CAP88-PC V4 Training

Module 1.2

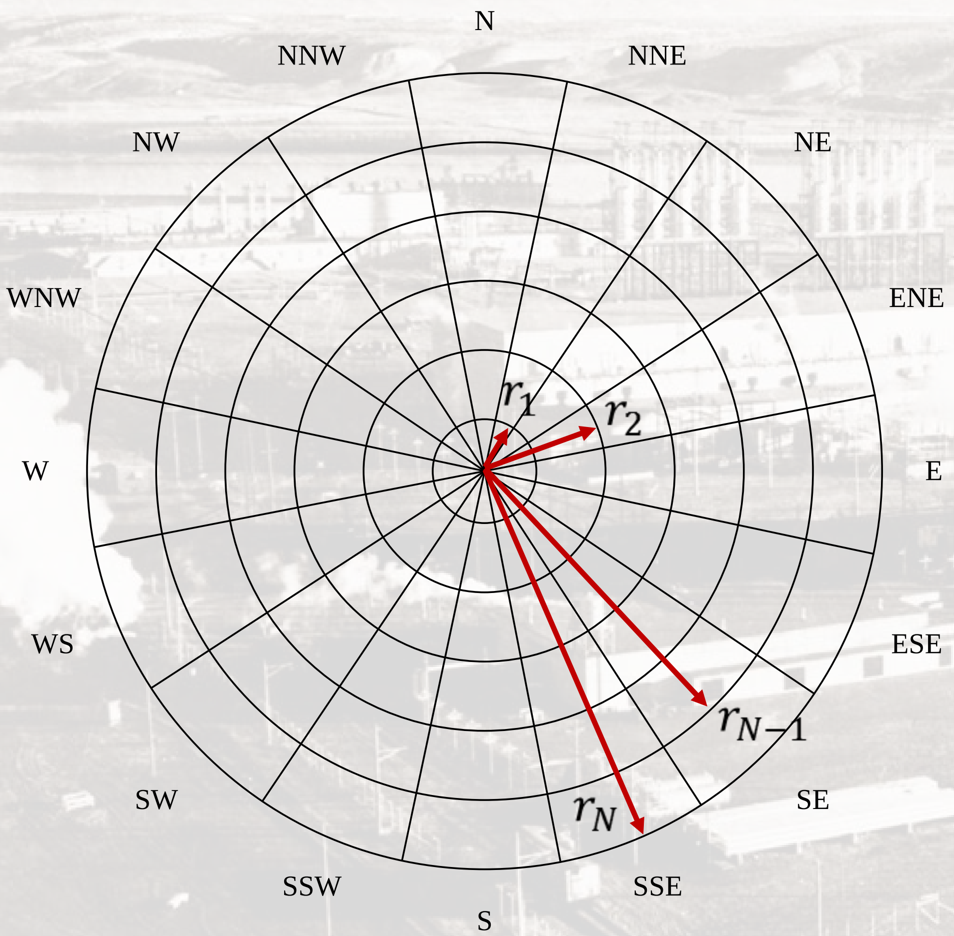
Equations Used For Calculating Dose

Trinity Engineering Associates | United States Environmental Protection Agency

CAP88 METHODOLOGY

1. Calculate χ / Q values in each sector
2. Calculate air concentrations in each sector
3. Calculate deposition rates in each sector
4. Calculate ground concentrations in each sector
5. Calculate concentrations in vegetables, milk, and meat produced in each sector
6. Calculate concentrations in vegetables, milk, and meat ingested by a receptor in each sector
7. Calculate dose and risk to a receptor in each sector

Assessment Area & Sectors



CAP88 calculates the dose to receptors in sectors defined user defined rings and the 16 compass directions.

CALCULATION OF χ / Q VALUES

1. Calculate χ / Q values in each sector
2. Calculate air concentrations in each sector
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4. Calculate ground concentrations in each sector
5. Calculate concentrations in vegetables, milk, and meat produced in each sector
6. Calculate concentrations in vegetables, milk, and meat ingested by a receptor in each sector
7. Calculate dose and risk to a receptor in each sector

PLUME DISPERSION

$$\chi(x,y,z) = \begin{cases} \dfrac{Q\left[\exp\left(\dfrac{-[z-H(x)]^2}{2[\sigma_z(x)]^2}\right) + \exp\left(\dfrac{-[z+H(x)]^2}{2[\sigma_z(x)]^2}\right)\right]}{2\pi\mu\sigma_y(x)\sigma_z(x)} \exp\left(\dfrac{-y^2}{2\left[\sigma_y(x)\right]^2}\right) & \text{, if } x < 2x_L \\ \dfrac{Q}{2\sqrt{\pi}\mu L\sigma_y(x)} \exp\left(\dfrac{-y^2}{2\left[\sigma_y(x)\right]^2}\right) & \text{, if } x \geq 2x_L \end{cases}$$

x is the distance downwind

y is the crosswind distance

z is the distance above the ground

Q is the release rate

μ is the wind speed

$\sigma_y(x)$ is the horizontal dispersion coefficient

$\sigma_z(x)$ is the vertical dispersion coefficient

$H(x)$ is the effective stack height

x_L is the distance where $\sigma_z(x_L) = 0.47 \times L$

PLUME DISPERSION (CONTINUED)

Averaging the concentration along the y direction:

$$\chi_{\text{ave}}(x,z;Q,\mu) = \begin{cases} \dfrac{Q}{2\sqrt{2\pi}\mu\sigma_z y_s}\left[\exp\left(\dfrac{-[z-H]^2}{2\sigma_z^2}\right) + \exp\left(\dfrac{-[z+H]^2}{2\sigma_z^2}\right)\right] & \text{, if } x < 2x_L \\ \dfrac{Q}{2\sqrt{2}\mu L y_s} & \text{, if } x \geq 2x_L \end{cases}$$

The ground level concentration is found by setting $z = 0$:

$$\chi_{\text{ave}}(x,0;Q,\mu) = \begin{cases} \dfrac{Q}{\sqrt{2\pi}\mu\sigma_z(x) y_s(x)}\left[\exp\left(\dfrac{-[H(x)]^2}{2\sigma_z^2}\right)\right] & \text{, if } x < 2x_L \\ \dfrac{Q}{2\sqrt{2}\mu L y_s(x)} & \text{, if } x \geq 2x_L \end{cases}$$

DISPERSION COEFFICIENTS

$$\sigma_y(x) = \frac{x^A}{C}$$

$$\sigma_z(x) = \frac{x^D}{F}$$

Class	Distance (m)	*A*	*C*	*D*	*F*
A	$x \le 1{,}000$	0.9757	3.9280	1.0000	5.0200
	$1{,}000 < x \le 3{,}000$	0.8660	1.8410	1.0000	5.0200
	$3{,}000 < x \le 10{,}000$	0.8660	1.8410	1.0000	5.0200
	$x > 10{,}000$	0.6294	0.2083	1.0000	5.0200
B	$x \le 1{,}000$	0.9986	6.2050	1.0000	8.3500
	$1{,}000 < x \le 3{,}000$	0.8493	2.2130	1.0000	8.3500
	$3{,}000 < x \le 10{,}000$	0.8493	2.2130	1.0000	8.3500
	$x > 10{,}000$	0.6303	0.2946	1.0000	8.3500
C	$x \le 1{,}000$	0.9767	7.6230	0.9540	10.0150
	$1{,}000 < x \le 3{,}000$	0.8540	3.2660	0.8330	4.4000
	$3{,}000 < x \le 10{,}000$	0.8540	3.2660	0.8330	4.4000
	$x > 10{,}000$	0.6254	0.3977	0.5524	0.3320
D	$x \le 1{,}000$	0.9600	10.0000	0.8061	7.4800
	$1{,}000 < x \le 3{,}000$	0.8670	5.2610	0.6715	2.9500
	$3{,}000 < x \le 10{,}000$	0.8670	5.2610	0.5099	0.8100
	$x > 10{,}000$	0.6342	0.6166	0.5251	0.9300
E	$x \le 1{,}000$	0.9615	14.1300	0.8600	15.5000
	$1{,}000 < x \le 3{,}000$	0.8670	7.3570	0.6290	3.1500
	$3{,}000 < x \le 10{,}000$	0.8670	7.3570	0.4054	[illegible]
	$x > 10{,}000$	0.6260	0.8042	0.1110	0.0349

PLUME RISE

$$H(x) = h + \Delta h(x)$$

h is the height of the stack

Δh is the plume rise

CAP88 provides for four methods for calculating the plume rise:

- Buoyant
- Momentum
- Fixed
- None

BUOYANT PLUME RISE

For Stability Classes A, B, C, and D:

$$\Delta h(x) = \begin{cases} \dfrac{1.6\, F^{1/3}\, x^{2/3}}{\mu} & , x < 10h \\ \dfrac{1.6\, F^{1/3}\, (10h)^{2/3}}{\mu} & , x \geq 10h \end{cases}$$

$$F = 3.7 \times 10^{-5} Q_H$$

Buoyant Plume Rise

For Stability Classes E, F, and G:

$$\Delta h(x) = \begin{cases} \dfrac{1.6\,F^{1/3}\,x^{2/3}}{\mu} & ,x < 2.4\dfrac{\mu}{\sqrt{S}} \\ 2.9\left(\dfrac{F}{\mu S}\right)^{1/3} & ,x \geq 2.4\dfrac{\mu}{\sqrt{S}} \end{cases}$$

$$S = \frac{g}{T_a}\left(\frac{dT_a}{dz} + \Gamma\right)$$

g is the gravitational acceleration

T_a is the air temperature

dT_a/dz is the vertical temperature gradient

Γ is the adiabatic lapse rate of atmosphere (0.0098 K/m)

Class	dT_a/dz (K/m)
E	7.280E-02
F	1.090E-01
G	1.455E-01

Momentum Plume Rise

$$\Delta h = \frac{1.5\, v\, d}{\mu}$$

v is the effluent stack gas velocity

d is the inside stack diameter

CALCULATION OF AIR CONCENTRATIONS

1. Calculate χ / Q values in each sector
2. Calculate air concentrations in each sector
3. Calculate deposition rates in each sector
4. Calculate ground concentrations in each sector
5. Calculate concentrations in vegetables, milk, and meat produced in each sector
6. Calculate concentrations in vegetables, milk, and meat ingested by a receptor in each sector
7. Calculate dose and risk to a receptor in each sector

In-Flight Decay/Ingrowth Calculations

The atom concentration in air for each radionuclide, $n_i(t) = \chi_i(t)/\lambda_i$, was calculated by solving the following system of ordinary differential equations (ODEs) as a function of time based on the windspeed:

$$\frac{dn_i}{dt} = -\lambda_i^{\mathrm{e}} n_i(t) + \sum_{j=1}^{i-1} \lambda_{j,i} n_j(t)$$

$$\lambda_i^{\mathrm{e}} \equiv \lambda_i + \lambda_{l,i}$$

$$\lambda_{j,i} \equiv \gamma_{j,i} \lambda_j$$

λ_i is the radioactive decay constant

$\lambda_{l,i}$ is the physical removal constant

$\gamma_{j,i}$ is the branching ratio from nuclide j to nuclide i

Calculate of Deposition Rates

1. Calculate χ/Q values in each sector
2. Calculate air concentrations in each sector
3. Calculate deposition rates in each sector
4. Calculate ground concentrations in each sector
5. Calculate concentrations in vegetables, milk, and meat produced in each sector
6. Calculate concentrations in vegetables, milk, and meat ingested by a receptor in each sector
7. Calculate dose and risk to receptor in each sector

Wet Deposition Rate

$$R_s(x) = \Phi L \chi_{\text{ave}}(x)$$

$\chi_{\text{ave}}(x)$ is average concentration in plume up to lid height

L is lid height (tropospheric mixing layer)

Φ is the scavenging coefficient, calculated by multiplying the rainfall (in cm y^{-1}) by a constant (10^{-7} y cm^{-1} s^{-1})

Dry Deposition Rate

$$R_d(x,y) = V_d \chi(x,y,0)$$

$\chi(x,y,0)$ is the ground level air concentration

V_d is the deposition velocity

Parameter	V_d (m s^{-1})
Gases	0.0
Iodine	3.5×10^{-2}
Particulates	1.8×10^{-3}

PLUME DEPLETION

For dry deposition:

$$\frac{Q^1}{Q} = \exp\left\{-\frac{V_d}{\mu}\sqrt{\frac{2}{\pi}}\int_0^x \frac{\exp\left[\frac{-\left(H(x') - V_g x'/\mu\right)^2}{2\sigma_z^2(x')}\right]}{\sigma_z(x')}dx'\right\}$$

V_g is the gravitational velocity

For wet deposition:

$$\frac{Q^1}{Q} = \exp\{-\Phi t\}$$

t is the time required to reach the location

CALCULATION OF GROUND CONCENTRATION

1. Calculate χ / Q values in each sector
2. Calculate air concentrations in each sector
3. Calculate deposition rates in each sector
4. Calculate ground concentrations in each sector
5. Calculate concentrations in vegetables, milk, and meat produced in each sector
6. Calculate concentrations in vegetables, milk, and meat ingested by a receptor in each sector
7. Calculate dose and risk to a receptor in each sector

Ground Surface Decay/Ingrowth Calculations

The atom concentration in on the ground surface for each radionuclide, $n_i(t) = C_i^G(t)/\lambda_i$, was calculated by solving the following system of ordinary differential equations (ODEs) as a function of time:

$$\frac{dn_i}{dt} = d_i - \lambda_i^{\mathrm{e}} n_i(t) + \sum_{j=1}^{i-1} \lambda_{j,i} n_j(t)$$

$$\lambda_i^{\mathrm{e}} \equiv \lambda_i + \lambda_{l,i}$$

$$\lambda_{j,i} \equiv \gamma_{j,i} \lambda_j$$

d_i is the total deposition rate

λ_i is the radioactive decay constant

$\lambda_{l,i}$ is the physical removal constant (2% per year)

$\gamma_{j,i}$ is the branching ratio from nuclide j to nuclide i

Calculate of Concentrations in Vegetables, Milk, and Meat

1. Calculate χ / Q values in each sector
2. Calculate air concentrations in each sector
3. Calculate deposition rates in each sector
4. Calculate ground concentrations in each sector
5. Calculate concentrations in vegetables, milk, and meat produced in each sector
6. Calculate concentrations in vegetables, milk, and meat ingested by a receptor in each sector
7. Calculate dose and risk to receptor in each sector

Concentration in Leafy Vegetables

$$\sigma_z(x) = \frac{x^D}{F}$$

- $d_i(r, \theta)$ is the deposition rate in sector θ at distance r
- r_L is the fraction of deposited activity retained on leafy vegetables
- $\lambda_{E,i}$ is the effective removal constant of the ith radionuclide from soil
- $B_{L,i,V}$ is the concentration uptake factor the ith radionuclide for leafy vegetables
- $Y_{L,V}$ is the agricultural productivities by unit area for leafy vegetables
- λ_i is the radioactive decay constant of the ith radionuclide
- λ_W is the removal constant from plants due to weathering
- P is the effective surface density of soil (assuming a 15 cm plow layer)
- t_b is the period of long-term buildup for activity in sediment or soil
- $t_{L,h}$ is the time delay between harvest ingestion of leafy vegetables
- d_R is fraction of radioactivity retained after washing for leafy vegetables and produce

CONCENTRATION IN NON-LEAFY VEGETABLES

$$\frac{dn_i}{dt} = -\lambda_i^{e} n_i(t) + \sum_{j=1}^{i-1} \lambda_{j,i} n_j(t)$$

- $d_i(r,\theta)$ is the deposition rate in sector θ at distance r
- r_V is the fraction of deposited activity retained on non-leafy vegetables
- λ_{Ei} is the effective removal constant of the ith radionuclide from soil
- $B_{V,i,V}$ is the concentration uptake factor the ith radionuclide for non-leafy vegetables
- $Y_{V,V}$ is the agricultural productivities by unit area for non-leafy vegetables
- λ_i is the radioactive decay constant of the ith radionuclide
- λ_W is the removal constant from plants due to weathering
- P is the effective surface density of soil (assuming a 15 cm plow layer)
- t_b is the period of long-term buildup for activity in sediment or soil
- $t_{V,h}$ is the time delay between harvest ingestion of non-leafy vegetables

CONCENTRATION IN PASTURE GRASS

$$C_i^P(r,\theta) = d_i(r,\theta)\left\{\frac{r_P\left[1-e^{-(\lambda_i+\lambda_W)t_{P,e}}\right]}{Y_{P,V}(\lambda_i+\lambda_W)} + \frac{B_{P,i,V}\left[1-e^{-\lambda_{E,i}t_b}\right]}{P\lambda_{E,i}}\right\}e^{-\lambda_i t_{P,h}}$$

- $d_i(r,\theta)$ is the deposition rate in sector θ at distance r
- r_P is the fraction of deposited activity retained on pasture grass
- λ_{Ei} is the effective removal constant of the ith radionuclide from soil
- $B_{P,i,V}$ is the concentration uptake factor the ith radionuclide for pasture grass
- $Y_{P,V}$ is the agricultural productivities by unit area for pasture grass
- λ_i is the radioactive decay constant of the ith radionuclide
- λ_W is the removal constant from plants due to weathering
- P is the effective surface density of soil (assuming a 15 cm plow layer)
- t_b is the period of long-term buildup for activity in sediment or soil
- $t_{P,h}$ is the time delay between harvest ingestion of pasture grass

CONCENTRATION IN STORED FEED

L is lid height (tropospheric mixing layer)

- $d_i(r, \theta)$ is the deposition rate in sector θ at distance r
- r_S is the fraction of deposited activity retained on stored feed
- λ_{Ei} is the effective removal constant of the ith radionuclide from soil
- $B_{S,i,V}$ is the concentration uptake factor the ith radionuclide for stored feed
- $Y_{S,V}$ is the agricultural productivities by unit area for stored feed
- λ_i is the radioactive decay constant of the ith radionuclide
- λ_W is the removal constant from plants due to weathering
- P is the effective surface density of soil (assuming a 15 cm plow layer)
- t_b is the period of long-term buildup for activity in sediment or soil
- $t_{S,h}$ is the time delay between harvest ingestion of pasture grass

Parameter Values

Parameter	Leafy Vegetables	Non-Leafy Vegetables	Pasture Grass	Stored Feed
λ_W	2.9×10^{-3} h^{-1}	2.9×10^{-3} h^{-1}	2.9×10^{-3} h^{-1}	2.9×10^{-3} h^{-1}
λ_P	2.28×10^{-6} h^{-1} (2% per year)	2.28×10^{-6} h^{-1} (2% per year)	2.28×10^{-6} h^{-1} (2% per year)	2.28×10^{-6} h^{-1} (2% per year)
r	0.20	0.20	0.57	0.57
P	215 kg m^{-2}	215 kg m^{-2}	215 kg m^{-2}	215 kg m^{-2}
Y_V	0.716 kg m^{-2}	0.716 kg m^{-2}	0.28 kg m^{-2}	0.28 kg m^{-2}
t_e	1,440 h (60 days)	1,440 h (60 days)	720 h (30 days)	720 h (30 days)
t_b	8.776×10^{5} h (100 years)	8.776×10^{5} h (100 years)	8.776×10^{5} h (100 years)	8.776×10^{5} h (100 years)
t_h	0 h (0 days)	0 h (0 days)	0 h (0 days)	2,160 h (90 days)
d_R	0.5	N/A	N/A	N/A

CONCENTRATION IN ANIMAL FEED

V_g is the gravitational velocity

- $C_i^P(r,\theta)$ is the concentration of the ith radionuclide in pasture grass in milk in sector θ at distance r
- $C_i^S(r,\theta)$ is the concentration of the ith radionuclide in stored feeds in milk in sector θ at distance r
- f_P is the fraction of the year that animals graze on pasture
- f_S is the fraction of daily feed that is pasture grass when the animal grazes on pasture

Parameter	Animal Feed
λ_i is the radi	0.40
	0.43

CONCENTRATION IN MEAT

$\lambda_{l,i}$ is the physical removal constant (2% per year)

- $F_{i,f}$ is the fraction of the animal's daily intake of the ith radionuclide which appears in each kilogram of flesh
- $C_i^{AF}(r,\theta)$ is the concentration of the ith radionuclide in the animal's feed in sector θ at distance r
- Q_F is the amount of feed consumed by the animal per day
- λ_i is the radiological decay constant of the ith radionuclide
- t_s is the average time from slaughter to consumption

Parameter	Meat
Q_F	15.6 kg d^{-1} (dry weight)
t_s	480 h (20 days)

CONCENTRATION IN MILK

$$C_i^M(r,\theta) = F_{i,M} C_i^{AF}(r,\theta) Q_F \exp(-\lambda_i t_f)$$

- $F_{i.M}$ is the average fraction of the animal's daily intake of the ith radionuclide which appears in each liter of milk
- $C_i^{AF}(r,\theta)$ is the concentration of the ith radionuclide in the animal's feed in sector θ at distance r
- Q_F is the amount of feed consumed by the animal per day
- λ_i is the radiological decay constant of the ith radionuclide
- t_f is the average transport time of the activity from the feed into the milk and to the receptor

Parameter	Milk
Q_F	15.6 kg d^{-1} (dry weight)
t_f	48 h (2 days)

Calculation of Dose and Risk to a Receptor

1. Calculate χ / Q values in each sector
2. Calculate air concentrations in each sector
3. Calculate deposition rates in each sector
4. Calculate ground concentrations in each sector
5. Calculate concentrations in vegetables, milk, and meat produced in each sector
6. **Calculate concentrations in vegetables, milk, and meat ingested by a receptor in each sector**
7. Calculate dose and risk to a receptor in each sector

Average Concentrations in Foods Ingested

$$\bar{C}_i^V(r,\theta) = \kappa_L^V C_i^V(r,\theta) + \kappa_R^V \sum_{m=1}^{N} \sum_{k=1}^{16} w_{m,k} C_i^V(r_m,\theta_k)$$

$$\bar{C}_i^M(r,\theta) = \kappa_L^M C_i^M(r,\theta) + \kappa_R^M \sum_{m=1}^{N} \sum_{k=1}^{16} w_{m,k} C_i^M(r_m,\theta_k)$$

$$\bar{C}_i^F(r,\theta) = \kappa_L^F C_i^F(r,\theta) + \kappa_R^F \sum_{m=1}^{N} \sum_{k=1}^{16} w_{m,k} C_i^F(r_m,\theta_k)$$

$$\bar{C}_i^L(r,\theta) = \kappa_L^V C_i^L(r,\theta) + \kappa_R^V \sum_{m=1}^{N} \sum_{k=1}^{16} w_{m,k} C_i^L(r_m,\theta_k)$$

AGRICULTURAL FRACTIONS

For population type runs (weighted by area): $w_{m,k} = \frac{1}{16}\frac{(r_m^2 - r_{m-1}^2)}{(r_N^2 - r_0^2)}$

For individual type runs (unweighted): $w_{m,k} = \frac{1}{16 \times N}$

- κ_L^V is the fraction of vegetables grown locally
- κ_R^V is the fraction of vegetables grown regionally in the assessment area
- κ_L^M is the fraction of milk produced locally
- κ_R^M is the fraction of milk produced regionally in the assessment area
- κ_L^F is the fraction of meat produced locally
- κ_R^F is the fraction of meat produced regionally in the assessment area

Calculation of Dose and Risk to a Receptor

1. Calculate χ/Q values in each sector
2. Calculate air concentrations in each sector
3. Calculate deposition rates in each sector
4. Calculate ground concentrations in each sector
5. Calculate concentrations in vegetables, milk, and meat produced in each sector
6. Calculate concentrations in vegetables, milk, and meat ingested by a receptor in each sector
7. Calculate dose and risk to a receptor in each sector

TOTAL DOSE RATE

$$D_{j,a}^{T}(r,\theta) = D_j^X(r,\theta) + D_j^G(r,\theta) + D_{j,a}^A(r,\theta) + D_{j,a}^D(r,\theta)$$

- $D_j^X(r,\theta)$ is the external air immersion dose rate the jth organ of a receptor in sector θ at distance r
- $D_j^G(r,\theta)$ is the external ground surface dose rate the jth organ of a receptor in sector θ at distance r
- $D_{j,a}^A(r,\theta)$ is the internal dose rate the jth organ of a receptor in age group a in sector θ at distance r from inhalation
- $D_{j,a}^D(r,\theta)$is the internal dose rate the jth organ of a receptor in age group a in sector θ at distance r from ingestion

External Dose from Direct Exposure to Activity in the Air (Immersion)

- $\mathrm{DFX}_{i,j}$ is the air immersion dose factor for the jth organ for the ith radionuclide
- $\chi_i(r, \theta)$ is the air concentration of the ith radionuclide

External Dose from Ground Surface

1. Calculate χ/Q values in each sector
2. Calculate air concentrations in each sector
3. Calculate deposition rates in each sector
4. Calculate ground concentrations in each sector
5. Calculate concentrations in vegetables, milk, and meat produced in each sector
6. Calculate concentrations in vegetables, milk, and meat ingested by a receptor in each sector
7. Calculate dose and risk to a receptor in each sector

- S_F is the attenuation factor accounting for shielding provided by residential structures
- $\mathrm{DFG}_{i,j}$ is the ground surface dose factor for the jth organ for the ith radionuclide
- $C_i^G(r,\theta)$ is the ground concentration of the ith radionuclide

Parameter	Value
y is the crosswi	0.5

Internal Dose from Inhalation

z is the distance above the ground

- R_a is the breathing rate of age group a
- $\mathrm{DFA}_{i,j,a}$ is the dose conversion factor for the inhalation of the ith radionuclide, for the jth organ for age group a
- $\chi_i(r, \theta)$ is the annual average ground-level concentration of the ith radionuclide in air in sector θ at distance r

Parameter	Adult	15-Year-Old	10-Year-Old	5-Year-Old	1-Year-Old	Infant
R_a ($m^3\ y^{-1}$)	5,260	5,570	3,730	2,680	1,810	1,370

INTERNAL DOSE FROM INGESTION

$\sigma_y(x)$ is the horizontal dispersion coefficient

- $\mathrm{DFI}_{i,j,a}$ is the DCF for the ingestion of the ith radionuclide, the jth organ, & age group a
- $\bar{C}_i^V(r,\theta)$ is the concentration of the ith radionuclide in non-leafy vegetables
- $\bar{C}_i^M(r,\theta)$ is the concentration of the ith radionuclide in milk
- $\bar{C}_i^F(r,\theta)$ is the concentration of the ith radionuclide in meat
- $\bar{C}_i^L(r,\theta)$is the concentration of the ith radionuclide in leafy vegetables
- U_a^V is the ingestion rate of non-leafy vegetables, fruit, and grains in age group a
- U_a^M is the ingestion rate of milk for individuals in age group a
- U_a^F is the ingestion rate of meat for individuals in age group a
- U_a^L is the ingestion rate of leafy vegetables for individuals in age group a
- f_g is the fraction of produce ingested grown in garden of interest
- f_L is the fraction of leafy vegetables grown in the garden of interest

Ingestion Dose Rate Parameters

Parameter	Adult	15-Year-Old	10-Year-Old	5-Year-Old	1-Year-Old	Infant
U_a^V	76.2	60.8	46.3	39.0	29.9	25.4
U_a^M	53	90	113	120	173	132
U_a^F	84	77	64	44	33	26
U_a^L	7.79	6.22	4.73	3.99	3.06	2.60

Parameter	Value
$F = 3.7$	1.00
	1.00

Population Dose

$$\text{Population Dose} = \sum_{m=1}^{N} \sum_{k=1}^{16} P_a(r,\theta) \times D_{j,a}^{T}(r,\theta)$$

- $P_a(r,\theta)$ is the population of age group a in sector θ at distance r

Total Risk

$$R_{j,a}^{T}(r,\theta) = R_{j}^{X}(r,\theta) + R_{j}^{G}(r,\theta) + R_{j,a}^{A}(r,\theta) + R_{j,a}^{D}(r,\theta)$$

$R_{j}^{X}(r,\theta)$ is the external air immersion risk to the jth organ of a receptor

$R_{j}^{G}(r,\theta)$ is the external ground surface risk to the jth organ of a receptor

$R_{j,a}^{A}(r,\theta)$ is the internal risk to the jth organ of a receptor in age group a

$R_{j,a}^{D}(r,\theta)$is the internal risk to the jth organ of a receptor in age group

External Risk from Direct Exposure to Activity in the Air (Immersion)

$$R_j^X(r,\theta) = \sum_i \mathrm{RFX}_{i,j} \times \chi_i(r,\theta)$$

- $\mathrm{RFX}_{i,j}$ is the air immersion risk conversion factor for the jth organ for the ith radionuclide (same for all age groups)
- $\chi_i(r,\theta)$ is the air concentration of the ith radionuclide

External Risk from Ground Surface

$$R_j^G(r,\theta) = S_F \sum_i \mathrm{RFG}_{i,j} \times C_i^G(r,\theta)$$

- S_F is the attenuation factor accounting for shielding provided by residential structures
- $\mathrm{RFG}_{i,j}$ is the ground surface risk conversion factor for the jth organ for the ith radionuclide
- $C_i^G(r,\theta)$ is the ground concentration of the ith radionuclide

Parameter	Value
S_F	0.5

INTERNAL RISK FROM INHALATION

$$R^A_{j,a}(r,\theta) = R_a \sum_i \mathrm{RFA}_{i,j,a} \times \chi_i(r,\theta)$$

- R_a is the breathing rate of age group a
- $\mathrm{RFA}_{i,j,a}$ is the risk conversion factor for the inhalation of the ith radionuclide, for the jth organ for age group a
- $\chi_i(r,\theta)$ is the annual average ground-level concentration of the ith radionuclide in air in sector θ at distance r

Parameter	Adult	15-Year-Old	10-Year-Old	5-Year-Old	1-Year-Old	Infant
R_a ($m^3\ y^{-1}$)	5,260	5,570	3,730	2,680	1,810	1,370

Internal Risk from Ingestion

$$R_{j,a}^{D}(r,\theta) = \sum_{i} \mathrm{RFI}_{i,j,a}\left[f_g U_a^V \bar{C}_i^V(r,\theta) + U_a^M \bar{C}_i^M(r,\theta) + U_a^F \bar{C}_i^F(r,\theta) + f_L U_a^L \bar{C}_i^L(r,\theta)\right]$$

- $\mathrm{RFI}_{i,j,a}$ is the RCF for the ingestion of the ith radionuclide, the jth organ, & age group a
- $\bar{C}_i^V(r,\theta)$ is the concentration of the ith radionuclide in non-leafy vegetables
- $\bar{C}_i^M(r,\theta)$ is the concentration of the ith radionuclide in milk
- $\bar{C}_i^F(r,\theta)$ is the concentration of the ith radionuclide in meat
- $\bar{C}_i^L(r,\theta)$is the concentration of the ith radionuclide in leafy vegetables
- U_a^V is the ingestion rate of non-leafy vegetables, fruit, and grains in age group a
- U_a^M is the ingestion rate of milk for individuals in age group a
- U_a^F is the ingestion rate of meat for individuals in age group a
- U_a^L is the ingestion rate of leafy vegetables for individuals in age group a
- f_g is the fraction of produce ingested grown in garden of interest
- f_L is the fraction of leafy vegetables grown in the garden of interest