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Tritium Oxide (HTO) Deposition Velocity for Use in Savannah River Site (SRS) Safety Analyses

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July 24, 2012



Health Physics Society Annual Meeting – Sacramento, CA

Presentation Outline

- Purpose of Assessment
- Background
- HTO Deposition Velocity Empirical and Theoretical Evaluations
- HTO Re-emission and Residence Empirical and Theoretical Evaluations
- Modeling Deposition Velocity and Re-emission
- Conclusions and Recommendations for SRS

The Challenge

- To determine and document a technical basis for an appropriate bounding SRS-specific tritium oxide (HTO) “dry” deposition velocity value for determining the dose consequences of tritium/tritium oxide releases in nuclear facility safety analysis reports

- Currently value (0.5 cm/sec) challenged by Defense Nuclear Safety Board Staff (DNFSB)
  - Used in the MELCOR Accident Consequence Code System Ver. 2 (MACCS2)
  - Not bounding
  - Does not account for re-emission

SRS Background



- Built in 1953 primarily to produce tritium and plutonium for nuclear weapons
- Located in SC, ~ 39 km SE of Augusta, GA
- ~800 km^2 of real estate and forest

- **Post cold war activities include:**
  - Management of excess nuclear materials and legacy waste
  - Environmental restoration and management
  - Meeting the needs of the U.S. nuclear weapons stockpile
    - Including - Ongoing tritium operations

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SRS Topography



- Approximately 85% SRS is forested
  - 68% of the forests are pine plantations
  - 6% mixed pine and hardwood
  - 26% swamp hardwood
- Path from potential release points to the SRS boundary is primarily through forested land

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Deposition Velocity (v_d) Description

- v_d is defined as the proportionality constant relating air concentration to the flux density of material deposited under a puff or plume release
  - For large particles, v_d is dominated by the gravity-driven terminal velocity of the particles
  - Deposition of HTO is controlled by atmospheric diffusion and the absorption properties of the soil and vegetation
- Atmospheric dispersion modeling crediting deposition of HTO requires consideration of re-emission of the vapor back into the atmosphere

Empirical Data Indicate v_d Range

- Representative published measurements of forest v_d indicate the range of found in experimental studies of the various forest stands

Vegetation Type	Stand deposition velocity (cm/sec)	References
Conifer forest	2.12 0.71	Kelliher et al. (1995)
Temperate deciduous forest	2.07 0.65	Kelliher et al. (1995)
Mixed deciduous forest	0.22	Baldocchi (1989)
SRS pine plantations	**0.07-1.2**	**Murphy et al. (1981), Murphy (1985)**
Douglas-fir forest	>1	Wharton et al. (2009)
Pine plantation	0.02 - 0.24	Ewers et al. (2001)
Oak-grass savannah	0.02 - 0.2	Baldocchi et al. (2004)
Aspen-hazel forest	0.0 - 2.8	Blanken et al. (1997)

Theoretical Evaluation of v_d at SRS

- Distribution of deposition velocity in a pine forest at SRS estimated from a model of canopy deposition velocities based on energy balance measurement taken in that stand:

$$v_d = v_{dmin} + (v_{dmax} - v_{dmin})\,(0.01218T + 0.0111S - 0.04374d_v)$$

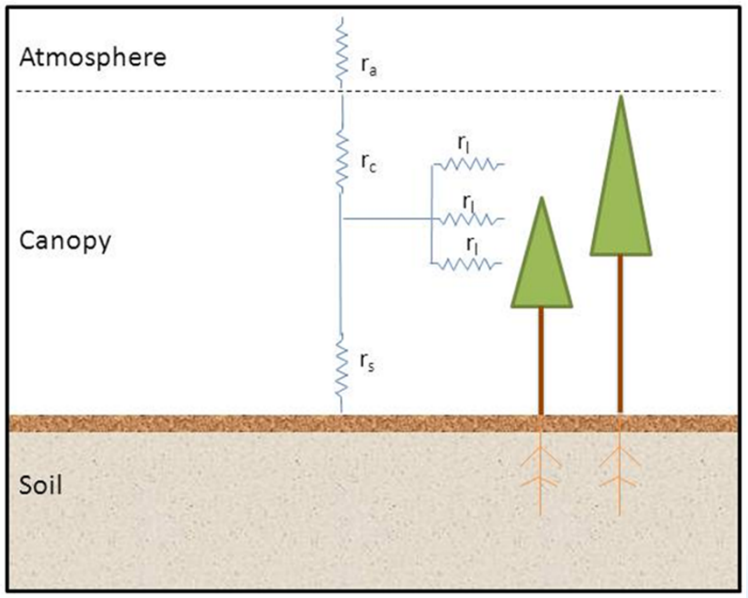
v_{dmin} - minimum deposition velocity (cm/sec)

v_{dmax} - maximum deposition velocity (cm/sec)

T - temperature (ºC)

S - solar radiation (W/m^2) and

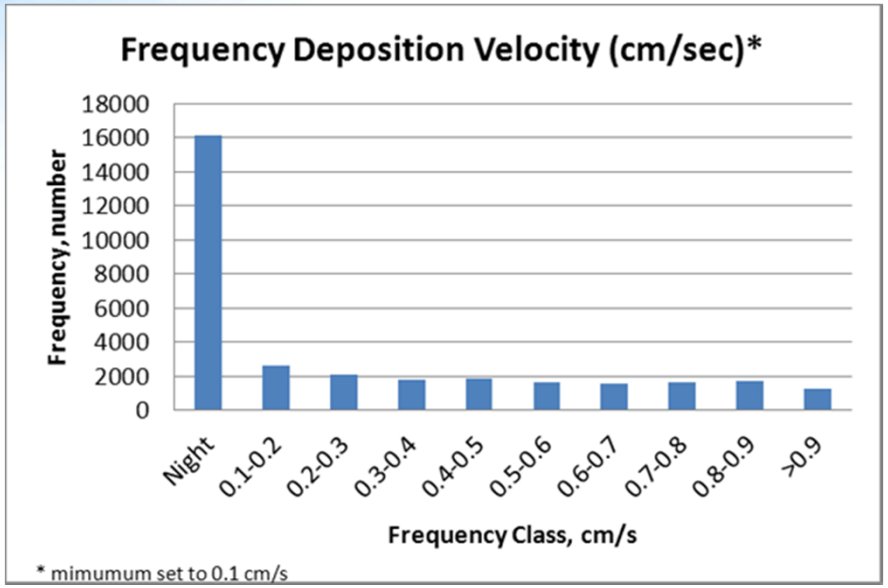
d_v - vapor density deficit, the difference between saturation density and actual vapor density based on relative humidity (g/m^3)



Network of resistances to HTO vapor transport in a forest

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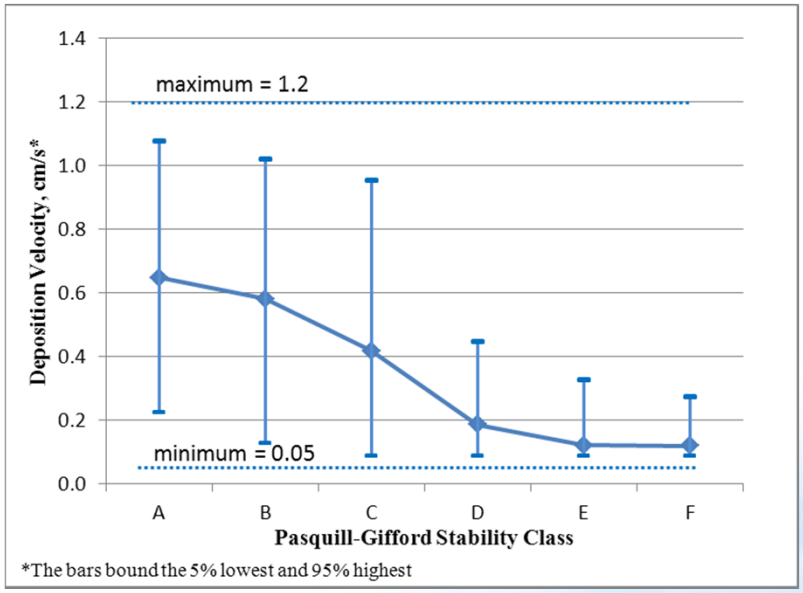
Wide Range of Daylight v_d/Nighttime most Bounding



Based on continuous record of 15-min values (35,040 observations/year) of temperature, relative humidity, and solar radiation collected at the center of SRS

- Annual Average v_d = 0.27 cm/sec
- Average Daytime v_d = 0.42 cm/sec

- **v_d minimum value at night < 0.1 cm/sec**
  - Recommended bounding value
  - Corresponds to meteorological conditions defining the 95th percentile maximum exposure



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Empirical Data Suggests SRS Residence Times

Measured residence time in vegetation

Species	Residence Time (hr)	Reference
Daytime		
Potato and grape	0.50	Guenot and Belot (1984)[1]
Grape	0.50	
Cabbage	0.88	Brudenell et al. (1997)[1]
Lettuce	0.88	
Alfalfa	0.33	Koranda and Martin (1971)[1]
Grass (stem)	0.42	Kline and Stewart (1974)[1]
Grass (leaves)	0.58	
Rice	0.50	Keum et al. (2006)[1]
Lettuce	0.53	Iyengar etal. (1981)[1]
Cabbage	0.75	
Pepper	0.77	
Pine (leaves)	**1**	**Murphy and Corey (1976)**
Nighttime		
Grass (leaves)	36.33	Kline and Stewart (1974)[1]
Grass (stem)	6.67	Brudenell et al. (1997)[1]
Lettuce	13.00	
Pine (leaves)	**3**	**Murphy and Corey (1976)**

[1]Adapted from Boyer et al. (2009)

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Theoretical Evaluation of Forest Residence Times

Residence time and v_d for vegetation are linked by common diffusion pathways:

$$\textbf{residence time} = -\ln(0.5) \cdot {}^{(V/A \cdot \rho_w)}/_{\rho_{as} \cdot R_H \cdot v_d}$$

	Daytime	Nighttime
A, surface area of vegetation per unit ground area (cm^2/cm^2),	6	6
V, volume of water in vegetation per unit ground area (cm^3/cm^2)	0.1	0.1
R_H, Relative Humidity (fraction)	0.5	1
Surface Temperature (^oC)	30	15
ρ_w. density of water(g/cm^3)	1	1
ρ_{as}, saturation vapor density at vegetation temperature (g/m^3)	31.0	12.4
V_d, Deposition Velocity (cm/sec)	0.5	0.1
Residence Time (min)*	**25**	**155**

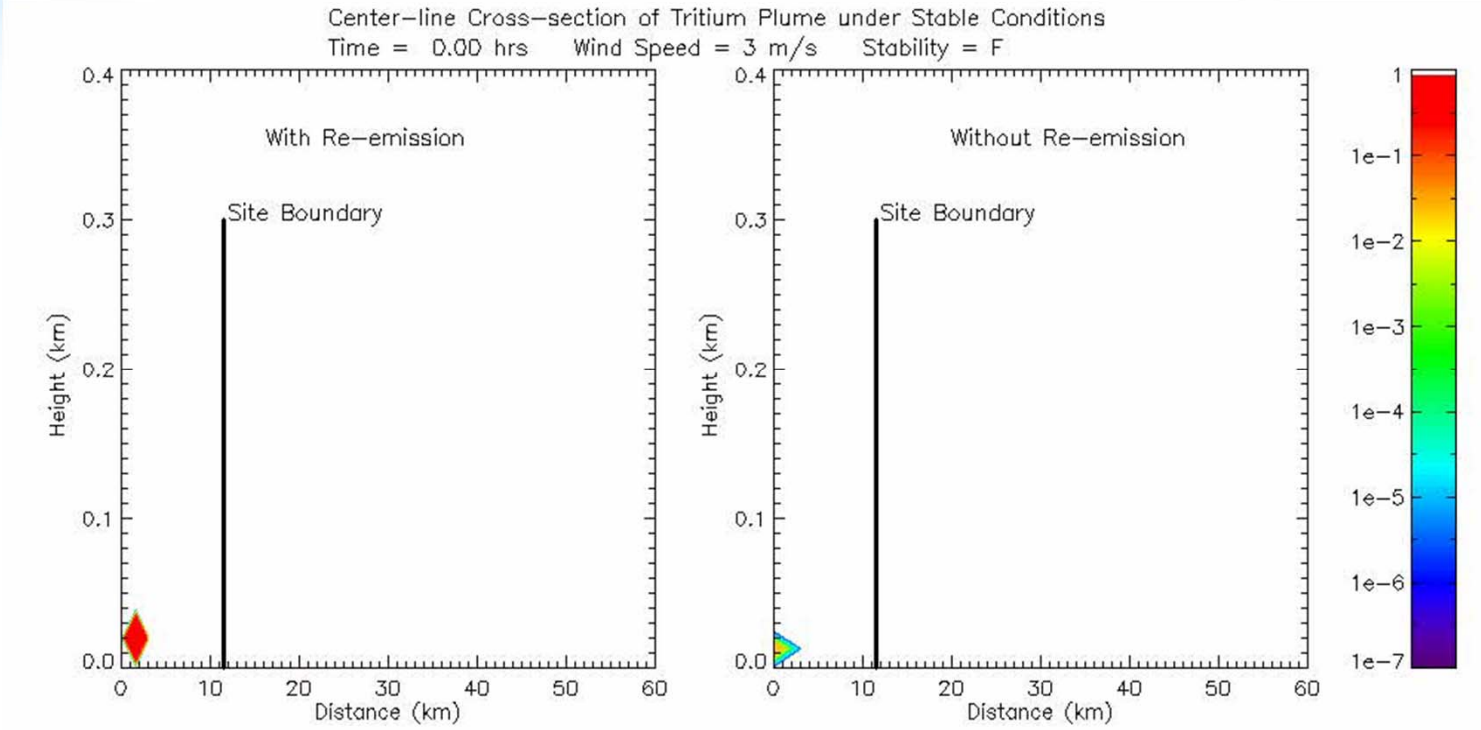
*Compares favorably with the empirical data [1 h daytime and 3 h nighttime values]

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Demonstrated Effects of v_d and Re-Emission

- Simple SRS atmospheric dispersion model created to simulate combined effects of deposition and re-emission
  - Demonstrates sensitivity of exposures to HTO re-emission
  - Employed SRS meteorology and expected range of v_d
- Model differs from typical dispersion models (i.e. MACCS2)
  - Simulates a puff (vs. plume) release resulting in a more concentrated cloud
  - Not intended to predict potential consequences to a the offsite individual

Demonstrated Effects of v_d and Re-Emission



Deposition Velocity (cm/sec)	% of HTO puff that passes the site boundary (~11.5 km) w/in 2 hours		
	No Re-emission	With Re-emission	
		2-hr	24-hr
0.0	100.00 %	100.00 %	100.00 %
0.1	93.33 %	99.96 %	100.00 %
0.5	70.89 %	99.70 %	100.00 %

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"Effective" v_d Recommendation for SRS

- HTO v_d in SRS forest vegetation
  - Daylight v_d 0.07 - >2.8 cm/sec (average v_d ~ 0.42 cm/sec)
  - Nighttime v_d likely < 0.1 cm/sec
- Re-emission of HTO inversely related to v_d
  - SRS the daylight average residence time is about 0.4 hours
  - Night residence time is around 2.5 hours
- Simulations with a simple atmospheric dispersion (puff) model demonstrate small net effect of deposition
  - Low initial deposition and the relatively rapid re-emission
  - "Effective" v_d for HTO of 0.0 cm/sec bounding value recommended for SRS safety analysis
    - MACCS2 code does not specifically address HTO re-emission

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