Tritium Dose Pathway Comparison – Regulatory Guide 1.109 and Beyond

Ken Sejkora

Entergy Nuclear Northeast – Pilgrim Station

Presented at the 15th Annual RETS-REMP Workshop

Wilmington, NC / 27-29 June 2005

Need For Investigation

- At 2003 RETS-REMP Workshop, I reported that tritium released via airborne pathways yielded an equivalent dose 100 to 1,000 times higher than releases via liquid pathways
- Several other licensees that have performed such a comparison have obtained similar results
- Choice of release pathway can be an important factor in overall tritium management strategy
- Inquiring minds want to know…Why does airborne pathway yield higher dose?

Basis for Comparison

- Effluent dose pathway models were based on Regulatory Guide 1.109…
  - "Calculation of Annual Doses from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I"
- RG-1.109 provides standard equations for calculating media concentrations to estimate annual intake of radionuclides
- Perform comparison of RG-1.109 models for liquid and airborne effluent pathways

Concentration in Water – Liquid Effluent Pathway

- Regulatory Guide 1.109 Equation A-1
- $C_w = 1100 * (M_p / F) * Q * \exp(-\lambda t)$
  - C_w = tritium concentration in water, pCi/L
  - 1100 = convert Ci/yr and ft^3/sec to pCi/L
  - M_p = mixing ratio (reciprocal of dilution factor)
  - F = flow rate in effluent stream (waste+dilution), ft^3/sec
  - Q = annual tritium release rate, Ci/yr
  - λ = tritium decay constant, 6.44E-6 hr^{-1}
  - t = transit time field to table, = 24 hours

Concentration in Vegetation – Liquid Effluent Pathway

- Regulatory Guide 1.109 Equation A-10
- $C_v = C_w$
  - C_v = tritium concentration in vegetation, pCi/kg
  - C_w = tritium concentration in water, pCi/L

Concentration in Air – Airborne Effluent Pathway

- Regulatory Guide 1.109 Equation C-3
- $x_i = 3.17E4 * Q * \chi/Q$
  - x_i = tritium concentration in air, pCi/m^3
  - 3.17E4 = 1E12 pCi/Ci / 3.15E7 sec/yr
  - Q = annual tritium release rate, Ci/yr
  - χ/Q = atmospheric dispersion factor, sec/m^3

Concentration in Vegetation – Airborne Effluent Pathway

- Regulatory Guide 1.109 Equation C-9
- $C_v = 3.17E7 * Q * \chi/Q * 0.75 * (0.5/H)$
  - C_v = tritium concentration in vegetation, pCi/kg
  - 3.17E7 = 1E12 pCi/Ci * 1E3 g/kg / 3.15E7 sec/yr
  - Q = annual tritium release rate, Ci/yr
  - χ/Q = atmospheric dispersion factor, sec/m^3
  - 0.75 = fraction of total plant mass that is water
  - 0.5 = ratio of tritium in plant water to atmospheric water
  - H = absolute humidity, g/m^3… 3 to 9 g H_20/m^3 air

Intake Pathway Differences

- No inhalation pathway for waterborne releases
  - Airborne tritium from cooling pond evaporation?
- No drinking ingestion pathway for airborne releases
  - Rainout of atmospheric tritium into surface water?
- Waterborne equations assume a plant is 100% water, in 100% equilibrium with irrigation tritium concentration… 100% from irrigation
- Airborne equations assume a plant is 75% water, and 50% of plant water arises from atmospheric water… 50% remainder from irrigation

Pathway Comparisons

- Assume 1.0 Curie of tritium released
- Liquid effluent release
  - 200,000 gpm circulating water flow, equals ~4E+11 Liters/yr dilution flow
  - Mixing Ratio = 0.2
- Airborne effluent release
  - Elevated χ/Q = 1.0E-6 sec/m^3
  - Ground-level χ/Q = 9.4E-6 sec/m^3

Pathway Concentrations

Media	Fresh Water	Salt Water	Elevated	Ground
Water pCi/L	5.0E-1	5.0E-1	--	--
Air pCi/m^3	--	--	3.2E-2	3.0E-1
Crops pCi/kg	5.0E-1	--	2.1E+0	2.0E+1
Milk pCi/L	2.5E-1	--	8.4E-2	2.2E-1
Meat pCi/kg	3.0E-1	--	1.0E-1	3.0E-1
Fish pCi/kg	4.5E-1	4.5E-1	--	--
Shellfish pCi/kg	4.5E-1	4.5E-1	--	--

Usage Factors - Child

Media	Fresh Water	Salt Water	Elevated	Ground
Water L/yr	510	Zero	--	--
Air m^3/yr	--	--	3700	3700
Crops kg/yr	546	--	546	546
Milk L/yr	330	--	330	330
Meat kg/yr	41	--	41	41
Fish kg/yr	7	7	--	--
Shellfish kg/yr	3	3	--	--

Pathway Dose – Child, mrem/yr

Media	Fresh Water	Salt Water	Elevated	Ground
Water Ingest.	5.2E-5	--	--	--
Breathing	--	--	3.6E-5	3.3E-4
Crops	5.6E-5	--	1.8E-4	1.7E-3
Milk	1.7E-5	--	5.6E-6	1.7E-5
Meat	2.5E-6	--	8.4E-7	2.5E-6
Fish	6.3E-7	6.3E-7	--	--
Shellfish	2.8E-7	2.8E-7	--	--
Total	1.3E-4	9.0E-7	2.2E-4	2.1E-3

"Dilution Factor" -- Liquid

- 1.0 Ci discharged in 1000 gal.
  - equals concentration of *2.6E-1 uCi/mL*
- Dilution flow = 200,000 gpm
  - equals 450 ft^3/sec, or 4E+11 L/yr
- Mixing ratio = 0.2
- Concentration in field = 4.9E-1 pCi/L
  - equals *4.9E-10 uCi/mL*
- "Dilution Factor" = 2.6E-1 / 4.9E-10
  - equals 5.3E+8

“Dilution Factor” -- Airborne

- 1.0 Ci discharged at 100,000 cfm
  - equals 3.2E-8 Ci/sec release rate
  - equals concentration of *6.7E-10 uCi/cc*
- χ/Q (ground-level release) = 1E-5 sec/m^3
- Concentration in field = 3.2E-13 Ci/m^3
  - equals *3.2E-13 uCi/cc*
- “Dilution Factor” = 6.7E-10 / 3.2E-13
  - equals 2.1E+3

"Dilution Factor" Comparison

- Liquid Effluent "Dilution Factor"…

  5.3E+8

- Airborne Effluent "Dilution Factor"…

  2.1E+3

- RG-1.109 modeling assumptions mean that liquid effluents appear to be diluted by an additional ***<u>five orders of magnitude</u>*** when compared to airborne effluents!!

“Dilution Factor” – Water Vapor

- 1.0 Ci discharged at 100,000 cfm
  - concentration of 6.7E-10 uCi/cc air
  - air at 90°F, 40%RH = 1.4E-5 g H_2O/cc air
  - 6.7E-10 / 1.4E-5 = *4.8E-5 uCi/mL H_2O*
- Concentration in field = 3.2E-13 uCi/cc air
  - Absolute humidity = 5.6E-6 g H_2O/cc air
  - 3.2E-13 / 5.6E-6 = *5.7E-8 uCi/mL H_2O*
- “Dilution Factor” = 4.8E-5 / 5.7E-8
  - equals 8.4E+2… within factor of 3 of airborne DF

"Dilution Factor" – Water Vapor

- Airborne Effluent "Dilution Factor"…

  2.1E+3

  - *x*/Q accounts for volumetric dilution between release point and receptor
- Water Vapor "Dilution Factor"…

  8.4E+2

  - What about all of the natural water vapor in air?
- RG-1.109 modeling assumptions do not appear to account for "dilution" by natural water vapor in air! Is this reasonable?

Model in Recent Literature

- Simpkins A.A. “Method for Estimating Ingestion Doses to the Public Near the Savannah River Site Following an Accidental Atmospheric Release”, Health Phys. 88(2):133–138; 2005
- Uses “PUFF-PLUME” dispersion model… comparable to *x*/Q dispersion? Not sure, but most likely it is.
- Provides equations for calculating ingestion doses from vegetables, milk, beef, fish, and water
- Alternative to RG-1.109?

Concentration in Vegetation

$$C_T^V = \frac{CONC \times 0.75 \times 0.5}{H}, \quad (3)$$

where

C_T^V = concentration in vegetation, Bq g^{-1};
$CONC$ = atmospheric concentration, Bq m^{-3};
0.75 = fraction of plant mass that is water (U.S. NRC 1977);
0.5 = concentration ratio of plant tritium to atmospheric tritium (Hamby and Bauer 1994); and
H = absolute humidity at the time of the accident (SRS annual average of 11 g m^{-3} used if no other data available) (Hamby 1990[†]).

- Virtually identical to RG-1.109 equation

Dose – Leafy Vegetables

$$Dose_{leafy} = \frac{CONC \times DCF \times 0.75 \times 0.54 \times CF \times I_l}{H} \int_0^{30} e^{-\lambda_w t} \quad (4)$$

where

CF = conversion factor (1,000 g kg^{-1}); and
λ_w = disappearance rate for tritium in vegetable water (1 d^{-1}).

- Note allowance for tritium loss following harvest, with an integral half-life of 1 day in leafy vegetables.

Dose - Vegetables

$$Dose_{veg} = \frac{CONC \times DCF \times CF \times 0.75 \times 0.54}{H} \left\{ \left(\int_0^{30} e^{-\lambda_w t} \right) \times \left[I_{v-30} + \frac{I_{v-335}}{30\ \mathrm{d}} \times \int_{30}^{365} e^{-\lambda_i t} \right] \right\}. \quad (5)$$

- Also allows for tritium removal (loss) mechanisms following harvest

Differences from RG-1.109

- Underlying approach very similar to RG-1.109, except…
- Allows for loss of tritium from vegetation following harvest
- Different usage factors:
  - Leafy: 21 kg/yr vs. 26 kg/yr
  - Vegetable: 129 kg/yr vs. 520 kg/yr
- Different Ingestion DCFs:
  - Based on ICRP-30 vs. ICRP-2

Tritium Dose Conversion Factors

- RG-1.109 Ingestion – mrem/pCi
  - Adult: 1.05E-7 Teen: 1.06E-7
  - Child: 2.03E-7 Infant: 3.08E-7
- RG-1.109 Inhalation – mrem/pCi
  - Adult: 1.58E-7 Teen: 1.59E-7
  - Child: 3.04E-7 Infant: 4.62E-7
  - Inhalation DCFs 50% higher than ingestion
- ICRP-30 – 1.73E-11 Sv/Bq
  - Non age-specific
  - Ingestion & Inhalation DCFs equal: 6.40E-8 mrem/pCi

Summary

- Regulatory Guide 1.109 airborne models for tritium do yield higher dose than liquid models in most cases
- Underlying model assumptions seem to yield higher degree of “dilution” for liquid effluents compared to airborne effluents
- Airborne model does not seem to adequately describe additional “dilution” by natural water vapor in air

Summary (continued)

- New models do not appear fundamentally different from RG-1.109, but may yield lower airborne doses due to differences in:
  - Usage factors
  - Dose Conversion Factors (ICRP-30)
  - Tritium losses following harvest

Looking Forward

- Measuring tritium in environmental samples
  - Vegetation should act as a good indicator of tritium in the environment… why?
  - Literature reports plants reach equilibrium with atmospheric water within 30 min.
  - Literature also reports tritium+water turns over in plant with half life of 1 day.
  - Water is easy to extract from plant for tritium analysis.
  - May help shed light on how representative airborne tritium models are.
  - In-field airborne tritium sampling??