RASCAL 4.3 Dispersion and Deposition Models

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Pacific Northwest
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RASCAL Background

- Radiological Assessment System for Consequence Analysis
- Confirmatory assessment tools for staff use in the evaluation of events at U. S. nuclear facilities.
- Initial version RASCAL 1.3 published in 1989 based on earlier NRC codes MESORAD (1986), MESOI (1983), with roots in DOE codes dating from 1974 (MESODIF)
- Recent RASCAL Versions 3.05 (NUREG-1887 2007), 4.2 (NUREG-1940 2012), and 4.3 (Draft Technical Supplement 2013)[1]

[1]Available from http://pbadupws.nrc.gov/docs/ML1328/ML13281A490.pdf

RASCAL Modules

- Source Term Estimation
  - U.S. Power Reactors
  - U.S. Spent Fuel Storage Facilities
  - U.S. Fuel Cycle Facilities
- Atmospheric Transport and Dispersion Calculations
  - Small particles and gases
  - UF_6
- Early and Intermediate Phase Dose Calculations
- Supporting Modules
  - Meteorological data acquisition and processing (MetFetch)
  - Nuclear facility data base
  - Radionuclide data base

Recent RASCAL Evolution

	RASCAL 3.05	RASCAL 4.2	RASCAL 4.3
Source Term	Base Case NUREG-1465 LOCA	Minor changes NUREG-1465 LOCA	• Major changes • Add SOARCA LTSBO • Import, export, & merge capabilities
Atm. Transport and Dispersion	• 3 domains (10,25, 50 mi) • 48 hr limit • Gaussian Puff and Plume • Pasquill-Gifford Dispersion with low speed adjustment • Constant dep. velocities • Wet deposition by washout • Iodine ⅓ part, ⅓ I_2, ⅓ CH_3I	• Time-based dispersion with low speed adjustment • Dispersion parameters estimated by turbulence • Temporal and spatial varying dep. velocities • Iodine 25% part, 30% I_2, 45% CH_3I • Revised decay scheme to include short daughters implicitly	• Add 100 mi domain • 96 hr limit
Dose Calculation	• TEDE, Cloudshine, CEDE, Groundshine using ICRP 26/30 methodology • Finite Cloudshine • Limited radionuclide set	• Add option of using ICRP 60/72 methodology • All radionuclides in FGR 12 with half lives > 10 min.	• Add child thyroid
Meteorological Data	• Manual	• Manual	• Manual or Internet

Why ATD Changes?

- Update the technical basis
  - Pasquill-Gifford dispersion is based on data collected prior to 1960
  - Turbulence and dispersion theory advanced significantly from 1960 to 1990
  - Dispersion experiments conducted prior to 1970 are biased toward moderate to high wind speed conditions
  - NRC licensees are installing instrumentation capable of supplying turbulence data
  - Computers permit more realistic dispersion assessments
- The new model parameterizations will facilitate future ATD model upgrades

RASCAL 4 Dispersion Models

$\sigma_y(t) = 0.5 \int_0^t \sigma_v(t)dt$	t ≤ 3600 s
$\sigma_y(t) = \sigma_y(3600) + 0.2(t - 3600)$	t > 3600 s
$\sigma_z(t) = \int_0^t \sigma_w(t) f_z(t)dt$	
$f_z(t) = \left[1.0 + 0.9(t/T)^{1/2}\right]^{-1}$	T = 50 s

RASCAL 4 Turbulence Parameterizations

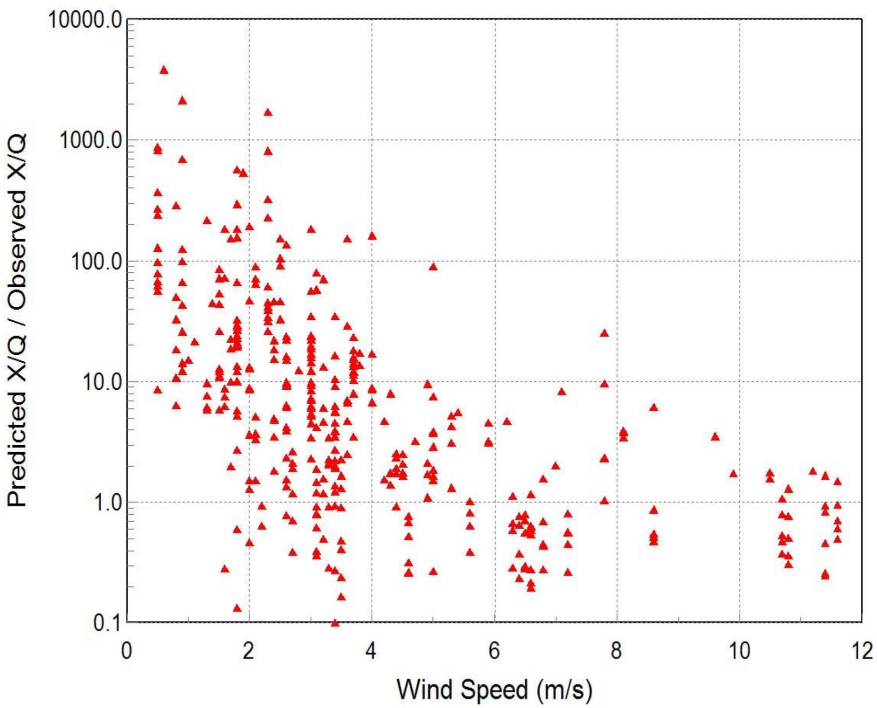
$\sigma_v = \sigma_w = 1.3u_*(1 - z_p/H)$	Stable, $z_p < 0.9$ H
$\sigma_v = \sigma_w = 1.3u_* exp(-2f z_p/u_*)$	Neutral
$\sigma_v = u_*(12 - 0.5H/L)^{1/3}$	Unstable
$\sigma_w = 1.3u_*(1.0 - 3.0\, z_p/L)^{1/3}$	Unstable, $z_p \leq H/2$
$\sigma_w = 1.3u_*(1.0 - 1.5\, H/L)^{1/3}$	Unstable, $z_p > H/2$

Where:

- σ_y = horizontal dispersion parameter (m)
- σ_v = lateral turbulence component (m/s)
- σ_z = vertical dispersion parameter (m)
- σ_w = vertical turbulence component (m/s)
- t = time since release to atmosphere (s)
- u_* = friction velocity (m/s)
- z_p = plume height (m)
- H = mixing layer height (m)
- L = Monin-Obukhov length (m)

Low Wind Speed Correction

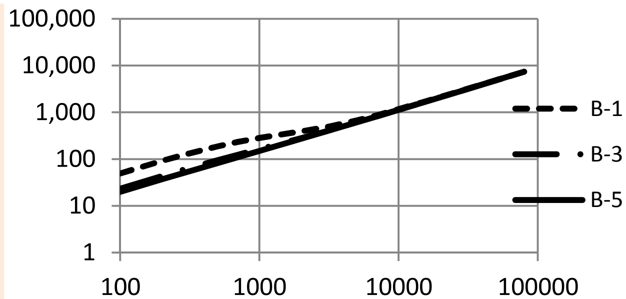
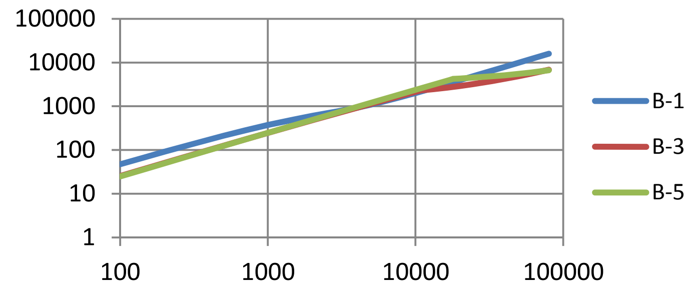
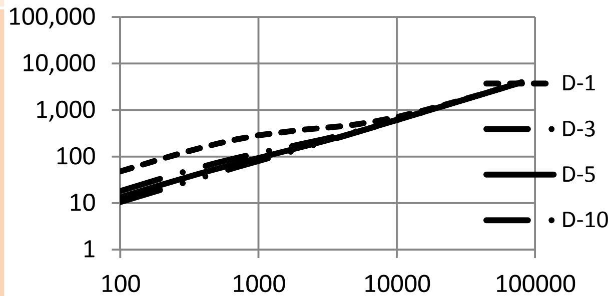
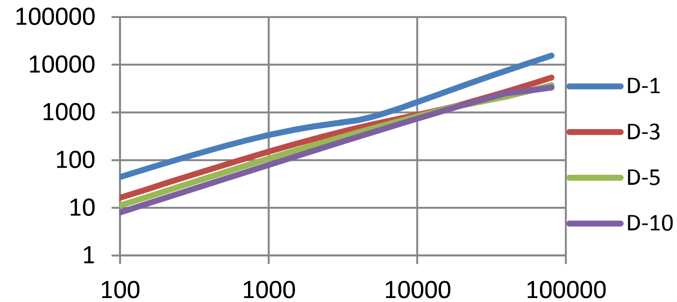
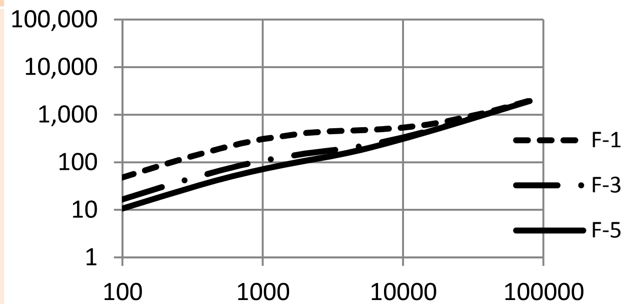
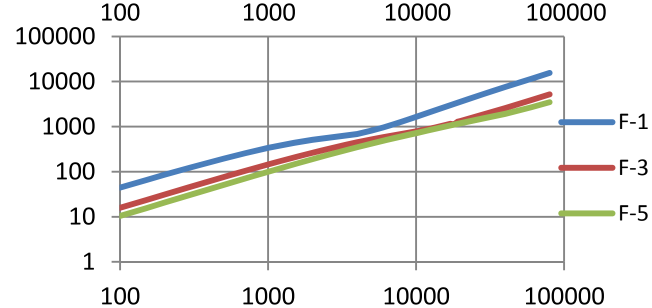
- Why?
  - Gaussian plume model is incomplete
  - Low wind speed conditions are not adequately represented in dispersion data
  - Limited dispersion data indicate concentrations are significantly over estimated at low speeds



RASCAL 4 Low Wind Speed Correction

$\Sigma_y = \left(\sigma_y^2 + \Delta\sigma_y^2\right)^{1/2}$	
$\Sigma_z = (\sigma_z^2 + \Delta\sigma_z^2)^{1/2}$	
$\Delta\sigma^2(t) = A(1 - (1 + t/T)exp(-t/T))$	*t* = travel time or time after release (s)
$A_y = (0.64T_y)^2$	$T_y = 1000$ s
$A_z = (0.845T_z)^2$	$T_z = 100$ s

RASCAL σ_y Comparison

	RASCAL 3.05	RASCAL 4
B Stability		
D Stability		
F Stability		

RASCAL σ_z Comparison

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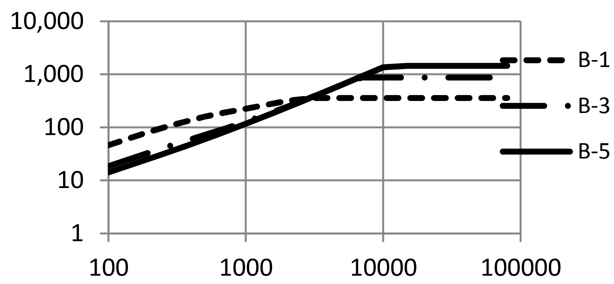
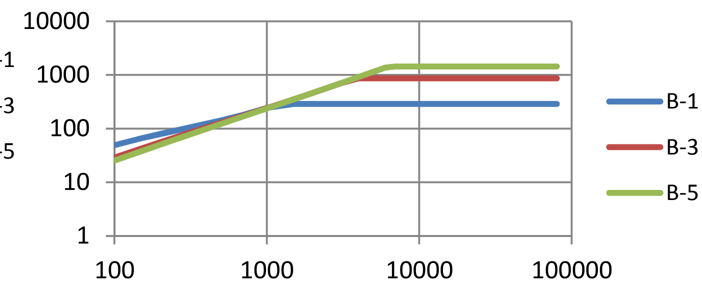
<tr><td>B Stability</td><td>
</td><td>
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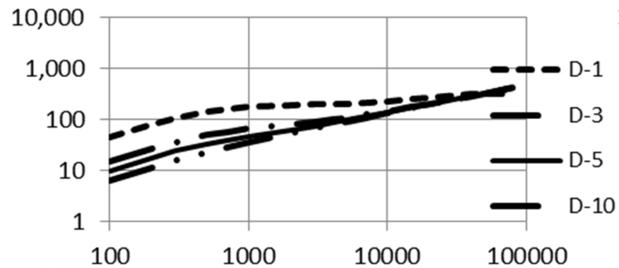
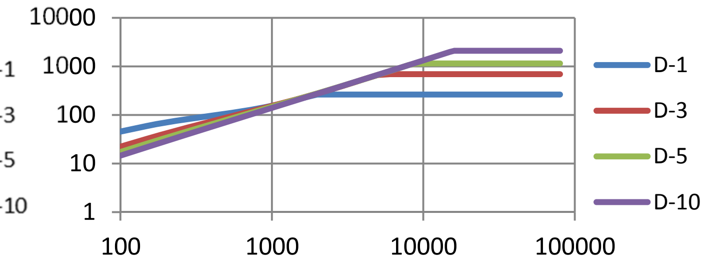
<tr><td>D Stability</td><td>
</td><td>
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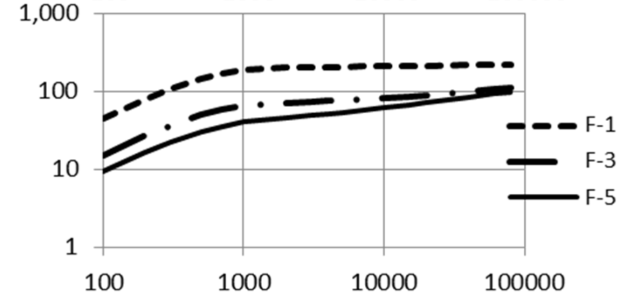
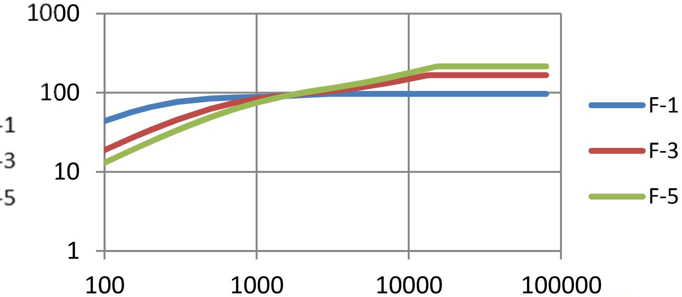
<tr><td>F Stability</td><td>
</td><td>
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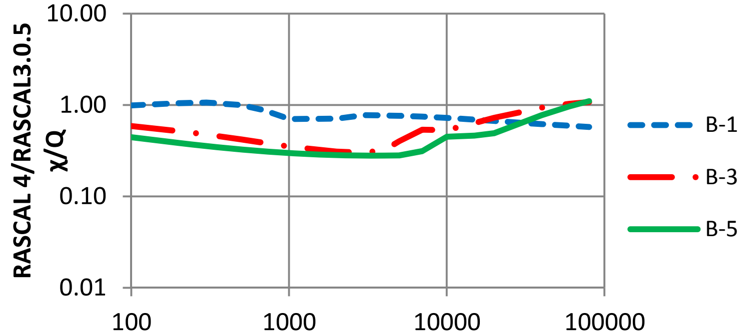
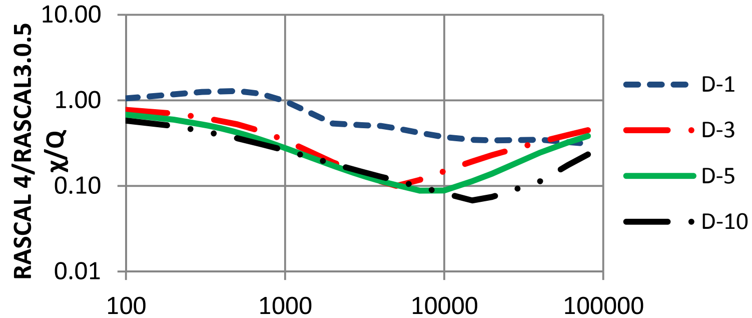
RASCAL χ/Q Comparison

B Stability



D Stability



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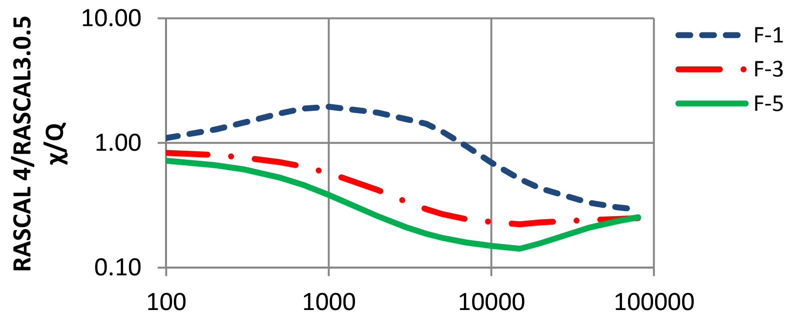
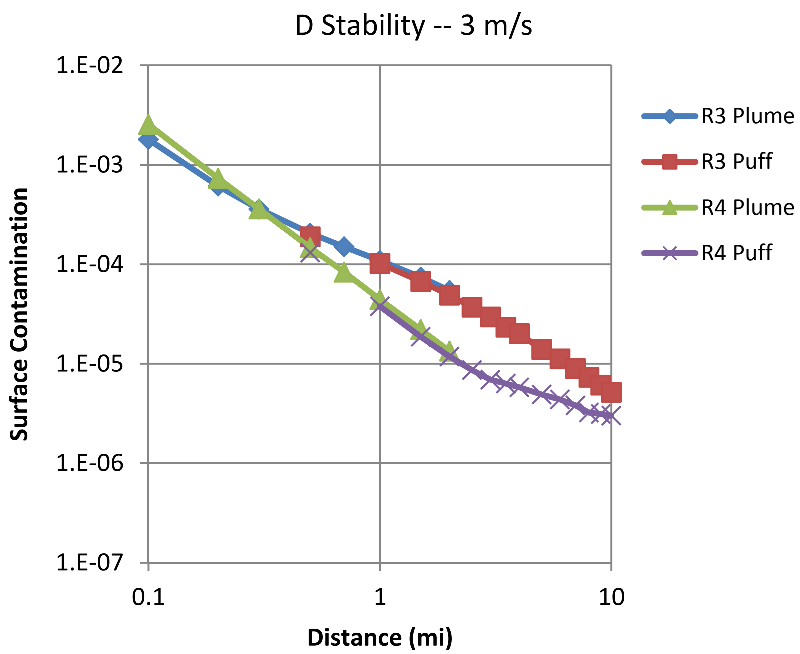


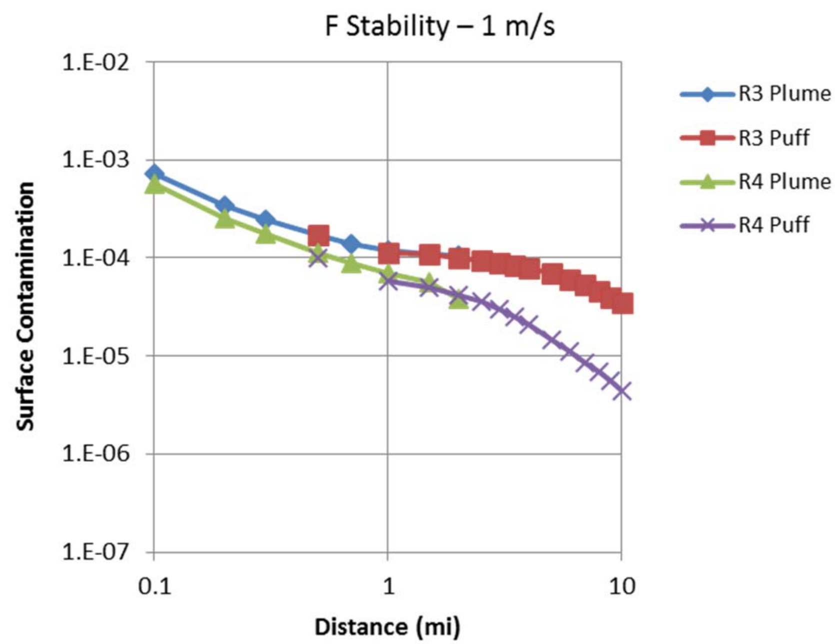
Representative RASCAL 4 Dry Deposition Velocities[1,2]

	Stability	Wind Speed				
		1 m/s	2 m/s	3 m/s	5 m/s	10 m/s
Particles[3]	B	0.0047	0.0064	0.0073	0.0082	
	D	0.0039	0.0056	0.0065	0.0076	0.0086
	F	0.0031	0.0048	0.0058	0.0070	
Reactive Gases	B	0.0037	0.0062	0.0082	0.011	
	D	0.0027	0.0047	0.0064	0.0091	0.014
	F	0.0021	0.0037	0.0051	0.0073	

1) Deposition velocity units: m/s
2) Z_0 = 10 cm
3) ~ 1 µm particles

RASCAL Dry Deposition Comparison





RASCAL 4 Wet Deposition

Precipitation Type	Washout Coefficient[1,2]	Wet Deposition Velocity[3,4]
Light rain	0.25	2.8×10^{-5}
Moderate or heavy rain	3.3	8.3×10^{-4}
Light snow	0.006[5] / 0.00[6]	8.3×10^{-6}
Moderate or heavy snow[5]	0.3[5] / 0.00[6]	4.2×10^{-4}

[1]Particles
[2]Units:1/hr
[3]Gases
[4]Units: m/s
[5]Temperature ≥ -3^{0}C
[6]Temperature < -3^{0}C

Why These Parameterizations?

- Based on peer-reviewed literature
  - Panofsky and Dutton (1984)
  - Stull (1988)
- Developed under extensive peer review in the Hanford Environmental Dose Reconstruction Project
  - Formal QA procedures
  - Extensive peer review (Gifford, Hanna, Nappo, Randerson, Dabbert, Petersen, et al.)
  - Parameter uncertainty/variability estimates
  - Formal validation

Atmospheric Iodine

- Natural iodine occurs in many forms
  - 6 to 33% associated with particles
  - 10 to 75% of the gaseous iodine occurs in reactive species (I_2)
  - 25 to 90% of the gaseous iodine occurs in slightly or non-reactive species (CH_3I)
- Physical form controls iodine deposition on surfaces
- Physical form determines the dose from inhaled iodine
- Iodine isotopes are at the top of the list of radionuclides that are important to inhaled dose in nuclear reactor accidents

Iodine Species in the Atmosphere

	Distance	Particulate Iodine	Gaseous Iodine in Reactive Species
Reactor containment		95%	97% to 100% (first 2 hr)
Hanford stacks		0% to 6%	30% to 90%
NRTS expts (1963)	50 m to 300 m	8% to 30%	65% to 80%
Hanford expts (1963)	200 m to 3200 m	10% to 30%	49% to 82%
Hanford plumes (1964-1967)	5 km to 8 km	5% to 14%	35% to 48%
Hanford Green Run (1949)	1 km to 55 km	6% to 39%	
Chernobyl (1986)	> 1000 km	7% to 54%	11% to 54%
Fukushima (2011)	> 1000 km	2% to 34%	
RASCAL 4		25%	40%

Iodine Deposition

- Historic practice
  - Iodine deposition velocities vary depending on surface 0.1 cm/s to 3 cm/s
  - Typical values (Voilleque and Keller, 1981)
    - I_2 vapor → 1 cm/s
    - Iodine associated with particles → 0.1 cm/s
    - CH_3I → 0.0003 to 0.01 cm/s
- RASCAL Assumes
    - Deposition velocity for CH_3I = 0.0
    - Thus, deposition velocity for iodine = Particulate fraction × dry deposition velocity for particles + Reactive gas fraction × dry deposition velocity for reactive gases

Representative RASCAL Iodine Deposition Velocities

STABILITY CLASS	WIND SPEED				
	1 m/s	2 m/s	3 m/s	5 m/s	10 m/s
B	0.0023	0.0035	0.0043	0.0055	
D	0.0018	0.0028	0.0035	0.0046	0.0063
F	0.0014	0.0023	0.0030	0.0039	

RASCAL 4 Doses from Iodine

- Cloudshine is independent of iodine form
- Groundshine and ingestion pathway doses (including the cow-milk pathway) depend only on the deposited iodine (atmospheric concentration, iodine speciation, and deposition velocity)
- Inhalation doses are a function of the form of iodine inhaled (atmospheric concentration and iodine speciation)
- RASCAL 4 assumes that atmospheric iodine is 25% particles, 30% I_2 and 45% CH_3I. This speciation contributes to the deposition of iodine and to the inhalation doses if the ICRP 60/72 dose coefficients are selected. This speciation dose not enter into inhalations doses if ICRP 26/30 dose conversion factors are used.

Iodine-131 Dose Coefficients[1] (ICRP-60/72)

	Adult (7300 d)	Adult (7300 d)	Child (365 d)
Iodine Form \ Organ	CED	Thyroid	Thyroid
Particle	7.39E-09	1.47E-07	1.43E-06
Reactive Gas (I_2)	1.98E-08	3.93E-07	3.24E-06
Non-reactive Gas (CH_3I)	1.54E-08	3.07E-07	2.53E-06
RASCAL (weighted avg)	1.47E-08	2.93E-07	2.47E-06

1) Sv/Bq inhaled

Composite Thyroid Dose Coefficients

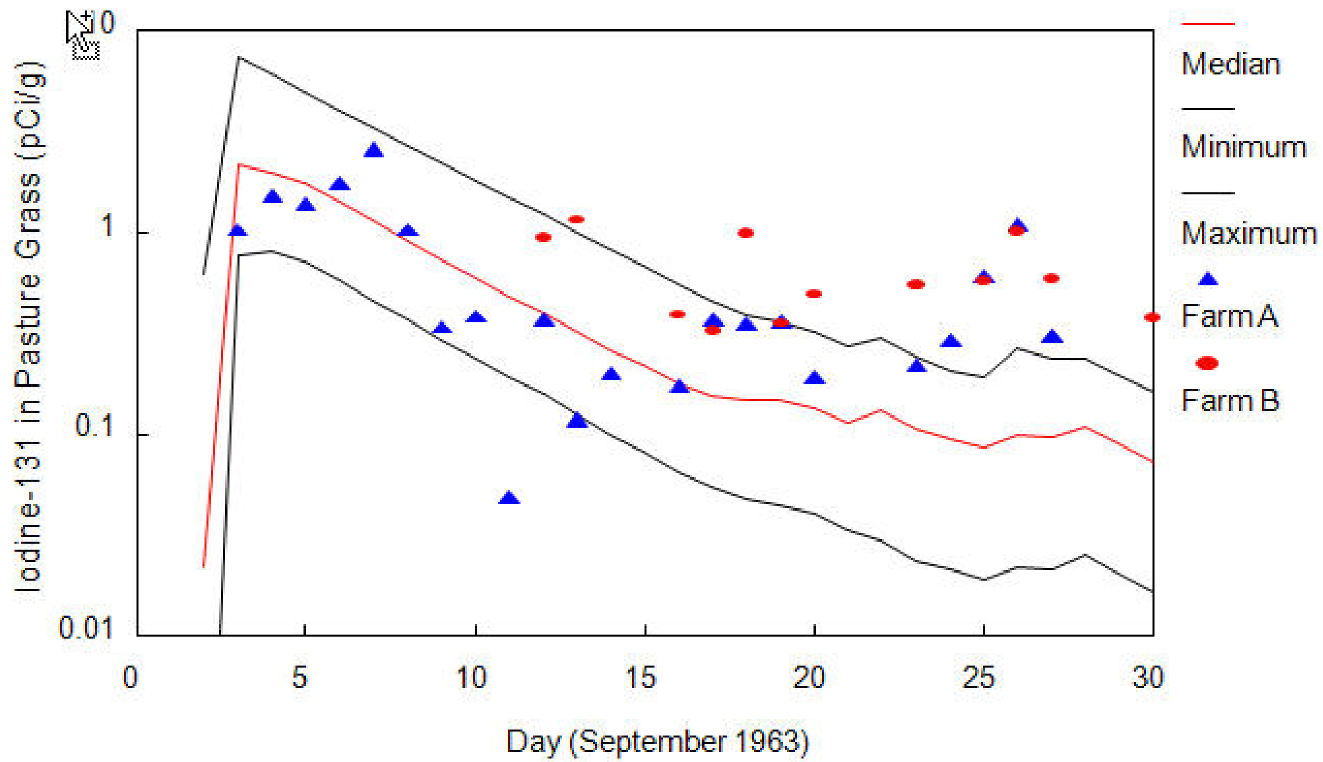
		Dose Coefficients (Sv/Bq)[1]				
Age	Breathing Rate (m^3/s)	I-131	I-132	I-133	I-134	I-135
100 days	5.28E-05	2.52E-06	3.40E-08	6.78E-07	7.02E-09	1.39E-07
1 year	9.72E-05	2.47E-06	3.03E-08	6.12E-07	6.24E-09	1.24E-07
5 years	1.58E-04	1.40E-06	1.57E-08	3.18E-07	3.23E-09	6.43E-08
10 years	3.11E-04	7.10E-07	7.02E-09	1.42E-07	1.44E-09	2.88E-08
15 years	3.83E-04	4.59E-07	4.53E-09	9.09E-08	9.30E-10	1.85E-08
20 years	4.17E-04	2.93E-07	2.87E-09	5.70E-08	5.90E-10	1.17E-08

1) Based on ICRP 60/72 dose coefficients weighted by RASCAL iodine partitioning fractions

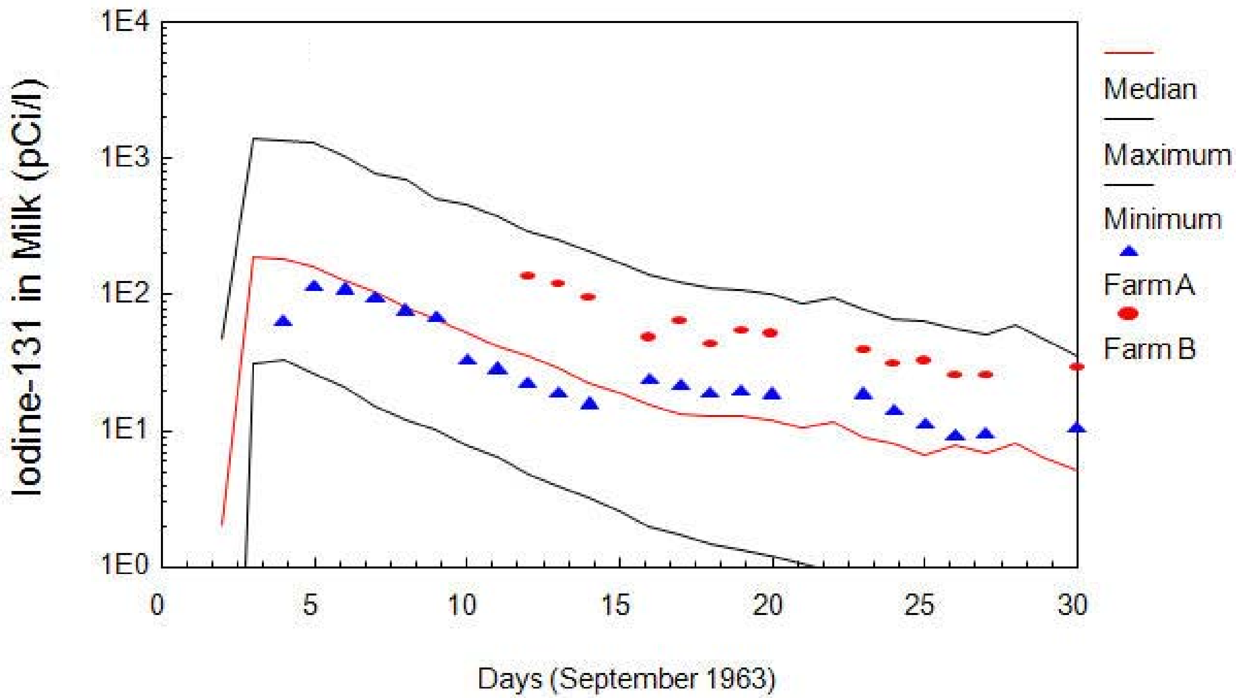
Thoughts Related to Iodine

- Deposition samples are likely to have a greater variation than model predictions.
- The variability of deposition samples is likely to be greater than the variation of iodine in milk.

Predicted and Measured Iodine-131 in Grass Samples near Hanford



Measured and Predicted Iodine-131 in Milk Samples near Hanford



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Final Thoughts Related to Iodine

- Don't trust published filter efficiencies when applied to iodine particles

- More data are needed on the speciation of iodine in the atmosphere following reactor accidents, particularly the gaseous components

Questions?

- Contact:

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RASCAL Sponsor

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More Detailed Information

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