Risk Assessment of Transportation of Radioactive Materials Using RADTRAN

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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

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RADTRAN History - Continued

- RADTRAN 5 (1998)
  - New stop model
  - Allowed about 85% user defined input; 15% user choices
- 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
  - http://www.evolutionnext.com/radcat

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RADTRAN Projections

- RADTRAN 5.5 (to be launched FY05)
  - Fully functional atmospheric dispersion model (from RISKIND)
  - Expanded radionuclide library (150 nuclides)
- RADTRAN 6
  - All of RADTRAN 5.5
  - Loss of Shielding Model
  - Economic model
  - Emphasis toward RMEI, critical group risks
  - Alternate ingestion dose calculation method

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.

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**

RADTRAN Inputs

INPUTS FOR INCIDENT-FREE TRANSPORTATION	INPUTS FOR TRANSPORTATION ACCIDENTS
Package dimensions Package external dose rate Vehicle dimensions Vehicle speeds Vehicle external dose rate Route characteristics Population densities Stop characteristics Urban building density	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

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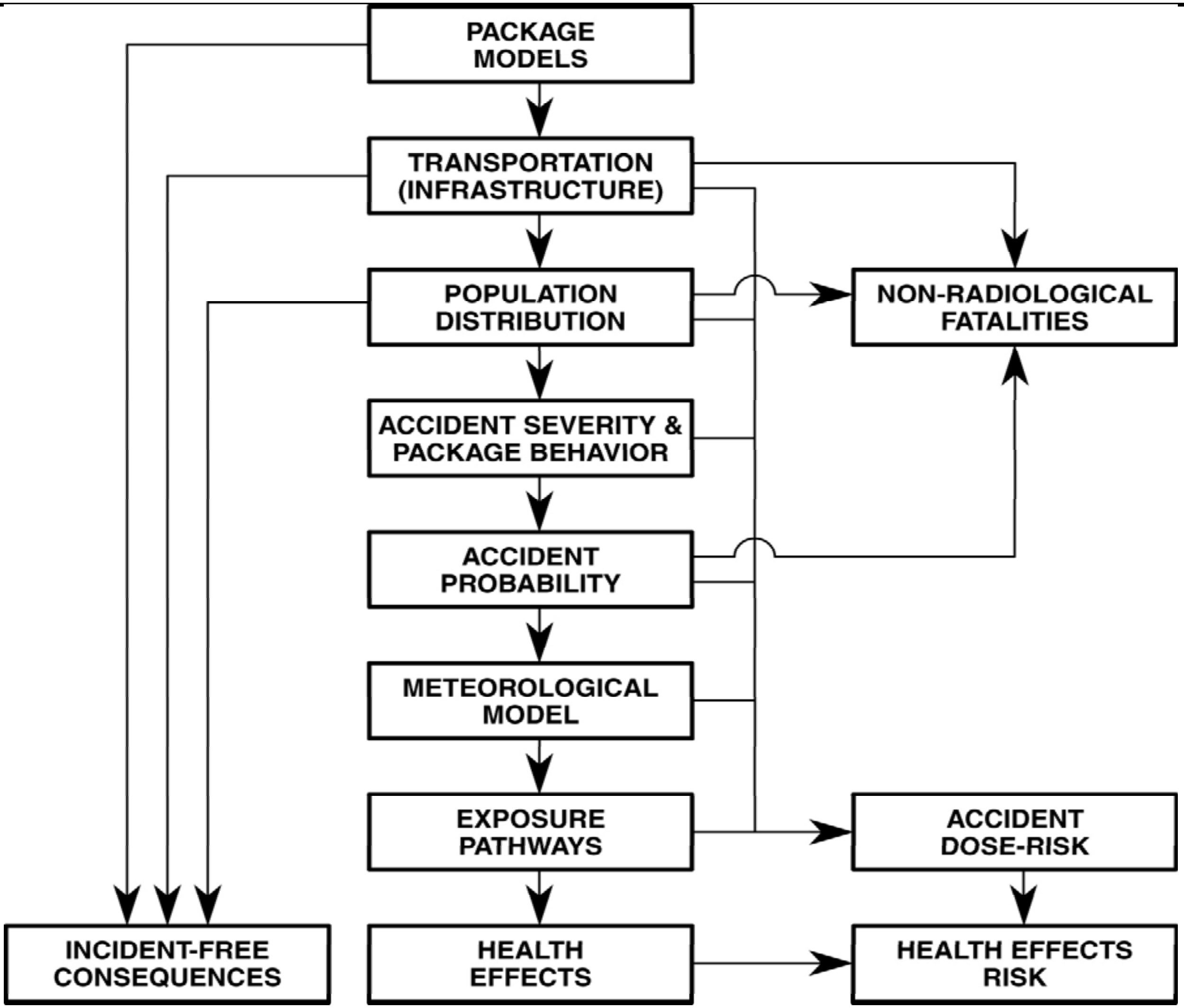
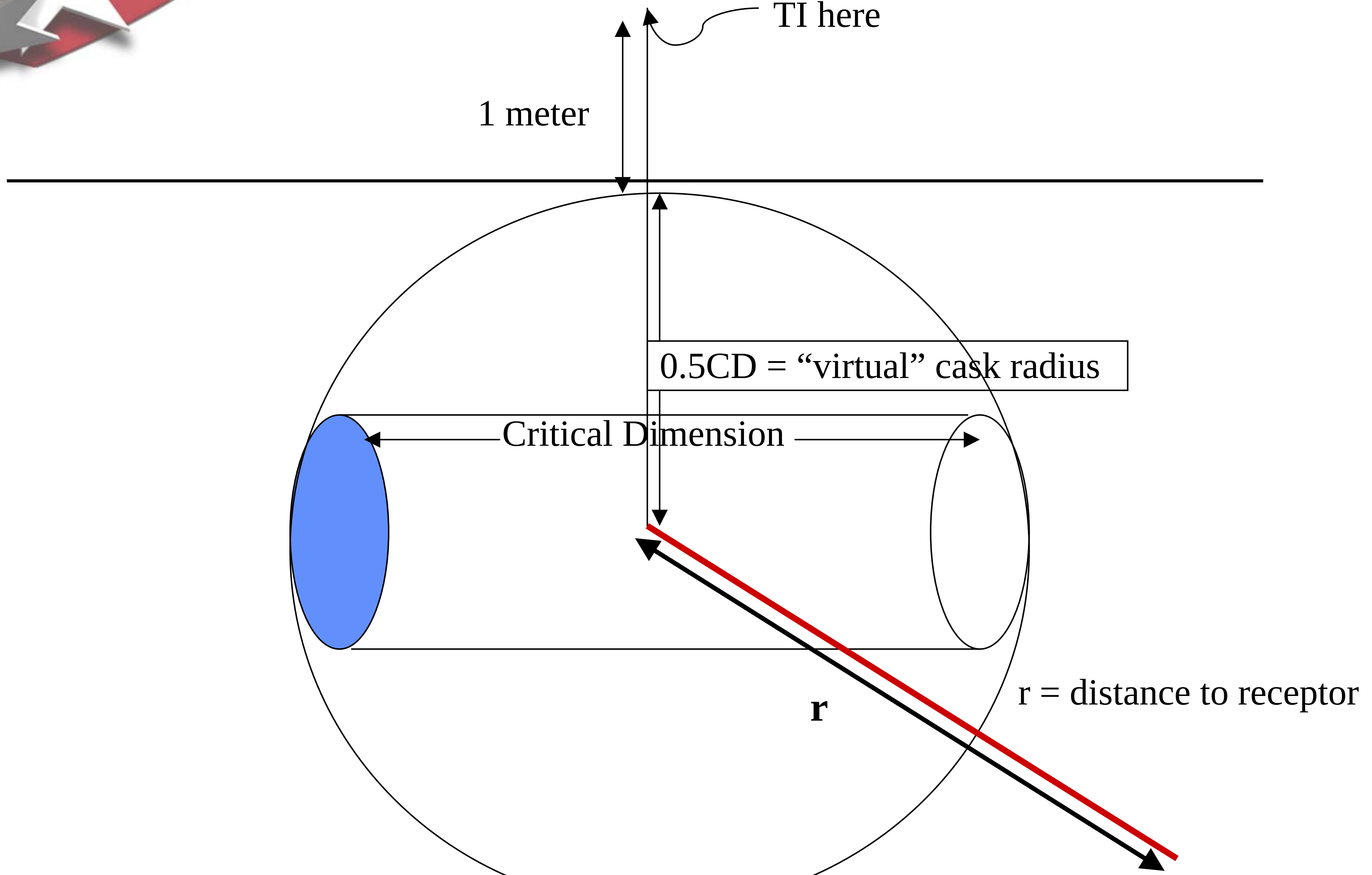
How RADTRAN Works

- **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.**

RADTRAN Flow diagram





Fundamental Incident-free Model

Calculation of “Off-Link” Dose

$$D = \frac{4 \bullet Q_1 \bullet DIST \bullet DRp \bullet PD}{V} \left\{ fg \bullet \int_{min}^{d} I_g(x)dx + f_n \bullet \int_{min}^{d} I_n(x)dx \right\}$$

PD (population density), DR_p, DIST (m), and V (velocity; mps), d and min are user-defined parameters

RADTRAN 5 carries out calculation and then multiplies by # of packages per shipment and total # of shipments to calculate total population dose per link

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Neutron Dose Calculation

$$DR_N(r) = Q_1 \cdot DR_{p\ or\ v} \cdot f_N \cdot \frac{k_0}{r^2} \cdot e^{(-\mu \cdot r)} \cdot \left(1 + a_1 \cdot r + a_2 \cdot r^2 + a_3 \cdot r^3 + a_4 \cdot r^4\right)$$

$DR_N(r)$ = Neutron dose rate at distance r (mrem/hr)

r = Radial distance from source (m)

Q_1 = Unit conversion factor

f_N = Fraction of dose rate at 1 meter from package that is neutron radiation

$DR_{p\ or\ v}$ = Package or vehicle dose rate at 1m (mrem/hr)

k_0 = Point source shape factor (m^2)

μ = Linear attenuation coefficient (m^{-1})

a_1, a_2, a_3, a_4 = dimensionless coefficients; default values set

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General Equation for Gamma Dose to Population Along the Route

$$D(x) = \frac{2 \cdot Q_1 \cdot k_0 \cdot DR_v}{V} \cdot \int_x^{\infty} \left(\frac{e^{(-\mu \cdot r)} \cdot B(r)}{r \cdot \left(r^2 - x^2\right)^{0.5}} \right) dr$$

$D(x)$ = Total integrated dose absorbed by an individual at distance x (rem)

Q_1 = Unit conversion factor

k_0 = Point source package shape factor (m^2)

DR_v = Shipment dose rate at 1 meter from surface (mrem/hr)

V = Shipment speed (m/s)

μ = Attenuation coefficient (m^{-1})

r = Perpendicular distance of individual from shipment path (m)

$B(r)$ = Buildup factor expressed as a geometric progression

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Final Equation for Dose to Population Along the Route

$$D_{off} = 4 \cdot Q \cdot k_0 \cdot DR_v \cdot \frac{PD_L}{V_L} \cdot NSH_L \cdot DIST_L \cdot \left[f_G \cdot (I + J) + f_N \cdot (K + L)\right]$$

D_{off}	=	Integrated population dose per km of strip (person-rem)
Q	=	Units conversion factor
k_0	=	Point source package shape factor (m^2)
DR_v	=	Shipment dose rate at 1 meter from surface (mrem/hr)
PD_L	=	Population density for segment L (persons/km^2)
V_L	=	Shipment speed for segment L (m/s)
NSH_L	=	Number of shipments that travel on segment L
$DIST_L$	=	Distance on segment L (km)
f_G	=	Fraction of dose rate at 1 meter from package that is gamma radiation
f_N	=	Fraction of dose rate at 1 meter from package that is neutron radiation
I, K	=	Integrals as in general equation for non-urban populations
J, L	=	Integrals as in general equation; factor includes pedestrian-to-resident ratio

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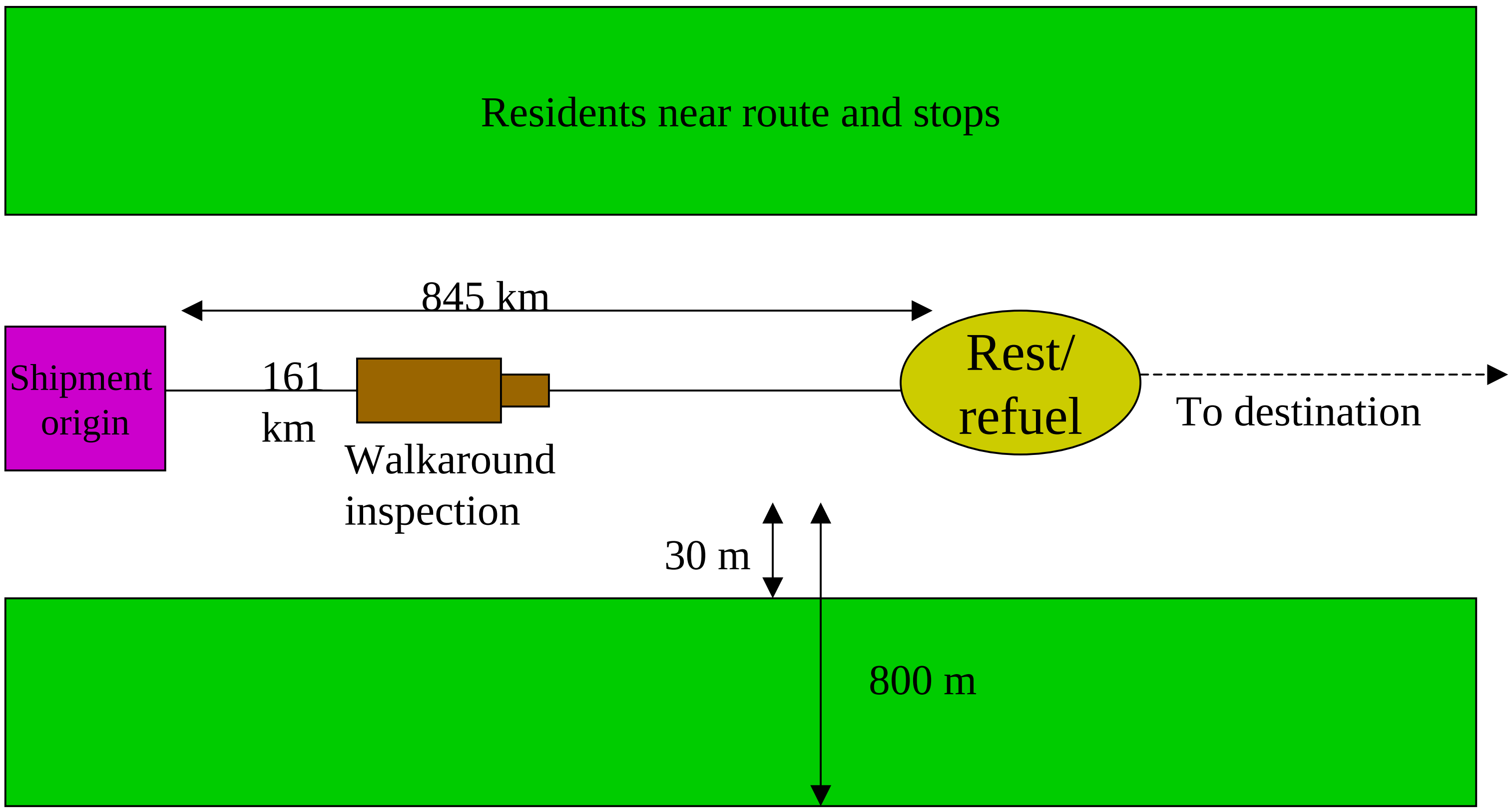
Incident-free Transportation: Legal-weight Truck Route and Stops



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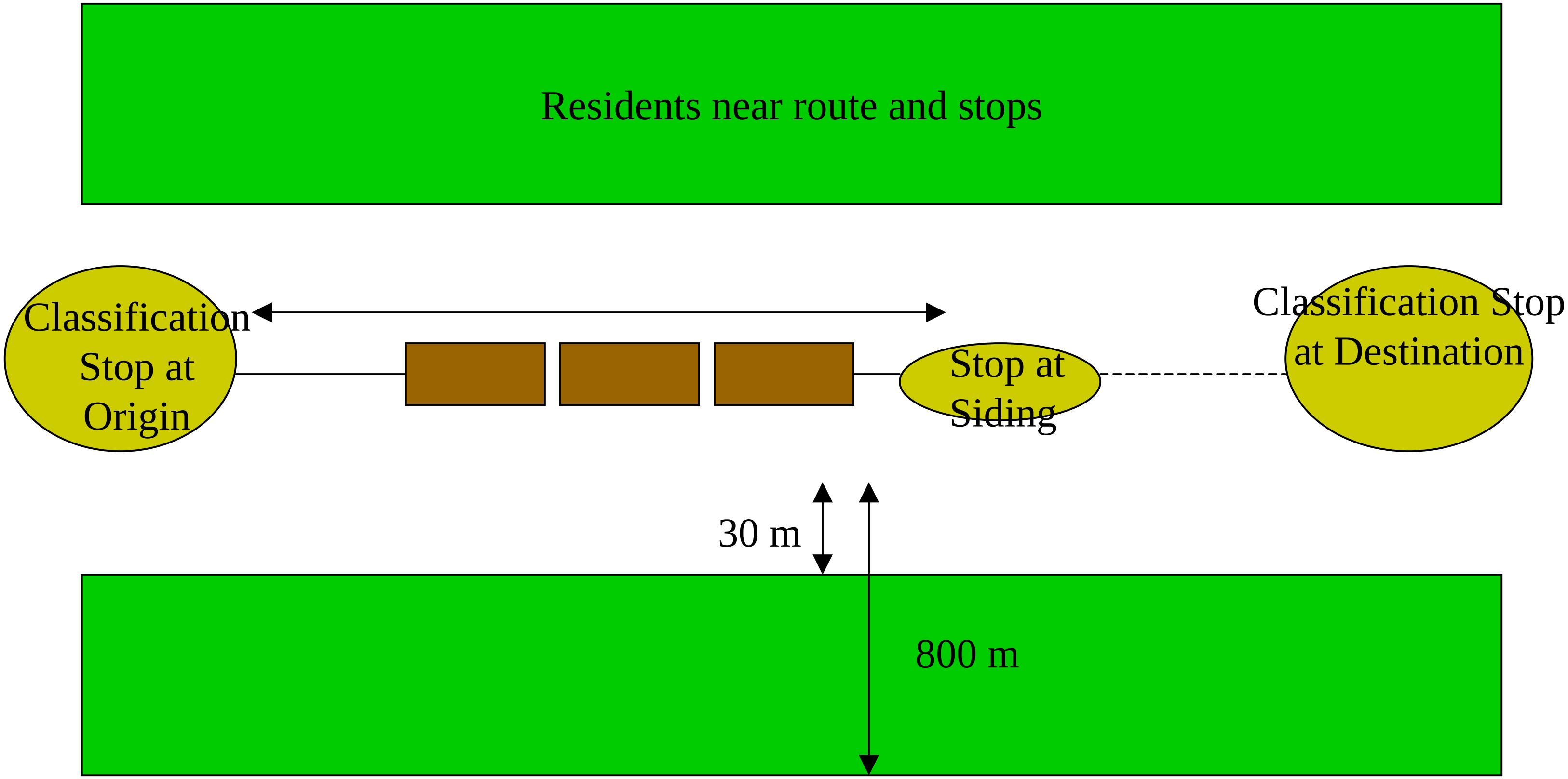
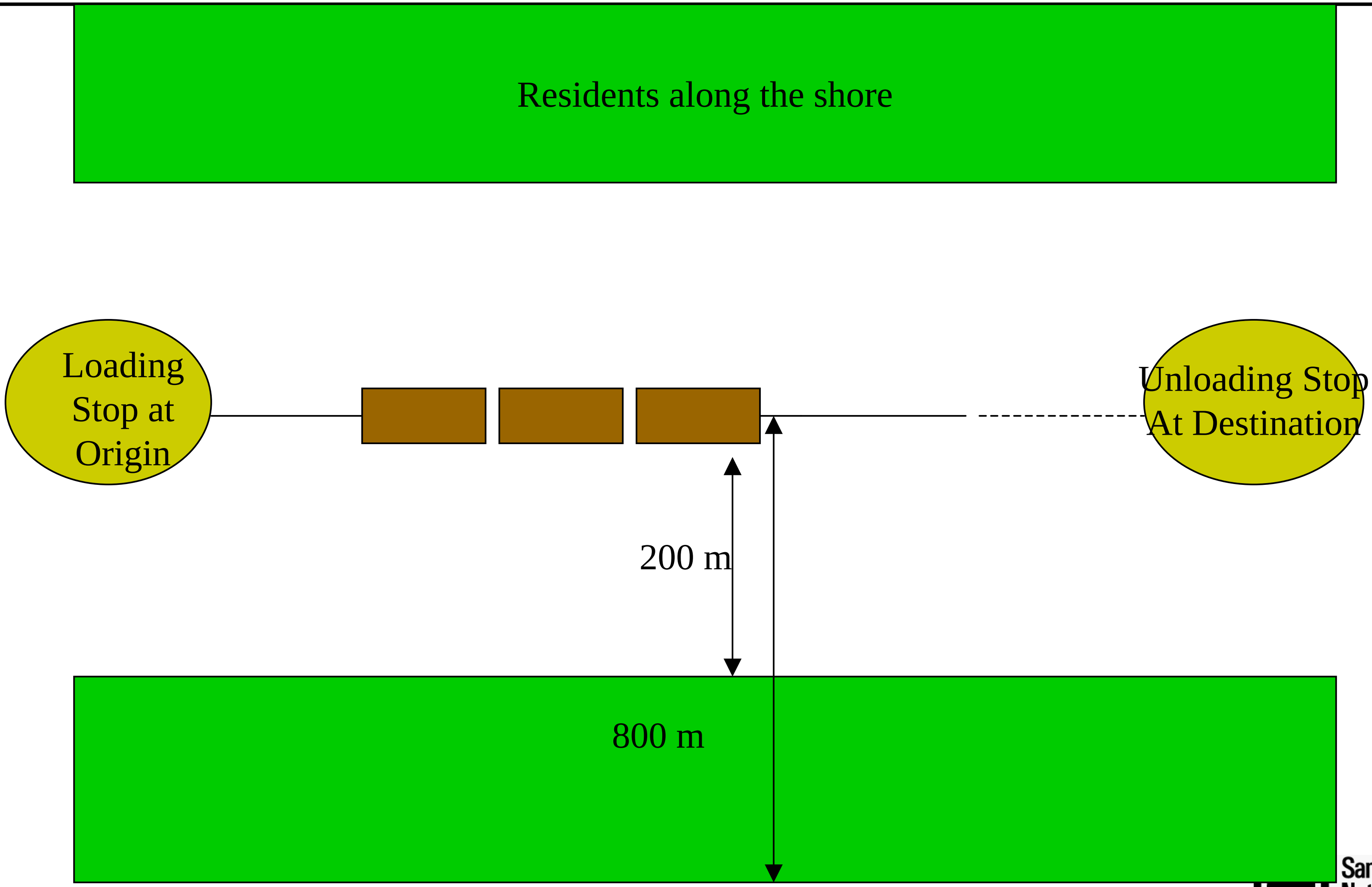
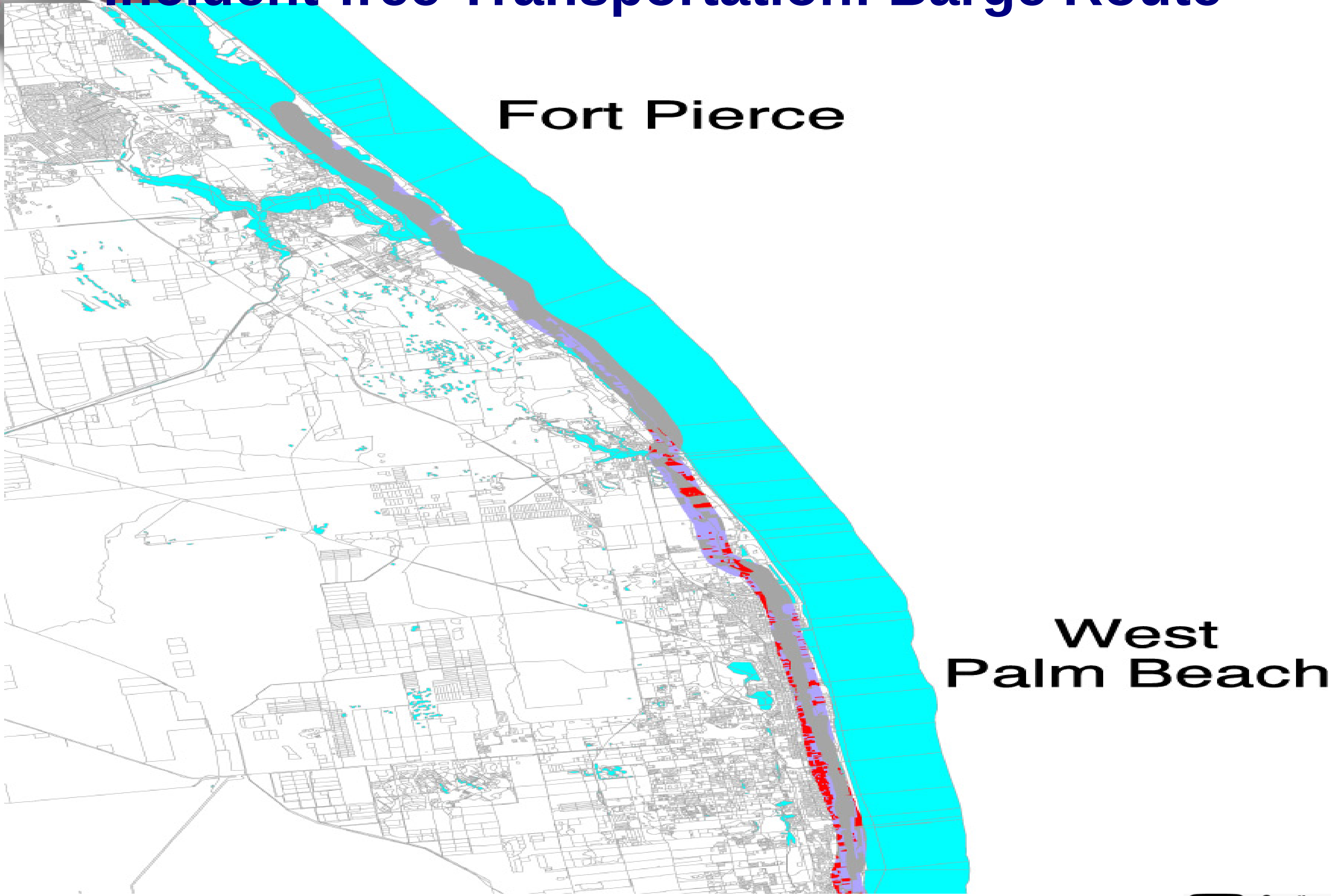
Incident-free Transportation: Rail Route and Stops



Incident-free Transportation: Barge Route and Stops



Incident-free Transportation: Barge Route



Final Equation for Dose to Occupants of Vehicles Sharing the Route Moving in the Opposite Direction

$$D_{opp} = Q_2 \cdot k_0 \cdot DR_v \cdot \frac{N}{V_L^2} \cdot PPV \cdot DIST_L \cdot NSH \cdot \left[f_G \cdot I_G + f_N \cdot I_N \right]$$

D_{opp}	=	Integrated population dose per km of strip (person-rem)
Q_2	=	Conversion factor
k_0	=	Point source package shape factor (m^2)
DR_v	=	Shipment dose rate at 1 meter from surface (mrem/hr)
N	=	One-way traffic count (average number of vehicles that pass per hour)
V	=	Average velocity of all traffic (m/s)
PPV	=	Vehicle occupancy (average number of person per vehicle)
$DIST_L$	=	Distance traveled on segment L
NSH	=	Number of shipments
f_G	=	Fraction of dose rate at 1 meter from package that is gamma radiation
f_N	=	Fraction of dose rate at 1 meter from package that is neutron radiation
$I_{G,}$ I_N	=	Integrals as in the general equation

Final Equation for Dose to Occupants of Vehicles Sharing the Route Moving in the Same Direction

$$D_{sdir} = Q_2 \cdot k_0 \cdot DR_v \cdot \frac{N}{V^2} \cdot PPV \cdot DIST_L \cdot NSH \cdot [F_1 + F_2]$$

D_{sdir} = Integrated population dose per km of strip (person-rem)
Q_2 = Conversion factor
k_0 = Point source package shape factor (m^2)
DR_v = Shipment dose rate at 1 meter from surface (mrem/hr)
N = One-way traffic count (average number of vehicles that pass per hour)
V = Average velocity of all traffic (m/s)
PPV = Vehicle occupancy (average number of person per vehicle)
$DIST_L$ = Distance traveled on segment L
NSH = Number of shipments

$$F_1 = 2 \cdot V \cdot \left[\left[F_G \cdot \int_{2V}^{\infty}\left[\frac{e^{(-\mu_G \cdot r)} B_G(\mu r)}{r^2}\right] dr\right] + \left[F_N \cdot \int_{2V}^{\infty}\left[\frac{e^{(-\mu_N \cdot r)} B_N(\mu r)}{r^2}\right] dr\right]\right]$$

$$F_2 = \frac{V}{x} \cdot \left[\left[F_G \cdot \int_{2V}^{\infty}\left[\frac{e^{(-\mu_G \cdot r)} B_G(\mu r)}{r^2}\right] dr\right] + \left[F_N \cdot \int_{2V}^{\infty}\left[\frac{e^{(-\mu_N \cdot r)} B_N(\mu r)}{r^2}\right] dr\right]\right]$$

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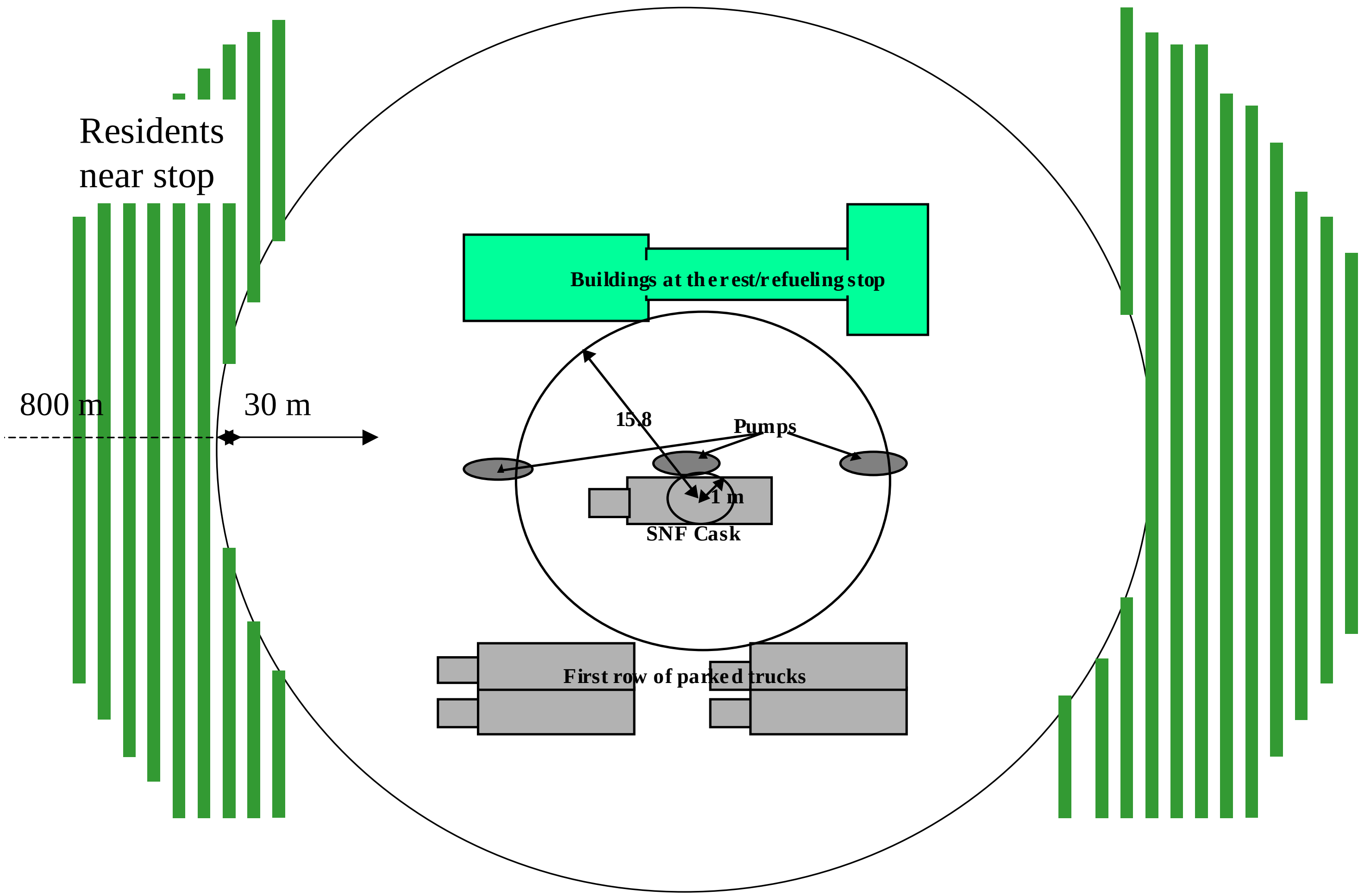
Truck Stop Model



Dose to People at Stops
Number of People at an Average Distance

$$D = Q_4 \cdot DR \cdot P \cdot T \cdot NSH \cdot SF \cdot \left[\left(FG \cdot TR_G \right) + \left(FN \cdot TR_N \right) \right] \cdot \frac{k_0}{r^2}$$

D	= Integrated population dose for stop (person-rem)
Q_4	= Conversion factor
k_0	= Point source shape factor for vehicle (m^2)
DR	= Vehicle dose rate at 1 meter from surface (mrem/hr)
P	= Average number of expected persons
T	= Duration of stop (hr)
NSH	= Number of shipment by vehicle
SF	= Shielding factor at stops
r	= Average radial source-to-receptor distance (m)
FG	= Fraction of vehicle dose rate from gamma radiation
FN	= Fraction of vehicle dose rate from neutron radiation
TR_G, TR_N	= Term for gamma, neutron radiation source strength

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Dose to People at Stops
Population Density in an Annulus

$$D1_{stop} = 2\pi \cdot Q_4 \cdot k_0 \cdot DR \cdot PD \cdot T \cdot NSH \cdot SF \cdot [\ln(max) - \ln(min)]$$

$D1_{stop}$ = Integrated population dose for stop (person-rem)

Q_4 = Conversion factor

k_0 = Point source shape factor for vehicle (m^2)

DR = Vehicle dose rate at 1 meter from surface (mrem/hr)

PD = Population density of annular area at stop (persons/km^2)

T = Duration of stop (hr)

NSH = Number of shipment by vehicle

SF = Shielding factor at stop

max = Maximum radial distance from source

min = Minimum radial distance from source

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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

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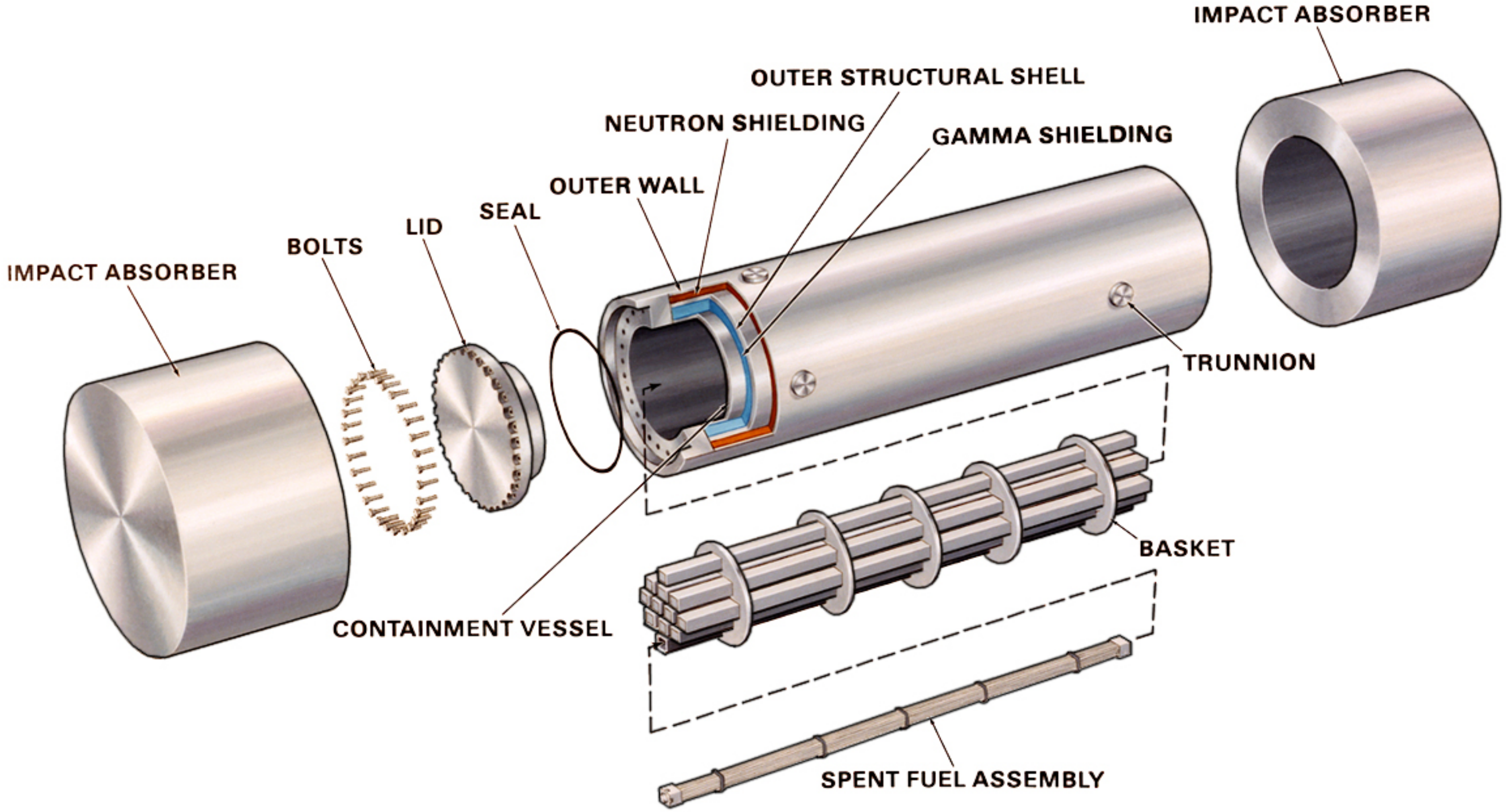
SPENT FUEL CASK



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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 Se 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 Fi ✹ (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 $T_a - T_f$

Transportation Accidents : Matrix of NUREG/CR-6672 Cases (detail)

>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	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 Se 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
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	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
No Impact	21 No Release ✶ Prob 0.99996		20 Seal Failure by Fi ✹ (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	A $T_a – T_f$	B $T_a – T_f$

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Change Severity Categories By Probability Weighting

$$RF_{Sci,m} = \frac{\sum_{j,m} RF_{Cj} * P_{Cj}}{P_{Sci}}$$

$$P_{Sci} = \sum_{j} P_{Cj}$$

j	=	**the cases included in severity category *I***
P_{Cj}	=	**the case *j* probability**
P_{Sci}	=	**the accident severity *i* probability**

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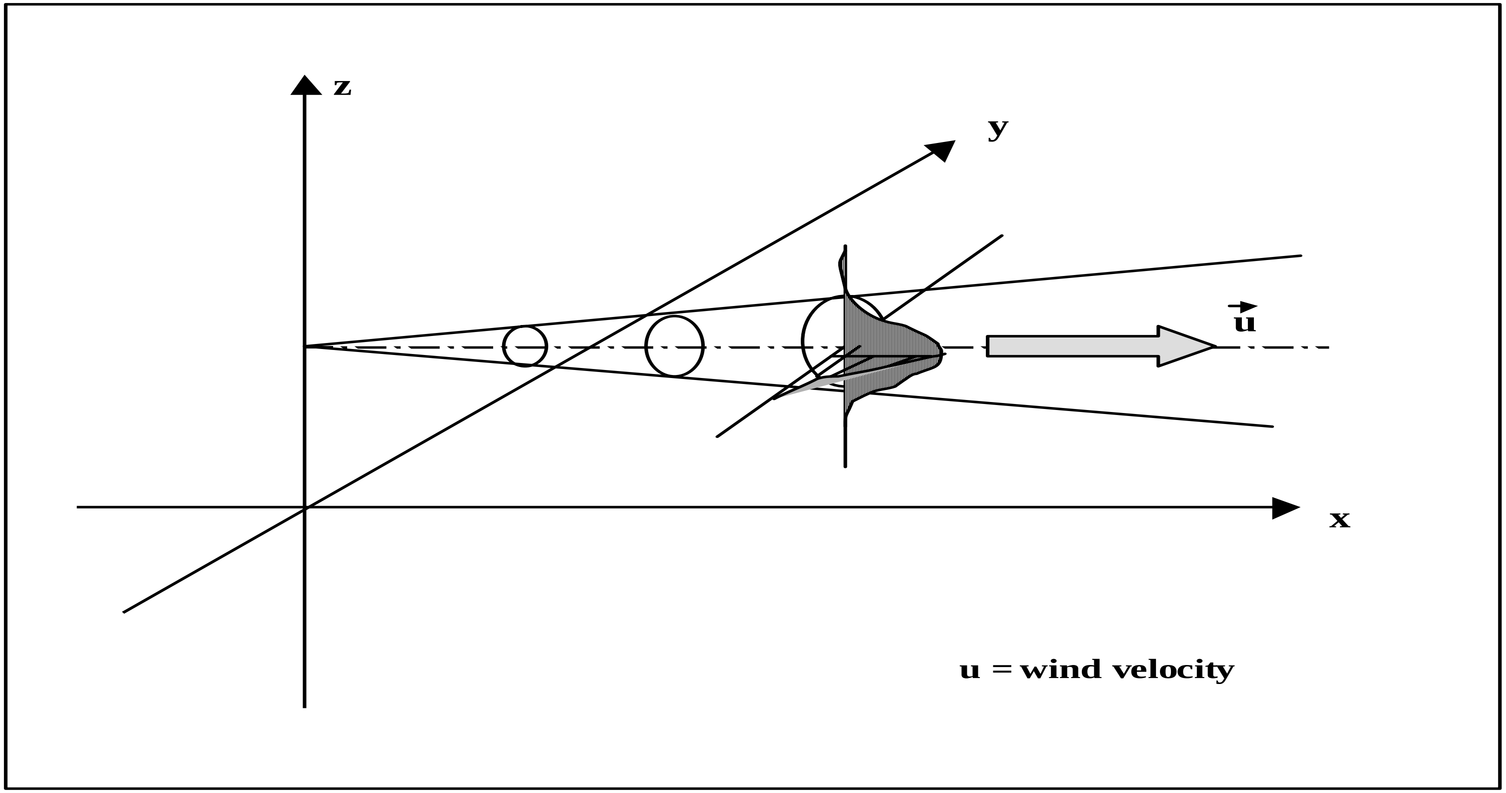
Severity category	NUREG/CR-6672 Case	Severity fraction	PWR release fractions				
			Kr	Cs	Ru	Particulates	Crud
1	19	0.99993	0.00000	0.00000	0.00000	0.00000	0.00000
2	2, 3	6.06E-05	1.36E-01	4.09E-09	1.02E-07	1.02E-07	1.36E-03
3	18	5.86E-06	8.39E-01	1.68E-05	6.71E-08	6.71E-08	2.52E-03
4	1, 5, 6, 8	4.95E-07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

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

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Gaussian Dispersion With Deposition

Deposition from an Elevated Source

$$\frac{\omega}{Q} = \frac{V_d}{2\pi u \sigma_y \sigma_z} \exp\left[\frac{-y^2}{2\sigma_y^2}\right] \exp\left[\frac{-\left(H - \left[\frac{xV_d}{u}\right]\right)^2}{2\sigma_z^2}\right]$$

Deposition velocity

$$V_d = \left[\frac{gd^2\rho}{18\mu}\right]$$

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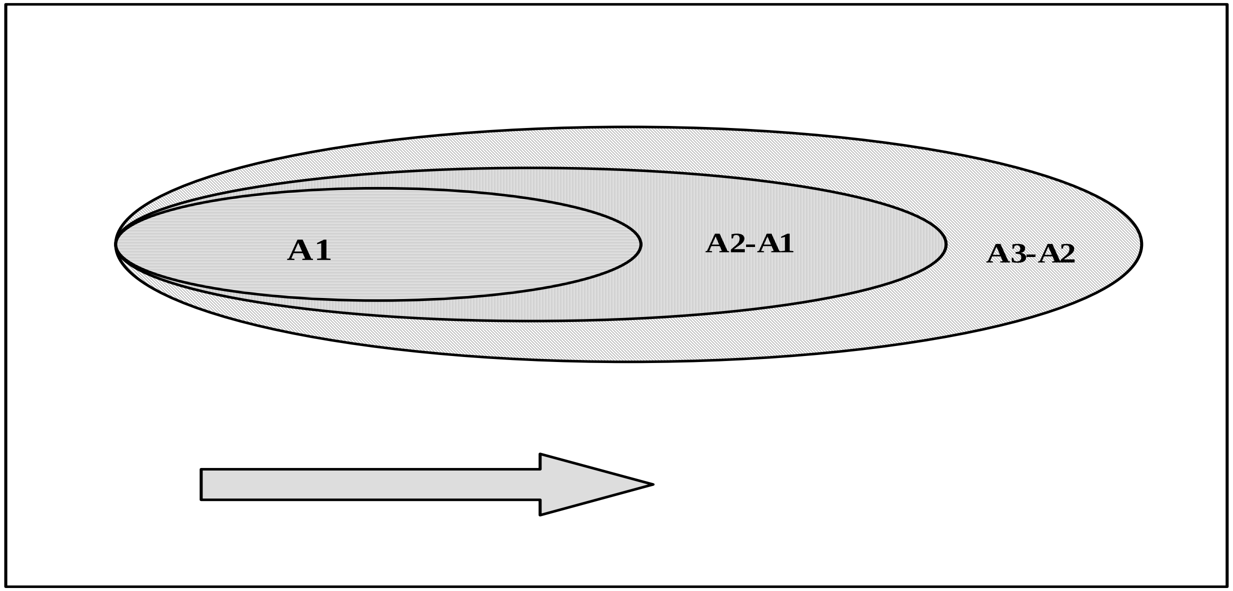
Dispersion Footprint



Gaussian Dispersion With Deposition In RADTRAN

The amount deposited in the first isopleth area is:

$$DEP_1^0 = \overline{CHI}_1 \cdot V_d \cdot A_1$$

The amount of material deposited in the nth area, n≥2, is

$$DEP_n^0 = \overline{CHI}_n \cdot V_d \cdot \left[A_n - A_{n-1}\right]$$

The total amount of material deposited out to A_n is then

$$DEP_n^0 = DEP_1^0 + \sum_{i=2}^{n} DEP_i^0$$

When deposition occurs, a revised value of the airborne concentration is calculated:

$$CHI_n^1 = \sqrt{\left(CHI_n \cdot \left(1 - DEP_n^N\right) \cdot CHI_{n-1}^0 \cdot \left(1 - DEP_{n-1}^N\right)\right)}$$

A revised estimate of the material deposited is given by

$$DEP_n^1 = CHI_n^0 \cdot V_d \cdot \left[A_n - A_{n-1}\right]$$

Dose to an Individual from Inhalation of Dispersed Materials

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

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)
CHI_n = dilution factor in nth isopleth area (Ci-sec/m^3/Ci-released)
BR = Breathing rate (m^3/sec)

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Integrated Population Dose from Inhalation of Dispersed Materials

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

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
$RESP_{p,j}$ = Fraction of aerosolized radionuclide p that is respirable in accident of severity j
RPC_p = Dose conversion factor of p^{th} isotope (rem/Ci)
IF = Integral of time-integrated atmospheric dilution factors over downwind areas
BR = Breathing rate (m^3/sec)
PD_L = Population density on link L (persons/km^2)
A_n = Area of n^{th} isopleth (m^2)

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Integrated Population Dose from Groundshine

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

DR(T) = Groundshine dose rate at time T (rem/day)

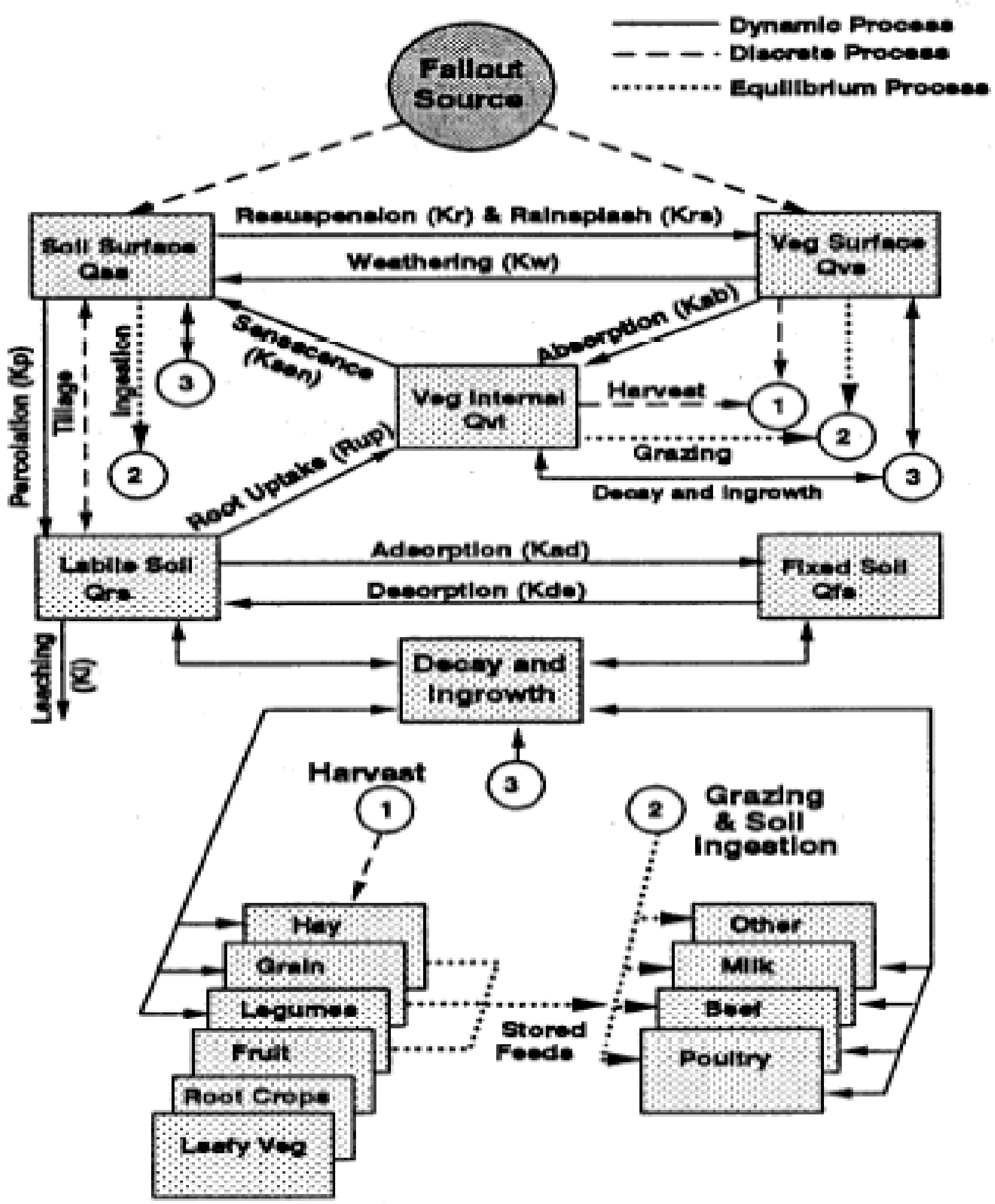
CL_p = Ground concentration (deposition) of radionuclide p ($\mu Ci/m^2$)

GDF = Groundshine dose factor for radionuclide p (rem-m^2/day-μCi)

$t_{1/2}$ = Half-life of radionuclide p (days)

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

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

$\gamma_{j,L}$ = 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

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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.)
- Interdicton threshold
- Evacuation time
- Survey interval
- LCF/person-rem for occupational and public exposure
- Genetic effects/person-rem
- Duration of shipping campaign

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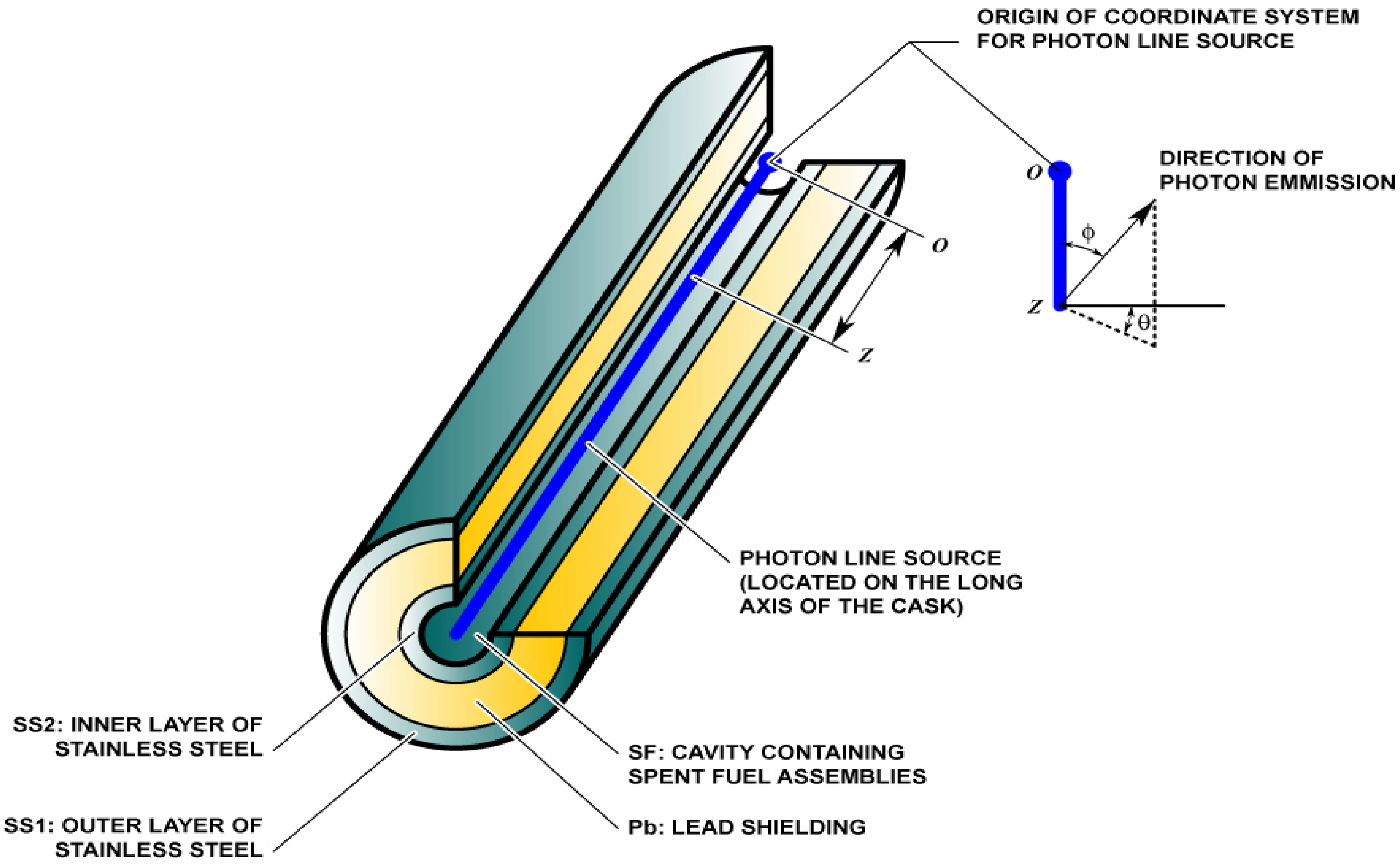
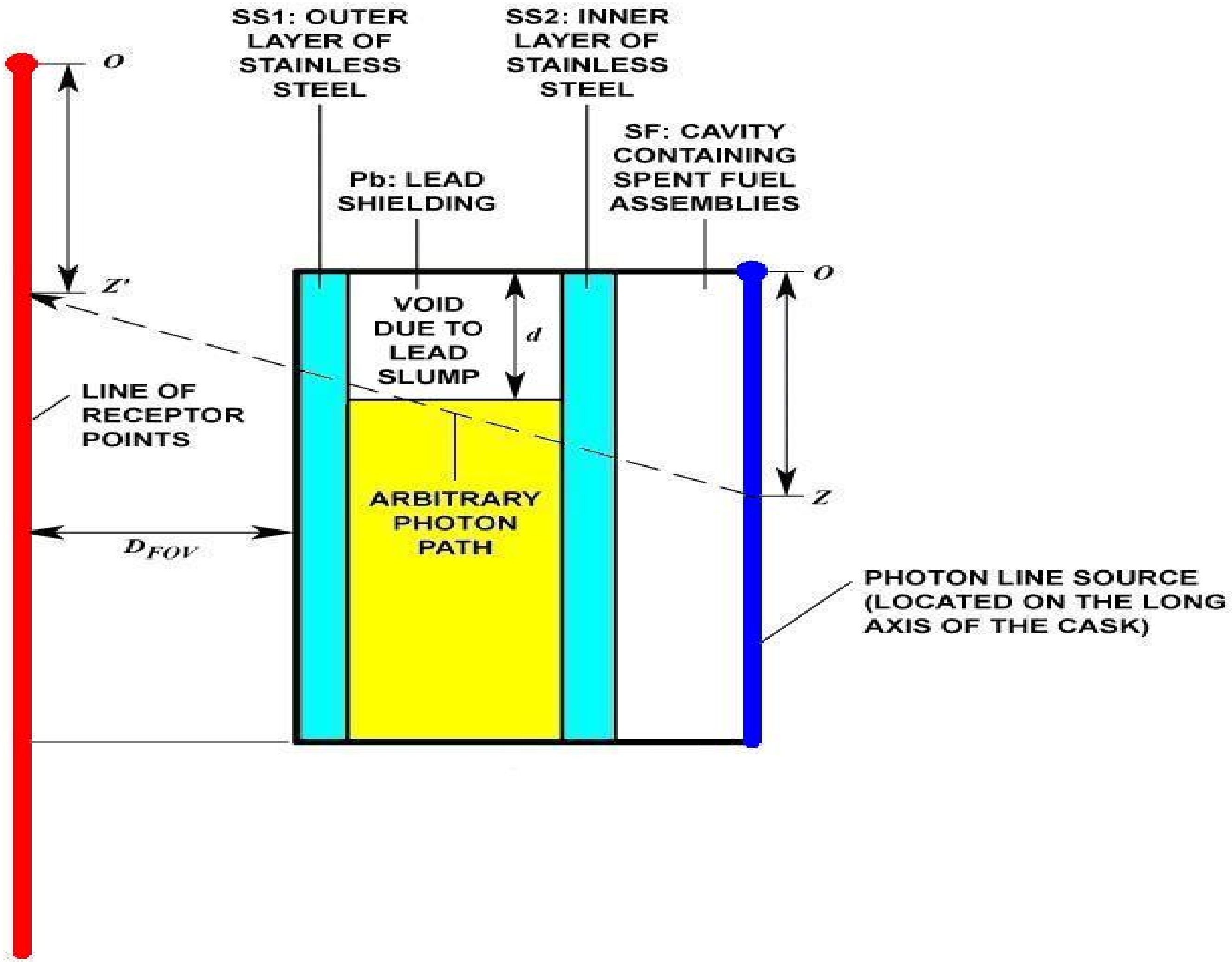
Loss-of-Shielding 3-D Model



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



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Integration With Other Systems

- RADTRAN uses a text input file that can be created with any commercial text editor or with RADCAT, or can be made from a text template.
- RADTRAN output can be either a text file or an Excel (spreadsheet) file
- RADTRAN output can be read electronically into an ACCESS database.
- RADTRAN uses routing code output (e.g., TRAGIS) for distances and population densities.

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Comparison to Similar Codes

- RISKIND:
  - Can run only one scenario at a time
  - User input of, e.g., radionuclides is difficult
  - No LOS module
- HOTSPOT
  - Designed for explosions
  - Uses much more memory
  - No incident-free module
  - No LOS module
- MACCS 2
  - Designed for reactor accidents
  - More complex than needed for transportation
  - GUI input file generator not yet available

The RADTRAN Team at SNL

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