MILDOS

Version 4.21

Bruce Biwer
Sunita Kamboj
David LePoire
Argonne National Laboratory

2021 Spring RAMP Users Group Virtual Meeting
April 14, 2021

Overview

- **MILDOS**
  - Program scope
  - Uranium reserves and mining / milling
  - MILDOS development and basis
- **Models and Methodology**
  - Receptor options
  - Radionuclides, source types, and source terms
  - Air dispersion, ground concentrations, and resuspension
  - Media concentrations
  - Exposure calculations
- **Sensitivity Analysis**
- **Results Analysis / Output Options**
- **Specialized Input**
  - Meteorological data input
  - Map usage
- **ISR Example**

MILDOS

Computer code

- Based on U.S. Nuclear Regulatory Commission (NRC) guidance

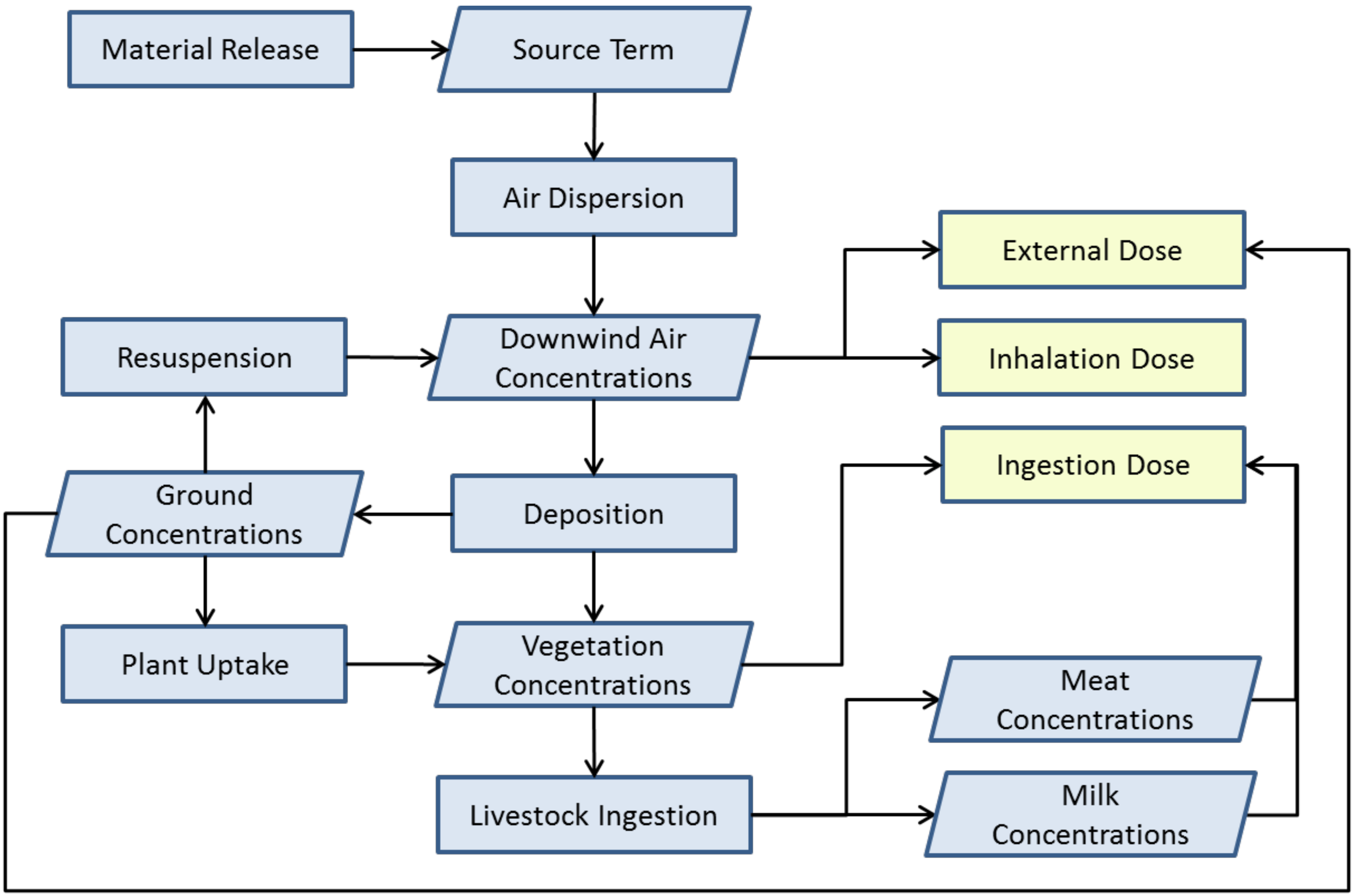
Licensing tool

- Applicants and licensees
- NRC staff

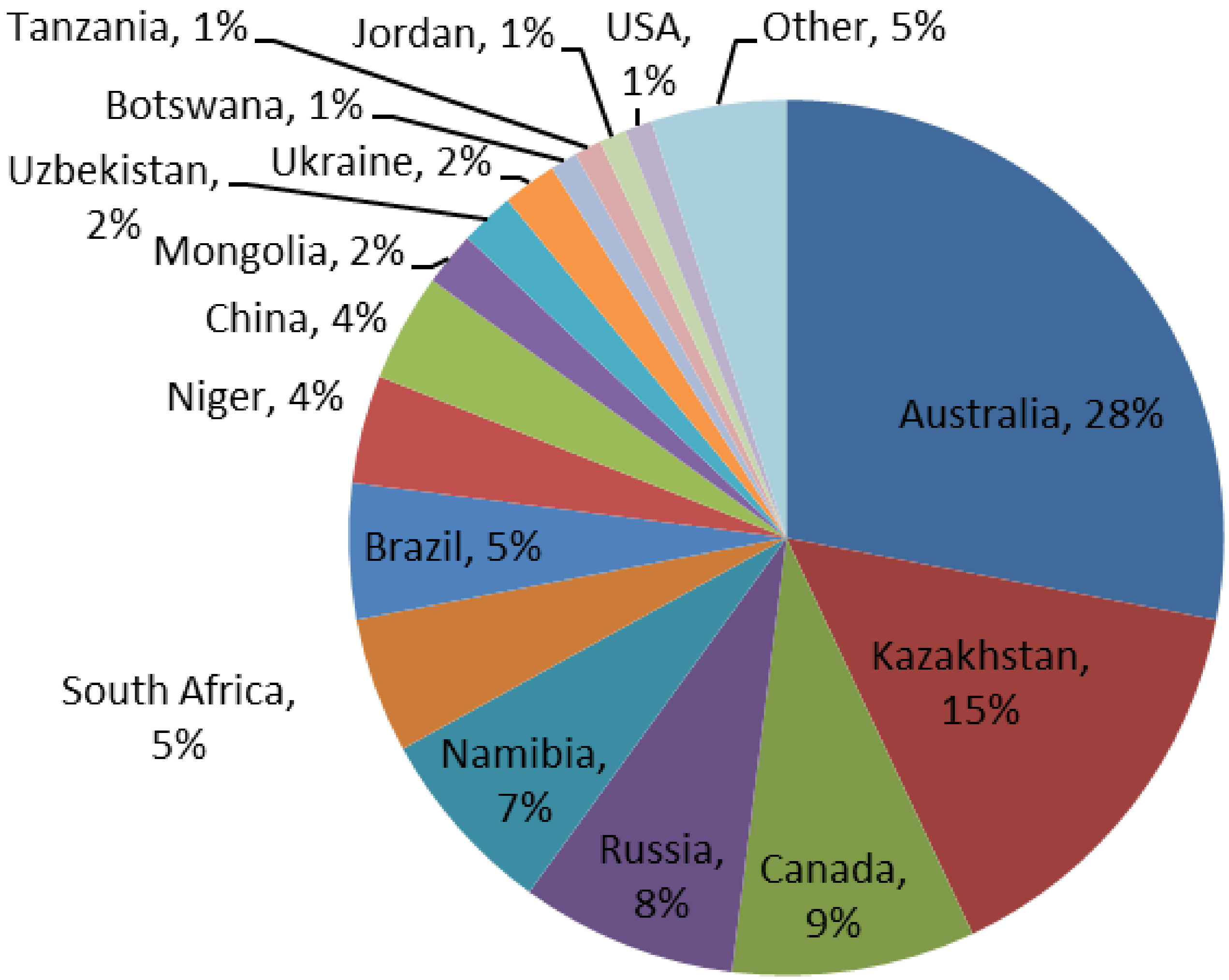
Program Scope

- **Impact estimation from radioactive emissions from uranium milling facilities (traditional ore and in-situ recovery)**
  - Dose commitments to individuals and regional population
  - Air, ground, and food concentrations
  - Different processes occur at different times in the facility's operational lifetime
    - For example: well drilling, operations, storage, restoration
- **Only radioactive emissions from airborne release**
  - Uses sector averaged plume model
  - Includes deposition, resuspension, accumulation, weathering, decay & ingrowth
  - No release to surface water or groundwater
- **Exposure pathways include**
  - External from groundshine and cloudshine
  - Inhalation
  - Ingestion of meat, milk, and vegetables

Exposure Pathways

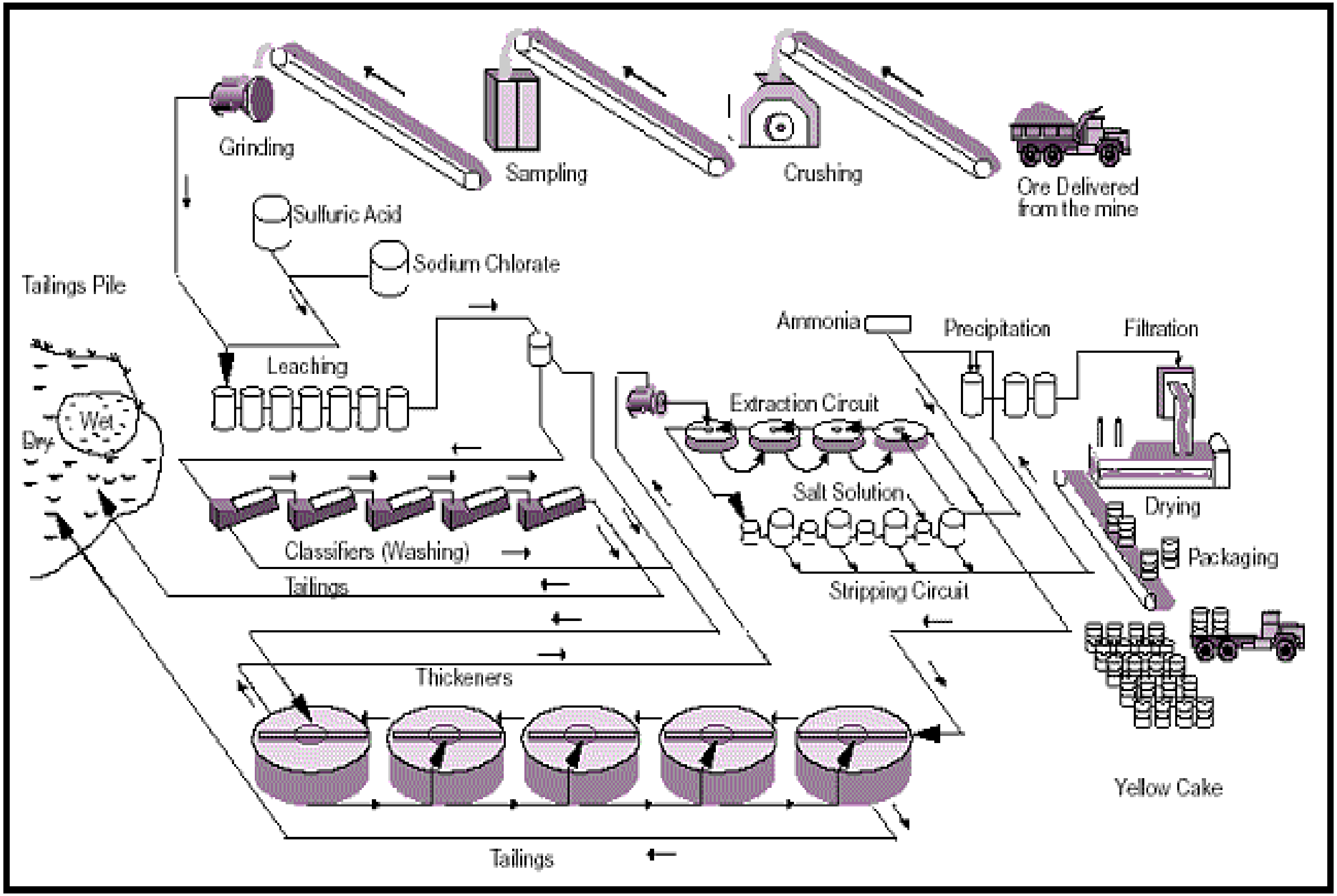


Uranium Resources, 2019



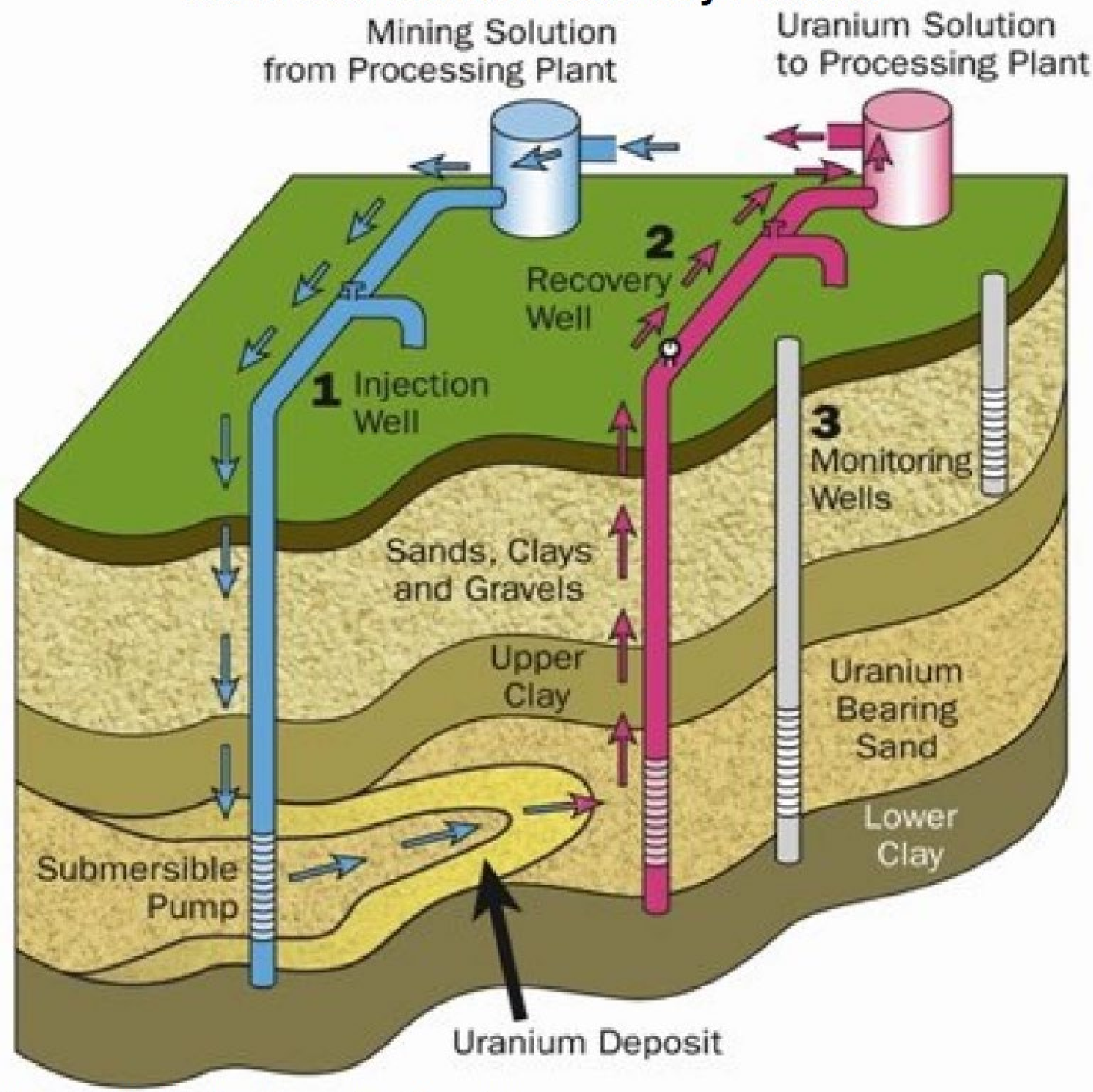
https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/uranium-resources/supply-of-uranium.aspx

Conventional Uranium Ore Milling Process



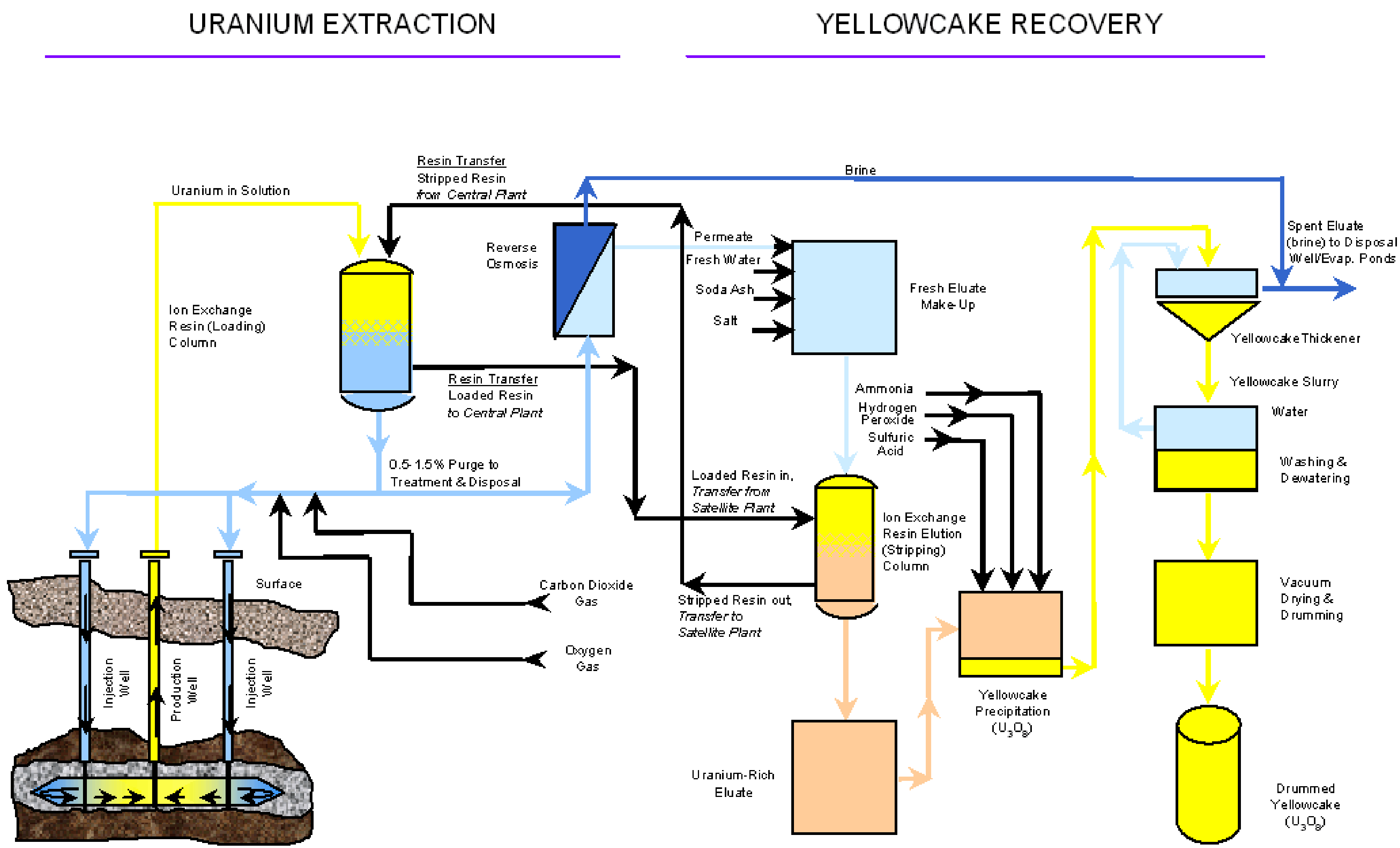
In Situ Recovery

The In Situ Uranium Recovery Process



Source: U.S. Nuclear Regulatory Commision.

In Situ Recovery (cont.)



MILDOS Development

- 1979: UDAD (Uranium Dispersion and Dosimetry)
- 1981: MILDOS
- 1989: MILDOS-AREA to include large-area sources and changes in dosimetry methodologies
- 1997/8: MILDOS-AREA 3.0X to include ISL specific sources, update interface to Windows, and update results for regulations
- 2012: MILDOS-AREA 3.10 – refinement of interface, bug fixes, update interface to work with new Windows operating systems
- 2016 : MILDOS-AREA 4.0 – Windows 7 to 10, rewrite of code with integration of conventional and ISR mining/milling, Th-232 series nuclides added
- 2016 (September): MILDOS-AREA 4.01 – Maintenance release: GUI upgrades, GIS module update, runtime speed improvements, bug fixes
- 2018 (April): MILDOS-AREA 4.02 – Maintenance release: 64-bit application, re-project raster map data, intermediate output (Rn-222 eq. fractions)

MILDOS Development (cont.)

- 2019 (April) : MILDOS 4.1 – Revised ISR models (well fields treated as area sources; purge and ion exchange treated as separate point sources). Shielding/infiltration factor added individual receptor indoor inhalation exposure. Users are now able to modify food transfer factors as well as particulate deposition velocities and densities. Users can specify custom output tables in a variety of formats to review and summarize results
- 2020 (April): MILDOS 4.2 – An 80-km population wheel generator is now available in MILDOS4 based on U.S. Census estimates. The custom output table interface was augmented to allow users to also specify custom output graphs in a variety of formats (column, scatter, and radar) to review results
- 2020 (September): MILDOS 4.21 – Parallel programming algorithms added to speed some calculations. Standard report generation at the end of runs that include population calculations is now faster due to a separate upgrade

NRC Reference Materials

- **Regulatory Guides**
  - 3.46 – Standard Format and Content of License Applications, including Environmental Reports, for In Situ Uranium Solution Mining (1982)
  - 3.51 – Calculational Models for Estimating Radiation Doses to Man from Airborne Radioactive Materials Resulting from Uranium Milling Operations (1982)
  - 3.59 – Methods for Estimating Radioactive and Toxic Airborne Source Terms for Uranium Milling Operations (1987)
  - 4.14 – Radiological Effluent and Environmental Monitoring at Uranium Mills (1980)

- **Interim Staff Guidance**
  - DUWP-ISG-001, Evaluations of Uranium Recovery Facility Surveys of Radon and Radon Progeny in Air and Demonstrations of Compliance with 10 CFR 20.1301, Final Report (2019)

NRC Reference Materials (cont.)

- **Reports**
  - *Final Generic Environmental Impact Statement on Uranium Milling* [NUREG-0706 (1980)]
  - Standard Review Plan for In Situ Leach Uranium Extraction License Applications [NUREG-1569 (2003)]
  - *Compliance Determination Procedures for Environmental Radiation Protection Standards for Uranium Recovery Facilities 40 CFR Part 190* [NUREG-0859 (1982)]
  - *Consolidated Guidance: 10 CFR Part 20 – Standards for Protection Against Radiation* [NUREG-1736 (2001)]

Regulatory Guide 3.59

Methods for Estimating Radioactive and Toxic Airborne Source Terms for Uranium Milling Operations (1987)

- **Particle process emissions**
  - Ore handling and storage
  - Grinding and crushing
  - Yellowcake drying and packaging
- **Particle wind blown emissions**
  - Dusting (erosion) rate calculation
- **Radon emissions**
  - Ore storage
  - Crushing and grinding
  - Tailings
  - In situ leaching

Regulatory Guide 3.51

Calculational Models for Estimating Radiation Doses to Man from Airborne Radioactive Materials Resulting from Uranium Milling Operations (1982)

- **Recommended Dose Models**
  - Individual / Population
  - Inhalation, External (Ground / Air), Ingestion (Vegetables, Meat, Milk)

- **10 CFR 20 compliance (Standards for Protection Against Radiation)**
  - 10 CFR 20.1101(b): concept of as low as reasonably achievable (ALARA)
  - 10 CFR 20 1101(d): annual maximum of 10 mrem to member of the public from airborne releases (excluding Rn-222 and its daughters)
  - 10 CFR 20 1301(a)(1): annual maximum of 100 mrem to member of the public
  - 10 CFR 20 1302(b)(2)(i): compliance with above can be shown if effluent air and ground releases do not exceed the values specified in Table 2 of Appendix B to part 20 at the boundary of the unrestricted area and the external dose rate is less than 2 mrem per hour

Regulatory Guide 3.51(cont.)

- **40 CFR 190 compliance (Environmental Radiation Protection Standards for Nuclear Power Operations)**
  - Annual dose equivalent of 25 mrem to whole body, 75 mrem to thyroid, 25 mrem to any other organ
  - Excludes emission of radon and daughters

Documentation

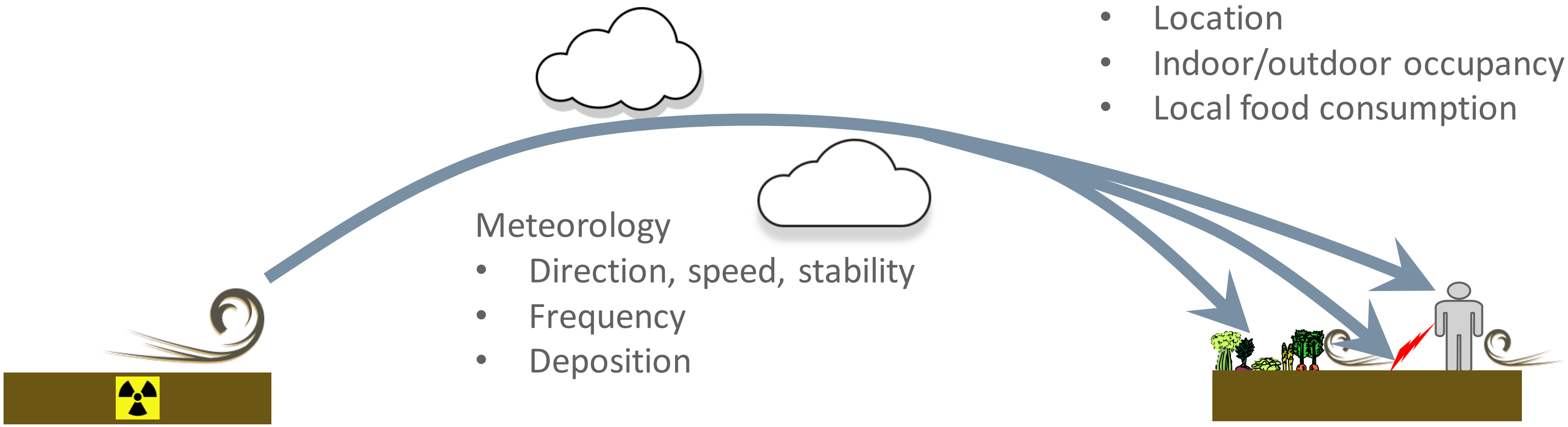
- 1979 – *Uranium Dispersion and Dosimetry (UDAD) Code* [NUREG/CR-0553]
- 1981 – *MILDOS – A Computer Program for Calculating Environmental Radiation Doses From Uranium Recovery Operations* [NUREG/CR-2011]
- *1984 - Methods for Estimating Radioactive and Toxic Airborne Source Terms for Uranium Milling Operations* [NUREG/CR-4088]
- 1989 – *MILDOS-AREA: An Enhanced Version of MILDOS for Large-Area Sources* [ANL/ES-161]
- 1997 – *MILDOS-AREA: An Update with Incorporation of In Situ Leach Uranium Recovery Technology* [NRC letter report; App. D in NUREG-1569]
- 2016 – *Technical Manual and User's Guide for MILDOS-AREA Version 4* [NUREG/CR-7212]
- 2016 – *MILDOS-AREA Version 4 Computational Verification Report* [NUREG/CR-7213]

Documentation (cont.)

- 2019 – *Technical Manual and User's Guide for MILDOS Version 4.1* [NUREG/CR-7258]
- 2019 – *MILDOS Version 4.1 Computational Verification Report* [NUREG/CR-7259]
- 2020 – MILDOS 4.21 Release Notes

Documents available at mildos.evs.anl.gov

Input Components



Receptor
- Location
- Indoor/outdoor occupancy
- Local food consumption

Meteorology
- Direction, speed, stability
- Frequency
- Deposition

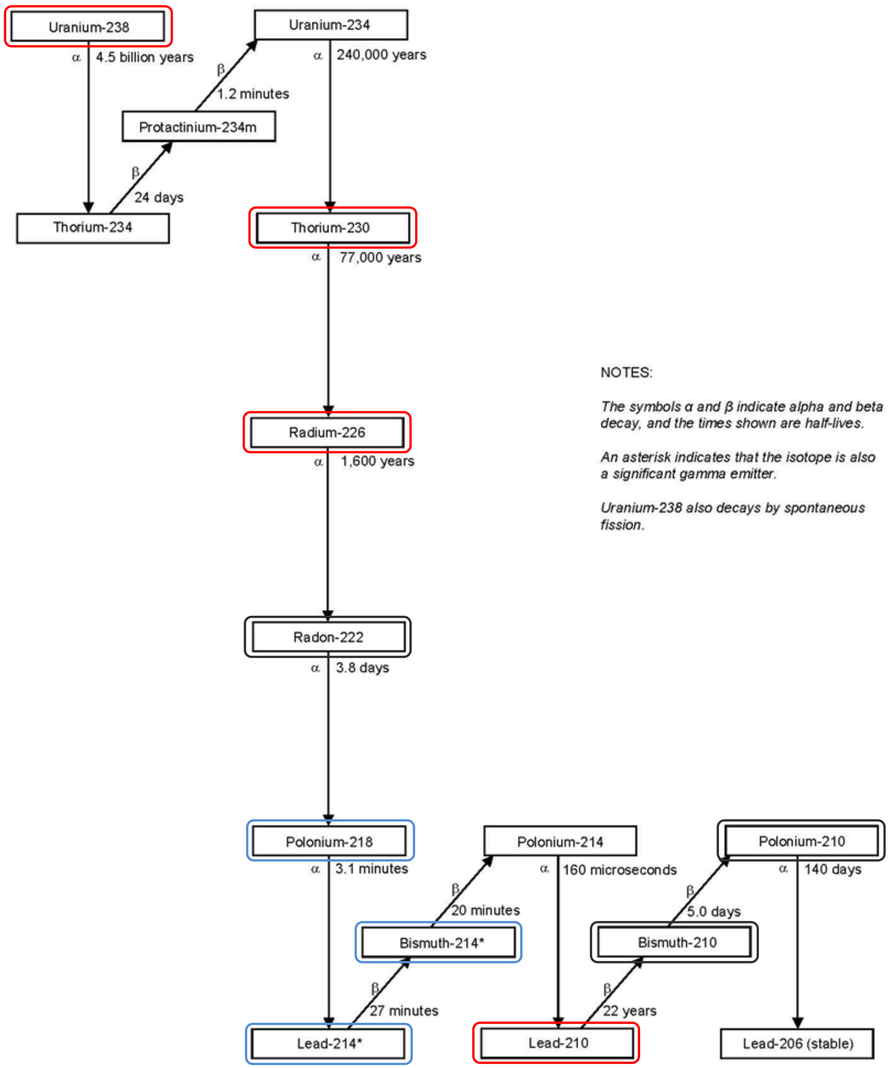
Source release
- Types
- Radon / Particulates Releases
- Particulate characterization
- Source time dependence

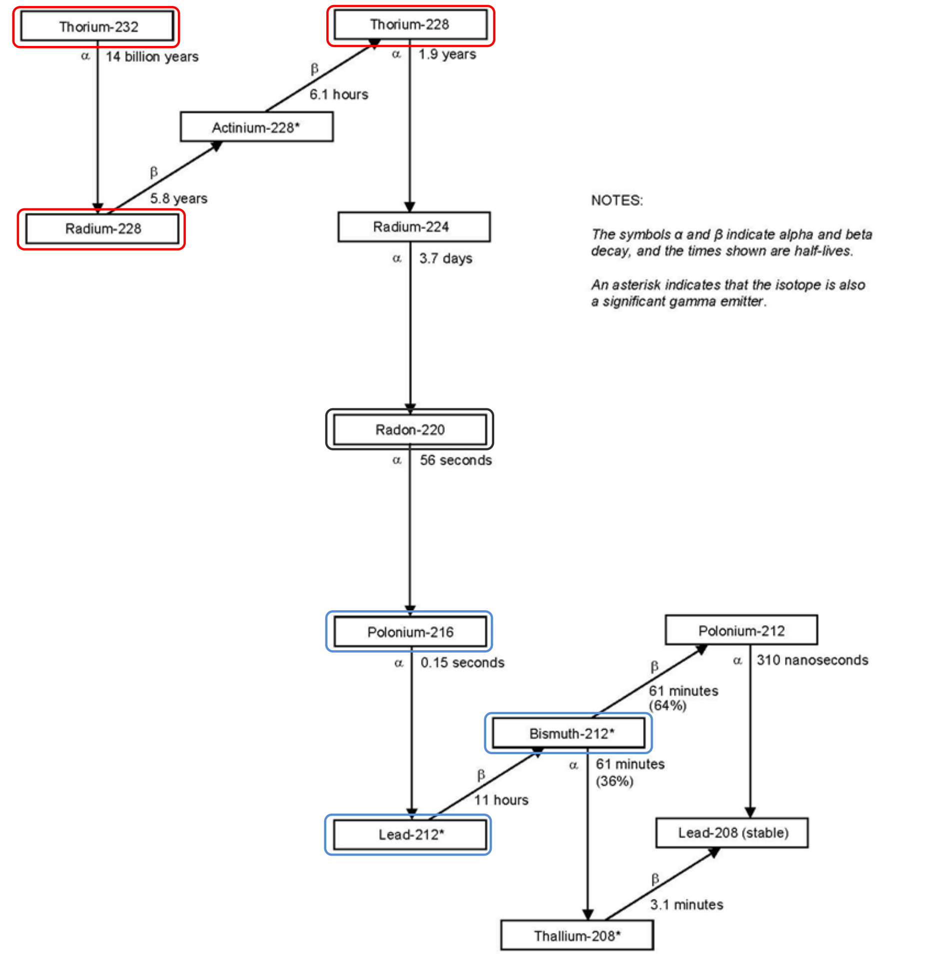
Land
- Food yield
- Weathering
- Resuspension

Receptor Options

- **Individual receptors**
  - Number of receptors not limited (constrained by available computer memory)
  - Age group (infant, child, teenager, adult)
  - Indoor and outdoor occupancy fractions
  - Vegetable, meat, and milk ingestion rates
- **Local Population (optional)**
  - 80-km grid / 16 directions / centered on 1st emission source
  - 12 segments in each direction between 1, 2, 3, 4, 5, 10, 20, 30, 40, 50, 60, 70, and 80 km
  - Fraction of population in each age group (for ingestion)

Radionuclides



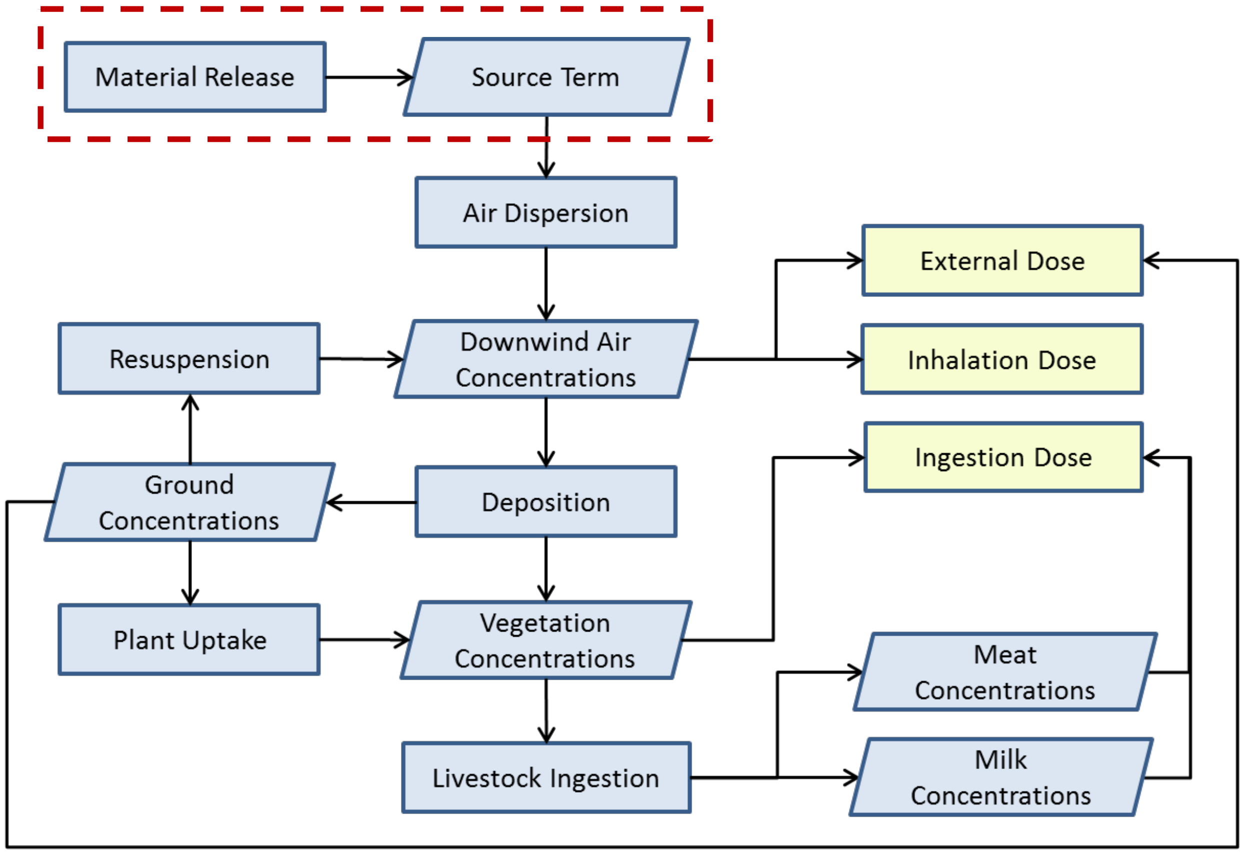


particulate source term; downwind air and ground concentrations (red box)

downwind air and ground concentrations (blue box)

downwind air concentrations (black box)

Sources



Material Release
Source Term
Air Dispersion
Downwind Air Concentrations
Resuspension
External Dose
Inhalation Dose
Ingestion Dose
Ground Concentrations
Deposition
Plant Uptake
Vegetation Concentrations
Meat Concentrations
Livestock Ingestion
Milk Concentrations

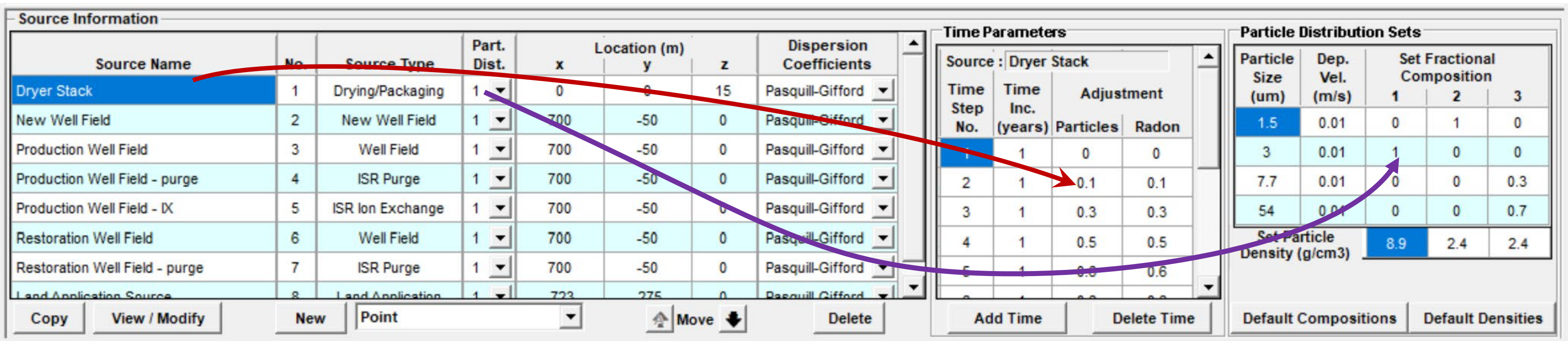
8 Named Source Types

- **Point source (1)**
  - Plume rise (momentum driven or buoyancy-induced)
- **Generic area source (2)**
  - Erosion model or user-specified release rates
  - Circle, rectangle, and polygon shape options
- **ISR New well field (area) (3)**
- **ISR Well field**
  - Vent; production or restoration well field (area) (4)
  - Purge or bleed (point) (5)
  - Ion exchange (point) (6)
- **Drying and packaging source (7)**
  - Plume rise (momentum driven or buoyancy-induced) (point)
- **Land application (area) (8)**

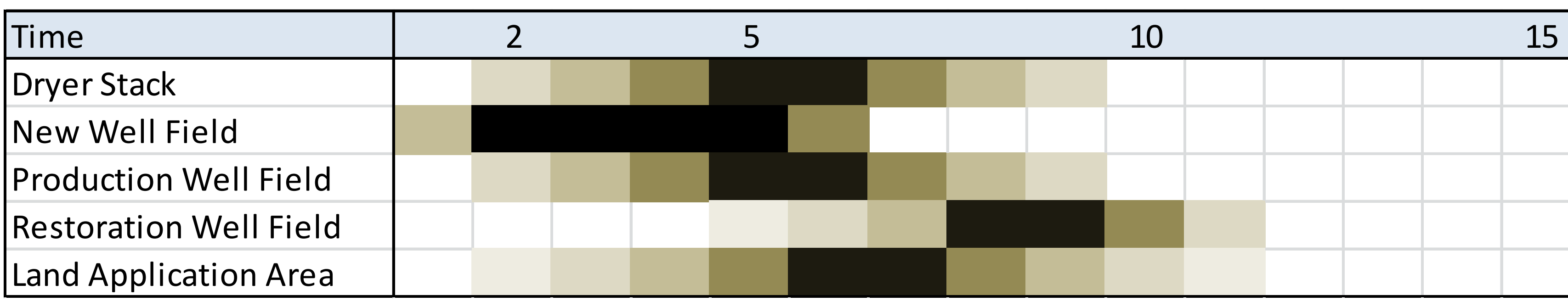
Source Characteristics - All Sources
(Main Program Window)

- Type, location, particulate size

Only 0.3 micron particles in Set 1

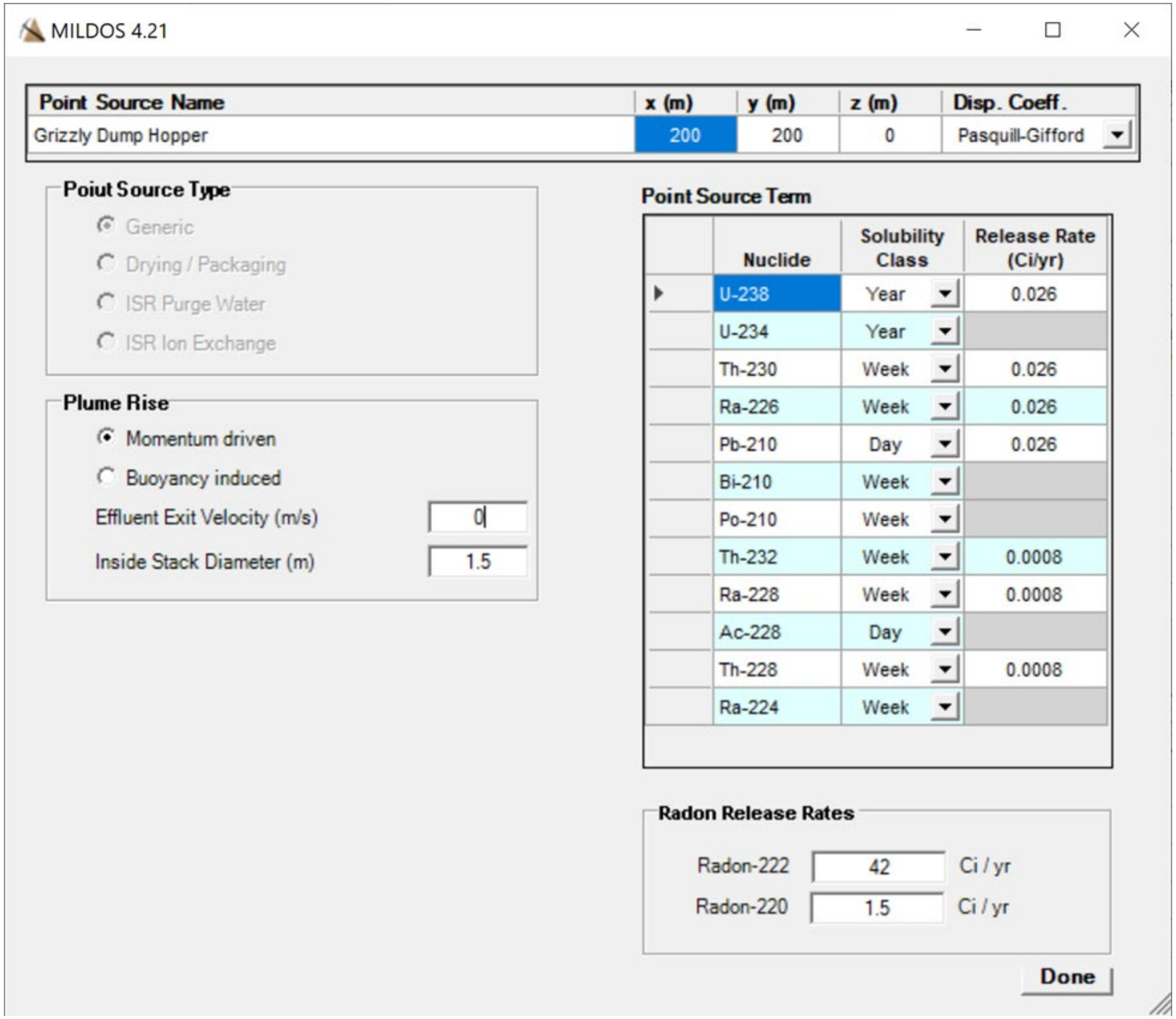


- And time dependence



Point Source

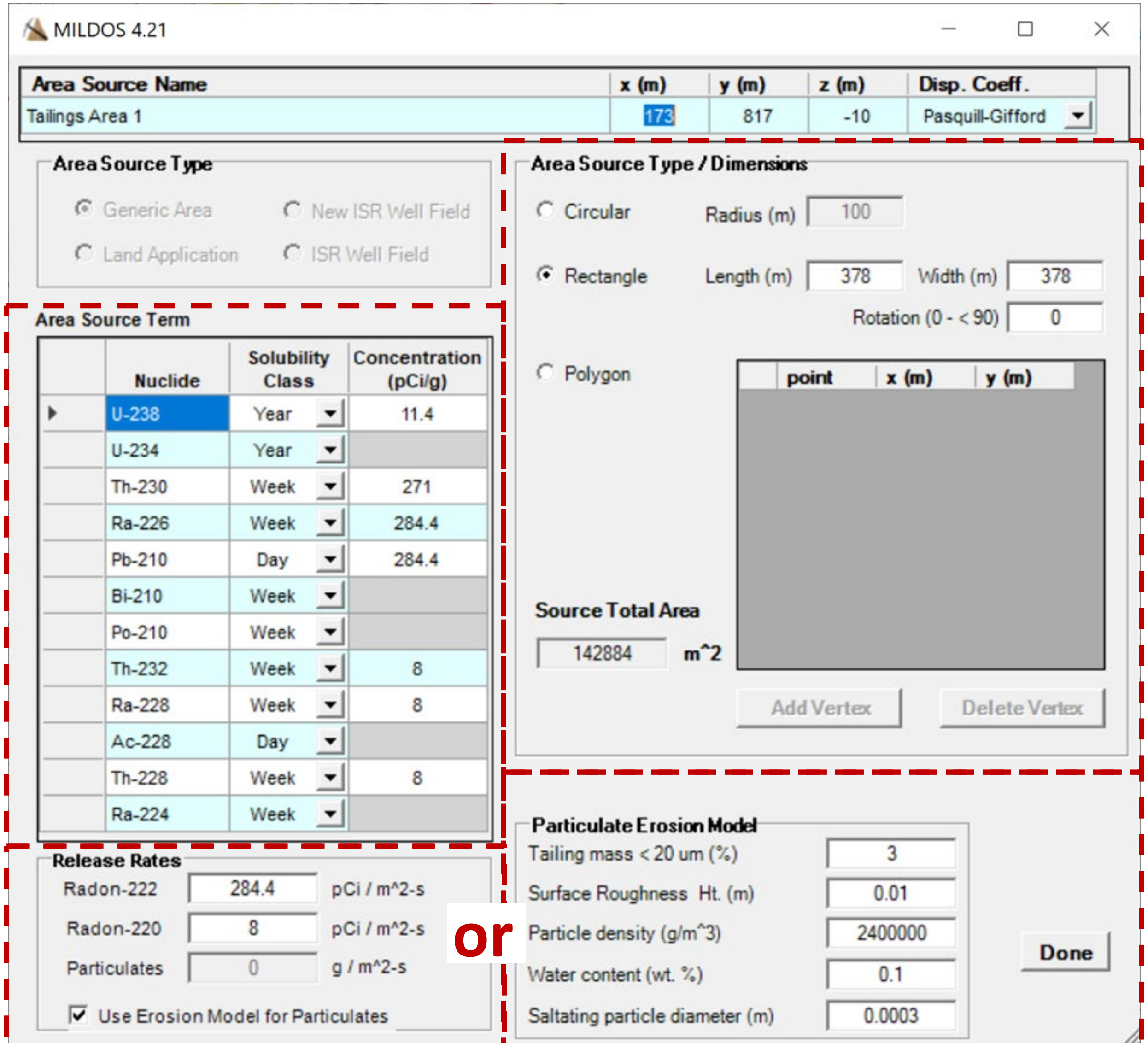
- Release rates
- Lung clearance classes
- Plume rise model
  - Momentum-driven
  - Buoyancy-induced



Area Source

Inventory

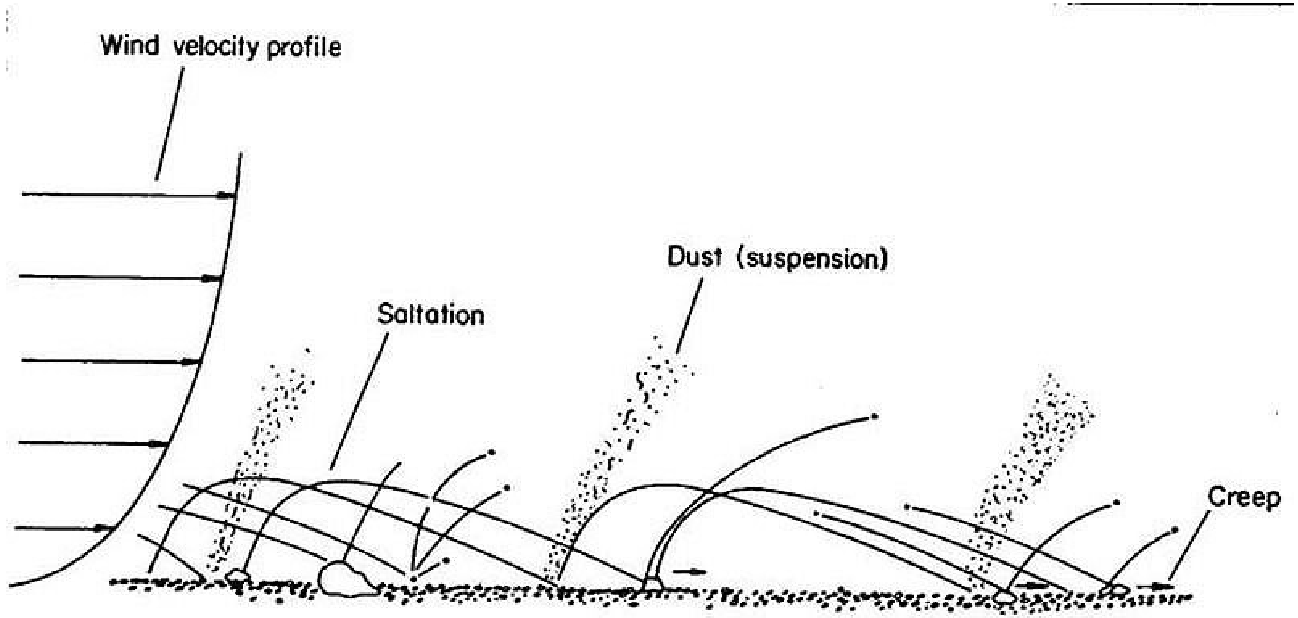
Release



Shape & Size

Erosion Model -- Particulate Release Rate

- Available for area sources only
- Based on saltation process
- Empirical (derivation in NUREG-0706, App. G)



In Situ Recovery

New Well Field Development

Well Fields

Drying and Packaging of Yellowcake

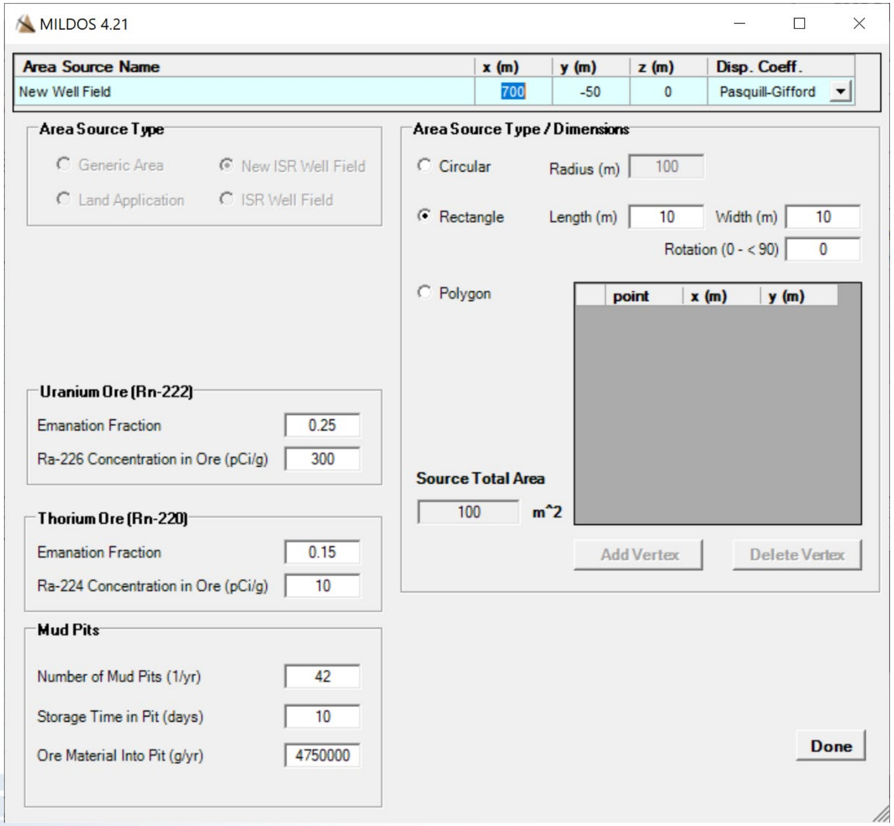
Purge/Bleed and Land Application

Ion Exchange

New Well Field

- **Particulates: No release**
  - During drilling, a bentonite slurry flows out of the drill head and through the borehole

- **Radon: released from the cuttings that are temporarily stored in the “mud” pits**
  - average mass of cutting that are temporarily stored in the slurry pits
    - Number of mud pits generated per year
    - Average mass of cutting in a mud pit
    - Storage time of cuttings in mud pit



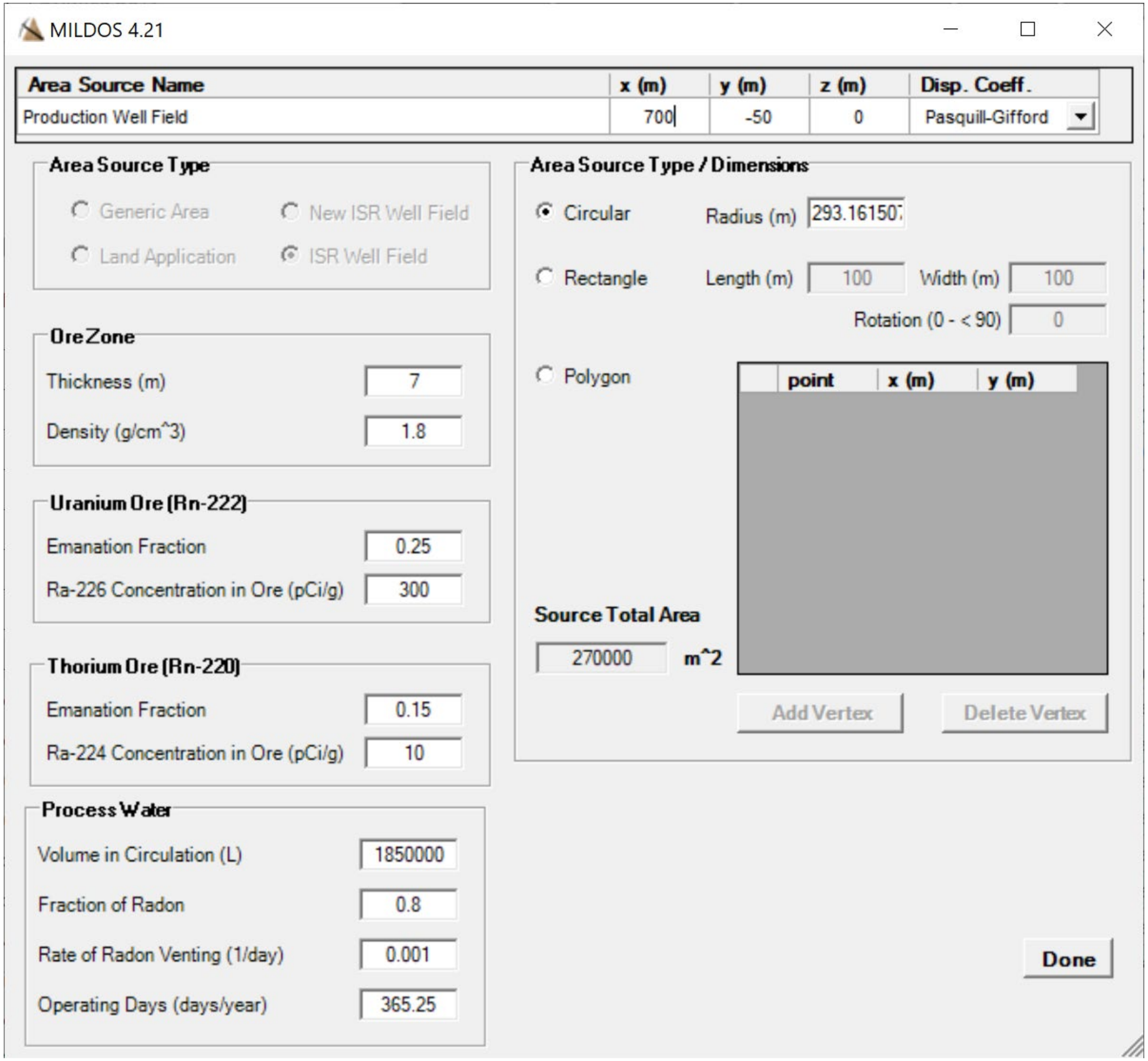
‘Production’ Well Field

- **Particulates: No release**
  - Closed loop from the production well through the ion exchange column to the injection well
- **Radon: Released from the ore body into the process water**
  - Radon circulates and builds up in the process water – released in 3 ways:
    - Purge: From process water that is purged
      - » Production well extracts more fluid than is pumped in through the injection well to maintain a cone of depression to prevent migration of mining solutions out of the ore in the production area
    - Resin Unloading: From the process water that is discharged during resin unloading from the ion exchange columns
    - Venting: From pipes and valves

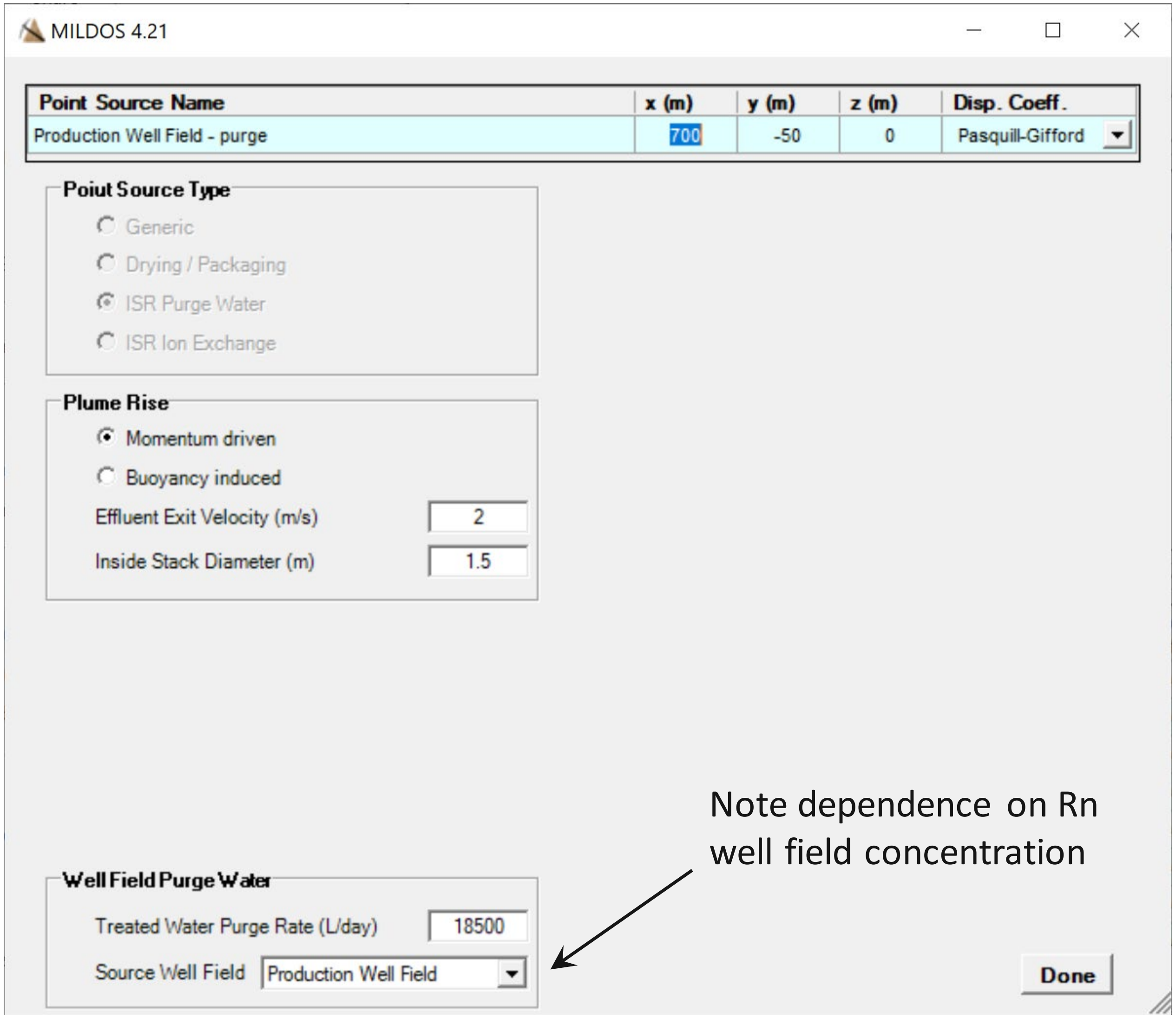
‘Restoration’ Well Field

- **Pump and treat with fresh water injection. Similar to production well.**
- **Particulates: No release**
  - There is a closed loop from the well through to the injection well
- **Radon: Released from the ore body into the process water**
  - Radon circulates and builds up in the process water – released in 2 ways:
    - Purge: From process water that is purged
      - » Well extracts more fluid than is pumped in through the injection well to maintain a cone of depression to prevent migration of mining solutions out of the ore in the production area
    - Venting: From pipes and valves

Well Field – vent (area source)

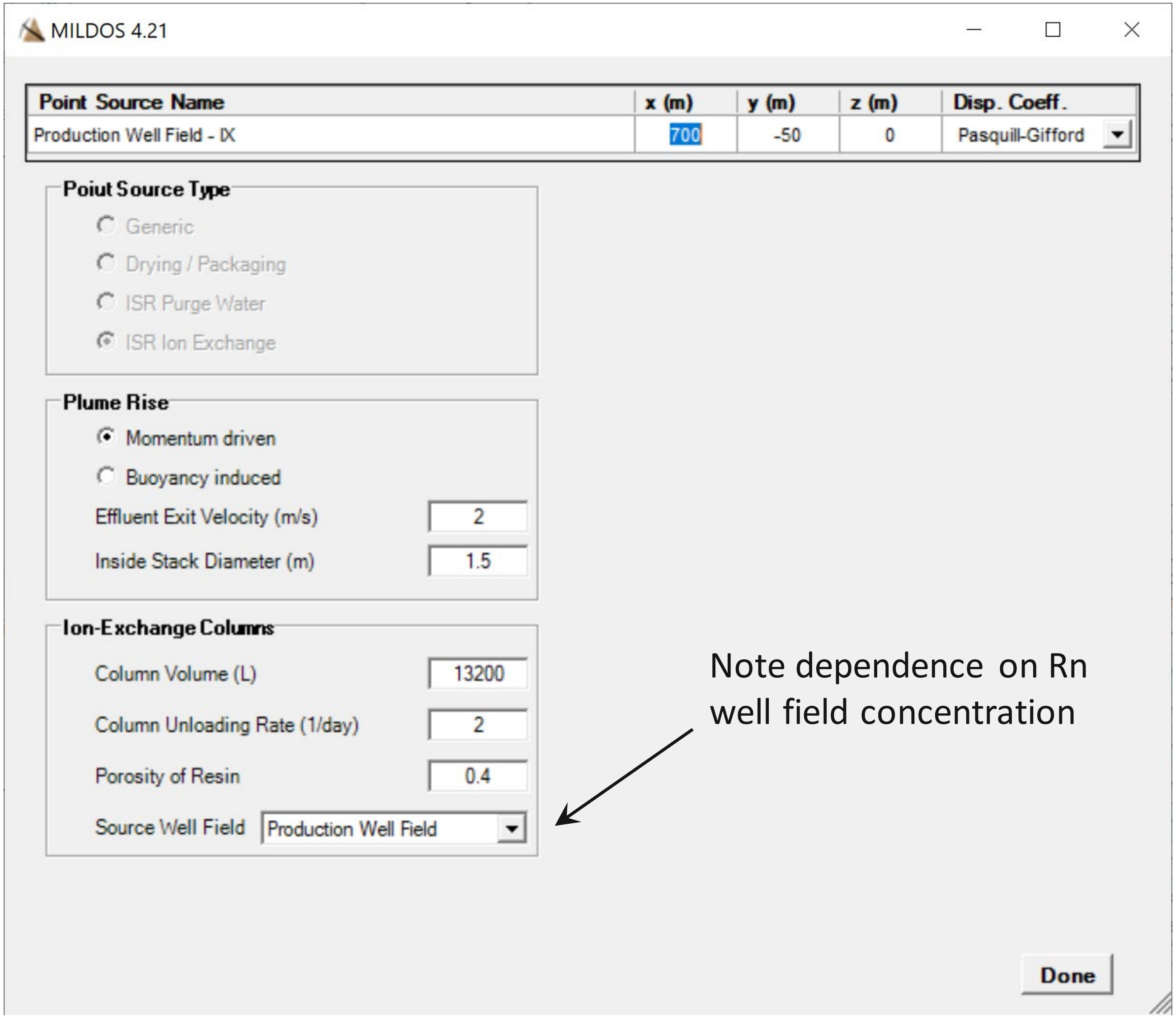


Well Field - purge (point source)



Note dependence on Rn well field concentration

Well Field – ion exchange (point source)

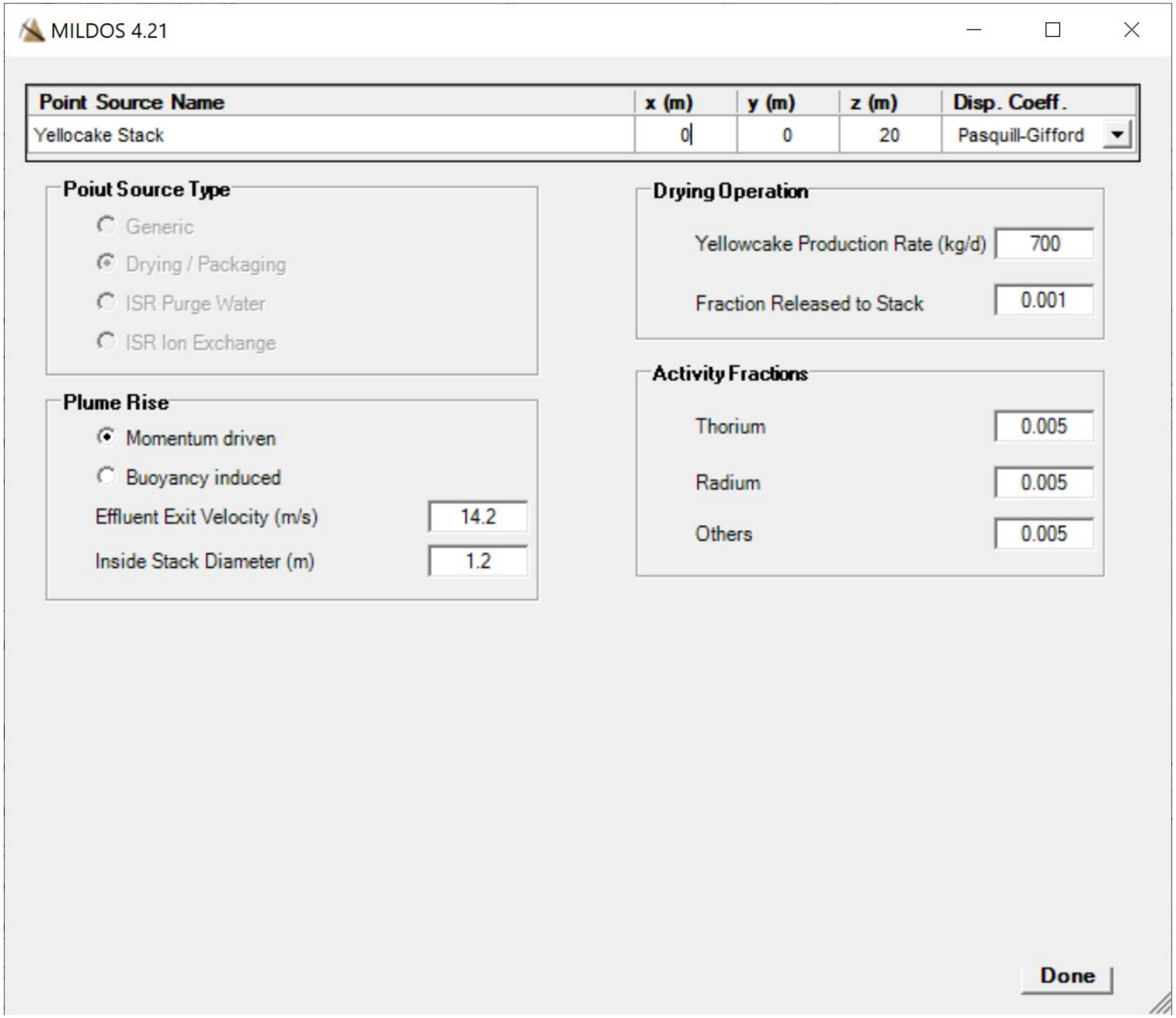


Note dependence on Rn well field concentration

Drying and Packaging

- **Particulates:**
  - Stack release from thermal dryers
    - Use a fraction of the production based on information from facilities that are operational
    - Progeny releases are a fraction of the uranium releases
  - No release from vacuum dryers under normal operating conditions
- **U-238 series only**
  - Purified yellowcake (no Rn or Th-series)

Drying and Packaging (cont.)

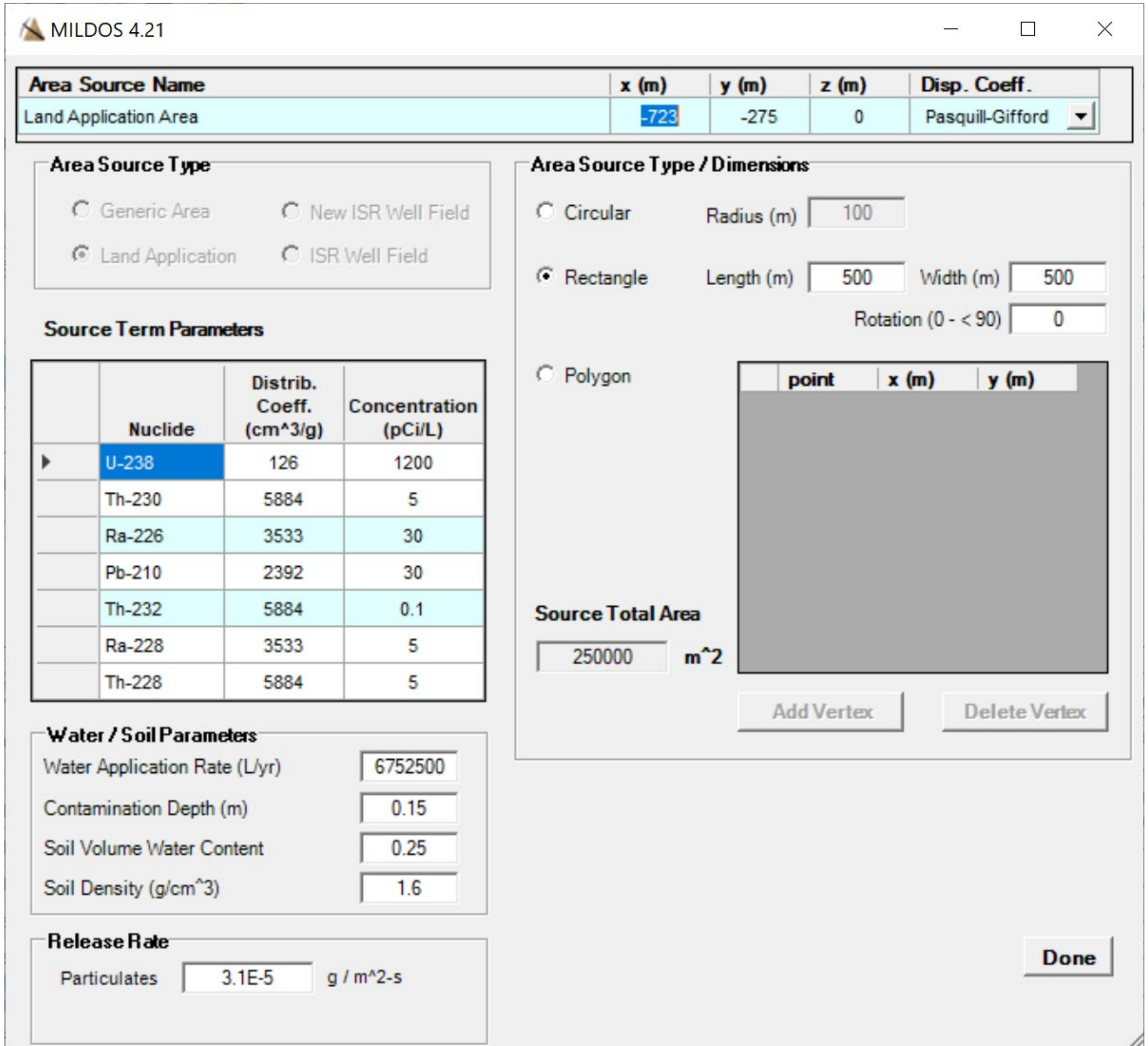


Land Application Area

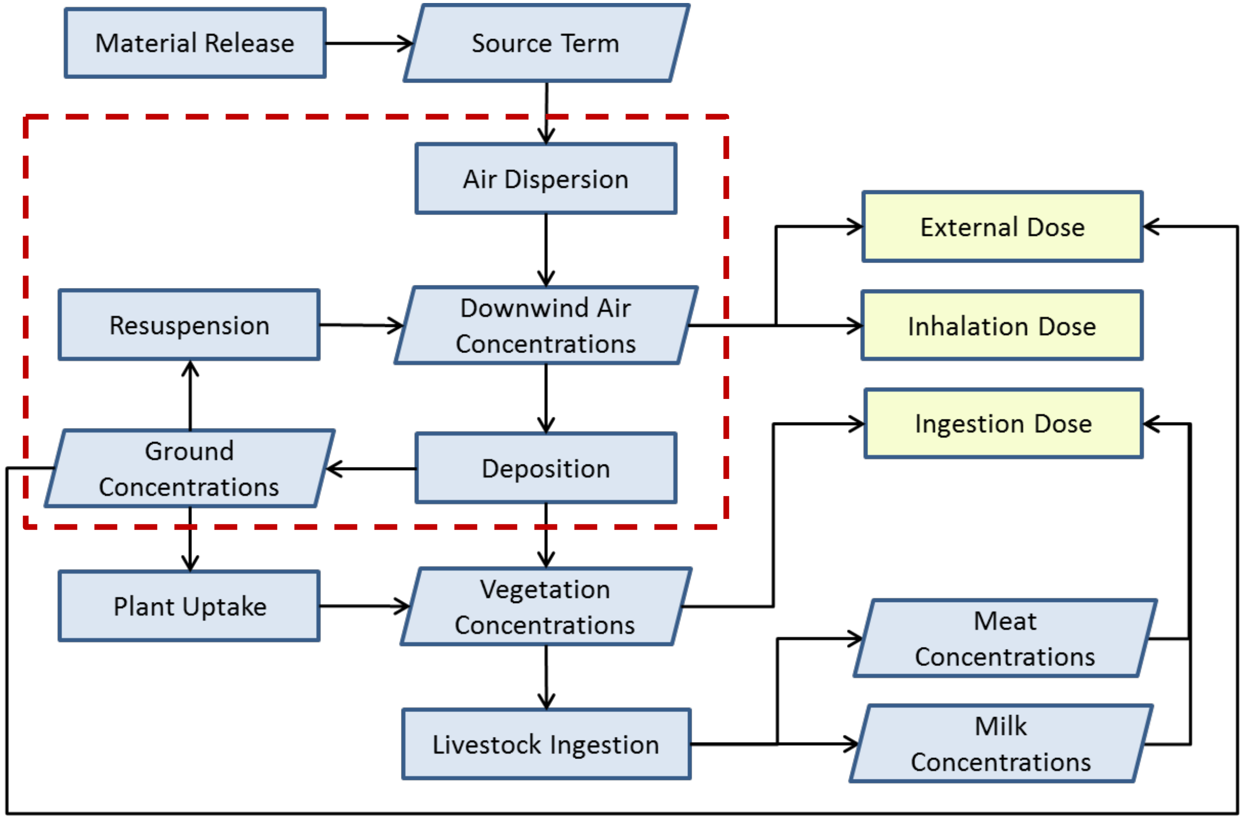
- **Release of particulates**
  - Surface soil is contaminated
    - Purge water from production wells and waste water from well field restoration are treated to unrestricted release levels and disposed of by irrigating the land

  - Uniform contamination over a specified depth
  - Equilibrium adsorption of nuclide between soil and the applied irrigation
  - Release from the area source

Land Application Area

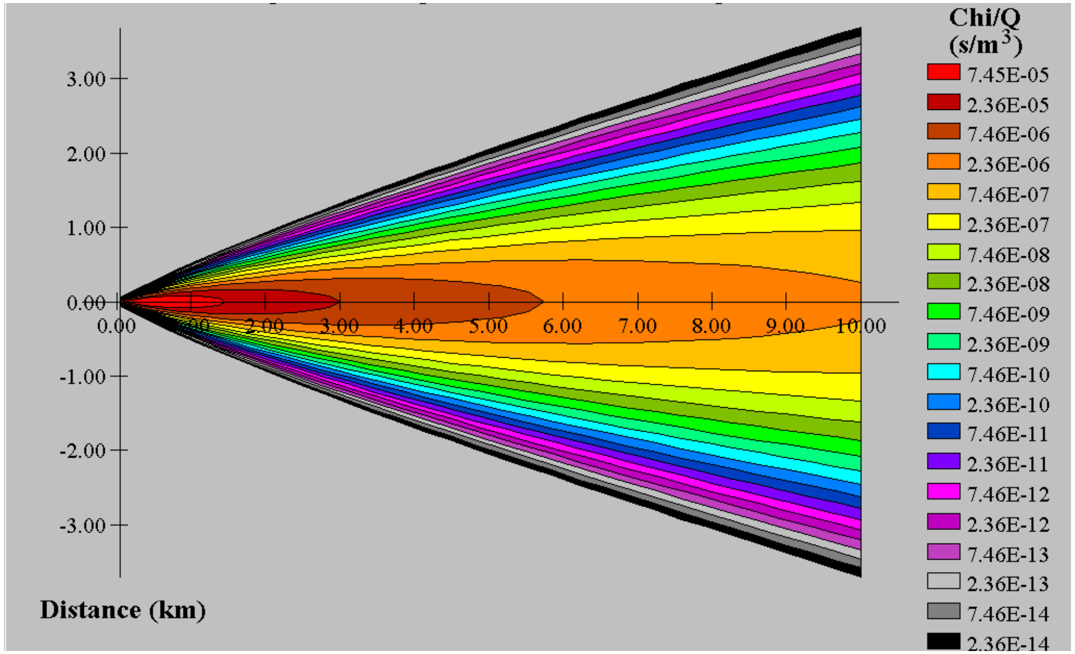


Downwind Air and Ground Concentrations



Air Dispersion Model

- **Chronic Gaussian plume area source**
  - Based on discrete puff point source
  - Sector average time-integrated air concentrations
  - Plume reflection
  - Integrate over source area
- **Effective release height**
  - Physical release height
  - Thermal and momentum plume rise
  - Vertical settling
  - Terrain height adjustment
  - Wind speed correction
- **Plume depletion**
  - Conservation of mass
  - Dry and wet deposition
- **Buoyancy induced dispersion**



Gaussian Puff Time-Dependent Dispersion

$$C_a(i,x,y,z,t)=\frac{Q_{x_i}}{(2\pi)^{3/2}\sigma_y^2\sigma_z}\exp\left(\frac{-r^2}{2\sigma_y^2}\right)\left[\exp\left(\frac{-(z-H)^2}{2\sigma_z^2}\right)+\exp\left(\frac{-(z+H)^2}{2\sigma_z^2}\right)\right]$$

$C_a(i,x,y,z,t)$	=	air concentration of radionuclide i at x,y,z from a release at $0,0,H$ at time t after release (Ci/m^3)
Q_{xi}	=	depleted source strength of nuclide i at distance x (Ci)
σ_y	=	horizontal dispersion coefficient (m)
σ_z	=	vertical dispersion coefficient (m)
r^2	=	$(x - u_H t)^2 + y^2$, assumes Gaussian symmetry, that is, $\sigma_x = \sigma_y$ (m^2)
x	=	downwind receptor distance from the release point (m)
y	=	crosswind distance from the plume centerline (m)
u_H	=	average wind speed at the effective release height (m/s)
t	=	time following release (s)
H	=	effective release height (m)

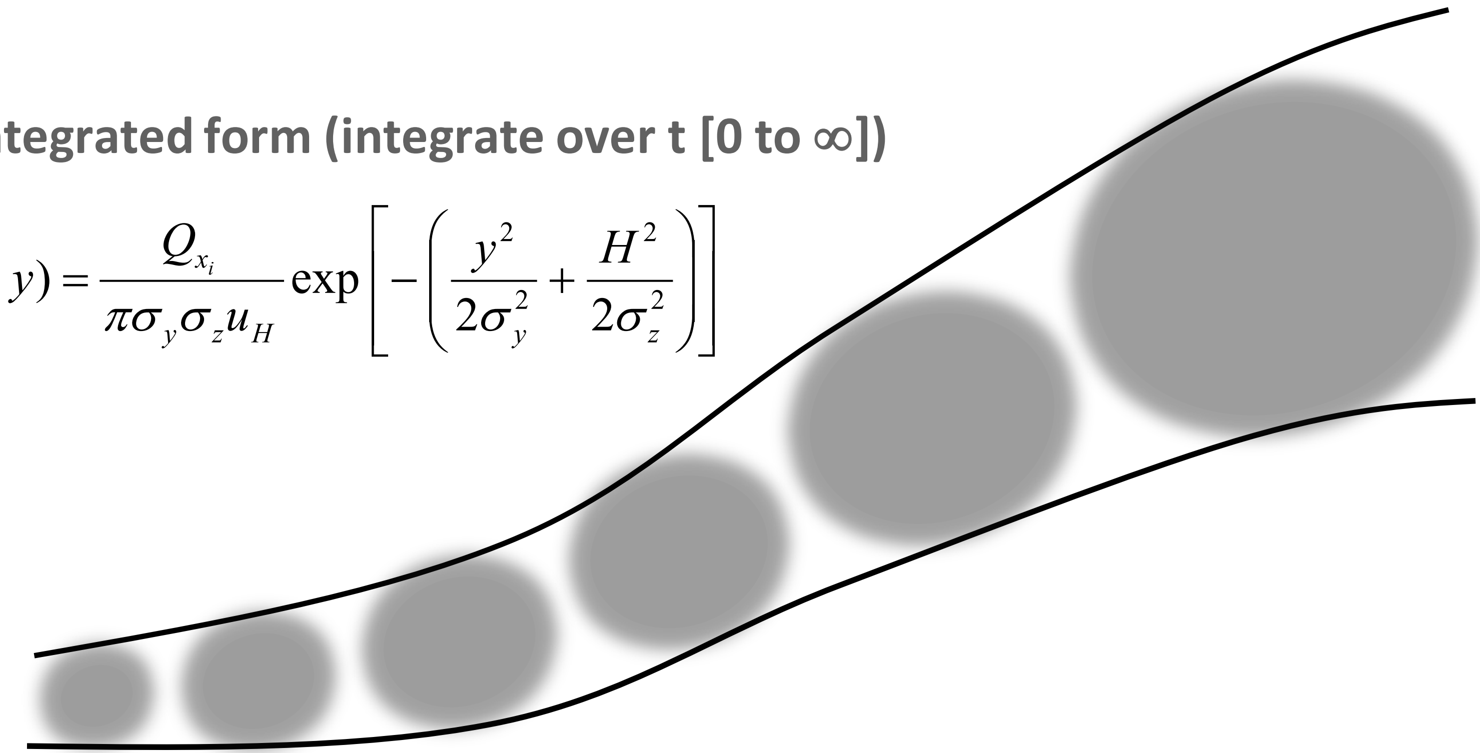
Continuous Point Source

- **Ground-level air concentrations (z = 0)**

$$C_a(i,x,y,0,t) = \frac{2Q_{x_i}}{(2\pi)^{3/2}\sigma_y^2\sigma_z}\left\{exp - \left(\frac{r^2}{2\sigma_y^2} + \frac{H^2}{2\sigma_z^2}\right)\right\}$$

- **Time-integrated form (integrate over t [0 to ∞])**

$$\overline{C}_a(i,x,y) = \frac{Q_{x_i}}{\pi\sigma_y\sigma_z u_H}\exp\left[-\left(\frac{y^2}{2\sigma_y^2} + \frac{H^2}{2\sigma_z^2}\right)\right]$$

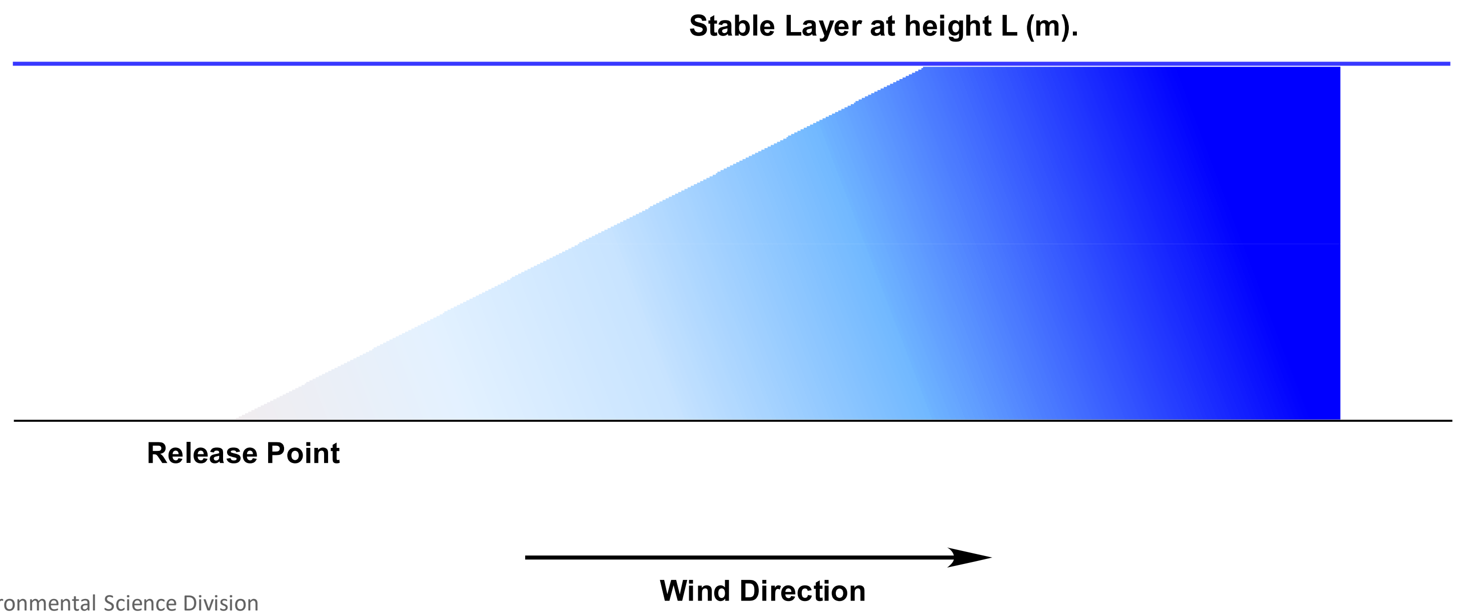


Plume Reflection

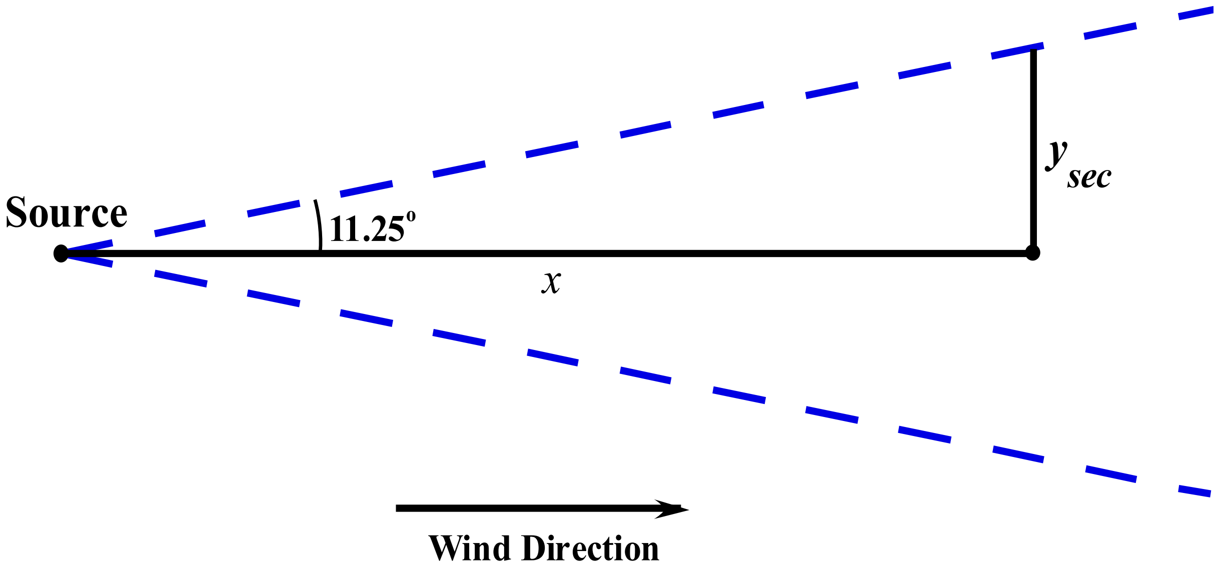
- **Plume may become confined by a stable layer (lid height; mixing layer height) (integrate over z [0 to L])**

$$\overline{C}_a(i,x,y) = \frac{Q_{x_i}}{\sqrt{2\pi}\sigma_y u_H L}\exp\left[-\left(\frac{y^2}{2\sigma_y^2}\right)\right]$$

- **Transition between non-mixing and total mixing equations taken from NUREG/CR-0523 (MESODIF-II)**



Chronic Point Source Air Concentrations (Integration over y)

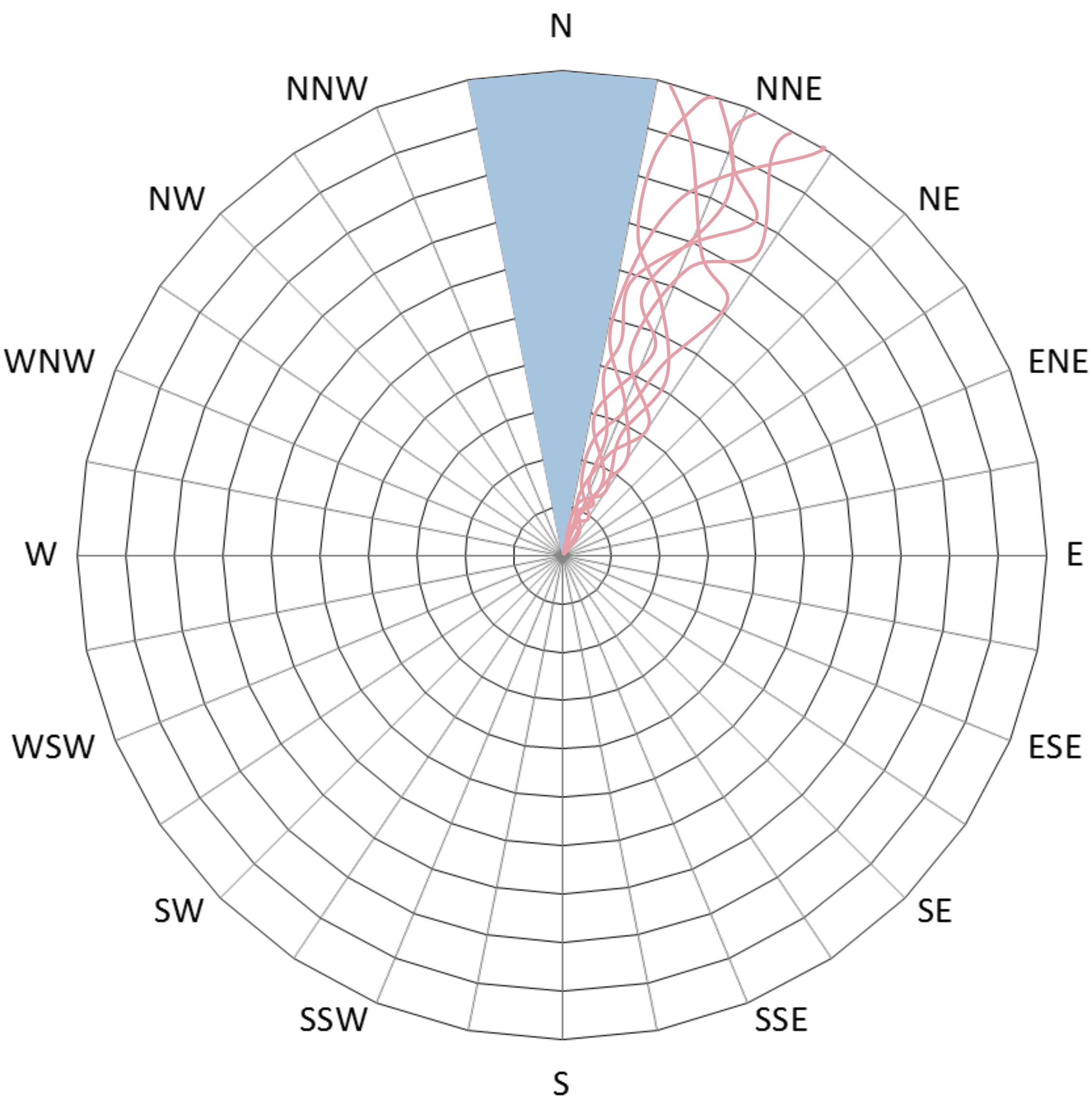


$$\overline{C_{sec}}(i,x) = \frac{Q_{x_i}}{\sqrt{2\pi}\,\sigma_z u_H y_{sec}} exp\left(\frac{-H^2}{2\sigma_z^2}\right)$$ **Non-mixing**

$$\overline{C_{sec}}(i,x) = \frac{Q_{x_i}}{2 y_{sec} u_H L}.$$ **Mixing**

Meteorological Data Grid

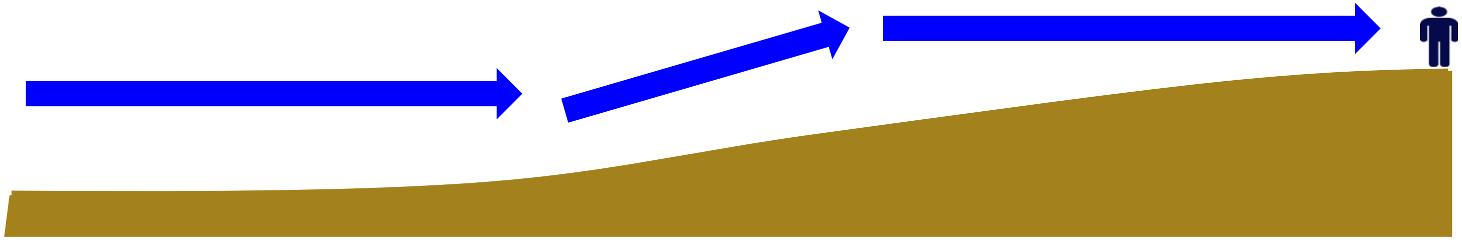
- **16 directions**
- **22.5º sectors**



Effective Release Height

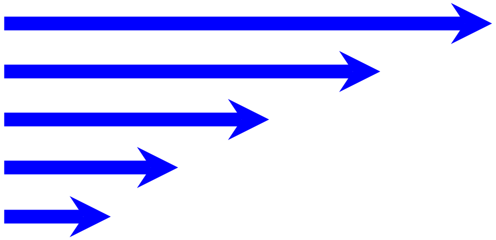
$$H = \max(h + \Delta h - h_v, 0) - (1 - P_c)[\min(\max(h + \Delta h - h_v, 0), \max(E_r - E_p, 0))]$$

- **Physical release height (h)**
- **Plume rise (*Δh*)**
  - Momentum driven : dependent on stack diameter, emission velocity, and wind speed
  - Buoyant : dependent on stability class, downwind distance, wind speed, heat flux (cal/s), ambient temperature
- **Vertical Settling (h_v)**
  - Dependent on settling velocity, downwind distance, and wind speed
- **Terrain height adjustment**
  - E_p, reference point for the release height
  - E_r, receptor elevation
  - P_c, 0.5 for PG stability categories A,B,C,D; 0.3 for E and F; 1 for non-terrain lifted plume



Wind Speed Adjustment

$$\frac{u_H}{u_a} = \left(\frac{H}{z_a}\right)^p$$



u_a = wind speed at measurement height (m/s)

z_a = height of anemometer for wind speed measurement (m)

p = power for height ratio (unitless) :

	Stability Class					
Population Zone	A	B	C	D	E	F
Rural	0.07	0.07	0.10	0.15	0.35	0.55
Suburban/urban	0.15	0.15	0.20	0.25	0.40	0.60

Pasquill Stability Classes

Meteorological Conditions Defining Pasquill Stability Classes

Surface wind speed (m/s)	Daytime insolation			Night-time conditions	
	Strong	Moderate	Slight	Thin overcast or > 4/8 low cloud	<= 4/8 cloudiness
< 2	A	A - B	B	E	F
2 - 3	A - B	B	C	E	F
3 - 5	B	B - C	C	D	E
5 - 6	C	C - D	D	D	D
> 6	C	D	D	D	D

A: Extremely unstable conditions

B: Moderately unstable conditions

C: Slightly unstable conditions

D: Neutral conditions

E: Slightly stable conditions

F: Moderately stable conditions

G: Extremely stable – folded into F

Notes:

1. Strong insolation corresponds to sunny midday in midsummer in England; slight insolation to similar conditions in midwinter.
2. Night refers to the period from 1 hour before sunset to 1 hour after sunrise.
3. The neutral category D should also be used, regardless of wind speed, for overcast conditions during day or night and for any sky conditions during the hour preceding or following night as defined above.

Source: https://www.ready.noaa.gov/READYpgclass.php

Plume Depletion and Deposition

- **Conservation of mass (activity)**
- **Dry deposition**

$$Q_{x_i} = Q_{0_i} \exp\left[-\frac{V_{d_i}}{\sqrt{\frac{\pi}{2}} u_H} \int_0^x F(x)dx \right]$$

$$F(x) = \frac{\exp\left(\frac{-H^2}{2\sigma_z^2} \right)}{\sigma_z}$$

Non-mixing

$$F(x) = \frac{1}{L}$$

Mixing

Q_{xi}	=	depleted source strength of nuclide *i* at distance *x* (Ci/s)
Q_{0i}	=	initial amount of radionuclide *i* released (Ci/s)
V_{di}	=	deposition velocity for radionuclide *i* (m/s)

Plume Depletion and Deposition (cont.)

- **Wet Deposition**
  - Washout coefficient, V_w (1/s)

$$V_w = -\frac{1}{C_a}\frac{dC_a}{dt}\,, \qquad V_w = W_C R\,, \qquad Q_{WET_{x_i}} = Q_{0_i}\, exp\left(-\frac{V_w x}{u_H}\right).$$

W_C = 1 x 10^{-3} (1/s)(mm/h)$^{-1}$ for stability classes A to D and
1.0 x 10^{-4} 1/s)(mm/h)$^{-1}$ for stability classes E and F, and

R = rainfall rate (mm/h)

- **Dry and Wet Deposition**

$$Q_{x_i} = Q_{0_i}\, exp\left\{-\left[\frac{V_w x}{u_H} + \frac{V_{d_i}}{\sqrt{\frac{\pi}{2}}u_H}\int_0^x F(x)dx\right]\right\}.$$

Dispersion Coefficients

- **Pasquill-Gifford stability classes (A through F)**
- **Pasquill coefficients (ground-level release)**

$$\sigma_z' = ax^b + c$$

- **Briggs coefficients (rural or urban)**

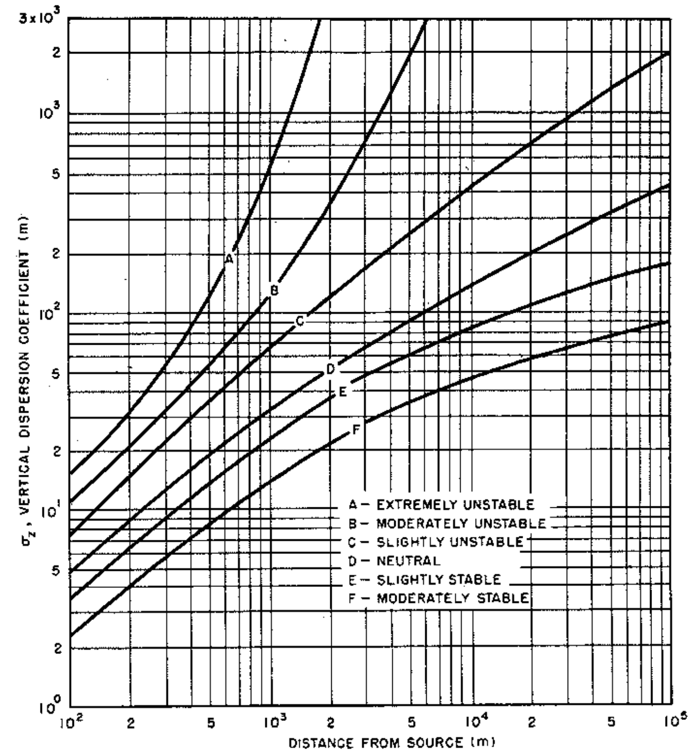
$$\sigma_z' = ax(1 + bx)^c$$

- **Buoyancy induced dispersion**

$$\sigma_{zb} = \frac{\Delta h}{3.5}$$

- **Final form**

$$\sigma_z = \left(\sigma_{zb}^2 + \sigma_z'^2\right)^{1/2}$$

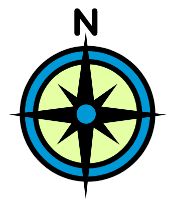


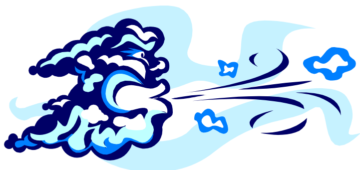
Meteorology and Atomic Energy 1968
Air Resources Laboratories
U.S. Dept. of Commerce, 1968

Account for Variation in Weather

- **Chronic (long-term) model**

- **Variations in:**
  - Wind direction
  - Wind speed
  - Atmospheric stability class





- **Estimated air concentrations**
  - Weighted average based on frequency of occurrence
  - For a given source / receptor pair (fixed direction):

    6 (wind speeds) x 6 (stability classes) = 36 calculations

$$C_{air,avg} = \left(\sum_{i=1 \ to \ 6}^{wind} \ \sum_{j=1 \ to \ 6}^{stability} C_{air,i,j} \right) \div 36$$

Meteorological Data

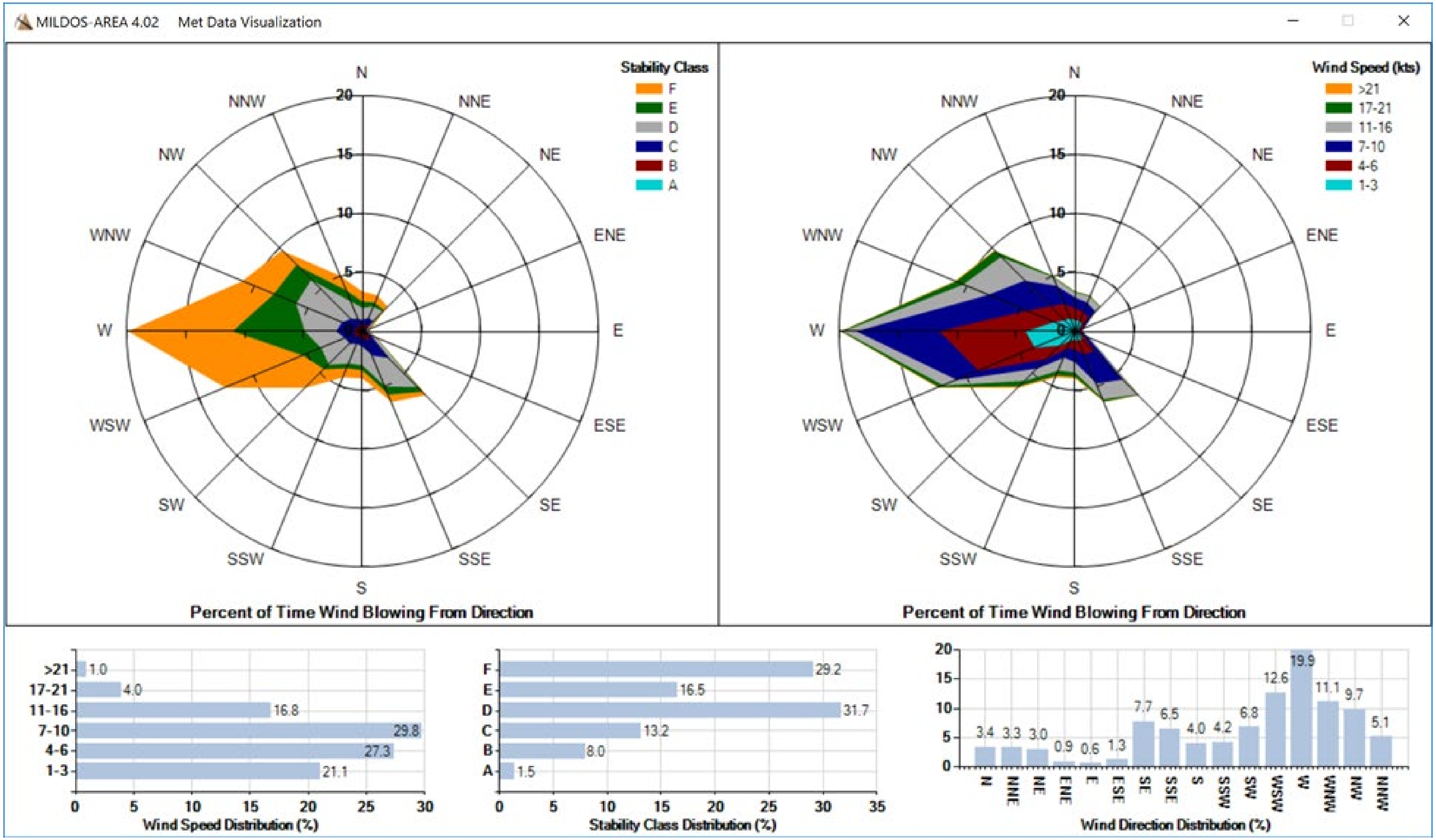
- **Joint-frequency data**
  - Fraction (frequency) of time wind is blowing:
    - Under conditions for a given stability class (A through F)
    - In a given direction (16 directions)
    - At a given wind speed (6 wind speed bins/ranges)
  - Fractions sum to 1
- **STability ARray (STAR) format**
  - Used in previous U.S. EPA regulatory models
  - Well-suited to chronic releases

Column	Value
1	Blank
2-4	Wind Direction (N, NNE, NE, ENE, E, etc.)
5	Blank
6	Stability Category (A, B, C, D, E, or F)
7	Blank
8-14	Wind speeds 1 – 3 knots (0.67 m/s)
15-21	Wind speeds 4 – 6 knots (2.46 m/s)
22-28	Wind speeds 7 – 10 knots (4.47 m/s)
29-35	Wind speeds 11 – 16 knots (6.93 m/s)
36-42	Wind speeds 17 – 21 knots (9.61 m/s)
43-49	Wind speeds > 21 knots (12.5 m/s)

Partial STAR File Example

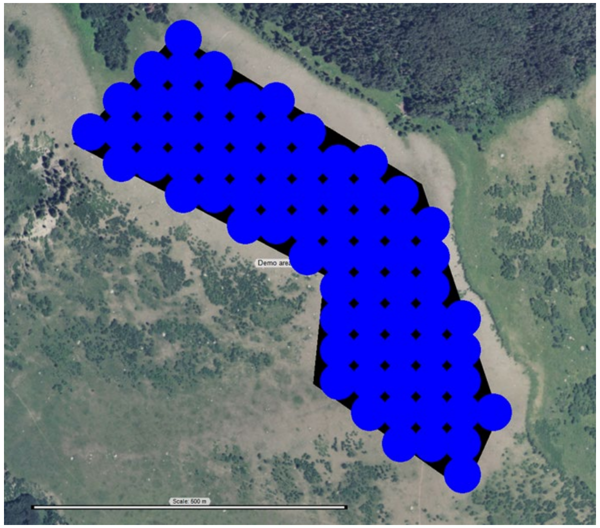
N	A	.00131	.00012	.00000	.00000	.00000	.00000
NNE	A	.00229	.00000	.00000	.00000	.00000	.00000
NE	A	.00165	.00036	.00000	.00000	.00000	.00000
ENE	A	.00096	.00047	.00000	.00000	.00000	.00000
E	A	.00136	.00036	.00000	.00000	.00000	.00000
ESE	A	.00160	.00012	.00000	.00000	.00000	.00000
SE	A	.00091	.00024	.00000	.00000	.00000	.00000
SSE	A	.00000	.00000	.00000	.00000	.00000	.00000
S	A	.00057	.00000	.00000	.00000	.00000	.00000
SSW	A	.00062	.00024	.00000	.00000	.00000	.00000
SW	A	.00131	.00012	.00000	.00000	.00000	.00000
WSW	A	.00177	.00024	.00000	.00000	.00000	.00000
W	A	.00266	.00107	.00000	.00000	.00000	.00000
WNW	A	.00108	.00036	.00000	.00000	.00000	.00000
NW	A	.00160	.00012	.00000	.00000	.00000	.00000
NNW	A	.00108	.00036	.00000	.00000	.00000	.00000
N	B	.00359	.00059	.00000	.00000	.00000	.00000
NNE	B	.00347	.00071	.00000	.00000	.00000	.00000
NE	B	.00444	.00131	.00000	.00000	.00000	.00000
ENE	B	.00761	.00249	.00095	.00000	.00000	.00000

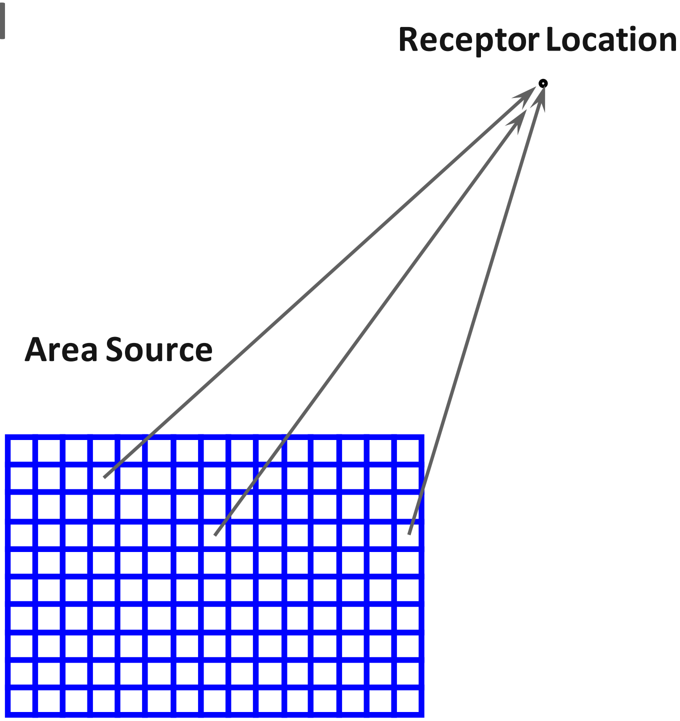
Meteorological Data Visualization



Area Source Model

- Source areas segmented into uniform grids
- Point-to-point dispersion estimates
- Normalized air concentration at receptor is average from all grid points
- Air concentration at receptor is calculated from normalized air concentration and release from all source grid points





Ground Concentrations

$$C_g(i,p,x,t) = V_{d_p}\,\overline{C_{\sec}}(i,p,x,t)\,\frac{1-\exp\left[-(\lambda_i+\lambda_e)t\right]}{\lambda_i+\lambda_e}$$

$C_g(\mathrm{i},p,x,t)$ = ground concentration of radionuclide *i* associated with particle size *p* at a distance *x* (in m) after time t (Ci/m^2),

V_{d_p} = deposition velocity for particle size *p* (m/s),

$\overline{C_{\sec}}(i,p,x,t)$ = sector-averaged air concentration of radionuclide *i* at a distance *x* (in m) from the source (Ci/m^3) during time *t* (here the dependence on particle size is being explicitly pointed out),

λ_i = radioactive decay constant for radionuclide *i* (1/s), and

λ_e = decay constant to account for environmental loss from soil (1/s)

$$C_g(i,p,x,t_j) = V_{d_p}\,\overline{C_{\sec}}(i,p,x,t_{s_j})\,\frac{1-\exp\left[-(\lambda_i+\lambda_e)t_{s_j}\right]}{\lambda_i+\lambda_e} + \sum_{k=1}^{j-1}\left(C_g(i,p,x,t_k)\exp\left[-(\lambda_i+\lambda_e)t_{j-k}\right]\right)$$

$C_g(i,p,x,t_j)$ = ground concentration of radionuclide *i* on particle size *p* at a distance *x* (in m) after time step *j* (Ci/m^2),

$C_g(i,p,x,t_{j-1})$ = ground concentration of radionuclide *i* on particle size *p* at a distance *x* (in m) after time step *j-1* (Ci/m^2), and

t_{sj} = length of time assigned to time step *j* (s)

Resuspension

$$R(t)=\begin{cases}\dfrac{V_{d_r}}{V_{d_p}}R_I\exp(-\lambda_r t),\ \text{for } t\le t_R\\[2ex]\dfrac{V_{d_r}}{V_{d_p}}R_F,\ \text{for } t> t_R\end{cases},$$

$R(t)$ = ratio of resuspended air concentration to ground concentration for a ground concentration at time t after deposition (1/m),

V_{dr} = deposition velocity for the reference particle size that corresponds to the values of R_I and R_F (m/s),

V_{dp} = deposition velocity for particle size p (m/s),

R_I = initial value of the resuspension factor for fresh deposits (1/m),

λ_r = resuspension factor decay constant (1/yr) [(ln 2)/resuspension half-life],

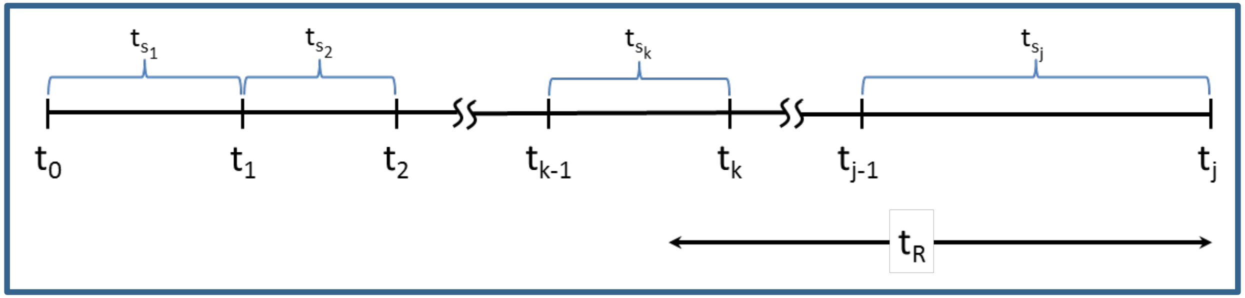
R_F = final value of the resuspension factor after time (1/m), and

t_R = time required for the resuspension factor to decrease from its initial to final value (yr), $t = t_R$, when

$$\frac{V_{d_r}}{V_{d_p}}R_F=\frac{V_{d_r}}{V_{d_p}}R_I\exp(-\lambda_r t_R)\longrightarrow t_R=-\frac{1}{\lambda_r}\ln\frac{R_F}{R_I}.$$

Resuspended Air Concentration

$$C_{air_R}(i,p,x,t_j) = R(t)C_g(i,p,x,t_j)$$



$$C_{air_R}(i,p,x,t_j) = \sum_{m=1}^{k-1} \overline{C_{sec}}(i,p,x,t_{s_m})\, V_{d_r} R_F \frac{\exp[-(\lambda_i+\lambda_e)(t_j - t_m)] - \exp[-(\lambda_i+\lambda_e)(t_j - t_m + t_{s_m})]}{\lambda_i+\lambda_e} +$$

$$\sum_{m=k+1}^{j} \overline{C_{sec}}(i,p,x,t_{s_m})\, V_{d_r} R_I \frac{\exp[-(\lambda_i+\lambda_e+\lambda_r)(t_j - t_m)] - \exp[-(\lambda_i+\lambda_e+\lambda_r)(t_j - t_m + t_{s_m})]}{\lambda_i+\lambda_e+\lambda_r} +$$

$$\overline{C_{sec}}(i,p,x,t_{s_k})\, V_{d_r} \left[R_F \left(\frac{\exp[-(\lambda_i+\lambda_e)t_R] - \exp[-(\lambda_i+\lambda_e)(t_j - t_{k-1})]}{\lambda_i+\lambda_e} \right) + R_I \left(\frac{\exp[-(\lambda_i+\lambda_e+\lambda_r)(t_j - t_k)] - \exp[-(\lambda_i+\lambda_e+\lambda_r)t_R]}{\lambda_i+\lambda_e+\lambda_r} \right) \right]$$

$$t_j = \sum_{m=1}^{j} t_{s_m}$$

k = time step of the transition interval where both initial and final resuspension factor contributions occur when t_j is $> t_R$

Total Air Concentrations

- **Particulates (for a given radionuclide)**
  - Sum of direct and resuspended air concentrations
  - Summed over all particulate sizes

- **Radon**
  - Shorter half-lives, need to account for decay

$$Q_{x\_Rn} = \left(3.17 \times 10^{-8}\ \mathrm{yr/s}\right) Q_{0\_Rn} \exp\left(-\lambda_{Rn}\tau\right)$$ downwind source strength

$$\overline{C_{\sec}}\left(Rn, x, t_j\right) = \left(\frac{\chi}{Q}\right)_{gas} Q_{x\_Rn}$$ radon air concentration

Q_{x_Rn} = depleted downwind source strength of Rn at distance *x* downwind (Ci/s),

Q_{0_Rn} = source strength of Rn at the release point (Ci/yr),

λ_{Rn} = radon decay constant (1/s) [(ln 2)/(Rn decay half-life)],

τ = transit time between source and receptor, calculated as the downwind distance divided by the average wind speed (x/u_H) (s),

$\overline{C_{\sec}}(Rn, x, t_j)$ = sector-averaged air concentration of radon at a distance x (in m) from the source during time step j (Ci/m^3) and

$(\chi/Q)_{gas}$ = normalized air concentration for a gas (i.e., a nondepositing molecule) (s/m^3)

Total Air Concentrations (cont.)

- **Radon Daughter Radionuclides**

$$\overline{C_{\sec}}(i_n, x, t_j) = \overline{C_{\sec}}(Rn, x, t_0)\left(\prod_{i=2}^{n} \lambda_i\right)\left\{\sum_{i=1}^{n}\left[\frac{\exp(-\lambda_i \tau)}{\prod_{\substack{m=1 \\ m \neq i}}^{n}(\lambda_m - \lambda_i)}\right]\right\}$$

for n = 2,…,4 for Rn-220 and n = 2,…,7 for Rn-222,

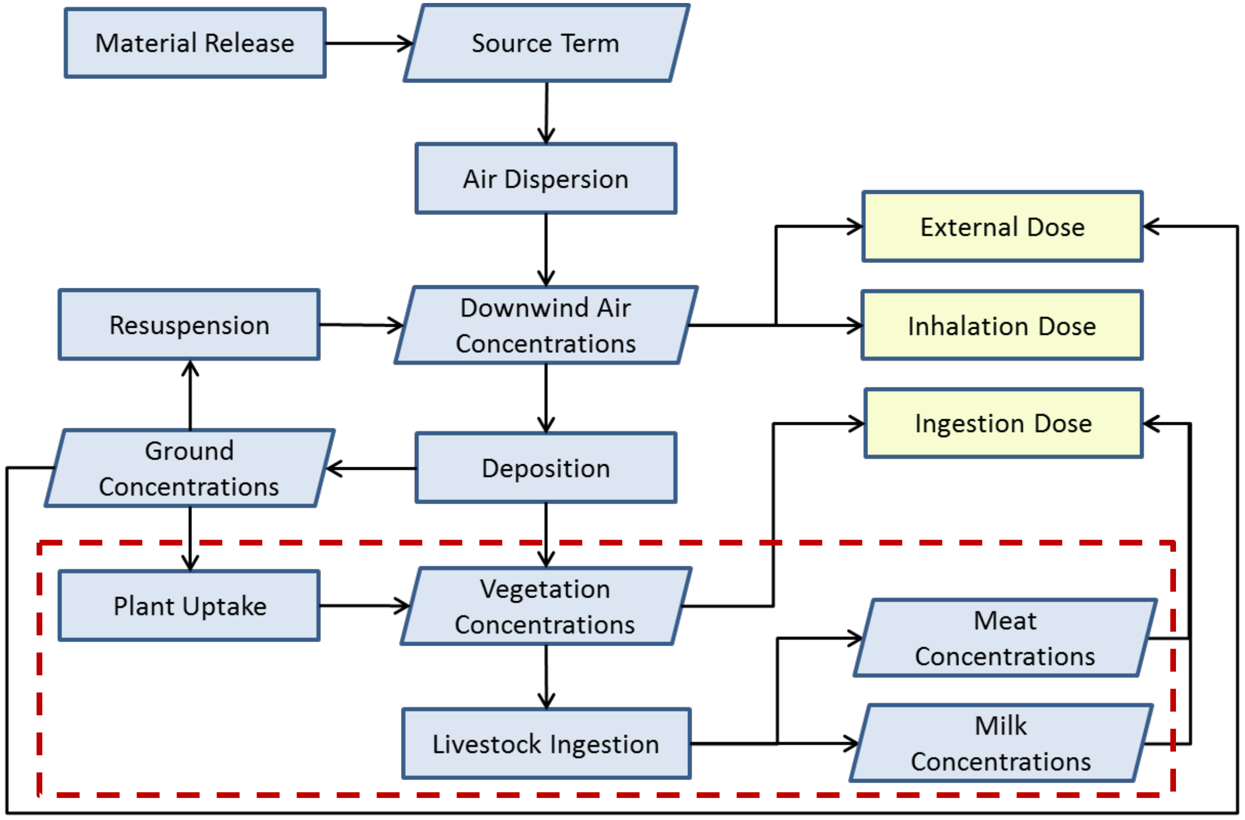
where

$\overline{C_{\sec}}(i_n, x, t_j)$ = sector-averaged air concentration of radon daughter i_n at a distance *x* (in m) from the source during time step *j* (Ci/m^3),

λ_i and λ_m = radioactive decay constants for radon daughters (1/s), and

$\overline{C_{\sec}}(Rn, x, t_0)$ = what would be the sector-averaged air concentration of radon at a distance *x* (in m) from the source (Ci/m^3) without accounting for radioactive decay

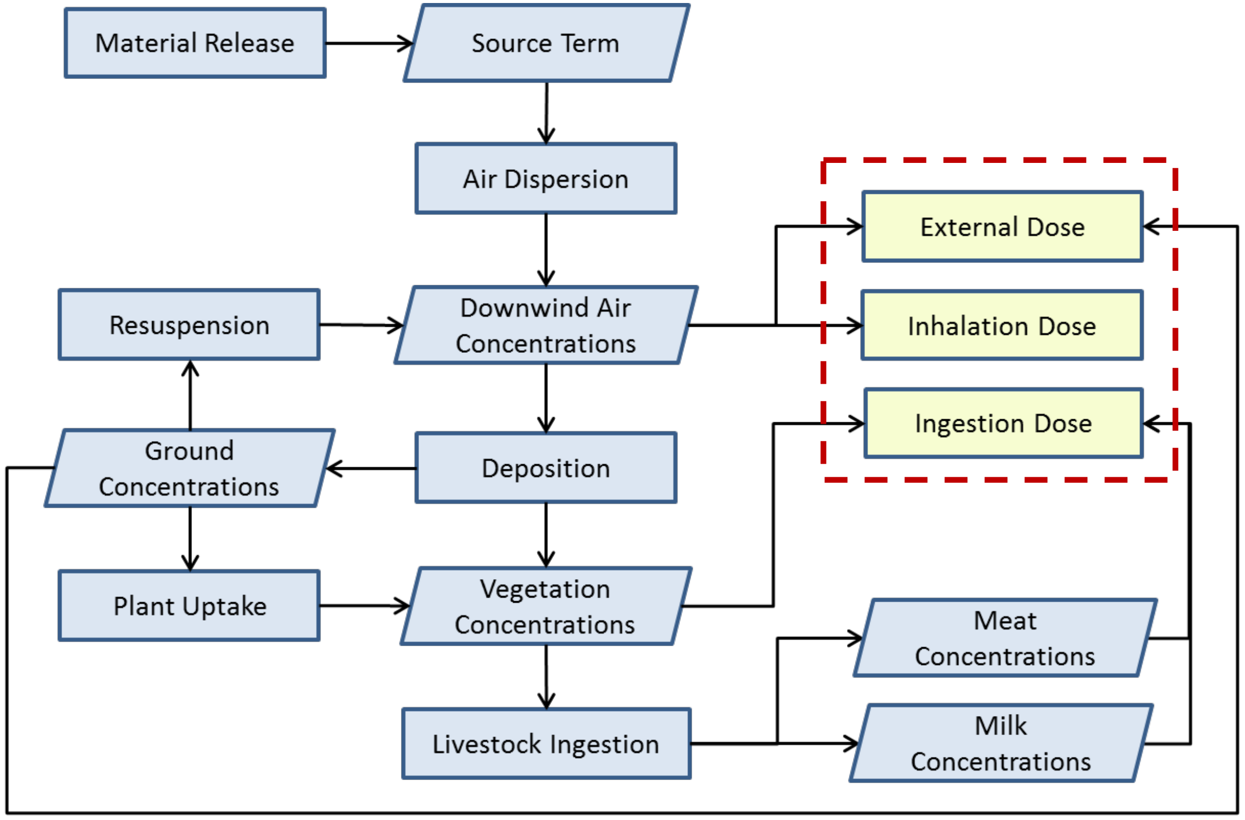
Concentrations in Food



Ingestion Pathway

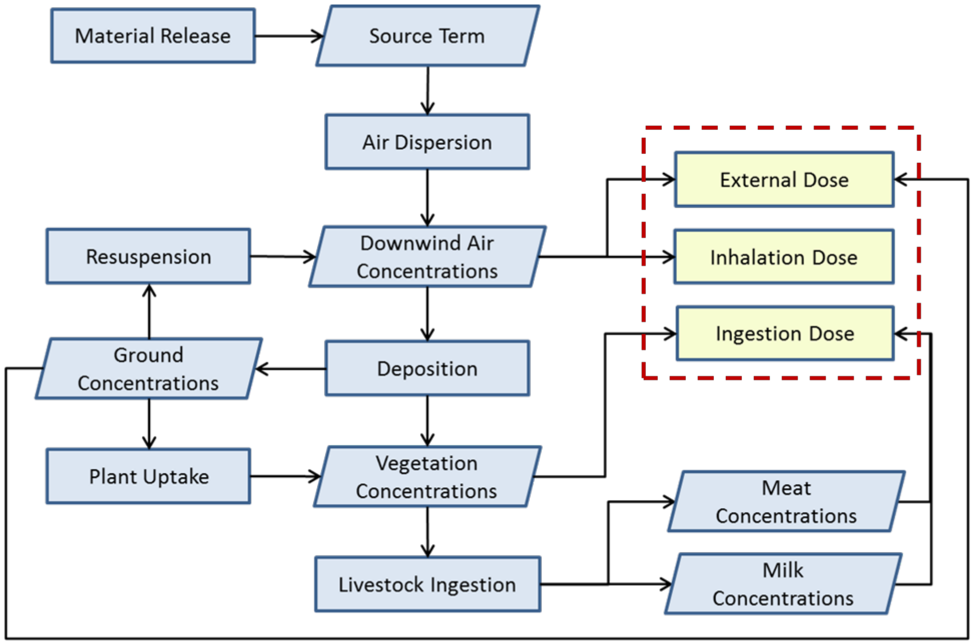
- **Radionuclide concentration in plants from air and ground concentrations**
  - edible above-ground vegetables
  - potatoes
  - other edible below-ground vegetables
  - pasture grass
  - hay
- **Pasture grass and hay for the meat and milk ingestion pathways**
- **The plants become contaminated from root uptake and foliar deposition**

Exposure Calculations



Pathway Doses

- **External:**
  - immersion in air particulates
  - groundshine
- **Inhalation:**
  - plume passage (direct)
  - resuspension
  - radon
- **Ingestion**
  - Plants, meat and milk



- **Accounts for age, organ, location of receptor**
- **Population ingestion dose considers yields**

External (Cloudshine and Groundshinte)

$$D_{ext,o}(x,t_j) = 10^{12}\left(F_{in}S_{in} + F_{out}\right)\left(\sum_i \left[DC_{cld,io}\overline{C_{air}}\left(i,x,t_j\right) + DC_{gnd,io}C_g(i,x,t_j)\right]\right)$$

- **External dose by:**
  - Nuclide (i)
  - Organ (o)
  - Location (x)
  - Time (t)

$D_{ext,o}(x,t_j)$ = external dose rate to organ *o* in individual from outside airborne and deposited activity at distance *x* and time step *j* (mrem/yr),

10^{12} = unit conversion factor (pCi/Ci),

F_{in}, F_{out} = indoor and outdoor occupancy fractions, respectively (unitless),

S_{in} = indoor shielding factor (unitless),

$\overline{C_{air}}(i,x,t_j)$ = total air concentration of radionuclide *i* during time step t_j at distance *x* (Ci/m^3),

$C_g(i,x,t_j)$ = ground concentration of radionuclide *i* from a given source after time step *j* (Ci/m^2),

$DC_{cld,io}$ = external air immersion dose coefficient for radionuclide *i* in organ *o* (mrem/yr per pCi/m^3), and

$DC_{gnd,io}$ = external groundshine dose coefficient for radionuclide *i* in organ *o* (mrem/yr per pCi/m^2)

Inhalation (Particulates)

- **Inhalation dose by:**
  - Nuclide (i) [for selected lung clearance class]
  - Particle size (p)
  - Organ (o)
  - Age group (k)
  - Location (x)
  - Time (t)

$$D_{inh,kop}(x,t_j) = 10^{12} \sum_p \sum_i \overline{C_{air}}(i,p,x,t_j)\, DC_{inh,ikop}\, IR$$

$D_{inh,kop}(x,t_j)$ = inhalation dose rate to organ *o* in an individual in age group *k* from particulates from time step t_j (mrem/yr),

10^{12} = unit conversion factor (pCi/Ci),

$\overline{C_{air}}(i,p,x,t_j)$ = total air concentration of radionuclide *i* on particle size *p* during time step t_j at distance *x* (Ci/m^3),

$DC_{inh,ikop}$ = inhalation dose coefficient for radionuclide *i*, age group *k*, organ *o*, and particle size *p* (mrem/pCi), and

IR = inhalation rate (7,300 m^3/yr)

Inhalation (Rn-222)

- **Uses Rn-222 air concentration and includes contribution from daughters**

$$D_{inh,Rn222}(x,t_j) = 10^{12}\overline{C_{air}}\left(Rn222,x,t_j\right) IR \times \left[DC_{inh,Rn222}\left(F_{in}+F_{out}\right)+DC_{inh,Rn222\_D}\left(F_{in}E_{in\_eq}+F_{out}E_{out\_eq}\right)\right]$$

- **Option to estimate outdoor equilibrium fraction**
  - Divides the working level (WL) at receptor location by WL if Rn-222 and daughters were in equilibrium

$$E_{out\_eq} = \frac{1.03\times10^{-6}A+5.07\times10^{-6}B+3.73\times10^{-6}C}{1.03\times10^{-6}+5.07\times10^{-6}+3.73\times10^{-6}}$$

$D_{inh,Rn222}(x,t_j)$ = inhalation dose rate to an individual from Rn-222 from time step t_j (mrem/yr),
10^{12} = unit conversion factor (pCi/Ci),
$\overline{C_{air}}(Rn222,x,t_j)$ = air concentration of Rn-222 during time step t_j at distance x (Ci/m^3),
F_{in}, F_{out} = indoor and outdoor occupancy fractions, respectively (unitless),
E_{in_eq}, E_{out_eq} = equilibrium fraction of radon daughters with radon in indoor and outdoor air, respectively (unitless),
$DC_{inh,Rn222}$ = inhalation dose coefficient for Rn-222 (mrem/pCi), and
$DC_{inh,Rn222\_D}$ = inhalation dose coefficient for all Rn-222 daughters (mrem/pCi)

A, B, and C are the air concentrations of Po-218, Pb-214, and Bi-214, respectively, relative to the Rn-222 air concentration

Inhalation (Rn-220)

- **No equilibrium with daughters**
- **Uses the working level**

$$D_{inh,Rn220}(x,t_j) = (F_{in} + F_{out})WL_{Rn220}(x,t_j)DC_{inh,Rn220}$$

$$WL_{Rn220} = 9.48\times10^{-10}A' + 1.23\times10^{-4}B' + 1.17\times10^{-5}C'$$

$D_{inh,Rn220}(x,t_j)$ = inhalation dose rate to an individual from Rn-220 from time step t_j (mrem/yr),
$WL_{Rn220}(x,t_j)$ = WL of Rn-220 during time step t_j at distance x (WL), and
$DC_{inh,Rn220}$ = inhalation dose coefficient for Rn-220 (mrem/yr per *WL*)

A', B', and C' are the air concentrations (pCi/m^3), respectively, of Po-216, Pb-212, and Bi-212 at the receptor location

Ingestion

$$D_{ing,ko}(i,x,t_j) = I_k(i,x,t_j) DC_{ing,iko}$$

$$I_k(i,x,t_j) = U_{mk} C_m(i,x,t_j) + U_{bk} C_b(i,x,t_j) + F_{va} U_{vk} \sum_v F_{vck} C_v(i,x,t_j)$$

- **Ingestion of milk, meat, and plant food**
- **External dose by:**
  - Nuclide (i)
  - Organ (o)
  - Age group (k)
  - Location (x)
  - Time (t)

$I_k(i,x,t_j)$ = ingestion rate of radionuclide *i* by an individual in age group *k* during time step t_j (pCi/yr),

U_{mk}, U_{bk} = milk (L/yr) and meat (kg/yr) ingestion rates for age group *k*,

$C_m(i,x,t_j)$ = average milk concentration for radionuclide *i* during time step *j* (pCi/L),

$C_b(i,x,t_j)$ = average meat concentration for radionuclide *i* during time step *j* (pCi/kg),

F_{va} = fraction of radionuclide activity remaining in vegetables after food preparation (unitless),

U_{vk} = vegetable ingestion rate for age group *k* (kg/yr)(wet weight),

F_{vck} = fraction of vegetable category *c* consumed by age group *k* (unitless),

$C_v(i,x,t_j)$ = concentration of radionuclide *i* in vegetation type *v* during time step *j* (pCi/kg) (wet weight),

$D_{ing,ko}(i,x,t_j)$ = ingestion dose rate to organ *o* from radionuclide *i* of an individual in age group *k* from time step t_j (mrem/yr), and

$DC_{ing,iko}$ = ingestion dose coefficient for radionuclide *i* in organ *o* of an individual in age group *k* (mrem/pCi ingested).

Population Dose

- **Inhalation & External**
  - Multiply individual dose by segment population and sum

$$PD_{ext,o}(t_j) = 10^{-3}\sum_s \left(n_s D_{ext,o}(s,t_j)\right)$$

$PD_{ext,o}(t_j)$ = total population external dose to organ o from time step j (person-rem/yr),

10^{-3} = unit conversion factor (rem/mrem),

n_s = number of people residing in population segment s, and

$D_{ext,o}(s,t_j)$ = external dose rate to organ o in an individual from a given source from time step j (mrem/yr) where the midpoint of segment s corresponds to distance x. For population calculations, 100 percent occupancy is assumed for all individuals, with an indoor occupancy of 14 h/day at a shielding factor of 0.7 (that is, F_{in} = 14/24, F_{out} = 10/24, and S_{in} = 0.7).

$$PD_{inh,o}(t_j) = 10^{-3}\sum_s \sum_k n_{ks} D_{inh,ko}(s,t_j)$$

$PD_{inh,o}(t_j)$ = total population inhalation dose rate to organ o from time step t_j (person-rem/yr),

10^{-3} = unit conversion factor (rem/mrem),

n_{ks} = number of people in age group k residing in population segment s, and

$D_{inh,ko}(s,t_j)$ = inhalation dose rate to organ o in an individual in age group k from a given source from time step t_j (mrem/yr) wheree the midpoint of segment s corresponds to distance x].

Population Dose - Ingestion

- **Calculate the average radionuclide concentration in vegetables**

$$C_{v\_avg}(i,s,t_j) = \sum_v W_{vs} C_{vs}(i,x,t_j)$$

- **Find total activity in foodstuffs grown in the area**

$$Q_f(i,t_j) = \sum_s \sum_f P_{fs} C_f(i,s,t_j)$$

$C_{v\_avg}(i,s,t_j)$ = concentration of radionuclide *i* in vegetables averaged over all vegetable types in population segment *s* during time step *j* (pCi/kg) (wet weight),

$C_{vs}(i,x,t_j)$ = concentration of radionuclide *i* in vegetation type *v* during time step *j* (pCi/kg) (wet weight),

W_{vs} = weighting factor for vegetable type *v* in population segment *s* (fraction of total production) (unitless),

$Q_f(i,t_j)$ = total amount of radionuclide *i* in food type *f* (vegetables, meat, and milk) produced in the region during time step *j* (pCi/yr) (wet weight),

$C_f(i,s,t_j)$ = concentration of radionuclide *i* in food type *f* in population segment *s* during time step *j* (pCi/kg) (wet weight), and

P_{fs} = annual production rate of food type *f* in population segment *s* (kg/yr).

Population Dose - Ingestion (cont.)

- **Find the fraction eaten by each age group**

$$F_{fk} = \frac{F_{pk} U_{fk}}{\sum_k F_{pk} U_{fk}}$$

- **Distribute all of the food grown and account for food processing loss**

$$PD_{ing,ko}(i,t_j) = 10^{-3} \sum_f \sum_i \sum_k F_{fa} Q_f(i,t_j) F_{fk} DC_{ing,iko}$$

F_{fk} = fraction of food type *f* consumed by individuals in age group *k* (unitless),

F_{pk} = fraction of the population belonging to age group *k* (unitless),

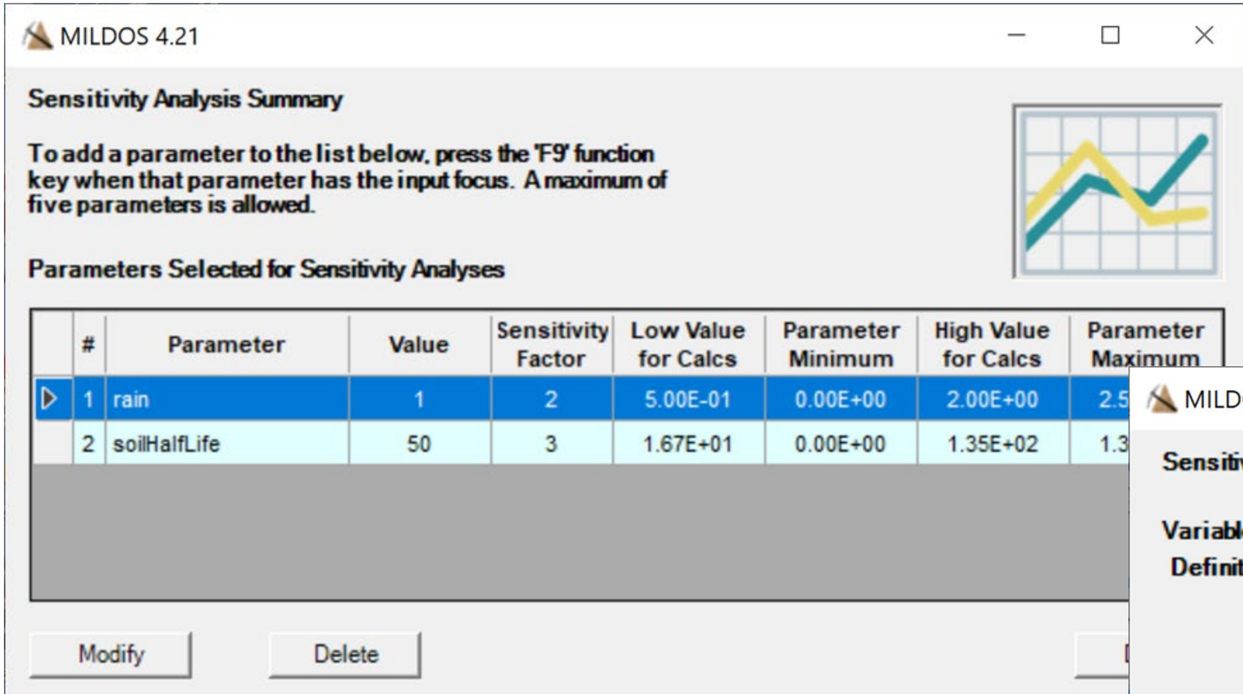
U_{fk} = average consumption rate of food type *f* for an individual in age group *k* (kg/yr for vegetables and meat, L/yr for milk),

$PD_{ing,ko}(i,tj)$ = population ingestion dose rate to organ *o* from radionuclide *i* of an individual in age group *k* from time step t_j (person-rem/yr),

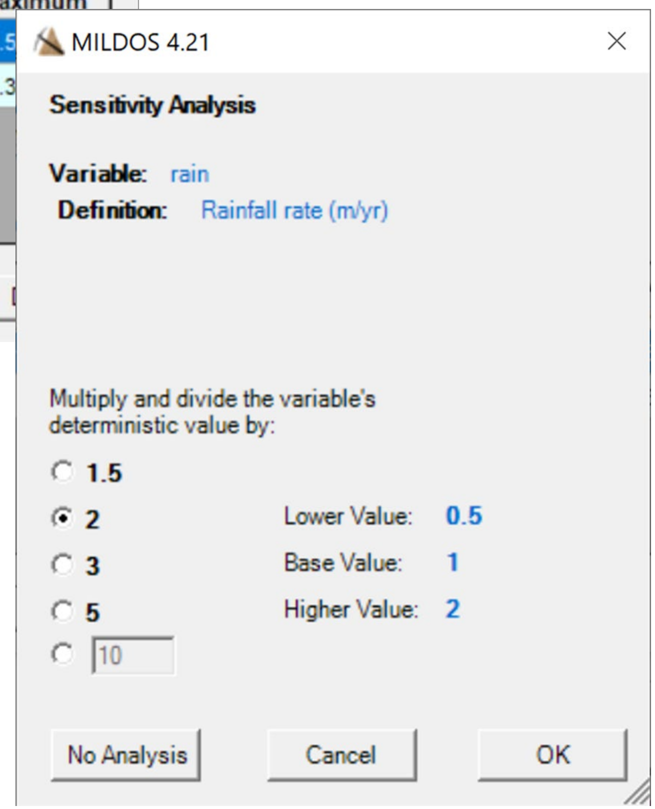
$DC_{ing,iko}$ = ingestion dose coefficient for radionuclide *i* in organ *o* of an individual in age group *k* (mrem/pCi ingested), and

F_{fa} = fraction of radionuclide activity remaining in food type *f* after food preparation (unitless).

Sensitivity Analysis



Press 'F9'

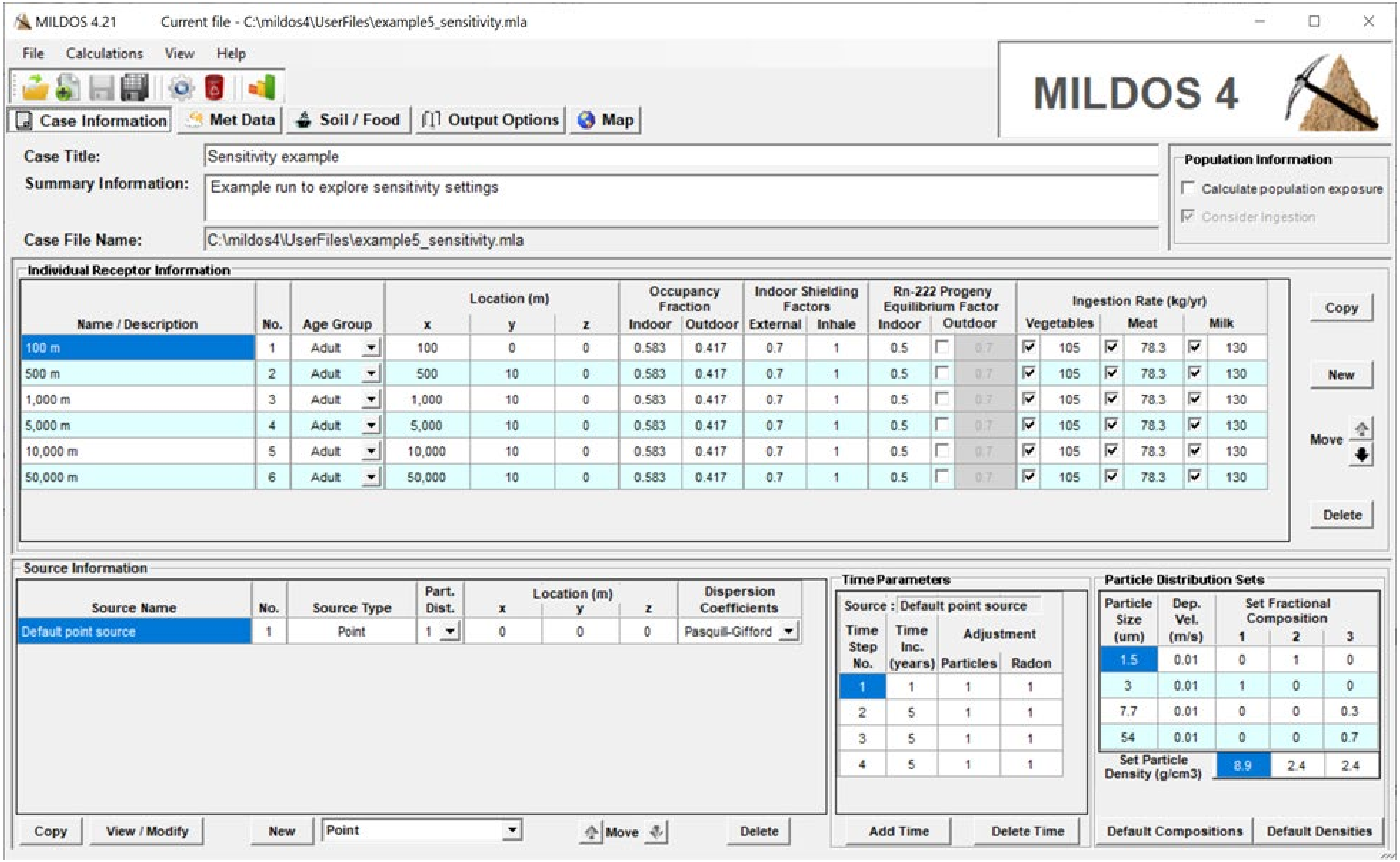


Press 'Alt + Z' or use menu bar item

Sensitivity Implementation

- **3 runs of MILDOS 4 for the selected parameter**
  - Base value of the parameter (specified input value for the parameter)
  - Lower value of the parameter determined by sensitivity factor
  - Higher value of the parameter determined by sensitivity factor
- **Values of other parameters are fixed and do not change**
- **If more than one parameter selected for sensitivity analysis**
  - First run is with all parameters at their base value
  - Then 2 runs for each selected parameter (low and high values) using the base values for the other selected parameters
- **Not all input parameters are available for sensitivity analysis**
  - For example, parameters such as x, y, z location positions and meteorological joint frequency distribution fractions cannot be selected for sensitivity analysis

Sensitivity Example

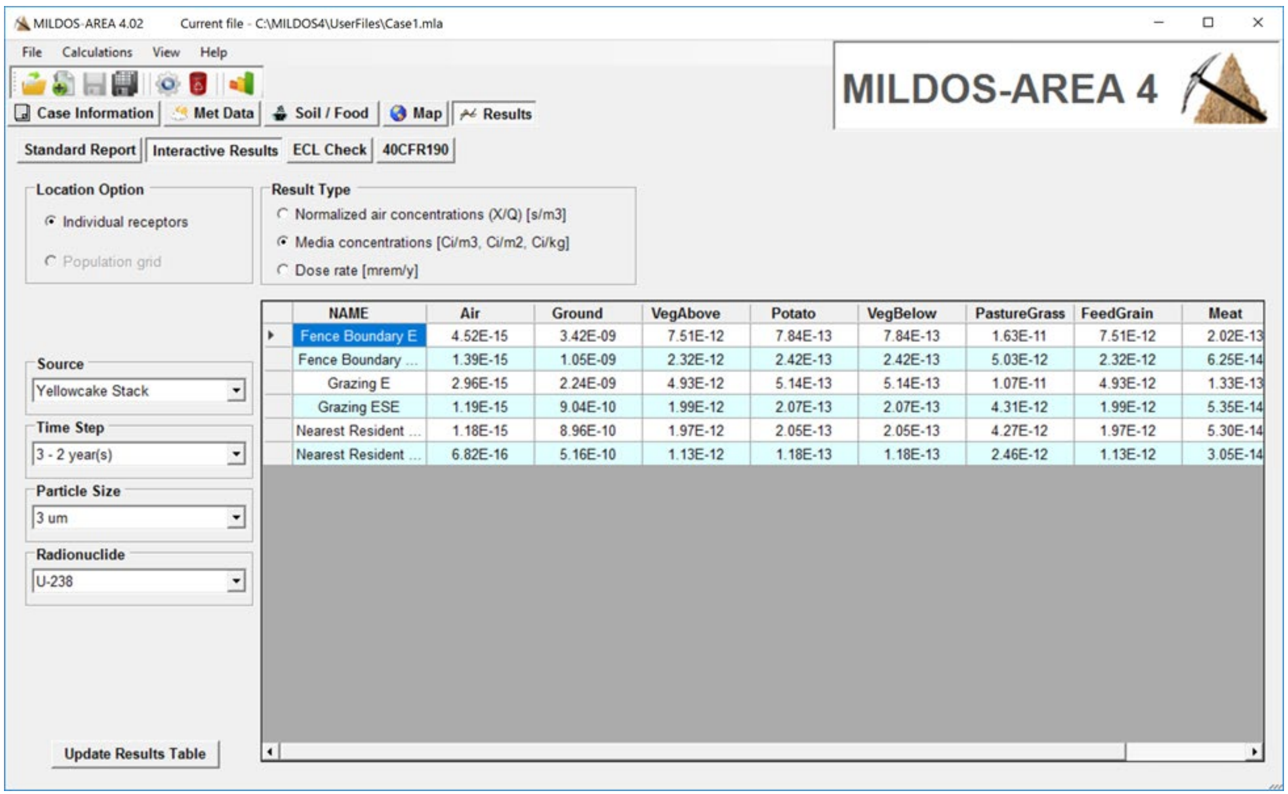


Sensitivity Results

- **Side-by-side comparison of end points under the Results/Sensitivity tabs**
- **End point value depends on all of the dimensions involved**
  - Can have a broad range of results for same end point over same and/or different sites, for example:
    - Rain fall rate – affects (increasing rate decreases) particulate nuclide air concentrations
      - Smaller or larger delta air concentrations will result depending on such other dimensions as distance and direction (i.e. wind speed and stability class combinations)
      - Which in turn affects other media concentrations and ultimately exposure
    - Soil half-life – affects (shorter life decreases) particulate ground concentrations
      - In this case, larger delta ground concentrations with time (larger delta between low and high input results at later time steps)
      - Which in turn affects resuspended air concentrations, produce concentrations and ultimately exposure

Options for Results Analysis

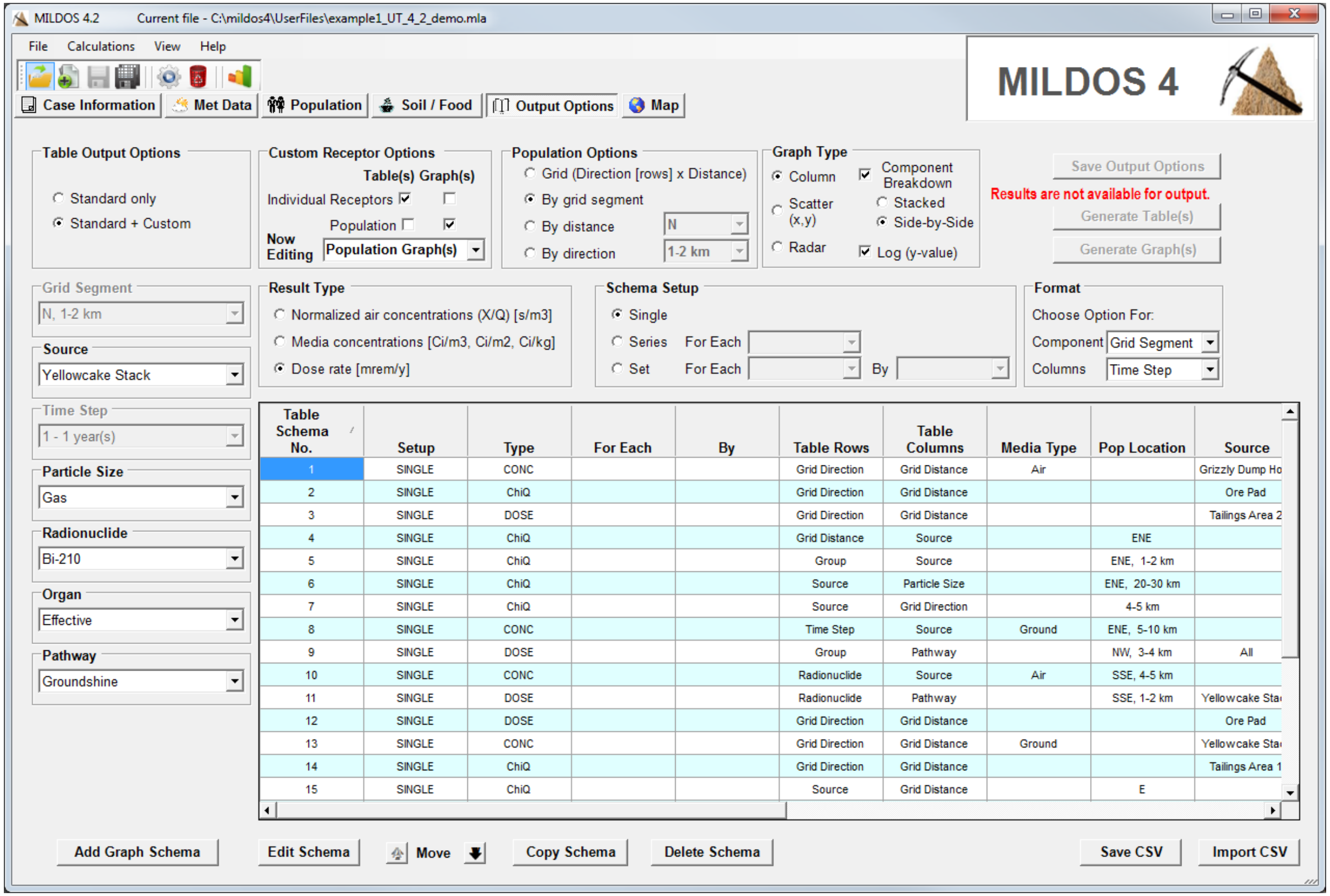
- **User file format (database) and GIS module provide flexibility, capability, and opportunity in scenario definition, evaluation, and results presentation**



Customizable Table and Graph Output Options

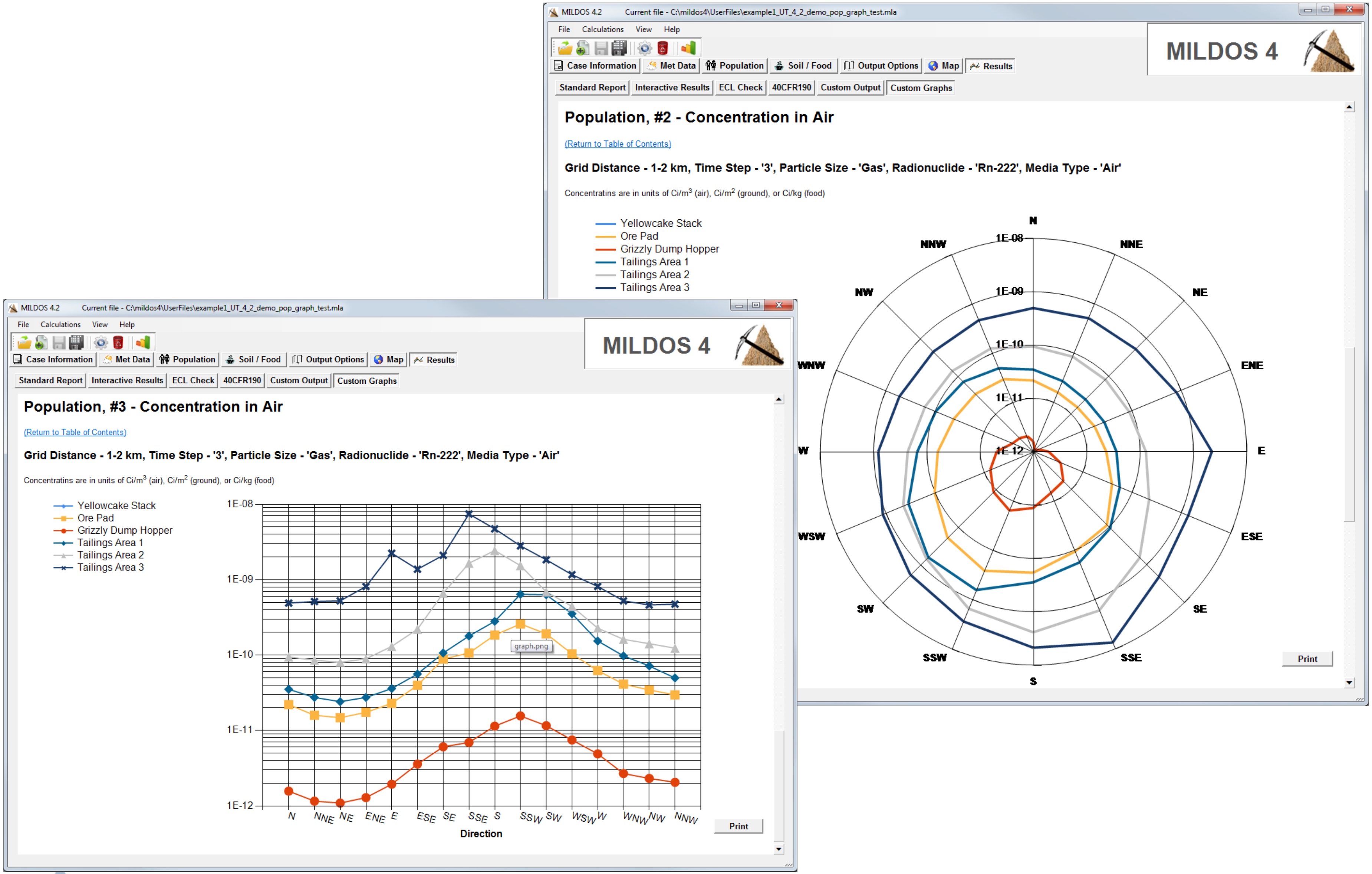
- **Impacts**
  - Normalized Air Conc. (χ/Q)
  - Media Concentrations
  - Doses
- **Receptors**
- **Sources**
- **Radionuclide**
  - U-238 / Th-232 decay chains
- **Particle Size**
  - Gas, 1.5, 3, 7.7, or 54 μm
- **Time Step**
- **Media**
  - Air / ground / 7 food stuffs
- **Organ**
  - Effective, bone, lung, liver, kidney
- **Pathway**
  - Inhalation and ingestion (plant, meat, milk)
  - Ground or cloud shine
- **Format**
  - Single table or graph; Series (e.g., dose for each time step); or Set (e.g., conc. for each nuclide by media type)

Customizable Output Options

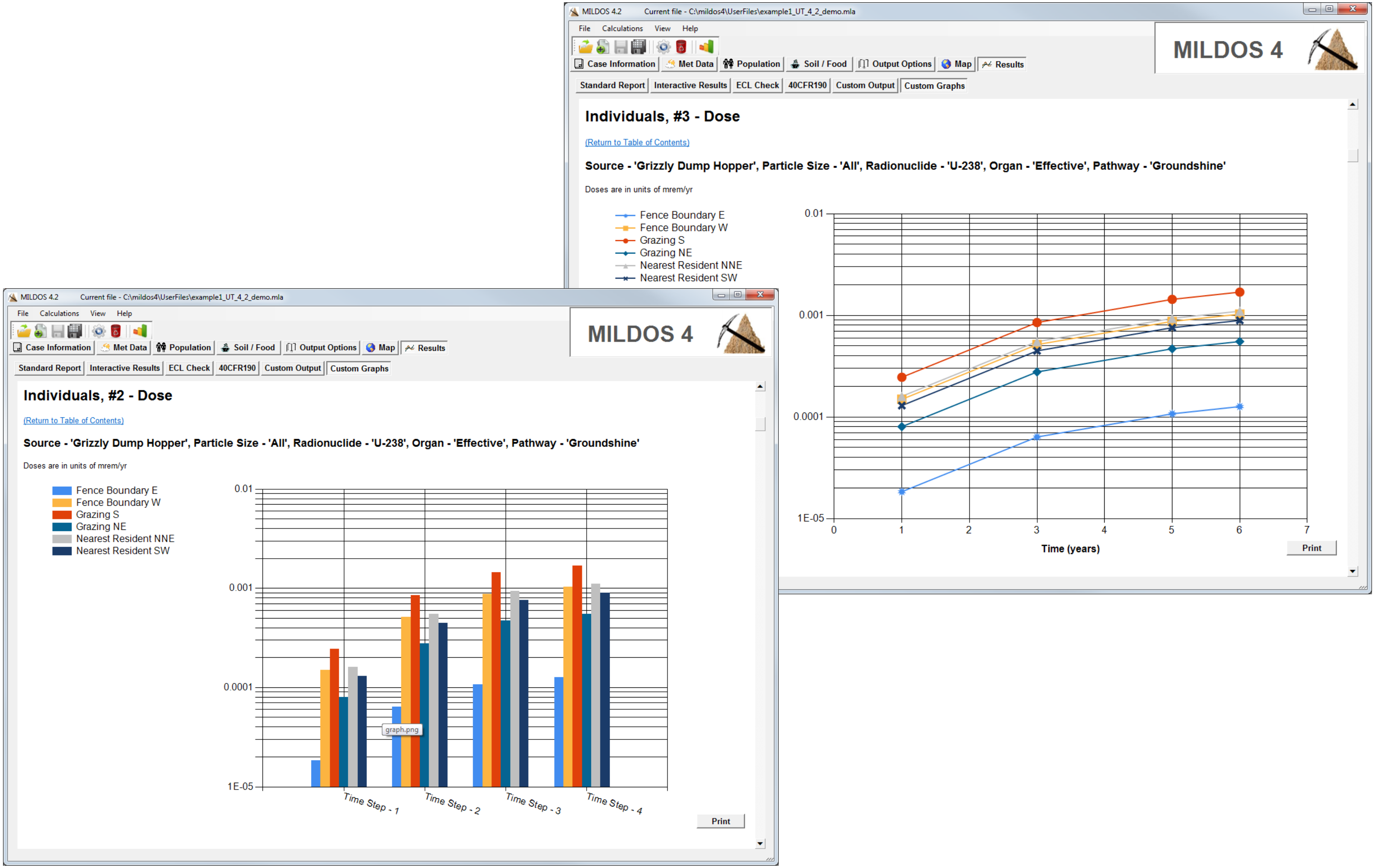


- Save/Import/Export table schema
- Output generation any time results are available

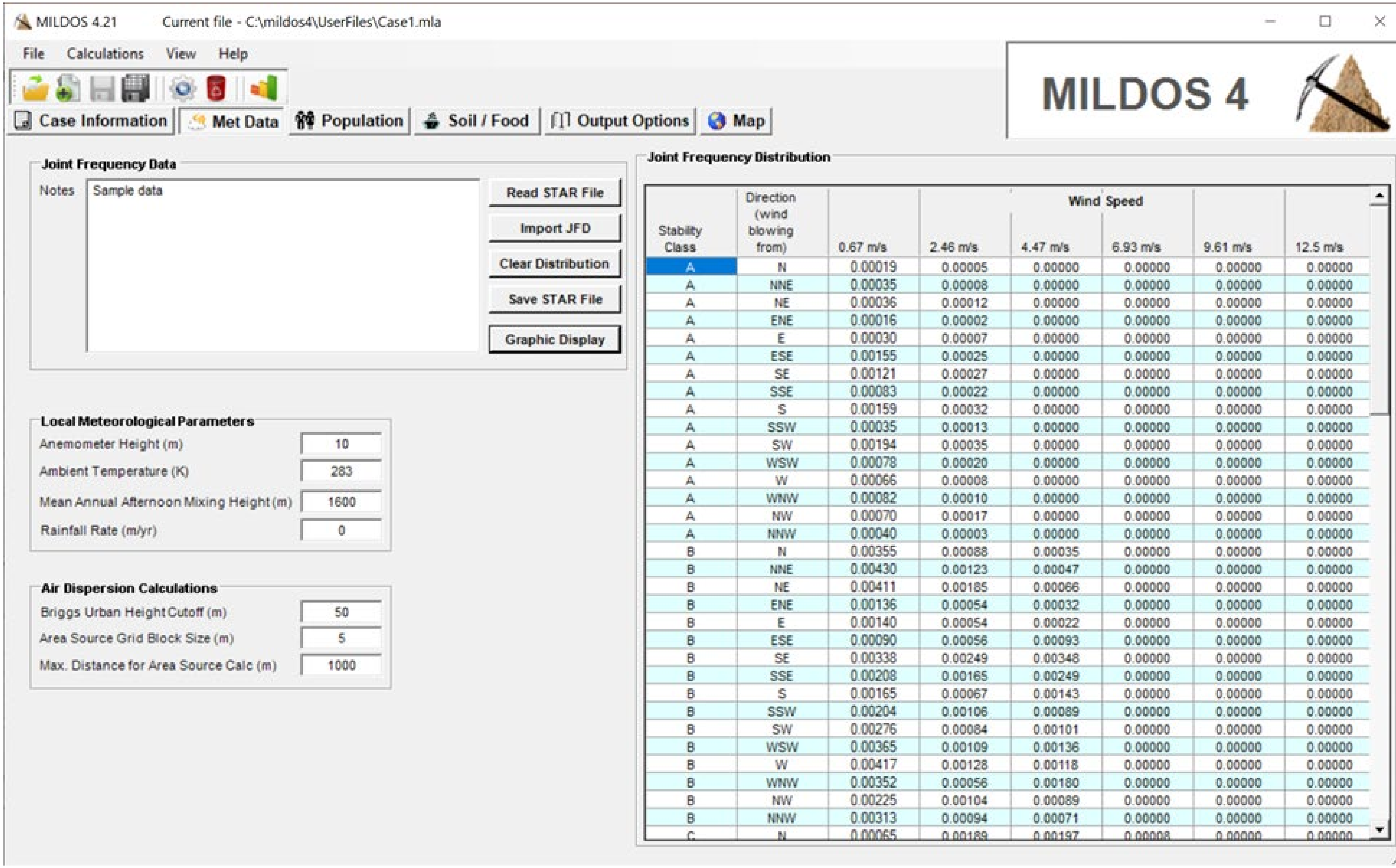
Same Data, Different Perspectives



Same Data, Different Perspectives (cont.)



Meteorological Data Options



Stability Class	Direction (wind blowing from)	Wind Speed					
		0.67 m/s	2.46 m/s	4.47 m/s	6.93 m/s	9.61 m/s	12.5 m/s
A	N	0.00019	0.00005	0.00000	0.00000	0.00000	0.00000
A	NNE	0.00035	0.00008	0.00000	0.00000	0.00000	0.00000
A	NE	0.00036	0.00012	0.00000	0.00000	0.00000	0.00000
A	ENE	0.00016	0.00002	0.00000	0.00000	0.00000	0.00000
A	E	0.00030	0.00007	0.00000	0.00000	0.00000	0.00000
A	ESE	0.00155	0.00025	0.00000	0.00000	0.00000	0.00000
A	SE	0.00121	0.00027	0.00000	0.00000	0.00000	0.00000
A	SSE	0.00083	0.00022	0.00000	0.00000	0.00000	0.00000
A	S	0.00159	0.00032	0.00000	0.00000	0.00000	0.00000
A	SSW	0.00035	0.00013	0.00000	0.00000	0.00000	0.00000
A	SW	0.00194	0.00035	0.00000	0.00000	0.00000	0.00000
A	WSW	0.00078	0.00020	0.00000	0.00000	0.00000	0.00000
A	W	0.00066	0.00008	0.00000	0.00000	0.00000	0.00000
A	WNW	0.00082	0.00010	0.00000	0.00000	0.00000	0.00000
A	NW	0.00070	0.00017	0.00000	0.00000	0.00000	0.00000
A	NNW	0.00040	0.00003	0.00000	0.00000	0.00000	0.00000
B	N	0.00355	0.00088	0.00035	0.00000	0.00000	0.00000
B	NNE	0.00430	0.00123	0.00047	0.00000	0.00000	0.00000
B	NE	0.00411	0.00185	0.00066	0.00000	0.00000	0.00000
B	ENE	0.00136	0.00054	0.00032	0.00000	0.00000	0.00000
B	E	0.00140	0.00054	0.00022	0.00000	0.00000	0.00000
B	ESE	0.00090	0.00056	0.00093	0.00000	0.00000	0.00000
B	SE	0.00338	0.00249	0.00348	0.00000	0.00000	0.00000
B	SSE	0.00208	0.00165	0.00249	0.00000	0.00000	0.00000
B	S	0.00165	0.00067	0.00143	0.00000	0.00000	0.00000
B	SSW	0.00204	0.00106	0.00089	0.00000	0.00000	0.00000
B	SW	0.00276	0.00084	0.00101	0.00000	0.00000	0.00000
B	WSW	0.00365	0.00109	0.00136	0.00000	0.00000	0.00000
B	W	0.00417	0.00128	0.00118	0.00000	0.00000	0.00000
B	WNW	0.00352	0.00056	0.00180	0.00000	0.00000	0.00000
B	NW	0.00225	0.00104	0.00089	0.00000	0.00000	0.00000
B	NNW	0.00313	0.00094	0.00071	0.00000	0.00000	0.00000
C	N	0.00065	0.00189	0.00197	0.00008	0.00000	0.00000

Meteorological Data Import Options

- **Standard formats**
  - Integrated surface hourly (ISH) data (DS-3505 format)
    - Available from the National Centers for Environmental Information (> 1,000 stations in U.S.) – ftp://ftp.ncdc.noaa.gov/pub/data/noaa/
  - AERMET surface file (SFC)
    - Input for current U.S. EPA regulatory model (AERMOD)
    - Often available from state air quality agencies
- **Non-standard formats**
  - Vertical temperature difference (delta-T) data (NRC-administered facilities)
  - Solar radiation (day) and delta-T (night) data (SRDT)
  - Standard deviation of wind elevation angle (σ_E)
  - Standard deviation of wind azimuth angle (σ_A)

Meteorological Data Import Options (cont.)

- **Obtaining ISH data example**
  - From ‘isd-history.csv’ file at NCEI ftp web site (text file also available)
  - Find station number

	A	B	C	D	E	F	G	H	I	J	K
1	USAF	WBAN	STATION NAME	CTRY	STATE	ICAO	LAT	LON	ELEV(M)	BEGIN	END
7642	333012	99999	MYKOLAIV	UP			47.05	31.917	58	20040713	20210312
7643	333120	99999	NOVOHRAD-VOL	UP			50.6	27.633	218	19590101	20200924
7644	333170	99999	SHEPETIVKA	UP			50.167	27.033	278	19361231	20210313
7645	333250	99999	ZHYTOMYR	UP			50.233	28.733	224	19480102	20210313
7646	333390	99999	FASTOV	UP			50.083	29.917	209	19800402	20011222
7647	333450	99999	ZHULIANY INTL	UP		UKKK	50.402	30.451	178.6	19320101	20210313
7648	333451	99999	ANTONOV INTL	UP		UKKM	50.603	30.192	157.6	20040713	20210313
7649	333460	99999	KIEV/BORISPOL	UP			50.35	30.917	125	19590101	19900424
7650	333463	99999	KIEV/BORISPOL	UP			50.35	30.917	125	19900424	19901218
7651	333470	99999	BORYSPIL INTL	UP		UKBB	50.345	30.895	130.1	19610404	20210313
7652	333530	99999	BOGUS SOVIET	UP						19910403	20030511
7653	333560	99999	YAHOTYN	UP			50.217	31.8	128	19590101	20200924
7654	333620	99999	PRILUKY	UP			50.583	32.383	133	19550101	20200924
7655	333680	99999	GREBENKA	UP			50.133	32.45	114	19590101	19880502
7656	333740	99999	LOHVICA	UP			50.367	33.267	127	19840112	19890930
7657	333760	99999	HADIACH	UP			50.367	33.983	154	19590101	20200924
7658	333770	99999	LUBNY	UP			50	33.017	158	19460101	20210313
7659	333820	99999	LEBEDIN	UP			50.583	34.483	142	19890701	19990327
7660	333910	99999	MOSTISKA	UP			49.8	23.15	216	19590101	20020609
7661	333920	99999	YAVOROV	UP			49.933	23.383	229	19890701	19940420

isd-history

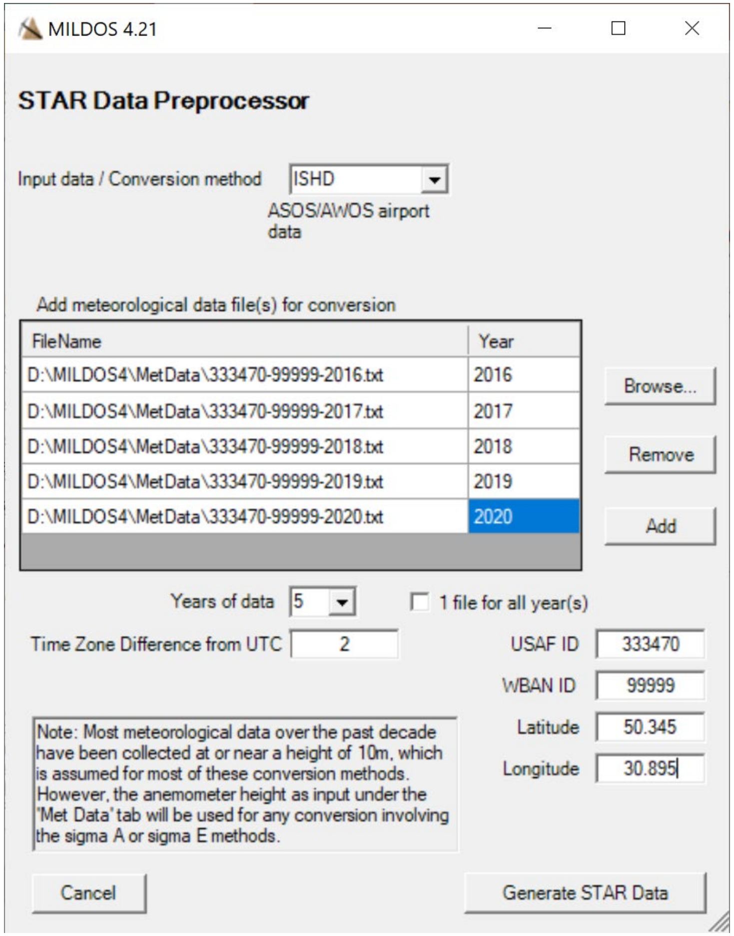
Meteorological Data Import Options (cont.)

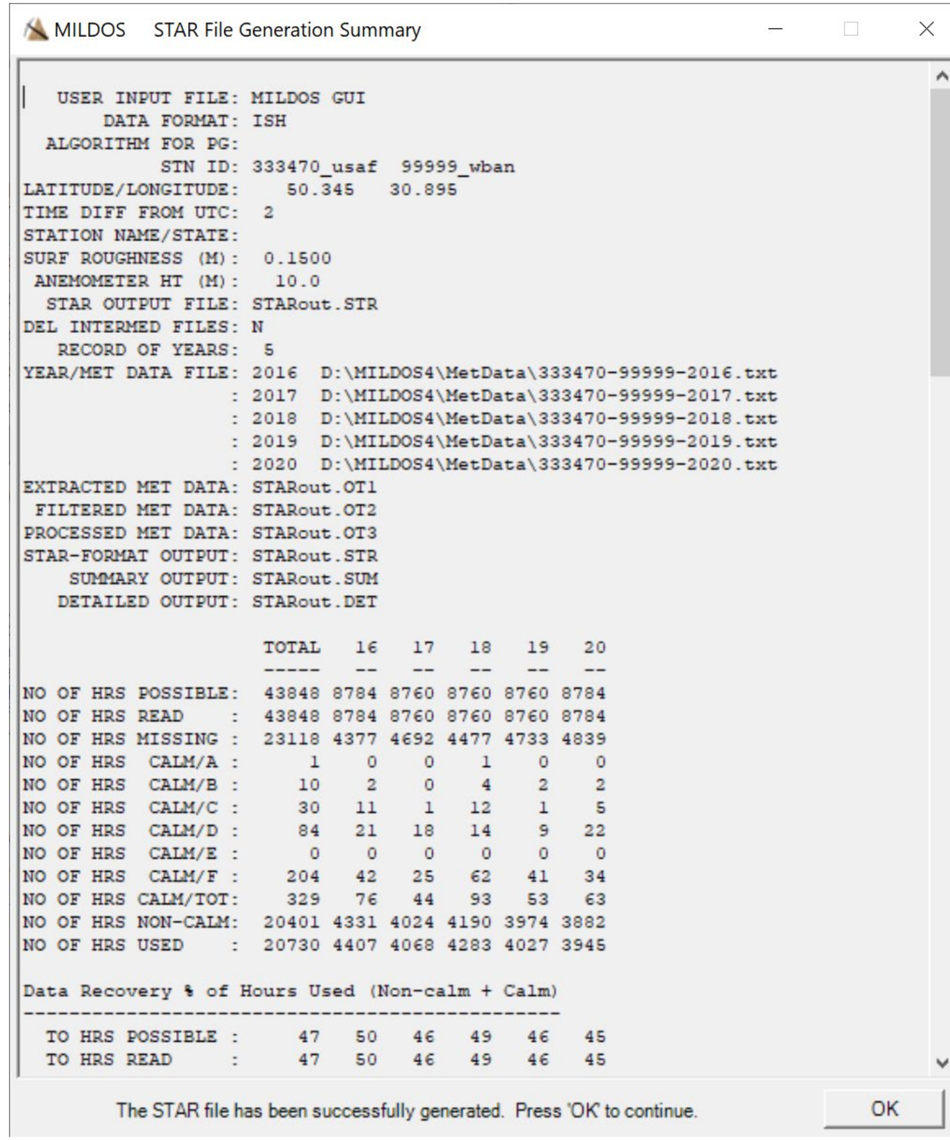
- **From ‘isd-inventory.csv’ file at NCEI ftp web site**
  - Determine what annual data is available
  - Try for minimum of 5 years, if possible
- **Go to desired annual folder and download file(s) of interest**
  - e.g. , ftp://ftp.ncdc.noaa.gov/pub/data/noaa/2020/333470-99999-2020.gz
  - *.gz compressed file type on Windows requires a utility program such as WinZip or 7-Zip to open

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	USAF	WBAN	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
203693	333470	99999	2009	1572	1408	1515	1443	1524	1464	1518	1511	1459	1534	1434	1477
203694	333470	99999	2010	1478	1322	1471	1432	1483	1437	1483	1483	1437	1483	1435	1484
203695	333470	99999	2011	1484	1337	1496	1453	1500	1469	1555	1515	1476	1532	1463	1506
203696	333470	99999	2012	1587	1433	1544	1485	1535	1474	1485	1479	1435	1480	1499	1542
203697	333470	99999	2013	1541	1403	1567	1459	1534	1484	1490	1506	1463	1512	1460	1549
203698	333470	99999	2014	1515	1367	1486	1447	1560	1469	1527	1503	1435	1494	1463	1557
203699	333470	99999	2015	1540	1373	1497	1471	1500	1456	1511	1494	1457	1494	1470	1473
203700	333470	99999	2016	1485	1368	1466	1436	1535	1472	1504	1520	1440	1520	1462	1521
203701	333470	99999	2017	1536	1363	1522	1451	1517	1445	1531	1491	1458	1512	1462	1530
203702	333470	99999	2018	1527	1370	1526	1434	1503	1465	1559	1514	1411	1504	1480	1536
203703	333470	99999	2019	1526	1385	1480	1443	1525	1487	1520	1517	1425	1504	1451	1508
203704	333470	99999	2020	1508	1410	1480	1429	1487	1433	1483	1484	1441	1489	1428	1488
203705	333470	99999	2021	1488	1098	620	0	0	0	0	0	0	0	0	0
203706	333530	99999	1991	0	0	0	3	2	6	5	2	5	3	11	4
203707	333530	99999	1992	4	5	3	4	2	5	3	2	2	7	0	0
203708	333530	99999	2001	0	0	0	0	0	0	1	0	0	0	0	0
203709	333530	99999	2002	0	0	0	1	0	0	0	0	0	0	0	0
203710	333530	99999	2003	0	0	0	0	1	0	0	0	0	0	0	0
203711	333560	99999	1959	93	0	64	55	44	35	43	0	34	1	0	0
203712	333560	99999	1960	0	0	0	0	0	17	2	0	3	2	0	16

isd-inventory

Import Meteorological Data





ISH Data Input

- **UTC time zone offset**

Time Zones in the United States

Standard Time	UTC Offset
Eastern	-5h
Central	-6h
Mountain	-7h
Pacific	-8h

Time Zones in the Ukraine

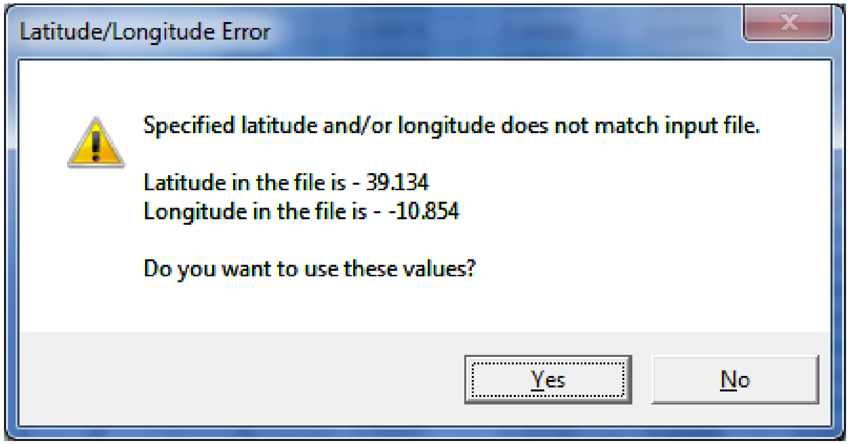
Standard Time	UTC Offset
EET	+2h
MSK	+3h

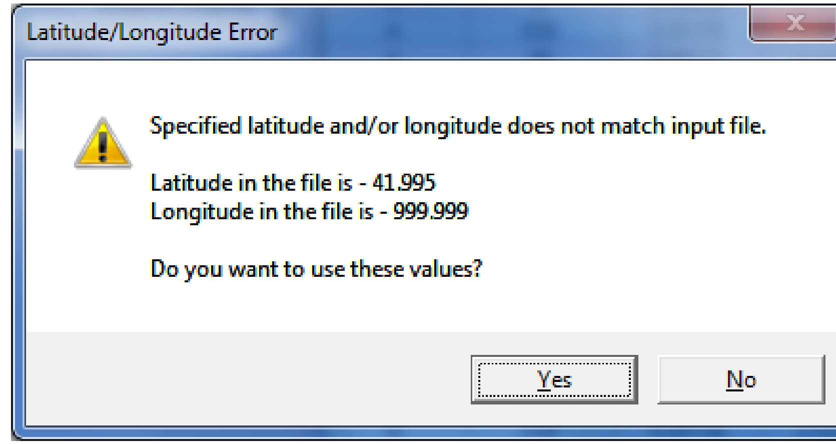
- **Can view the USAF ID, WBAN ID, latitude, and longitude in the data file**

```
0179333470999992016010100004+50345+030895FM-15+013099999V0203501N00401009751
0179333470999992016010100304+50345+030895FM-15+013099999V0203501N00401007321
0202333470999992016010101004+50345+030895FM-15+013099999V0203601N00401010971
0179333470999992016010101304+50345+030895FM-15+013099999V0203601N00401008531
0202333470999992016010102004+50345+030895FM-15+013099999V0200101N00401008531
0179333470999992016010102304+50345+030895FM-15+013099999V0200301N00301009141
0179333470999992016010103004+50345+030895FM-15+013099999V0200501N00301009751
0179333470999992016010103304+50345+030895FM-15+013099999V0200601N00301009751
0179333470999992016010104004+50345+030895FM-15+013099999V0200601N00301006101
0179333470999992016010104304+50345+030895FM-15+013099999V0200701N00301008531
0179333470999992016010105004+50345+030895FM-15+013099999V0200701N00201008531
0179333470999992016010105304+50345+030895FM-15+013099999V0200801N00301008531
0179333470999992016010106004+50345+030895FM-15+013099999V0200701N00401006711
```

Meteorological Data Issues

- Sometimes ISH data from NCEI has a few characters (or more) out of place



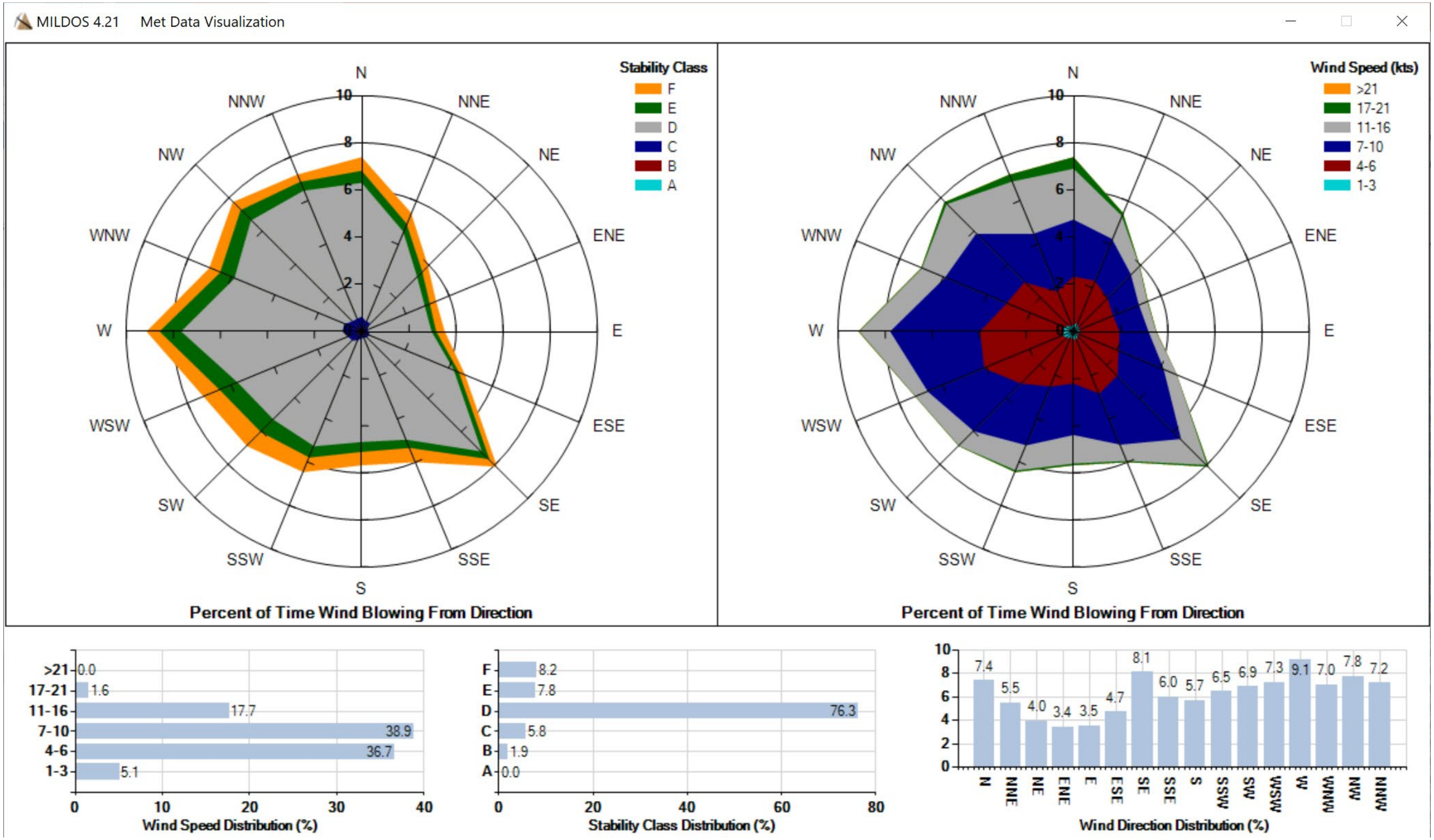


- Found problems by importing into Excel using fixed width columns and sorting on the longitude column (could then search original file and 'fix')

11602	1.48E+26	39117	-108517	FM-12+14739999	9V
11603	1.48E+26	39117	-108517	FM-12+14739999	9V
11604	1.48E+26	39117	-108517	FM-12+14739999	9V
11605	1.48E+26	39117	-108517	FM-12+14739999	9V
11606	1.48E+26	39117	-108517	FM-12+14739999	9V
11607	1.96E+26	39117	-108517	FM-12+14739999	9V
11608	2.45E+26	39134	-10854	SY-MT+1475KGJT	V0
11609					

12786	2.597E+26	+41995-	87934	FM-16+02	V0302605N002	
12787	2.637E+26	+41995-	87934	FM-15+02	V0302605N002	
12788	2.737E+26	+41995-	87934	FM-15+02	V0302705I	(K
12789	3.707E+26	+41995-	87934	FM-15+02	V0309999	4:
12790	1.473E+25	+41995+	999999	FM-15+02	V0309999999	
12791						
12792						

Example Case – Imported Meteorological Data



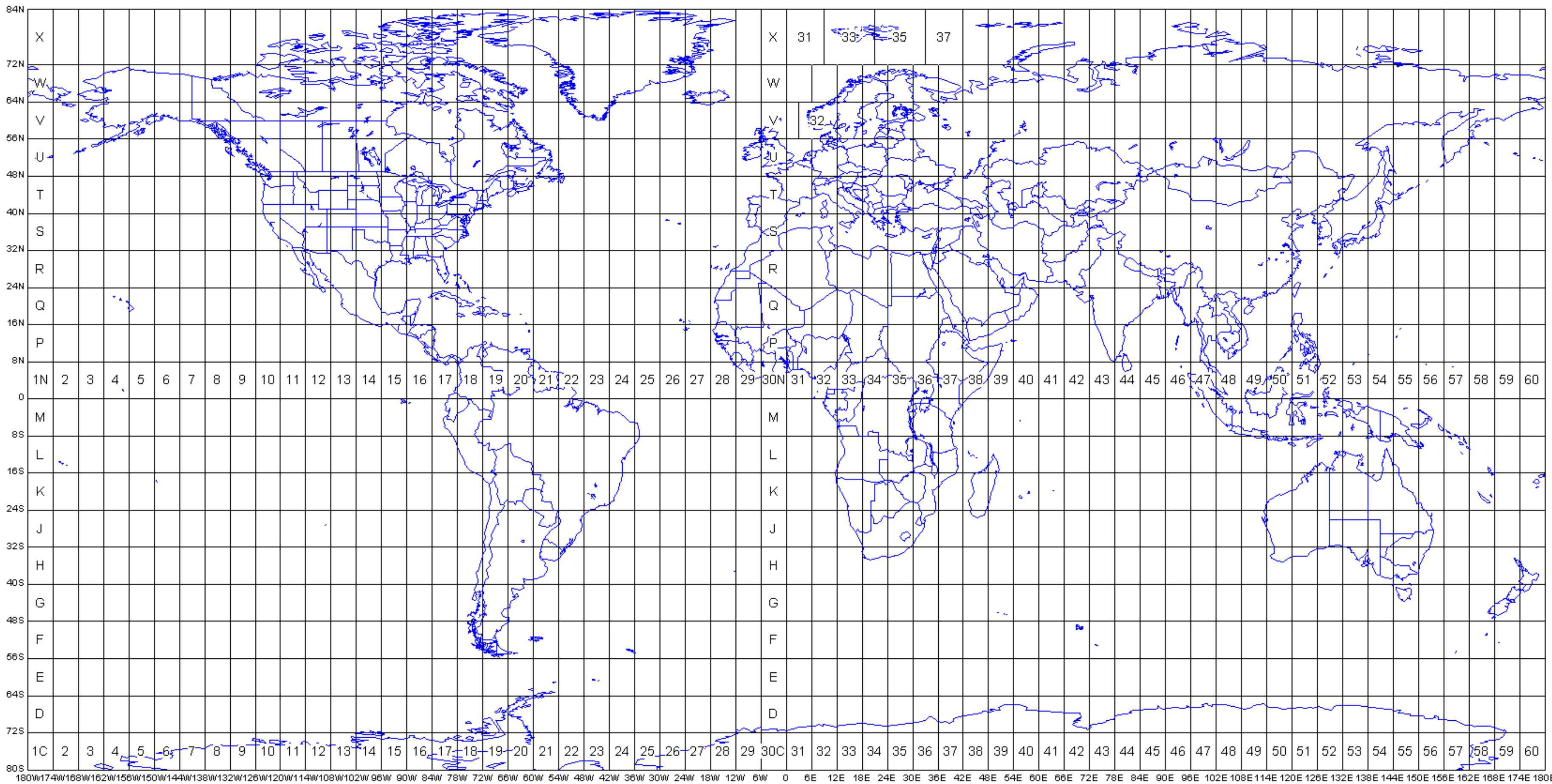
Map Interface

- **Cartesian coordinate system (x,y) with distance units in meters**
- **Local coordinates**
  - 1st emission source located at origin (0,0)
- **Universal Transverse Mercator (UTM) coordinates**
  - Projection with 60 northern zones and 60 southern zones
  - Zones widths are 6° in longitude
  - Zones are numbered 1 through 60 starting at 180°W longitude
  - Continental United States lies in northern zones 10 through 19 (10N through 19N)
  - Ukraine lies in norther zones 34 through 37 (34N through 37N)
  - Easting – east-west direction (x) coordinate
  - Northing – north-south direction (y) coordinate

Datum – mathematical model that describes the shape of the earth (WGS84 and NAD83 are the most recent) WGS84 is a global representation

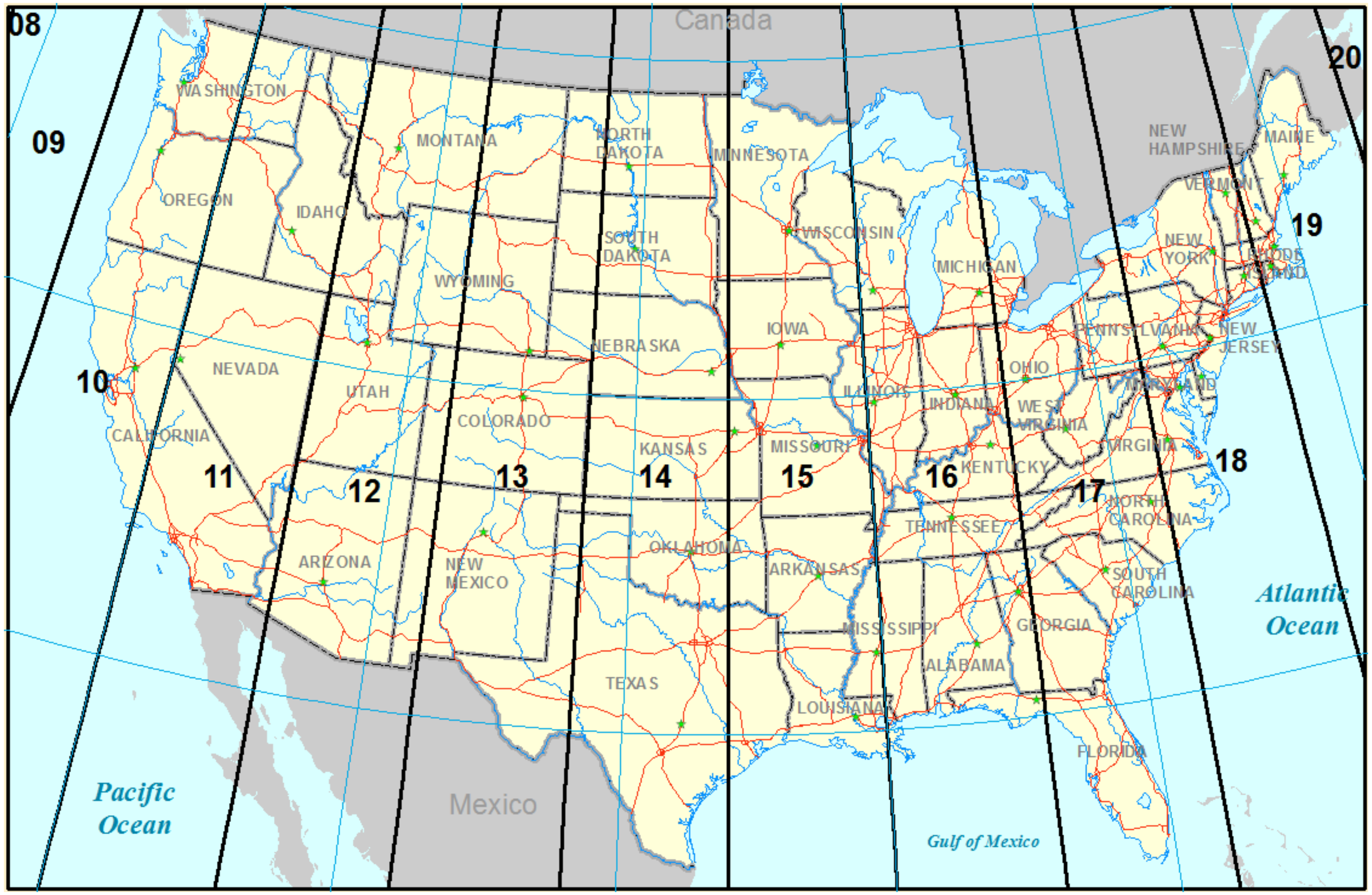
Projection – representation of a curved surface on a flat plan (datum is integral to projection)

Universal Transverse Mercator (UTM) Projection



http://www.dmap.co.uk/utmworld.htm

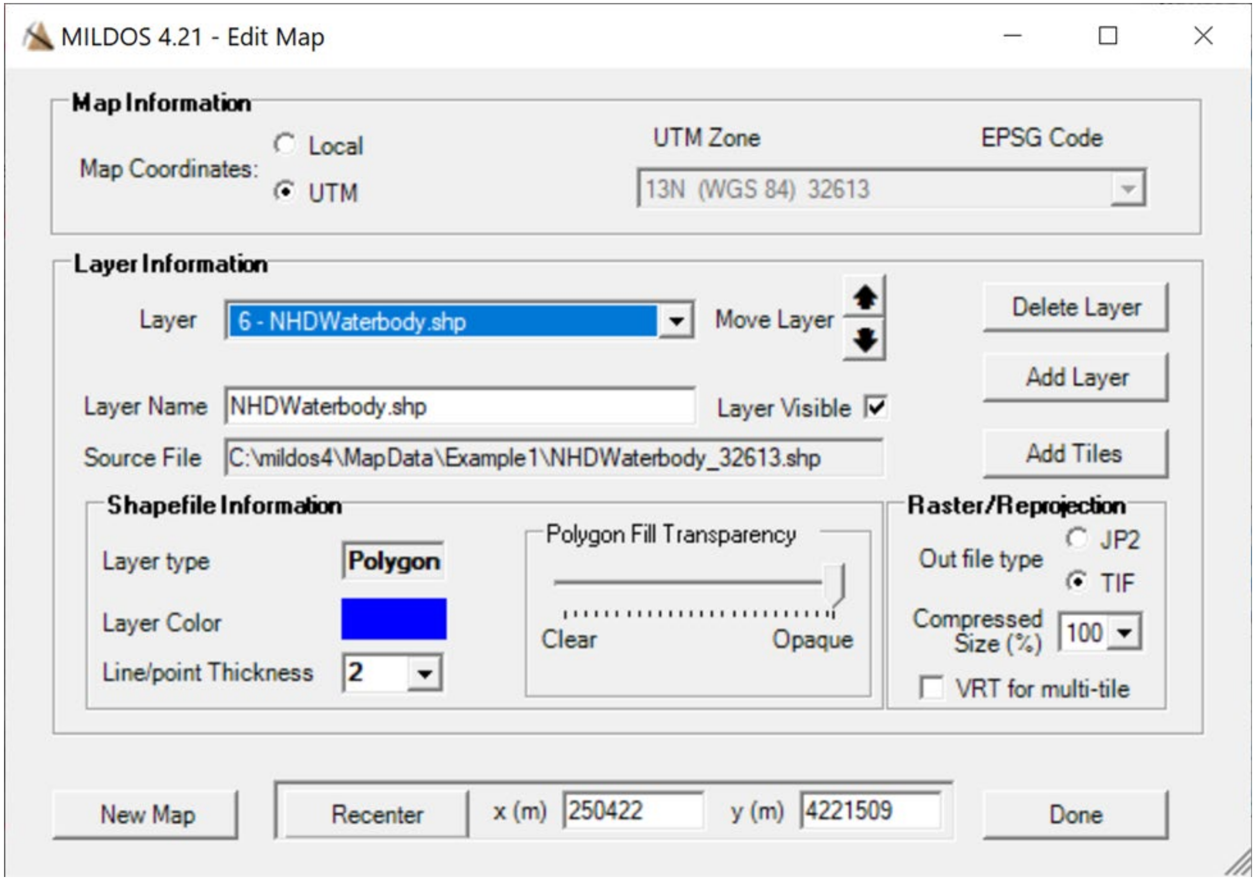
UTM Zones in the Contiguous United States



Map Data

- **Geographic Information System (GIS) module [MapWinGIS]**
  - Limited subset of capabilities
- **Data is geo-referenced**
  - Vector: stored as points, lines, or polygons (collection of coordinated points)
  - Raster: image stored as matrix of cells (e.g., digital pictures or a scanned map)
- **Managed as layers - one vector or image file per layer**
  - May be re-ordered, displayed in order (highest index drawn on top)
  - May be set to invisible
- **All layers must be in the same projection to display properly**
  - Many shapefiles use the decimal degree format
  - Web Mercator format is becoming more popular for raster data
  - Capability exists to re-project raster (image) and shapefiles (vector) into the proper UTM format

Map Management



Supported Raster Data

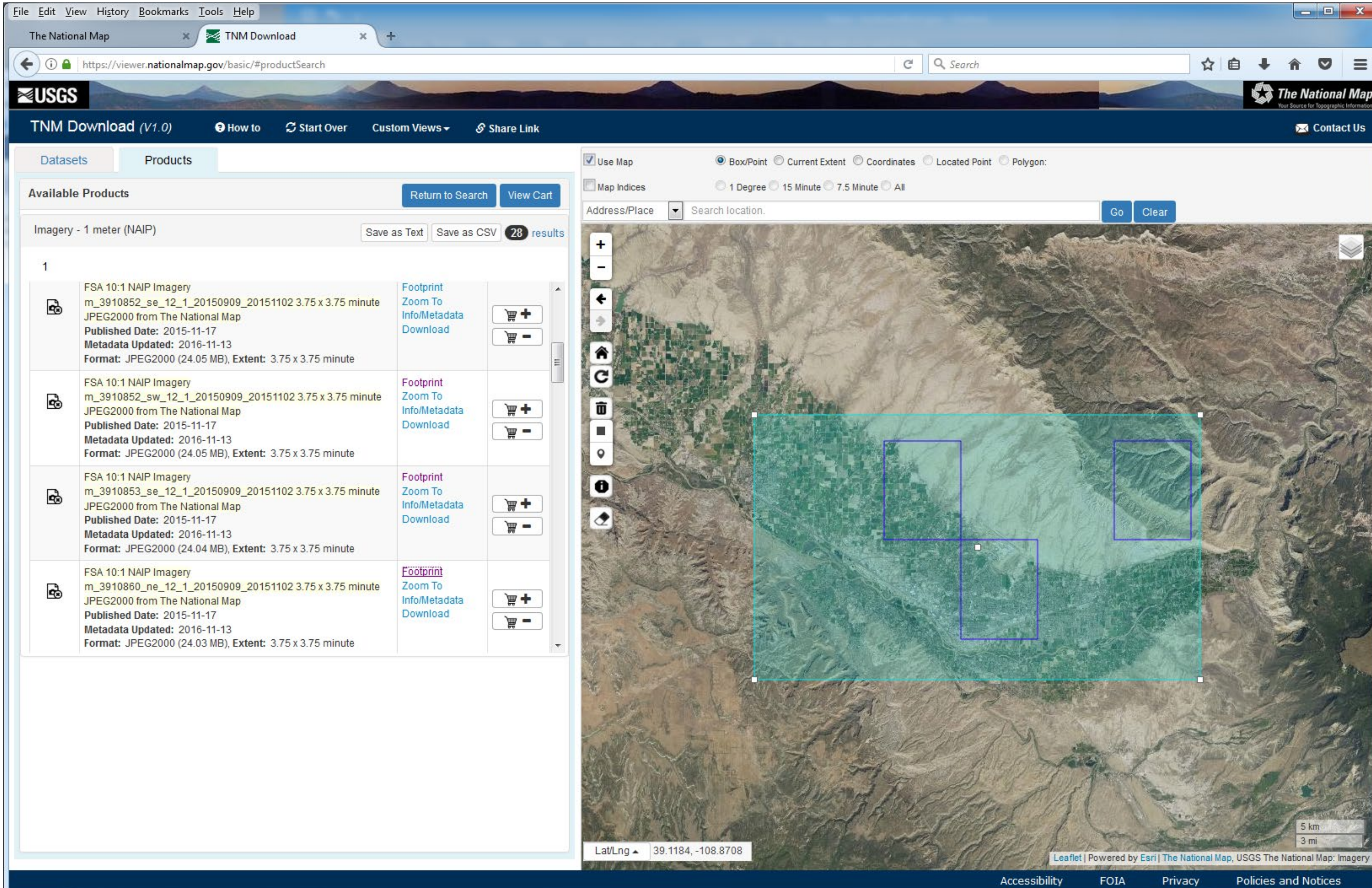
File Type	File Extension
Bitmap	.bmp
Graphics Interchange Format (GIF)	.gif
Joint Photographic Experts Group (JPEG) & JPEG2000	.jpg, jp2
Portable Network Graphics (PNG)	.png
Multiresolution Seamless Image Database (MrSID)	.sid
Tagged Image File Format (TIFF)	.tif
Geodata Data Abstraction Library (GDAL) Virtual TIFF	.vrt

Sources of Free Map Data

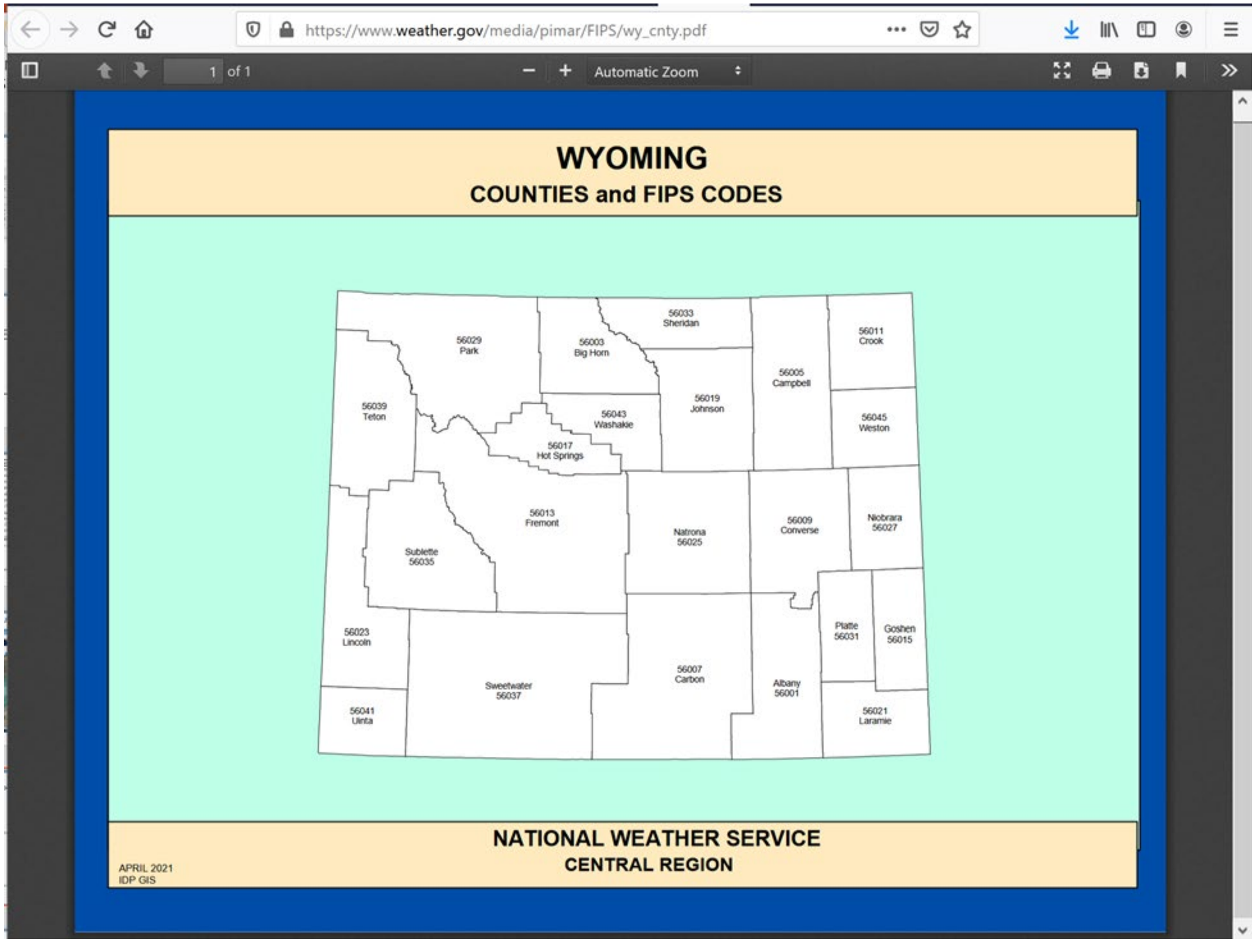
- **The National Map**
  - nationalmap.gov
  - https://apps.nationalmap.gov/viewer/
    (jpeg2000 image files now in WGS 1984 Web Mercator Auxiliary Sphere projection; needs re-projection before use in MILDOS 4)
- **State / County / Local GIS Portal Examples**
  - New Mexico (https://rgis.unm.edu/rgis6/)
  - Utah (http://gis.utah.gov/)
  - Wyoming (https://data.geospatialhub.org/)
- **U.S. Census Bureau**
  - Comprehensive shapefile collection (Tiger/Line data)
  - https://www.census.gov/programs-surveys/geography/guidance/tiger-data-products-guide.html
- **U.S. Department of Transportation**
  - National Transportation Atlas DB
  - https://www.bts.gov/geospatial/national-transportation-atlas-database

National Map Data
US Topo
Historical Topo Maps
Structures
Transportation
Boundaries
Geographic Names
USGS Map Indicies
Hydrography
Contours
Land Cover
Elevation
Orthoimagery

The National Map (provided through the USGS)



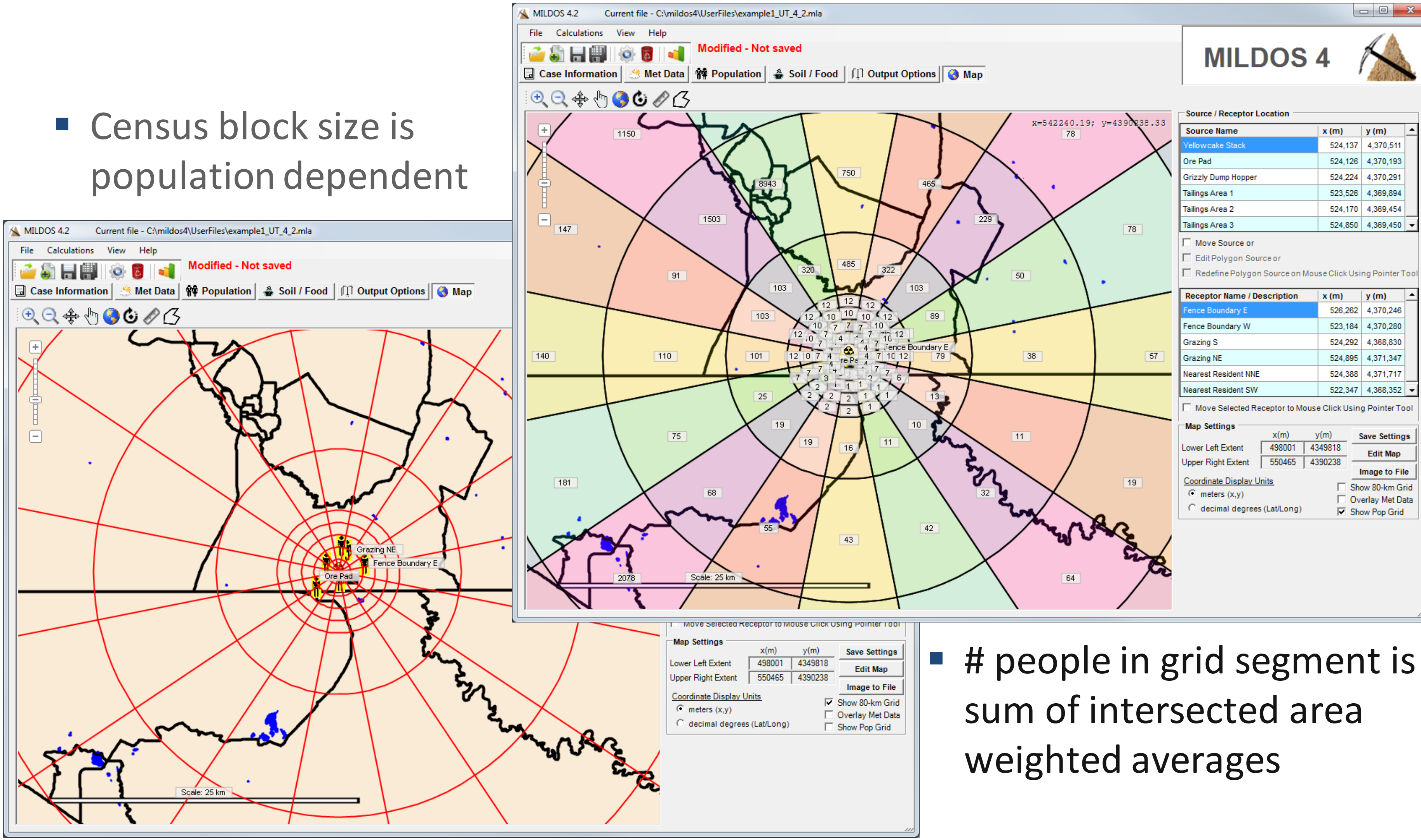
Tiger File Downloads -
File Names Based on County FIPS Codes



https://www.weather.gov/pimar/FIPSCodes

U.S. Census Population at the Block Level

- Census block size is population dependent



- # people in grid segment is sum of intersected area weighted averages

ISR Example

- **9 well fields**
  - Different time frames
  - Different sizes and locations
- **Each field modeled using 5 source inputs over time (new well field, production well field (vent), production well field purge, restoration well field (vent), restoration well field purge)**
  - 1st well field assumed in production at start
  - Production starts after all wells drilled
  - Restoration starts after production completed
- **Ion exchange tanks in main processing facility**
  - Handles product solution from all fields
- **Purge/bleed release for all fields at main processing facility**
  - Purge rate set the same for all producing fields (330,000 L/d) and the same for all restoration well fields (300,000 L/d)
- **Time frame of 11 years**

More Information

- **Web sites**

  mildos.evs.anl.gov
  ramp.nrc-gateway.gov

- **Contacts**

Argonne NATIONAL LABORATORY

U.S.NRC United States Nuclear Regulatory Commission *Protecting People and the Environment*

Bruce Biwer
bbiwer@anl.gov

Dave LePoire
dlepoire@anl.gov

Sunita Kamboj
skamboj@anl.gov

Casper Sun – NRC project manager
(301) 415-1646
casper.sun@nrc.gov

For technical support, send questions or comments to mildos@anl.gov