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Dispersion of Accidental Releases of Radioactive Materials Using RADTRAN

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National Nuclear Security Administration

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.

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RADTRAN History

- **RADTRAN I and II developed for NUREG-0170**
  - ***EIS for the Transportation of Radioactive Materials by Air and Other Means (USNRC, 1977)***
  - **Developed by Sandia National Laboratories**
- **RADTRAN III, funded by DOE, made available to users outside SNL (1986)**
- **Menu system for RADTRAN 4 (1992) allowed greatly increased user-defined input and route-specific development**
- **RADTRAN now used in essentially all DOE and most NRC environmental assessments and impact statements**

RADTRAN History - Continued

- RADTRAN 5 (1998)
  - New stop model
  - Allowed about 85% user defined input; 15% user choices
- Copyright Sandia National Labs 2003
- Downloadable RADTRAN 5 with graphical user interface (GUI) input file generator RADCAT
- RADTRAN 6 – FY08
  - https://radtran.sandia.gov/radcat

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SOME OBSERVATIONS

- For historical reasons, risks from both incident-free transportation and transportation accidents have been overestimated.
- Absolute "collective risk" for very low-dose chronic exposure has been questioned by NRC.
  - Use collective dose/risk for comparative risks
- Focus of risk assessments is shifting toward
    - Separate reporting of consequences
    - Doses and risks to RMEI and critical groups
    - Doses and risks to first responders

RADTRAN 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

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RADTRAN 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

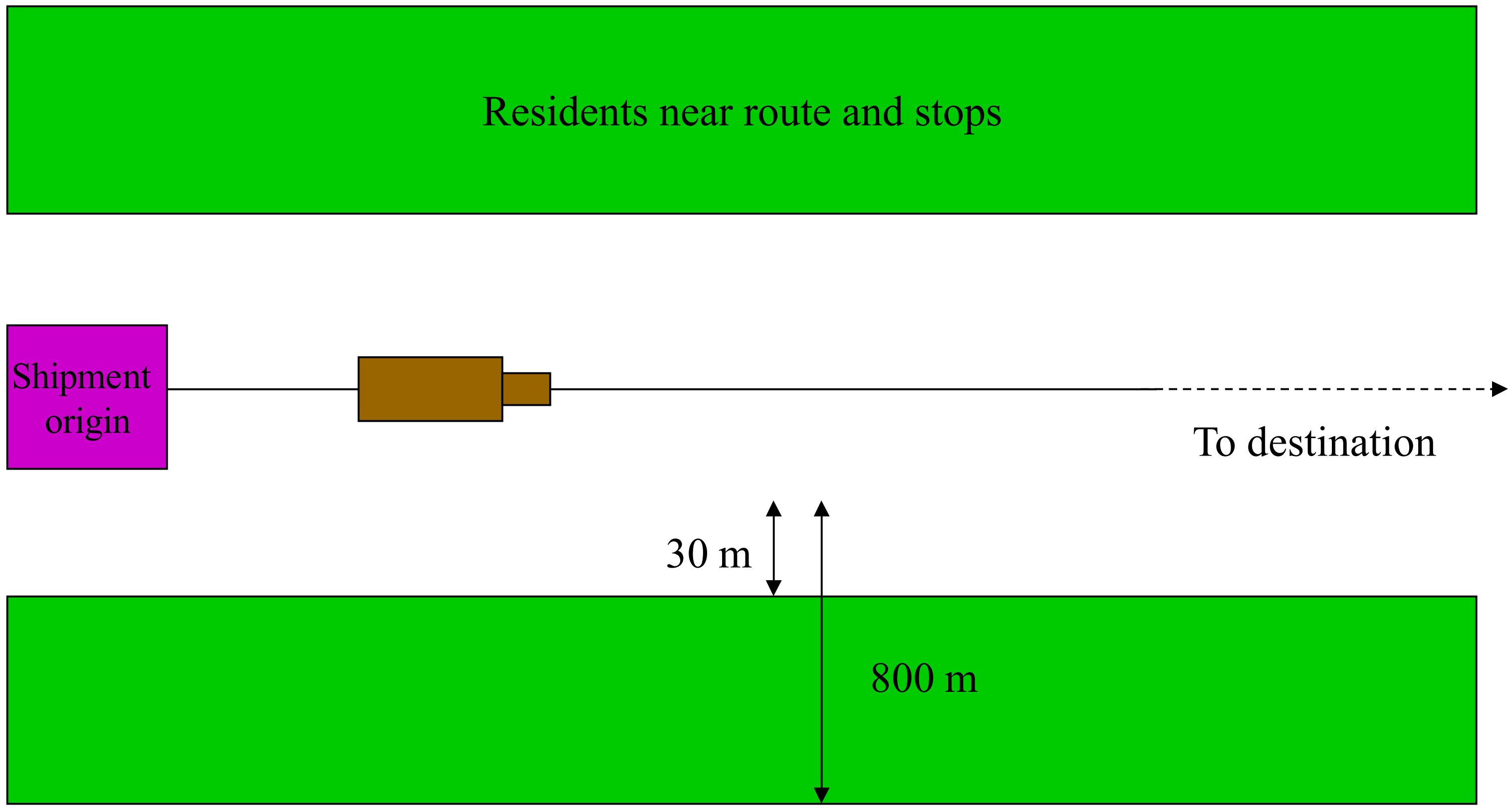
Critical group doses and dose risks

Doses and dose risks from loss of lead shielding

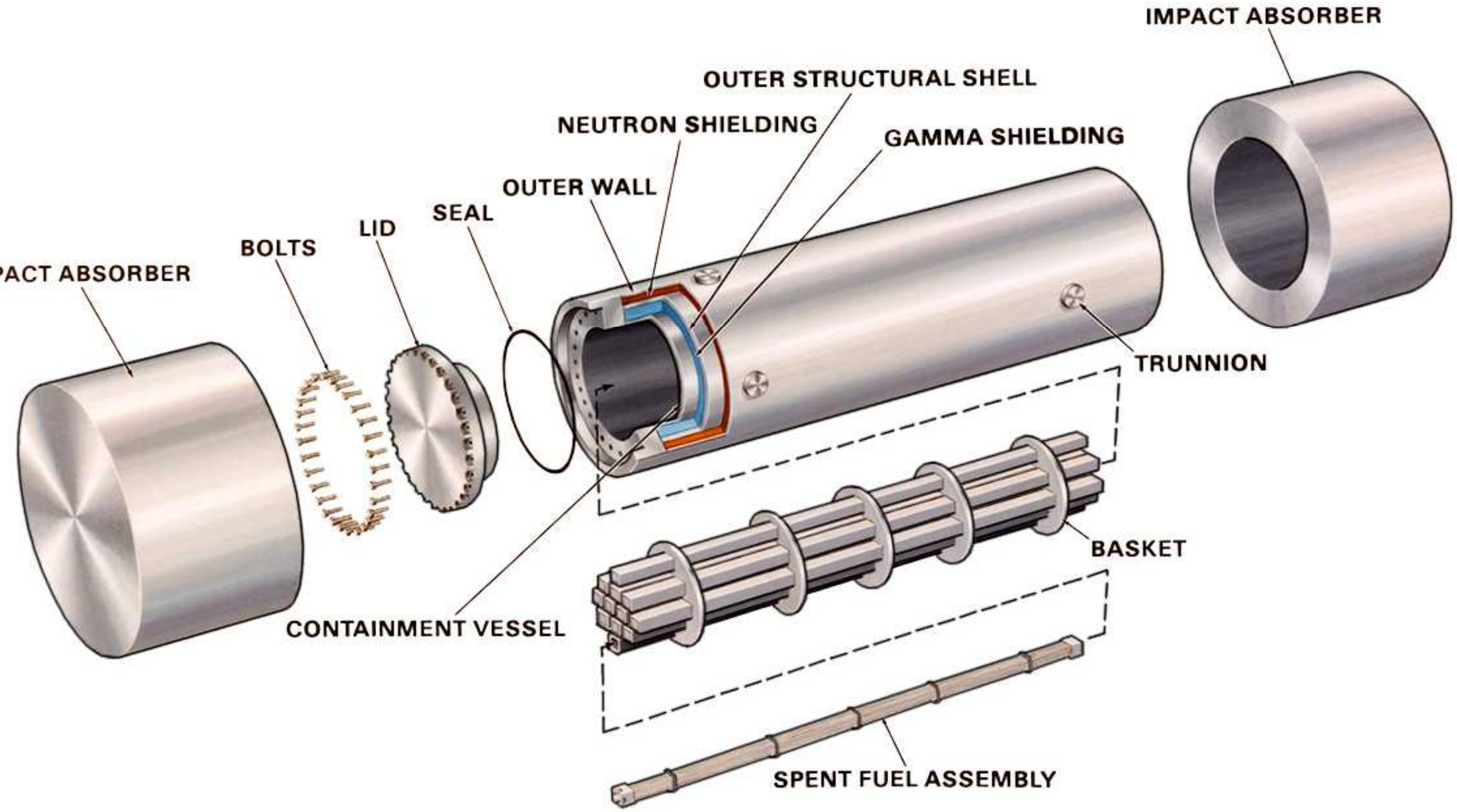
How RADTRAN Works

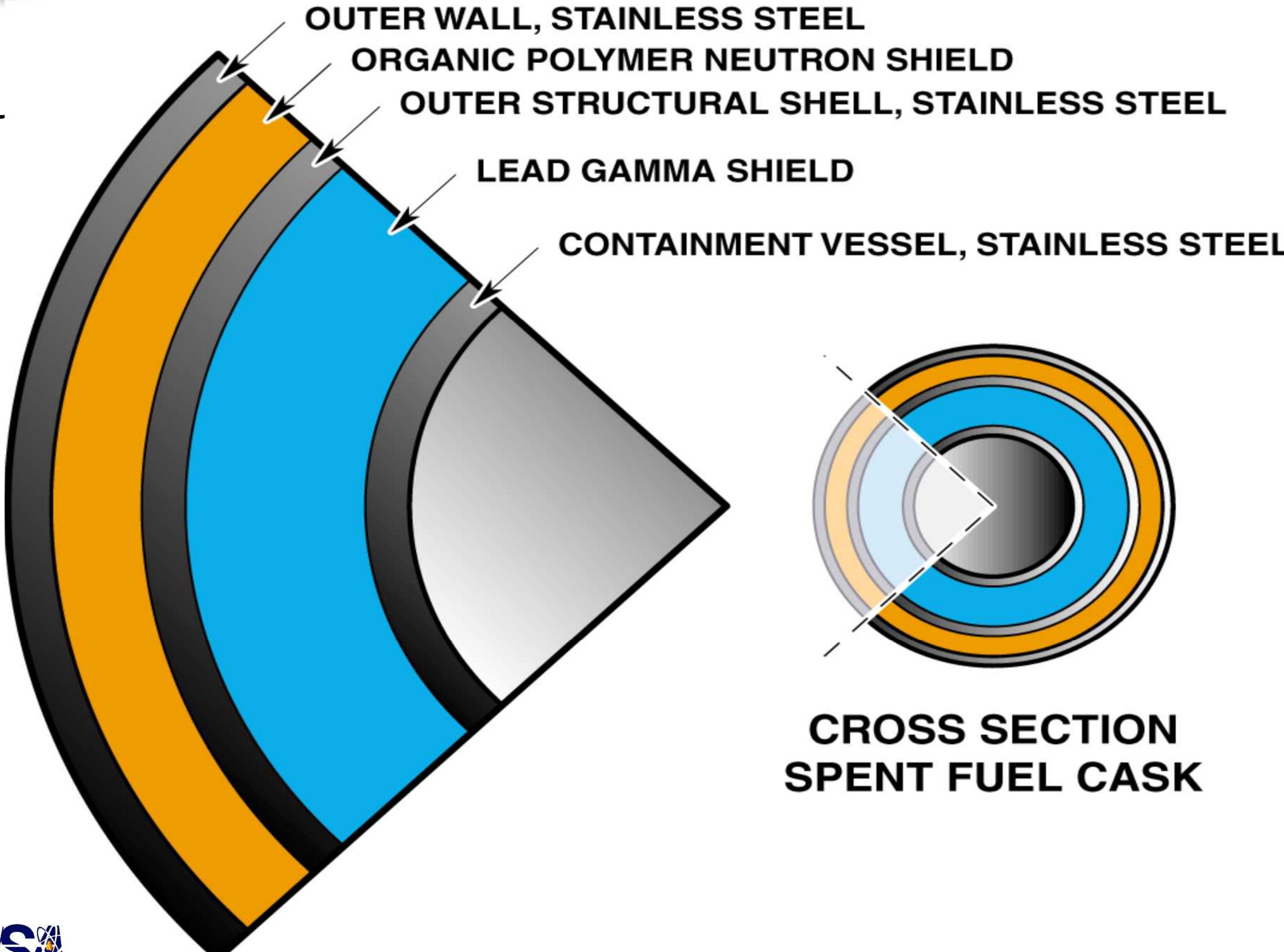
- Text input file is generated by the user directly or using the generator RADCAT
- RADTRAN reads in input file as R5IN.DAT (RADTRAN.INPUT)
- RADTRAN reads in text files of default values:
  - RT5STD.DAT
  - RT5DAT.DAT
  - RT5ISO.DAT (internal radionuclide library)
  - INGEST.BIN (output from ingestion dose code COMIDA)
- All defaults can be overwritten except collective occupational doses at rail classification stops
- RADTRAN reads numbers and multiplies them according to the program. It is a very forgiving code; numbers between 10^{30} and 10^{-30} can be entered.
- Input is echoed in the output.

Potential Receptors
Legal-weight Truck Route



SPENT FUEL CASK





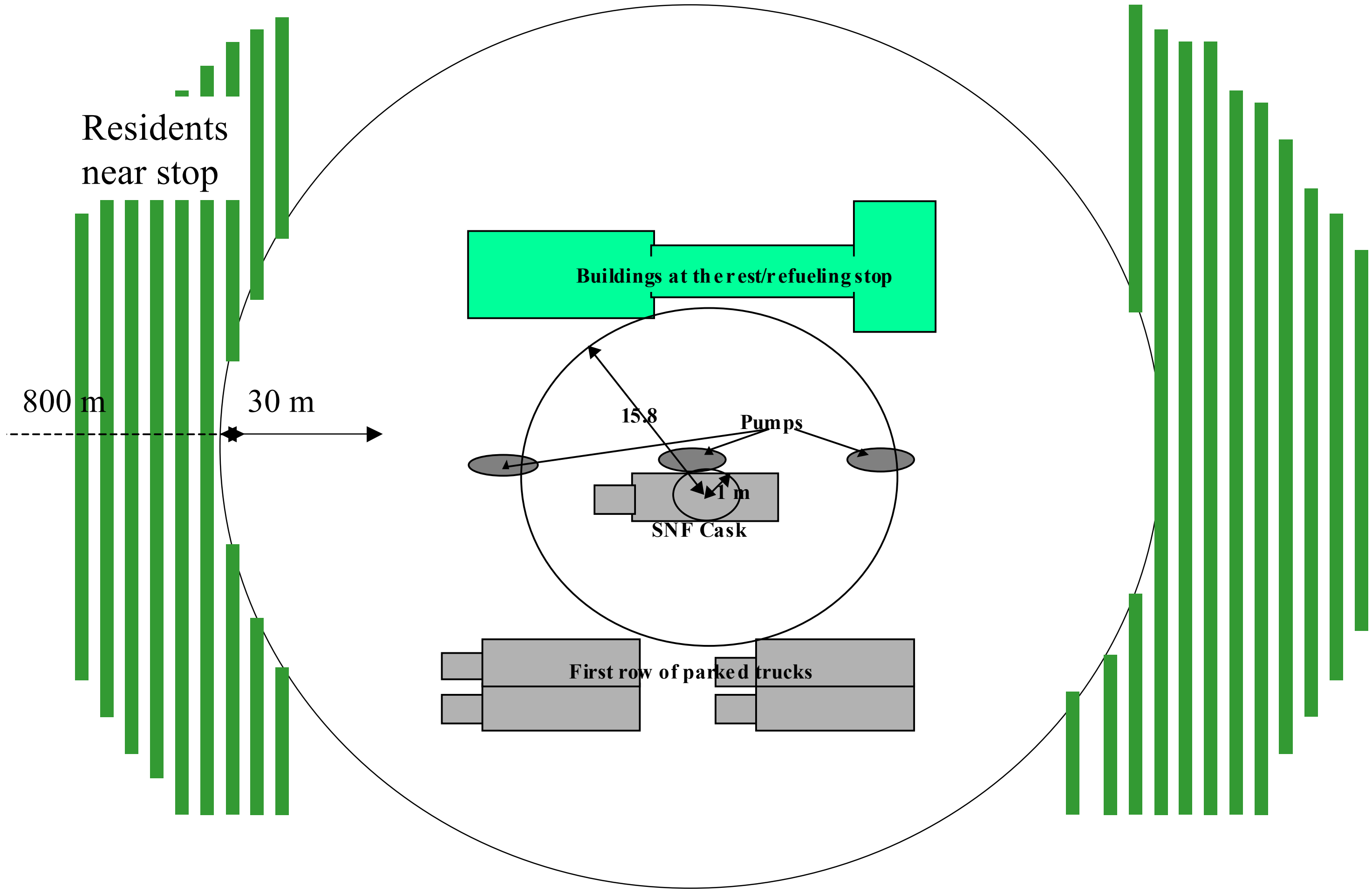
CROSS SECTION
SPENT FUEL CASK

Transportation Accidents

Three types of accidents:

- **Accidents involving a release: dispersion of released material.**
- **Loss of lead gamma shielding (LOS): occurs only with lead-shielded casks.**
- **Accidents with neither release nor LOS: 99.99% of accidents are of this type; use stop model.**

Truck Stop Model



Probability of an Accident

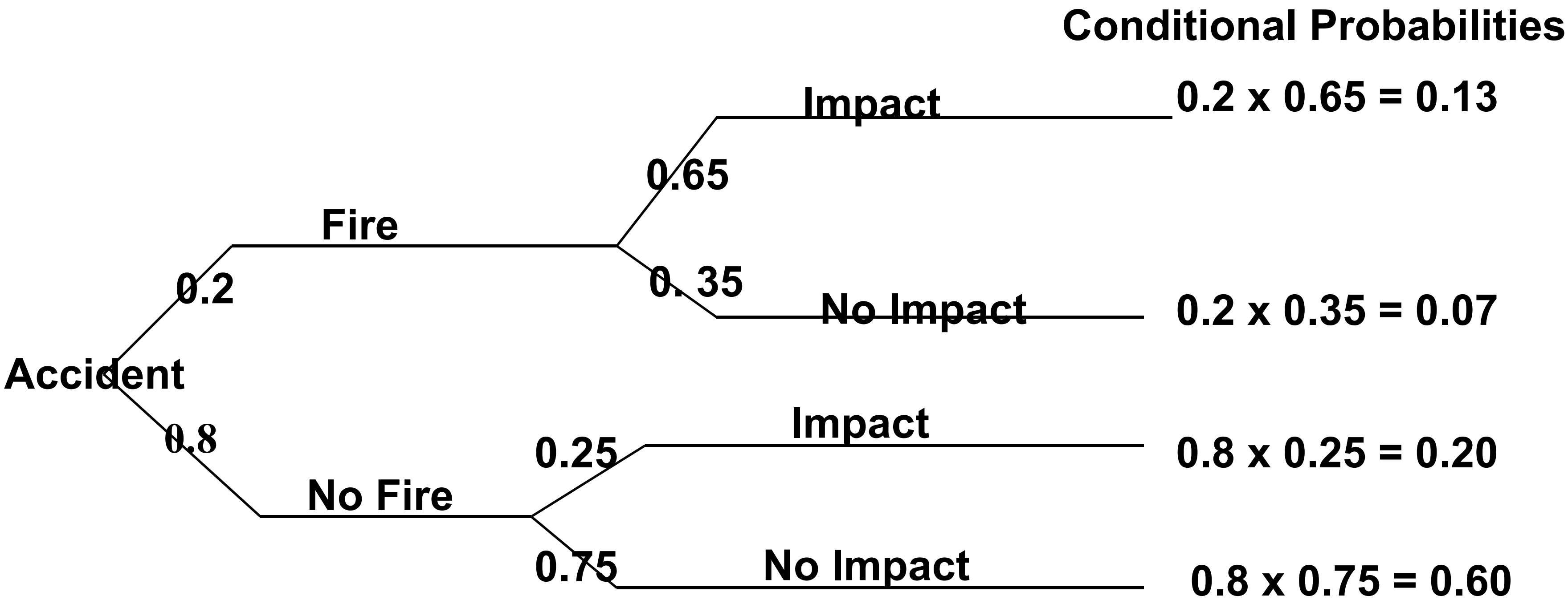
$$\gamma_{j,L} = AR_L \cdot SV_{j,L} \cdot NSH_L \cdot DIST_L$$

where:

$\gamma_{j,L}$ = Probability of an accident of severity j on link L

AR_L = Accident rate on link L (accidents/vehicle-km)
$SV_{j,L}$ = Conditional probability of occurrence of an accident of severity j on link L
NSH_L = Number of shipments on link L
$DIST_L$ = Length of link L (km)

Typical Event Tree



Transportation Accidents : Matrix of NUREG/CR-6672 Cases

>120	3 Seal Failure on Impact (Part) 1.9E-05 (Ru) 1.9E-05 (Cs) 1.8E-05 (Kr) 8.0E-01 (Crud) 6.4E-02 Prob 4.49E-09	13 Seal Failure on Impact (Part) 2.0E-05 (Ru) 2.0E-05 (Cs) 1.8E-05 (Kr) 8.2E-01 (Crud) 6.5E-02 Prob 3.82E-11	14 Seal Failure on Impact (Part) 2.1E-05 (Ru) 2.1E-05 (Cs) 2.0E-05 (Kr) 8.9E-01 (Crud) 7.1E-02 Prob 1.27E-12	15 Seal Failure on Impact (Part) 2.2E-05 (Ru) 2.2E-05 (Cs) 2.2E-05 (Kr) 9.1E-01 (Crud) 7.4E-02 Prob 1.88E-14	19 Failure by Shear/Puncture Sea Failure from Fire (Part) 2.2E-05 (Ru) 2.3E-05 (Cs) 2.2E-05 (Kr) 9.1E-01 (Crud) 7.4E-02 Prob 1.88E-17
90 – 120	2 Seal Failure on Impact (Part) 1.3E-05 (Ru) 1.3E-05 (Cs) 8.6E-06 (Kr) 8.0E-01 (Crud) 4.4E-02 Prob 1.17E-07	10 Seal Failure by Impact (Part) 1.3E-05 (Ru) 1.3E-05 (Cs) 8.8E-06 (Kr) 8.2E-01 (Crud) 4.5E-02 Prob 9.93E-10	11 Seal Failure by Impact (Part) 1.5E-05 (Ru) 1.5E-05 (Cs) 9.6E-06 (Kr) 8.9E-01 (Crud) 4.9E-02 Prob 3.30E-11	12 Seal Failure by Impact (Part) 1.5E-05 (Ru) 1.5E-05 (Cs) 1.4E-05 (Kr) 9.1E-01 (Crud) 5.1E-02 Prob 4.91E-13	18 Failure by Shear/Puncture Sea Failure from Fire (Part) 1.5E-05 (Ru) 1.8E-05 (Cs) 1.4E-05 (Kr) 9.1E-01 (Crud) 5.1E-02 Prob 4.91E-16
60 – 90	1 Seal Failure on Impact (Part) 2.5E-07 (Ru) 2.5E-07 (Cs) 1.2E-08 (Kr) 4.1E-01 (Crud) 1.4E-03 Prob 8.60E-06	7 Seal Failure by Impact (Part) 2.6E-07 (Ru) 2.6E-07 (Cs) 1.3E-08 (Kr) 4.3E-01 (Crud) 1.5E-03 Prob 7.31E-08	8 Seal Failure by Impact (Part) 2.9E-07 (Ru) 2.9E-07 (Cs) 1.5E-08 (Kr) 4.9E-01 (Crud) 1.7E-03 Prob 2.43E-09	9 Seal Failure by Impact (Part) 6.8E-06 (Ru) 6.8E-06 (Cs) 2.7E-05 (Kr) 8.5E-01 (Crud) 4.5E-03 Prob 3.61E-11	17 Failure by Shear/Puncture, Seal Failure from Fire (Part) 8.9E-06 (Ru) 5.0E-05 (Cs) 5.5E-05 (Kr) 8.5E-01 (Crud) 5.4E-03 Prob 3.61E-14
30 – 60	Barge Only (Crud) 3.0E-05	4 Seal Failure by Fire (Part) 1.0E-07 (Ru) 1.0E-07 (Cs) 4.1E-09 (Kr) 1.4E-01 (Crud) 1.4E-03 Prob 3.05E-05	5 Seal Failure by Fire (Part) 1.3E-07 (Ru) 1.3E-07 (Cs) 5.4E-09 (Kr) 1.8E-01 (Crud) 1.8E-03 Prob 1.01E-06	6 Seal Failure by Fire (Part) 1.4E-05 (Ru) 1.4E-05 (Cs) 3.6E-05 (Kr) 8.4E-01 (Crud) 5.4E-03 Prob 1.51E-08	16 Failure by Shear/Puncture, Seal Failure from Fire (Part) 1.8E-05 (Ru) 8.4E-05 (Cs) 9.6E-05 (Kr) 8.4E-01 (Crud) 6.4E-03 Prob 5.69E-11
No Impact	21 No Release Prob 0.99996			20 Seal Failure by Fir (Part) 2.5E-07 (Ru) 2.5E-07 (Cs) 1.7E-05 (Kr) 8.4E-01 (Crud) 9.4E-03 Prob 6.32E-06	
	No Fire	T_a - T_s	T_a - T_b	A $T_a - T_f$	B $T_a - T_f$

Severity category	NUREG/CR-6672 Case	Severity fraction	PWR release fractions				
			Kr	Cs	Ru	Particulates	Crud
1	19	0.99993	0.00000	0.00000	0.00000	0.00000	0.00000
2	2, 3	6.06E-05	1.36E-01	4.09E-09	1.02E-07	1.02E-07	1.36E-03
3	18	5.86E-06	8.39E-01	1.68E-05	6.71E-08	6.71E-08	2.52E-03
4	1, 5, 6, 8	4.95E-07	4.49E-01	1.35E-08	3.37E-07	3.37E-07	1.83E-03
5	4	7.49E-08	8.35E-01	3.60E-05	3.77E-06	3.77E-06	3.16E-03
6	7, 9, 10, 11, 12, 13, 14, 15, 16, 17	3.00E-10	8.40E-01	2.40E-05	2.14E-05	5.01E-06	3.17E-03

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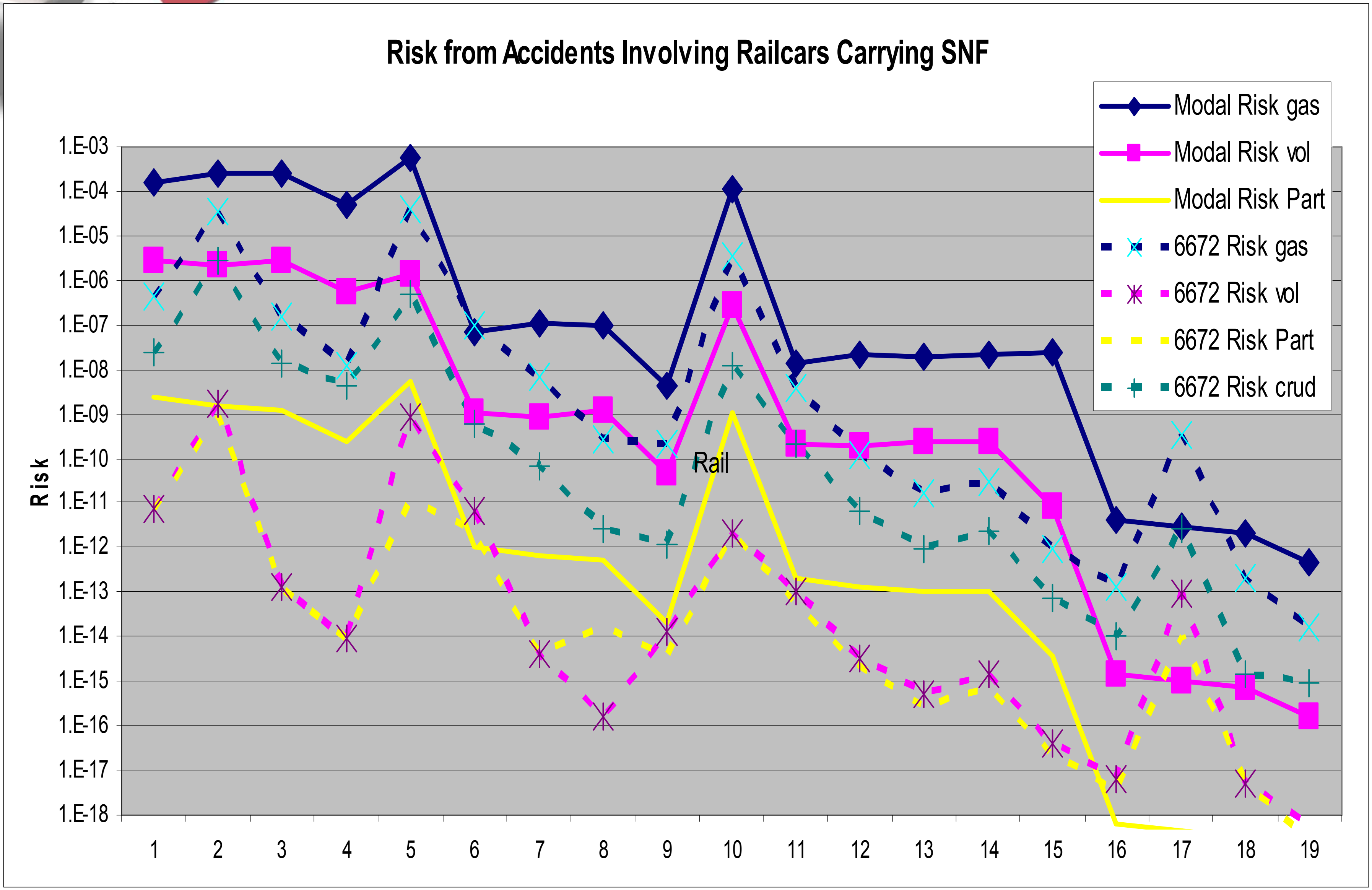

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Gaussian Dispersion

Gaussian Dispersion from a Ground-Level Source

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

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

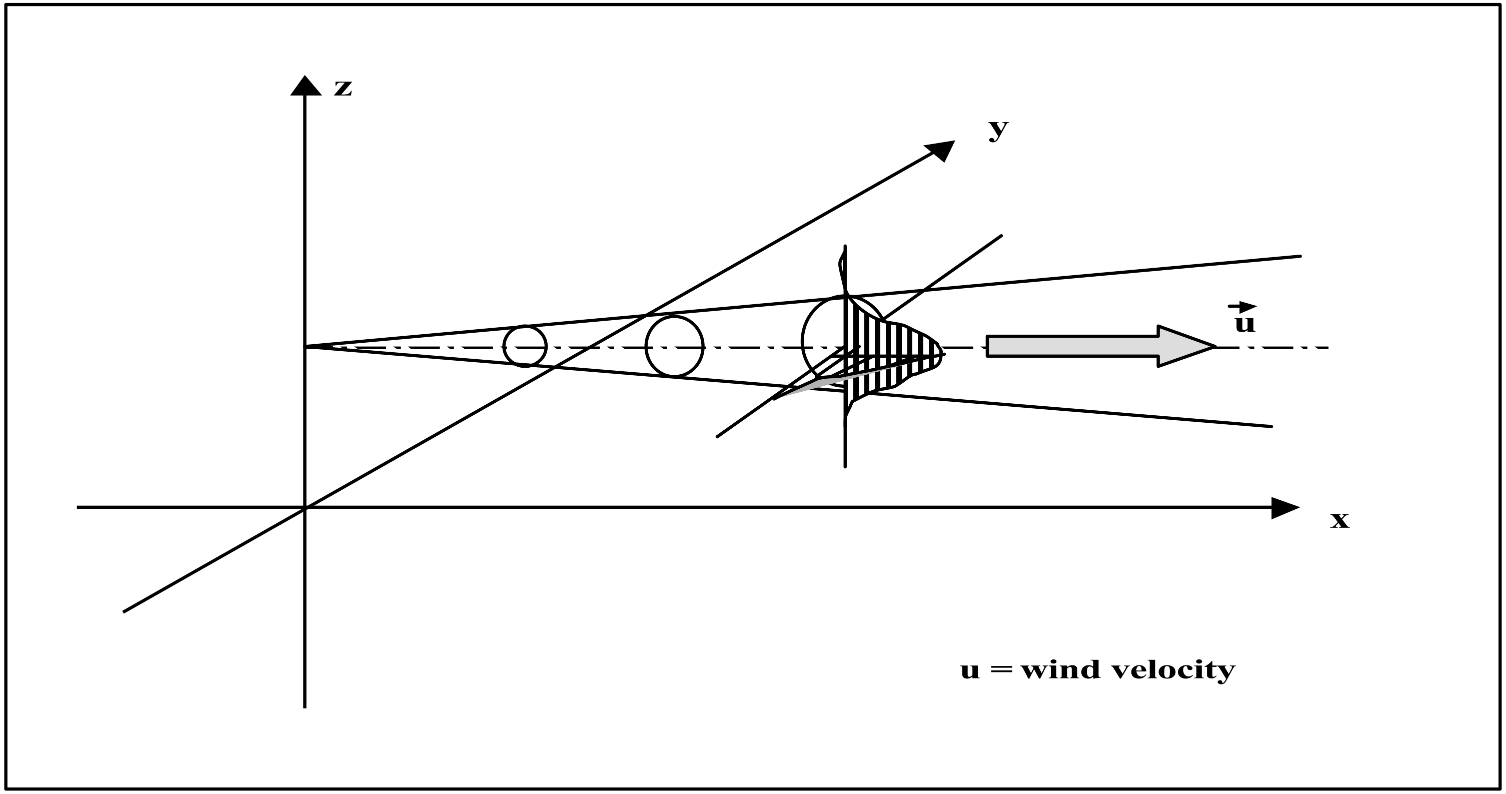
$$\frac{X}{Q} = \frac{1}{2\pi u \sigma_y \sigma_z}$$

Gaussian Dispersion from an Elevated Source

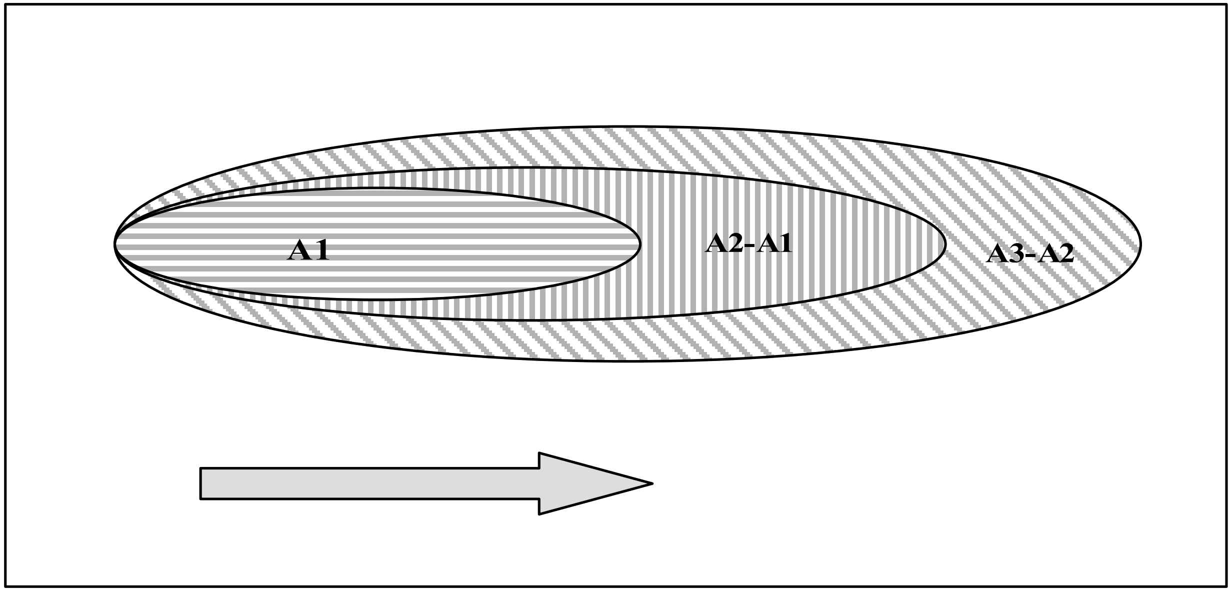
$$\frac{X}{Q} = \frac{1}{2\pi u \sigma_y \sigma_z} \exp\left[\frac{-y^2}{2\sigma_y^2}\right] \exp\left[\frac{-H^2}{2\sigma_z^2}\right]$$

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

Atmospheric Dispersion



Dispersion Footprint



Model for Dose to an Individual from Inhalation of Dispersed Materials

$$D_{inh} = \sum_{m}^{\text{all materials}} \sum_{p}^{\text{all radionuclides}} \sum_{o}^{\text{all organs}} \left(Ci_p \cdot PPS_L \cdot RF_{p,j} \cdot AER_{p,j} \cdot RESP_{p,j} \cdot RPC_{p,o} \cdot \mathbf{X}_n \cdot BR \right)$$

where:

D_{inh} = Individual inhalation dose (rem)
Ci_p = Number of curies of isotope p in package (Ci)
PPS_L = Number of packages on link L
$RF_{p,j}$ = Fraction of package contents released in accident of severity j
$AER_{p,j}$ = Fraction of released material that is aerosol in accident of severity j
$RESP_{p,j}$ = Fraction of aerosolized material that is respirable in accident of severity j
$RPC_{p,o}$ = Dose conversion factor of p^{th} isotope and o^{th} organ (rem/Ci)
$\mathbf{X}_n$ = dilution factor (chi) in nth isopleth area ($Ci\text{-}sec/m^3/Ci\text{-}released$)
BR = Breathing rate (m^3/sec)

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Model for Integrated Population Dose from Direct Inhalation of Dispersed Material

$$D_{inh}^{pop} = Q_7 \cdot Ci_p \cdot PPS_L \cdot RF_{p,j} \cdot AER_{p.j} \cdot RESP_{p,j} \cdot RPC_p \cdot IF \cdot BR \cdot PD_L \cdot A_n$$

where:

D_{inh} = Population inhalation dose (rem)

Q_7 = Conversion factor

Ci_p = Number of curies of isotope p in package (Ci)

PPS_L = Number of packages on link L

$RF_{p,j}$ = Fraction of radionuclide p released in accident of severity j

$AER_{p,j}$ = Fraction of released radionuclide p that is aerosol in accident of severity j

$RESP_{p,j}$ = Respirable f**raction of aerosolized radionuclide p in accident of severity j**

RPC_p = Dose conversion factor of p^{th} isotope (rem/Ci)

IF = **Integral of time-integrated atmospheric dilution factors, X, over downwind areas**

BR = Breathing rate (m^3/sec)

PD_L = Population density on line L (persons/km^2)

A_n = Area of n^{th} isopleth (m^2)

Model for Dose to an Individual from Cloudshine

$$D^{ind}_{cld} = \sum_{m}^{materials} \sum_{p}^{radionuclides} \sum_{o}^{organs} \left(Ci_p \cdot PPS \cdot RF_{p,j} \cdot AER_{p,j} \cdot \mathbf{X}_n \cdot CDF \right)$$

where:

D_{cld} = Individual cloudshine dose (rem)
Ci_p = Number of curies of isotope p in package (Ci)
PPS = Number of packages
$RF_{p,j}$ = Fraction of radionuclide p that is released in accident of severity j
$AER_{p,j}$ = Fraction of radionuclide p that released material that is aerosol in accident of severity j
$\mathbf{X}_n$ = Time-integrated concentration of radionuclide p in n_{th} isopleth (Ci-sec/m^3)
CDF = Cloudshine dose factor for radionuclide p (rem-m^3/Ci-sec)

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Model for Integrated Population Dose from Cloudshine

$$\overline{D^{pop}_{cld\ p,\ j,\ L,\ m} = Q_7 \cdot Ci_p \cdot PPS_{L,\ m} \cdot RF_{p,\ j} \cdot AER_{p.j} \cdot CDF_p \cdot IF \cdot PD_L}$$

where:

D_{cld} = Population cloudshine dose (rem)

Q_7 = Conversion factor

Ci_p = Number of curies of isotope p in package (Ci)

$PPS_{L,m}$ = Number of packages of material m per shipment on link L

$RF_{p,j}$ = Fraction of radionuclide p released in accident of severity j

$AER_{p,j}$ = Fraction of released radionuclide p that is aerosol in accident of severity j

CDF_p = Cloudshine dose conversion factor of p^{th} isotope (rem-m^3/Ci-sec)

IF = **Integral of time-integrated atmospheric dilution factors, X, over downwind areas**

PD_L = Population density on line L (persons/km^2)

$$[(UBF \cdot BDF) + (USWF \cdot RPD)]$$

Model for Integrated Population Dose from Groundshine

$$DR(T) = CL_p \cdot GDF \cdot \left[0.63 \cdot e^{-0.0031 \cdot t_{1/2}} + 0.37 \cdot e^{-0.000021 \cdot t_{1/2}}\right] \cdot e^{\frac{-0.693 \cdot ET}{t_{1/2}}}$$

where:

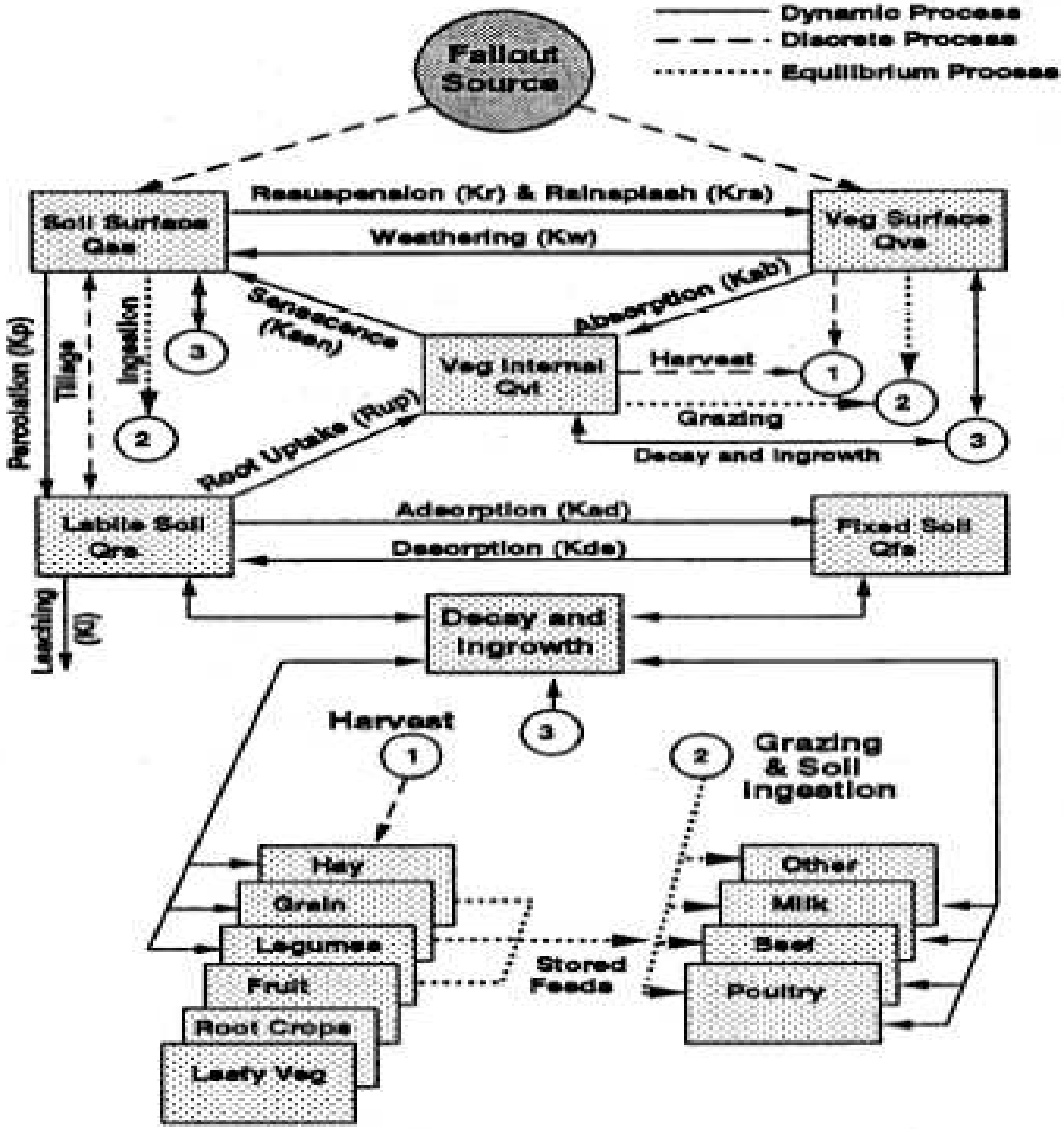
DR(T) = Groundshine dose rate at time T (rem/day)
CL_p = Contamination level of radionuclide p ($\mu Ci/m^2$)
GDF = Groundshine dose factor for radionuclide p ($rem\text{-}m^2/day\text{-}\mu Ci$)
$t_{1/2}$ = Half-life of radionuclide p (days)
ET = Elapsed time (days)

Calculation of Total Groundshine Dose

$$D_{gnd-total} = \sum_{n=1}^{NAREAS} D_{gnd_n}$$

where:

$D_{gnd\text{-}total}$ = Total groundshine dose (person-rem)
D_{gnd} = Groundshine dose for the p^{th} radionuclide in the n^{th} isopleth in accident of severity j on link l (person-rem)



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Inhalation Dose-Risk

$$RISK_L^{INH} = \sum_{p=1}^{n} \sum_{j=1}^{NSEV} \gamma_{j,L} \cdot D_{inh_{p,j,L}}$$

where:

$\gamma_{j,L}$ = Probability of an accident of severity j on link L

D_{inh} = Dose from inhalation of isotope p in an accident of severity j on link L (person-rem)

NSEV = Number of accident-severity categories

n = Number of radionuclides in package

Resuspension Dose-Risk

$$RISK_L^{RES} = \sum_{p=1}^{n} \sum_{j=1}^{NSEV} \gamma_{j,L} \cdot D_{res_{p,j,L}}$$

where:

$\gamma_{j,L}$ = Probability of an accident of severity j on link L

D_{res} = Dose from resuspension of isotope p in an accident of severity j on link L (person-rem)

NSEV = Number of accident-severity categories

n = Number of radionuclides in package

Cloudshine Dose-Risk

$$RISK_L^{CLD} = \sum_{p=1}^{n} \sum_{j=1}^{NSEV} \gamma_{j,L} \cdot Dcld_{p,j,L}$$

where:

$\gamma_{j,L}$ = Probability of an accident of severity j on link L

D_{cld} = Dose from cloudshine of isotope p in an accident of severity j on link L (person-rem)

NSEV = Number of accident-severity categories

n = Number of radionuclides in package

Groundshine Dose-Risk

$$RISK_L^{GND} = \sum_{p=1}^{n} \sum_{j=1}^{NSEV} \gamma_{j,L} \cdot D_{gnd_{p,j,L}}$$

where:

$\gamma_{j,L}$ = Probability of an accident of severity j on link L

D_{gnd} = Dose from groundshine of isotope p in an accident of severity j on link L (person-rem)

NSEV = Number of accident-severity categories

n = Number of radionuclides in package

Ingestion Dose-Risk

$$RISK_L^{ING} = \sum_{p=1}^{n} \sum_{j=1}^{NSEV} \gamma_{j,L} \cdot D_{ing_{p,j,L}}$$

where:

$\gamma_{j,L}$ = Probability of an accident of severity j on link L

D_{ing} = Dose from ingestion of isotope p in an accident of severity j on link L (person-rem)

NSEV = Number of accident-severity categories

n = Number of radionuclides in package

Overall Dose-Risk from Dispersion

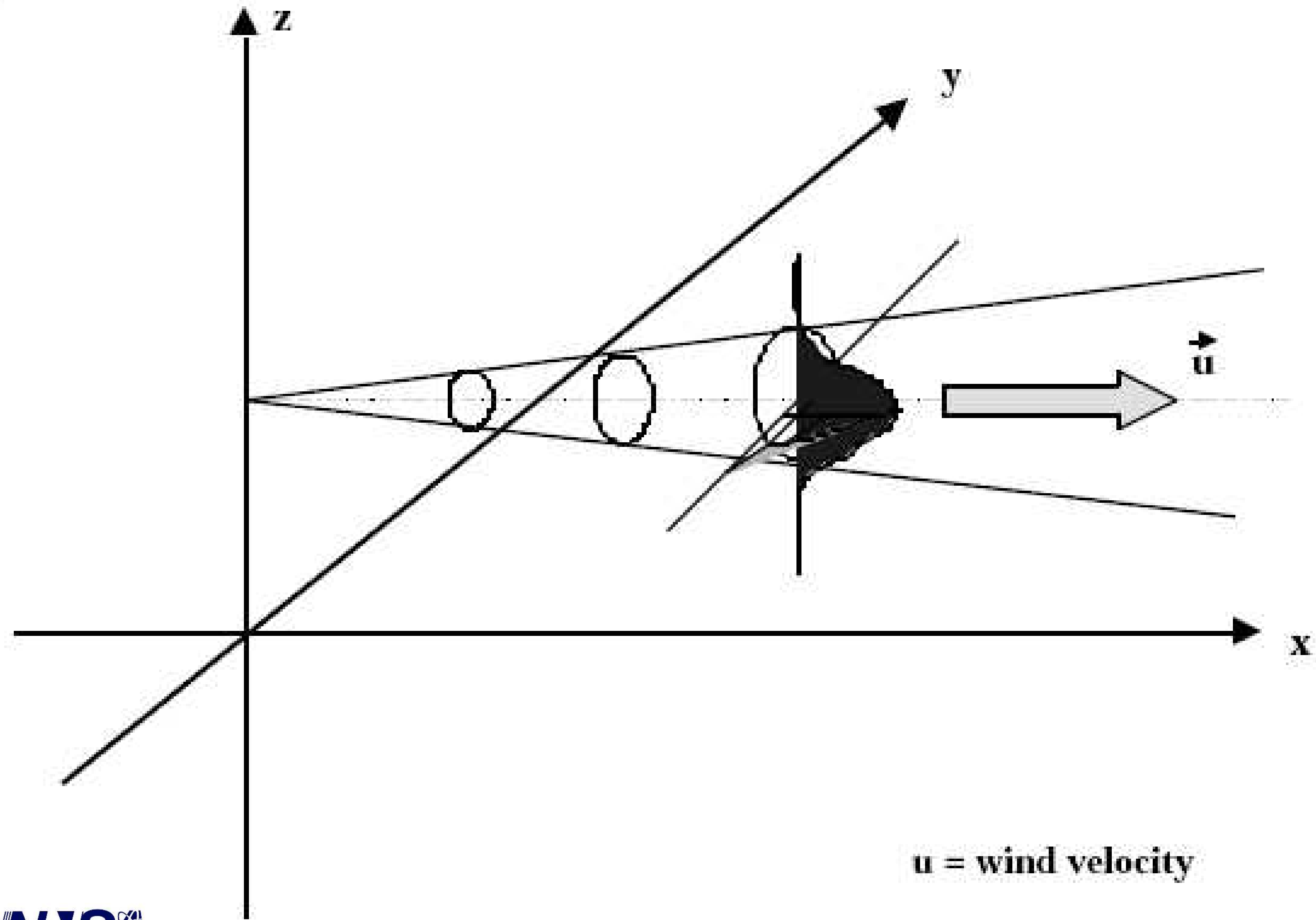
$$RISK_L^{TOTAL} = \sum_{n}^{inh,res,cld,gnd} RISK^n$$

where:

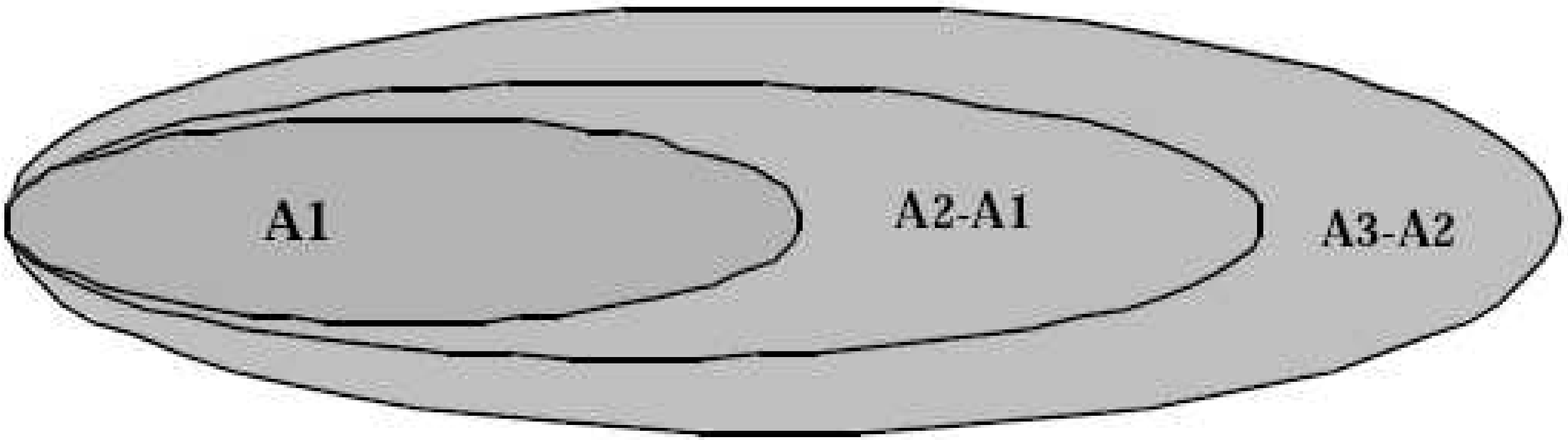
$RISK^{INH}$ = Inhalation dose risk
$RISK^{RES}$ = Resuspension dose risk
$RISK^{CLD}$ = Cloudshine dose risk
$RISK^{GND}$ = Groundshine dose risk
n = Index for risk class

Note: Ingestion dose risk is listed separately and should not be added to the other pathways because the population exposed via this pathway is entirely different.

Diagram of Gaussian Dispersion



Typical Plume Footprint



Basic Gaussian Dispersion Model for Dilution at Ground Level for an Elevated Release along the Plume Centerline

$$\frac{X}{Q} = \frac{1}{\pi \cdot \sigma_y \cdot \sigma_z \cdot \mu} \cdot e^{\left(\frac{-H^2}{2 \cdot \sigma_z^2}\right)}$$

where:

X = Concentration of dispersed substance at ground level (Ci/m^3)
Q = Rate of release of dispersed substance (Ci/sec)
μ = Wind speed (m/sec)
σ_y = Crosswind meteorological constant (m) [y-axis Gaussian half-width]
σ_z = Vertical meteorological constant (m) [z-axis Gaussian half-width]
H = Release height (m)

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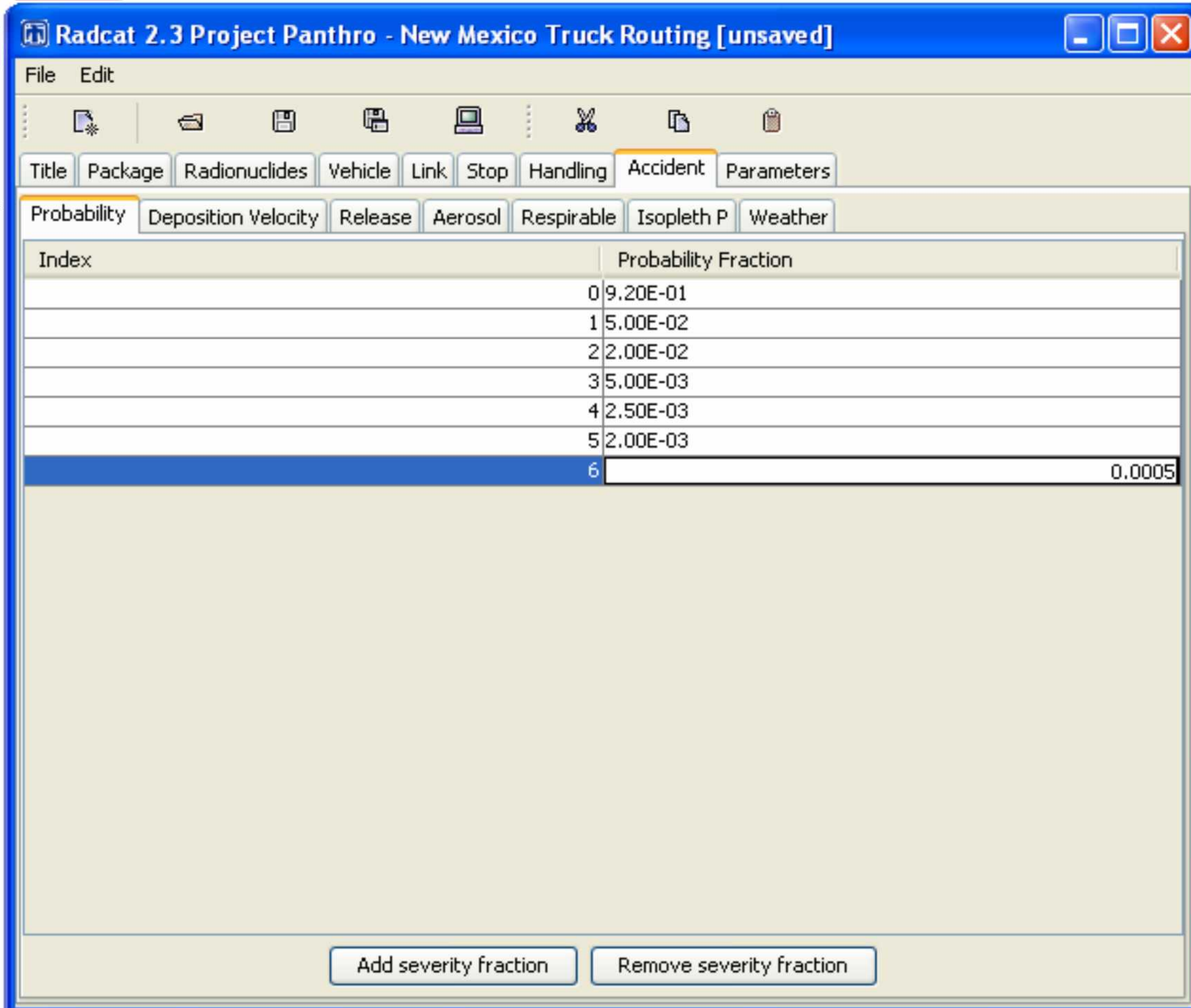
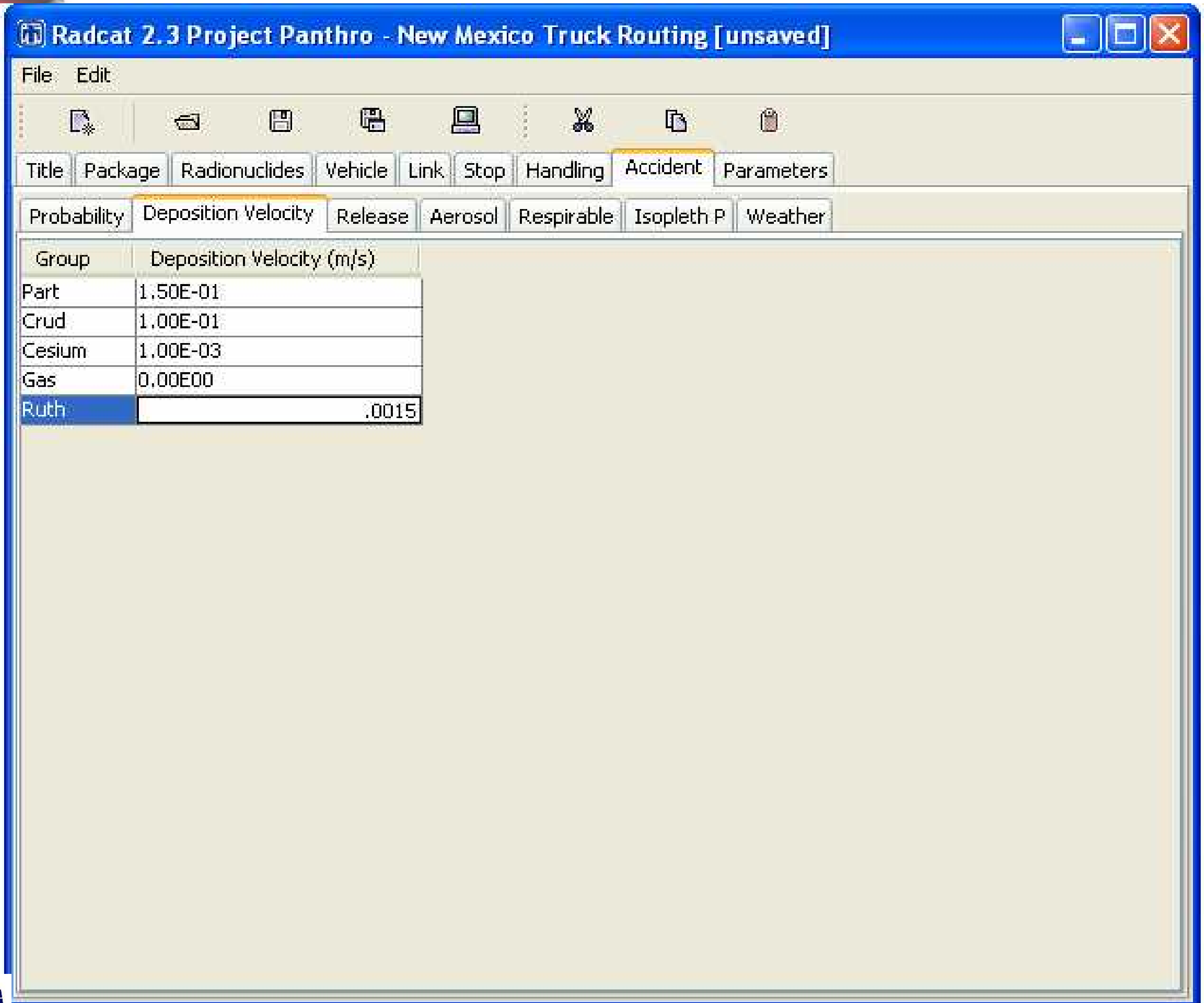
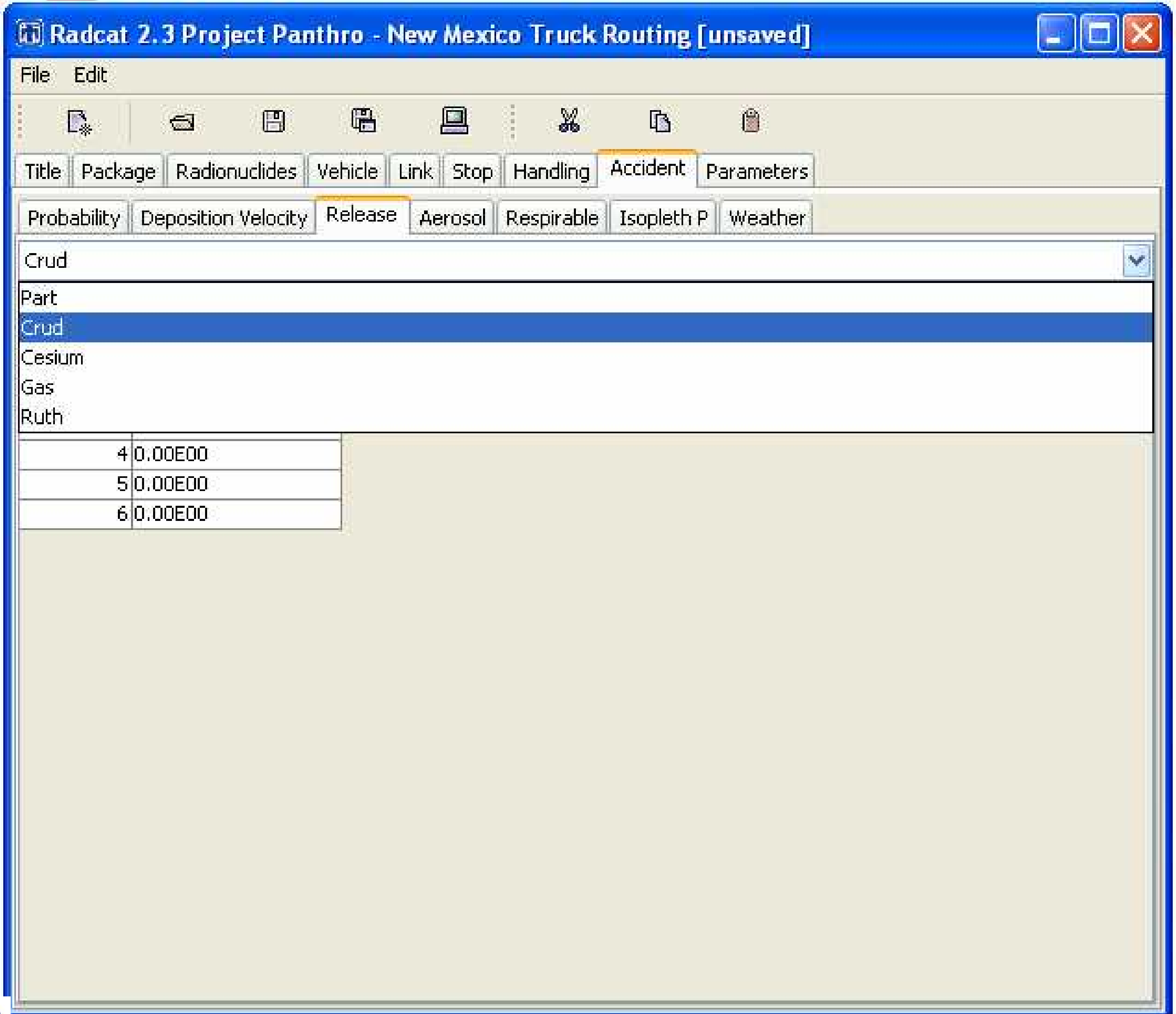
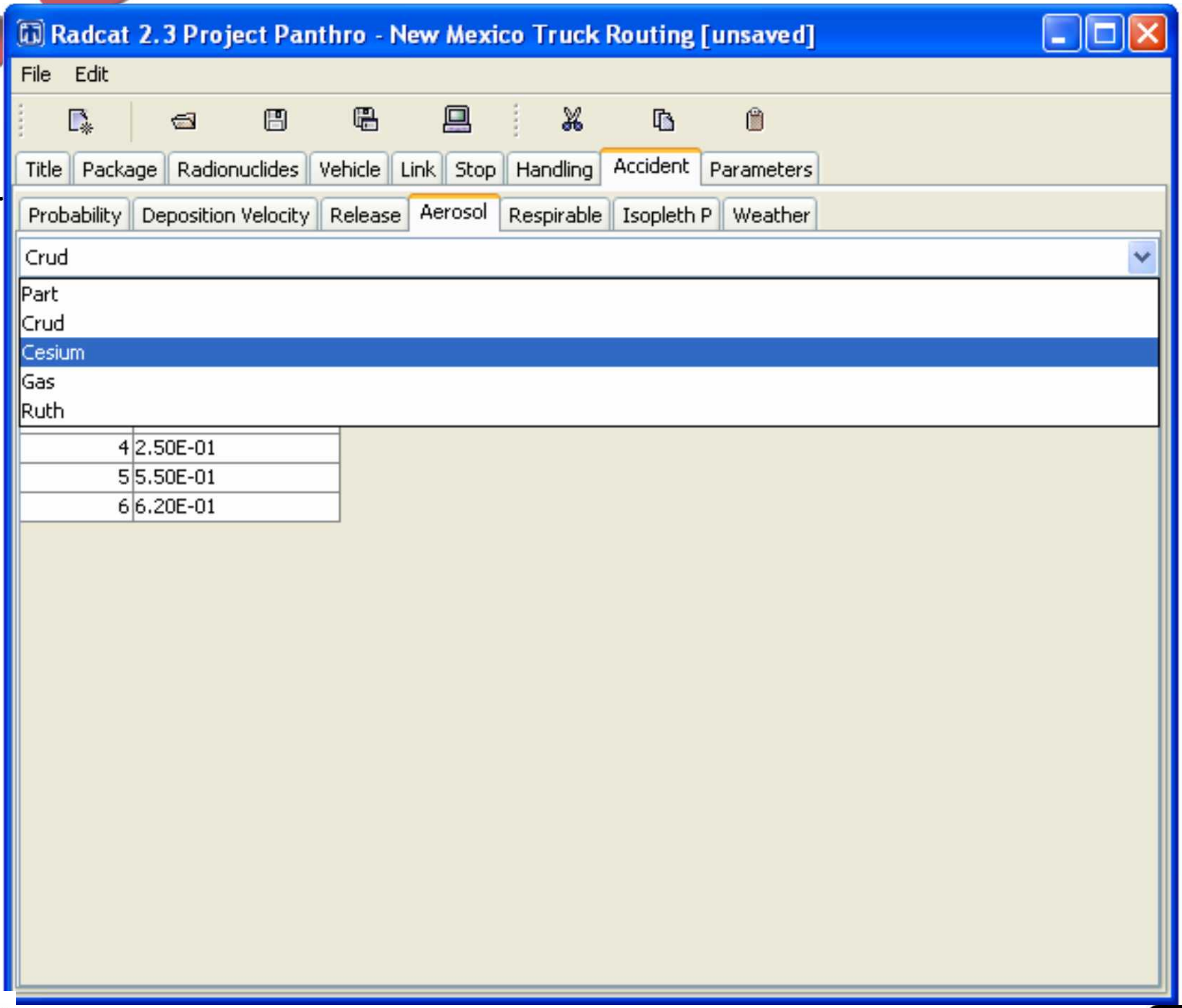
Example of Radionuclide Inventory

PACKAGE	SFUEL	1.000E+01	1.000 0.000	4.80
EU154	8.42E+03	PARTS		
PM147	2.58E+04	PARTS		
CM242	3.76E+02	PARTS		
AM242M	1.33E+01	PARTS		
CM243	2.88E+01	PARTS		
AM243	2.51E+01	PARTS		
CS134	6.99E+04	CESIUM		
CS137	7.90E+04	CESIUM		
CE144	3.87E+04	PARTS		
RU106	4.43E+04	RUTH		
SR90	5.36E+04	PARTS		
PU239	2.14E+02	PARTS		
PU240	4.28E+02	PARTS		
AM241	4.36E+02	PARTS		
PU241	6.52E+04	PARTS		
CM244	5.62E+03	PARTS		
PU238	4.81E+03	PARTS		
CO60	5.78E+01	CRUD		


Radcat 2.3 Project Panthro - New Mexico Truck Routing [unsaved]
File
Edit
Title
Package
Radionuclides
Vehicle
Link
Stop
Handling
Accident
Parameters
Probability
Deposition Velocity
Release
Aerosol
Respirable
Isopleth P
Weather
Index
Probability Fraction
0 9.20E-01
1 5.00E-02
2 2.00E-02
3 5.00E-03
4 2.50E-03
5 2.00E-03
6 0.0005
Add severity fraction
Remove severity fraction


Radcat 2.3 Project Panthro - New Mexico Truck Routing [unsaved]
File Edit
Title Package Radionuclides Vehicle Link Stop Handling Accident Parameters
Probability Deposition Velocity Release Aerosol Respirable Isopleth P Weather
Group | Deposition Velocity (m/s)
Part | 1.50E-01
Crud | 1.00E-01
Cesium | 1.00E-03
Gas | 0.00E00
Ruth | .0015


Radcat 2.3 Project Panthro - New Mexico Truck Routing [unsaved]
File Edit
Title Package Radionuclides Vehicle Link Stop Handling Accident Parameters
Probability Deposition Velocity Release Aerosol Respirable Isopleth P Weather
Crud
Part
Crud
Cesium
Gas
Ruth
4 0.00E00
5 0.00E00
6 0.00E00


Radcat 2.3 Project Panthro - New Mexico Truck Routing [unsaved]
File
Edit
Title
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Vehicle
Link
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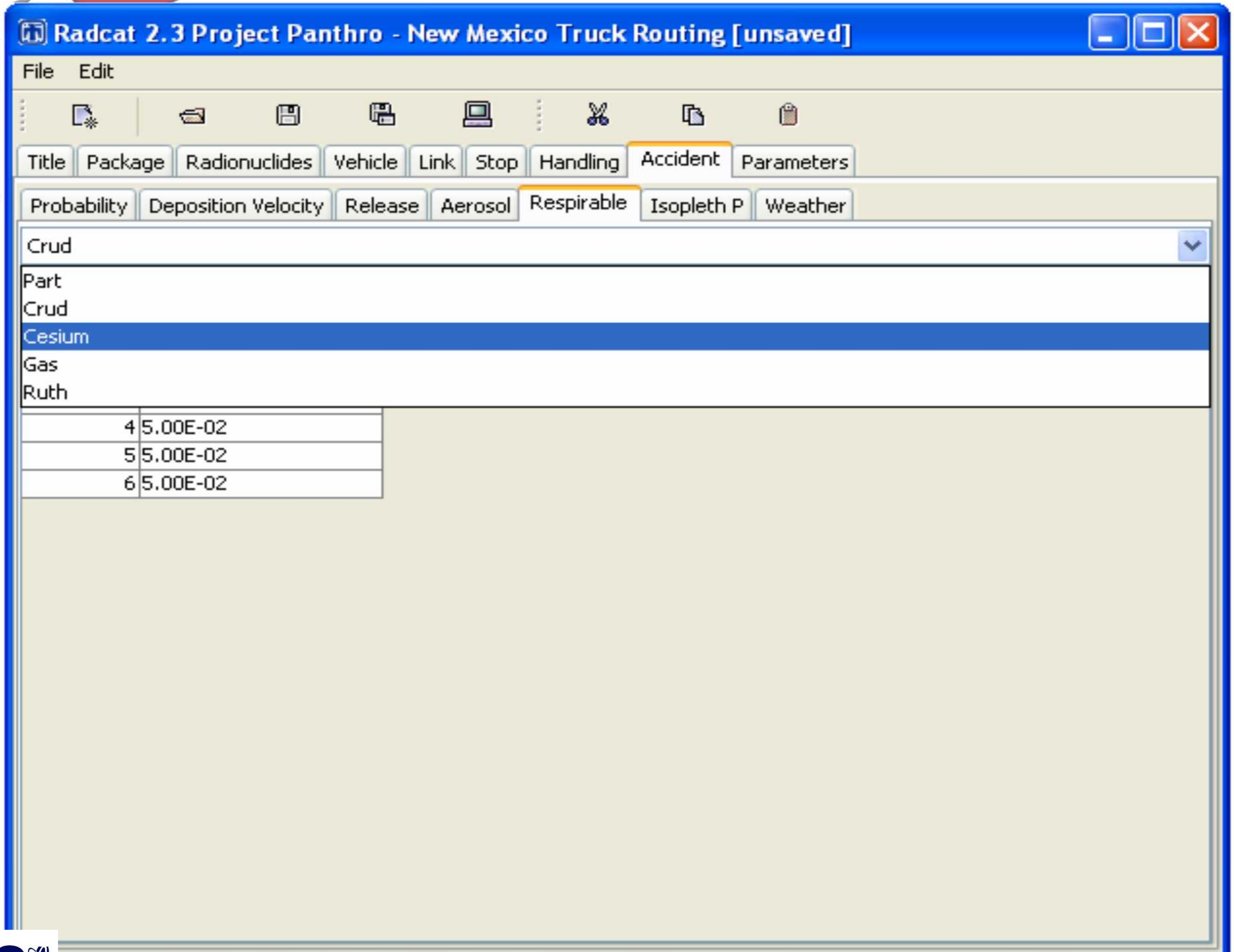
Accident
Parameters
Probability
Deposition Velocity
Release
Aerosol
Respirable
Isopleth P
Weather
Crud
Part
Crud
Cesium
Gas
Ruth
4 2.50E-01
5 5.50E-01
6 6.20E-01


Radcat 2.3 Project Panthro - New Mexico Truck Routing [unsaved]
File
Edit
Title
Package
Radionuclides
Vehicle
Link
Stop
Handling
Accident
Parameters
Probability
Deposition Velocity
Release
Aerosol
Respirable
Isopleth P
Weather
Crud
Part
Crud
Cesium
Gas
Ruth
4 5.00E-02
5 5.00E-02
6 5.00E-02

Radcat 2.3 Project Panthro - New Mexico Truck Routing [unsaved]

File Edit

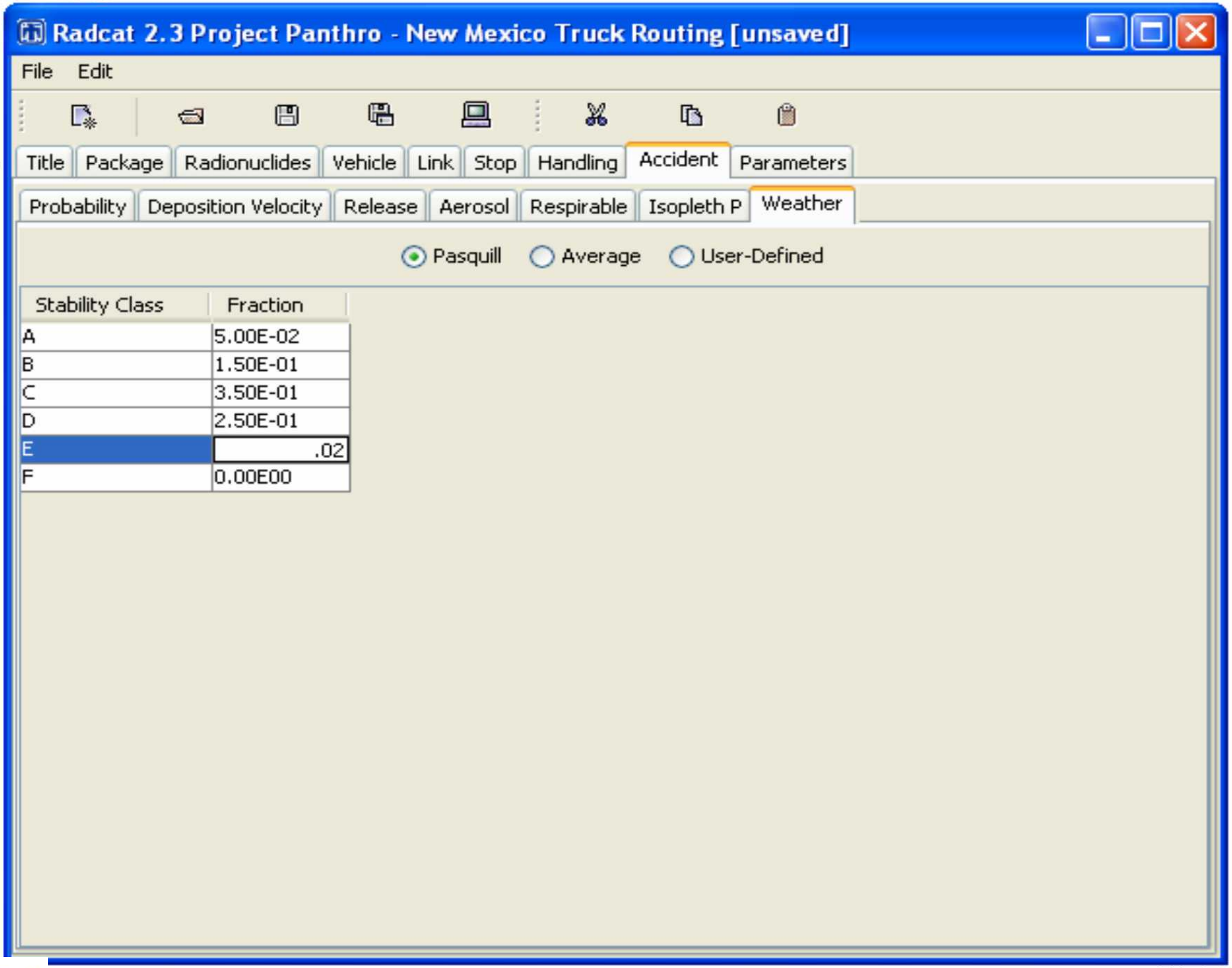
Title | Package | Radionuclides | Vehicle | Link | Stop | Handling | Accident | Parameters

Probability | Deposition Velocity | Release | Aerosol | Respirable | Isopleth P | Weather

○ Pasquill ◉ Average ○ User-Defined

Isopleth Area Size (m²)	Time Integrated Concentration	Center-Line Distance (m)
4.59E02	3.42E-03	3.30E01
1.53E03	1.72E-03	6.80E01
3.94E03	8.58E-04	1.05E02
1.25E04	3.42E-04	2.44E02
3.04E04	1.72E-04	3.69E02
6.85E04	8.58E-05	5.61E02
1.76E05	3.42E-05	1.02E03
4.45E05	1.72E-05	1.63E03
8.59E05	8.58E-06	2.31E03
2.55E06	3.42E-06	4.27E03
4.45E06	1.72E-06	5.47E03
1.03E07	8.58E-07	1.11E04
2.16E07	3.42E-07	1.31E04
5.52E07	1.72E-07	2.13E04
1.77E08	8.58E-08	4.05E04
4.89E08	5.42E-08	7.00E04
8.12E08	4.30E-08	8.99E04
1.35E09	3.42E-08	1.21E05

Add Average Area | Remove Average Area


Radcat 2.3 Project Panthro - New Mexico Truck Routing [unsaved]
File
Edit
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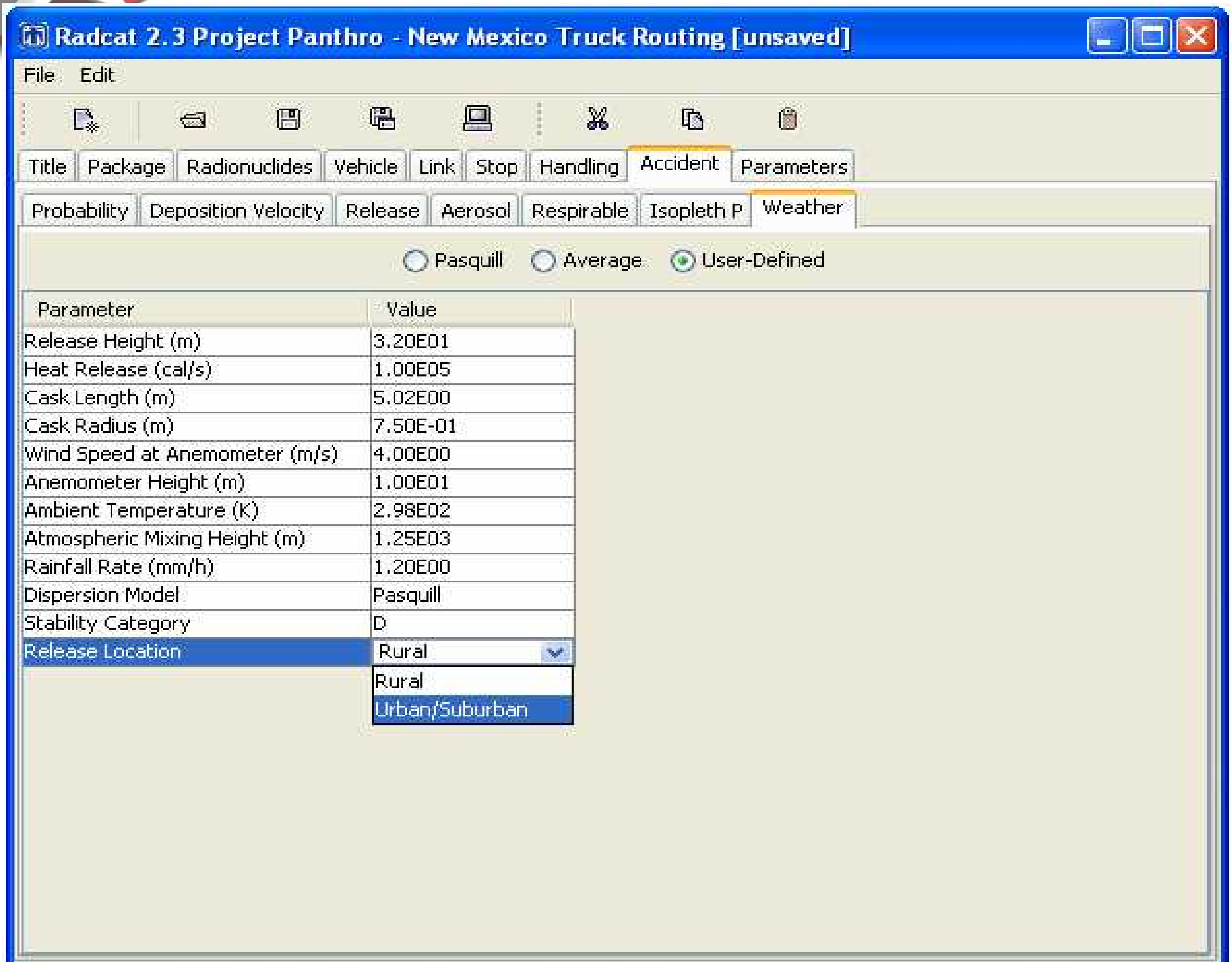
Package
Radionuclides
Vehicle
Link
Stop
Handling
Accident
Parameters
Probability
Deposition Velocity
Release
Aerosol
Respirable
Isopleth P
Weather
Pasquill
Average
User-Defined
Stability Class
Fraction
A
5.00E-02
B
1.50E-01
C
3.50E-01
D
2.50E-01
E
.02
F
0.00E00


Radcat 2.3 Project Panthro - New Mexico Truck Routing [unsaved]
File
Edit
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Package
Radionuclides
Vehicle
Link
Stop
Handling
Accident
Parameters
Probability
Deposition Velocity
Release
Aerosol
Respirable
Isopleth P
Weather
Pasquill
Average
User-Defined
Parameter
Value
Release Height (m) 3.20E01
Heat Release (cal/s) 1.00E05
Cask Length (m) 5.02E00
Cask Radius (m) 7.50E-01
Wind Speed at Anemometer (m/s) 4.00E00
Anemometer Height (m) 1.00E01
Ambient Temperature (K) 2.98E02
Atmospheric Mixing Height (m) 1.25E03
Rainfall Rate (mm/h) 1.20E00
Dispersion Model Pasquill
Stability Category D
Release Location Rural
Rural
Urban/Suburban

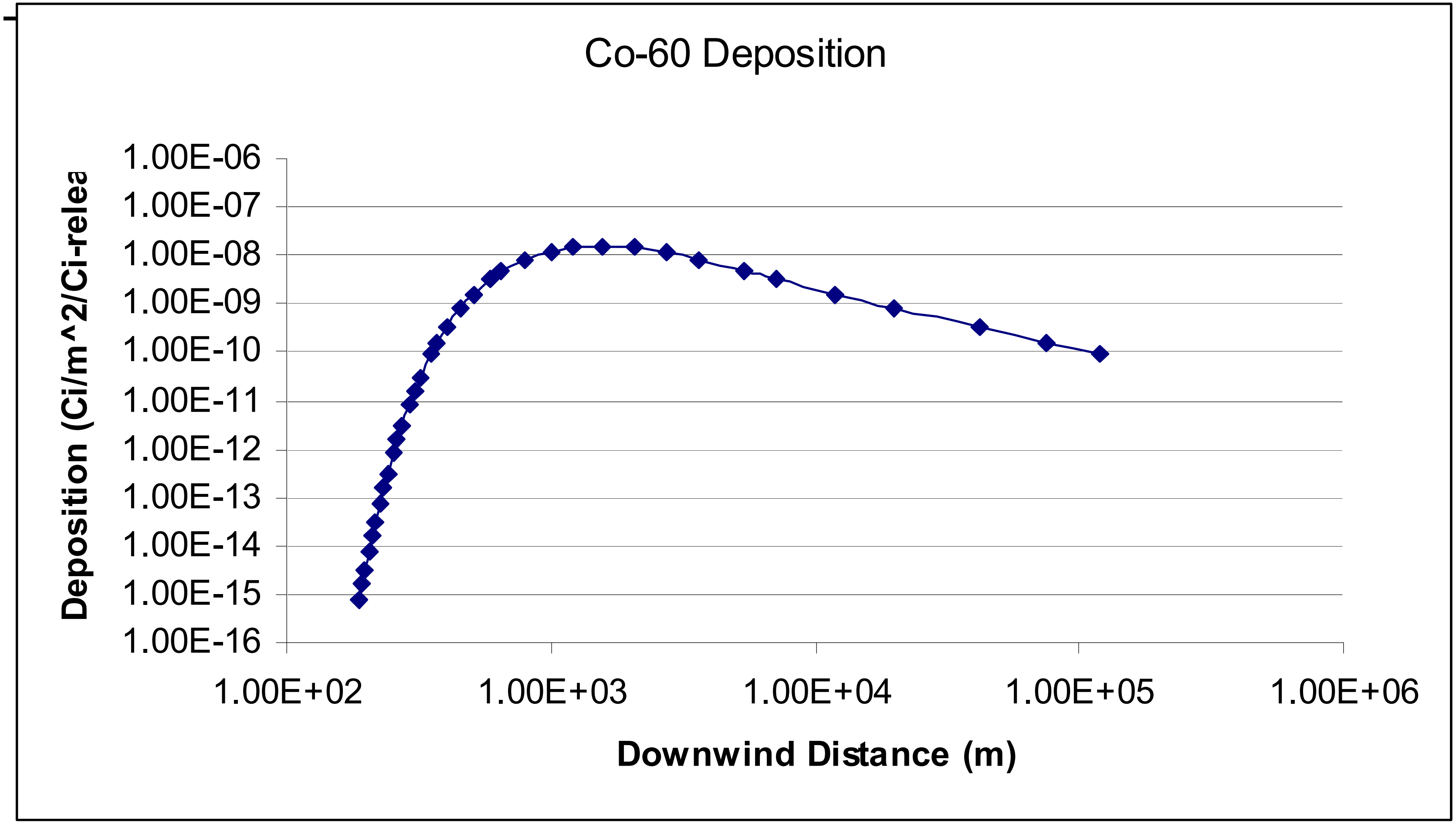
Example of Accident Risk Output

EXPECTED VALUES OF POPULATION RISK IN PERSON-SV						
	GROUND	INHALED	RESUSPD	CLOUDSH	TOTAL	
LINK_1	9.44E-03	2.22E-03	2.02E-04	8.64E-06	1.19E-02	
LINK_2	9.44E-03	2.22E-03	2.02E-04	8.64E-06	1.19E-02	
LINK_3	6.09E-03	1.43E-03	1.30E-04	5.57E-06	7.65E-03	
RURAL	9.44E-03	2.22E-03	2.02E-04	8.64E-06	1.19E-02	
SUBURB	9.44E-03	2.22E-03	2.02E-04	8.64E-06	1.19E-02	
URBAN	6.09E-03	1.43E-03	1.30E-04	5.57E-06	7.65E-03	
TOTALS:	2.50E-02	5.87E-03	5.34E-04	2.29E-05	3.14E-02	
SOCIETAL INGESTION RISK - PERSON-SV						
LINK	GONADS	EFFECTIVE				
LINK_1	4.90E-01	4.82E-01				
TOTAL	4.90E-01	4.82E-01				
SOCIETAL INGESTION RISK BY ORGAN - PERSON-SV						
LINK	BREAST	LUNGS	RED MAR	BONE SUR	THYROID	REMAINDER
LINK_1	4.12E-01	4.20E-01	4.84E-01	5.80E-01	4.18E-01	5.34E-01
TOTAL	4.12E-01	4.20E-01	4.84E-01	5.80E-01	4.18E-01	5.34E-01

National Nuclear Security Administration

Sandia National Laboratories

^{60}Co Elevated Release

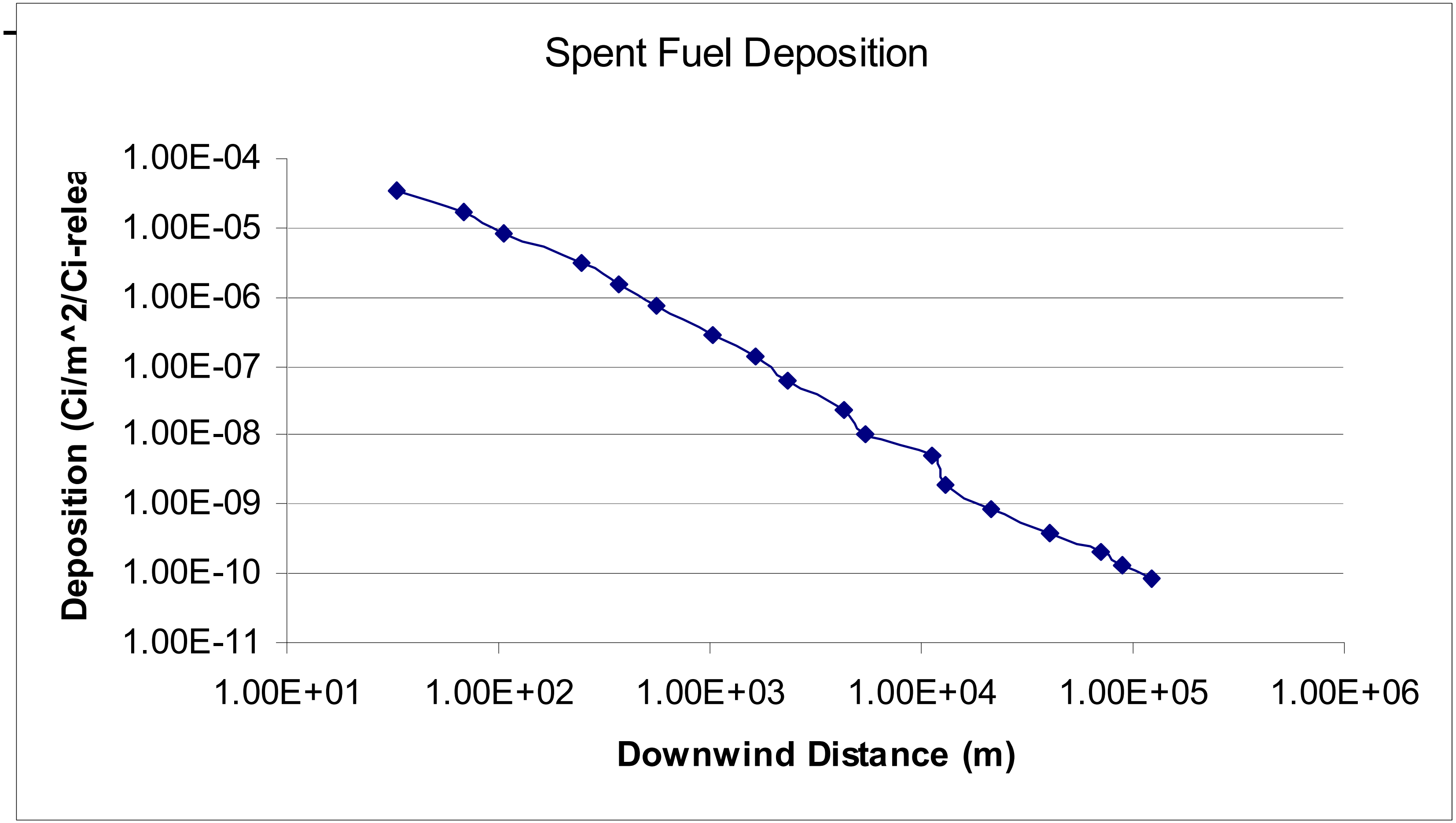


- **User-defined atmospheric dispersion of ^{60}Co on a rural truck route**

National Nuclear Security Administration

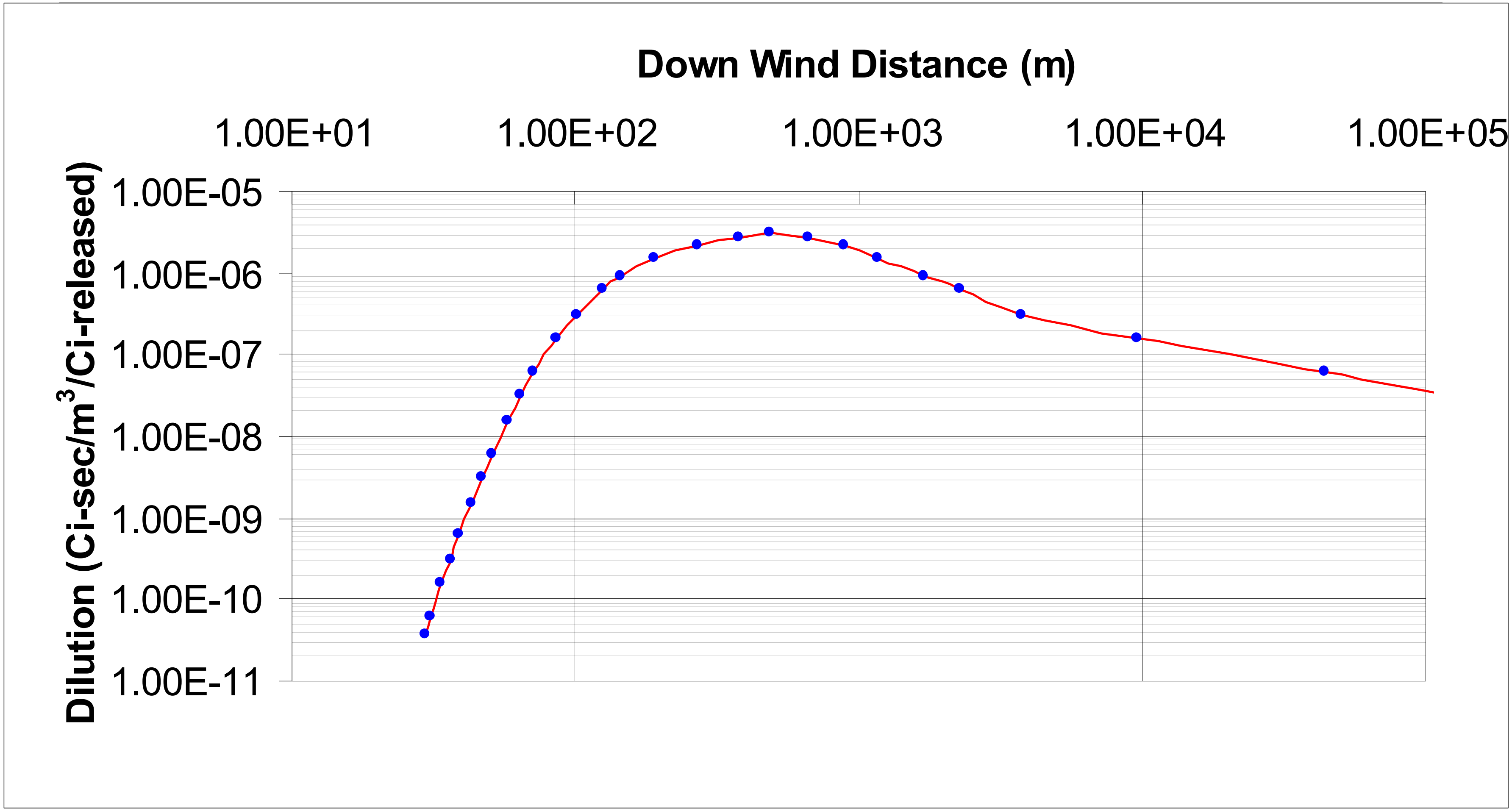
Sandia National Laboratories

Spent Fuel Ground Release

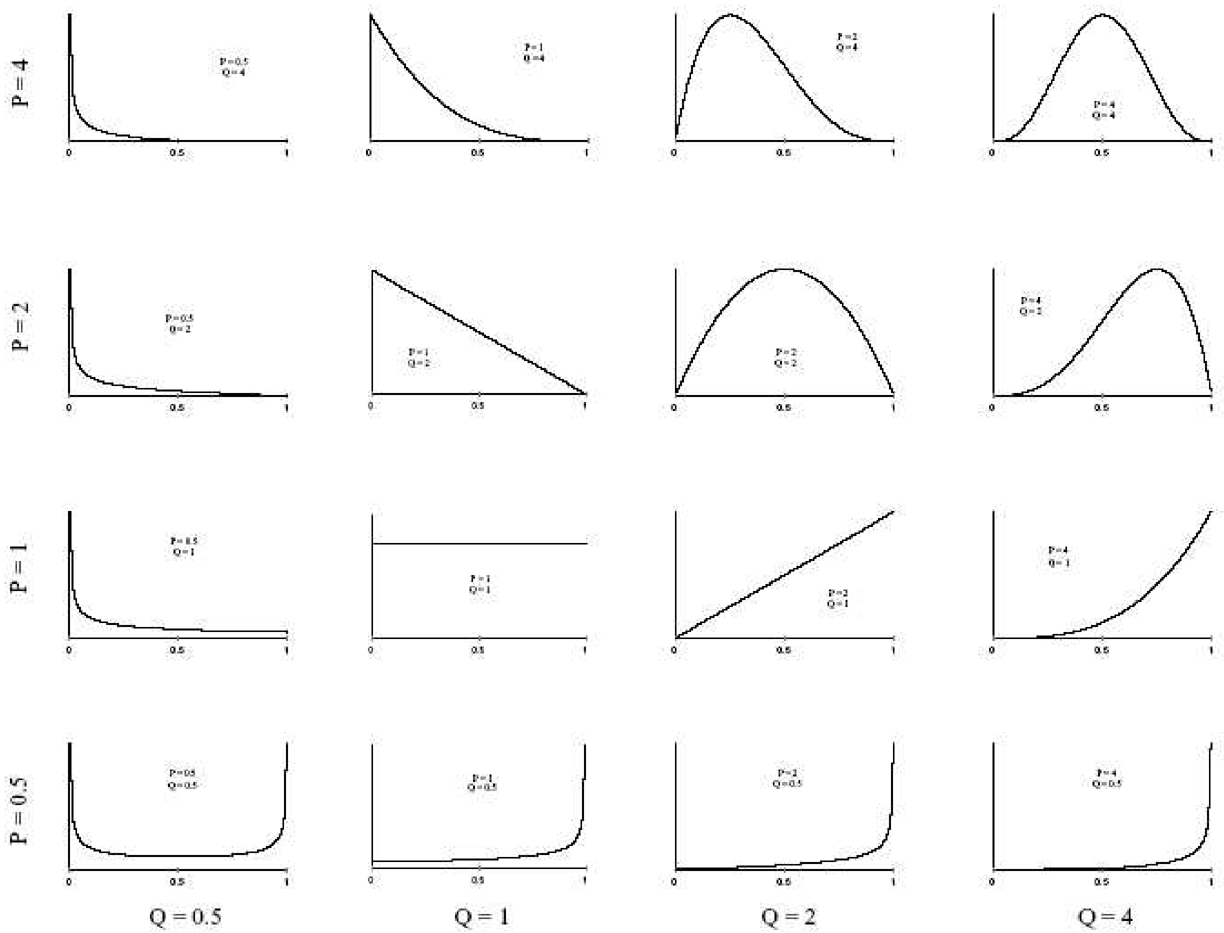


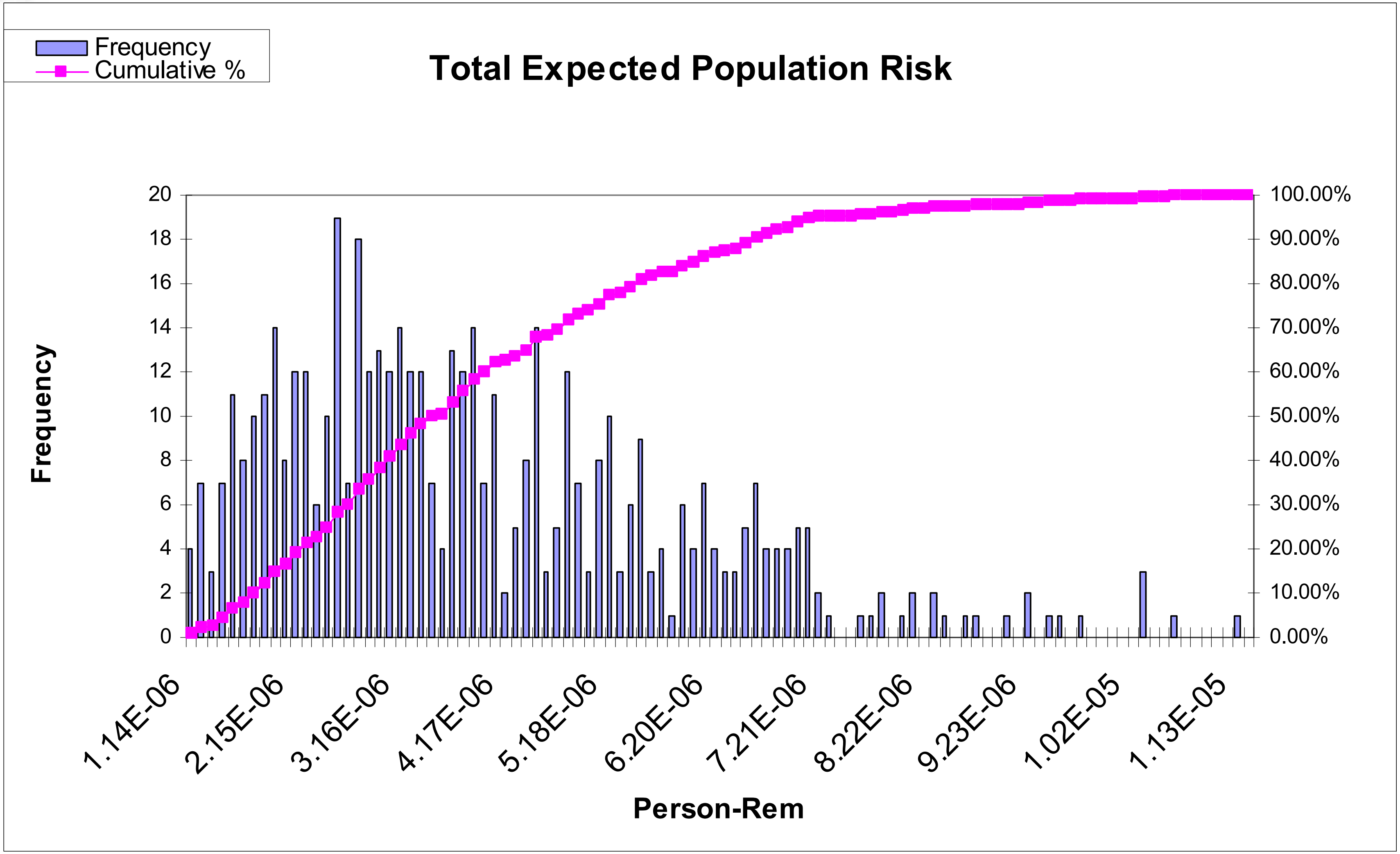
- National average weather atmospheric dispersion of spent fuel on a truck route

RADTRAN Output
Atmospheric Dispersion Model



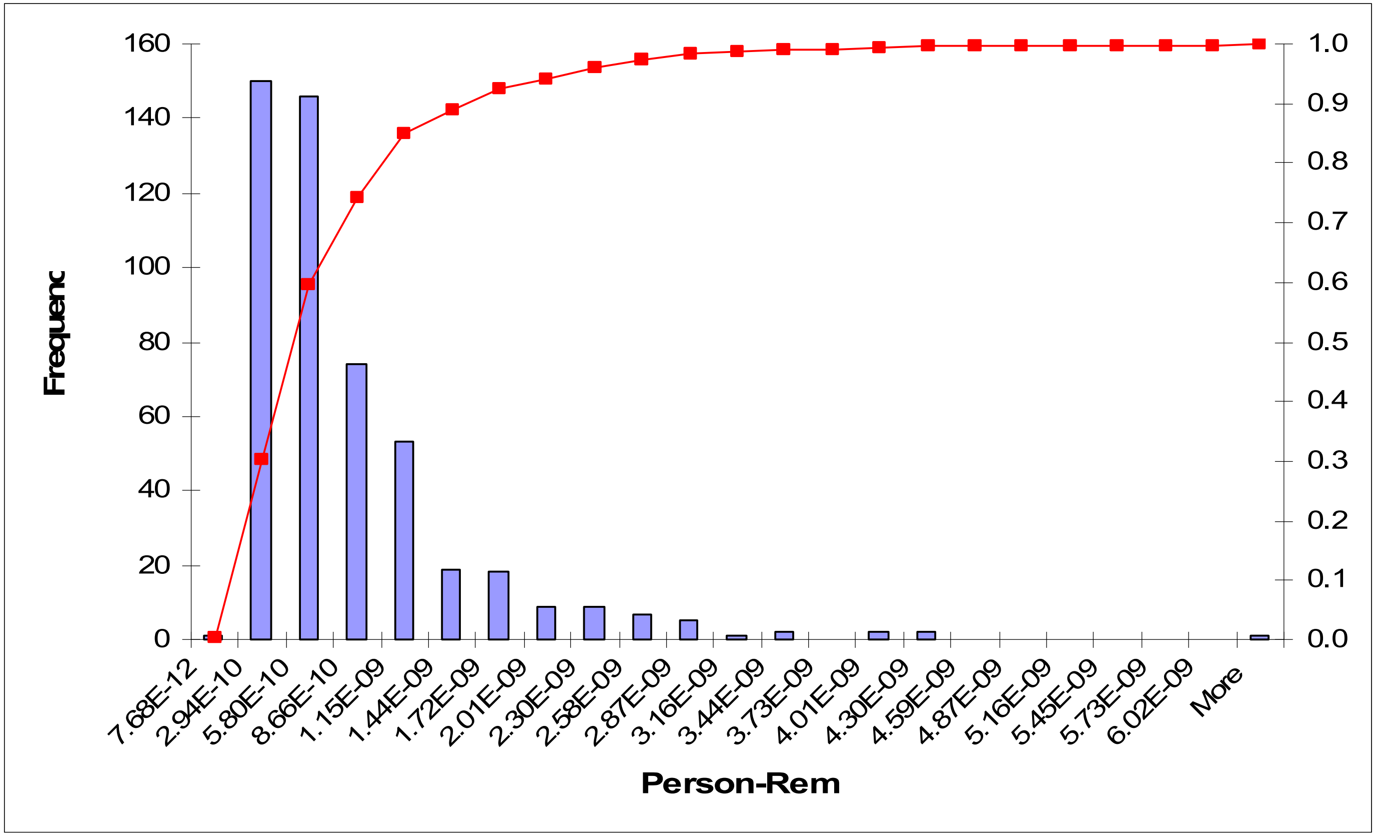
Uncertainty in RADTRAN: Beta Distributions





Greatest frequency at 2.55 E -06 person-rem

Uncertainty in RADTRAN



Accident Inhalation Dose Risk

Economic Model: Post-Accident Events

- Population evacuated by first-response emergency workers
- Measurement of dose rates across isopleth areas
- Cleanup of buildings, roads, and other surfaces
- Sequestration of crops and livestock
  - Sequester crops for one year
  - Sequester livestock for two years
- Clean up to a predetermined cleanup level
  - 0.2 $\mu Ci/m^2$

Economic Model: Cost Categories

- Cleanup
  - Buildings
    - Residential
    - Commercial
    - Industrial
  - Roads
  - Soil
- Agricultural Sequestration
  - Crops
  - Livestock
- Emergency and Evacuation

National Nuclear Security Administration

Sandia National Laboratories

Additional Viewgraphs

Selected IAEA A1 and A2 Values

RADIONUCLIDE	A1		A2	
	TBq	Ci	TBq	Ci
AM241	10	270.27	0.003	0.08
AM242m	10	270.27	0.003	0.08
AM243	5	135.14	0.003	0.08
CM242	40	1081.08	0.01	0.27
CO60	0.1	2.70	0.1	2.70
CS134	0.7	18.92	0.7	18.92
CS137	2	54.05	0.6	16.22
FE55	40	1081.08	40	1081.08
I131	30	810.81	0.7	18.92
NI63	40	1081.08	30	810.81
PU238	10	270.27	0.001	0.03
PU239	10	270.27	0.001	0.03
TC99	40	1081.08	0.9	24.32
U232	10	270.27	0.001	0.03
U234	40	1081.08	0.09	2.43
U235	Unlimited	Unlimited	Unlimited	Unlimited

NNSA National Nuclear Security Administration

Sandia National Laboratories

Selected USNRC A1 and A2 Values

Red = Same as IAEA Values

RADIONUCLIDE	A1		A2	
	TBq	Ci	TBq	Ci
AM241	2	54.05	0.0002	0.01
AM242m	2	54.05	0.0002	0.01
AM243	2	54.05	0.0002	0.01
CM242	40	1081.08	0.02	0.54
CO60	0.4	10.81	0.4	10.81
CS134	0.6	16.22	0.5	13.51
CS137	2	54.05	0.5	13.51
FE55	0.2	5.41	0.2	5.41
I131	3	81.08	0.5	13.51
NI63	40	1081.08	30	810.81
PU238	2	54.05	0.0002	0.01
PU239	2	54.05	0.0002	0.01
TC99	40	1081.08	0.9	24.32
U232	3	81.08	0.0003	0.01
U234	10	270.27	0.001	0.03
U235	Unlimited	Unlimited	Unlimited	Unlimited

Package Regulations

Type A packages

414. *Type A packages* shall not contain activities greater than the following:

(a) for *special form radioactive material* — A_1; or
(b) for all other *radioactive material* — A_2.

Type B(U) and Type B(M) packages

416. *Type B(U)* and *Type B(M) packages* shall not contain:

(a) activities greater than those authorized for the *package design*,
(b) radionuclides different from those authorized for the *package design*, or
(c) contents in a form, or a physical or chemical state, different from those authorized for the *package design*,

Activity Limits for Packages

TABLE 3. ACTIVITY LIMITS FOR EXCEPTED PACKAGES

Physical state of contents	Instrument or article		Materials
	Item limits[a]	*Package* limits[a]	*Package* limits[a]
Solids:			
special form	$10^{-2}A_1$	A_1	$10^{-3}A_1$
other forms	$10^{-2}A_2$	A_2	$10^{-3}A_2$
Liquids	$10^{-3}A_2$	$10^{-1}A_2$	$10^{-4}A_2$
Gases			
tritium	$2 \times 10^{-2}A_2$	$2 \times 10^{-1}A_2$	$2 \times 10^{-2}A_2$
special form	$10^{-3}A_1$	$10^{-2}A_1$	$10^{-3}A_1$
other forms	$10^{-3}A_2$	$10^{-2}A_2$	$10^{-3}A_2$

USNRC Package Regulations

A Type A package can withstand the rigors of routine highway, rail, or waterway transport, but not necessarily retain its integrity in a transportation accident.

The maximum radioactivity of special form radioactive material that can be carried in a Type A package is A1. The maximum radioactivity of other radioactive material that can be carried in a Type A package is A2.

Type B packages are designed to withstand accidents. Spent fuel casks are a particular variety of Type B packages. The accident sequence is shown on the next slide.

Approval Standards for Type B Spent Fuel Shipping Casks

Spent Fuel Casks are certified to be accident resistant. They must withstand:

- Ten meter (thirty foot) drop onto unyielding surface.
- 1.2 meter (forty inch) drop onto a steel puncture pin.
- Thirty minute fully engulfing 800 ^{o}C (1475 ^{o}F) fire.