SAND2013-6918C

Ingestion Dose Model for RADTRAN

PATRAM 2013
August 18-23, 2013

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

RADTRAN Overview

RADTRAN calculates risks and consequences of transportation accidents.

Accidents can involve a release of radioactive material.

Released and dispersed radioactive material can deliver an external radiation dose (groundshine, cloudshine), an inhalation dose, and an ingestion dose.

The ingestion dose is a societal dose. It is the subject of this paper.

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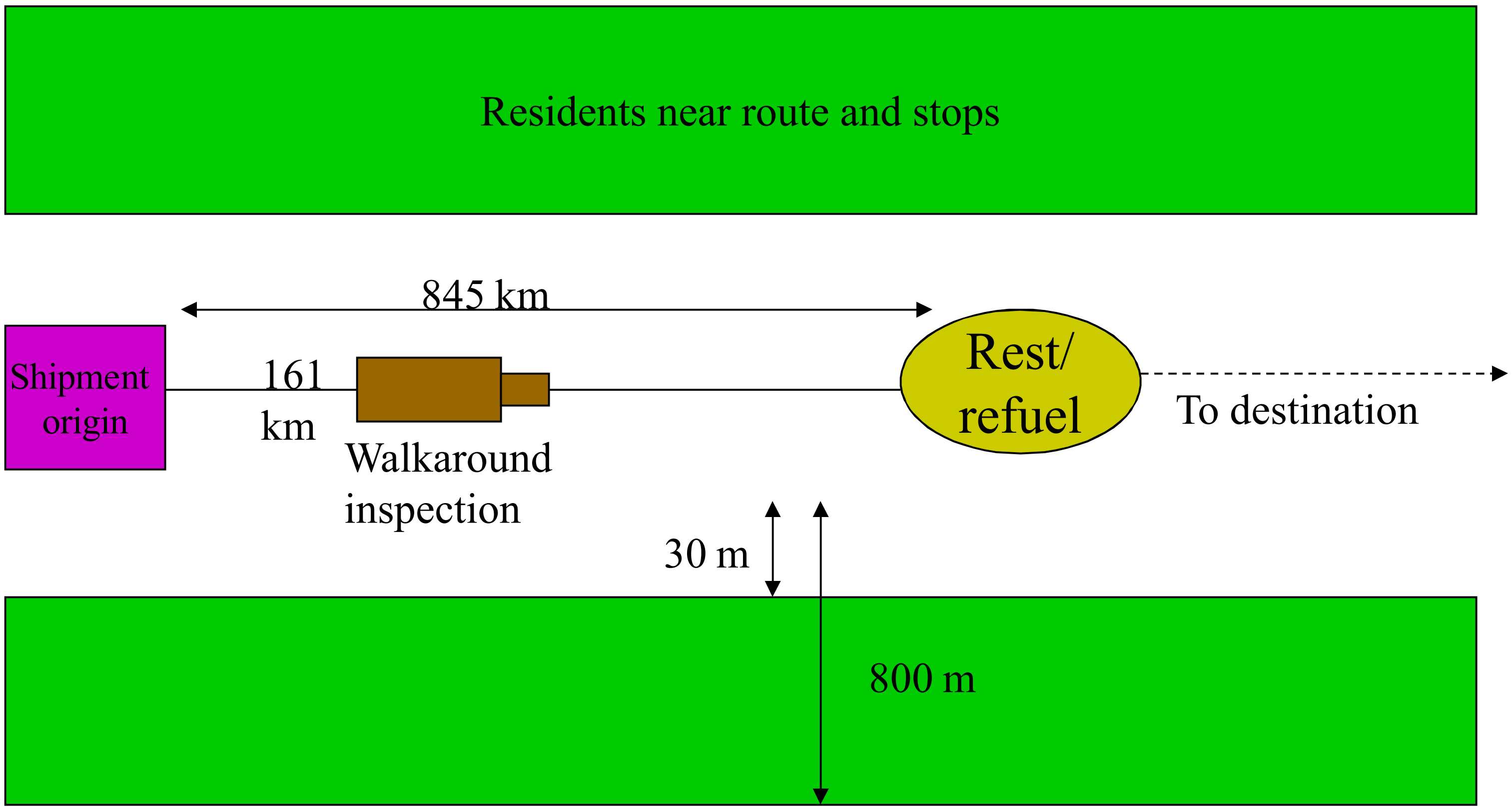
Incident-free Transportation: Legal-weight Truck Route and Stops



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Potential Fallout "Targets"

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Uptake of Deposited Radionuclides

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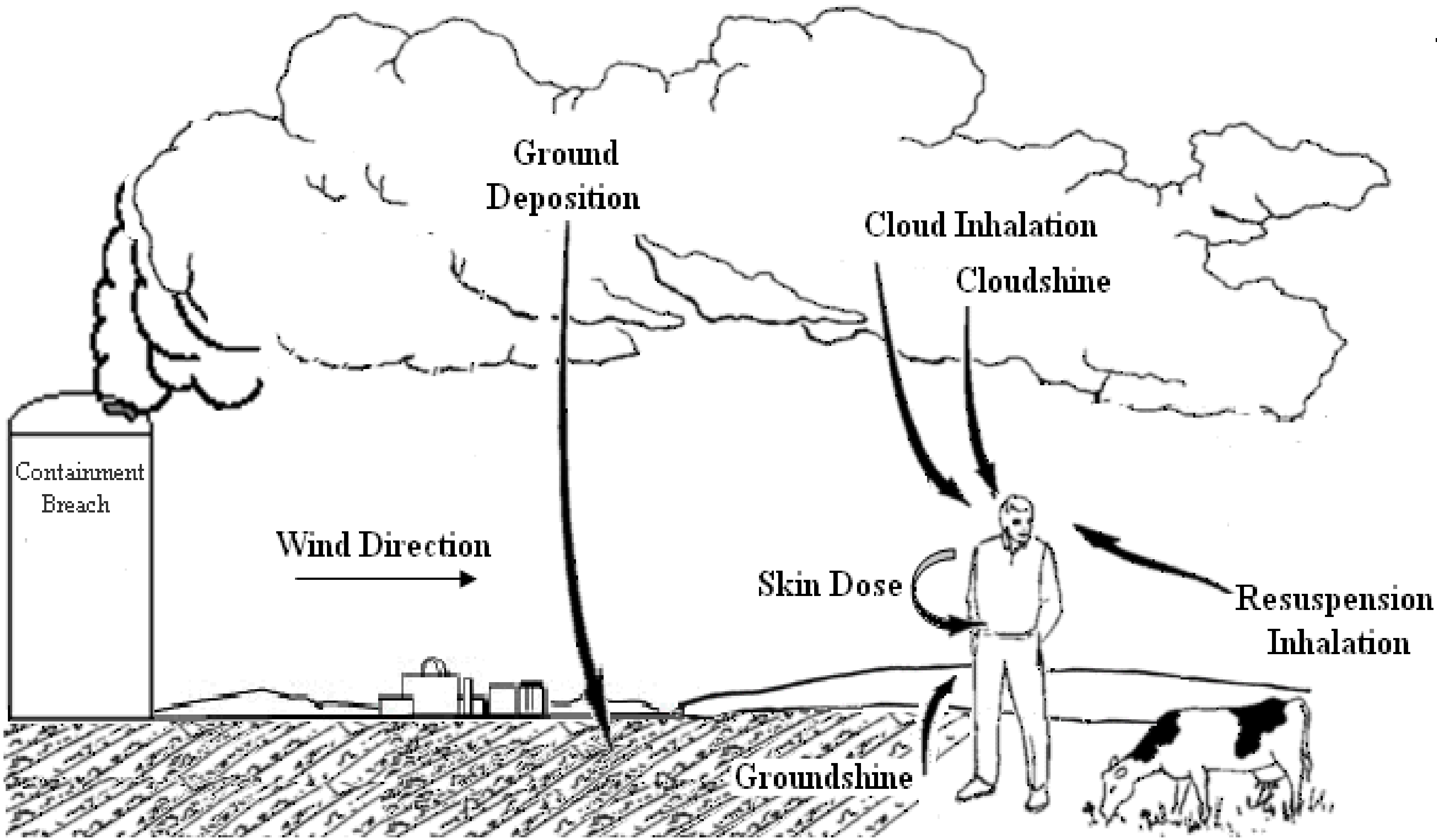
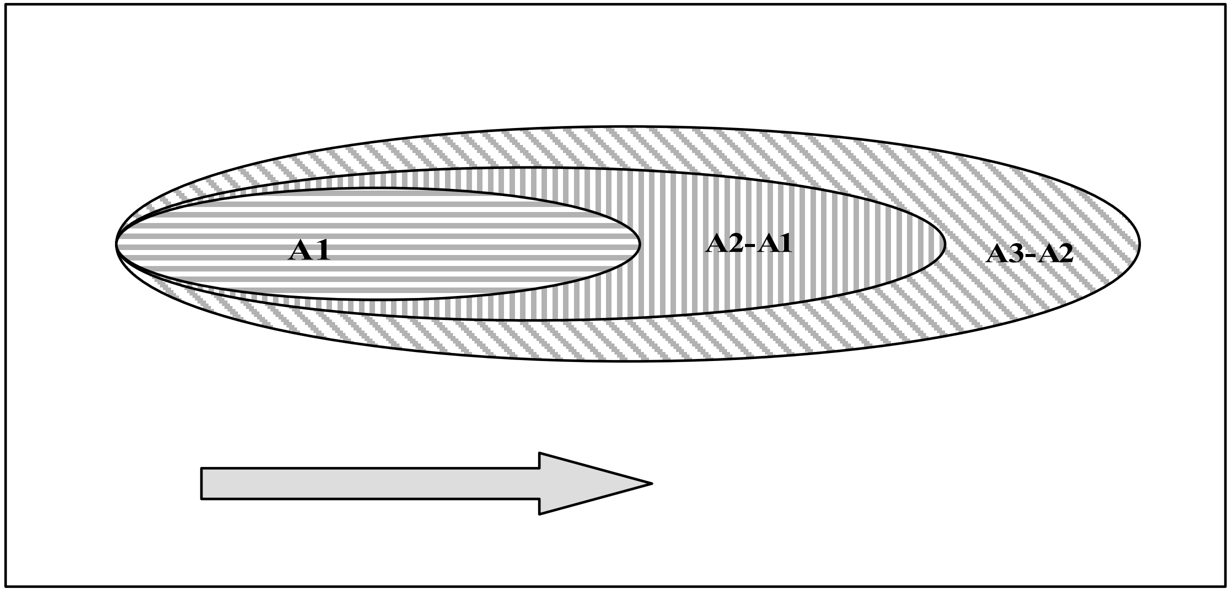
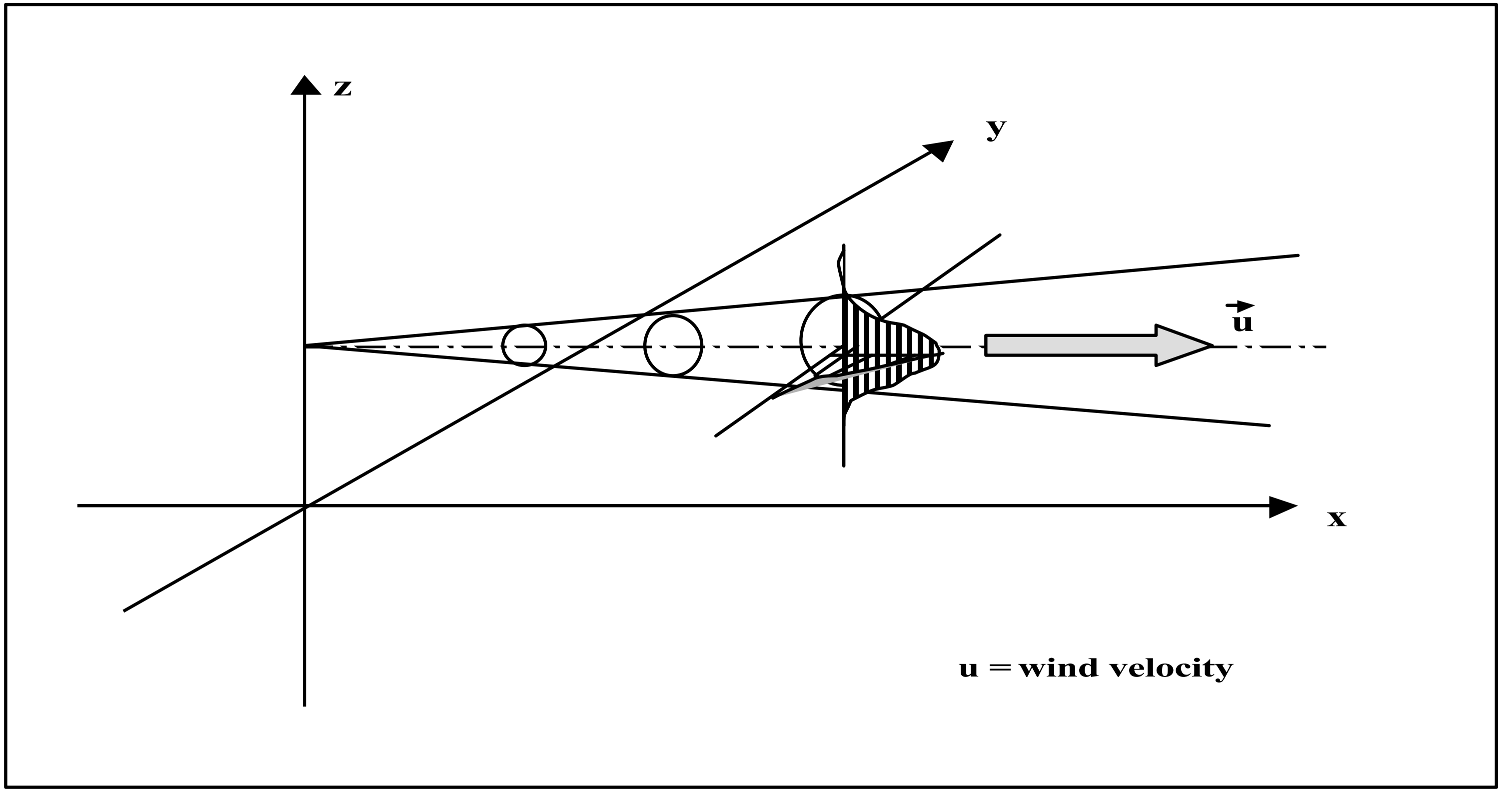
Physiological Pathways



Dispersion Footprint



Atmospheric Dispersion



Gaussian Dispersion

Gaussian Dispersion from a Ground-Level Source

$$\frac{CHI}{Q} = \frac{1}{2\pi u \sigma_y \sigma_z} \exp\left[\frac{-y^2}{2\sigma_y^2}\right] \exp\left[\frac{-z^2}{2\sigma_z^2}\right]$$

At y = 0 and z = 0: ground level and plume centerline

$$\frac{CHI}{Q} = \frac{1}{2\pi u \sigma_y \sigma_z}$$

Gaussian Dispersion from an Elevated Source

$$\frac{CHI}{Q} = \frac{1}{2\pi u \sigma_y \sigma_z} \exp\left[\frac{-y^2}{2\sigma_y^2}\right] \exp\left[\frac{-H^2}{2\sigma_z^2}\right]$$

From Turner, B. D. Workbook of Atmospheric DIspersion Estimates, 1970

RADTRAN Inputs

INPUTS FOR TRANSPORTATION ACCIDENTS

Radionuclide inventory
Accident rate (route characteristic)
Conditional probability of accident severity
Release, aerosol, respirable fractions
Particle settling velocity
Meteorological parameters
Population densities
Fraction of land in agriculture

OUTPUTS FOR TRANSPORTATION ACCIDENTS

Collective "dose risks:" inhalation, resuspension, groundshine, cloudshine**, ingestion**
Collective doses
MEI doses and dose risks
Doses and dose risks per radionuclide
Critical group doses and dose risks
Doses and dose risks from loss of lead shielding

Factors Governing Exposure

(1) the quantity of radioactive material taken up by the agricultural commodity ingested; e.g, 1.2 percent of ^{137}Cs deposited on grass could be transferred to milk,

(2) the chemical form and activity of ingested radioactive material in any particular organ or tissue (the ingestion dose conversion factor); for example, the bone surface dose from dissolved ^{137}Cs is 1.4×10^{-8} Sv Bq^{-1},

(3) the type and energy of ionizing radiation ingested, and

(4) the extent to which a target organ is saturated with stable (non-radioactive) isotopes of the radionuclide in question.

Equation for Ingestion Dose

$$D_{ingest} = \sum_{i}^{Radionuclides} (INGEST_{i,j} \; x \; Clvl_{i,j,k} \; x \; Area_k)$$

$INGEST_{i,j}$ = ingestion dose due to ground contamination by radionuclide i in State j [$Sv/Bq_{deposited}$]

$INGEST$ = food transfer factor ft x ingestion DCF

$Clvl_{i,j,k}$ = deposited activity of I in area k in State j [$Bq_{deposited}/m^2$]
$Area_k$ = area of isopleth k [m^2]

$$ft_{i,j} = Fraction\ land_j \left((Crop_j)(fc_i) + (Milk_j)(fm_i) + (Meat_j)(fb_i) \right)$$

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Sample Problem

A truck carries transuranic waste in a RH-72B cask from Argonne National Laboratory to the Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico. The truck transits rural areas in Illinois, Missouri, Oklahoma, Texas, and New Mexico. An accident involving a release is assumed to take place in one of the states transited, but not in more than one. The accident is modeled in each state transited. The resulting ingestion dose is calculated for each of the modeled accidents

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State Dependent Food Transfer Factors for States Transited

State	*Agric (fraction of state land)*	*Crop*	*Milk*	*Meat*
		kg/km^2-yr	**liters/km^2-yr**	**kg/km^2-yr**
IL	0.81	3.29×10^5	8.36×10^3	6.70×10^3
MO	0.66	6.76×10^4	7.38×10^3	5.56×10^3
OK	0.74	3.10×10^4	2.97×10^3	3.87×10^3
TX	0.78	2.19×10^4	2.53×10^3	3.26×10^3
NM	0.61	2.60×10^3	1.17×10^3	6.61×10^2

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Radionuclides Released From a RH-72B Cask In an Accident

Nuclide	Bq	Frac. Released	Bq Released	Ingestion Sv/Bq
^{137}Cs	$9.77x10^{12}$	$7.68x10^{-5}$	$7.50x10^{8}$	2.50×10^{-11}
^{60}Co	$4.96x10^{11}$	$9.30x10^{-6}$	$4.61x10^{6}$	3.40×10^{-9}
^{90}Sr	$9.77x10^{12}$	$9.30x10^{-6}$	$9.08x10^{7}$	2.80×10^{-8}
^{238}Pu	$1.99x10^{14}$	$9.30x10^{-6}$	$1.85x10^{9}$	2.30×10^{-7}
^{239}Pu	$4.00x10^{12}$	$9.30x10^{-6}$	$3.71x10^{7}$	2.50×10^{-7}
^{240}Pu	$1.99x10^{12}$	$9.30x10^{-6}$	$1.85x10^{7}$	2.50×10^{-7}
^{241}Am	$2.39x10^{12}$	$9.30x10^{-6}$	$2.22x10^{7}$	2.00×10^{-7}
^{241}Pu	$1.99x10^{12}$	$9.30x10^{-6}$	$1.85x10^{7}$	4.80×10^{-9}
^{233}U	$5.96x10^{9}$	$9.30x10^{-6}$	$5.54x10^{4}$	5.10×10^{-8}
^{235}U	$2.19x10^{8}$	$9.30x10^{-6}$	$2.04x10^{3}$	4.70×10^{-8}
^{238}U	$1.41x10^{7}$	$9.30x10^{-6}$	$1.31x10^{2}$	4.50×10^{-8}

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Radionuclide Food Transfer Coefficients (Inventory Constituting 99% of Risk)

Atomic Number	Element	Transfer Coefficients		
		Soil-to-Plant	Grass-to-Meat	Grass-to-Milk
55	Cesium	1.00×10^{-02}	4.00×10^{-03}	1.20×10^{-02}
27	Cobalt	9.40×10^{-03}	1.30×10^{-02}	1.00×10^{-03}
38	Strontium	1.70×10^{-02}	6.00×10^{-04}	8.00×10^{-04}
94	Plutonium	2.50×10^{-04}	1.40×10^{-05}	2.00×10^{-06}
95	Americium	2.50×10^{-04}	2.00×10^{-04}	5.00×10^{-06}
92	Uranium	2.50×10^{-03}	3.40×10^{-04}	5.00×10^{-04}

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Air Concentration And Ground Deposition Of Radioactive Material From the Accident

Downwind distance (m)	Plume footprint area (m^2)	Dilution (Bq-sec /Bq-m^3 released)	Deposition (Bq m^{-2}/Bq-released)	Downwind distance (m)
22	5	0.0358	3.58×10^{-4}	22
27	27	0.0278	2.78×10^{-4}	27
35	82	0.0199	1.99×10^{-4}	35
50	244	0.0119	1.19×10^{-4}	50
65	471	0.00795	7.95×10^{-5}	65
99	1210	0.00398	3.98×10^{-5}	99
145	2750	0.00199	1.99×10^{-5}	145
235	7400	7.95×10^{-4}	7.95×10^{-6}	235
335	15100	3.98×10^{-4}	3.98×10^{-6}	335
476	30100	1.99×10^{-4}	1.99×10^{-6}	476

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Total Food Transfer Factor $ft_{i,j}$

Nuclide	IL	MO	OK	TX	NM
^{137}Cs	3.69×10^{-7}	1.18×10^{-7}	6.08×10^{-8}	5.09×10^{-8}	1.18×10^{-8}
^{60}Co	2.52×10^{-6}	4.29×10^{-7}	2.22×10^{-7}	1.66×10^{-7}	1.61×10^{-8}
^{90}Sr	4.54×10^{-6}	7.65×10^{-7}	3.93×10^{-7}	2.93×10^{-7}	2.78×10^{-8}
^{238}Pu	6.67×10^{-8}	1.12×10^{-8}	5.78×10^{-9}	4.31×10^{-9}	4.04×10^{-7}
^{239}Pu	6.67×10^{-8}	1.12×10^{-8}	5.78×10^{-9}	4.31×10^{-9}	4.04×10^{-7}
^{240}Pu	6.67×10^{-8}	1.12×10^{-8}	5.78×10^{-9}	4.31×10^{-9}	4.04×10^{-7}
^{241}Am	6.77×10^{-8}	1.19×10^{-8}	6.32×10^{-9}	4.79×10^{-9}	4.81×10^{-7}
^{241}Pu	6.67×10^{-8}	1.12×10^{-8}	5.78×10^{-9}	4.31×10^{-9}	4.04×10^{-7}
^{233}U	6.71×10^{-7}	1.15×10^{-7}	5.94×10^{-8}	4.46×10^{-8}	4.46×10^{-9}
^{235}U	6.71×10^{-7}	1.15×10^{-7}	5.94×10^{-8}	4.46×10^{-8}	4.46×10^{-9}
^{238}U	6.71×10^{-7}	1.15×10^{-7}	5.94×10^{-8}	4.46×10^{-8}	4.46×10^{-9}

Ingestion Dose (Sv)

Nuclide	IL	MO	OK	TX	NM
^{137}Cs	2.3×10^{-7}	7.4×10^{-8}	3.8×10^{-8}	3.2×10^{-8}	7.4×10^{-9}
^{60}Co	1.3×10^{-6}	2.2×10^{-7}	1.2×10^{-7}	8.7×10^{-8}	8.4×10^{-9}
^{90}Sr	3.9×10^{-4}	6.5×10^{-5}	3.3×10^{-5}	2.5×10^{-5}	2.4×10^{-6}
^{238}Pu	9.5×10^{-4}	1.6×10^{-4}	8.2×10^{-5}	6.1×10^{-5}	5.7×10^{-6}
^{239}Pu	2.1×10^{-5}	3.5×10^{-6}	1.8×10^{-6}	1.3×10^{-6}	1.3×10^{-7}
^{240}Pu	1.0×10^{-5}	1.7×10^{-6}	8.9×10^{-7}	6.7×10^{-7}	6.2×10^{-8}
^{241}Am	1.0×10^{-5}	1.8×10^{-6}	9.4×10^{-7}	7.1×10^{-7}	7.1×10^{-8}
^{241}Pu	2.0×10^{-7}	3.3×10^{-8}	1.7×10^{-8}	1.3×10^{-8}	1.2×10^{-9}
^{233}U	6.3×10^{-8}	1.1×10^{-8}	5.6×10^{-9}	4.2×10^{-9}	4.2×10^{-10}
^{235}U	2.1×10^{-9}	3.7×10^{-10}	1.9×10^{-10}	1.4×10^{-10}	1.4×10^{-11}
^{238}U	1.3×10^{-10}	2.3×10^{-11}	1.2×10^{-11}	8.8×10^{-12}	8.8×10^{-13}

Total Ingestion Dose (person-Sv) For An Accident On This Route

State in which the accident happens				
IL	MO	OK	TX	NM
1.38×10^{-3}	2.31×10^{-4}	1.19×10^{-4}	8.90×10^{-5}	8.36×10^{-6}

Some Comparisons	
Internal Dose from ^{40}K (average adult)	2.64×10^{-5} Sv
Internal Dose from ^{14}C (average adult)	1.75×10^{-6} Sv
Dose from one serving of contaminated spinach (30 gm)	4.1×10^{-6} Sv

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