1.2E-22
S-35	1.9E-20	2.1E-23
Cl-36	6.4E-18	9.7E-21
Cl-38	1.4E-14	2.4E-17
Ar-37	0.0E+00	0.0E+00
Ar-39	2.0E-18	3.0E-21
Ar-41	1.3E-14	2.1E-17
K-40	1.5E-15	2.6E-18
K-42	3.1E-15	5.3E-18
K-43	1.0E-14	1.7E-17
Ca-41	0.0E+00	0.0E+00
Ca-45	1.1E-19	1.3E-22
Ca-47+	1.1E-14	1.9E-17
Sc-44	2.2E-14	3.6E-17
Sc-46	2.0E-14	3.4E-17
Sc-47	9.7E-16	1.4E-18
Sc-48	3.3E-14	5.6E-17
Ti-44+	2.3E-14	3.7E-17

Continuation of Table 15

Radionuclides[a]	Adjacent source	Distant Source
	Soft tissue	Red marrow
	$AF_{1,I}$ [b]	$AF_{2,II}$ [c]
	((Gy-Eq)/ (Bq*s))	((Gy-Eq)/ (Bq*s))
V-48	2.9E-14	4.9E-17
V-49	0.0E+00	0.0E+00
Cr-51	3.3E-16	5.1E-19
Mn-52	3.4E-14	5.8E-17
Mn-53	0.0E+00	0.0E+00
Mn-54	8.6E-15	1.4E-17
Mn-56	1.6E-14	2.8E-17
Fe-52+	3.2E-14	5.3E-17
Fe-55	0.0E+00	0.0E+00
Fe-59	1.2E-14	2.0E-17
Fe-60+	1.1E-14	1.9E-17
Co-55+	2.0E-14	3.3E-17
Co-56	3.4E-14	5.8E-17
Co-57	9.6E-16	1.4E-18
Co-58	1.0E-14	1.7E-17
Co-58m+	1.0E-14	1.7E-1
Co-60	2.4E-14	4.1E-17
Ni-59	0.0E+00	0.0E+00
Ni-63	2.3E-22	1.2E-25
Ni-65	5.4E-15	9.1E-18
Cu-64	2.0E-15	3.2E-18
Cu-67	1.0E-15	1.6E-18
Zn-65	5.8E-15	9.8E-18
Zn-69	8.3E-18	1.2E-20
Zn-69m+	4.4E-15	7.0E-18
Ga-67	1.4E-15	2.1E-18
Ga-68	1.0E-14	1.7E-17
Ga-72	2.6E-14	4.3E-17
Ge-68+	1.0E-14	1.7E-17
Ge-71	1.9E-23	4.9E-24
Ge-77+	1.1E-14	1.8E-17
As-72	1.9E-14	3.1E-17
As-73	1.9E-17	1.8E-20
As-74	8.0E-15	1.3E-17
As-76	4.7E-15	7.7E-18
As-77	9.2E-17	1.4E-19
Se-75	3.7E-15	5.8E-18
Se-79	2.2E-20	2.4E-23
Br-76	2.5E-14	4.2E-17

Continuation of Table 15

Radionuclides[a]	Adjacent source	Distant Source
	Soft tissue	Red marrow
	$AF_{1,I}$ [b]	$AF_{2,II}$ [c]
	((Gy-Eq)/ (Bq*s))	((Gy-Eq)/ (Bq*s))
Br-77	3.3E-15	5.2E-18
Br-82	2.7E-14	4.4E-17
Kr-81	5.6E-17	8.7E-20
Kr-85	2.7E-17	4.3E-20
Kr-85m	1.5E-15	2.2E-18
Kr-87	7.9E-15	1.3E-17
Rb-81	6.4E-15	1.0E-17
Rb-83	5.2E-15	8.4E-18
Rb-84	9.4E-15	1.6E-17
Rb-86	1.0E-15	1.7E-18
Rb-87	2.2E-19	2.9E-22
Sr-82	1.2E-14	1.9E-17
Sr-85	5.3E-15	8.6E-18
Sr-85m+	6.8E-15	1.1E-17
Sr-87m	3.4E-15	5.2E-18
Sr-89	4.3E-17	6.8E-20
Sr-90+	1.5E-16	2.4E-19
Sr-91+	1.1E-14	1.8E-17
Sr-92+	1.6E-14	2.7E-17
Y-87+	8.1E-15	1.3E-17
Y-88	2.5E-14	4.3E-17
Y-90	1.5E-16	2.4E-19
Y-91	8.2E-17	1.3E-19
Y-91m+	5.7E-15	9.1E-18
Y-92	3.1E-15	5.1E-18
Y-93	1.2E-15	1.9E-18
Zr-88+	2.9E-14	5.0E-17
Zr-93+	6.0E-20	4.0E-23
Zr-95+	1.6E-14	2.6E-17
Zr-97+	1.6E-14	2.6E-17
Nb-93m	2.8E-19	1.9E-22
Nb-94	1.6E-14	2.7E-17
Nb-95	7.9E-15	1.3E-17
Nb-97	6.9E-15	1.1E-17
Mo-93+	1.6E-18	1.1E-21
Mo-99+	2.5E-15	3.9E-18
Tc-95m	7.1E-15	1.1E-17
Tc-96	2.6E-14	4.2E-17
Tc-96m+	2.6E-14	4.2E-17

Continuation of Table 15

Radionuclides[a]	Adjacent source	Distant Source
	Soft tissue	Red marrow
	$AF_{1,I}$ [b]	$AF_{2,II}$ [c]
	((Gy-Eq)/ (Bq*s))	((Gy-Eq)/ (Bq*s))
Tc-97	2.3E-18	1.3E-21
Tc-97m	4.6E-18	4.2E-21
Tc-98	1.5E-14	2.4E-17
Tc-99	2.1E-19	2.8E-22
Tc-99m	1.1E-15	1.6E-18
Ru-97	2.2E-15	3.4E-18
Ru-103+	5.0E-15	7.9E-18
Ru-105+	9.0E-15	1.4E-17
Ru-106+	2.6E-15	4.3E-18
Rh-99	5.9E-15	9.4E-18
Rh-101	2.3E-15	3.6E-18
Rh-102	2.2E-14	3.6E-17
Rh-102m	6.0E-15	9.7E-18
Rh-103m	7.5E-19	3.4E-22
Rh-105	8.0E-16	1.2E-18
Pd-103+	8.0E-18	4.8E-21
Pd-107	3.9E-24	2.3E-27
Pd-109	4.3E-17	5.8E-20
Ag-105	5.2E-15	8.3E-18
Ag-108m	1.7E-14	2.8E-17
Ag-110m	2.8E-14	4.7E-17
Ag-111	2.8E-16	4.4E-19
Cd-109	3.4E-17	3.3E-20
Cd-113m	1.6E-18	2.3E-21
Cd-115+	4.0E-15	6.4E-18
Cd-115m	2.7E-16	4.4E-19
In-111	3.7E-15	5.7E-18
In-113m	2.7E-15	4.1E-18
In-114m	9.1E-16	1.4E-18
In-115m	1.6E-15	2.4E-18
Sn-113+	2.7E-15	4.2E-18
Sn-117m	1.3E-15	1.9E-18
Sn-119m	9.4E-18	3.9E-21
Sn-121m+	5.9E-18	3.0E-21
Sn-123	1.0E-16	1.7E-19
Sn-125	7.3E-15	1.2E-17
Sn-126+	2.1E-14	3.3E-17
Sb-122	4.7E-15	7.6E-18
Sb-124	1.8E-14	3.0E-17

Continuation of Table 15

Radionuclides[a]	Adjacent source	Distant Source
	Soft tissue	Red marrow
	$AF_{1,I}$ [b]	$AF_{2,II}$ [c]
	((Gy-Eq)/ (Bq*s))	((Gy-Eq)/ (Bq*s))
Sb-125+	4.4E-15	7.0E-18
Sb-126	3.0E-14	4.8E-17
Te-121	5.9E-15	9.4E-18
Te-121m+	7.2E-15	1.1E-17
Te-123m	1.2E-15	1.8E-18
Te-125m	4.3E-17	2.1E-20
Te-127	5.4E-17	8.4E-20
Te-127m+	6.7E-17	9.1E-20
Te-129	6.1E-16	9.8E-19
Te-129m+	7.2E-16	1.1E-18
Te-131m+	1.9E-14	3.1E-17
Te-132+	2.6E-14	4.2E-17
I-123	1.4E-15	2.1E-18
I-124	1.1E-14	1.8E-17
I-125	4.9E-17	2.1E-20
I-126	4.7E-15	7.4E-18
I-129	3.5E-17	1.7E-20
I-131	4.0E-15	6.2E-18
I-132	2.3E-14	3.9E-17
I-133	6.6E-15	1.1E-17
I-134	2.7E-14	4.4E-17
I-135	1.8E-14	3.1E-17
Xe-122	1.1E-14	1.7E-17
Xe-123+	7.4E-15	1.2E-17
Xe-127	2.5E-15	3.8E-18
Xe-131m	5.1E-17	5.3E-20
Xe-133	2.0E-16	2.4E-19
Xe-135	2.5E-15	3.9E-18
Cs-129	2.6E-15	4.1E-18
Cs-131	3.1E-17	1.3E-20
Cs-132	7.2E-15	1.1E-17
Cs-134	1.6E-14	2.7E-17
Cs-134m +	1.6E-14	2.6E-17
Cs-135	5.2E-20	6.4E-23
Cs-136	2.2E-14	3.6E-17
^{137}Cs	5.9E-15	9.6E-18
Ba-131+	4.4E-15	6.9E-18
Ba-133	3.7E-15	5.7E-18
Ba-133m	2.3E-15	3.4E-18

Continuation of Table 15

Radionuclides[a]	Adjacent source	Distant Source
	Soft tissue	Red marrow
	$AF_{1,I}$ [b]	$AF_{2,II}$ [c]
	((Gy-Eq)/ (Bq*s))	((Gy-Eq)/ (Bq*s))
Ba-140+	2.4E-14	4.1E-17
La-137	3.8E-17	1.9E-20
La-140	2.2E-14	3.8E-17
Ce-139	1.2E-15	1.8E-18
Ce-141	6.1E-16	9.2E-19
Ce-143+	2.7E-15	4.2E-18
Ce-144+	7.6E-16	1.2E-18
Pr-142	6.6E-16	1.1E-18
Pr-143	8.2E-18	1.2E-20
Nd-147+	1.2E-15	1.9E-18
Nd-149+	3.9E-15	6.0E-18
Pm-143	3.0E-15	4.9E-18
Pm-144	1.6E-14	2.6E-17
Pm-145	6.8E-17	4.8E-20
Pm-147	8.5E-20	1.1E-22
Pm-148m	2.1E-14	3.4E-17
Pm-149	1.2E-16	1.9E-19
Pm-151	3.2E-15	5.0E-18
Sm-145+	1.7E-16	1.2E-19
Sm-147	0.0E+00	0.0E+00
Sm-151	3.6E-21	1.7E-24
Sm-153	3.1E-16	4.0E-19
Eu-147	4.6E-15	7.4E-18
Eu-148	2.2E-14	3.7E-17
Eu-149	3.9E-16	5.4E-19
Eu-150b	4.6E-16	7.3E-19
Eu-150a	1.5E-14	2.4E-17
Eu-152	1.1E-14	1.9E-17
Eu-152m	2.9E-15	4.8E-18
Eu-154	1.2E-14	2.0E-17
Eu-155	3.5E-16	4.8E-19
Eu-156	1.3E-14	2.1E-17
Gd-146+	2.7E-14	4.3E-17
Gd-148	0.0E+00	0.0E+00
Gd-153	4.9E-16	6.0E-19
Gd-159	4.5E-16	6.8E-19
Tb-157	6.40E-18	4.70E-21
Tb-158	7.70E-15	1.30E-17
Tb-160	1.10E-14	1.90E-17

Continuation of Table 15

Radionuclides[a]	Adjacent source	Distant Source
	Soft tissue	Red marrow
	$AF_{1,I}$ [b]	$AF_{2,II}$ [c]
	((Gy-Eq)/ (Bq*s))	((Gy-Eq)/ (Bq*s))
Dy-159	1.20E-16	9.30E-20
Dy-165	2.40E-16	3.80E-19
Dy-166+	4.70E-16	6.80E-19
Ho-166	2.90E-16	4.70E-19
Ho-166m	1.80E-14	2.90E-17
Er-169	2.80E-19	3.90E-22
Er-171	3.70E-15	5.70E-18
Tm-167	1.10E-15	1.60E-18
Tm-170	3.40E-17	4.30E-20
Tm-171	2.20E-18	2.20E-21
Yb-169	2.10E-15	3.00E-18
Yb-175	3.90E-16	6.10E-19
Lu-172	1.80E-14	3.10E-17
Lu-173	8.00E-16	1.10E-18
Lu-174	9.10E-16	1.40E-18
Lu-174m+	1.10E-15	1.60E-18
Lu-177	3.00E-16	4.60E-19
Hf-172+	1.90E-14	3.10E-17
Hf-175	3.50E-15	5.30E-18
Hf-181	5.60E-15	8.80E-18
Hf-182+	1.40E-14	2.30E-17
Ta-178a	9.70E-15	1.40E-17
Ta-179	1.10E-16	1.20E-19
Ta-182	1.20E-14	2.10E-17
W-178	7.70E-16	1.10E-18
W-181	1.50E-16	1.60E-19
W-185	9.50E-19	1.30E-21
W-187	4.80E-15	7.80E-18
W-188+	6.50E-16	1.00E-18
Re-184	8.70E-15	1.40E-17
Re-184m+	1.00E-14	1.70E-17
Re-186	1.60E-16	2.20E-19
Re-187	0.00E+00	0.00E+00
Re-188	6.40E-16	1.00E-18
Re-189	6.30E-16	9.70E-19
Os-185	7.20E-15	1.10E-17
Os-191	4.60E-16	6.30E-19
Os-191m+	5.00E-16	6.70E-19
Os-193	6.90E-16	1.10E-18

Continuation of Table 15

Radionuclides[a]	Adjacent source	Distant Source
	Soft tissue	Red marrow
	$AF_{1,I}$ [b]	$AF_{2,II}$ [c]
	((Gy-Eq)/ (Bq*s))	((Gy-Eq)/ (Bq*s))
Os-194+	1.00E-15	1.70E-18
Ir-189	4.70E-16	6.30E-19
Ir-190	1.50E-14	2.30E-17
Ir-192	8.50E-15	1.30E-17
Ir-194	1.00E-15	1.70E-18
Pt-188+	1.60E-14	2.70E-17
Pt-191	2.50E-15	3.80E-18
Pt-193	1.80E-21	2.30E-23
Pt-193m	5.00E-17	6.10E-20
Pt-195m	3.70E-16	4.70E-19
Pt-197	1.60E-16	2.20E-19
Pt-197m+	7.80E-16	1.10E-18
Au-193	1.20E-15	1.70E-18
Au-194	1.00E-14	1.70E-17
Au-195	4.00E-16	5.10E-19
Au-198	4.30E-15	6.70E-18
Au-199	7.50E-16	1.10E-18
Hg-194+	1.00E-14	1.70E-17
Hg-195m+	3.20E-15	4.90E-18
Hg-197	3.30E-16	4.20E-19
Hg-197m+	9.80E-16	1.30E-18
Hg-203	2.40E-15	3.70E-18
Tl-200	1.30E-14	2.10E-17
Tl-201	5.30E-16	7.20E-19
Tl-202	4.60E-15	7.20E-18
Tl-204	9.40E-18	1.30E-20
Pb-201+	7.90E-15	1.20E-17
Pb-202+	4.60E-15	7.10E-18
Pb-203	2.80E-15	4.30E-18
Pb-205	2.60E-21	3.00E-23
Pb-210+	1.80E-17	2.40E-20
Pb-212+	1.40E-14	2.30E-17
Bi-205	1.60E-14	2.70E-17
Bi-206	3.30E-14	5.30E-17
Bi-207	1.50E-14	2.60E-17
Bi-210+	1.30E-17	2.00E-20
Bi-210m	2.60E-15	4.00E-18
Bi-212+	1.30E-14	2.20E-17
Po-210	8.80E-20	1.40E-22

Continuation of Table 15

Radionuclides[a]	Adjacent source	Distant Source
	Soft tissue	Red marrow
	$AF_{1,I}$ [b]	$AF_{2,II}$ [c]
	((Gy-Eq)/ (Bq*s))	((Gy-Eq)/ (Bq*s))
At-211	1.30E-15	2.10E-18
Rn-222	1.70E-14	2.90E-17
Ra-223+	2.80E-15	4.30E-18
Ra-224+	1.40E-14	2.40E-17
Ra-225+	2.30E-15	3.60E-18
Ra-226	1.70E-14	2.90E-17
Ra-228+	2.10E-14	3.60E-17
Ac-225	2.20E-15	3.60E-18
Ac-227+	3.70E-15	5.80E-18
Ac-228	2.30E-14	3.90E-17
Th-227+	3.80E-15	5.80E-18
Th-228+	1.40E-14	2.40E-17
Th-229+	2.90E-15	4.40E-18
Th-230+	2.30E-18	3.10E-21
Th-231	7.10E-17	9.40E-20
Th-232+	7.70E-15	1.30E-17
Th-234+	2.80E-16	4.40E-19
Pa-230+	6.40E-15	1.00E-17
Pa-231+	8.90E-16	1.30E-18
Pa-233	1.90E-15	2.90E-18
U-230+	1.80E-16	2.80E-19
U-232+	1.00E-14	1.80E-17
U-233	2.70E-18	3.90E-21
U-234+	8.20E-19	9.80E-22
U-235+	1.50E-15	2.20E-18
U-236	4.50E-19	4.90E-22
U-238+	2.80E-16	4.40E-19
Np-235	6.50E-18	8.40E-21
Np-236b+	4.10E-16	6.20E-19
Np-236a	8.80E-16	1.30E-18
Np-237+	2.00E-15	3.10E-18
Np-239	1.40E-15	2.10E-18
Pu-236	5.80E-16	9.90E-19
Pu-237	3.10E-16	4.40E-19
Pu-238	3.70E-19	3.00E-22
Pu-239	5.90E-19	7.90E-22
Pu-240	3.60E-19	2.90E-22
Pu-241+	1.10E-20	1.70E-23
Pu-242	3.10E-19	2.60E-22

Continuation of Table 15

Radionuclides[a]	Adjacent source	Distant Source
	Soft tissue	Red marrow
	$AF_{1,I}$ [b]	$AF_{2,II}$ [c]
	((Gy-Eq)/ (Bq*s))	((Gy-Eq)/ (Bq*s))
Pu-244+	3.50E-15	5.70E-18
Am-241	8.70E-17	9.10E-20
Am-242m+	1.00E-16	1.40E-19
Am-243+	1.70E-15	2.60E-18
Am-244	8.10E-15	1.30E-17
Cm-240	5.20E-16	8.90E-19
Cm-241+	4.80E-15	7.60E-18
Cm-242	4.70E-19	3.30E-22
Cm-243	1.10E-15	1.70E-18
Cm-244	3.50E-19	2.00E-22
Cm-245	6.50E-16	9.60E-19
Cm-246	3.20E-19	1.90E-22
Cm-247	3.40E-15	5.30E-18
Bk-247	8.20E-16	1.20E-18
Bk-249	5.90E-17	9.20E-20
Cf-248+	4.70E-19	2.40E-22
Cf-249	3.40E-15	5.30E-18
Cf-251	1.00E-15	1.60E-18
Cf-253	6.10E-17	9.60E-20

End of Table 15

Table A-2 Inhalation committed absorbed dose and contamination absorbed dose conversion factors (EPR-D-Values 2006 Table 16 A). In this table, *NG* refers to a negligible amount and *ND* means there is no data.

Radionuclide	Inhalation			Contamination
	Red marrow	Respiratory tract Low LET	Respiratory tract High LET	Basal membrane of the skin
	$DF^{L+H}_{2,IIIE}$ (Δ)	$DF^{L}_{3E,IIIE}$ (Δ)	$DF^{HS}_{3E,IIIE}$ (Δ)	$DF^{L}_{6E,V}$
	(Gy/Bq)	(Gy/Bq)	(Gy/Bq)	(Gy/(Bq*s/cm^2))
H-3	2.20E-12	5.40E-12	NG	0.00E+00
C-14	6.50E-12	1.10E-09	NG	8.80E-11
P-32	2.50E-10	3.60E-09	NG	4.70E-10
S-35	1.70E-11	1.10E-09	NG	9.40E-11
Cl-36	3.50E-11	2.80E-09	NG	4.40E-10
Cr-51	2.20E-12	1.10E-11	NG	2.80E-13
Fe-55	1.30E-11	5.60E-12	NG	2.80E-13
Co-57	7.40E-12	1.60E-10	NG	2.10E-11
Co-60	1.30E-10	2.40E-09	NG	2.90E-10
Ni-63	2.80E-12	1.10E-09	NG	2.80E-13
Zn-65	3.60E-11	1.50E-10	NG	6.70E-12
Ge-68	9.40E-11	3.40E-08	NG	4.20E-10
Se-75	2.40E-11	2.90E-10	NG	2.80E-11
Sr-89	2.50E-10	3.40E-09	NG	4.60E-10
Sr-90+	1.80E-10	3.70E-07	NG	8.80E-10
Y-90	3.40E-10	3.50E-09	NG	4.70E-10
Y-91	2.90E-10	3.50E-09	NG	4.60E-10
Zr-95+	1.20E-10	2.30E-09	NG	3.30E-10
Nb-95	5.90E-11	1.10E-09	NG	4.00E-10
Nb-95m+	6.00E-11	2.00E-09	NG	ND
Mo-99+	7.70E-11	2.70E-09	NG	5.10E-10
Tc-99m	1.70E-12	8.40E-11	NG	6.50E-11
Ru-103+	9.00E-11	2.00E-09	NG	1.80E-10
Ru-106+	2.90E-10	5.70E-09	NG	4.90E-10
Pd-103+	4.90E-13	4.50E-10	NG	2.80E-13
Cd-109	5.20E-12	2.10E-09	NG	1.40E-10
Te-132+	3.30E-10	4.40E-09	NG	6.60E-10
I-125	2.90E-12	1.00E-10	NG	2.80E-13
I-129	5.20E-12	1.20E-09	NG	ND
I-131	3.30E-11	2.40E-09	NG	4.00E-10
Cs-134	1.10E-10	2.30E-09	NG	3.00E-10
^{137}Cs	6.50E-11	2.90E-09	NG	4.40E-10
Ba-133	5.40E-11	8.90E-10	NG	2.70E-11
Ce-141	5.70E-11	2.90E-09	NG	4.80E-10
Ce-144+	3.40E-10	7.40E-09	NG	7.30E-10
Pm-147	2.70E-11	1.40E-09	NG	1.60E-10

Continuation of Table 16

Radionuclide[a]	Inhalation			Contamination
	Red marrow	Respiratory tract Low LET	Respiratory tract High LET	Basal membrane of the skin
	$DF^{L+H}_{2,IIIE}$ $(\Delta)^{b}$	$DF^{L}_{3E,IIIE}$ $(\Delta)^{c}$	$DF^{HS}_{3E,IIIE}$ $(\Delta)^{d}$	$DF^{L}_{6E,V}$ [e]
	(Gy/Bq)	(Gy/Bq)	(Gy/Bq)	(Gy/(Bq*s/cm^2))
Eu-152	1.40E-10	1.90E-09	NG	2.10E-10
Eu-154	2.00E-10	4.00E-09	NG	5.00E-10
Gd-153	2.90E-11	7.90E-10	NG	3.10E-11
Tm-170	2.00E-10	3.20E-09	NG	4.50E-10
Yb-169	8.60E-11	2.30E-09	NG	2.70E-10
Re-188	3.40E-11	2.30E-09	NG	5.20E-10
Ir-192	5.90E-11	3.00E-09	NG	4.50E-10
Au-198	3.70E-11	2.40E-09	NG	4.60E-10
Hg-203	3.30E-11	2.80E-08	NG	2.50E-10
Po-210	2.10E-09	NG	3.90E-06	2.80E-13
Ra-226+	3.90E-09	NG	3.80E-06	1.00E-09
Th-230	2.30E-09	NG	3.40E-06	ND
Th-232	2.00E-09	NG	2.50E-06	ND
U-232	9.20E-10	NG	4.40E-06	1.50E-12
U-234	8.20E-10	NG	3.20E-06	ND
U-235+	2.80E-09	NG	3.20E-06	ND
U-237	3.80E-11	3.60E-09	NG	ND
U-238	7.30E-10	NG	2.80E-06	ND
U natural	ND	NG	2.80E-06	ND
U depleted	ND	NG	2.80E-06	ND
U enriched	ND	NG	3.20E-06	ND
Np-237+	1.80E-09	NG	3.50E-06	ND
Pu-238	1.70E-09	NG	4.40E-06	2.80E-13
Pu-239	1.60E-09	NG	3.90E-06	ND
Pu-240	1.60E-09	NG	3.90E-06	ND
Pu-241+	2.10E-11	NG	8.90E-08	2.80E-13
Pu-242	1.50E-09	NG	3.60E-06	ND
Am-241	1.60E-09	NG	4.40E-06	7.40E-13
Cm-242	1.70E-09	NG	5.20E-06	2.80E-13
Cm-244	1.70E-09	NG	4.80E-06	2.80E-13
Cf-252	ND	2.30E-10	2.2E-06(j)	ND

End of Table 16

Table A-3 Inhalation committed RBE-weighted dose conversion factors (EPR-D-Values Table 18A). *NA* means not applicable. A plus (+) sign refers to significance of radioactive progeny in the conversion factor.

Radionuclide	Inhalation			
	Red marrow	AI Region	Colon	Thyroid
	$AF_{2,IIIR}$ (Δ)	$AF_{3R,IIIR}$ (Δ)	$AF_{4,IIIR}$ (Δ)	$AF_{5,IIIR}$ (Δ)
	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)
H-3	2.10E-11	2.10E-11	2.10E-11	NA
Be-7	1.50E-11	1.00E-10	2.40E-11	NA
Be-10	7.10E-11	1.00E-08	1.90E-09	NA
C-11	2.00E-12	2.10E-12	2.20E-12	NA
C-14	2.80E-12	2.80E-12	2.80E-12	NA
N-13	0.00E+00	0.00E+00	0.00E+00	NA
F-18	2.70E-11	5.30E-11	2.90E-12	NA
Na-22	1.20E-09	7.50E-10	8.70E-10	NA
Na-24	1.50E-10	1.20E-10	1.10E-10	NA
Mg-28	5.50E-10	2.60E-09	2.40E-09	NA
Al-26	4.40E-09	2.00E-08	4.40E-09	NA
Si-31	4.30E-12	1.40E-10	1.20E-10	NA
Si-32+	2.90E-09	2.80E-08	2.50E-09	NA
P-32	2.60E-09	1.30E-08	1.20E-09	NA
P-33	1.30E-10	1.80E-09	1.40E-10	NA
S-35	2.20E-10	1.50E-09	3.10E-10	NA
Cl-36	2.40E-10	9.30E-09	2.70E-10	NA
Cl-38	4.10E-12	8.20E-11	4.30E-12	NA
Ar-37	0.00E+00	0.00E+00	0.00E+00	NA
Ar-39	0.00E+00	0.00E+00	0.00E+00	NA
Ar-41	0.00E+00	0.00E+00	0.00E+00	NA
K-40	8.40E-10	8.50E-10	2.30E-09	NA
K-42	7.60E-11	9.60E-11	1.20E-10	NA
K-43	6.70E-11	7.00E-11	9.50E-11	NA
Ca-41	3.20E-12	9.20E-11	1.90E-11	NA
Ca-45	8.30E-11	2.40E-09	5.20E-10	NA
Ca-47+	2.60E-10	4.50E-09	2.30E-09	NA
Sc-44	1.70E-11	2.60E-10	3.10E-10	NA
Sc-46	5.50E-10	8.10E-09	1.70E-09	NA
Sc-47	9.90E-12	1.20E-09	8.70E-10	NA
Sc-48	1.80E-10	1.60E-09	1.80E-09	NA
Ti-44+	2.10E-09	3.00E-08	5.60E-09	NA
V-48	7.50E-10	6.20E-09	2.20E-09	NA
V-49	5.50E-12	1.50E-10	3.30E-11	NA
Cr-51	1.00E-11	2.00E-10	4.70E-11	NA
Mn-52	8.30E-10	2.70E-09	1.50E-09	NA

Continuation of Table 18

Radionuclide[a]	Inhalation			
	Red marrow	AI Region	Colon	Thyroid
	$AF_{2,IIIR}$ $(\Delta)^{b}$	$AF_{3R,IIIR}$ $(\Delta)^{c}$	$AF_{4,IIIR}$ $(\Delta)^{d}$	$AF_{5,IIIR}$ $(\Delta)^{e}$
	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)
Mn-53	2.70E-11	1.80E-10	3.70E-11	NA
Mn-54	5.60E-10	1.90E-09	5.50E-10	NA
Mn-56	2.10E-11	1.90E-10	1.80E-10	NA
Fe-52+	8.80E-10	1.00E-09	1.60E-09	NA
Fe-55	4.70E-11	2.00E-10	3.80E-11	NA
Fe-59	1.50E-09	5.10E-09	1.30E-09	NA
Fe-60+	1.40E-09	1.10E-08	2.10E-09	NA
Co-55+	6.10E-11	8.50E-10	1.30E-09	NA
Co-56	9.00E-10	1.10E-08	2.40E-09	NA
Co-57	3.80E-11	1.20E-09	2.30E-10	NA
Co-58	2.70E-10	3.30E-09	7.10E-10	NA
Co-58m+	1.50E-12	3.70E-11	3.40E-11	NA
Co-60	7.20E-10	9.30E-09	1.80E-09	NA
Ni-59	1.80E-11	2.30E-10	4.70E-11	NA
Ni-63	4.40E-11	5.70E-10	1.20E-10	NA
Ni-65	2.60E-10	1.30E-10	1.20E-10	NA
Cu-64	9.10E-12	1.50E-10	1.30E-10	NA
Cu-67	3.80E-11	8.70E-10	4.20E-10	NA
Zn-65	1.70E-10	1.60E-09	3.40E-10	NA
Zn-69	1.10E-13	2.40E-11	7.50E-12	NA
Zn-69m+	1.70E-11	4.00E-10	6.40E-10	NA
Ga-67	4.50E-11	3.00E-10	2.50E-10	NA
Ga-68	5.60E-12	7.40E-11	3.20E-11	NA
Ga-72	1.30E-10	7.30E-10	1.20E-09	NA
Ge-68+	2.90E-10	2.60E-08	2.30E-09	NA
Ge-71	5.90E-13	1.50E-10	2.10E-11	NA
Ge-77+	3.50E-11	8.50E-10	2.40E-10	NA
As-72	9.10E-11	2.30E-09	2.30E-09	NA
As-73	1.10E-11	2.10E-09	3.90E-10	NA
As-74	1.90E-10	6.50E-09	1.60E-09	NA
As-76	3.80E-11	2.20E-09	2.20E-09	NA
As-77	6.50E-12	6.90E-10	5.80E-10	NA
Se-75	2.30E-10	1.40E-09	3.10E-10	NA
Se-79	5.60E-11	1.90E-09	3.70E-10	NA
Br-76	1.10E-10	1.10E-09	1.40E-10	NA
Br-77	2.90E-11	1.70E-10	4.70E-11	NA
Br-82	1.60E-10	9.20E-10	2.60E-10	NA
Kr-81	0.00E+00	0.00E+00	0.00E+00	NA
Kr-85	0.00E+00	0.00E+00	0.00E+00	NA
Kr-85m	0.00E+00	0.00E+00	0.00E+00	NA

Continuation of Table 18

Radionuclide[a]	Inhalation			
	Red marrow	AI Region	Colon	Thyroid
	$AF_{2,IIIR}$ $(\Delta)^{b}$	$AF_{3R,IIIR}$ $(\Delta)^{c}$	$AF_{4,IIIR}$ $(\Delta)^{d}$	$AF_{5,IIIR}$ $(\Delta)^{e}$
	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)
Kr-87	0.00E+00	0.00E+00	0.00E+00	NA
Rb-81	1.00E-11	1.20E-11	9.00E-12	NA
Rb-83	4.10E-10	2.80E-10	3.60E-10	NA
Rb-84	8.40E-10	5.40E-10	7.40E-10	NA
Rb-86	1.10E-09	6.00E-10	1.00E-09	NA
Rb-87	2.90E-10	1.50E-10	2.60E-10	NA
Sr-82	4.30E-09	4.10E-08	1.00E-08	NA
Sr-85	2.80E-10	1.70E-09	3.20E-10	NA
Sr-85m+	8.50E-13	4.20E-12	2.20E-12	NA
Sr-87m	3.90E-12	2.30E-11	2.30E-11	NA
Sr-89	1.90E-09	1.90E-08	4.20E-09	NA
Sr-90+	3.70E-09	4.50E-08	8.40E-09	NA
Sr-91+	5.30E-10	1.70E-08	4.20E-09	NA
Sr-92+	6.10E-11	4.10E-10	6.50E-10	NA
Y-87+	8.60E-11	9.10E-10	6.40E-10	NA
Y-88	8.70E-10	5.70E-09	1.20E-09	NA
Y-90	1.00E-10	5.10E-09	4.40E-09	NA
Y-91	5.60E-10	2.00E-08	4.30E-09	NA
Y-91m+	1.30E-12	1.70E-11	5.10E-12	NA
Y-92	5.80E-12	4.50E-10	4.90E-10	NA
Y-93	1.60E-11	1.00E-09	1.60E-09	NA
Zr-88+	6.50E-10	2.80E-09	5.50E-10	NA
Zr-93+	1.70E-10	1.30E-09	2.30E-10	NA
Zr-95+	1.70E-09	6.30E-09	1.20E-09	NA
Zr-97+	3.50E-10	1.90E-09	2.90E-09	NA
Nb-93m	6.60E-12	1.20E-09	2.20E-10	NA
Nb-94	5.70E-10	1.00E-08	2.00E-09	NA
Nb-95	2.10E-10	2.80E-09	6.50E-10	NA
Nb-97	1.90E-12	5.40E-11	2.40E-11	NA
Mo-93+	1.80E-11	1.00E-09	1.50E-10	NA
Mo-99+	2.00E-10	2.40E-09	2.00E-09	NA
Tc-95m	1.80E-10	1.90E-09	4.50E-10	3.30E-10
Tc-96	2.40E-10	1.30E-09	8.50E-10	6.80E-10
Tc-96m+	2.00E-12	1.30E-11	7.70E-12	1.20E-11
Tc-97	2.10E-12	4.60E-10	6.80E-11	7.00E-11
Tc-97m	1.80E-11	2.80E-09	6.30E-10	5.80E-10
Tc-98	4.10E-10	8.20E-09	1.80E-09	1.40E-09
Tc-99	2.10E-11	3.40E-09	7.30E-10	6.50E-10
Tc-99m	1.70E-12	1.20E-11	7.90E-12	4.00E-11
Ru-97	3.80E-11	2.20E-10	4.20E-10	NA

Continuation of Table 18

Radionuclide[a]	Inhalation			
	Red marrow	AI Region	Colon	Thyroid
	$AF_{2,IIIR}$ $(\Delta)^b$	$AF_{3R,IIIR}$ $(\Delta)^c$	$AF_{4,IIIR}$ $(\Delta)^d$	$AF_{5,IIIR}$ $(\Delta)^e$
	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)
Ru-103+	4.10E-10	4.50E-09	2.80E-09	NA
Ru-105+	2.40E-11	2.40E-10	7.70E-10	NA
Ru-106+	2.60E-09	5.50E-08	2.70E-08	NA
Rh-99	1.60E-10	2.00E-09	5.60E-10	NA
Rh-101	1.20E-10	2.30E-09	4.00E-10	NA
Rh-102	7.50E-10	5.90E-09	1.50E-09	NA
Rh-102m	3.00E-10	7.70E-09	1.50E-09	NA
Rh-103m	9.10E-14	3.20E-12	9.30E-13	NA
Rh-105	1.70E-11	4.80E-10	5.60E-10	NA
Pd-103+	8.30E-12	1.20E-09	3.30E-10	NA
Pd-107	2.10E-12	3.70E-10	6.90E-11	NA
Pd-109	1.70E-12	5.10E-10	8.10E-10	NA
Ag-105	1.90E-10	1.90E-09	4.80E-10	NA
Ag-108m	7.50E-10	7.10E-09	1.70E-09	NA
Ag-110m	1.20E-09	9.50E-09	2.50E-09	NA
Ag-111	8.60E-11	4.90E-09	2.20E-09	NA
Cd-109	6.10E-11	3.70E-09	6.40E-10	NA
Cd-113m	1.20E-10	7.30E-09	1.30E-09	NA
Cd-115+	7.30E-11	2.30E-09	2.10E-09	NA
Cd-115m	3.20E-10	1.90E-08	4.10E-09	NA
In-111	1.60E-10	3.60E-10	3.00E-10	NA
In-113m	3.20E-12	2.10E-11	1.40E-11	NA
In-114m	1.50E-08	2.50E-08	6.00E-09	NA
In-115m	1.60E-11	6.60E-11	8.60E-11	NA
Sn-113	3.10E-10	5.10E-09	1.20E-09	NA
Sn-117m	4.50E-10	3.20E-09	1.10E-09	NA
Sn-119m	1.20E-10	2.70E-09	5.90E-10	NA
Sn-121m	2.00E-10	4.20E-09	9.20E-10	NA
Sn-123	7.00E-10	1.60E-08	3.70E-09	NA
Sn-125	1.70E-09	1.20E-08	5.10E-09	NA
Sn-126+	3.00E-09	3.80E-08	9.40E-09	NA
Sb-122	4.10E-10	2.90E-09	2.70E-09	NA
Sb-124	1.40E-09	1.40E-08	3.40E-09	NA
Sb-125+	7.50E-10	6.80E-09	1.50E-09	5.80E-10
Sb-126	1.10E-09	7.80E-09	2.90E-09	NA
Te-121	2.70E-10	1.10E-09	5.60E-10	6.70E-10
Te-121m+	6.80E-10	3.90E-09	1.20E-09	2.40E-09
Te-123m	5.20E-10	3.50E-09	8.40E-10	2.20E-09
Te-125m	4.70E-10	3.50E-09	7.80E-10	2.10E-09
Te-127	2.60E-11	1.50E-10	2.30E-10	5.90E-11

Continuation of Table 18

Radionuclide[a]	Inhalation			
	Red marrow	AI Region	Colon	Thyroid
	$AF_{2,IIIR}$ $(\Delta)^{b}$	$AF_{3R,IIIR}$ $(\Delta)^{c}$	$AF_{4,IIIR}$ $(\Delta)^{d}$	$AF_{5,IIIR}$ $(\Delta)^{e}$
	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)
Te-127m+	1.30E-09	9.20E-09	2.00E-09	5.80E-09
Te-129	3.00E-11	5.10E-11	2.00E-11	7.50E-12
Te-129m+	2.20E-09	1.60E-08	3.90E-09	1.00E-08
Te-131m+	2.80E-10	1.50E-09	1.50E-09	1.10E-07
Te-132+	5.40E-10	4.50E-09	3.40E-09	7.40E-10
I-123	7.40E-12	6.20E-12	7.20E-12	4.60E-08
I-124	1.40E-10	1.30E-10	7.80E-11	2.40E-08
I-125	1.50E-11	1.20E-11	1.50E-11	8.80E-08
I-126	1.30E-10	1.30E-10	7.20E-11	6.60E-08
I-129	2.10E-11	1.90E-11	3.30E-11	7.40E-10
I-131	9.10E-11	8.80E-11	6.10E-11	7.40E-08
I-132	3.10E-11	2.70E-11	3.00E-11	3.60E-09
I-133	4.50E-11	4.40E-11	5.30E-11	7.60E-08
I-134	1.90E-11	1.50E-11	1.40E-11	7.00E-10
I-135	2.70E-11	2.80E-11	3.00E-11	1.30E-08
Xe-122	0.00E+00	0.00E+00	0.00E+00	NA
Xe-123+	8.30E-13	6.90E-13	8.00E-13	4.10E-10
Xe-127	0.00E+00	0.00E+00	0.00E+00	NA
Xe-131m	0.00E+00	0.00E+00	0.00E+00	NA
Xe-133	0.00E+00	0.00E+00	0.00E+00	NA
Xe-135	0.00E+00	0.00E+00	0.00E+00	NA
Cs-129	1.80E-11	1.90E-11	2.10E-11	NA
Cs-131	1.20E-11	2.00E-11	2.00E-11	NA
Cs-132	1.60E-10	1.50E-10	1.80E-10	NA
Cs-134	1.30E-09	1.20E-09	1.50E-09	NA
Cs-134m+	1.50E-12	3.20E-12	1.90E-12	NA
Cs-135	1.10E-10	1.20E-10	1.50E-10	NA
Cs-136	8.30E-10	7.90E-10	9.70E-10	NA
^{137}Cs	7.90E-10	7.60E-10	9.70E-10	NA
Ba-131+	1.60E-10	3.00E-11	6.70E-10	NA
Ba-133	2.50E-10	4.00E-11	8.20E-10	NA
Ba-133m	8.70E-11	8.60E-12	1.00E-09	NA
Ba-140+	1.30E-09	1.60E-09	6.20E-09	NA
La-137	4.50E-11	4.50E-10	8.60E-11	NA
La-140	3.00E-10	2.10E-09	2.50E-09	NA
Ce-139	8.00E-11	1.90E-09	3.70E-10	NA
Ce-141	1.10E-10	5.20E-09	1.20E-09	NA
Ce-143+	4.00E-11	1.90E-09	1.70E-09	NA
Ce-144+	8.90E-10	5.00E-08	9.70E-09	NA
Pr-142	1.30E-11	1.30E-09	2.00E-09	NA

Continuation of Table 18

Radionuclide[a]	Inhalation			
	Red marrow	AI Region	Colon	Thyroid
	$AF_{2,IIIR}$ $(\Delta)^b$	$AF_{3R,IIIR}$ $(\Delta)^c$	$AF_{4,IIIR}$ $(\Delta)^d$	$AF_{5,IIIR}$ $(\Delta)^e$
	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)
Pr-143	8.30E-11	6.50E-09	2.10E-09	NA
Nd-147+	1.40E-10	5.20E-09	1.80E-09	NA
Nd-149+	2.90E-12	1.40E-10	1.10E-10	NA
Pm-143	1.30E-10	1.30E-09	2.40E-10	NA
Pm-144	6.30E-10	4.60E-09	9.50E-10	NA
Pm-145	2.70E-11	8.30E-10	1.50E-10	NA
Pm-147	6.00E-11	2.40E-09	4.60E-10	NA
Pm-148m	8.00E-10	1.00E-08	2.20E-09	NA
Pm-149	3.00E-11	1.70E-09	1.60E-09	NA
Pm-151	2.70E-11	8.10E-10	1.10E-09	NA
Sm-145+	5.80E-11	1.50E-09	3.10E-10	NA
Sm-147	4.40E-09	5.30E-07	0.00E+00	NA
Sm-151	2.00E-11	6.60E-10	1.40E-10	NA
Sm-153	2.30E-11	1.00E-09	1.10E-09	NA
Eu-147	1.60E-10	1.80E-09	5.30E-10	NA
Eu-148	7.20E-10	4.60E-09	1.20E-09	NA
Eu-149	3.20E-11	6.10E-10	1.40E-10	NA
Eu-150b	6.20E-10	4.80E-09	1.10E-09	NA
Eu-150a	5.10E-12	3.10E-10	5.20E-10	NA
Eu-152	5.40E-10	7.10E-09	1.60E-09	NA
Eu-152m	9.80E-12	3.90E-10	6.40E-10	NA
Eu-154	7.00E-10	1.20E-08	2.70E-09	NA
Eu-155	8.00E-11	2.30E-09	4.90E-10	NA
Eu-156	4.60E-10	9.40E-09	3.20E-09	NA
Gd-146+	2.60E-09	8.90E-09	2.10E-09	NA
Gd-148	4.70E-08	7.70E-07	0.00E+00	NA
Gd-153	4.30E-10	1.90E-09	4.10E-10	NA
Gd-159	7.00E-11	4.40E-10	7.20E-10	NA
Tb-157	8.00E-12	2.20E-10	4.70E-11	NA
Tb-158	4.40E-10	5.70E-09	1.30E-09	NA
Tb-160	6.20E-10	9.50E-09	2.30E-09	NA
Dy-159	3.60E-11	6.50E-10	1.40E-10	NA
Dy-165	9.00E-13	8.30E-11	7.10E-11	NA
Dy-166+	1.60E-10	5.20E-09	3.10E-09	NA
Ho-166	2.40E-11	1.40E-09	2.10E-09	NA
Ho-166m	7.90E-10	8.20E-09	1.80E-09	NA
Er-169	5.00E-11	1.50E-09	6.30E-10	NA
Er-171	1.00E-11	2.70E-10	4.30E-10	NA
Tm-167	9.70E-11	2.00E-09	8.60E-10	NA
Tm-170	4.40E-10	1.00E-08	2.30E-09	NA

Continuation of Table 18

Radionuclide[a]	Inhalation			
	Red marrow	AI Region	Colon	Thyroid
	$AF_{2,IIIR}$ $(\Delta)^{b}$	$AF_{3R,IIIR}$ $(\Delta)^{c}$	$AF_{4,IIIR}$ $(\Delta)^{d}$	$AF_{5,IIIR}$ $(\Delta)^{e}$
	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)
Tm-171	3.70E-11	8.40E-10	1.80E-10	NA
Yb-169	2.00E-10	4.50E-09	1.10E-09	NA
Yb-175	2.80E-11	1.10E-09	7.20E-10	NA
Lu-172	3.20E-10	3.00E-09	1.40E-09	NA
Lu-173	1.10E-10	2.00E-09	3.70E-10	NA
Lu-174	1.10E-10	2.10E-09	4.00E-10	NA
Lu-174m	1.70E-10	4.70E-09	9.20E-10	NA
Lu-177	5.70E-11	1.80E-09	9.70E-10	NA
Hf-172	3.20E-09	1.20E-08	2.80E-09	NA
Hf-175	6.60E-10	2.10E-09	5.30E-10	NA
Hf-181	1.80E-09	6.40E-09	1.70E-09	NA
Hf-182	1.60E-09	1.50E-08	3.00E-09	NA
Ta-178a	5.10E-12	4.60E-11	4.10E-11	NA
Ta-179	1.40E-11	5.10E-10	9.40E-11	NA
Ta-182	4.40E-10	1.10E-08	2.20E-09	NA
W-178	1.30E-11	5.20E-12	3.30E-10	NA
W-181	5.30E-12	2.10E-12	1.00E-10	NA
W-185	1.40E-11	4.30E-12	8.00E-10	NA
W-187	2.40E-11	1.60E-11	9.20E-10	NA
W-188	1.20E-10	9.60E-10	4.50E-09	2.70E-09
Re-184	2.30E-10	3.00E-09	6.70E-10	6.30E-10
Re-184m	2.30E-10	6.20E-09	1.10E-09	1.10E-09
Re-186	4.00E-11	2.30E-09	1.10E-09	1.90E-09
Re-187	1.40E-13	2.20E-11	3.90E-12	4.20E-12
Re-188	3.30E-11	1.00E-09	6.70E-10	2.80E-09
Re-189	2.10E-11	6.70E-10	4.40E-10	1.40E-09
Os-185	2.70E-10	2.40E-09	5.60E-10	NA
Os-191	7.30E-11	3.20E-09	9.50E-10	NA
Os-191m	4.40E-12	1.90E-10	1.50E-10	NA
Os-193	2.40E-11	9.80E-10	1.30E-09	NA
Os-194+	6.20E-10	3.40E-08	6.30E-09	NA
Ir-189	3.80E-11	1.30E-09	3.90E-10	NA
Ir-190	3.60E-10	4.40E-09	1.50E-09	NA
Ir-192	4.30E-10	9.40E-09	2.00E-09	NA
Ir-194	3.30E-11	1.40E-09	2.00E-09	NA
Pt-188+	2.20E-10	5.10E-10	1.20E-09	NA
Pt-191	3.10E-11	2.70E-11	3.10E-10	NA
Pt-193	2.80E-12	3.40E-12	5.30E-11	NA
Pt-193m	2.00E-11	2.20E-11	5.60E-10	NA
Pt-195m	3.10E-11	3.40E-11	7.60E-10	NA

Continuation of Table 18

Radionuclide[a]	Inhalation			
	Red marrow	AI Region	Colon	Thyroid
	$AF_{2,IIIR}$ (Δ)[b]	$AF_{3R,IIIR}$ (Δ)[c]	$AF_{4,IIIR}$ (Δ)[d]	$AF_{5,IIIR}$ (Δ)[e]
	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)
Pt-197	9.80E-12	1.30E-11	3.90E-10	NA
Pt-197m+	2.30E-12	6.70E-12	5.10E-11	NA
Au-193	7.20E-12	1.30E-10	1.70E-10	NA
Au-194	5.40E-11	3.80E-10	3.90E-10	NA
Au-195	2.70E-11	2.40E-09	4.00E-10	NA
Au-198	5.70E-11	2.00E-09	1.50E-09	NA
Au-199	2.10E-11	9.60E-10	6.80E-10	NA
Hg-194+	2.30E-09	4.00E-09	2.70E-09	NA
Hg-195m+	1.50E-09	1.20E-09	7.90E-10	NA
Hg-197	6.70E-10	3.80E-10	3.30E-10	NA
Hg-197m+	1.20E-09	5.50E-10	6.80E-10	NA
Hg-203	1.90E-09	3.10E-09	8.40E-10	NA
Tl-200	5.80E-11	5.50E-11	9.00E-11	NA
Tl-201	2.00E-11	2.20E-11	7.30E-11	NA
Tl-202	1.20E-10	1.10E-10	2.70E-10	NA
Tl-204	2.00E-10	2.00E-10	1.30E-09	NA
Pb-201+	2.40E-11	1.60E-11	8.20E-11	NA
Pb-202+	3.60E-10	2.40E-10	4.40E-10	NA
Pb-203	4.80E-11	2.80E-11	1.60E-10	NA
Pb-205	2.60E-11	6.00E-12	3.00E-11	NA
Pb-210+	6.00E-08	1.20E-06	2.80E-09	NA
Pb-212+	1.10E-09	4.60E-09	0.00E+00	NA
Bi-205	2.80E-10	2.50E-09	8.70E-10	NA
Bi-206	3.80E-10	3.60E-09	1.90E-09	NA
Bi-207	4.20E-10	7.10E-09	1.60E-09	NA
Bi-210+	1.80E-09	4.00E-08	2.10E-09	NA
Bi-210m	5.70E-10	1.20E-06	4.50E-09	NA
Bi-212+	1.80E-11	4.60E-09	0.00E+00	NA
Po-210	5.70E-08	1.20E-06	6.40E-15	NA
At-211	3.80E-10	2.80E-08	1.10E-12	NA
Rn-222	0.00E+00	0.00E+00	0.00E+00	NA
Ra-223+	7.40E-09	3.00E-06	7.10E-09	NA
Ra-224+	4.30E-09	1.20E-06	3.90E-09	NA
Ra-225+	5.70E-08	2.80E-06	2.60E-09	NA
Ra-226	2.20E-09	1.10E-06	1.70E-09	NA
Ra-228+	4.60E-08	8.40E-06	1.10E-08	NA
Ac-225	1.20E-07	3.40E-06	4.30E-09	NA
Ac-227+	6.50E-08	8.50E-06	1.00E-08	NA
Ac-228	9.90E-11	2.90E-09	4.20E-10	NA
Th-227+	1.80E-08	3.80E-06	4.20E-09	NA

Continuation of Table 18

Radionuclide[a]	Inhalation			
	Red marrow	AI Region	Colon	Thyroid
	$AF_{2,IIIR}$ (Δ)[b]	$AF_{3R,IIIR}$ (Δ)[c]	$AF_{4,IIIR}$ (Δ)[d]	$AF_{5,IIIR}$ (Δ)[e]
	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)
Th-228+	4.40E-08	8.10E-06	6.50E-09	NA
Th-229+	1.50E-07	8.70E-06	6.90E-09	NA
Th-230+	1.40E-08	1.30E-06	1.20E-10	NA
Th-231	7.50E-12	3.90E-10	5.20E-10	NA
Th-232+	4.40E-08	7.00E-06	7.80E-09	NA
Th-234+	8.40E-10	2.40E-08	6.10E-09	NA
Pa-230+	2.20E-09	2.90E-07	7.50E-10	NA
Pa-231+	3.30E-08	3.80E-06	3.30E-09	NA
Pa-233	2.60E-10	6.00E-09	1.50E-09	NA
U-230+	5.20E-08	6.10E-06	3.10E-10	NA
U-232+	5.10E-08	8.90E-06	6.20E-09	NA
U-233	1.00E-08	1.40E-06	4.90E-11	NA
U-234+	1.00E-08	1.30E-06	1.00E-10	NA
U-235+	9.60E-09	1.30E-06	1.70E-09	NA
U-236	9.40E-09	1.30E-06	8.80E-11	NA
U-238+	1.00E-08	1.20E-06	6.70E-09	NA
Depleted U	9.30E-09	1.20E-06	5.50E-10	NA
Np-235	1.30E-11	5.20E-10	8.70E-11	NA
Np-236b+	1.20E-09	1.30E-07	2.60E-10	NA
Np-236a	2.90E-10	8.90E-09	1.60E-09	NA
Np-237+	1.10E-08	1.20E-06	2.10E-09	NA
Np-239	3.40E-11	1.20E-09	1.20E-09	NA
Pu-236	1.40E-08	1.60E-06	1.10E-10	NA
Pu-237	3.30E-11	8.70E-10	1.50E-10	NA
Pu-238	1.40E-08	1.60E-06	8.30E-11	NA
Pu-239	1.30E-08	1.50E-06	5.20E-11	NA
Pu-240	1.30E-08	1.50E-06	8.30E-11	NA
Pu-241+	9.90E-11	1.70E-08	3.90E-11	NA
Pu-242	1.20E-08	1.40E-06	6.80E-11	NA
Pu-244+	1.30E-08	1.30E-06	6.40E-09	NA
Am-241	7.40E-09	1.30E-06	4.10E-10	NA
Am-242m+	7.00E-09	1.20E-06	1.70E-09	NA
Am-243+	7.40E-09	1.30E-06	2.10E-09	NA
Am-244	1.90E-11	4.10E-10	5.40E-10	NA
Cm-240	5.70E-09	1.10E-06	7.50E-11	NA
Cm-241+	2.70E-10	1.50E-08	1.20E-09	NA
Cm-242	7.70E-09	1.40E-06	7.00E-11	NA
Cm-243	8.00E-09	1.40E-06	1.10E-09	NA
Cm-244	7.80E-09	1.40E-06	6.40E-11	NA
Cm-245	7.30E-09	1.30E-06	5.30E-10	NA

Continuation of Table 18

Radionuclide[a]	Inhalation			
	Red marrow	AI Region	Colon	Thyroid
	$AF_{2,IIIR}$ $(\Delta)^{b}$	$AF_{3R,IIIR}$ $(\Delta)^{c}$	$AF_{4,IIIR}$ $(\Delta)^{d}$	$AF_{5,IIIR}$ $(\Delta)^{e}$
	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)
Cm-246	7.30E-09	1.30E-06	5.90E-11	NA
Cm-247	6.90E-09	1.20E-06	1.50E-09	NA
Cm-248	2.70E-08	4.60E-06	ND	NA
Bk-247	1.60E-08	1.30E-06	5.00E-10	NA
Bk-249	4.70E-11	1.20E-09	2.30E-10	NA
Cf-248+	1.70E-08	1.40E-06	4.50E-11	NA
Cf-249	1.70E-08	1.40E-06	5.00E-10	NA
Cf-250	1.70E-08	1.40E-06	4.30E-11	NA
Cf-251	1.70E-08	1.40E-06	1.50E-09	NA
Cf-252	3.30E-08	2.50E-06	ND	NA
Cf-253	5.10E-09	3.90E-07	5.20E-10	NA
Cf-254	1.10E-06	2.50E-05	1.20E-07	NA
^{239}Pu/[9]	1.30E-08	1.50E-06	5.20E-11	NA
^{241}Am/[9]	7.40E-09	1.30E-06	4.10E-10	NA

End of Table 18

Table A-4 Inhalation committed RBE-weighted dose and contamination RBE-weighted dose conversion factors (EPR-D-Values 2006 table 19A). ***NA*** **means not applicable. A plus (+) sign refers to significance of radioactive progeny in the conversion factor.**

Radionuclides[a]	Inhalation			Contamination
	Red marrow	Colon	Thyroid	Derma of skin
	$AF_{2,IV}$ (Δ)	$AF_{4,IV}$ (Δ)	$AF_{5,IV}$ (Δ)	$AF_{6R,V}$
	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/(s*Bq/cm^2))
H-3	2.10E-11	2.20E-11	NA	0.00E+00
Be-7	1.10E-11	9.60E-11	NA	7.10E-13
Be-10	1.10E-11	8.10E-09	NA	1.70E-10
C-11	1.80E-12	3.40E-12	NA	1.40E-11
C-14	2.30E-10	2.50E-10	NA	0.00E+00
N-13	0.00E+00	0.00E+00	NA	0.00E+00
F-18	6.50E-11	1.50E-11	NA	1.80E-10
Na-22	3.50E-09	2.60E-09	NA	9.00E-11
Na-24	3.90E-10	4.00E-10	NA	3.60E-10
Mg-28	9.70E-10	1.20E-08	NA	5.30E-10
Al-26	6.60E-10	1.90E-08	NA	3.40E-10
Si-31	8.40E-14	6.50E-10	NA	3.30E-10
Si-32+	6.40E-09	9.10E-09	NA	3.60E-10
P-32	6.40E-09	5.50E-09	NA	3.60E-10
P-33	3.20E-10	6.50E-10	NA	1.30E-12
S-35	2.40E-10	2.80E-10	NA	0.00E+00
Cl-36	7.10E-10	8.70E-10	NA	2.10E-10
Cl-38	8.10E-12	1.50E-11	NA	4.30E-10
Ar-37	0.00E+00	0.00E+00	NA	0.00E+00
Ar-39	0.00E+00	0.00E+00	NA	0.00E+00
Ar-41	0.00E+00	0.00E+00	NA	0.00E+00
K-40	2.50E-09	6.80E-09	NA	2.70E-10
K-42	2.10E-10	4.50E-10	NA	4.50E-10
K-43	1.80E-10	3.10E-10	NA	2.10E-10
Ca-41	1.80E-11	7.00E-11	NA	1.00E-12
Ca-45	4.70E-10	1.90E-09	NA	1.80E-12
Ca-47+	1.10E-09	8.90E-09	NA	4.60E-10
Sc-44	4.70E-11	1.60E-09	NA	4.10E-10
Sc-46	3.80E-10	7.20E-09	NA	4.20E-11
Sc-47	1.90E-11	4.10E-09	NA	7.40E-11
Sc-48	4.10E-10	8.50E-09	NA	1.70E-10
Ti-44+	5.40E-10	2.40E-08	NA	4.10E-10
V-48	5.50E-10	9.50E-09	NA	1.60E-10
V-49	2.20E-13	1.40E-10	NA	2.70E-12
Cr-51	9.60E-12	2.00E-10	NA	3.90E-12
Mn-52	8.00E-10	6.90E-09	NA	7.90E-11
Mn-53	1.10E-11	1.60E-10	NA	ND(f)

Radionuclides[a]	Inhalation			Contamination
	Red marrow	Colon	Thyroid	Derma of skin
	$AF_{2,IV}$ $(\Delta)^{b}$	$AF_{4,IV}$ $(\Delta)^{c}$	$AF_{5,IV}$ $(\Delta)^{d}$	$AF_{6R,V}$ [e]
	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/(s*Bq/cm^2))
Mn-54	3.60E-10	1.70E-09	NA	1.30E-11
Mn-56	2.40E-11	1.00E-09	NA	3.60E-10
Fe-52+	3.80E-10	8.40E-09	NA	6.50E-10
Fe-55	1.80E-11	1.70E-10	NA	4.10E-12
Fe-59	7.70E-10	5.50E-09	NA	4.50E-11
Fe-60+	7.70E-10	8.30E-09	NA	3.40E-11
Co-55+	1.60E-10	6.20E-09	NA	ND
Co-56	7.80E-10	9.30E-09	NA	1.10E-10
Co-57	3.50E-11	9.00E-10	NA	1.10E-11
Co-58	2.40E-10	2.80E-09	NA	1.90E-11
Co-58m+	1.30E-12	1.60E-10	NA	2.30E-11
Co-60	5.80E-10	7.00E-09	NA	3.40E-11
Ni-59	6.40E-13	2.10E-10	NA	4.70E-12
Ni-63	1.60E-12	5.30E-10	NA	0.00E+00
Ni-65	7.10E-12	6.80E-10	NA	3.00E-10
Cu-64	1.90E-11	6.80E-10	NA	1.50E-10
Cu-67	7.00E-11	2.00E-09	NA	ND
Zn-65	7.30E-10	1.30E-09	NA	1.00E-11
Zn-69	5.60E-13	3.90E-11	NA	2.10E-10
Zn-69m+	9.60E-11	2.00E-09	NA	2.40E-10
Ga-67	2.60E-11	1.20E-09	NA	9.20E-12
Ga-68	5.80E-12	2.00E-10	NA	3.90E-10
Ga-72	1.70E-10	6.30E-09	NA	2.70E-10
Ge-68+	2.90E-10	7.00E-09	NA	4.00E-10
Ge-71	1.70E-12	6.20E-11	NA	4.80E-12
Ge-77+	9.10E-11	7.50E-10	NA	4.80E-10
As-72	2.50E-10	1.10E-08	NA	ND
As-73	3.50E-11	1.70E-09	NA	1.00E-11
As-74	3.30E-10	7.00E-09	NA	2.00E-10
As-76	1.30E-10	1.10E-08	NA	4.00E-10
As-77	2.50E-11	2.80E-09	NA	1.40E-10
Se-75	5.80E-10	9.70E-10	NA	1.30E-11
Se-79	1.40E-10	6.60E-10	NA	0.00E+00
Br-76	2.90E-10	6.50E-10	NA	0.00E+00
Br-77	7.80E-11	1.50E-10	NA	0.00E+00
Br-82	4.30E-10	8.10E-10	NA	7.80E-11
Kr-81	0.00E+00	0.00E+00	NA	0.00E+00
Kr-85	0.00E+00	0.00E+00	NA	0.00E+00
Kr-85m	0.00E+00	0.00E+00	NA	0.00E+00
Kr-87	0.00E+00	0.00E+00	NA	0.00E+00
Rb-81	2.60E-11	3.40E-11	NA	ND

Radionuclides[a]	Inhalation			Contamination
	Red marrow	Colon	Thyroid	Derma of skin
	$AF_{2,IV}$ $(\Delta)^b$	$AF_{4,IV}$ $(\Delta)^c$	$AF_{5,IV}$ $(\Delta)^d$	$AF_{6R,V}$ ^{e}
	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/(s*Bq/cm^2))
Rb-83	1.20E-09	1.10E-09	NA	ND
Rb-84	2.50E-09	2.20E-09	NA	1.10E-10
Rb-86	3.30E-09	3.10E-09	NA	3.30E-10
Rb-87	8.60E-10	7.90E-10	NA	3.00E-12
Sr-82	4.80E-09	3.50E-08	NA	3.90E-12
Sr-85	3.70E-10	1.10E-09	NA	1.30E-11
Sr-85m+	1.60E-12	1.10E-11	NA	2.00E-11
Sr-87m	6.20E-12	1.20E-10	NA	6.40E-11
Sr-89	2.00E-09	1.40E-08	NA	3.20E-10
Sr-90+	4.00E-09	3.30E-08	NA	5.00E-10
Sr-91+	1.30E-10	1.80E-08	NA	3.20E-10
Sr-92+	6.40E-11	3.40E-09	NA	5.50E-10
Y-87+	1.20E-10	3.00E-09	NA	ND
Y-88	4.70E-10	4.70E-09	NA	2.70E-11
Y-90	3.70E-13	2.10E-08	NA	3.90E-10
Y-91	2.40E-12	1.90E-08	NA	3.20E-10
Y-91m+	2.30E-12	2.70E-11	NA	2.60E-11
Y-92	4.80E-12	2.60E-09	NA	4.40E-10
Y-93	4.40E-12	8.30E-09	NA	4.20E-10
Zr-88+	1.90E-10	2.10E-09	NA	3.70E-11
Zr-93+	7.70E-12	1.00E-09	NA	5.40E-13
Zr-95+	2.30E-10	5.10E-09	NA	4.70E-11
Zr-97+	1.20E-10	1.50E-08	NA	6.30E-10
Nb-93m	1.90E-12	9.30E-10	NA	5.40E-13
Nb-94	3.60E-10	8.30E-09	NA	8.80E-11
Nb-95	1.60E-10	2.80E-09	NA	9.30E-12
Nb-97	4.10E-12	1.40E-10	NA	2.90E-10
Mo-93+	4.70E-11	4.30E-10	NA	3.60E-12
Mo-99+	6.10E-10	4.90E-10	6.70E-11	2.30E-10
Tc-95m	1.90E-10	1.50E-09	5.10E-10	ND
Tc-96	4.50E-10	3.00E-09	1.00E-09	3.10E-11
Tc-96m+	3.90E-12	2.80E-11	1.10E-11	3.30E-11
Tc-97	3.50E-12	2.30E-10	1.10E-10	2.90E-12
Tc-97m	2.90E-11	2.20E-09	9.10E-10	4.90E-12
Tc-98	4.60E-10	6.10E-09	2.20E-09	5.00E-11
Tc-99	3.30E-11	2.50E-09	1.00E-09	8.70E-12
Tc-99m	4.20E-12	3.70E-11	8.50E-11	2.50E-12
Ru-97	3.90E-11	7.20E-10	NA	1.10E-11
Ru-103+	1.30E-10	4.30E-09	NA	1.00E-11
Ru-105+	2.20E-11	1.50E-09	NA	2.60E-10
Ru-106+	2.90E-10	4.40E-08	NA	4.50E-10

Radionuclides[a]	Inhalation			Contamination
	Red marrow	Colon	Thyroid	Derma of skin
	$AF_{2,IV}$ $(\Delta)^b$	$AF_{4,IV}$ $(\Delta)^c$	$AF_{5,IV}$ $(\Delta)^d$	$AF_{6R,V}$ [e]
	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/(s*Bq/cm^2))
Rh-99	1.40E-10	2.50E-09	NA	2.40E-11
Rh-101	7.70E-11	1.70E-09	NA	8.40E-12
Rh-102	5.50E-10	4.50E-09	NA	8.60E-11
Rh-102m	1.50E-10	6.20E-09	NA	1.50E-10
Rh-103m	5.00E-15	5.70E-12	NA	4.30E-13
Rh-105	1.20E-11	2.80E-09	NA	7.30E-11
Pd-103+	1.50E-12	1.50E-09	NA	2.60E-12
Pd-107	4.20E-14	3.00E-10	NA	0.00E+00
Pd-109	8.00E-13	4.10E-09	NA	2.30E-10
Ag-105	1.40E-10	1.70E-09	NA	1.50E-11
Ag-108m	4.70E-10	5.50E-09	NA	3.50E-10
Ag-110m	7.30E-10	7.90E-09	NA	5.90E-11
Ag-111	2.20E-11	9.70E-09	NA	2.20E-10
Cd-109	1.50E-11	2.80E-09	NA	3.60E-12
Cd-113m	2.30E-11	5.70E-09	NA	0.00E+00
Cd-115+	6.50E-11	1.00E-08	NA	3.50E-10
Cd-115m	6.80E-11	1.80E-08	NA	2.90E-10
In-111	7.40E-11	1.50E-09	NA	1.50E-11
In-113m	2.40E-12	8.10E-11	NA	1.20E-10
In-114m	1.20E-09	2.80E-08	NA	6.20E-12
In-115m	4.90E-12	4.80E-10	NA	2.20E-10
Sn-113+	8.10E-11	5.10E-09	NA	1.20E-10
Sn-117m	6.70E-11	5.20E-09	NA	4.20E-12
Sn-119m	1.10E-11	2.60E-09	NA	2.20E-12
Sn-121m+	1.70E-11	4.00E-09	NA	3.50E-11
Sn-123	5.80E-11	1.60E-08	NA	2.90E-10
Sn-125	1.90E-10	2.40E-08	NA	6.70E-10
Sn-126+	1.40E-09	4.00E-08	NA	3.30E-10
Sb-122	2.10E-10	1.20E-08	NA	3.10E-10
Sb-124	8.40E-10	1.40E-08	NA	2.00E-10
Sb-125+	6.40E-10	5.70E-09	6.50E-10	3.70E-11
Sb-126	8.90E-10	1.20E-08	NA	2.20E-10
Te-121	3.30E-10	1.20E-09	2.40E-10	1.10E-11
Te-121m+	8.10E-10	2.90E-09	8.60E-10	1.70E-11
Te-123m	5.90E-10	2.70E-09	7.80E-10	3.50E-12
Te-125m	5.20E-10	2.80E-09	7.70E-10	3.80E-12
Te-127	1.00E-11	1.10E-09	1.70E-11	1.30E-10
Te-127m+	1.50E-09	7.10E-09	2.10E-09	5.30E-12
Te-129	9.40E-13	1.20E-10	7.50E-13	3.00E-10
Te-129m+	2.50E-09	1.40E-08	3.70E-09	1.10E-10
Te-131m+	3.40E-10	6.00E-09	9.30E-08	4.30E-10

Radionuclides[a]	Inhalation			Contamination
	Red marrow	Colon	Thyroid	Derma of skin
	$AF_{2,IV}$ $(\Delta)^b$	$AF_{4,IV}$ $(\Delta)^c$	$AF_{5,IV}$ $(\Delta)^d$	$AF_{6R,V}$ ^{e}
	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/(s*Bq/cm^2))
Te-132+	5.40E-10	1.30E-08	3.20E-08	3.00E-10
I-123	6.50E-12	1.20E-11	7.80E-10	4.40E-12
I-124	1.40E-10	1.40E-10	5.10E-08	ND
I-125	1.30E-11	2.40E-11	2.60E-08	4.30E-12
I-126	1.40E-10	1.20E-10	9.60E-08	1.00E-10
I-129	2.10E-11	5.40E-11	7.30E-08	2.20E-12
I-131	9.60E-11	1.20E-10	8.10E-08	1.10E-10
I-132	2.60E-11	4.60E-11	3.40E-09	2.90E-10
I-133	4.70E-11	1.10E-10	8.20E-08	2.60E-10
I-134	1.10E-11	2.10E-11	5.40E-10	3.50E-10
I-135	4.00E-11	7.30E-11	1.60E-08	2.30E-10
Xe-122	0.00E+00	0.00E+00	NA	0.00E+00
Xe-123+	7.30E-13	1.30E-12	4.40E-10	0.00E+00
Xe-127	0.00E+00	0.00E+00	NA	0.00E+00
Xe-131m	0.00E+00	0.00E+00	NA	0.00E+00
Xe-133	0.00E+00	0.00E+00	NA	0.00E+00
Xe-135	0.00E+00	0.00E+00	NA	0.00E+00
Cs-129	4.70E-11	6.80E-11	NA	0.00E+00
Cs-131	3.40E-11	6.00E-11	NA	2.30E-12
Cs-132	4.50E-10	5.40E-10	NA	0.00E+00
Cs-134	3.70E-09	4.40E-09	NA	1.10E-10
Cs-134m+	4.00E-12	7.40E-12	NA	0.00E+00
Cs-135	3.40E-10	4.60E-10	NA	2.00E-14
Cs-136	2.40E-09	2.90E-09	NA	4.60E-11
^{137}Cs	2.30E-09	2.90E-09	NA	1.40E-10
Ba-131+	1.80E-10	2.30E-09	NA	1.40E-11
Ba-133	2.50E-10	2.70E-09	NA	1.50E-11
Ba-133m	6.80E-11	4.00E-09	NA	ND
Ba-140+	1.10E-09	2.30E-08	NA	4.90E-10
La-137	5.10E-12	3.90E-10	NA	ND
La-140	2.60E-10	1.30E-08	NA	3.20E-10
Ce-139	3.50E-11	1.60E-09	NA	5.10E-12
Ce-141	1.80E-11	5.50E-09	NA	5.60E-11
Ce-143+	3.50E-11	8.40E-09	NA	4.50E-10
Ce-144+	2.40E-11	4.20E-08	NA	4.30E-10
Pr-142	4.50E-12	1.00E-08	NA	3.60E-10
Pr-143	1.40E-12	9.40E-09	NA	2.00E-10
Nd-147+	3.00E-11	8.30E-09	NA	1.30E-10
Nd-149+	3.80E-12	5.50E-10	NA	5.10E-10
Pm-143	6.50E-11	9.90E-10	NA	ND
Pm-144	3.30E-10	3.70E-09	NA	ND

Radionuclides[a]	Inhalation			Contamination
	Red marrow	Colon	Thyroid	Derma of skin
	$AF_{2,IV}$ $(\Delta)^b$	$AF_{4,IV}$ $(\Delta)^c$	$AF_{5,IV}$ $(\Delta)^d$	$AF_{6R,V}$ ^{e}
	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/(s*Bq/cm^2))
Pm-145	7.10E-12	6.40E-10	NA	ND
Pm-147	9.40E-13	2.00E-09	NA	2.10E-13
Pm-148m	4.10E-10	9.30E-09	NA	9.90E-11
Pm-149	2.10E-12	7.90E-09	NA	2.30E-10
Pm-151	3.70E-11	5.30E-09	NA	1.80E-10
Sm-145+	1.50E-11	1.40E-09	NA	ND
Sm-147	6.80E-11	0.00E+00	NA	0.00E+00
Sm-151	3.00E-13	6.40E-10	NA	1.60E-14
Sm-153	9.50E-12	5.70E-09	NA	1.40E-10
Eu-147	9.80E-11	2.40E-09	NA	ND
Eu-148	4.40E-10	4.90E-09	NA	ND
Eu-149	1.40E-11	6.10E-10	NA	ND
Eu-150b	3.10E-10	4.40E-09	NA	ND
Eu-150a	3.10E-12	2.80E-09	NA	ND
Eu-152	2.30E-10	6.70E-09	NA	6.90E-11
Eu-152m	1.50E-11	3.40E-09	NA	2.50E-10
Eu-154	2.50E-10	1.20E-08	NA	1.30E-10
Eu-155	1.50E-11	2.20E-09	NA	2.00E-12
Eu-156	2.30E-10	1.50E-08	NA	1.80E-10
Gd-146+	4.40E-10	8.90E-09	NA	ND
Gd-148	9.70E-11	0.00E+00	NA	0.00E+00
Gd-153	2.50E-11	1.80E-09	NA	5.00E-12
Gd-159	4.60E-12	3.70E-09	NA	2.00E-10
Tb-157	7.00E-13	2.10E-10	NA	ND
Tb-158	1.60E-10	5.40E-09	NA	ND
Tb-160	2.20E-10	1.00E-08	NA	1.30E-10
Dy-159	1.10E-11	6.30E-10	NA	3.40E-12
Dy-165	3.50E-13	4.10E-10	NA	2.70E-10
Dy-166+	1.20E-11	1.50E-08	NA	3.60E-10
Ho-166	3.30E-12	1.10E-08	NA	3.30E-10
Ho-166m	3.70E-10	7.70E-09	NA	2.90E-11
Er-169	8.40E-13	3.00E-09	NA	1.60E-11
Er-171	1.70E-11	2.30E-09	NA	2.40E-10
Tm-167	3.10E-11	4.10E-09	NA	2.00E-11
Tm-170	8.10E-12	1.10E-08	NA	2.10E-10
Tm-171	7.20E-13	8.20E-10	NA	5.20E-14
Yb-169	7.00E-11	4.70E-09	NA	1.20E-11
Yb-175	7.40E-12	3.40E-09	NA	4.70E-11
Lu-172	3.20E-10	6.50E-09	NA	ND
Lu-173	3.10E-11	1.60E-09	NA	ND
Lu-174	2.70E-11	1.70E-09	NA	ND

Radionuclides[a]	Inhalation			Contamination
	Red marrow	Colon	Thyroid	Derma of skin
	$AF_{2,IV}$ $(\Delta)^{b}$	$AF_{4,IV}$ $(\Delta)^{c}$	$AF_{5,IV}$ $(\Delta)^{d}$	$AF_{6R,V}$ [e]
	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/(s*Bq/cm^2))
Lu-174m+	1.60E-11	4.00E-09	NA	ND
Lu-177	7.60E-12	4.20E-09	NA	5.20E-11
Hf-172+	4.00E-10	1.10E-08	NA	ND
Hf-175	8.50E-11	2.30E-09	NA	3.40E-11
Hf-181	1.30E-10	7.50E-09	NA	6.30E-11
Hf-182+	3.10E-10	1.30E-08	NA	6.60E-11
Ta-178a	1.30E-11	2.30E-10	NA	ND
Ta-179	7.70E-12	4.10E-10	NA	ND
Ta-182	2.50E-10	9.30E-09	NA	6.20E-11
W-178	2.90E-11	1.40E-09	NA	ND
W-181	1.10E-11	4.40E-10	NA	3.00E-12
W-185	1.60E-11	3.40E-09	NA	4.00E-11
W-187	5.40E-11	4.90E-09	NA	1.70E-10
W-188+	1.80E-10	1.90E-08	6.30E-09	3.70E-10
Re-184	2.90E-10	2.20E-09	1.60E-09	1.60E-11
Re-184m+	3.00E-10	3.70E-09	2.80E-09	1.60E-11
Re-186	9.90E-11	4.20E-09	4.80E-09	2.20E-10
Re-187	3.50E-13	1.30E-11	1.10E-11	0.00E+00
Re-188	8.00E-11	3.10E-09	6.60E-09	3.60E-10
Re-189	5.20E-11	1.90E-09	3.50E-09	ND
Os-185	1.60E-10	2.10E-09	NA	1.60E-11
Os-191	1.90E-11	4.30E-09	NA	5.20E-12
Os-191m+	1.10E-12	7.10E-10	NA	7.50E-12
Os-193	9.50E-12	6.20E-09	NA	2.20E-10
Os-194+	4.40E-11	2.70E-08	NA	3.70E-10
Ir-189	1.80E-11	1.80E-09	NA	ND
Ir-190	2.90E-10	6.50E-09	NA	4.00E-11
Ir-192	1.90E-10	8.50E-09	NA	1.30E-10
Ir-194	8.90E-12	1.00E-08	NA	3.70E-10
Pt-188+	2.30E-10	5.40E-09	NA	2.20E-11
Pt-191	5.00E-11	2.10E-09	NA	2.10E-11
Pt-193	1.20E-13	2.50E-10	NA	2.00E-12
Pt-193m	2.80E-12	3.60E-09	NA	4.50E-12
Pt-195m	1.40E-11	4.90E-09	NA	7.50E-12
Pt-197	2.40E-12	3.00E-09	NA	1.10E-10
Pt-197m+	9.20E-13	4.10E-10	NA	3.40E-10
Au-193	1.50E-11	8.50E-10	NA	ND
Au-194	1.30E-10	1.90E-09	NA	1.40E-11
Au-195	2.40E-11	1.80E-09	NA	6.00E-12
Au-198	7.60E-11	7.30E-09	NA	2.10E-10
Au-199	2.10E-11	3.30E-09	NA	1.20E-11

Radionuclides[a]	Inhalation			Contamination
	Red marrow	Colon	Thyroid	Derma of skin
	$AF_{2,IV}$ (Δ)[b]	$AF_{4,IV}$ (Δ)[c]	$AF_{5,IV}$ (Δ)[d]	$AF_{6R,V}$ [e]
	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/(s*Bq/cm^2))
Hg-194+	2.10E-09	4.10E-09	NA	1.60E-11
Hg-195m+	1.40E-10	4.00E-09	NA	1.60E-11
Hg-197	5.90E-11	1.70E-09	NA	5.10E-12
Hg-197m+	7.80E-11	3.50E-09	NA	1.10E-11
Hg-203	7.30E-10	3.50E-09	NA	1.80E-11
Tl-200	1.50E-10	2.80E-10	NA	3.80E-11
Tl-201	5.60E-11	2.30E-10	NA	4.80E-12
Tl-202	3.50E-10	7.90E-10	NA	2.10E-11
Tl-204	5.90E-10	3.90E-09	NA	1.50E-10
Pb-201+	4.70E-11	7.10E-10	NA	4.80E-12
Pb-202+	5.40E-10	1.20E-09	NA	2.10E-11
Pb-203	6.80E-11	1.30E-09	NA	2.30E-11
Pb-205	1.90E-11	1.90E-10	NA	2.00E-12
Pb-210+	2.50E-08	1.30E-08	NA	1.90E-10
Pb-212+	6.60E-09	1.90E-08	NA	6.10E-10
Bi-205	3.00E-10	3.70E-09	NA	2.80E-11
Bi-206	5.60E-10	8.80E-09	NA	9.80E-11
Bi-207	3.10E-10	6.50E-09	NA	7.00E-11
Bi-210+	7.30E-10	1.00E-08	NA	1.90E-10
Bi-210m	1.70E-10	1.90E-08	NA	ND
Bi-212+	1.30E-12	0.00E+00	NA	5.70E-10
Po-210	2.30E-08	1.90E-14	NA	9.30E-17
At-211	1.10E-09	3.70E-12	NA	7.20E-11
Rn-222	0.00E+00	0.00E+00	NA	8.60E-15
Ra-223+	2.90E-08	3.00E-08	NA	1.30E-11
Ra-224+	1.90E-08	2.70E-08	NA	9.20E-13
Ra-225+	2.70E-08	1.10E-08	NA	1.50E-11
Ra-226	7.70E-09	6.90E-09	NA	4.90E-10
Ra-228+	2.70E-08	5.80E-08	NA	2.40E-10
Ac-225	1.10E-09	2.00E-08	NA	1.30E-12
Ac-227+	2.90E-08	3.50E-08	NA	8.10E-12
Ac-228	3.30E-11	2.20E-09	NA	2.30E-10
Th-227+	1.40E-08	1.60E-08	NA	2.10E-11
Th-228+	2.40E-08	4.00E-08	NA	1.50E-12
Th-229+	2.90E-08	2.90E-08	NA	2.20E-11
Th-230+	2.50E-10	5.10E-10	NA	5.10E-13
Th-231	1.80E-12	2.60E-09	NA	9.00E-12
Th-232+	1.90E-08	4.10E-08	NA	5.10E-13
Th-234+	1.80E-11	2.70E-08	NA	1.20E-10
Pa-230+	2.00E-10	3.30E-09	NA	2.50E-11
Pa-231+	8.20E-09	1.20E-08	NA	6.50E-12

Radionuclides[a]	Inhalation			Contamination
	Red marrow	Colon	Thyroid	Derma of skin
	$AF_{2,IV}$ (Δ)[b]	$AF_{4,IV}$ (Δ)[c]	$AF_{5,IV}$ (Δ)[d]	$AF_{6R,V}$ [e]
	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/(s*Bq/cm^2))
Pa-233	4.50E-11	6.50E-09	NA	4.40E-11
U-230+	4.30E-09	1.40E-09	NA	7.30E-13
U-232+	2.40E-08	3.80E-08	NA	1.30E-12
U-233	8.30E-10	2.10E-10	NA	7.00E-12
U-234+	8.20E-10	4.30E-10	NA	1.10E-12
U-235+	8.20E-10	7.30E-09	NA	1.30E-11
U-236	7.70E-10	3.70E-10	NA	1.10E-12
U-238+	7.80E-10	2.90E-08	NA	1.40E-12
Depleted U	7.70E-10	1.50E-09	NA	7.10E-13
Np-235	6.40E-13	4.00E-10	NA	ND
Np-236b+	2.30E-11	1.30E-09	NA	ND
Np-236a	3.10E-11	7.10E-09	NA	ND
Np-237+	2.10E-10	9.20E-09	NA	4.70E-11
Np-239	2.60E-11	6.00E-09	NA	5.20E-11
Pu-236	2.20E-10	4.50E-10	NA	ND
Pu-237	1.10E-11	6.70E-10	NA	ND
Pu-238	2.10E-10	3.60E-10	NA	6.00E-13
Pu-239	2.00E-10	2.30E-10	NA	2.30E-13
Pu-240	2.00E-10	3.60E-10	NA	5.70E-13
Pu-241+	1.60E-12	1.70E-10	NA	1.70E-14
Pu-242	1.90E-10	3.00E-10	NA	4.90E-13
Pu-244+	2.70E-10	2.70E-08	NA	4.90E-12
Am-241	1.20E-10	1.90E-09	NA	3.70E-12
Am-242m+	1.10E-10	7.60E-09	NA	1.30E-12
Am-243+	1.60E-10	9.70E-09	NA	3.90E-13
Am-244	4.30E-11	2.90E-09	NA	6.00E-11
Cm-240	9.20E-11	3.60E-10	NA	ND
Cm-241+	1.10E-10	5.20E-09	NA	ND
Cm-242	1.20E-10	3.30E-10	NA	5.40E-13
Cm-243	1.50E-10	4.80E-09	NA	1.80E-11
Cm-244	1.20E-10	2.90E-10	NA	5.10E-13
Cm-245	1.30E-10	2.40E-09	NA	4.50E-12
Cm-246	1.10E-10	2.70E-10	NA	1.70E-12
Cm-247	1.80E-10	6.40E-09	NA	1.10E-11
Cm-248	6.90E-10	ND	NA	2.80E-10
Bk-247	2.70E-10	2.20E-09	NA	ND
Bk-249	7.30E-13	1.10E-09	NA	1.30E-11
Cf-248+	2.70E-10	2.00E-10	NA	ND
Cf-249	3.30E-10	2.10E-09	NA	1.70E-11
Cf-250	2.70E-10	1.90E-10	NA	3.50E-12
Cf-251	2.90E-10	6.80E-09	NA	3.60E-11

Table A-5 RBE-weighted dose conversion factors for immersion in a radioactive gas (EPR-D-Values 2006 table 20).

Radionuclide	Red marrow $AF_{2,VI}$ (Gy-Eq)/(Bq*s/m^3)	Radionuclide	Red marrow $AF_{2,VI}$ (Gy-Eq)/(Bq*s/m^3)
N-13	4.60E-14	Kr-87	4.00E-14
Ar-37	0.00E+00	Xe-122	4.50E-14
Ar-39	6.60E-18	Xe-123	3.50E-14
Ar-41	6.30E-14	Xe-127	1.10E-14
Kr-81	2.40E-16	Xe-131m	2.30E-16
Kr-85	1.10E-16	Xe-133	1.10E-15
Kr-85m	6.40E-15	Xe-135	1.10E-14

Radionuclides[a]	Inhalation			Contamination
	Red marrow	Colon	Thyroid	Derma of skin
	$AF_{2,IV}$ $(\Delta)^b$	$AF_{4,IV}$ $(\Delta)^c$	$AF_{5,IV}$ $(\Delta)^d$	$AF_{6R,V}$ ^{e}
	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/Bq)	((Gy-Eq)/(s*Bq/cm^2))
Cf-252	6.40E-10	ND	NA	3.70E-10
Cf-253	7.70E-11	2.40E-09	NA	3.80E-12
Cf-254	2.80E-08	5.00E-07	NA	3.50E-09
^{239}Pu/^{9}Be	2.00E-10	2.30E-10	NA	2.30E-13
^{241}Am/^{9}Be	1.20E-10	1.90E-09	NA	3.70E-12
End of Table 19				

Table A-6 Criticality limit values (EPR-D-Values table 28). References to the provided citations be found in EPA-D-Values 2006).

Radio-nuclide	Estimates of criticality limit			NMC-II criteria	Criticality criteria used in D-values	
	Ref. [68]	Ref. [69]	Ref. [70]		M_c	A_c
	(g)	(g)	(g)	(g)	(g)	(TBq)
Rn-222			1.50E+01		1.50E+01	8.50E+04
Ra-223			1.50E+01		1.50E+01	2.90E+04
Ra-224			1.50E+01		1.50E+01	8.80E+04
Ra-225			1.50E+01		1.50E+01	2.20E+04
Ra-226			Unlimited		Unlimited	Unlimited
Ra-228			1.50E+01		1.50E+01	1.50E+02
Ac-227			Unlimited		Unlimited	Unlimited
Ac-225			1.50E+01		1.50E+01	4.00E+01
Ac-228			1.50E+01		1.50E+01	1.20E+06
Th-227			1.50E+01		1.50E+01	1.70E+04
Th-228			Unlimited		Unlimited	Unlimited
Th-229			Unlimited		Unlimited	Unlimited
Th-230			Unlimited		Unlimited	Unlimited
Th-231			1.50E+01		1.50E+01	3.00E+05
Th-232			Unlimited		Unlimited	Unlimited
Th-234			1.50E+01		1.50E+01	1.30E+04
Pa-230			1.50E+01		1.50E+01	1.80E+04
Pa-231			1.00E+04		1.00E+04	1.80E+01
Pa-233			1.50E+01		1.50E+01	1.20E+04
U-230			1.50E+01		1.50E+01	1.50E+04
U-232			5.00E+02		5.00E+02	4.00E+02
U-233	5.50E+02 6.70E+02		1.95E+02		2.00E+02	7.00E-02
U-234			5.00E+02		5.00E+02	1.20E-01
U-235	7.60E+02 2.00E+04		2.90E+02	1.00E+03	1.00E+03	8.00E-05
^{235}U>20%				1.00E+03	1.00E+03	8.00E-05
^{235}U 10% - 20%				1.00E+04	1.00E+04	8.00E-04
U-236			Unlimited		Unlimited	Unlimited
U-238			Unlimited		Unlimited	Unlimited
Np-235			5.00E+02		5.00E+02	2.60E+04
Np-236b			1.50E+01		1.50E+01	7.30E-03
Np-236a			1.50E+01		1.50E+01	3.30E+05
Np-237		2.00E+04 3.00E+04	1.00E+04		1.00E+04	2.60E-01
Np-239			Unlimited		Unlimited	Unlimited
Pu-236			5.00E+02	5.00E+02	5.00E+02	9.90E+03
Pu-237			1.50E+01(b)	5.00E+02	1.50E+01	6.80E+03

Continuation of Table 28

Radio-nuclide	Estimates of criticality limit			NMC-II criteria	Criticality criteria used in D-values	
	Ref. [68]	Ref. [69]	Ref. [70]		M_c	A_c
	(g)	(g)	(g)	(g)	(g)	(TBq)
Pu-238		3.00E+03 4.00E+03	1.00E+03	5.00E+02	5.00E+02	3.00E+02
Pu-239	5.10E+02 5.00E+03	4.50E+02	1.45E+02	5.00E+02	5.00E+02	1.00E+00
Pu-240		1.50E+04 2.00E+04	1.00E+04	5.00E+02	5.00E+02	4.00E+00
Pu-241		2.00E+02	6.00E+01	5.00E+02	5.00E+02	2.00E+03
Pu-242		4.00E+04 6.00E+04	1.80E+04	5.00E+02	5.00E+02	7.00E-02
Pu-244			5.00E+02	5.00E+02	5.00E+02	3.30E-04
Am-241		1.60E+04 2.40E+04	1.00E+04		1.00E+04	1.30E+03
Am-242m		1.30+01	4.00E+00		4.00E+00	1.40E+00
Am-243		2.50E+04 3.50E+04	1.00E+04		1.00E+04	7.40E+01
Am-244			2.00E+00		2.00E+00	9.40E+04
Cm-240			2.00E+00		2.00E+00	1.50E+03
Cm-241			2.00E+00		2.00E+00	1.20E+03
Cm-242			5.00E+02		5.00E+02	6.10E+04
Cm-243		9.00E+01	3.50E+01		3.50E+01	6.70E+01
Cm-244		3.00E+03 5.00E+03	1.00E+03		1.00E+03	3.00E+03
Cm-245		3.00E+01	1.40E+01		1.40E+01	8.90E-02
Cm-246			5.00E+02		5.00E+02	5.70E+00
Cm-247		9.00E+02	3.00E+02		3.00E+02	1.00E-03
Cm-248			5.00E+02		5.00E+02	7.90E-02
Bk-247			2.00E+00		2.00E+00	7.80E-02
Bk-249			5.00E+02		5.00E+02	3.00E+04
Cf-248			2.00E+00		2.00E+00	1.20E+02
Cf-249		1.00E+01	4.00E+00		4.00E+00	6.10E-01
Cf-251		5.00E+00	2.00E+00		2.00E+00	8.10E+00
Cf-250			5.00E+02		5.00E+02	2.90E+01
Cf-252			5.00E+02		5.00E+02	1.00E+04
Cf-253			2.00E+00		2.00E+00	2.10E+03
Cf-254			2.00E+00		2.00E+00	6.30E+02

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