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Estimation of External Contamination and Exposure Rates Due to Fission Product Release

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Abstract

In the event of a radiological incident, the release of fission products into the surrounding environment and the ensuing external contamination present a challenge for triage assessment by emergency response personnel. Reference exposure rate and skin dose rate calibration data for emergency response personnel are currently lacking for cases where receptors are externally contaminated with fission products. Simulations were conducted to compute reference exposure rate coefficients and skin dose rate coefficients from photon-emitting fission products of radiological concern. To accomplish this task, simplified mathematical skin phantoms were created using surface area and height specifications from International Commission on Radiological Protection Publication 89. Simulations were conducted using Monte Carlo radiation transport code using newborn, 1-y-old, 5-y-old, 10-y-old, 15-y-old, and adult phantoms for 22 photon-emitting radionuclides. Exposure rate coefficient data were employed in a case study simulating the radionuclide inventory for a 17 × 17 Westinghouse pressurized water reactor, following three burn-up cycles at 14,600 MWd per metric ton of uranium. The decay times following the final cycle represent the relative activity fractions over a period of 0.5–30 d.

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The resulting data can be used as calibration standards for triage efforts in emergency response protocols.

Keywords

emergency planning; exposure; radiation; fission products; skin dose

INTRODUCTION

IN THE event of a radiological incident, the release of fission products into the surrounding environment with ensuing external contamination to members of the public presents a challenge for triage assessment by emergency response personnel. Emergency response personnel operate a plurality of instrumentation to assess exposure and dose rates to externally contaminated receptors (Scarboro et al. 2009; Manger et al. 2011; Dewji et al. 2013; Anigstein et al. 2016a and b) for which standard reference data for instrumentation calibration is deficient. In the scope of this work, external exposure rate coefficients were computed as a standard reference value available to a broad range of instrumentation that may be used to assay contamination during a radiological emergency event, which is an operational quantity that could be correlated with the skin dose contaminated with fission products. Reference data for exposure rate and skin absorbed dose rate coefficients were computed for photon-emitting fission product sources that are externally deposited on a person, resulting in skin contamination.

METHODOLOGY

Reference skin absorbed dose-rate coefficients and exposure- rate coefficients were generated in the scope of this work. This was accomplished by creating mathematical skin phantoms representing newborn to adult ages, simulating surface skin contamination on the phantoms from identified photon-emitting fission products of radiological interest, and computing coefficients normalized per unit-deposited activity (in becquerel) of radionuclide homogeneously distributed on the phantom using Monte Carlo radiation transport code. Exposure rate coefficients were computed at distances of 5 cm, 30 cm, 60 cm, and 90 cm from the midline height of the body.

Fission product identification

To determine fission products of radiological concern, a case study employing a Westinghouse 17 × 17 pressurized water reactor (PWR) was conducted to determine the radionuclide inventory of fission products following three burn-up cycles. This was accomplished using the ORIGEN-ARP radiation burn-up package in the ORIGEN-ARP/SCALE 6.3 code developed at Oak Ridge National Laboratory (ORNL) (Bowman and Gauld 2010). Fuel was assumed to have an enrichment of 4.0% ²³⁵U. Burn-up cycles were assumed to last 1 y at 14,600 MWd per metric ton of uranium (MTU). The burn-up and decay cycles are summarized in Table 1. Decay periods of 30 d were meant to represent outage periods; e.g., refueling. From the output of the third burn-up cycle, a radionuclide

inventory of fission products was generated as a function of post-release/shutdown decay time.

This methodology was validated and integrated with the methodology employed by Freibert (2010), who identified fission products present at fuel release from *Nuclear Chemical Engineering* (Benedict et al. 1981) and published by the US Nuclear Regulatory Commission (NRC) Report 1465 (NUREG-1465), *Accident Source Terms for Light-Water Nuclear Power Plants* (Soffer et al. 1995). From the identified list of photon-emitting fission products, Freibert established a toxicology index and prioritized a final list of photon-emitting fission products. Photon-emitting fission products are of interest in the scope of this study to determine exposure rates as a function of distance from a contaminated person.

The identified photon-emitting radionuclides of concern following a fission product release are given in Table 2 and represent the radionuclides investigated in the scope of this study (with associated decay modes/yields). The activities (in becquerel) of the 22 fission products of radiological interest were excerpted from the SCALE simulation output and are summarized in Table 3 (note $^{137\text{m}}\text{Ba}$ can be considered to be in equilibrium with ^{137}Cs). Table 3 summarizes the activities from the 22 radionuclides, as well as the fraction of the sum of their activities to the total radionuclide inventory computed in SCALE. The contributions of the 22 fission products increase from 7% to 64% over the 30 d decay period, with 50% of the total activity comprising these 22 radionuclides 5 d after shutdown, demonstrating the increase in contribution to the total fission product activity as the decay time increases. The fraction of the activity of each of the 22 fission products to the total radionuclide inventory in the SCALE simulation is depicted in Fig. 1.

Mathematical skin phantom

Skin phantoms were designed for each age listed in International Commission on Radiological Protection (ICRP) Publication 89 (2002) using the adult phantom model as a template created by Veinot et al. (2017) to compute skin doses due to noble gas exposures in various room sizes. ICRP Publication 89 outlines specifications for the surface area and height of each phantom—newborn, 1-y-old, 5-y-old, 10-y-old, 15-y-old (male and female), and adult (male and female). The physiological specifications are summarized in Table 4 for each phantom.

Using the data from ICRP Publication 89 (2002), a width (radius) for each phantom was calculated to create a simplified phantom geometry represented by a hemispherical head situated atop a cylindrical body. The phantom is comprised of an International Commission on Radiation Units and Measurements (ICRU) four-component tissue interior (density 1.00 g cm^{-3}) and skin (90 μm thick), whose tissue material compositions are specified by ICRU Report 46 (White and Wilson 1992). Skin dose in the sensitive layer is tallied over the 50–90 μm thickness. The phantoms stand on a concrete floor and are encased in a room filled with uncontaminated air. Fig. 2 depicts the skin phantom rendering in Visual Editor (VisEd) (Pelowitz et al. 2014).

Monte Carlo simulations

The Monte Carlo N-Particle (MCNP) 6.1 radiation transport code (Pelowitz et al. 2014) was employed to conduct the simulations for each phantom (age and gender) for each photon-emitting 110 radionuclide. The photon energies and intensities employed in the calculation of the skin surface 111 contamination were obtained from ICRP Publication 107 (2008). Skin contamination for each individual radionuclide was simulated as 1- μm -thick unit contamination homogeneously and uniformly distributed within the outer regions of the surface of the skin phantom (Fig. 2).

To estimate exposure rate coefficients at specified distances from each phantom due to each radionuclide, point detector (F5) tallies were employed to simulate point detectors at distances of 5 cm, 30 cm, 60 cm, and 90 cm from the midline height of each phantom. Simulations were run until statistical convergence of 5% relative error for each output value was achieved in MCNP. The MCNP output was integrated with the air kerma per unit fluence (pGy cm^2) response functions reported in ICRP Publication 74 (1996) and normalized to the emission intensity to determine the exposure rate coefficient ($[\mu\text{R s}^{-1}] \text{Bq}^{-1}$) for each source radionuclide and phantom modeled.⁸ Energy deposition (MCNP F6) tallies were employed and output normalized to emission intensity to compute skin absorbed dose coefficients ($[\text{pGy s}^{-1}] \text{Bq}^{-1}$) for each radionuclide, with relative errors converging within 3%. In reality, skin doses due to many of the fission products in Table 1 would be dominated by beta and internal conversion (IC) electron contributions. In the scope of exposure rate coefficients, simulation of photons on the skin is required to determine exposure rates at a distance, for which electron contributions are negligible. In the MCNP simulations, skin and exposure rate coefficients are computed due to skin photon contamination. In the results, contributions due to photons and electrons (beta/IC) in skin dose are reported for completeness.

RESULTS

Exposure rate ($\mu\text{R s}^{-1}$) and skin absorbed dose rate coefficients (pGy s^{-1}) were computed from the Monte Carlo simulations and normalized per becquerel of exposure for each of the 22 fission products of radiological interest.

Skin absorbed dose rate and equivalent dose-rate coefficients

Skin dose coefficients due explicitly to the photon contributions for all phantoms are summarized in Table 5. Skin equivalent dose coefficients from fission products, inclusive of photon and electron contributions, are given for reference in Table 6. Progeny ingrowth of daughter products (except for $^{137}\text{Cs}/^{137\text{m}}\text{Ba}$ in equilibrium) are not considered in the computation of the skin dose and exposure rate coefficients. As tabulated in Table 5, the skin absorbed dose rate coefficient for the newborn (00Y) is as much as an order of magnitude higher than the remaining phantoms, because 1 Bq of the single radionuclide is distributed over the surface area of a smaller phantom, resulting in a higher dose coefficient.

⁸For exposure and dose quantities, traditional units (rather than International System [SI] units) are used when they are the units most likely to be provided by radiation detection instruments.

Skin doses due strictly to photon contributions ranged from 4.16×10^{-4} (pGy s⁻¹) Bq⁻¹ for the adult male to 3.24×10^{-3} (pGy s⁻¹) Bq⁻¹ for the newborn for ¹³¹I. Skin doses due strictly to photon contributions ranged from 6.78×10^{-4} (pGy s⁻¹) Bq⁻¹ for the adult male to 5.26×10^{-3} (pGy s⁻¹) Bq⁻¹ for the newborn for ¹³⁷Cs. When considering the photon and electron contributions to the total equivalent skin dose coefficient, the photon contribution is a minority contributor to the skin equivalent dose coefficient, as given in Table 7. Electron skin dose rate coefficients were obtained from ICRP Publication 107 (2008). The largest photon contribution is from ⁹⁵Nb with an average of 18.5% to the equivalent skin dose. This is due to the emission yields and energies, as ⁹⁵Nb emits a 766 keV photon with 99.8% yield. Electron emissions are 0.04 MeV with 100% and 341 keV with low yield (0.0003). The remaining 21 radionuclides have photon contributions comprising <10% of the equivalent skin dose.

Exposure rate coefficients

Exposure rate coefficients were computed for distances of 5 cm, 30 cm, 60 cm, and 90 cm from the midline height of the skin phantom. For all phantom ages and genders, the exposure rate coefficient data are summarized in Tables 8–11.

Fission products of notable concern for emergency response during a radiological release focus on ^{137m}Ba/¹³⁷Cs and ¹³¹I. The exposure rate coefficients for the newborn ranged from 9.16×10^{-8} (μR s⁻¹) Bq⁻¹ at 5 cm to 2.53×10^{-9} (μR s⁻¹) Bq⁻¹ at 90 cm for ¹³⁷Cs. The exposure rate coefficients for the adult male ranged from 1.68×10^{-8} (μR s⁻¹) Bq⁻¹ at 5 cm to 1.49×10^{-9} (μR s⁻¹) Bq⁻¹ at 90 cm for ¹³⁷Cs. The exposure rate coefficients for the newborn ranged from 5.79×10^{-8} (μR s⁻¹) Bq⁻¹ at 5 cm to 1.64×10^{-9} (μR s⁻¹) Bq⁻¹ at 90 cm for ¹³¹I. The exposure rate coefficients for the adult male ranged from 1.06×10^{-8} (μR s⁻¹) Bq⁻¹ at 5 cm to 9.62×10^{-10} (μR s⁻¹) Bq⁻¹ at 90 cm for ¹³¹I.

In Tables 8–11, the ¹⁴⁰La, ¹³⁶Cs, ^{148m}Pm, and ¹³⁴Cs dose and exposure rate coefficients dominate due to higher activities/yields per decay; however, it is important to note that the magnitude of the exposure and skin dose rate coefficients is relevant only in the context of the released fission product activity.

Minimum exposure rates as a function of skin dose

From a practical standpoint, when using commonly available ion chambers, an exposure rate of 10 mR h⁻¹ approximates the lowest exposure rate that can be measured with accuracy. To better correlate skin dose rates with exposure rates from a practical measurement standpoint, Table 12 summarizes skin dose rates (mrad h⁻¹) corresponding to 10 mR h⁻¹ exposure rates at 30 cm. As an example, assuming this to be the exposure rate from a radionuclide at 30 cm, 1.74×10^6 Bq of ¹⁴⁰Ba produces 10 mR h⁻¹ at 30 cm (adult male), which produces a skin dose rate of 18 mrem h⁻¹. For ¹³⁷Cs/^{137m}Ba, 5.19×10^5 Bq produces 10 mR h⁻¹ at 30 cm (adult male), which produces a skin dose rate of 5 mrem h⁻¹. For ¹³¹I, 8.15×10^5 Bq produces 10 mR h⁻¹ at 30 cm (adult male), which produces a skin dose rate of 8 mrem h⁻¹. Generally, for these three radionuclides, the exposure rate in mR h⁻¹ at 30 cm compares within a factor of ~2 to the skin dose rate in mrem h⁻¹.

Weighted exposure rate coefficients

The combined magnitude of the exposure rate coefficient with the fission product activity must be considered in the context of a case study employing radionuclide inventories following a realistic burn-up life cycle. Therefore, it is useful to determine the relative contribution of the photon-emitting radionuclide coefficient per becquerel (total activity in Table 3) of fission products. This will result in a weighted exposure rate coefficient due to the cumulative photon contributions of the 22 radionuclides per unit activity (Bq) of the entire fission product activity. A weighted exposure rate coefficient is summarized in eqn (1) for a discrete time stamp (t), spanning 0, 1, 2, 5, 10, 15, 20, 25, or 30 d postrelease:

$$\dot{X}_{\text{Weighted}}(t) = \frac{\sum_{i=1}^{22} \dot{X}_i \cdot A_i}{A_{\text{total}}(t)} \quad (1)$$

where:

i = a radionuclide from the 22 radionuclides of interest.

$\dot{X}_i$ = the exposure rate coefficient of the i th radionuclide from the 22 radionuclides.

A_i = the activity of the i th radionuclide at time t obtained from ORIGEN-ARP/SCALE simulation.

A_{total} = the sum of the activities of all radionuclides from ORIGEN-ARP/SCALE simulation.

$\dot{X}_{\text{Weighted}}$ = the exposure coefficient due to the 22 radionuclides of interest, weighted by the total activity of the entire fission product inventory (activity inclusive of the 22 radionuclides plus others).

Weighted exposure rate coefficients are tabulated in Table 13 for all phantoms and distances.

CONCLUSION

In this work, reference exposure rate and skin dose rate coefficient data were reported due to external skin contamination by 22 photon-emitting radionuclides present in fission products. These 22 radionuclides represent more than 50% of the fission product inventory at times greater than 5 d post-reactor shutdown. These fission products of interest were identified from ORIGEN-ARP/SCALE reactor burn-up and decay calculations and prioritized by a toxicity index developed by Freibert (2010). Mathematical skin phantoms were created for four pediatric (newborn, 1-y-old, 5-y-old, 10-y-old), 15-y-old, and adult gender-specific phantoms. The phantom design was derived from reference data from ICRP Publication 89 (2002) and ICRU Report 46 (White and Wilson 1992) specifications on phantom height/surface area and composition, respectively. Skin contamination was simulated as a 1- μm -thick homogeneous deposition layer. For each radionuclide, exposure rate coefficients were computed at 5 cm, 30 cm, 60 cm, and 90 cm distances from the midline of the phantom. Skin dose coefficients were computed for each phantom age/gender, where the photon contribution to the equivalent dose coefficient was quantified. For the majority of the 22 radionuclides of interest, actual skin dose was dominated by electron (beta) emissions;

however, the photon contribution was of interest in determining exposure rate coefficients at offset measurement distances from the phantom.

The reported data provide standard reference exposure rate and skin dose rate coefficients for fission product radionuclides of interest and can be used in conjunction with release fractions, atmospheric transport, deposition fractions, and specific reactor fission product inventories to determine exposure rates and skin doses for radiological protection and emergency response.

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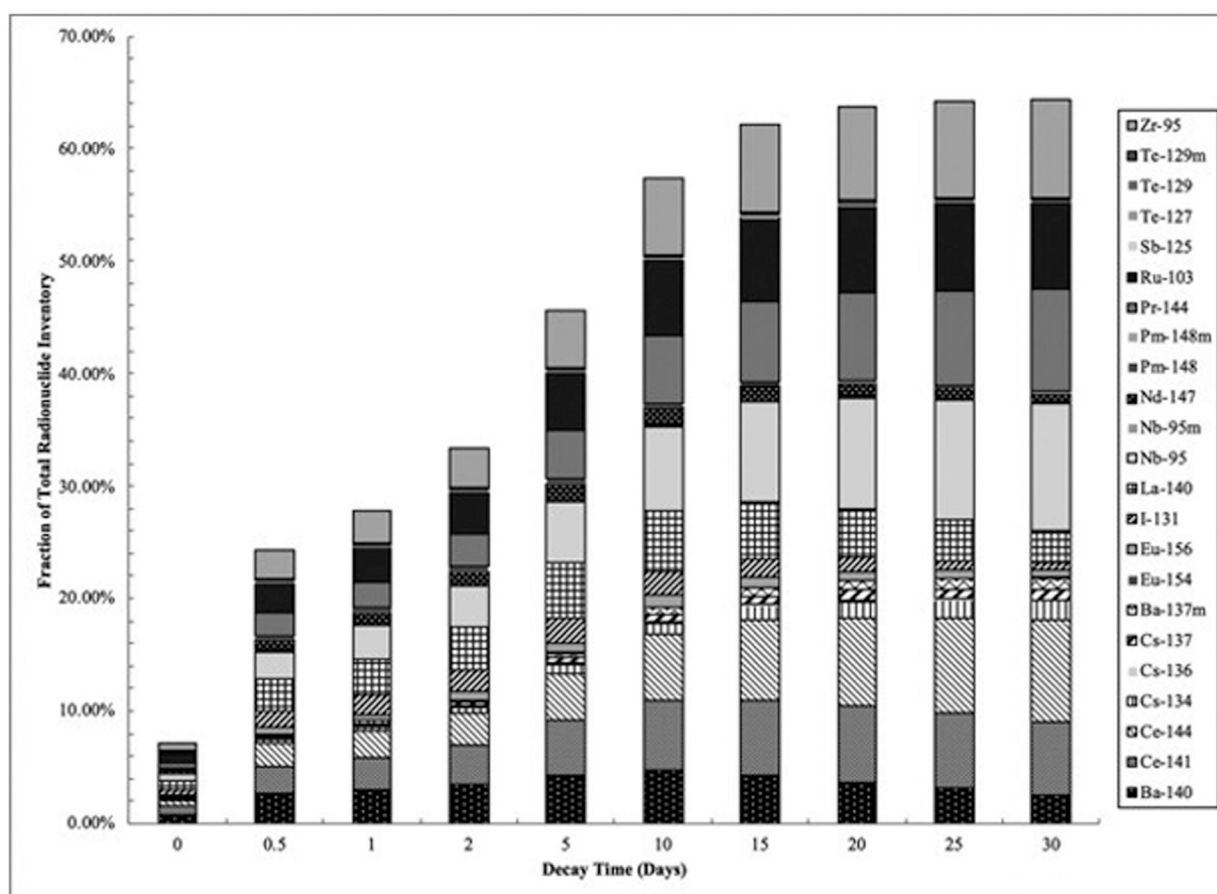


Fig. 1. ORIGIN-ARP/SCALE 6.3 generated activity inventory for fission products of interest as a function of decay time postrelease following three 1-y burn-up cycles at 14,600 MWd MTU⁻¹ for a 17 × 17 Westinghouse PWR.

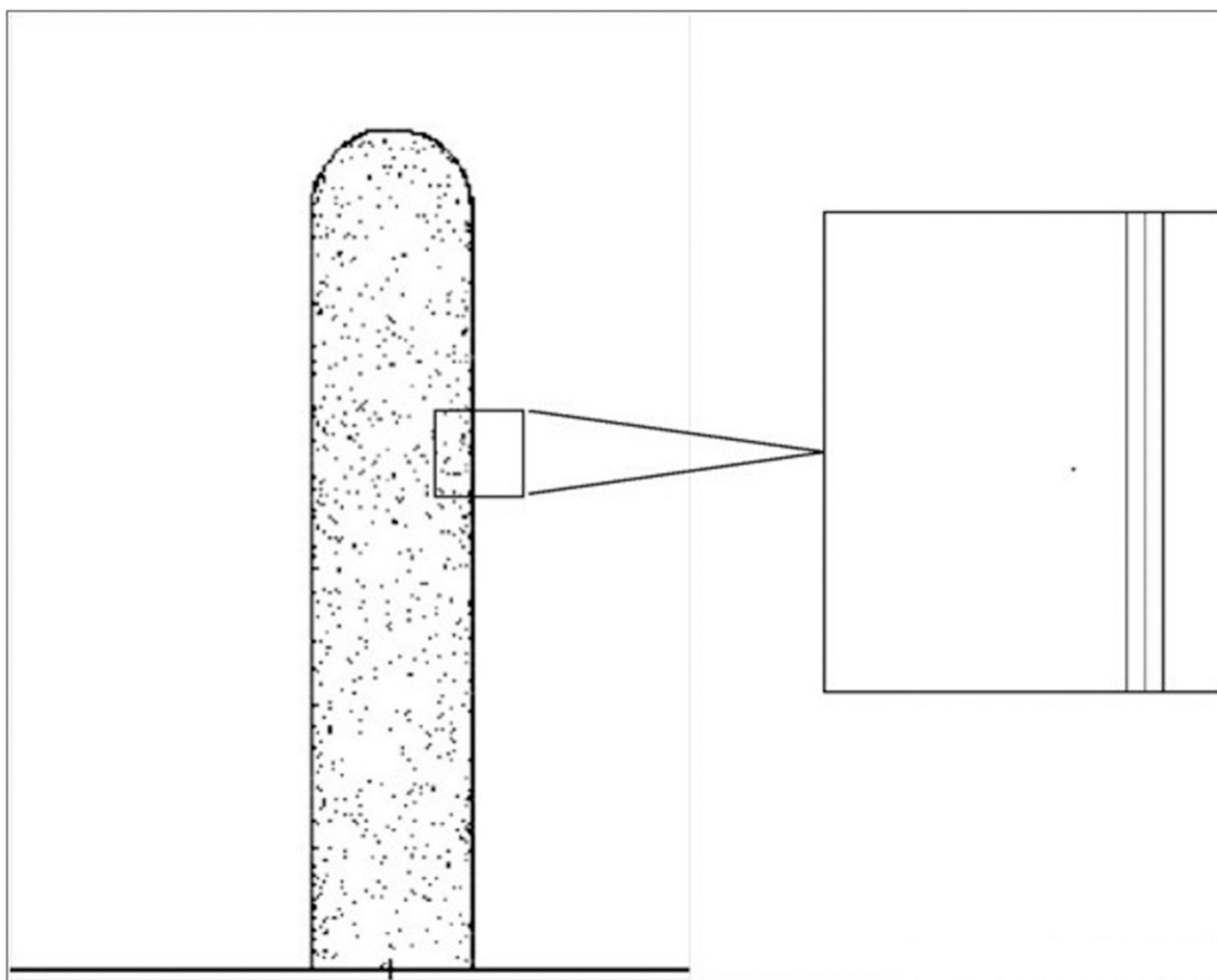


Fig. 2. Skin surface source contamination, shown in VisEd. Inner sensitive layer and outer layer of skin in the phantom are depicted in expanded box (right). Deposition is simulated outside the skin layer, but skin dose is determined from tally on inner sensitive skin layer.

Table 1.

ORIGEN-ARP/SCALE 6.3. Burn-up and decay cycles assumed in the generation of fission production libraries.

Cycle	Type	Duration (d)	Specifications/notes
1	Irradiation	365	Operation 14,600 MWd MTU ⁻¹
2	Decay	30	Outage
3	Irradiation	365	Operation 14,600 MWd MTLT ⁻¹
4	Decay	30	Outage
5	Irradiation	365	Operation 14,600 MWd MTLT ⁻¹
6	Decay	0	Release
7	Decay	0.5, 1, 2, 5, 10, 15, 20, 30	Postrelease

Table 2.

Photon-emitting fission products of interest following a radiological release.^a

Radionuclide	$t_{1/2}$	Decay mode ^b	Distribution (%)		
			Total (MeV per nuclear transformation)	Electron	Photon
¹⁴⁰ Ba	12.752	d	B ⁻	63.67	18.26
¹⁴¹ Ce	32.508	d	B ⁻	69.011	30.989
¹⁴⁴ Ce	284.91	d	B ⁻	82.551	17.449
¹³⁴ Cs	2.0648	y	B ⁻ ; EC	9.534	90.466
¹³⁶ Cs	13.16	d	B ⁻	6.375	93.625
¹³⁷ Cs/ ^{137m} Ba	30.1671	y	B ⁻	99.999	0.001
¹⁵⁴ Eu	8.593	y	B ⁻ ; EC	17.934	82.066
¹⁵⁶ Eu	15.19	d	B ⁻	27.061	72.939
¹³¹ I	8.0207	d	B ⁻	33.388	66.612
¹⁴⁰ La	1.6781	d	B ⁻	18.803	81.197
⁹⁵ Nb	34.991	d	B ⁻	5.508	94.492
^{95m} Nb	3.61	d	IT, B ⁻	72.091	27.909
¹⁴⁷ Nd	10.98	d	B ⁻	65.74	34.26
¹⁴⁸ Pm	5.368	d	B ⁻	55.913	44.087
^{148m} Pm	41.29	d	B ⁻ ; IT	7.862	92.138
¹⁴⁴ Pr	17.28	mo	B ⁻	97.668	2.332
¹⁰³ Ru	39.26	d	B ⁻	11.748	88.252
¹²⁵ Sb	2.75856	y	B ⁻	18.759	81.241
¹²⁷ Te	9.35	h	B ⁻	97.873	2.127
¹²⁹ Te	69.6	mo	B ⁻	89.681	10.319
^{129m} Te	33.6	d	IT; B ⁻	87.818	12.182
⁹⁵ Zr	64.032	d	B ⁻	13.933	86.067

^a From ICRP Publication 107 (2008).

^b B; beta; EC; electron capture; IT; isomeric transition.

Table 3.

Fission product activity (Bq) for radionuclides of interest computed as a function of decay time postrelease in days following three 1-y burn-up cycles at 14,600 MWd MTU⁻¹ for a 17 × 17 Westinghouse PWR.

Radionuclide	Decay time postrelease (d)									
	0.0	0.5	1.0	2.0	5.0	10.0	15.0	20.0	25.0	30.0
¹⁴⁰ Ba	6.72 × 10 ¹⁶	6.54 × 10 ¹⁶	6.36 × 10 ¹⁶	6.02 × 10 ¹⁶	5.12 × 10 ¹⁶	3.90 × 10 ¹⁶	2.97 × 10 ¹⁶	2.27 × 10 ¹⁶	1.73 × 10 ¹⁶	1.32 × 10 ¹⁶
¹⁴¹ Ce	6.36 × 10 ¹⁶	6.32 × 10 ¹⁶	6.25 × 10 ¹⁶	6.12 × 10 ¹⁶	5.74 × 10 ¹⁶	5.16 × 10 ¹⁶	4.64 × 10 ¹⁶	4.17 × 10 ¹⁶	3.75 × 10 ¹⁶	3.37 × 10 ¹⁶
¹⁴⁴ Ce	5.03 × 10 ¹⁶	5.02 × 10 ¹⁶	5.02 × 10 ¹⁶	5.00 × 10 ¹⁶	4.97 × 10 ¹⁶	4.91 × 10 ¹⁶	4.85 × 10 ¹⁶	4.79 × 10 ¹⁶	4.73 × 10 ¹⁶	4.68 × 10 ¹⁶
¹³⁴ Cs	8.97 × 10 ¹⁵	8.96 × 10 ¹⁵	8.96 × 10 ¹⁵	8.95 × 10 ¹⁵	8.92 × 10 ¹⁵	8.88 × 10 ¹⁵	8.84 × 10 ¹⁵	8.80 × 10 ¹⁵	8.76 × 10 ¹⁵	8.72 × 10 ¹⁵
¹³⁶ Cs	2.21 × 10 ¹⁵	2.15 × 10 ¹⁵	2.09 × 10 ¹⁵	1.99 × 10 ¹⁵	1.70 × 10 ¹⁵	1.30 × 10 ¹⁵	1.00 × 10 ¹⁵	7.69 × 10 ¹⁴	5.91 × 10 ¹⁴	4.54 × 10 ¹⁴
¹³⁷ Cs	5.17 × 10 ¹⁵	5.17 × 10 ¹⁵	5.17 × 10 ¹⁵	5.17 × 10 ¹⁵	5.17 × 10 ¹⁵	5.17 × 10 ¹⁵	5.17 × 10 ¹⁵	5.16 × 10 ¹⁵	5.16 × 10 ¹⁵	5.16 × 10 ¹⁵
^{137m} Ba	4.92 × 10 ¹⁵	4.90 × 10 ¹⁵	4.90 × 10 ¹⁵	4.90 × 10 ¹⁵	4.89 × 10 ¹⁵	4.89 × 10 ¹⁵	4.89 × 10 ¹⁵	4.89 × 10 ¹⁵	4.89 × 10 ¹⁵	4.89 × 10 ¹⁵
¹⁵⁴ Eu	3.65 × 10 ¹⁴	3.65 × 10 ¹⁴	3.65 × 10 ¹⁴	3.65 × 10 ¹⁴	3.65 × 10 ¹⁴	3.65 × 10 ¹⁴	3.64 × 10 ¹⁴	3.64 × 10 ¹⁴	3.63 × 10 ¹⁴	3.63 × 10 ¹⁴
¹⁵⁶ Eu	1.30 × 10 ¹⁶	1.27 × 10 ¹⁶	1.24 × 10 ¹⁶	1.19 × 10 ¹⁶	1.03 × 10 ¹⁶	8.24 × 10 ¹⁵	6.56 × 10 ¹⁵	5.22 × 10 ¹⁵	4.15 × 10 ¹⁵	3.31 × 10 ¹⁵
¹³¹ I	4.01 × 10 ¹⁶	3.89 × 10 ¹⁶	3.75 × 10 ¹⁶	3.47 × 10 ¹⁶	2.71 × 10 ¹⁶	1.77 × 10 ¹⁶	1.15 × 10 ¹⁶	7.46 × 10 ¹⁵	4.84 × 10 ¹⁵	3.14 × 10 ¹⁵
¹⁴⁰ La	6.97 × 10 ¹⁶	6.90 × 10 ¹⁶	6.82 × 10 ¹⁶	6.60 × 10 ¹⁶	5.80 × 10 ¹⁶	4.48 × 10 ¹⁶	3.42 × 10 ¹⁶	2.61 × 10 ¹⁶	1.99 × 10 ¹⁶	1.51 × 10 ¹⁶
⁹⁵ Nb	6.33 × 10 ¹⁶	6.33 × 10 ¹⁶	6.32 × 10 ¹⁶	6.32 × 10 ¹⁶	6.31 × 10 ¹⁶	6.26 × 10 ¹⁶	6.19 × 10 ¹⁶	6.09 × 10 ¹⁶	5.98 × 10 ¹⁶	5.86 × 10 ¹⁶
^{95m} Nb	6.91 × 10 ¹⁴	6.90 × 10 ¹⁴	6.89 × 10 ¹⁴	6.85 × 10 ¹⁴	6.71 × 10 ¹⁴	6.42 × 10 ¹⁴	6.11 × 10 ¹⁴	5.80 × 10 ¹⁴	5.49 × 10 ¹⁴	5.21 × 10 ¹⁴
¹⁴⁷ Nd	2.51 × 10 ¹⁶	2.43 × 10 ¹⁶	2.36 × 10 ¹⁶	2.21 × 10 ¹⁶	1.83 × 10 ¹⁶	1.34 × 10 ¹⁶	9.74 × 10 ¹⁵	7.10 × 10 ¹⁵	5.18 × 10 ¹⁵	3.78 × 10 ¹⁵
¹⁴⁶ Pm	8.99 × 10 ¹⁵	8.43 × 10 ¹⁵	7.91 × 10 ¹⁵	6.96 × 10 ¹⁵	4.74 × 10 ¹⁵	2.51 × 10 ¹⁵	1.34 × 10 ¹⁵	7.21 × 10 ¹⁴	3.97 × 10 ¹⁴	2.25 × 10 ¹⁴
^{145m} Pm	1.35 × 10 ¹⁵	1.34 × 10 ¹⁵	1.33 × 10 ¹⁵	1.31 × 10 ¹⁵	1.24 × 10 ¹⁵	1.14 × 10 ¹⁵	1.05 × 10 ¹⁵	9.68 × 10 ¹⁴	8.90 × 10 ¹⁴	8.18 × 10 ¹⁴
¹⁴⁴ Pr	5.07 × 10 ¹⁶	5.02 × 10 ¹⁶	5.02 × 10 ¹⁶	5.01 × 10 ¹⁶	4.97 × 10 ¹⁶	4.91 × 10 ¹⁶	4.85 × 10 ¹⁶	4.79 × 10 ¹⁶	4.73 × 10 ¹⁶	4.68 × 10 ¹⁶
¹⁰³ Ru	6.76 × 10 ¹⁶	6.70 × 10 ¹⁶	6.64 × 10 ¹⁶	6.52 × 10 ¹⁶	6.19 × 10 ¹⁶	5.66 × 10 ¹⁶	5.19 × 10 ¹⁶	4.75 × 10 ¹⁶	4.35 × 10 ¹⁶	3.98 × 10 ¹⁶
¹²⁵ Sb	4.51 × 10 ¹⁴	4.51 × 10 ¹⁴	4.51 × 10 ¹⁴	4.51 × 10 ¹⁴	4.51 × 10 ¹⁴	4.50 × 10 ¹⁴	4.49 × 10 ¹⁴	4.48 × 10 ¹⁴	4.47 × 10 ¹⁴	4.46 × 10 ¹⁴
¹²⁷ Te	3.62 × 10 ¹⁵	3.55 × 10 ¹⁵	3.36 × 10 ¹⁵	2.91 × 10 ¹⁵	1.82 × 10 ¹⁵	8.97 × 10 ¹⁴	5.17 × 10 ¹⁴	3.59 × 10 ¹⁴	2.89 × 10 ¹⁴	2.57 × 10 ¹⁴
¹²⁹ Te	1.14 × 10 ¹⁶	3.34 × 10 ¹⁵	1.54 × 10 ¹⁵	1.20 × 10 ¹⁵	1.12 × 10 ¹⁵	1.01 × 10 ¹⁵	9.13 × 10 ¹⁴	8.23 × 10 ¹⁴	7.43 × 10 ¹⁴	6.70 × 10 ¹⁴
129m-jig	1.96 × 10 ¹⁵	1.95 × 10 ¹⁵	1.93 × 10 ¹⁵	1.89 × 10 ¹⁵	1.78 × 10 ¹⁵	1.60 × 10 ¹⁵	1.45 × 10 ¹⁵	1.30 × 10 ¹⁵	1.18 × 10 ¹⁵	1.06 × 10 ¹⁵
⁹⁵ Zr	6.29 × 10 ¹⁶	6.26 × 10 ¹⁶	6.23 × 10 ¹⁶	6.16 × 10 ¹⁶	5.96 × 10 ¹⁶	5.65 × 10 ¹⁶	5.35 × 10 ¹⁶	5.07 × 10 ¹⁶	4.80 × 10 ¹⁶	4.55 × 10 ¹⁶
Activity from fission product of	6.23 × 10 ¹⁷ (7.1%)	6.08 × 10 ¹⁷ (24.2%)	5.99 × 10 ¹⁷ (27.8%)	5.83 × 10 ¹⁷ (33.3%)	5.39 × 10 ¹⁷ (45.6%)	4.77 × 10 ¹⁷ (57.4%)	4.29 × 10 ¹⁷ (62.1%)	3.90 × 10 ¹⁷ (63.7%)	3.59 × 10 ¹⁷ (64.2%)	3.33 × 10 ¹⁷ (64.4%)

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Radionuclide	Decay time postrelease (d)						
	0.0	0.5	1.0	2.0	5.0	10.0	15.0
Total activity from SCALE	8.73×10^{15}	2.51×10^{15}	2.16×10^{15}	1.75×10^{15}	1.18×10^{15}	8.32×10^{17}	6.91×10^{17}
						6.13×10^{17}	5.59×10^{17}
							5.17×10^{17}

Table 4.

Reference values for height and surface area defined in ICRP Publication 89 (2002).

Age	Height (m)		Surface area (m ²)	
	Male	Female	Male	Female
Newborn	0.51	0.51	0.24	0.24
1 y	0.76	0.76	0.48	0.48
5 y	1.09	1.09	0.78	0.78
10 y	1.38	1.38	1.12	1.12
15 y	1.67	1.61	1.62	1.55
Adult	1.76	1.63	1.90	1.66

Table 5.

Skin absorbed dose-rate coefficient due to skin deposition contamination from photon-emitting contribution of fission products for each age/gender phantom.

Radionuclide	Skin absorbed dose rate coefficient ($\mu\text{Gy s}^{-1} \text{Bq}^{-1}$)							
	00Y	01Y	05Y	10Y	15Y male	15Y female	Adult male	Adult female
^{140}Ba	1.55×10^{-3}	7.63×10^{-4}	4.63×10^{-4}	3.34×10^{-4}	2.22×10^{-4}	2.40×10^{-4}	1.97×10^{-4}	2.19×10^{-4}
^{141}Ce	5.25×10^{-4}	2.58×10^{-4}	1.59×10^{-4}	1.14×10^{-4}	7.50×10^{-5}	8.07×10^{-5}	6.71×10^{-5}	7.49×10^{-5}
^{144}Ce	1.22×10^{-4}	5.98×10^{-5}	3.69×10^{-5}	2.62×10^{-5}	1.74×10^{-5}	1.88×10^{-5}	1.56×10^{-5}	1.75×10^{-5}
^{134}Cs	1.36×10^{-2}	6.72×10^{-3}	4.17×10^{-3}	2.96×10^{-3}	1.97×10^{-3}	2.12×10^{-3}	1.76×10^{-3}	1.95×10^{-3}
^{136}Cs	1.84×10^{-2}	9.02×10^{-3}	5.52×10^{-3}	4.00×10^{-3}	2.68×10^{-3}	2.88×10^{-3}	2.36×10^{-3}	2.64×10^{-3}
$^{137}\text{Cs}/^{137\text{m}}\text{Ba}$	5.26×10^{-3}	2.60×10^{-3}	1.61×10^{-3}	1.14×10^{-3}	7.57×10^{-4}	8.22×10^{-4}	6.78×10^{-4}	7.52×10^{-4}
^{154}Eu	1.04×10^{-2}	5.16×10^{-3}	3.21×10^{-3}	2.26×10^{-3}	1.53×10^{-3}	1.64×10^{-3}	1.33×10^{-3}	1.48×10^{-3}
^{156}Eu	1.08×10^{-2}	5.46×10^{-3}	3.38×10^{-3}	2.33×10^{-3}	1.61×10^{-3}	1.70×10^{-3}	1.42×10^{-3}	1.58×10^{-3}
^{131}I	3.24×10^{-3}	1.61×10^{-3}	9.87×10^{-4}	7.03×10^{-4}	4.67×10^{-4}	5.05×10^{-4}	4.16×10^{-4}	4.66×10^{-4}
^{140}La	1.84×10^{-2}	9.11×10^{-3}	5.59×10^{-3}	4.02×10^{-3}	2.68×10^{-3}	2.92×10^{-3}	2.38×10^{-3}	2.63×10^{-3}
^{95}Nb	6.72×10^{-3}	3.30×10^{-3}	2.04×10^{-3}	1.46×10^{-3}	9.68×10^{-4}	1.05×10^{-3}	8.65×10^{-4}	9.63×10^{-4}
$^{95\text{m}}\text{Nb}$	4.96×10^{-4}	2.43×10^{-4}	1.50×10^{-4}	1.07×10^{-4}	7.10×10^{-5}	7.67×10^{-5}	6.34×10^{-5}	7.09×10^{-5}
^{147}Nd	1.03×10^{-3}	5.16×10^{-4}	3.21×10^{-4}	2.20×10^{-4}	1.51×10^{-4}	1.60×10^{-4}	1.30×10^{-4}	1.46×10^{-4}
^{148}Pm	4.73×10^{-3}	2.34×10^{-3}	1.46×10^{-3}	1.03×10^{-3}	6.94×10^{-4}	7.41×10^{-4}	6.12×10^{-4}	6.84×10^{-4}
$^{149\text{m}}\text{Pm}$	1.74×10^{-2}	8.51×10^{-3}	5.28×10^{-3}	3.76×10^{-3}	2.50×10^{-3}	2.71×10^{-3}	2.25×10^{-3}	2.48×10^{-3}
^{144}Pr	2.10×10^{-4}	1.05×10^{-4}	6.46×10^{-5}	4.61×10^{-5}	3.06×10^{-5}	3.37×10^{-5}	2.72×10^{-5}	3.04×10^{-5}
^{103}Ru	4.13×10^{-3}	2.05×10^{-3}	1.27×10^{-3}	8.89×10^{-4}	5.94×10^{-4}	6.44×10^{-4}	5.32×10^{-4}	5.92×10^{-4}
^{125}Sb	3.62×10^{-3}	1.78×10^{-3}	1.10×10^{-3}	7.85×10^{-4}	5.24×10^{-4}	5.60×10^{-4}	4.66×10^{-4}	5.14×10^{-4}
^{127}Te	3.65×10^{-5}	1.80×10^{-5}	1.12×10^{-5}	7.83×10^{-6}	5.22×10^{-6}	5.65×10^{-6}	4.68×10^{-6}	5.21×10^{-6}
^{129}Te	3.80×10^{-4}	1.89×10^{-4}	1.16×10^{-4}	8.16×10^{-5}	5.43×10^{-5}	5.93×10^{-5}	4.90×10^{-5}	5.44×10^{-5}
$^{129\text{m}}\text{Te}$	2.34×10^{-4}	1.16×10^{-4}	7.11×10^{-5}	5.10×10^{-5}	3.37×10^{-5}	3.66×10^{-5}	3.02×10^{-5}	3.35×10^{-5}
^{95}Zr	6.50×10^{-3}	3.20×10^{-3}	2.00×10^{-3}	1.41×10^{-3}	9.35×10^{-4}	1.02×10^{-3}	8.38×10^{-4}	9.30×10^{-4}

Skin equivalent dose rate coefficient due to skin deposition contamination from photon and electron contributions of fission products for each age/gender phantom.

Table 6.

Radionuclide	Skin equivalent dose rate coefficient (lpSv s ⁻¹ I _{Bq} ⁻¹)							Electron H_{skin} (pGy m ² s ⁻¹ Bq ⁻¹)
	00Y	01Y	05Y	10Y	15Y M	15Y F	Adult M	Adult F
¹⁴⁰ Ba	2.28 × 10 ⁻¹	1.14 × 10 ⁻¹	7.01 × 10 ⁻²	4.88 × 10 ⁻²	3.37 × 10 ⁻²	3.53 × 10 ⁻²	2.88 × 10 ⁻²	3.29 × 10 ⁻²
¹⁴¹ Ce	2.20 × 10 ⁻¹	1.10 × 10 ⁻¹	6.76 × 10 ⁻²	4.71 × 10 ⁻²	3.25 × 10 ⁻²	3.40 × 10 ⁻²	2.78 × 10 ⁻²	3.18 × 10 ⁻²
¹⁴⁴ Ce	1.14 × 10 ⁻¹	5.71 × 10 ⁻²	3.52 × 10 ⁻²	2.45 × 10 ⁻²	1.69 × 10 ⁻²	1.77 × 10 ⁻²	1.44 × 10 ⁻²	1.65 × 10 ⁻²
¹³⁴ Cs	1.68 × 10 ⁻¹	8.40 × 10 ⁻²	5.17 × 10 ⁻²	3.61 × 10 ⁻²	2.49 × 10 ⁻²	2.61 × 10 ⁻²	2.13 × 10 ⁻²	2.43 × 10 ⁻²
¹³⁶ Cs	1.97 × 10 ⁻¹	9.84 × 10 ⁻²	6.05 × 10 ⁻²	4.23 × 10 ⁻²	2.92 × 10 ⁻²	3.06 × 10 ⁻²	2.49 × 10 ⁻²	2.85 × 10 ⁻²
¹³⁷ Cs/ ^{137m} Ba	2.29 × 10 ⁻¹	1.15 × 10 ⁻¹	7.06 × 10 ⁻²	4.92 × 10 ⁻²	3.40 × 10 ⁻²	3.55 × 10 ⁻²	2.90 × 10 ⁻²	3.32 × 10 ⁻²
¹⁵⁴ Eu	2.52 × 10 ⁻¹	1.26 × 10 ⁻¹	7.74 × 10 ⁻²	5.40 × 10 ⁻²	3.73 × 10 ⁻²	3.90 × 10 ⁻²	3.18 × 10 ⁻²	3.64 × 10 ⁻²
¹⁵⁶ Eu	2.29 × 10 ⁻¹	1.15 × 10 ⁻¹	7.06 × 10 ⁻²	4.91 × 10 ⁻²	3.40 × 10 ⁻²	3.55 × 10 ⁻²	2.90 × 10 ⁻²	3.31 × 10 ⁻²
¹³¹ I	2.04 × 10 ⁻¹	1.02 × 10 ⁻¹	6.28 × 10 ⁻²	4.37 × 10 ⁻²	3.02 × 10 ⁻²	3.16 × 10 ⁻²	2.58 × 10 ⁻²	2.95 × 10 ⁻²
¹⁴⁰ La	2.83 × 10 ⁻¹	1.41 × 10 ⁻¹	8.70 × 10 ⁻²	6.07 × 10 ⁻²	4.19 × 10 ⁻²	4.39 × 10 ⁻²	3.58 × 10 ⁻²	4.09 × 10 ⁻²
⁹⁵ Nb	3.62 × 10 ⁻²	1.81 × 10 ⁻²	1.11 × 10 ⁻²	7.78 × 10 ⁻³	5.34 × 10 ⁻²	5.62 × 10 ⁻³	4.59 × 10 ⁻³	5.23 × 10 ⁻²
^{95m} Nb	2.15 × 10 ⁻¹	1.07 × 10 ⁻¹	6.60 × 10 ⁻²	4.60 × 10 ⁻²	3.18 × 10 ⁻²	3.32 × 10 ⁻²	2.71 × 10 ⁻²	3.10 × 10 ⁻²
¹⁴⁷ Nd	2.20 × 10 ⁻¹	1.10 × 10 ⁻¹	6.76 × 10 ⁻²	4.71 × 10 ⁻²	3.26 × 10 ⁻²	3.40 × 10 ⁻²	2.78 × 10 ⁻²	3.18 × 10 ⁻²
¹⁴⁶ Pm	2.69 × 10 ⁻¹	1.34 × 10 ⁻¹	8.27 × 10 ⁻²	5.76 × 10 ⁻²	3.98 × 10 ⁻²	4.16 × 10 ⁻²	3.40 × 10 ⁻²	3.89 × 10 ⁻²
^{148m} Pm	1.97 × 10 ⁻¹	9.81 × 10 ⁻²	6.04 × 10 ⁻²	4.22 × 10 ⁻²	2.90 × 10 ⁻²	3.05 × 10 ⁻²	2.49 × 10 ⁻²	2.84 × 10 ⁻²
¹⁺⁴ Pr	2.86 × 10 ⁻¹	1.43 × 10 ⁻¹	8.79 × 10 ⁻²	6.12 × 10 ⁻²	4.23 × 10 ⁻²	4.42 × 10 ⁻²	3.61 × 10 ⁻²	4.13 × 10 ⁻²
¹⁰³ Ru	7.50 × 10 ⁻¹	3.75 × 10 ⁻¹	2.31 × 10 ⁻¹	1.61 × 10 ⁻¹	1.11 × 10 ⁻¹	1.16 × 10 ⁻¹	9.48 × 10 ⁻²	1.08 × 10 ⁻¹
¹²⁵ Sb	1.00 × 10 ⁻¹	5.01 × 10 ⁻²	3.08 × 10 ⁻²	2.15 × 10 ⁻²	1.48 × 10 ⁻²	1.55 × 10 ⁻²	1.27 × 10 ⁻²	1.45 × 10 ⁻²
¹²⁷ Te	2.14 × 10 ⁻¹	1.07 × 10 ⁻¹	6.59 × 10 ⁻²	4.59 × 10 ⁻²	3.17 × 10 ⁻²	3.32 × 10 ⁻²	2.71 × 10 ⁻²	3.10 × 10 ⁻²
¹²⁹ Te	2.59 × 10 ⁻¹	1.30 × 10 ⁻¹	7.97 × 10 ⁻²	5.55 × 10 ⁻²	3.84 × 10 ⁻²	4.01 × 10 ⁻²	3.27 × 10 ⁻²	3.75 × 10 ⁻²
^{129m} Te	1.67 × 10 ⁻¹	8.37 × 10 ⁻²	5.15 × 10 ⁻²	3.59 × 10 ⁻²	2.48 × 10 ⁻²	2.59 × 10 ⁻²	2.11 × 10 ⁻²	2.42 × 10 ⁻²
⁹⁵ Zr	1.58 × 10 ⁻¹	7.90 × 10 ⁻²	4.87 × 10 ⁻²	3.39 × 10 ⁻²	2.34 × 10 ⁻²	2.45 × 10 ⁻²	2.00 × 10 ⁻²	2.29 × 10 ⁻²

Table 7.

Average percent contribution of photon skin absorbed dose coefficient to skin equivalent dose coefficient.

Radionuclide	Photon dose contribution (%)
¹⁴⁰ Ba	0.67
¹⁴¹ Ce	0.24
¹⁴⁴ Ce	0.11
¹³⁴ Cs	8.09
¹³⁶ Cs	9.30
¹³⁷ Cs/ ^{137m} Ba	2.29
¹⁵⁴ Eu	4.14
¹⁵⁶ Eu	4.78
¹³¹ I	1.59
¹⁴⁰ La	6.52
⁹⁵ Nb	18.50
^{95m} Nb	0.23
¹⁴⁷ Nd	0.47
¹⁴⁸ Pm	1.77
^{148m} Pm	8.81
¹⁴⁴ Pr	0.07
¹⁰³ Ru	5.50
¹²⁵ Sb	3.59
¹²⁷ Te	0.02
¹²⁹ Te	0.15
^{129m} Te	0.14
⁹⁵ Zr	4.11

Exposure rate coefficient at 5 cm distance at midheight due to skin deposition contamination by photon-emitting fission products for each age/gender phantom.

Table 8.

Radionuclide	Exposure rate coefficient ($\mu\text{R s}^{-1} \text{Bq}^{-1}$)							
	00Y	01Y	05Y	10Y	15Y male	15Y female	Adult male	Adult female
^{140}Ba	2.73×10^{-8}	1.60×10^{-8}	1.06×10^{-8}	7.79×10^{-9}	5.66×10^{-9}	5.91×10^{-9}	4.97×10^{-9}	5.59×10^{-9}
^{141}Ce	9.9×10^{-9}	5.85×10^{-9}	3.88×10^{-9}	2.85×10^{-9}	2.08×10^{-9}	2.17×10^{-9}	1.83×10^{-9}	2.06×10^{-9}
^{144}Ce	2.39×10^{-9}	1.40×10^{-9}	9.26×10^{-10}	6.78×10^{-10}	4.97×10^{-10}	5.18×10^{-10}	4.38×10^{-10}	4.91×10^{-10}
^{134}Cs	2.38×10^{-7}	1.40×10^{-7}	9.28×10^{-8}	6.81×10^{-8}	4.96×10^{-8}	5.17×10^{-8}	4.35×10^{-8}	4.89×10^{-8}
^{136}Cs	3.20×10^{-7}	1.88×10^{-7}	1.25×10^{-7}	9.18×10^{-8}	6.68×10^{-8}	6.96×10^{-8}	5.86×10^{-8}	6.58×10^{-8}
$^{137}\text{Cs}/^{137\text{m}}\text{Ba}$	9.16×10^{-8}	5.37×10^{-8}	3.57×10^{-8}	2.62×10^{-8}	1.91×10^{-8}	1.99×10^{-8}	1.68×10^{-8}	1.88×10^{-8}
^{154}Eu	1.82×10^{-7}	1.07×10^{-7}	7.12×10^{-8}	5.23×10^{-8}	3.82×10^{-8}	3.97×10^{-8}	3.34×10^{-8}	3.76×10^{-8}
^{156}Eu	1.89×10^{-7}	1.12×10^{-7}	7.47×10^{-8}	5.49×10^{-8}	3.99×10^{-8}	4.17×10^{-8}	3.51×10^{-8}	3.95×10^{-8}
^{131}I	5.79×10^{-8}	3.39×10^{-8}	2.25×10^{-8}	1.65×10^{-8}	1.20×10^{-8}	1.25×10^{-8}	1.06×10^{-8}	1.19×10^{-8}
^{140}La	3.20×10^{-7}	1.89×10^{-7}	1.26×10^{-7}	9.25×10^{-8}	6.74×10^{-8}	7.02×10^{-8}	5.91×10^{-8}	6.63×10^{-8}
^{95}Nb	1.17×10^{-7}	6.85×10^{-8}	4.56×10^{-8}	3.34×10^{-8}	2.43×10^{-8}	2.54×10^{-8}	2.14×10^{-8}	2.40×10^{-8}
$^{95\text{m}}\text{Nb}$	9.00×10^{-9}	5.25×10^{-9}	3.49×10^{-9}	2.56×10^{-9}	1.86×10^{-9}	1.95×10^{-9}	1.64×10^{-9}	1.84×10^{-9}
^{147}Nd	1.90×10^{-8}	1.11×10^{-8}	7.40×10^{-9}	5.42×10^{-9}	3.95×10^{-9}	4.14×10^{-9}	3.48×10^{-9}	3.90×10^{-9}
^{148}Pm	8.27×10^{-8}	4.86×10^{-8}	3.24×10^{-8}	2.38×10^{-8}	1.73×10^{-8}	1.81×10^{-8}	1.52×10^{-8}	1.71×10^{-8}
$^{148\text{m}}\text{Pm}$	3.04×10^{-7}	1.78×10^{-7}	1.18×10^{-7}	8.68×10^{-8}	6.33×10^{-8}	6.59×10^{-8}	5.55×10^{-8}	6.24×10^{-8}
^{144}Pr	3.68×10^{-9}	2.17×10^{-9}	1.45×10^{-9}	1.07×10^{-9}	7.75×10^{-10}	8.08×10^{-10}	6.81×10^{-10}	7.64×10^{-10}
^{103}Ru	7.29×10^{-8}	4.26×10^{-8}	2.83×10^{-8}	2.08×10^{-8}	1.51×10^{-8}	1.58×10^{-8}	1.33×10^{-8}	1.49×10^{-8}
^{125}Sb	6.37×10^{-8}	3.73×10^{-8}	2.48×10^{-8}	1.82×10^{-8}	1.32×10^{-8}	1.38×10^{-8}	1.16×10^{-8}	1.30×10^{-8}
^{127}Te	6.45×10^{-10}	3.78×10^{-10}	2.51×10^{-10}	1.84×10^{-10}	1.34×10^{-10}	1.40×10^{-10}	1.18×10^{-10}	1.32×10^{-10}
^{129}Te	6.71×10^{-9}	3.93×10^{-9}	2.61×10^{-9}	1.91×10^{-9}	1.39×10^{-9}	1.45×10^{-9}	1.22×10^{-9}	1.37×10^{-9}
$^{129\text{m}}\text{Te}$	4.07×10^{-9}	2.38×10^{-9}	1.59×10^{-9}	1.16×10^{-9}	8.47×10^{-10}	8.83×10^{-10}	7.44×10^{-10}	8.36×10^{-10}
^{95}Zr	1.13×10^{-7}	6.62×10^{-8}	4.41×10^{-8}	3.23×10^{-8}	2.35×10^{-8}	2.45×10^{-8}	2.07×10^{-8}	2.32×10^{-8}

Exposure rate coefficient at 30 cm distance at midheight due to skin deposition contamination by photon-emitting fission products for each age/gender phantom.

Table 9.

Radionuclide	Exposure rate coefficient ($\mu\text{R s}^{-1} \text{I}_0^{-1} \text{Bq}^{-1}$)							
	00Y	01Y	05Y	10Y	15Y male	15Y female	Adult male	Adult female
^{140}Ba	4.49×10^{-9}	3.42×10^{-9}	2.69×10^{-9}	2.19×10^{-9}	1.76×10^{-9}	1.81×10^{-9}	1.60×10^{-9}	1.74×10^{-9}
^{141}Ce	1.71×10^{-9}	1.30×10^{-9}	1.02×10^{-9}	8.27×10^{-10}	6.65×10^{-10}	6.86×10^{-10}	6.07×10^{-10}	6.62×10^{-10}
^{144}Ce	4.08×10^{-10}	3.11×10^{-10}	2.43×10^{-10}	1.98×10^{-10}	1.59×10^{-10}	1.64×10^{-10}	1.45×10^{-10}	1.58×10^{-10}
^{134}Cs	3.87×10^{-8}	2.96×10^{-8}	2.34×10^{-8}	1.91×10^{-8}	1.53×10^{-8}	1.57×10^{-8}	1.39×10^{-8}	1.51×10^{-8}
^{136}Cs	5.18×10^{-8}	3.97×10^{-8}	3.14×10^{-8}	2.56×10^{-8}	2.06×10^{-8}	2.12×10^{-8}	1.87×10^{-8}	2.04×10^{-8}
$^{137}\text{Cs}/^{137\text{m}}\text{Ba}$	1.49×10^{-8}	1.14×10^{-8}	9.00×10^{-9}	7.33×10^{-9}	5.88×10^{-9}	6.06×10^{-9}	5.35×10^{-9}	5.83×10^{-9}
^{154}Eu	2.94×10^{-8}	2.26×10^{-8}	1.79×10^{-8}	1.46×10^{-8}	1.17×10^{-8}	1.21×10^{-8}	1.07×10^{-8}	1.16×10^{-8}
^{156}Eu	3.03×10^{-8}	2.34×10^{-8}	1.86×10^{-8}	1.52×10^{-8}	1.22×10^{-8}	1.26×10^{-8}	1.11×10^{-8}	1.21×10^{-8}
131I	9.60×10^{-9}	7.30×10^{-9}	5.73×10^{-9}	4.66×10^{-9}	3.75×10^{-9}	3.86×10^{-9}	3.41×10^{-9}	3.71×10^{-9}
^{140}La	5.14×10^{-8}	3.96×10^{-8}	3.15×10^{-8}	2.57×10^{-8}	2.07×10^{-8}	2.13×10^{-8}	1.88×10^{-8}	2.05×10^{-8}
^{95}Nb	1.89×10^{-8}	1.45×10^{-8}	1.15×10^{-8}	9.34×10^{-9}	7.48×10^{-9}	7.71×10^{-9}	6.82×10^{-9}	7.42×10^{-9}
$^{95\text{m}}\text{Nb}$	1.52×10^{-9}	1.15×10^{-9}	9.01×10^{-10}	7.32×10^{-10}	5.88×10^{-10}	6.06×10^{-10}	5.36×10^{-10}	5.85×10^{-10}
^{147}Nd	3.15×10^{-9}	2.41×10^{-9}	1.89×10^{-9}	1.54×10^{-9}	1.24×10^{-9}	1.28×10^{-9}	1.13×10^{-9}	1.23×10^{-9}
^{148}Pm	1.33×10^{-8}	1.02×10^{-8}	8.11×10^{-9}	6.63×10^{-9}	5.32×10^{-9}	5.48×10^{-9}	4.84×10^{-9}	5.27×10^{-9}
$^{148\text{m}}\text{Pm}$	4.95×10^{-8}	3.78×10^{-8}	2.98×10^{-8}	2.43×10^{-8}	1.95×10^{-8}	2.01×10^{-8}	1.78×10^{-8}	1.93×10^{-8}
^{144}Pr	5.89×10^{-10}	4.55×10^{-10}	3.61×10^{-10}	2.96×10^{-10}	2.38×10^{-10}	2.45×10^{-10}	2.16×10^{-10}	2.36×10^{-10}
^{103}Ru	1.20×10^{-8}	9.11×10^{-9}	7.17×10^{-9}	5.84×10^{-9}	4.68×10^{-9}	4.83×10^{-9}	4.26×10^{-9}	4.64×10^{-9}
^{125}Sb	1.05×10^{-8}	7.97×10^{-9}	6.28×10^{-9}	5.11×10^{-9}	4.10×10^{-9}	4.23×10^{-9}	3.73×10^{-9}	4.06×10^{-9}
^{127}Te	1.07×10^{-10}	8.11×10^{-11}	6.38×10^{-11}	5.18×10^{-11}	4.16×10^{-11}	4.29×10^{-11}	3.79×10^{-11}	4.13×10^{-11}
^{129}Te	1.11×10^{-9}	8.42×10^{-10}	6.62×10^{-10}	5.39×10^{-10}	4.32×10^{-10}	4.46×10^{-10}	3.93×10^{-10}	4.28×10^{-10}
$^{129\text{m}}\text{Te}$	6.61×10^{-10}	5.06×10^{-10}	3.99×10^{-10}	3.26×10^{-10}	2.61×10^{-10}	2.69×10^{-10}	2.38×10^{-10}	2.59×10^{-10}
^{95}Zr	1.83×10^{-8}	1.40×10^{-8}	1.11×10^{-8}	9.04×10^{-9}	7.24×10^{-9}	7.46×10^{-9}	6.60×10^{-9}	7.18×10^{-9}

Exposure rate coefficient at 60 cm distance at midheight due to skin deposition contamination by photon-emitting fission products for each age/gender phantom.

Table 10.

Radionuclide	Exposure rate coefficient ($\mu\text{R s}^{-1} \text{Bq}^{-1}$)							
	00Y	01Y	05Y	10Y	15Y male	15Y female	Adult male	Adult female
^{140}Ba	1.54×10^{-9}	1.30×10^{-9}	1.12×10^{-9}	9.71×10^{-10}	8.25×10^{-10}	8.43×10^{-10}	7.67×10^{-10}	8.18×10^{-10}
^{141}Ce	5.92×10^{-10}	5.00×10^{-10}	4.29×10^{-10}	3.73×10^{-10}	3.18×10^{-10}	3.25×10^{-10}	2.96×10^{-10}	3.16×10^{-10}
^{144}Ce	1.41×10^{-10}	1.19×10^{-10}	1.03×10^{-10}	8.93×10^{-11}	7.60×10^{-11}	7.78×10^{-11}	7.10×10^{-11}	7.56×10^{-11}
^{134}Cs	1.32×10^{-8}	1.12×10^{-8}	9.63×10^{-9}	8.38×10^{-9}	7.14×10^{-9}	7.29×10^{-9}	6.64×10^{-9}	7.07×10^{-9}
^{136}Cs	1.76×10^{-8}	1.49×10^{-8}	1.29×10^{-8}	1.13×10^{-8}	9.61×10^{-9}	9.80×10^{-9}	8.92×10^{-9}	9.50×10^{-9}
$^{137}\text{Cs}/^{137\text{m}}\text{Ba}$	5.09×10^{-9}	4.29×10^{-9}	3.71×10^{-9}	3.23×10^{-9}	2.75×10^{-9}	2.81×10^{-9}	2.55×10^{-9}	2.72×10^{-9}
^{154}Eu	9.96×10^{-9}	8.45×10^{-9}	7.33×10^{-9}	6.41×10^{-9}	5.47×10^{-9}	5.58×10^{-9}	5.08×10^{-9}	5.41×10^{-9}
^{156}Eu	1.02×10^{-8}	8.72×10^{-9}	7.60×10^{-9}	6.66×10^{-9}	5.69×10^{-9}	5.81×10^{-9}	5.29×10^{-9}	5.64×10^{-9}
^{131}I	3.30×10^{-9}	2.77×10^{-9}	2.38×10^{-9}	2.07×10^{-9}	1.76×10^{-9}	1.80×10^{-9}	1.64×10^{-9}	1.75×10^{-9}
^{140}La	1.74×10^{-8}	1.48×10^{-8}	1.29×10^{-8}	1.13×10^{-8}	9.62×10^{-9}	9.81×10^{-9}	8.95×10^{-9}	9.53×10^{-9}
^{95}Nb	6.44×10^{-9}	5.44×10^{-9}	4.71×10^{-9}	4.10×10^{-9}	3.49×10^{-9}	3.57×10^{-9}	3.25×10^{-9}	3.46×10^{-9}
$^{95\text{m}}\text{Nb}$	5.25×10^{-10}	4.41×10^{-10}	3.79×10^{-10}	3.28×10^{-10}	2.79×10^{-10}	2.85×10^{-10}	2.60×10^{-10}	2.77×10^{-10}
^{147}Nd	1.08×10^{-9}	9.12×10^{-10}	7.87×10^{-10}	6.84×10^{-10}	5.83×10^{-10}	5.96×10^{-10}	5.43×10^{-10}	5.78×10^{-10}
^{148}Pm	4.51×10^{-9}	3.83×10^{-9}	3.33×10^{-9}	2.91×10^{-9}	2.48×10^{-9}	2.53×10^{-9}	2.30×10^{-9}	2.46×10^{-9}
$^{148\text{m}}\text{Pm}$	1.69×10^{-8}	1.43×10^{-8}	1.23×10^{-8}	1.07×10^{-8}	9.12×10^{-9}	9.32×10^{-9}	8.48×10^{-9}	9.04×10^{-9}
^{1+4}Pr	1.99×10^{-10}	1.70×10^{-10}	1.48×10^{-10}	1.29×10^{-10}	1.11×10^{-10}	1.13×10^{-10}	1.03×10^{-10}	1.09×10^{-10}
^{103}Ru	4.10×10^{-9}	3.45×10^{-9}	2.97×10^{-9}	2.58×10^{-9}	2.19×10^{-9}	2.24×10^{-9}	2.04×10^{-9}	2.18×10^{-9}
^{125}Sb	3.58×10^{-9}	3.01×10^{-9}	2.60×10^{-9}	2.26×10^{-9}	1.92×10^{-9}	1.96×10^{-9}	1.79×10^{-9}	1.90×10^{-9}
^{127}Te	3.66×10^{-11}	3.08×10^{-11}	2.65×10^{-11}	2.30×10^{-11}	1.96×10^{-11}	2.00×10^{-11}	1.82×10^{-11}	1.94×10^{-11}
^{129}Te	3.79×10^{-10}	3.19×10^{-10}	2.75×10^{-10}	2.39×10^{-10}	2.03×10^{-10}	2.07×10^{-10}	1.89×10^{-10}	2.01×10^{-10}
$^{129\text{m}}\text{Te}$	2.25×10^{-10}	1.90×10^{-10}	1.65×10^{-10}	1.43×10^{-10}	1.22×10^{-10}	1.24×10^{-10}	1.13×10^{-10}	1.21×10^{-10}
^{95}Zr	6.24×10^{-9}	5.27×10^{-9}	4.56×10^{-9}	3.97×10^{-9}	3.38×10^{-9}	3.45×10^{-9}	3.14×10^{-9}	3.35×10^{-9}

Exposure rate coefficient at 90 cm distance at midheight due to skin deposition contamination by photon-emitting fission products for each age/gender phantom.

Table 11.

Radionuclide	Exposure rate coefficient ($\mu\text{R s}^{-1} \text{Bq}^{-1}$)							
	00Y	01Y	05Y	10Y	15Y male	15Y female	Adult male	Adult female
^{140}Ba	7.66×10^{-10}	6.71×10^{-10}	6.04×10^{-10}	5.44×10^{-10}	4.78×10^{-10}	4.86×10^{-10}	4.50×10^{-10}	4.73×10^{-10}
^{141}Ce	2.94×10^{-10}	2.60×10^{-10}	2.35×10^{-10}	2.11×10^{-10}	1.86×10^{-10}	1.90×10^{-10}	1.76×10^{-10}	1.85×10^{-10}
^{144}Ce	6.98×10^{-11}	6.19×10^{-11}	5.60×10^{-11}	5.04×10^{-11}	4.45×10^{-11}	4.53×10^{-11}	$4.21\text{E-}11$	4.42×10^{-11}
^{134}Cs	6.56×10^{-9}	5.75×10^{-9}	5.18×10^{-9}	4.67×10^{-9}	4.12×10^{-9}	4.18×10^{-9}	3.88×10^{-9}	4.08×10^{-9}
^{136}Cs	8.74×10^{-9}	7.69×10^{-9}	6.94×10^{-9}	6.27×10^{-9}	5.54×10^{-9}	5.62×10^{-9}	5.21×10^{-9}	5.47×10^{-9}
$^{137}\text{Cs}/^{137\text{m}}\text{Ba}$	2.53×10^{-9}	2.22×10^{-9}	2.00×10^{-9}	1.80×10^{-9}	1.59×10^{-9}	1.61×10^{-9}	1.49×10^{-9}	1.57×10^{-9}
^{154}Eu	4.94×10^{-9}	4.36×10^{-9}	3.94×10^{-9}	3.57×10^{-9}	3.15×10^{-9}	3.20×10^{-9}	2.96×10^{-9}	3.11×10^{-9}
^{156}Eu	5.07×10^{-9}	4.49×10^{-9}	4.07×10^{-9}	3.69×10^{-9}	3.27×10^{-9}	3.32×10^{-9}	3.08×10^{-9}	3.24×10^{-9}
^{131}I	1.64×10^{-9}	1.44×10^{-9}	1.29×10^{-9}	1.16×10^{-9}	1.02×10^{-9}	1.04×10^{-9}	9.62×10^{-10}	1.01×10^{-9}
^{140}La	8.63×10^{-9}	7.62×10^{-9}	6.90×10^{-9}	6.25×10^{-9}	5.53×10^{-9}	5.62×10^{-9}	5.20×10^{-9}	5.47×10^{-9}
^{95}Nb	3.20×10^{-9}	2.81×10^{-9}	2.53×10^{-9}	2.29×10^{-9}	2.01×10^{-9}	2.05×10^{-9}	1.90×10^{-9}	2.00×10^{-9}
$^{95\text{m}}\text{Nb}$	2.61×10^{-10}	2.29×10^{-10}	2.06×10^{-10}	1.85×10^{-10}	1.63×10^{-10}	1.66×10^{-10}	1.54×10^{-10}	1.61×10^{-10}
^{147}Nd	5.36×10^{-10}	4.72×10^{-10}	4.27×10^{-10}	3.84×10^{-10}	3.39×10^{-10}	3.44×10^{-10}	3.19×10^{-10}	3.35×10^{-10}
^{148}Pm	2.24×10^{-9}	1.97×10^{-9}	1.79×10^{-9}	1.62×10^{-9}	1.43×10^{-9}	1.45×10^{-9}	1.34×10^{-9}	1.41×10^{-9}
$^{148\text{m}}\text{Pm}$	8.40×10^{-9}	7.37×10^{-9}	6.64×10^{-9}	5.99×10^{-9}	5.27×10^{-9}	5.36×10^{-9}	4.96×10^{-9}	5.22×10^{-9}
^{144}Pr	9.87×10^{-11}	8.72×10^{-11}	7.92×10^{-11}	7.18×10^{-11}	6.35×10^{-11}	6.44×10^{-11}	5.98×10^{-11}	6.29×10^{-11}
^{103}Ru	2.04×10^{-9}	1.78×10^{-9}	1.61×10^{-9}	1.44×10^{-9}	1.27×10^{-9}	1.29×10^{-9}	1.20×10^{-9}	1.26×10^{-9}
^{125}Sb	1.78×10^{-9}	1.57×10^{-9}	1.40×10^{-9}	1.26×10^{-9}	1.11×10^{-9}	1.13×10^{-9}	1.05×10^{-9}	1.10×10^{-9}
^{127}Te	1.82×10^{-11}	1.60×10^{-11}	1.43×10^{-11}	1.29×10^{-11}	1.13×10^{-11}	1.15×10^{-11}	1.07×10^{-11}	1.12×10^{-11}
^{129}Te	1.89×10^{-10}	1.65×10^{-10}	1.48×10^{-10}	1.34×10^{-10}	1.17×10^{-10}	1.19×10^{-10}	1.10×10^{-10}	1.16×10^{-10}
$^{129\text{m}}\text{Te}$	1.12×10^{-10}	9.83×10^{-11}	8.86×10^{-11}	7.99×10^{-11}	7.04×10^{-11}	7.15×10^{-11}	6.62×10^{-11}	6.98×10^{-11}
^{95}Zr	3.10×10^{-9}	2.72×10^{-9}	2.45×10^{-9}	2.21×10^{-9}	1.95×10^{-9}	1.98×10^{-9}	1.83×10^{-9}	1.93×10^{-9}

Table 12.

Skin dose rates (mrad h⁻¹) corresponding to 10 mR h⁻¹ exposure rates at 30 cm.

Radionuclide	Phantom							
	00Y	01Y	05Y	10Y	15Y male	15Y female	Adult male	Adult female
¹⁴⁰ Ba	5.08 × 10 ⁴	3.33 × 10 ⁴	2.61 × 10 ⁴	2.23 × 10 ⁴	1.91 × 10 ⁴	1.95 × 10 ⁴	1.80 × 10 ⁴	1.89 × 10 ⁴
¹⁴¹ Ce	1.29 × 10 ⁵	8.46 × 10 ⁴	6.63 × 10 ⁴	5.70 × 10 ⁴	4.89 × 10 ⁴	4.96 × 10 ⁴	4.58 × 10 ⁴	4.80 × 10 ⁴
¹⁴⁴ Ce	2.79 × 10 ⁵	1.84 × 10 ⁵	1.45 × 10 ⁵	1.24 × 10 ⁵	1.06 × 10 ⁵	1.08 × 10 ⁵	9.93 × 10 ⁴	1.04 × 10 ⁵
¹³⁴ Cs	4.34 × 10 ³	2.84 × 10 ³	2.21 × 10 ³	1.89 × 10 ³	1.63 × 10 ³	1.66 × 10 ³	1.53 × 10 ³	1.61 × 10 ³
¹³⁶ Cs	3.80 × 10 ³	2.48 × 10 ³	1.93 × 10 ³	1.65 × 10 ³	1.42 × 10 ³	1.44 × 10 ³	1.33 × 10 ³	1.40 × 10 ³
¹³⁷ Cs/ ^{137m} Ba	1.54 × 10 ⁴	1.01 × 10 ⁴	7.84 × 10 ³	6.71 × 10 ³	5.78 × 10 ³	5.86 × 10 ³	5.42 × 10 ³	5.69 × 10 ³
¹⁵⁴ Eu	8.57 × 10 ³	5.58 × 10 ³	4.32 × 10 ³	3.70 × 10 ³	3.19 × 10 ³	3.22 × 10 ³	2.97 × 10 ³	3.14 × 10 ³
¹⁵⁶ Eu	7.56 × 10 ³	4.91 × 10 ³	3.80 × 10 ³	3.23 × 10 ³	2.79 × 10 ³	2.82 × 10 ³	2.61 × 10 ³	2.74 × 10 ³
¹³¹ I	2.13 × 10 ⁴	1.40 × 10 ⁴	1.10 × 10 ⁴	9.38 × 10 ³	8.05 × 10 ³	8.19 × 10 ³	7.57 × 10 ³	7.95 × 10 ³
¹⁴⁰ La	5.51 × 10 ³	3.56 × 10 ³	2.76 × 10 ³	2.36 × 10 ³	2.02 × 10 ³	2.06 × 10 ³	1.90 × 10 ³	2.00 × 10 ³
⁹⁵ Nb	1.92 × 10 ³	1.25 × 10 ⁴	9.65 × 10 ²	8.33 × 10 ²	7.14 × 10 ³	7.29 × 10 ²	6.73 × 10 ²	7.05 × 10 ³
^{95m} Nb	1.41 × 10 ⁵	9.30 × 10 ⁴	7.33 × 10 ⁴	6.28 × 10 ⁴	5.41 × 10 ⁴	5.48 × 10 ⁴	5.06 × 10 ⁴	5.30 × 10 ⁴
¹⁴⁷ Nd	6.98 × 10 ⁴	4.56 × 10 ⁴	3.58 × 10 ⁴	3.06 × 10 ⁴	2.63 × 10 ⁴	2.66 × 10 ⁴	2.46 × 10 ⁴	2.59 × 10 ⁴
¹⁴⁸ Pm	2.02 × 10 ⁴	1.31 × 10 ⁴	1.02 × 10 ⁴	8.69 × 10 ³	7.48 × 10 ³	7.59 × 10 ³	7.02 × 10 ³	7.38 × 10 ³
^{148m} Pm	3.98 × 10 ³	2.60 × 10 ³	2.03 × 10 ³	1.74 × 10 ³	1.49 × 10 ³	1.52 × 10 ³	1.40 × 10 ³	1.47 × 10 ³
¹⁴⁴ Pr	4.86 × 10 ⁵	3.14 × 10 ⁵	2.43 × 10 ⁵	2.07 × 10 ⁵	1.78 × 10 ⁵	1.80 × 10 ⁵	1.67 × 10 ⁵	1.75 × 10 ⁵
¹⁰³ Ru	6.25 × 10 ⁴	4.12 × 10 ³	3.22 × 10 ³	2.76 × 10 ³	2.37 × 10 ³	2.40 × 10 ³	2.23 × 10 ³	2.33 × 10 ³
¹²⁵ Sb	9.52 × 10 ³	6.29 × 10 ³	4.90 × 10 ³	4.21 × 10 ³	3.61 × 10 ³	3.66 × 10 ³	3.40 × 10 ³	3.57 × 10 ³
¹²⁷ Te	2.00 × 10 ⁶	1.32 × 10 ⁶	1.03 × 10 ⁶	8.86 × 10 ⁵	7.62 × 10 ⁵	7.74 × 10 ⁵	7.15 × 10 ⁵	7.51 × 10 ⁵
¹²⁹ Te	2.33 × 10 ⁵	1.54 × 10 ⁵	1.20 × 10 ⁵	1.03 × 10 ⁵	8.89 × 10 ⁴	8.99 × 10 ⁴	8.32 × 10 ⁴	8.76 × 10 ⁴
^{129m} Te	2.53 × 10 ⁵	1.65 × 10 ⁵	1.29 × 10 ⁵	1.10 × 10 ⁵	9.50 × 10 ⁴	9.63 × 10 ⁴	8.87 × 10 ⁴	9.34 × 10 ⁴
⁹⁵ Zr	8.63 × 10 ³	5.64 × 10 ³	4.39 × 10 ³	3.75 × 10 ³	3.23 × 10 ³	3.28 × 10 ³	3.03 × 10 ³	3.19 × 10 ³

Table 13.

Weighted exposure rate coefficients (mR s^{-1}) per Bq total fission product.

	Decay time postrelease, t (d)	Distance	Phantom							
			00Y	01Y	05Y	10Y	15Y male	15Y female	Adult male	Adult female
0	2 in.		6.29×10^{-9}	3.70×10^{-9}	2.46×10^{-9}	1.81×10^{-9}	1.31×10^{-9}	1.37×10^{-9}	1.16×10^{-9}	1.30×10^{-9}
	1 ft.		1.02×10^{-9}	7.81×10^{-10}	6.19×10^{-10}	5.05×10^{-10}	4.05×10^{-10}	4.17×10^{-10}	3.69×10^{-10}	4.02×10^{-10}
	2 ft.		3.46×10^{-10}	2.93×10^{-10}	2.54×10^{-10}	2.22×10^{-10}	1.89×10^{-10}	1.93×10^{-10}	1.76×10^{-10}	1.87×10^{-10}
	3 ft.		1.72×10^{-10}	1.51×10^{-10}	1.37×10^{-10}	1.23×10^{-10}	1.09×10^{-10}	1.11×10^{-10}	1.03×10^{-10}	1.08×10^{-10}
0.5	2 in.		2.16×10^{-8}	1.27×10^{-8}	8.46×10^{-9}	6.21×10^{-9}	4.52×10^{-9}	4.71×10^{-9}	3.97×10^{-9}	4.46×10^{-9}
	1 ft.		3.50×10^{-9}	2.68×10^{-9}	2.13×10^{-9}	1.73×10^{-9}	1.39×10^{-9}	1.43×10^{-9}	1.27×10^{-9}	1.38×10^{-9}
	2 ft.		1.19×10^{-9}	1.01×10^{-9}	8.74×10^{-10}	7.63×10^{-10}	6.50×10^{-10}	6.63×10^{-10}	6.04×10^{-10}	6.44×10^{-10}
	3 ft.		5.91×10^{-10}	5.20×10^{-10}	4.70×10^{-10}	4.24×10^{-10}	3.74×10^{-10}	3.81×10^{-10}	3.53×10^{-10}	3.71×10^{-10}
1	2 in.		2.49×10^{-8}	1.46×10^{-8}	9.74×10^{-9}	7.14×10^{-9}	5.20×10^{-9}	5.42×10^{-9}	4.57×10^{-9}	5.13×10^{-9}
	1 ft.		4.03×10^{-9}	3.09×10^{-9}	2.45×10^{-9}	2.00×10^{-9}	1.60×10^{-9}	1.65×10^{-9}	1.46×10^{-9}	1.59×10^{-9}
	2 ft.		1.37×10^{-9}	1.16×10^{-9}	1.01×10^{-9}	8.78×10^{-10}	7.48×10^{-10}	7.63×10^{-10}	6.95×10^{-10}	7.41×10^{-10}
	3 ft.		6.80×10^{-10}	5.98×10^{-10}	5.41×10^{-10}	4.88×10^{-10}	4.31×10^{-10}	4.38×10^{-10}	4.06×10^{-10}	4.27×10^{-10}
2	2 in.		2.99×10^{-8}	1.76×10^{-8}	1.17×10^{-8}	8.58×10^{-9}	6.24×10^{-9}	6.51×10^{-9}	5.49×10^{-9}	6.16×10^{-9}
	1 ft.		4.84×10^{-9}	3.71×10^{-9}	2.94×10^{-9}	2.40×10^{-9}	1.92×10^{-9}	1.98×10^{-9}	1.75×10^{-9}	1.91×10^{-9}
	2 ft.		1.64×10^{-9}	1.39×10^{-9}	1.21×10^{-9}	1.05×10^{-9}	8.97×10^{-10}	9.16×10^{-10}	8.35×10^{-10}	8.90×10^{-10}
	3 ft.		8.17×10^{-10}	7.19×10^{-10}	6.49×10^{-10}	5.86×10^{-10}	5.17×10^{-10}	5.26×10^{-10}	4.87×10^{-10}	5.12×10^{-10}
5	2 in.		4.04×10^{-8}	2.38×10^{-8}	1.58×10^{-8}	1.16×10^{-8}	8.45×10^{-9}	8.81×10^{-9}	7.43×10^{-9}	8.33×10^{-9}
	1 ft.		6.55×10^{-9}	5.02×10^{-9}	3.98×10^{-9}	3.24×10^{-9}	2.60×10^{-9}	2.68×10^{-9}	2.37×10^{-9}	2.58×10^{-9}
	2 ft.		2.23×10^{-9}	1.89×10^{-9}	1.63×10^{-9}	1.43×10^{-9}	1.21×10^{-9}	1.24×10^{-9}	1.13×10^{-9}	1.20×10^{-9}
	3 ft.		1.11×10^{-9}	9.73×10^{-10}	8.78×10^{-10}	7.93×10^{-10}	7.00×10^{-10}	7.12×10^{-10}	6.59×10^{-10}	6.93×10^{-10}
10	2 in.		4.93×10^{-8}	2.90×10^{-8}	1.93×10^{-8}	1.41×10^{-8}	1.03×10^{-8}	1.07×10^{-8}	9.05×10^{-9}	1.02×10^{-8}
	1 ft.		7.98×10^{-9}	6.12×10^{-9}	4.85×10^{-9}	3.95×10^{-9}	3.17×10^{-9}	3.27×10^{-9}	2.89×10^{-9}	3.14×10^{-9}
	2 ft.		2.72×10^{-9}	2.30×10^{-9}	1.99×10^{-9}	1.74×10^{-9}	1.48×10^{-9}	1.51×10^{-9}	1.38×10^{-9}	1.47×10^{-9}
	3 ft.		1.35×10^{-9}	1.19×10^{-9}	1.07×10^{-9}	9.67×10^{-10}	8.53×10^{-10}	8.67×10^{-10}	8.03×10^{-10}	8.45×10^{-10}
15	2 in.		5.15×10^{-8}	3.02×10^{-8}	2.01×10^{-8}	1.48×10^{-8}	1.07×10^{-8}	1.12×10^{-8}	9.44×10^{-9}	1.06×10^{-8}
	1 ft.		8.34×10^{-9}	6.39×10^{-9}	5.06×10^{-9}	4.13×10^{-9}	3.31×10^{-9}	3.41×10^{-9}	3.01×10^{-9}	3.28×10^{-9}

Decay time postrelease, t (d)		Distance		Phantom						
				00Y	01Y	05Y	10Y	15Y male	15Y female	Adult male
20	2 ft.	2.84×10^{-9}	2.40×10^{-9}	2.08×10^{-9}	1.81×10^{-9}	1.54×10^{-9}	1.58×10^{-9}	1.44×10^{-9}	1.53×10^{-9}	
	3 ft.	1.41×10^{-9}	1.24×10^{-9}	1.12×10^{-9}	1.01×10^{-9}	8.91×10^{-10}	9.06×10^{-10}	8.39×10^{-10}	8.83×10^{-10}	
	2 in.	5.10×10^{-8}	3.00×10^{-8}	1.99×10^{-8}	1.46×10^{-8}	1.06×10^{-8}	1.11×10^{-8}	9.36×10^{-9}	1.05×10^{-8}	
	1 ft.	8.27×10^{-9}	6.34×10^{-9}	5.02×10^{-9}	4.09×10^{-9}	3.28×10^{-9}	3.38×10^{-9}	2.99×10^{-9}	3.25×10^{-9}	
	2 ft.	2.82×10^{-9}	2.38×10^{-9}	2.06×10^{-9}	1.80×10^{-9}	1.53×10^{-9}	1.56×10^{-9}	1.42×10^{-9}	1.52×10^{-9}	
	3 ft.	1.40×10^{-9}	1.23×10^{-9}	1.11×10^{-9}	1.00×10^{-9}	8.83×10^{-10}	8.98×10^{-10}	8.32×10^{-10}	8.75×10^{-10}	
25	2 in.	4.99×10^{-8}	2.93×10^{-8}	1.95×10^{-8}	1.43×10^{-8}	1.04×10^{-8}	1.08×10^{-8}	9.14×10^{-9}	1.03×10^{-8}	
	1 ft.	8.08×10^{-9}	6.19×10^{-9}	4.91×10^{-9}	3.99×10^{-9}	3.21×10^{-9}	3.30×10^{-9}	2.92×10^{-9}	3.18×10^{-9}	
	2 ft.	2.75×10^{-9}	2.33×10^{-9}	2.02×10^{-9}	1.76×10^{-9}	1.50×10^{-9}	1.53×10^{-9}	1.39×10^{-9}	1.48×10^{-9}	
	3 ft.	1.37×10^{-9}	1.20×10^{-9}	1.08×10^{-9}	9.78×10^{-10}	8.63×10^{-10}	8.77×10^{-10}	8.13×10^{-10}	8.55×10^{-10}	
	2 in.	4.86×10^{-8}	2.85×10^{-8}	1.90×10^{-8}	1.39×10^{-8}	1.01×10^{-8}	1.06×10^{-8}	8.90×10^{-9}	9.98×10^{-9}	
	1 ft.	7.87×10^{-9}	6.03×10^{-9}	4.78×10^{-9}	3.89×10^{-9}	3.12×10^{-9}	3.21×10^{-9}	2.84×10^{-9}	3.09×10^{-9}	
30	2 ft.	2.68×10^{-9}	2.27×10^{-9}	1.96×10^{-9}	1.71×10^{-9}	1.46×10^{-9}	1.49×10^{-9}	1.35×10^{-9}	1.44×10^{-9}	
	3 ft.	1.33×10^{-9}	1.17×10^{-9}	1.06×10^{-9}	9.53×10^{-10}	8.40×10^{-10}	8.54×10^{-10}	7.91×10^{-10}	8.33×10^{-10}	