



Risk Assessment of Transportation of Radioactive Materials Using RADTRAN

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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 History

- RADTRAN I 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)
 - Runs on SNL server via TRANSNET gateway
 - Remote access by telnet, dial-up
- 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
 - SI output
- **2001 security considerations required access via secure shell, making access difficult**
- **Copyright Sandia National Labs 2003**
- **Downloadable RADTRAN 5 with graphical user interface (GUI) input file generator RADCAT, 2004**
 - <https://radtran.sandia.gov/radcat>



RADTRAN Projections

- RADTRAN 5.5 – 5.6
 - Fully functional atmospheric dispersion model
 - Expanded radionuclide library (150 nuclides)
 - ICRP 72 inhalation dose conversion factors
 - Corrected resuspension model
 - Coded and compiled in FORTRAN 95
- RADTRAN 6
 - All of RADTRAN 5.5
 - Loss of Shielding Model
 - Economic model
 - Emphasis toward RMEI, critical group risks
 - Full SI input and output



Direction of RADTRAN Development

**Earlier direction: to develop and refine a
RAM transportation risk analysis protocol.**

**Current and future direction: to develop and
maintain the transportation risk
assessment tool.**



RADTRAN Organization

US Department of Energy

Office of Civilian Radioactive Waste Mgt

Sandia National Laboratories

Energy/Environment Division

Department 6765 (D. Miller)

RADTRAN PI (R. Weiner)

M. Dennis

D. Hinojosa

T. Heames

Summer interns



SOME OBSERVATIONS

- For historical reasons, risks from both incident-free transportation and transportation accidents have been overestimated.
- “Collective dose” for very low-dose chronic exposure has been questioned by NRC.
- 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
- Currently 390 registered users, about 25% non-US.



RADTRAN Inputs

INPUTS FOR INCIDENT-FREE TRANSPORTATION

- Package dimensions
- Package external dose rate
- Vehicle dimensions
- Vehicle speeds
- Vehicle external dose rate
- Route characteristics
- Population densities
- Stop characteristics
- Urban building density

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



RADTRAN Output

OUTPUTS FOR INCIDENT-FREE TRANSPORTATION

Collective external dose to residents along route
Collective external dose to public at stops
Collective external dose to urban non-residents
Collective dose to occupants of vehicles sharing route
Occupational external doses
MEI external doses

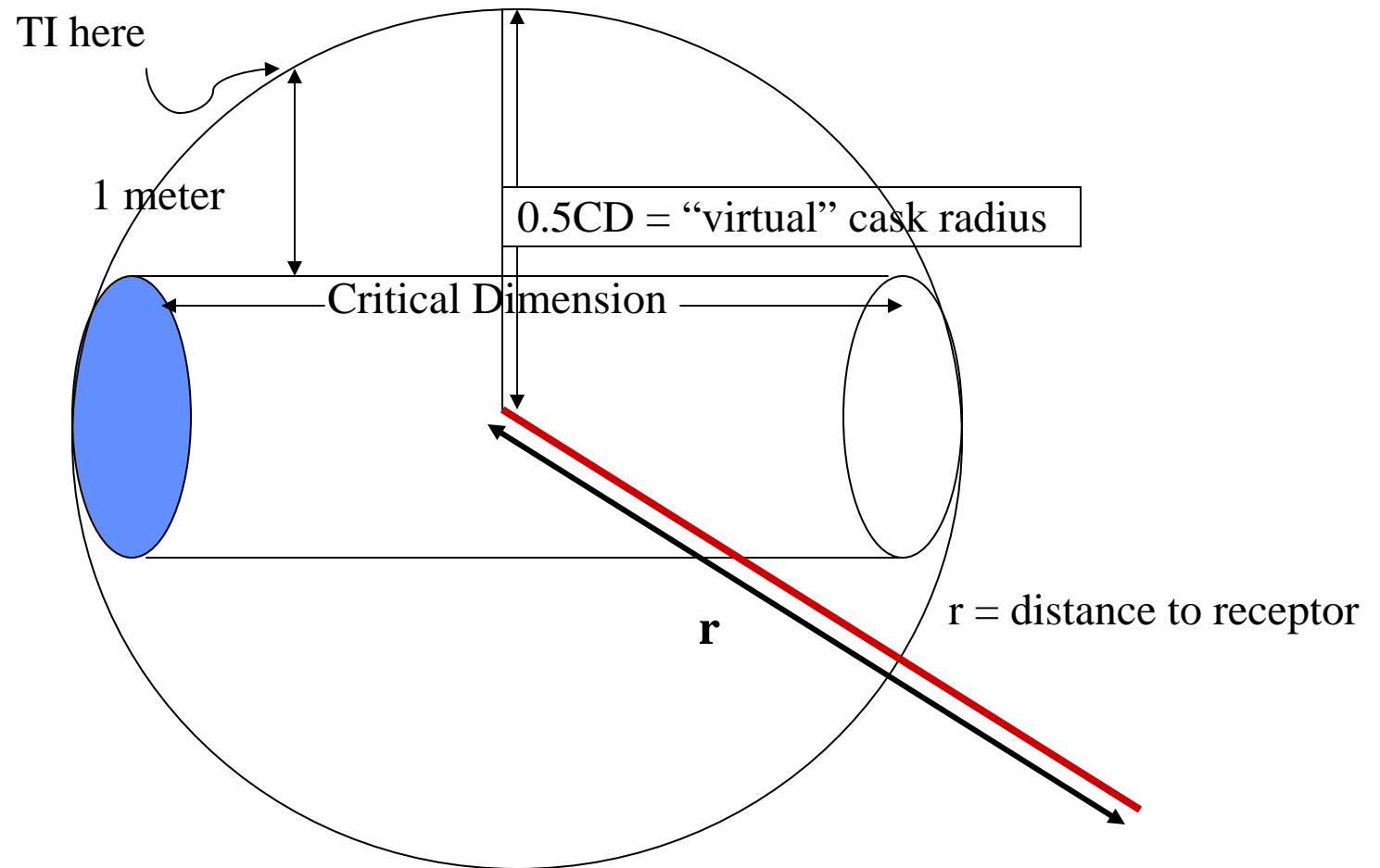
OUTPUTS FOR TRANSPORTATION ACCIDENTS

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 reads in text files of default values:
 - RT5STD.DAT
 - RT5DAT.DAT
 - RT5ISO.DAT
 - INGEST.BIN
- 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.

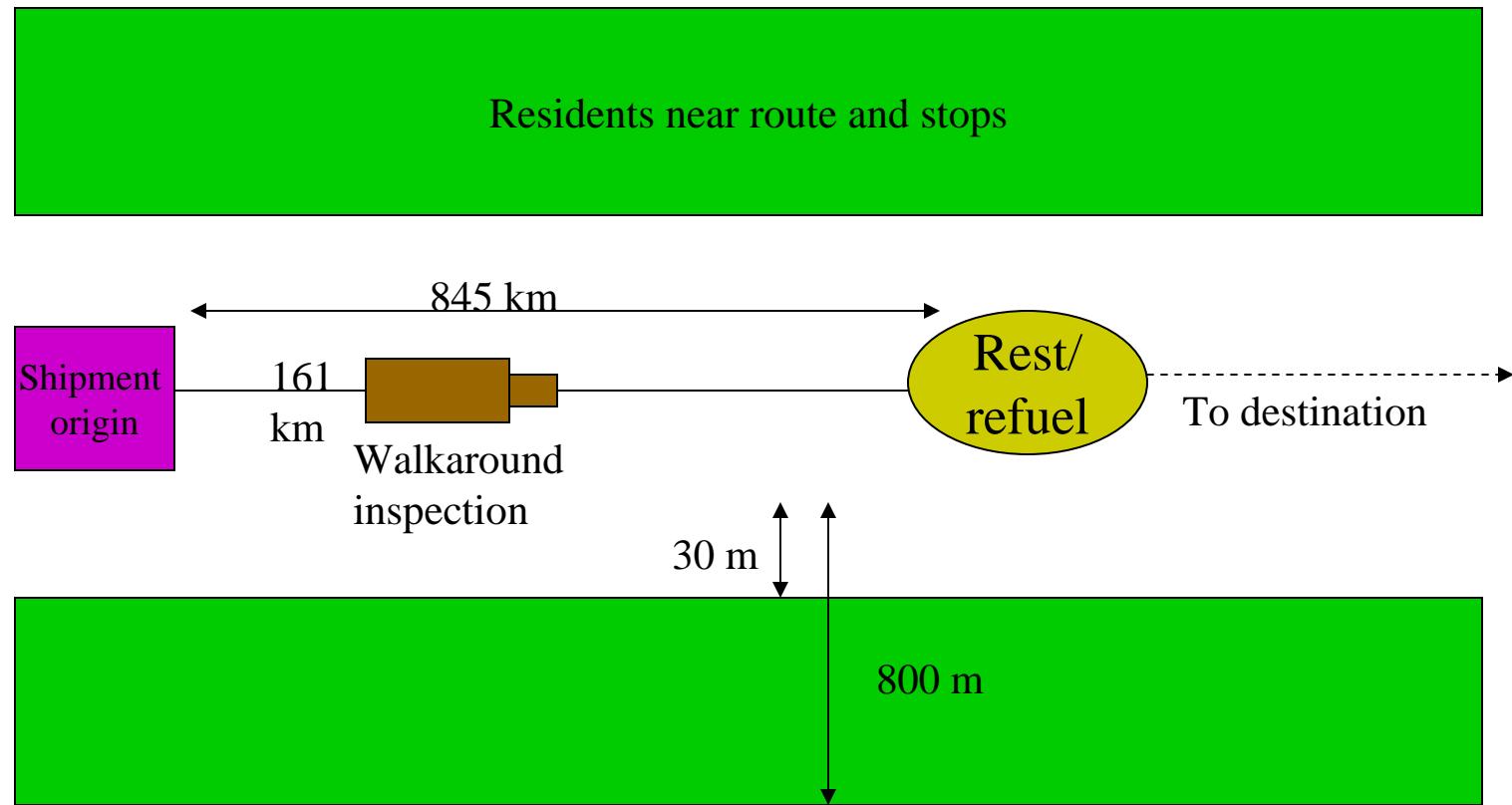


Fundamental Incident-free Model

File name 11

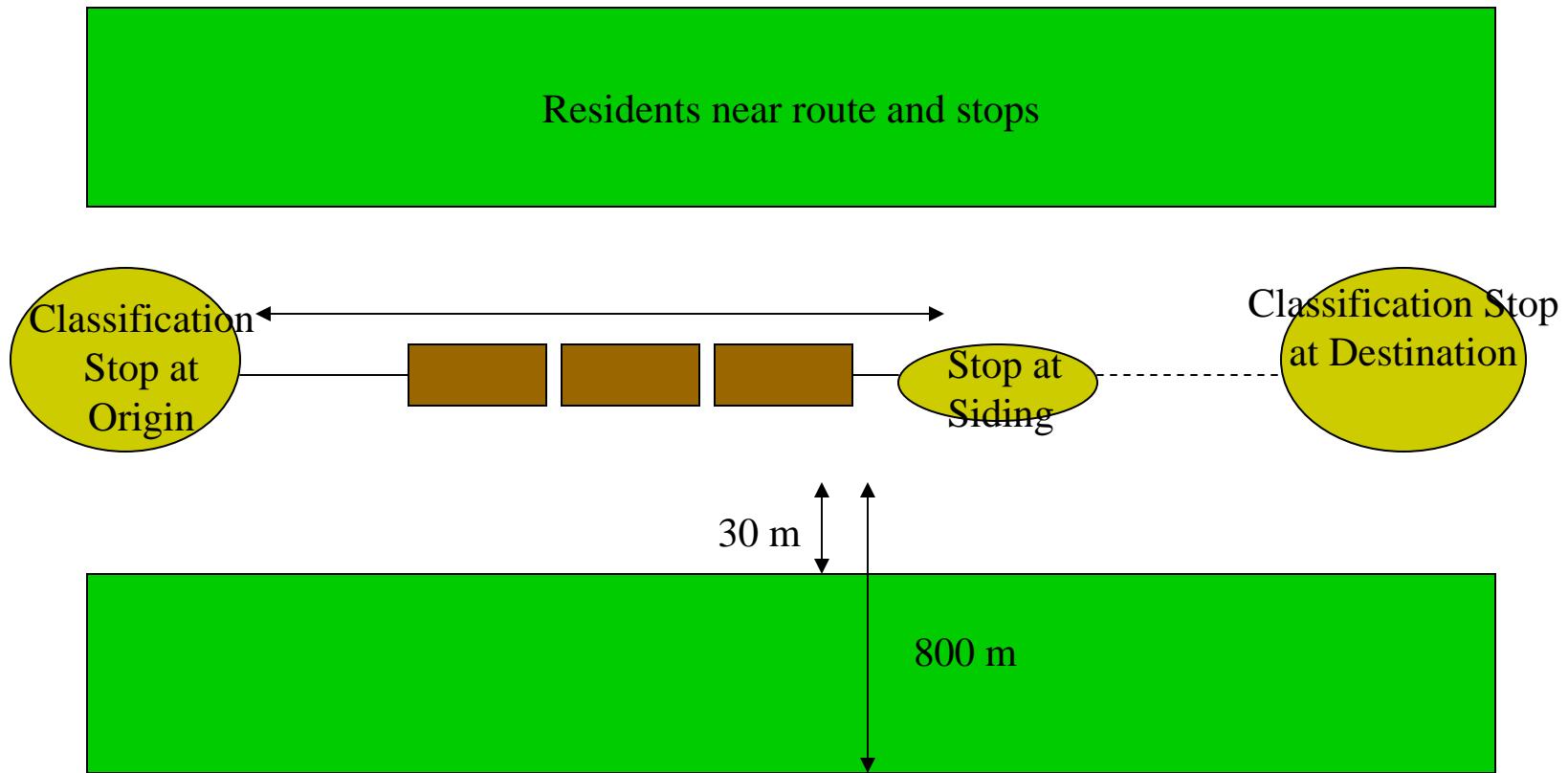


Incident-free Transportation: Legal-weight Truck Route and Stops



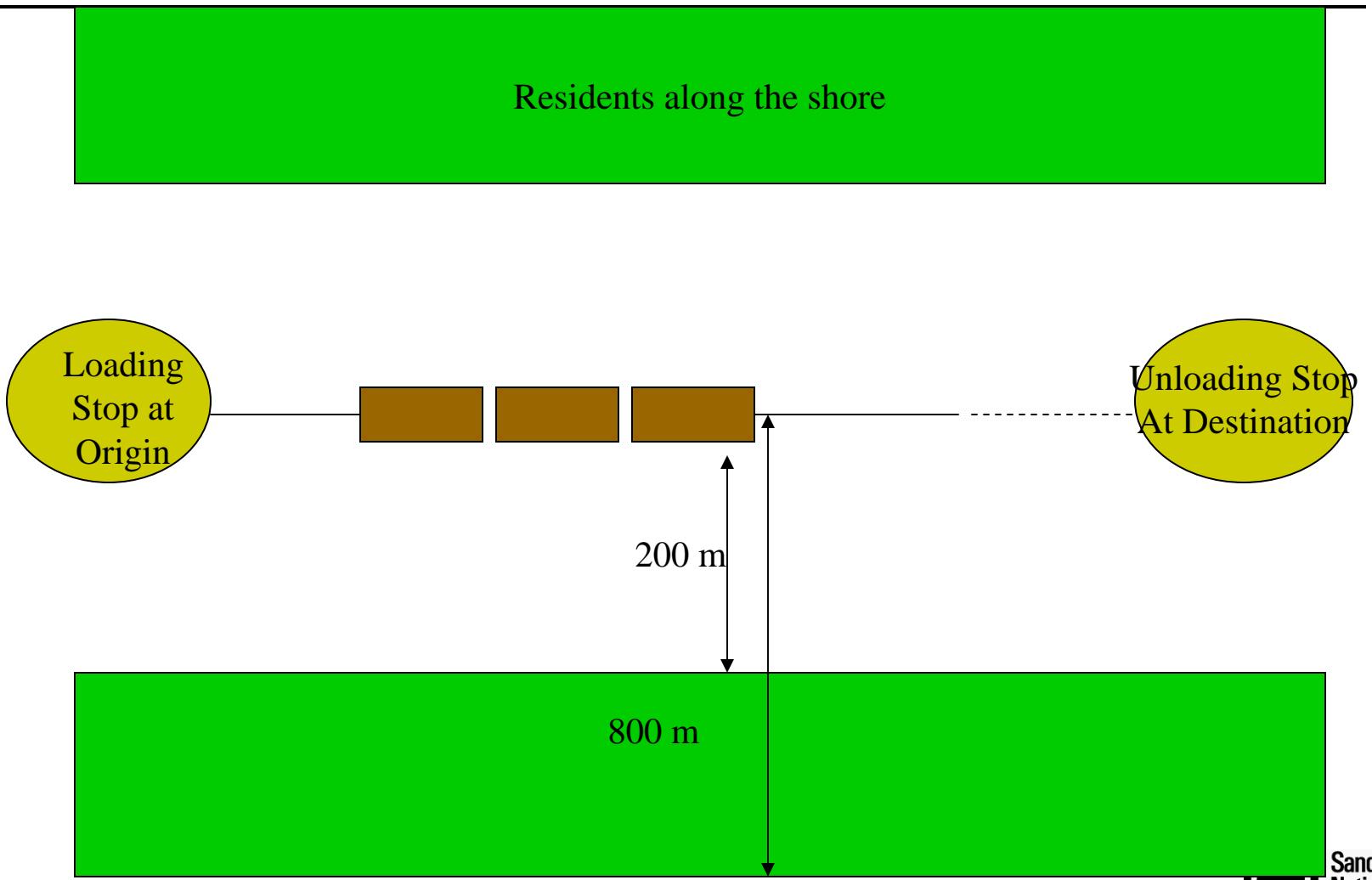


Incident-free Transportation: Rail Route and Stops

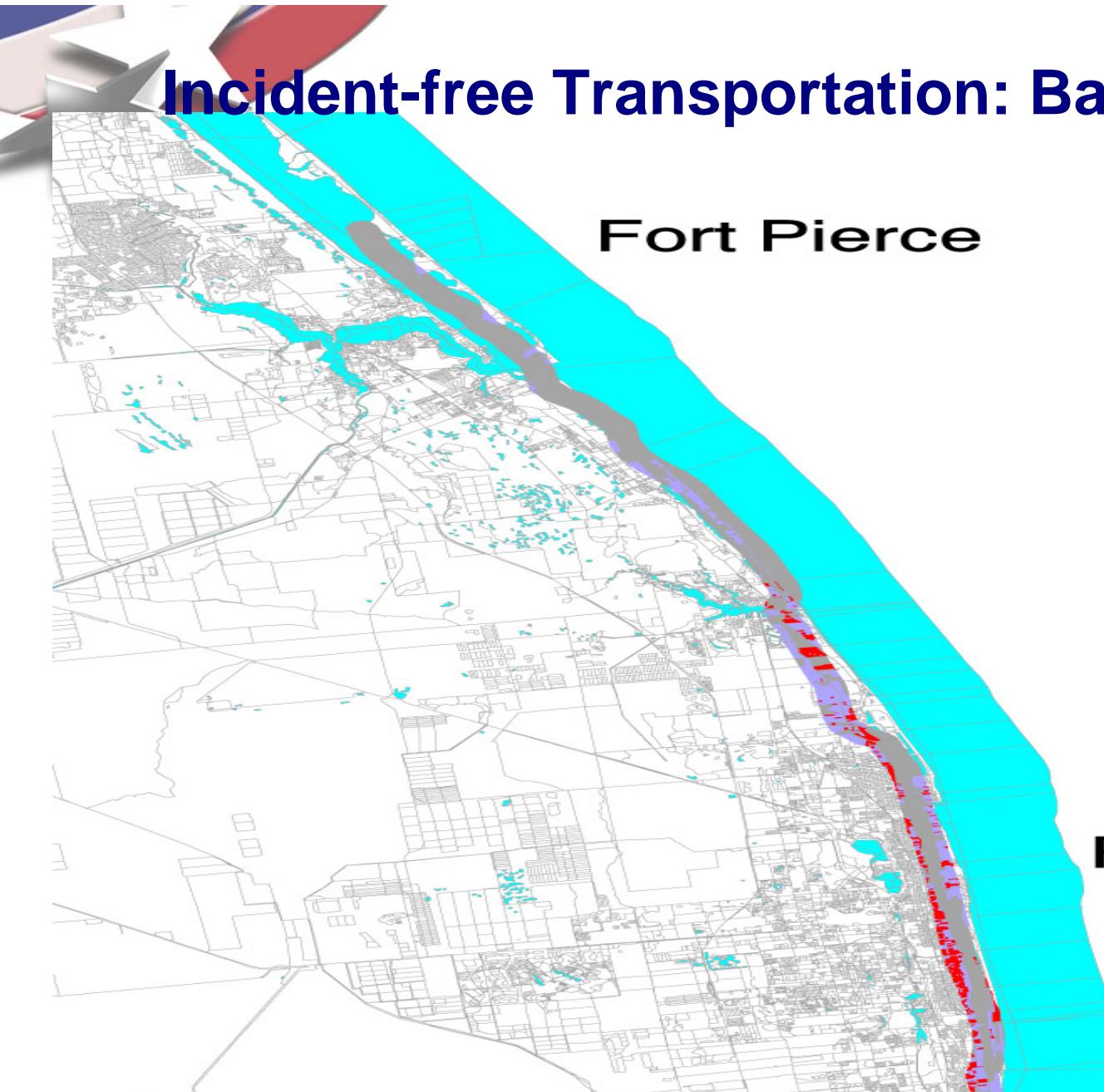




Incident-free Transportation: Barge Route and Stops



Incident-free Transportation: Barge Route

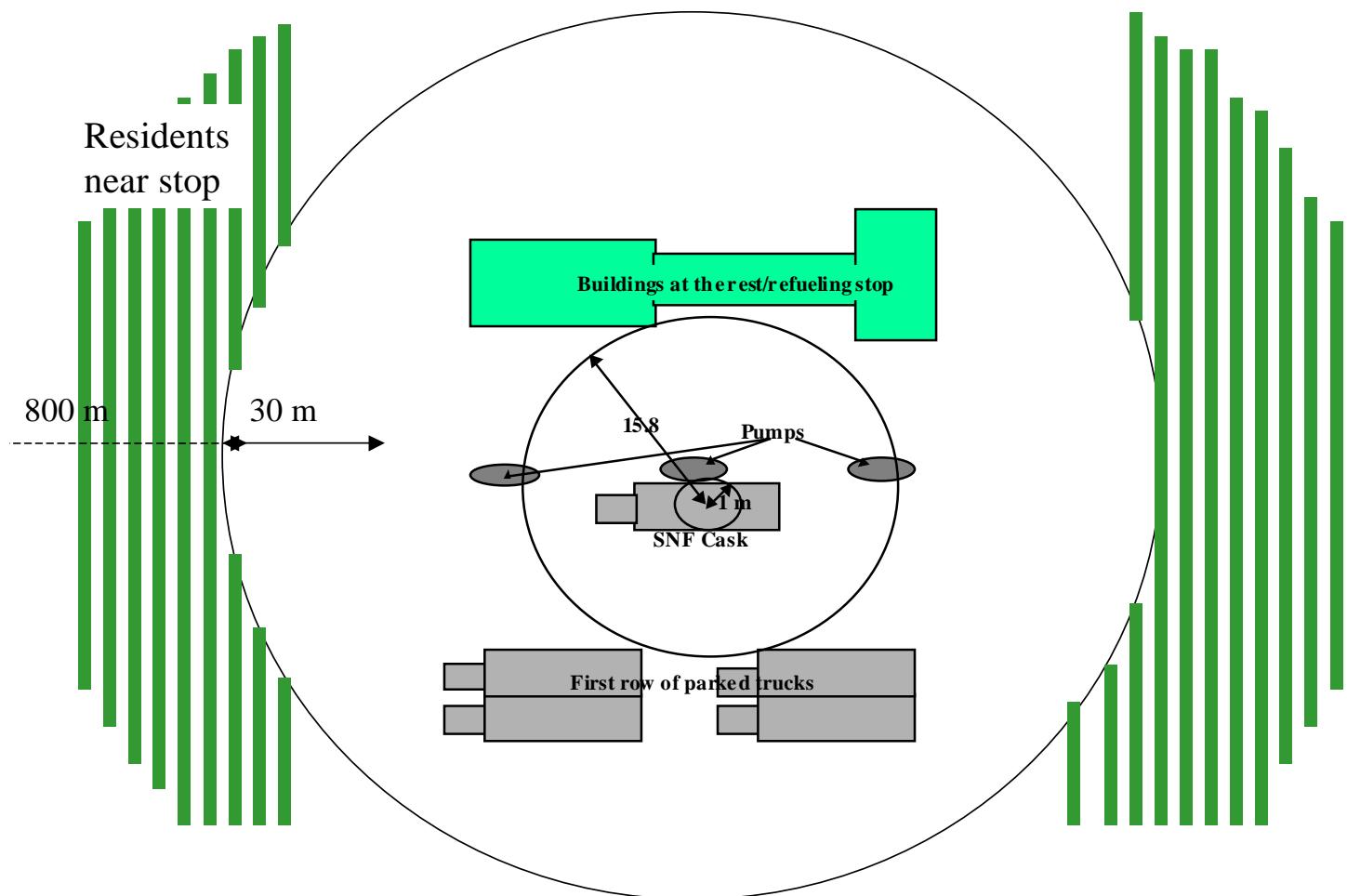


Fort Pierce

**West
Palm Beach**



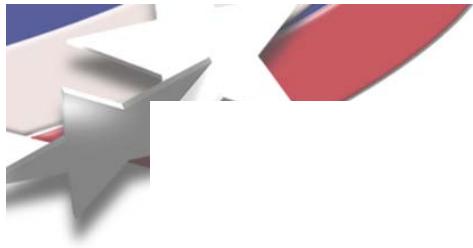
Truck Stop Model



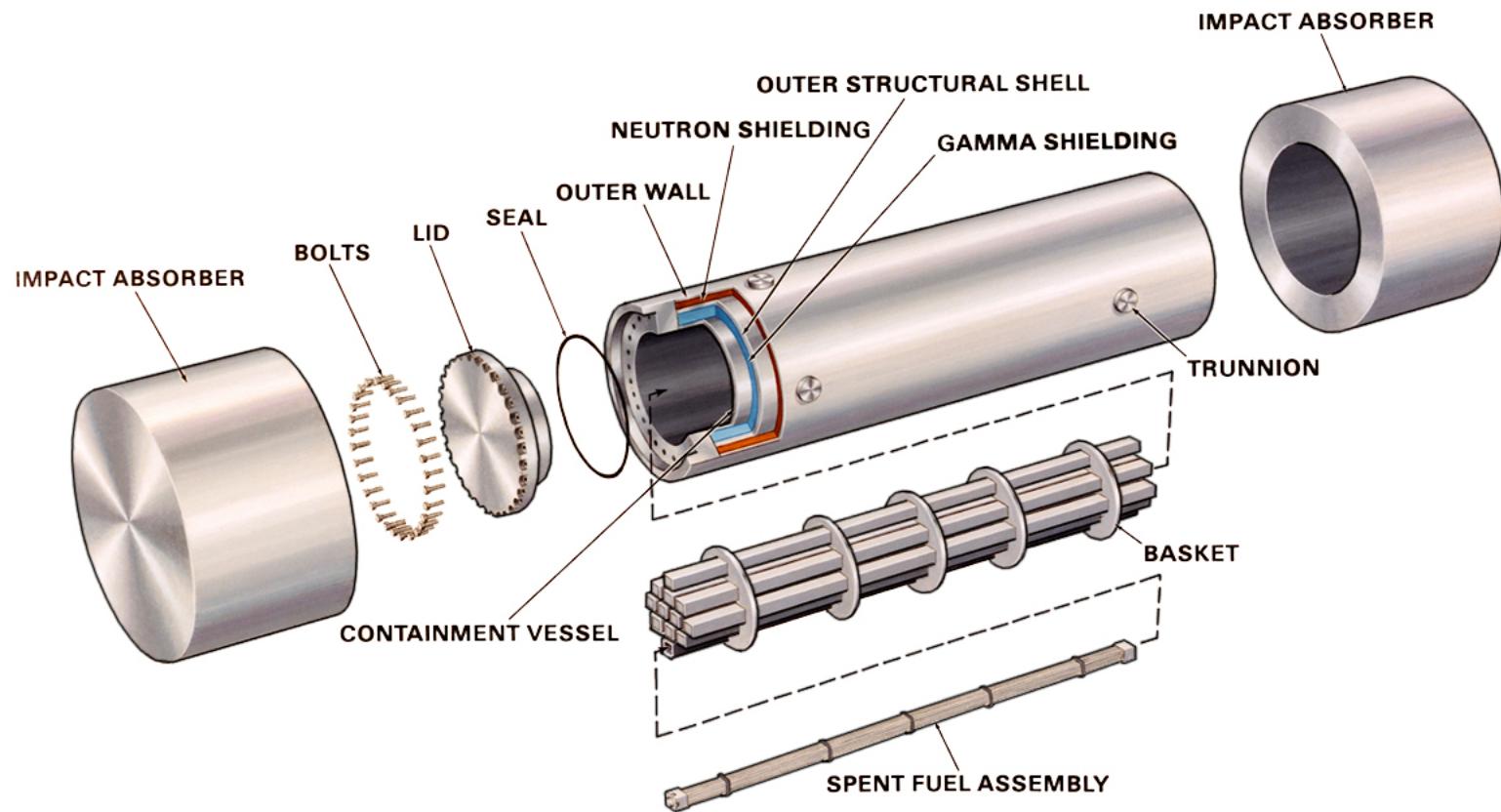


Default Values for Incident-free Transportation

- Residential shielding factors (rural, suburban, urban)
 - “Shielding factor” is the fraction of radiation that penetrates the shielding
- Fraction of urban residential population inside (and outside) of buildings
- Ratio of pedestrian density to urban residential population density
- Distance from route and vehicle speed for maximum exposure
- Distance of vehicle from the nearest population (shoulder, edge of right-of-way)
- LCF/person-rem for occupational and public exposure
- Genetic effects/person-rem
- Duration of shipping campaign
- Regulatory constraint flag
- Rail transport:
 - Minimum number of classification stops
 - Distance-dependent worker exposure factor
 - Dedicated rail flag



SPENT FUEL CASK





Transportation Accidents

Three types of accidents:

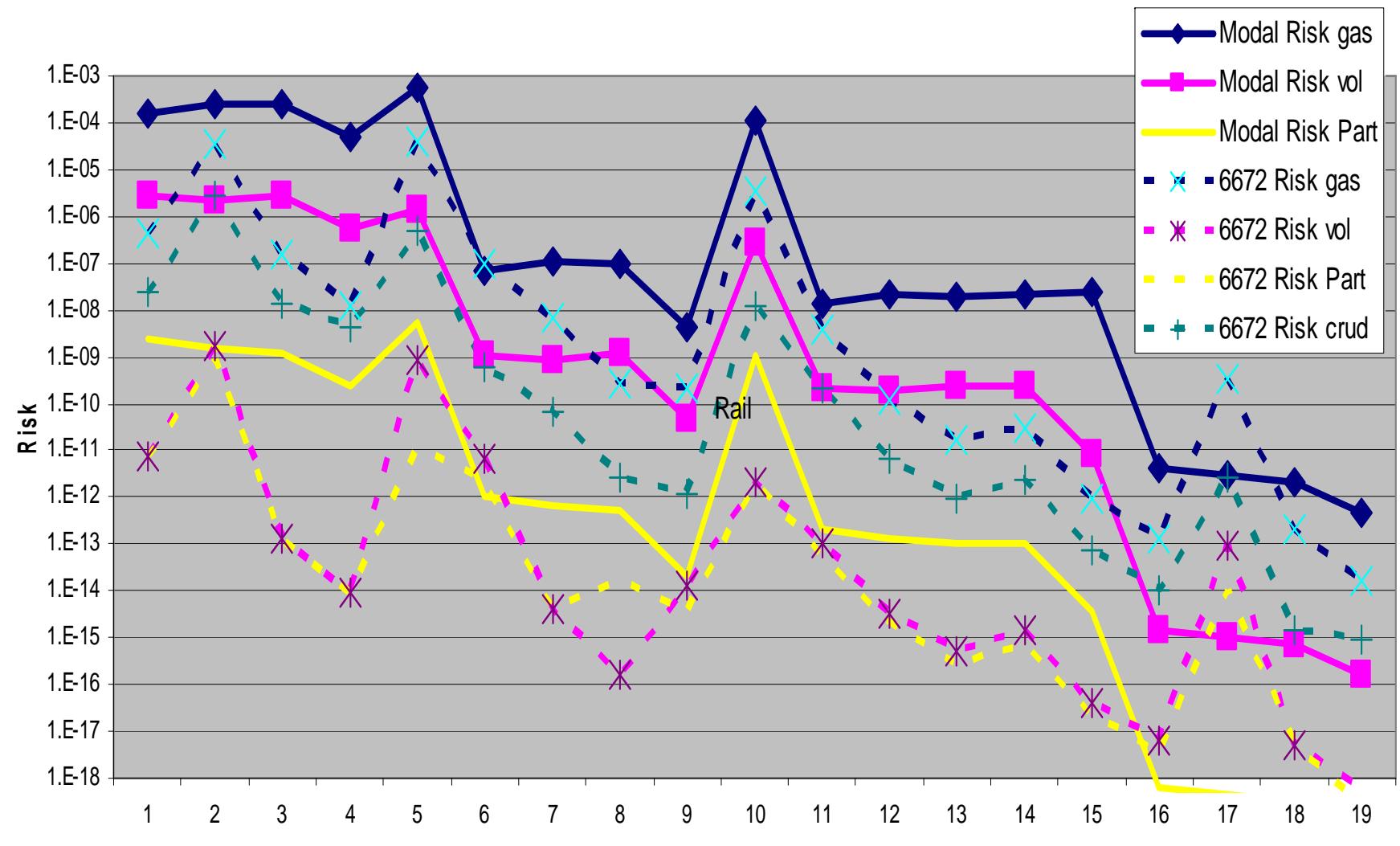
- Accidents involving a release: dispersion of released material.
- Loss of lead gamma shielding (LOS): occurs only with lead-shielded casks.
- Accidents with neither release nor LOS: 99.99% of accidents are of this type.



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 Seal 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 Seal 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 Fire * (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

Risk from Accidents Involving Railcars Carrying SNF



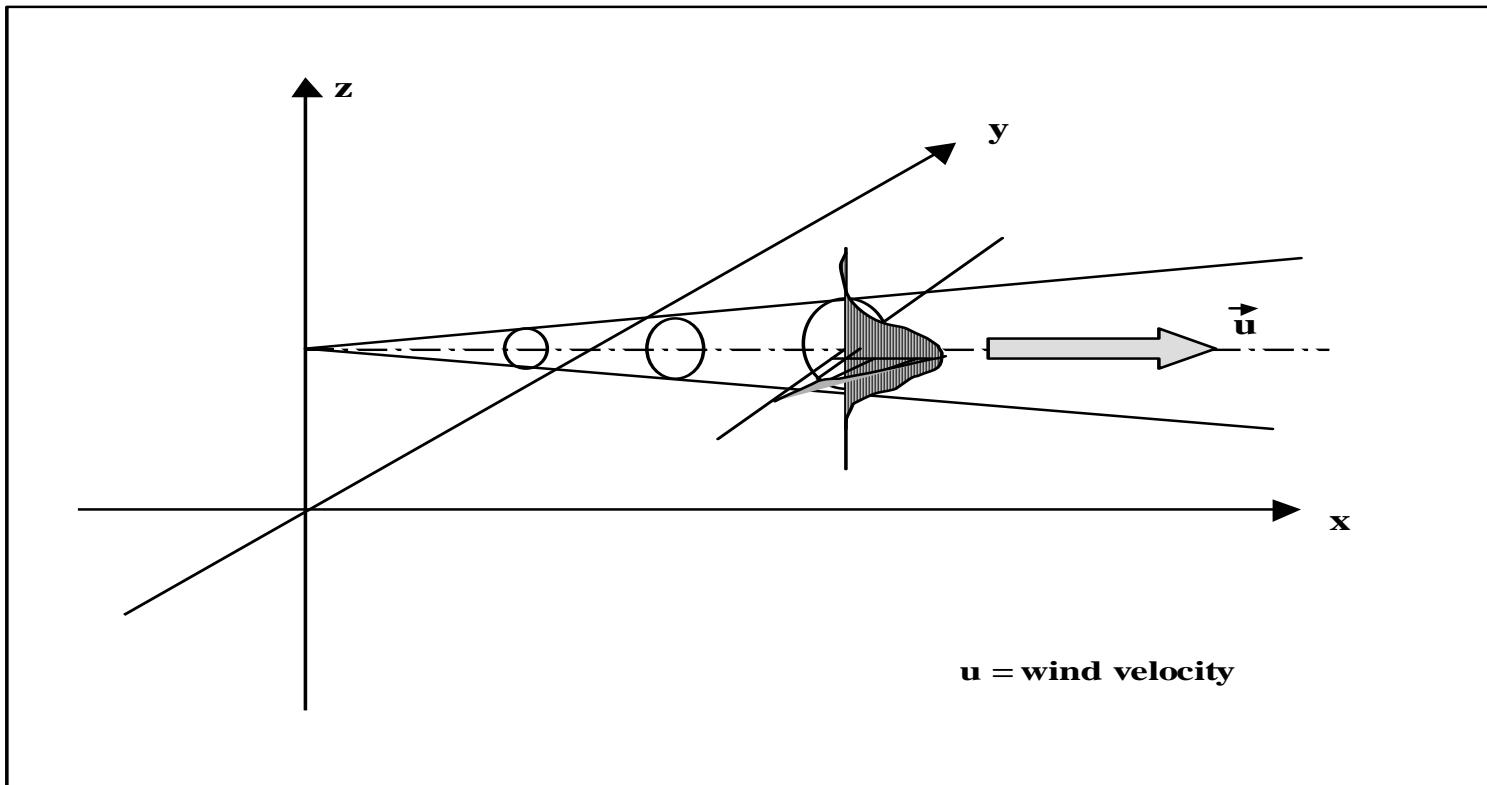
PWR release fractions							
Severity category	NUREG/CR-6672 Case	Severity fraction	Kr	Cs	Ru	Particulates	Crud
1	19	0.99993	0.00000	0.00000	0.00000	0.00000	0.00000
2	2, 3	6.06E-05	1.36E-01	4.09E-09	1.02E-07	1.02E-07	1.36E-03
3	18	5.86E-06	8.39E-01	1.68E-05	6.71E-08	6.71E-08	2.52E-03
4	1, 5, 6, 8	4.95E-07	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

File name 22



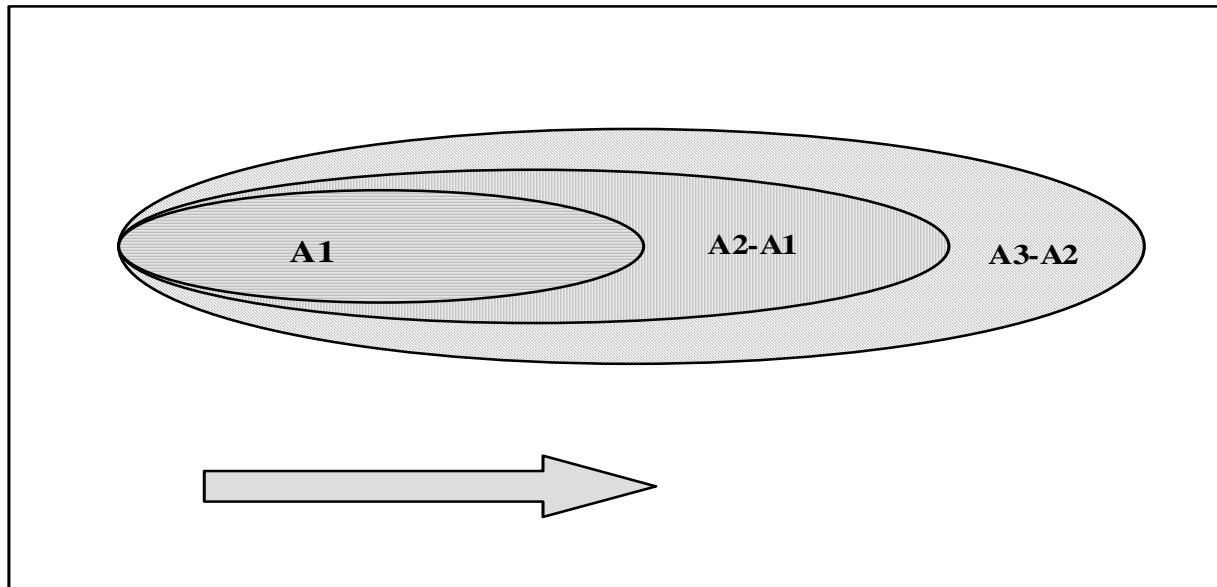


Atmospheric Dispersion





Dispersion Footprint



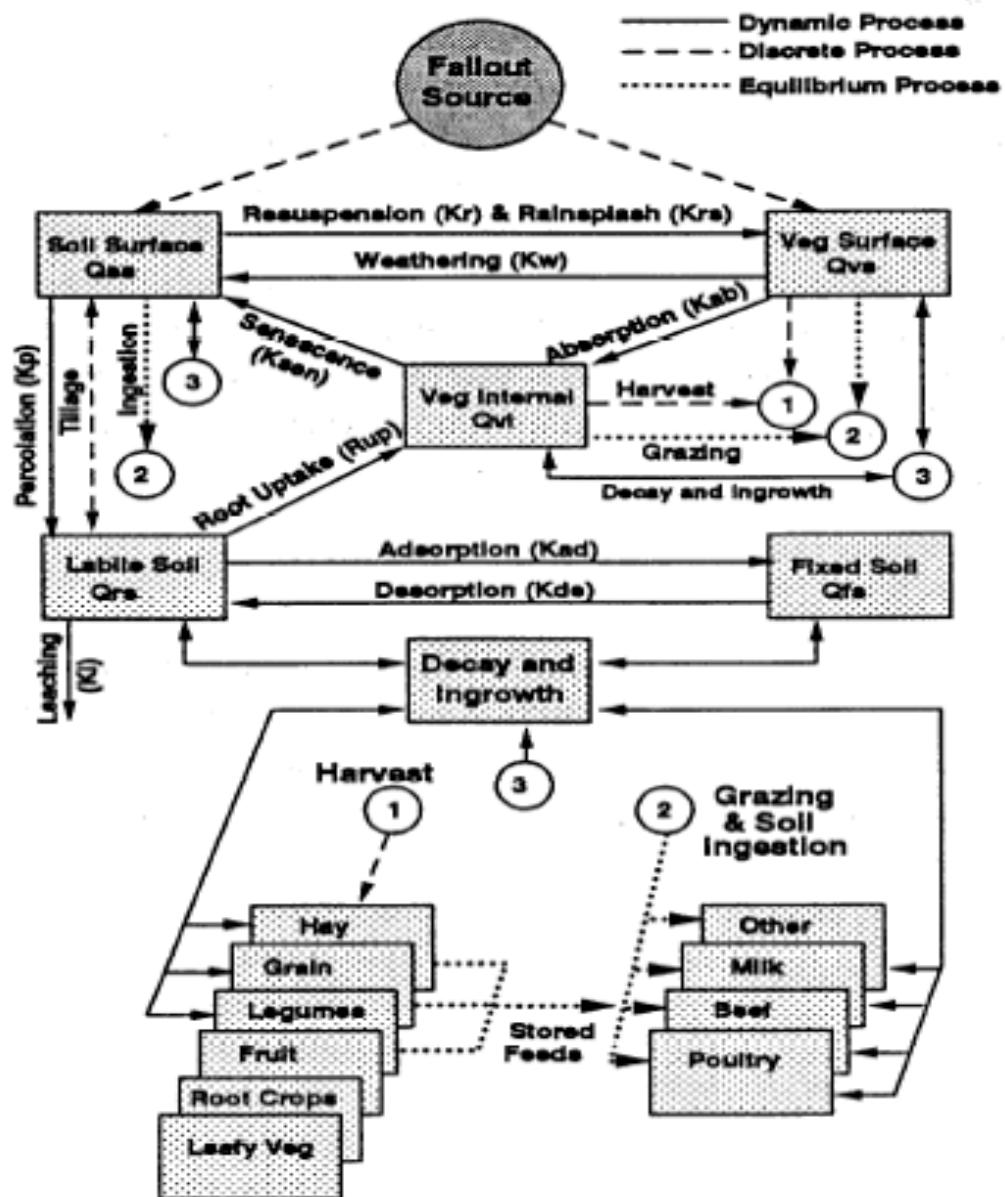


Example of Radionuclide Inventory

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			

Societal Ingestion Dose

COMIDA has been run and has output the ingestion dose for one curie of each radionuclide in the internal RADTRAN library. RADTRAN finds the output for each nuclide in the input file and multiplies by the activity, release fraction, etc.





Dose Risk Inhalation Example

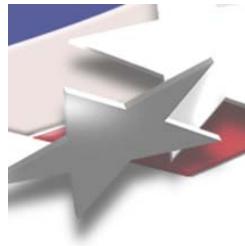
$$\text{RISK}_L^{\text{INH}} = \sum_{p=1}^n \sum_{j=1}^{\text{NSEV}} \gamma_{j,L} \cdot D_{\text{inh}}_{p,j,L}$$

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

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

NSEV = Number of accident severity categories

n = Number of radionuclides in package



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 Package Radionuclides Vehicle Link Stop Handling 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

Pasquill Average User-Defined

Isopleth Area Size (m ²)	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

... ... 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

Toolbar icons: New, Open, Save, Print, Cut, Copy, Paste, Find, Delete, Undo, Redo.

Tab bar: Title, Package, Radionuclides, Vehicle, Link, Stop, Handling, Accident, Parameters (highlighted).

Sub-tab bar: Probability, Deposition Velocity, Release, Aerosol, Respirable, Isopleth P, Weather (highlighted).

Dispersion Model Selection: Pasquill (radio button), Average (radio button), User-Defined (radio button).

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

Release Location dropdown menu:

- Rural
- Urban/Suburban

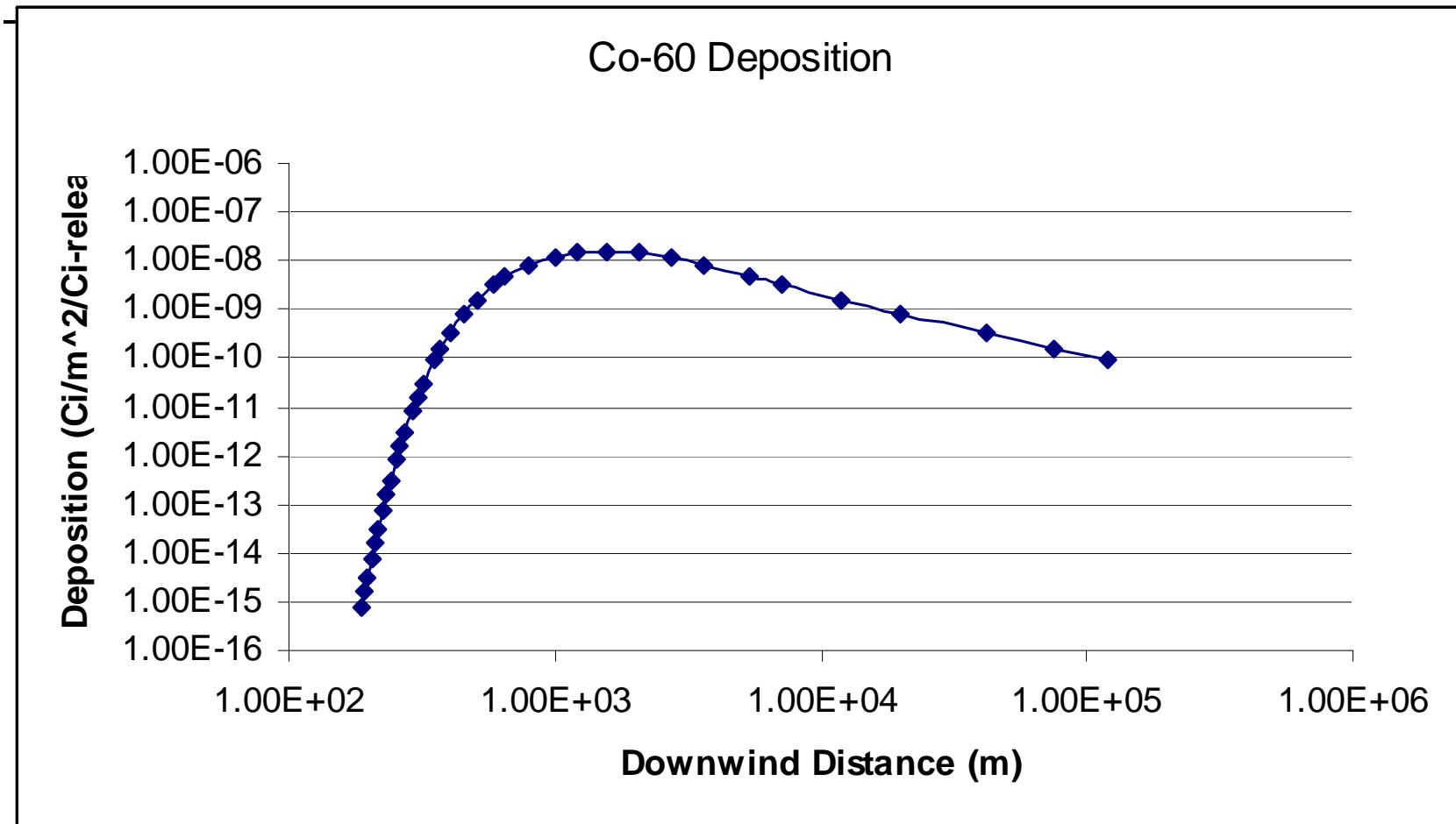


Example of Accident Risk Output

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



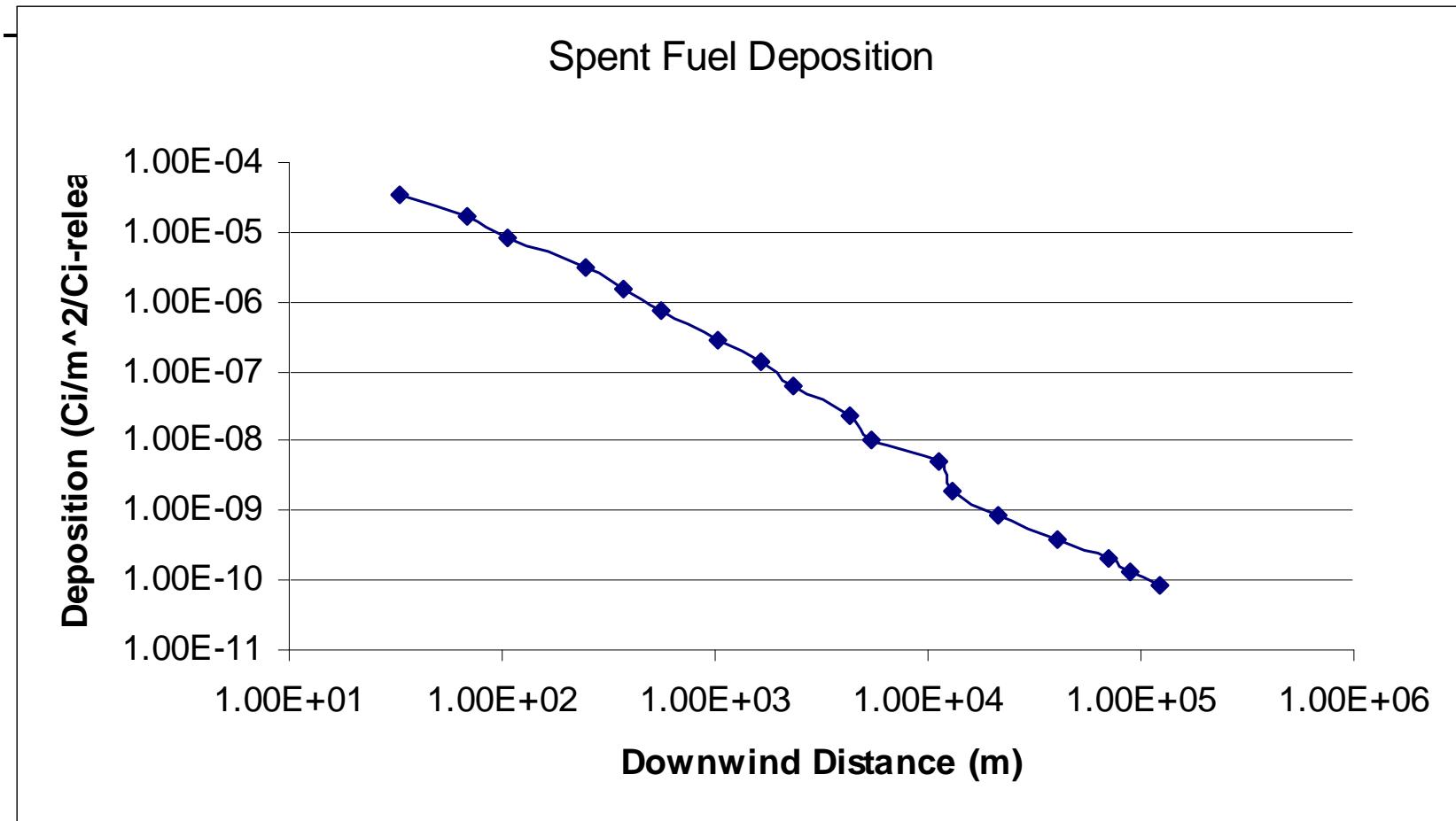
^{60}Co Elevated Release



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



Spent Fuel Ground Release

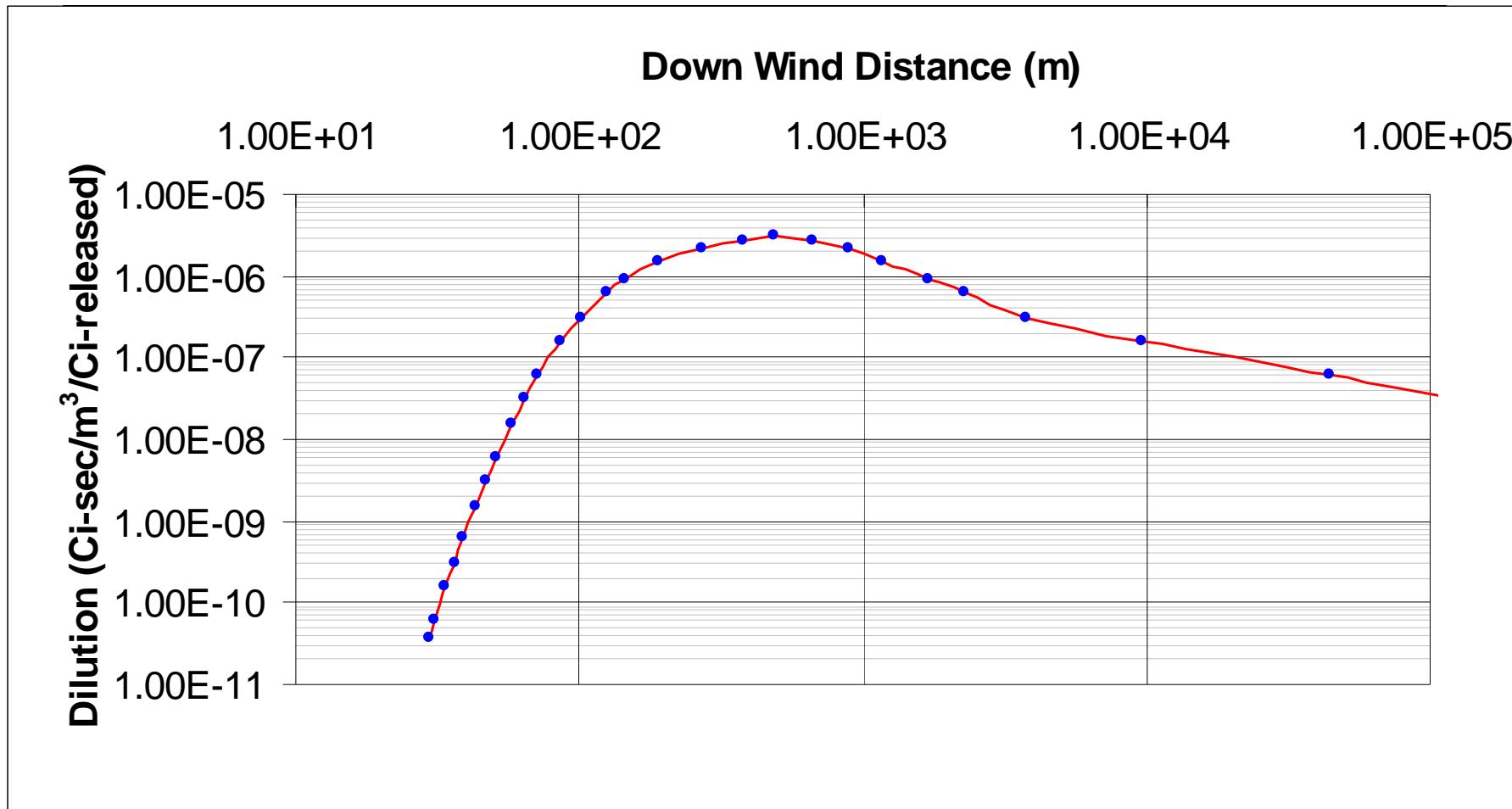


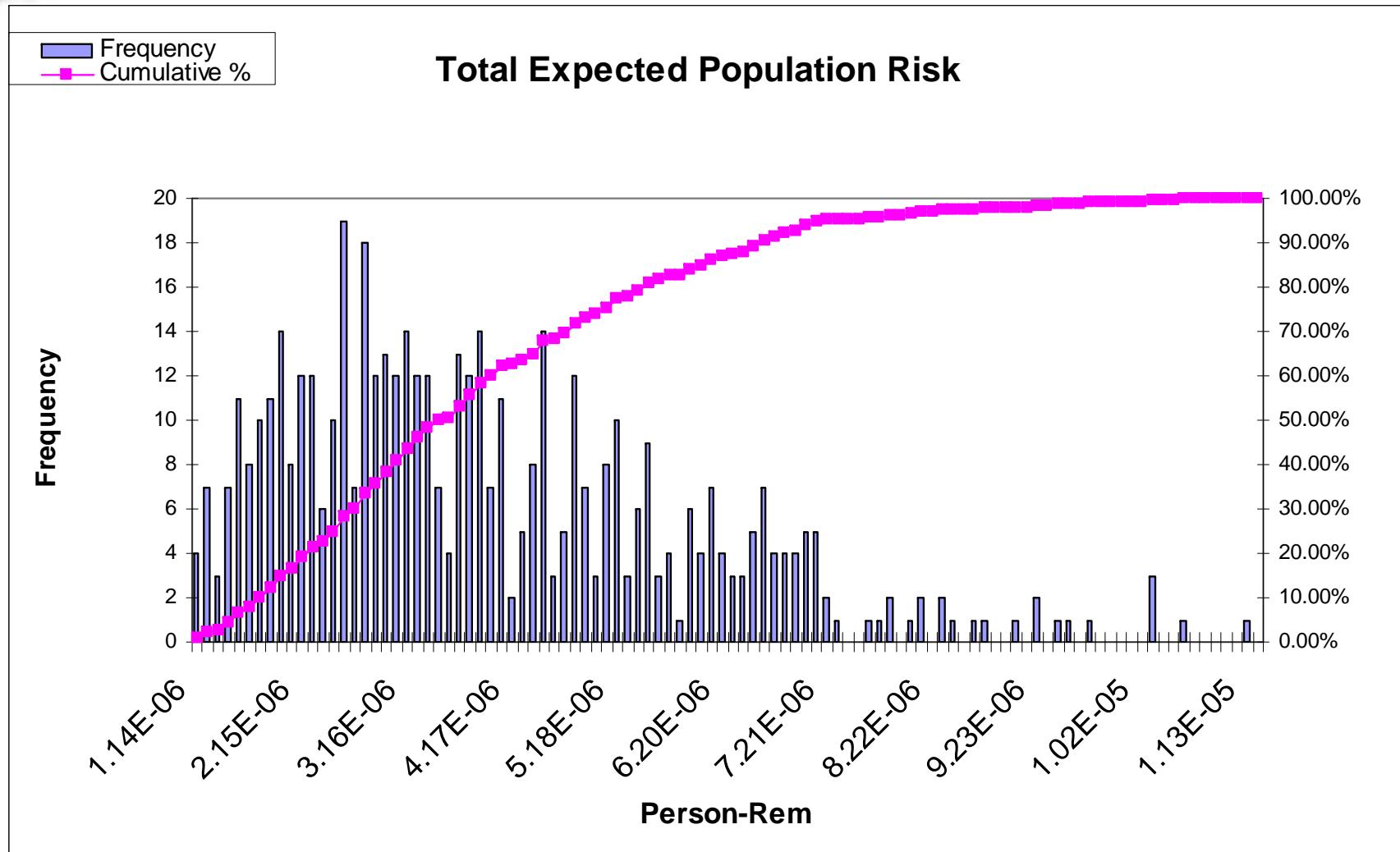
- National average weather atmospheric dispersion of spent fuel on a truck route



RADTRAN Output

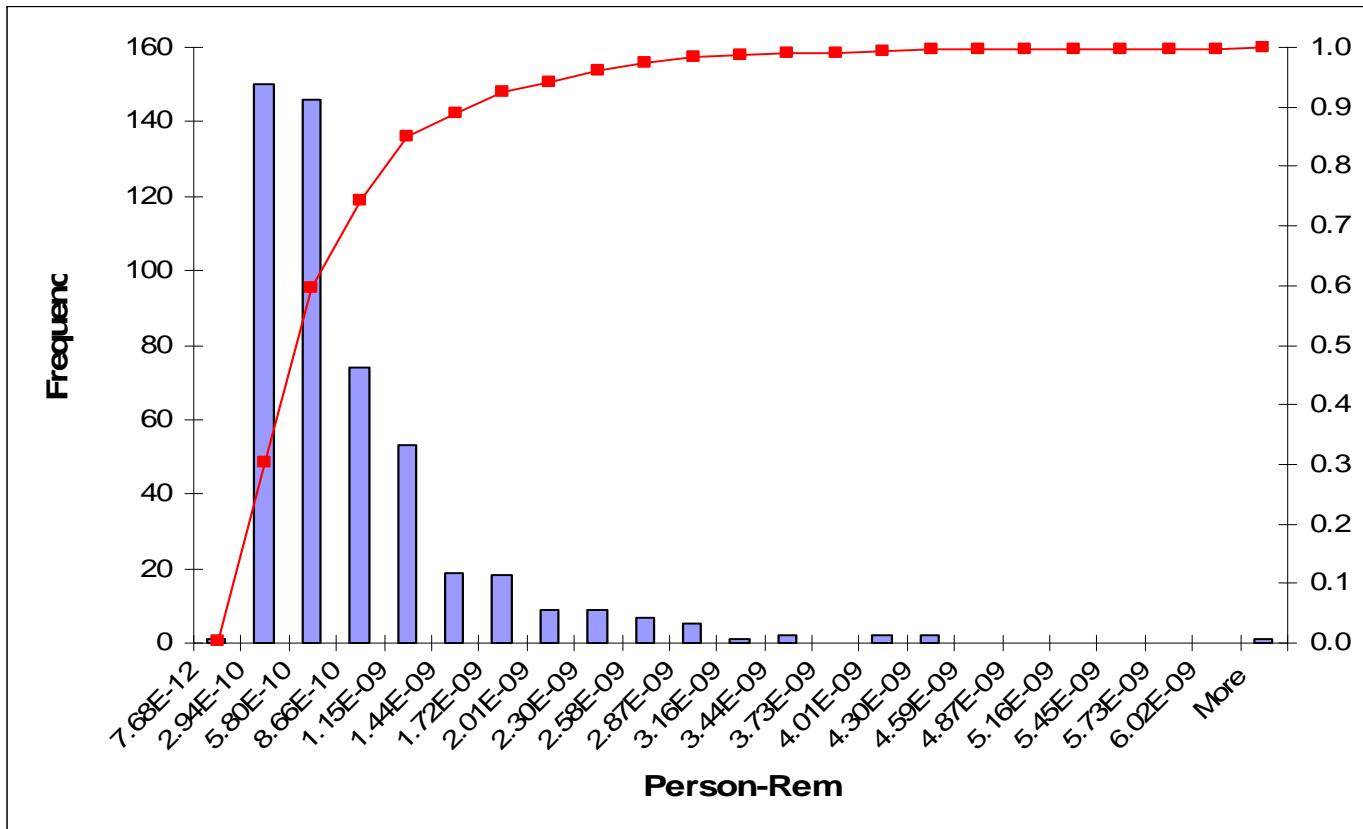
Atmospheric Dispersion Model







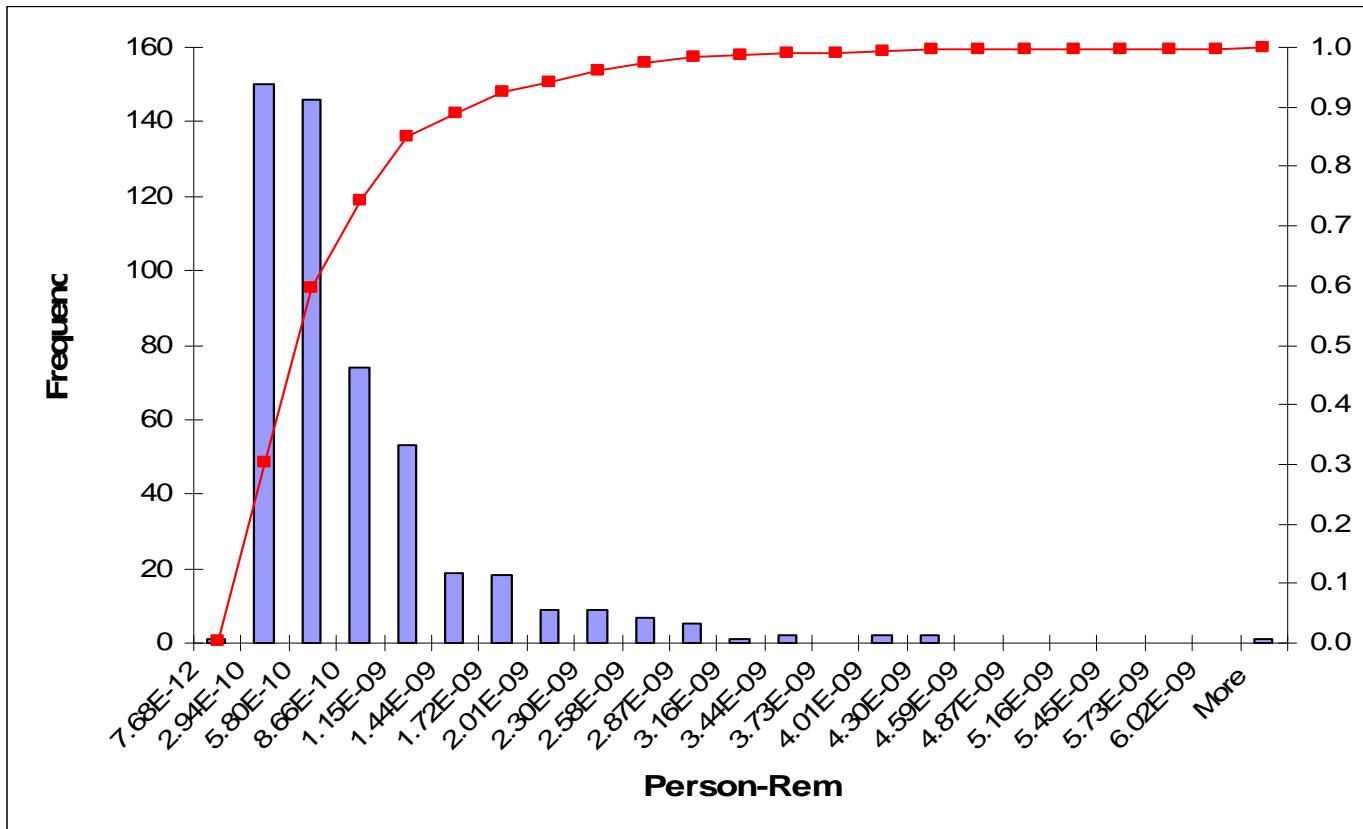
Uncertainty in RADTRAN



Accident Inhalation Dose Risk



Uncertainty in RADTRAN



Accident Inhalation Dose Risk

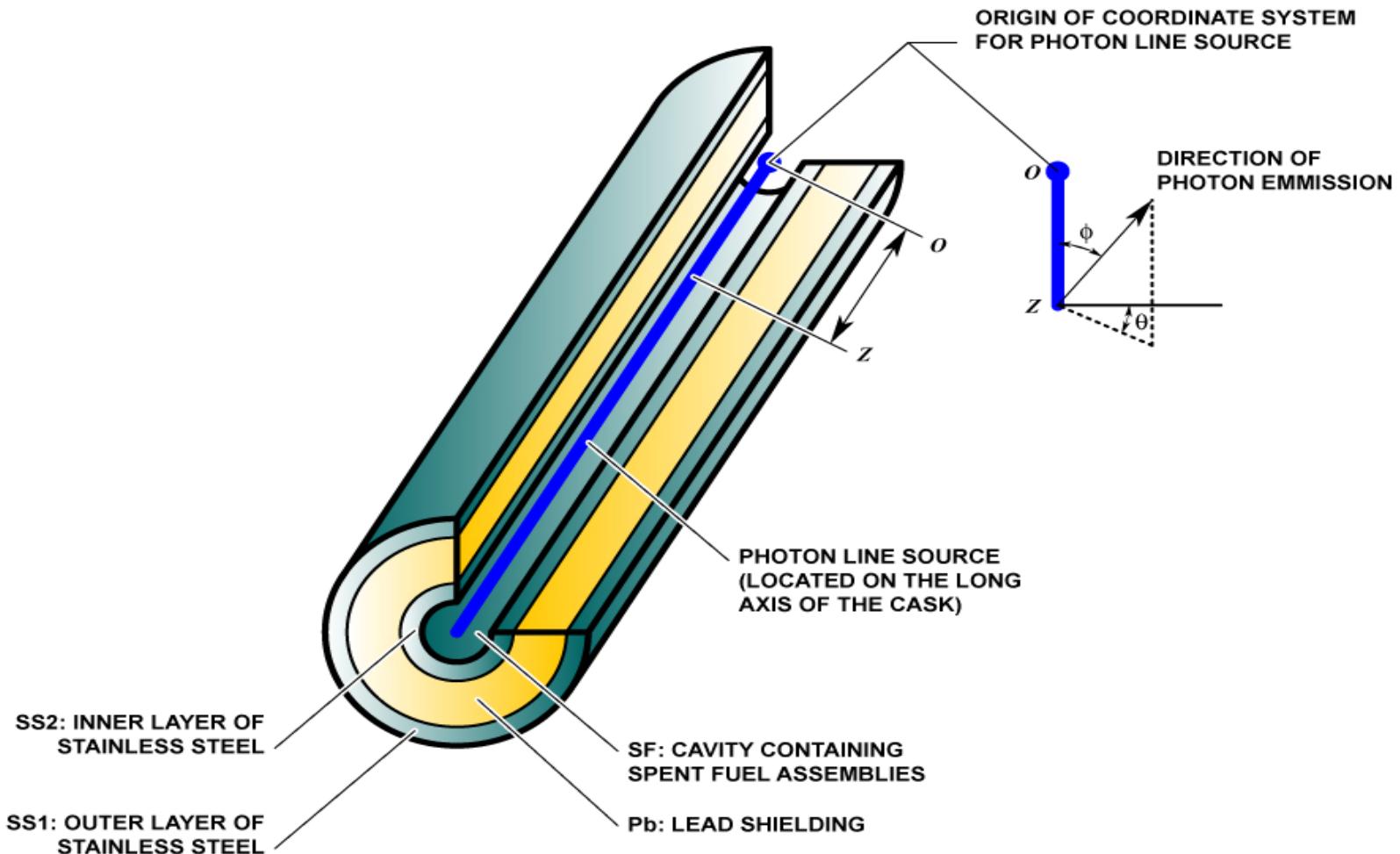


Default Values for Transportation Accidents

- Fraction of outside air in urban buildings
- Ratio of pedestrian density to urban residential population density
- Fraction of urban residential population inside (and outside) of buildings
- Average breathing rate
- Cleanup level (microcuries/sq. m.)
- Interdiction threshold
- Evacuation time
- Survey interval
- LCF/person-rem for occupational and public exposure
- Genetic effects/person-rem
- Duration of shipping campaign



Loss-of-Shielding 3-D Model





Loss-of-Shielding 2-D Model (Damaged Cask)

