Radon Emissions From Tailings Ponds

Presented To:

National Mining Association (NMA) /Nuclear Regulatory Commission (NRC) Uranium Recovery Workshop

Denver – July 2, 2009

Presented By:

Dr. Douglas B. Chambers

Environmental Excellence Since 1980
SENES Consultants Limited

Today's Discussion

- Subpart W
- Radon
- Radon diffusion
- Radon flux from tailings
- Radon from water cover
- EPA's proposed method of monitoring
- Summary observations

Subpart W
NESHAP for Radon Emissions from Operating Mill Tailings

- ***Uranium byproduct material or tailings* means waste produced by the extraction or concentration of uranium from any ore processed primarily for its source material content.**
- **Rn-222 flux from existing uranium mill tailings pile of less than 20 $pCi/m^2 \cdot s$**

Subpart W …(cont'd)
NESHAP for Radon Emissions from Operating Mill Tailings

- **New tailings impoundments must meet one of two work practices**
  - **For phased disposal, no more than two 40 acre cells (including existing impoundments can be in operation at any single time**
  - **For continuous disposal, tailings are dewatered and immediately disposed with no more than 10 acres in operation at any one time**
- **Annual radon flux testing required**

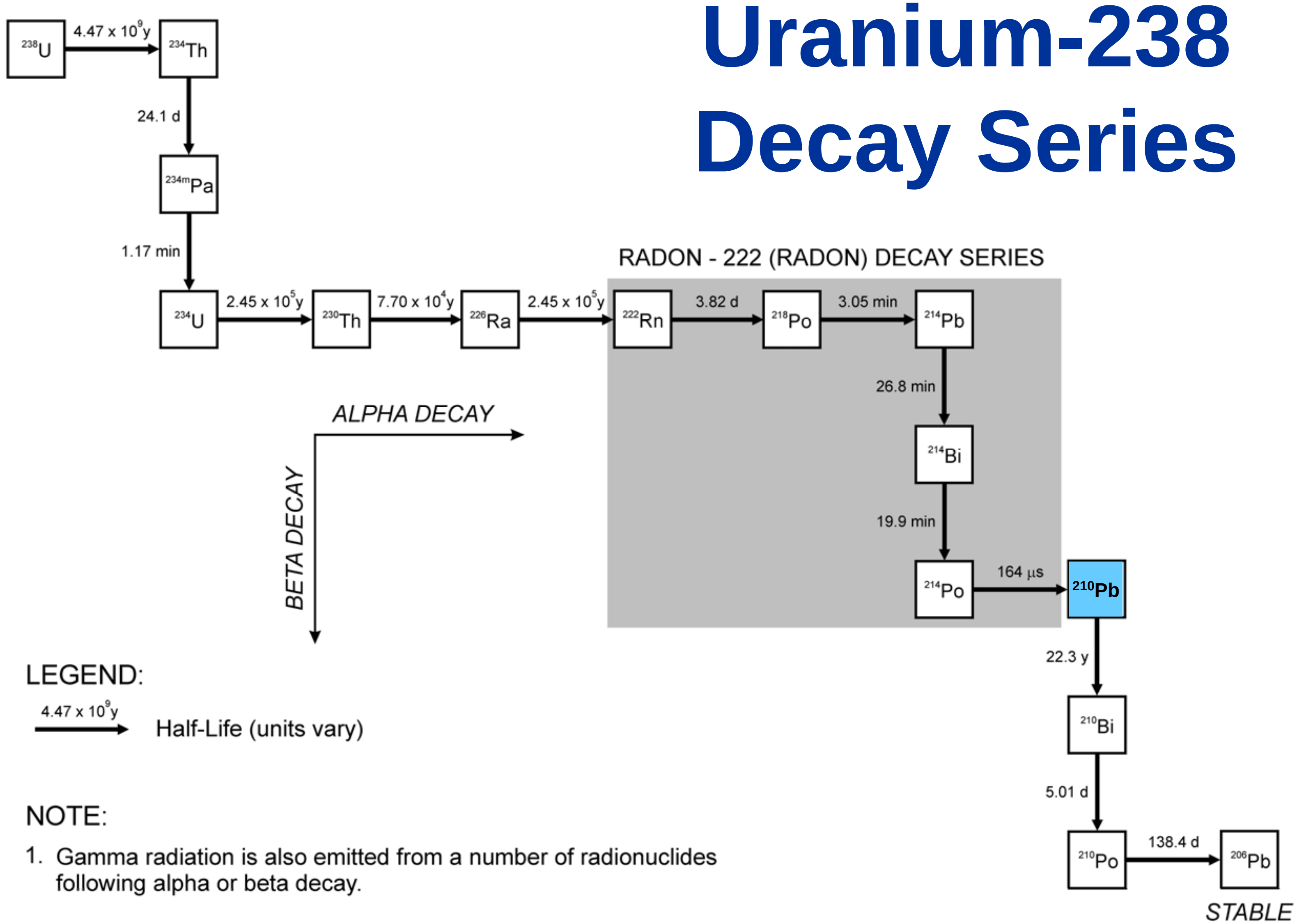
Nominal Radon Flux
(BID – Final Rule for Radon, EPA 1986)

- Dry Tailings (soil) 1 pCi Rn-222/m^2s per pCi Ra-226/g
- Saturated 0.3 pCi Rn-222/m^2s per pCi Ra-226/g
- Water Cover 0 pCi Rn-222/m^2s per pCi Ra-226/g

Radon

- Radon is everywhere
- Produced through radioactive decay of Ra-226
- Half-life of 3.82 days
- EPA has raised issue with ISR evaporation ponds
- EPA has raised issue with Pb-210

Uranium-238 Decay Series



LEGEND:

4.47 x 10^9 y → Half-Life (units vary)

NOTE:

1. Gamma radiation is also emitted from a number of radionuclides following alpha or beta decay.

Radon Production Rate

The radon production rate (q) in a porous radium-bearing material can be expressed as:

$$q = [Ra] \times \rho \times \frac{E}{P} \times \lambda$$

$$= \frac{\beta \times E}{P} = \frac{\beta}{P}$$

Where:

[Ra] = radium-226 concentration

ρ = bulk density (g/cm^3)

E = emanation coefficient

P = porosity (void fraction)

λ = radon decay constant

β = emanating power ($pCi/s\text{-}cm^3$)

Diffusion Length

$$L = \sqrt{\frac{D}{\lambda P}}$$

Where:

L = diffusion length

= distance to which concentration decreases by factor of e (= 2.718)

D = bulk diffusion coefficient (cm^2/s)

λ = radon decay constant

= $2.1 \times 10^{-6}/s$

P = porosity (void volume/total volume)

Diffusion of Radon Across a Medium

In general, when radon is covered by inert material, diffusive flux (J) can be expressed (approximately) as:

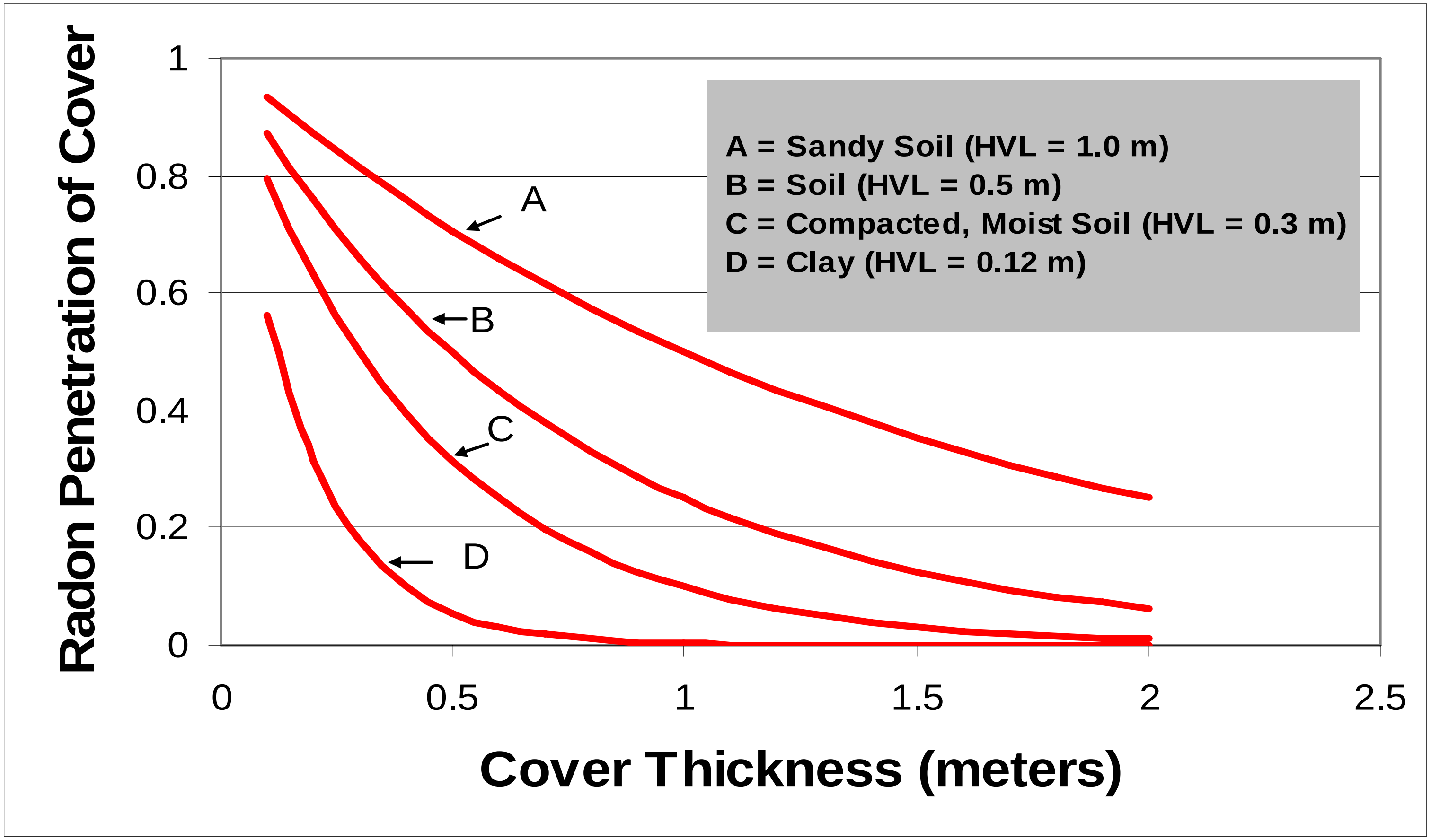
$$J = e^{\frac{-Z}{L}}$$

Where:

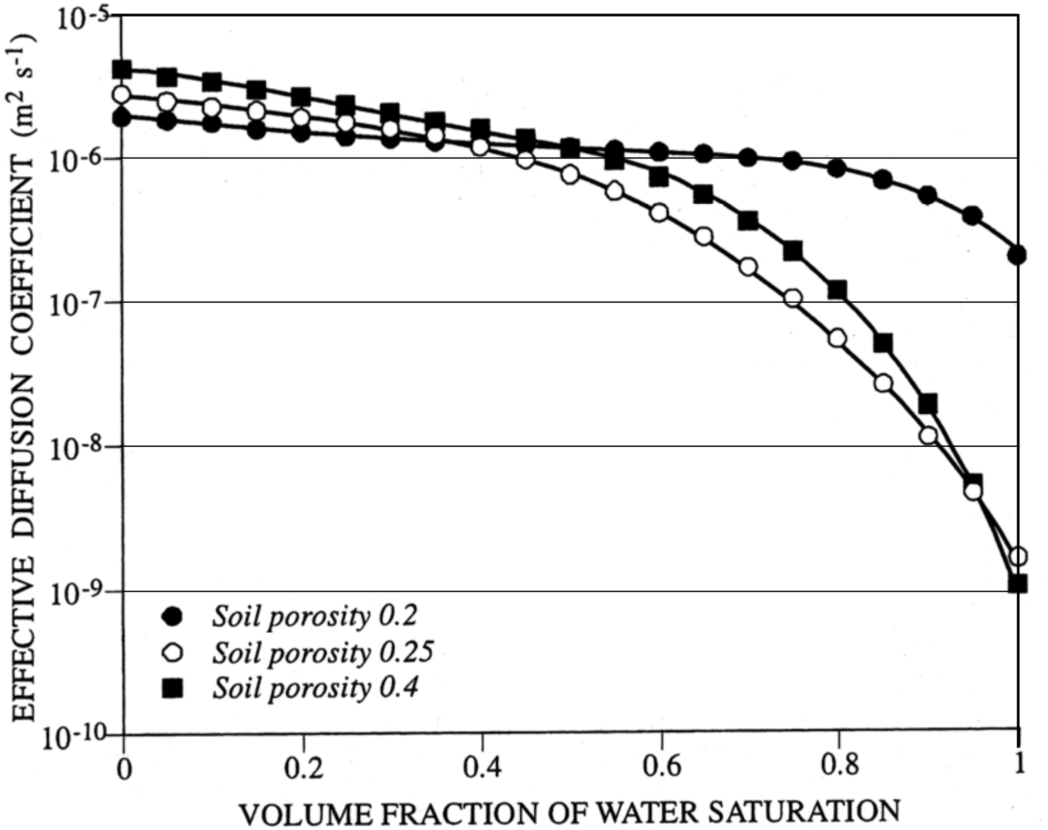
Z = “Cover” thickness

L = diffusion length

Diffusion of Radon Across a Medium

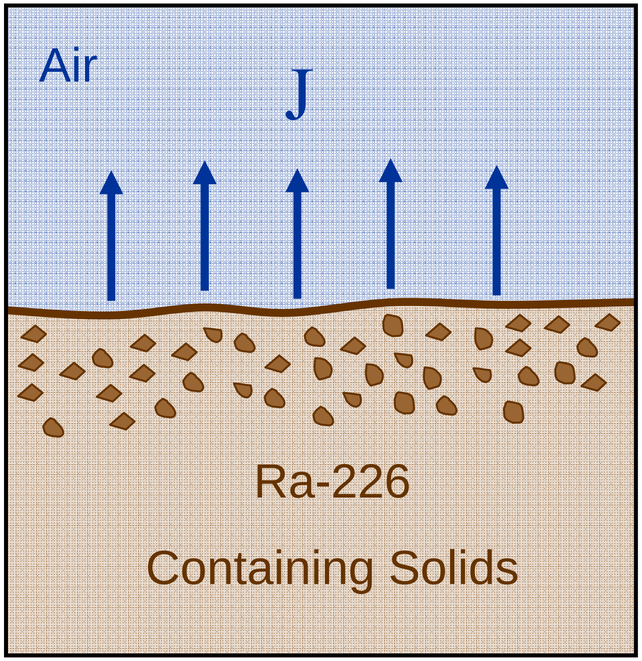


Experimental Diffusion Coefficients (UNSCEAR 2000)



SOURCE: After UNSCEAR 2000

Radon Flux



Based on Fick's Laws:

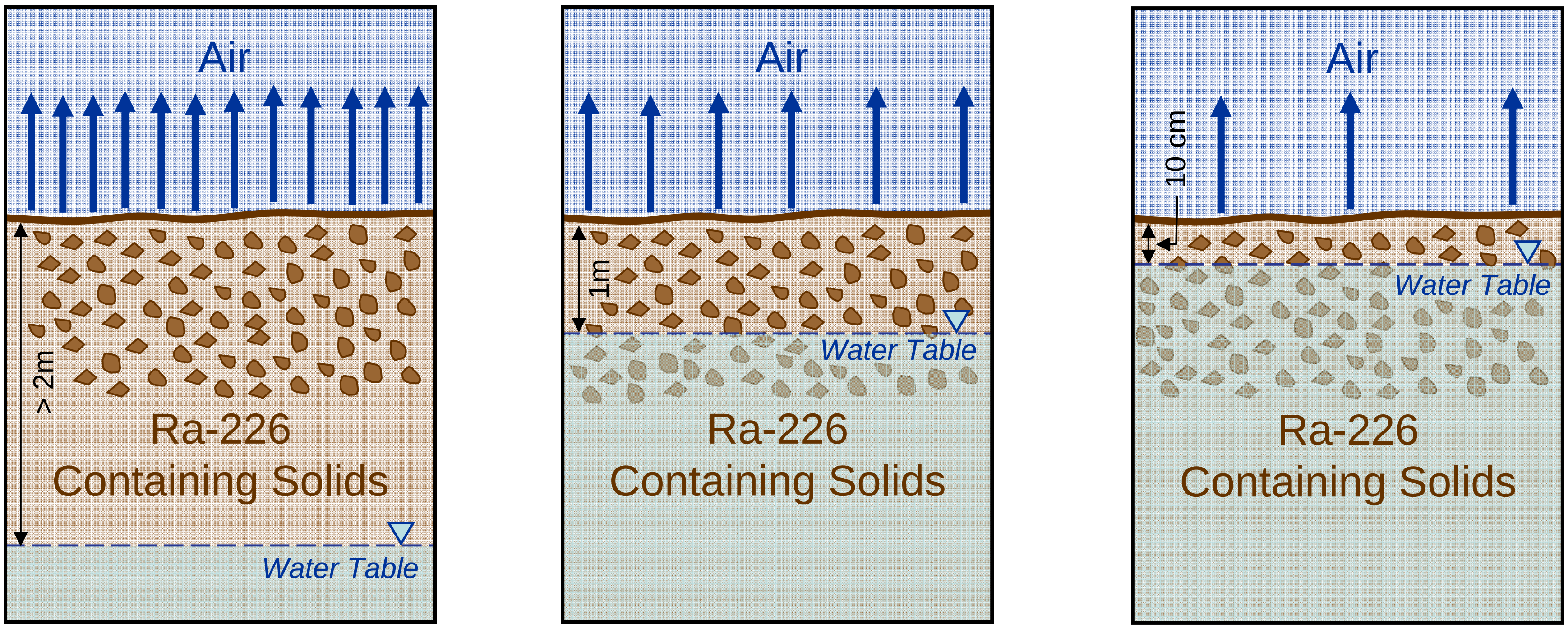
$$J = \beta \times L \quad (pCi/m^2 \cdot s)$$

Where:

β = emanating power ($pCi/m^3 \cdot s$)

L = diffusion length

Effects of Depth to Water Table



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

NMA THE AMERICAN RESOURCE

Radon From Water Cover (1)

- Two Mechanisms
  - Diffusion
  - Turbulent transfer

Radon From Water Cover (2)

Diffusion

- Diffusion coefficient in water << diffusion coefficient in air (1/100th)
- Rn-222 gas exchange via diffusion from surface of small lake has been measured (Experimental lakes, Ontario)

$$F\ (pCi/m^2 \cdot d) \cong k_{Rn}\ (m/d)\ x\ [C\text{-}Co]\ (pCi/m^3)$$
$$\cong k_{Rn}\ x\ C$$

- For $k_{Rn} \sim 0.5$m/d

C (pCi/L)	F ($pCi/m^2 \cdot s$)
10	5.8×10^{-5}
100	5.8×10^{-4}
1000	5.8×10^{-3}

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

NMA THE AMERICAN RESOURCE

Radon From Water Cover (3)

- Turbulence (wave action)
  - Rn-222 is produced at the rate of 2.1 x 10^{-6}/s from Ra-226
  - Assumes radon released at surface as it is produced from Ra-226 within "turbulent" layer

Ra-226 (pCi/L)	Depth of Turbulent Mixing (cm)	Rn-222 (pCi/$m^2 \cdot s$)
10	10	0.002
	50	0.01
100	10	0.02
	50	0.1
1000	10	0.2
	50	1

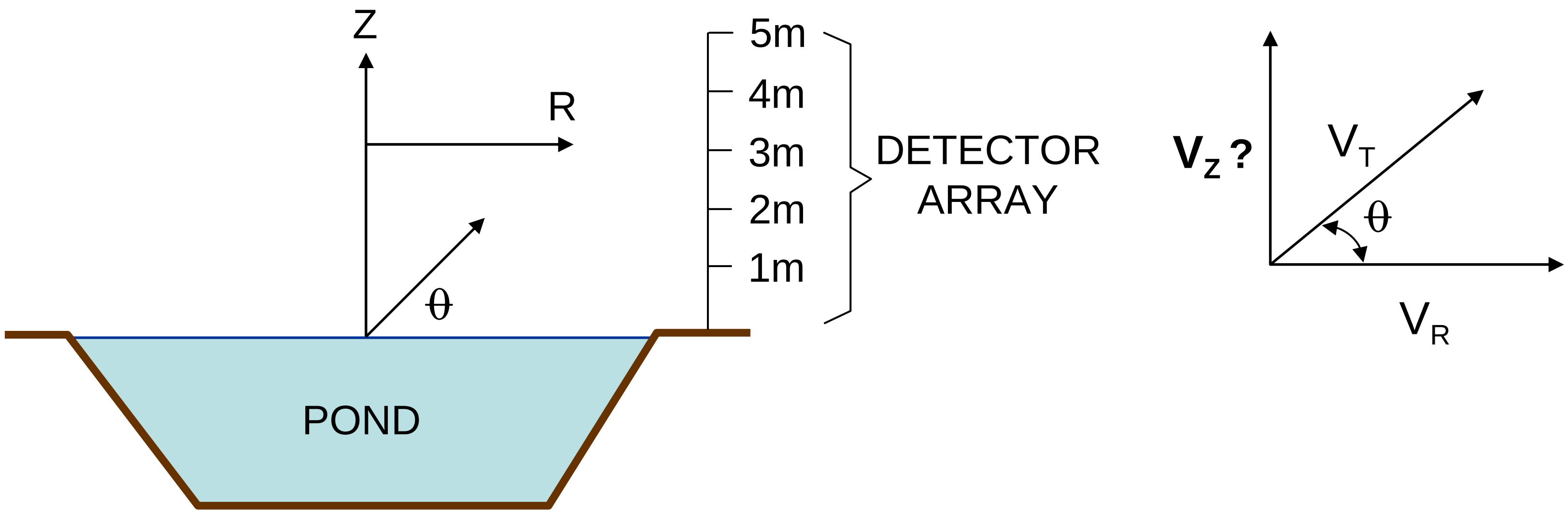
U.S.NRC United States Nuclear Regulatory Commission Protecting People and the Environment

NMA THE AMERICAN RESOURCE

Can We Measure Radon Flux From Water Covered Tailings ?

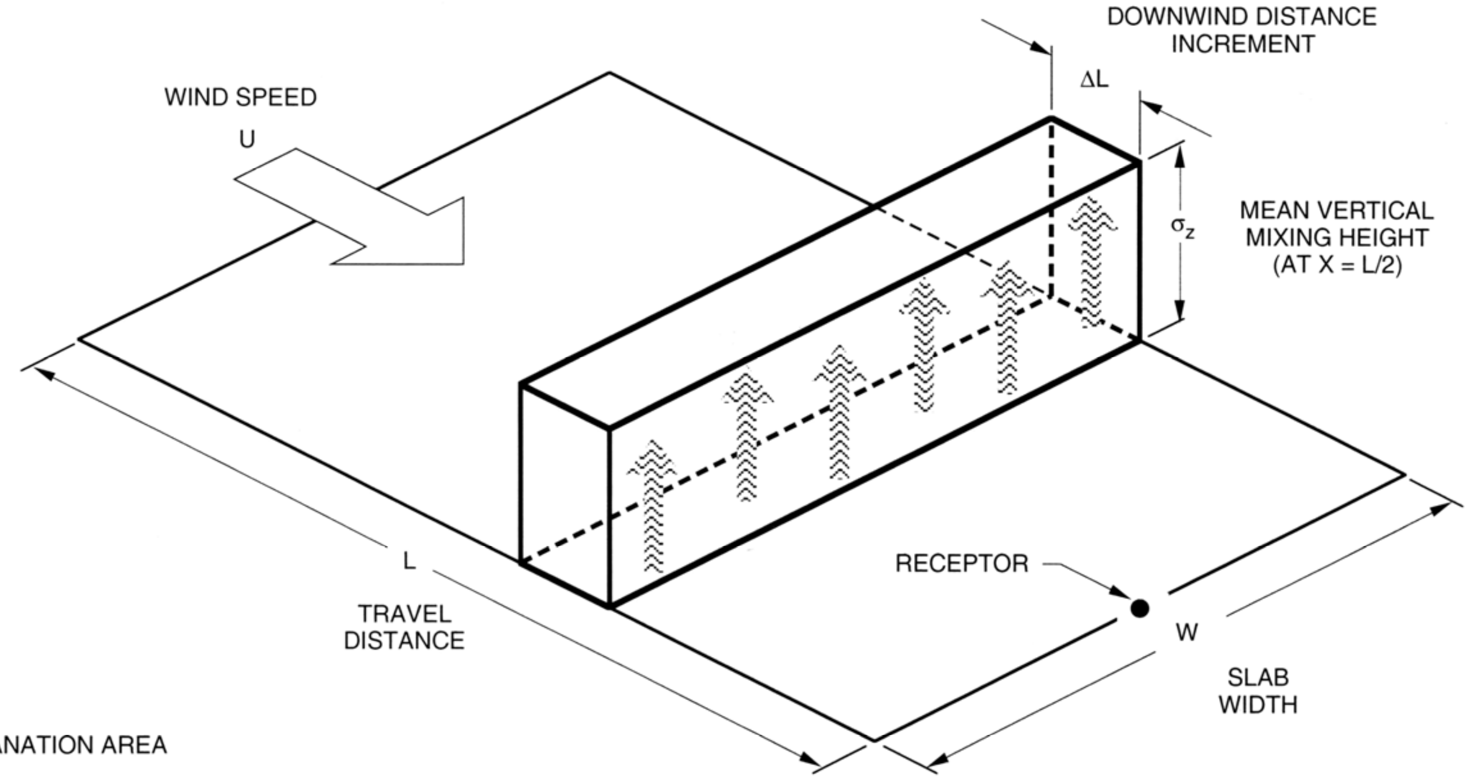
- **EPA's proposal**
- **Schiager's method**
- **Diurnal variation**
- **Rn-222 with distance**
- **Pb-210 with distance**

Pond Showing Z & R Directions and Detector Array



SOURCE: After EPA, 2009

Schiager's Box Model



NOTE:

$W\Delta L$ = EMANATION AREA

$\sigma_z W\Delta L$ = DILUTION VOLUME

$$C_X\ (pCi / m^3) = \frac{[\text{FLUX}, \Phi]\ [\text{AREA}, W\Delta L]\ [\text{TIME}, L/U]}{[\text{VOLUME}, \sigma_z W\Delta L]} = \frac{\Phi L}{U\sigma_z}$$

σ_z defined by stability class

SOURCE: After Schiager, 1974

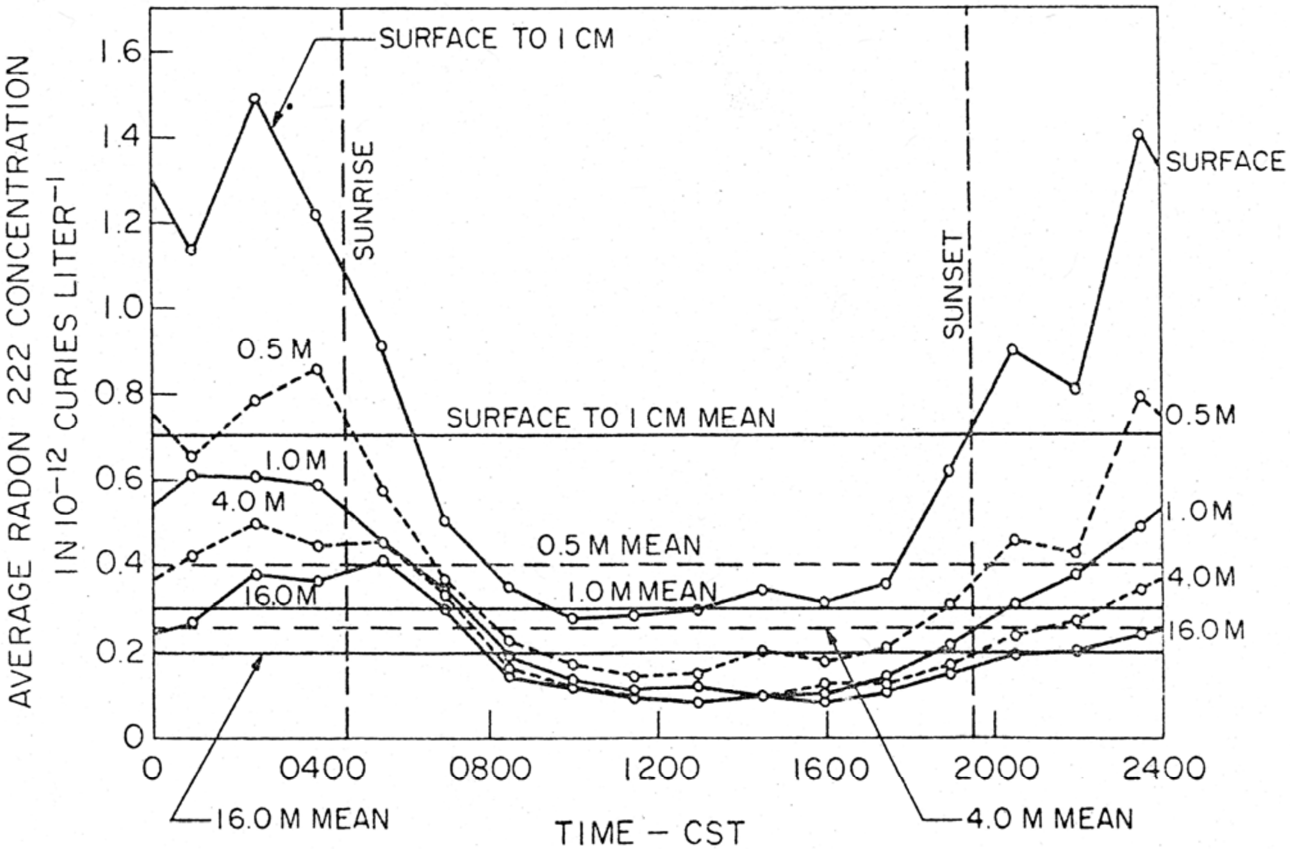
Incremental Radon

- **Using Schiager model**
  - **80 acres of pond**
  - **Radon flux of 1 $pCi/m^2 \cdot S$**
  - **L= 600 m**
  - **Sigma z from Turner workbook of (about) 24m**
  - **Assume u = 3 m/s**
- **Radon concentration at edge of cell**

  C = (1 x 600)/(3 x 24) pCi/m^3 x 1 m^3/1000L

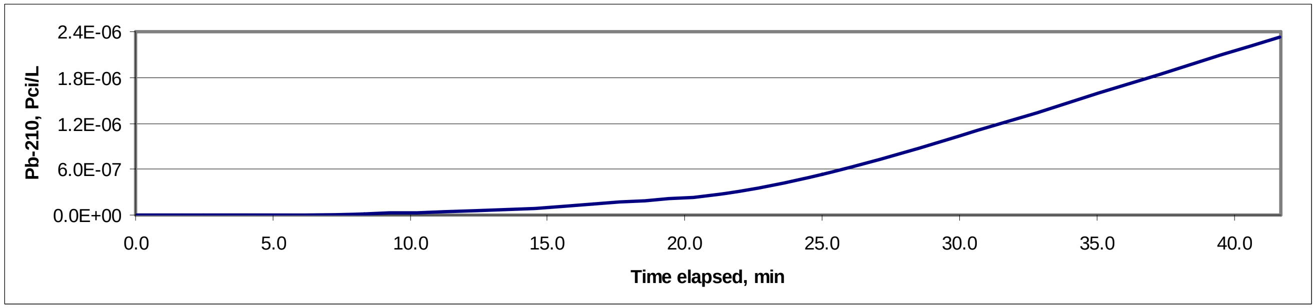
  = 0.08 pCi/L

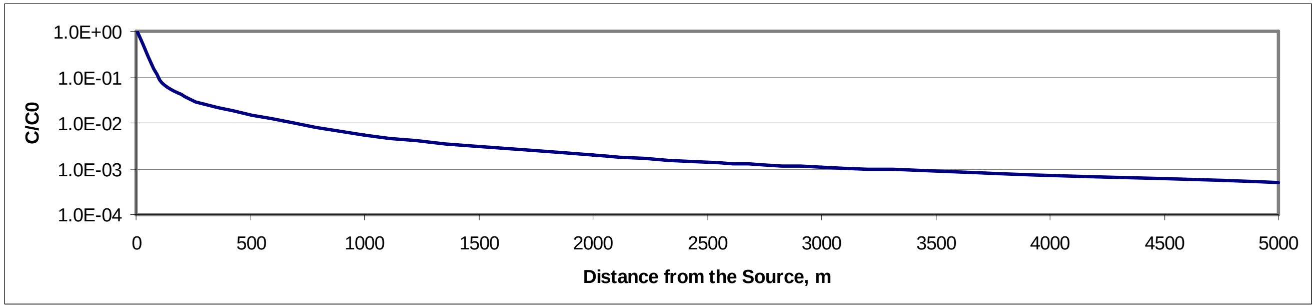
Rn-222 Concentration Diurnal Variation

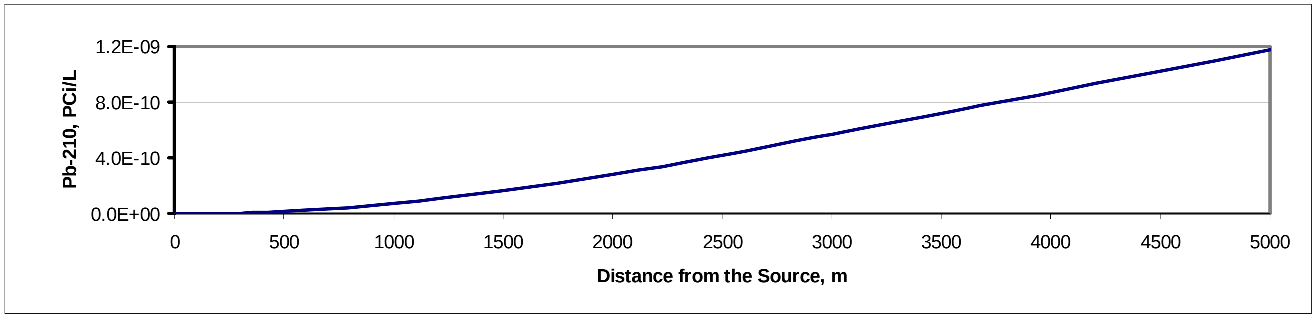


SOURCE: After Pearson, U.S. Department of Health & Welfare, 1967

Pb-210 with Distance*







* Denver Windrose, 80 acre source at 1pCi/m^2s, direction of maximum concentration

** Background Pb-210 ranges from $3x10^{-6}$ pCi/L to $30x10^{-6}$ pCi/L (UNSCEAR 2000)

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

NMA THE AMERICAN RESOURCE

Key Observations

- Rn-222 is everywhere
- Concentrations of Rn-222 vary with location, time of day, meteorological conditions .....
- Rn-222 flux from ponded areas << dry areas
- Practical limits on ability to measure Rn-222 (or Pb-210) from pond areas
- Suggest feasibility assessment (DQO process) prior to implementation of proposed monitoring practices