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Modeling Iodine Released During a Nuclear Power Plant Accident Assumptions

Terry Kraus, CHP, Sandia National Laboratories

Sandia National Laboratories

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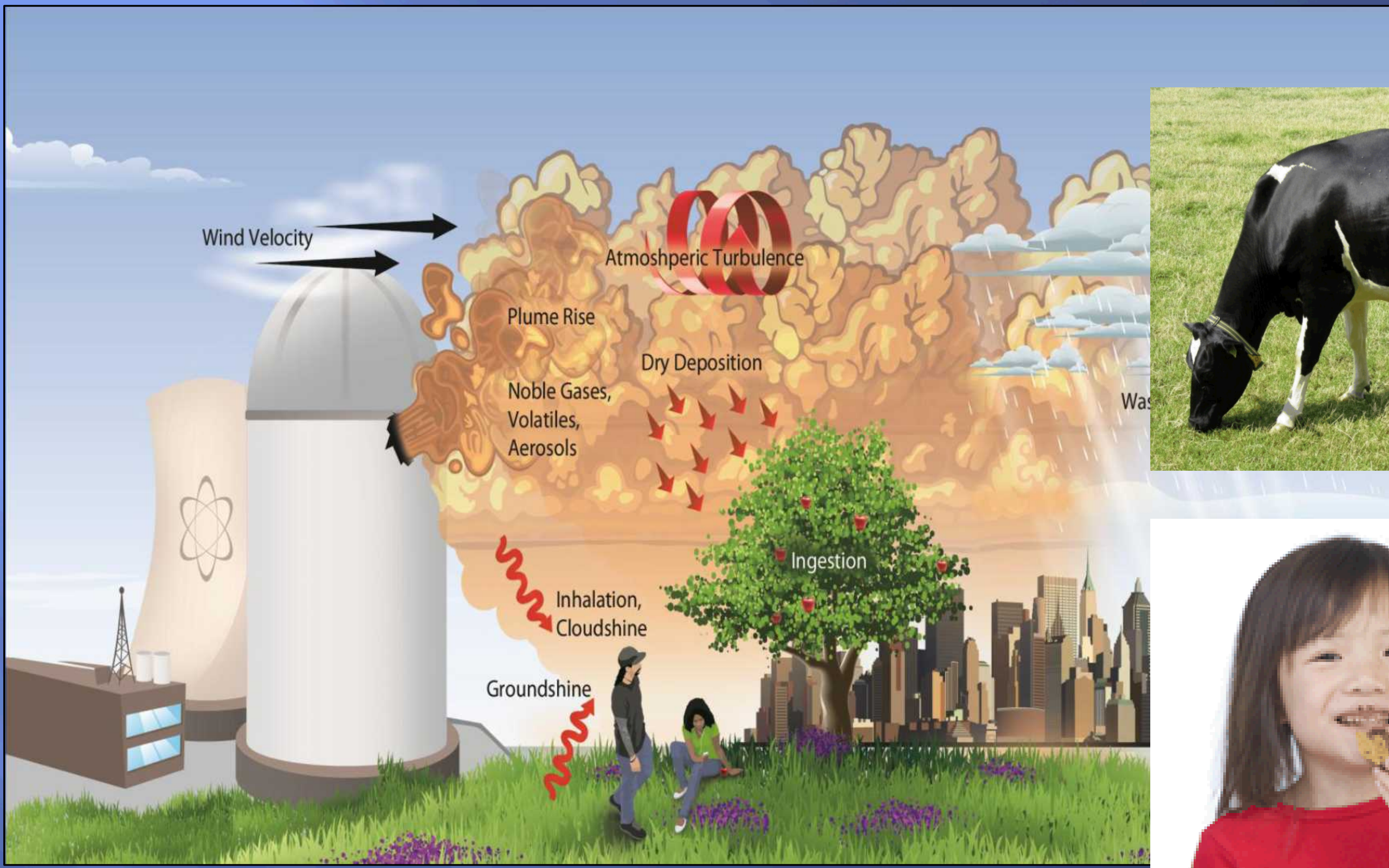
NNSA National Nuclear Security Administration

Purpose

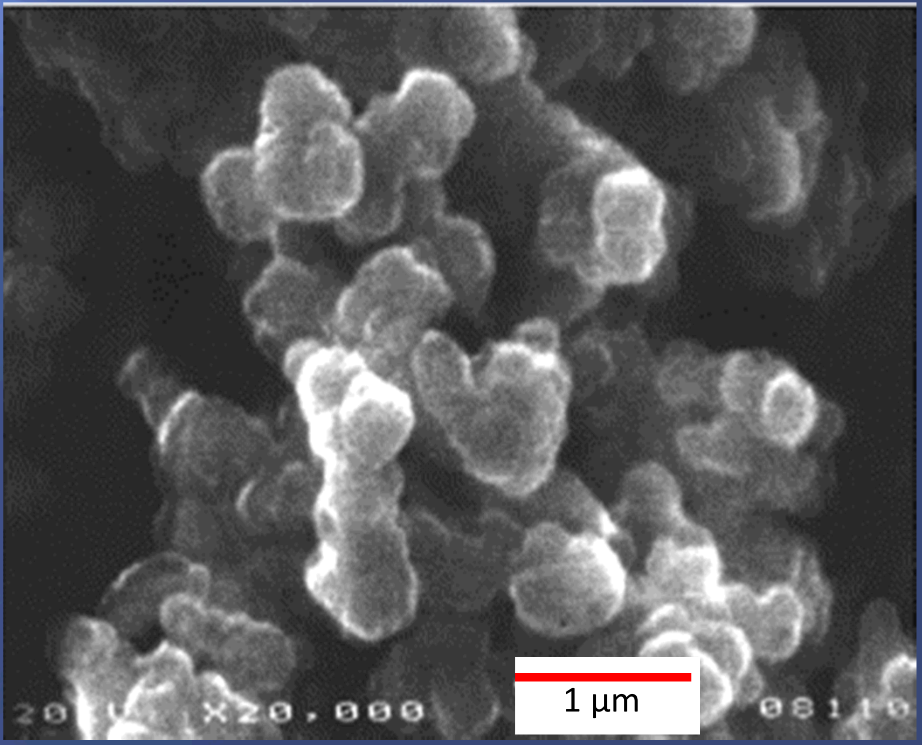
- Discuss the modeling of iodine released as a result of a nuclear power plant (NPP) accident
- Identify default assumptions for modeling iodine as being partitioned into different chemical forms
- Show how iodine chemical/physical form assumptions impact public protection decisions:
  - Potassium iodide (KI) administration,
  - Sheltering, evacuation and relocation, and
  - Ingestion pathway

Why Do We Care About Iodine?



What is Iodine Partitioning?

- Iodine released from a nuclear power plant (NPP) accidents can exist in multiple chemical and physical forms.
- Gaseous Iodine:
  - Organic or non-reactive (e.g., CH_3I)
  - Inorganic or reactive, (e.g., I_2)
- Particulate Iodine:
  - Varying particle size distributions
  - Big, ~ 1 - 5 µm
  - Small particle species (e.g., CsI, AgI), ~ 0.1 – 1.0 µm
  - Very small particles species (e.g., I_xO_y), ~ 0.02 µm



Why Do We Care About Iodine Partitioning?

- Inhalation dose coefficients (DCs) vary by:
  - Physical and chemical form
  - Particle size distribution (PSD)
- Deposition velocity is function of chemical and physical form
- Therefore, we need to know how iodine is partitioned in order to:
  - Perform atmospheric dispersion modeling to predict downwind air and ground concentrations,
  - Perform accurate radiological dose assessments /dose projections and
  - Provide suitable information to help decision makers make appropriate protective action decisions (e.g., sheltering, evacuation, food interdiction).

Iodine Partitioning Implemented by FRMAC

- The Federal Radiological Monitoring and Assessment Center (FRMAC) assumes the default iodine partitioning specified by the Nuclear Regulatory Commission (NUREG-1940, *RASCAL 4.3:Description of Models and Methods*, 2014)

- Iodine partitioning assumptions are based upon data from the Hanford Environmental Dose Reconstruction (HEDR) Project, Chernobyl and atmospheric iodine reports (See NUREG-1940).

FRMAC's Iodine Partitioning Assumptions

- It is difficult to know the actual partitioning between the different forms of iodine.
- Therefore, we have to make assumptions based on available data

Default iodine partitioning assumptions

Form		Default Fraction	Deposit on Ground?
Particulate	Aerosol, 1 µm AMAD, Lung Clearance Type = Fast	0.25	Yes
Reactive Gas	I_2	0.30	Yes
Non-Reactive Gas	CH_3I	0.45	No

Therefore,

- 55% of total iodine (i.e., particulate and reactive gas forms) is assumed to deposit on the ground
- 45% of total iodine (i.e., non-reactive gas) is assumed NOT to deposit on the ground in the local area

Comparing Dose Coefficients

Radio-nuclide	**1 Year Old Thyroid** Committed Equivalent Dose (rem/µCi)			Reactive ÷ Particulate	Non-Reactive ÷ Particulate
	Particulate (1 µm AMAD, Class F)	Reactive Gas (I_2)	Non-Reactive Gas (CH_3I)		
I-131	5.29	12.0	9.36	2.27	1.77
I-132	0.0603	0.140	0.122	2.32	0.80
I-133	1.30	2.96	2.34	1.80	1.80
I-134	0.0114	0.0269	0.0270	2.36	2.36
I-135	0.258	0.592	0.481	2.29	1.86

- 1 Year Old, Committed Equivalent Inhalation DCs for Reactive form of iodine are significantly greater (~1.9 – 2.4) than that for the particulate form.
- 1 Year Old, Committed Equivalent Inhalation DCs for Non-reactive form of iodine are significantly greater (~0.8 – 2.4) than that for the particulate form.

Comparing Dose Coefficients

Radio-nuclide	Adult Committed Effective Dose (rem/µCi)			Reactive ÷ Particulate	Non-Reactive ÷ Particulate
	Particulate (1 µm AMAD, Class F)	Reactive Gas (I_2)	Non-Reactive Gas (CH_3I)		
I-131	0.0274	0.0734	0.0570	2.68	2.08
I-132	0.000422	0.00114	0.000715	2.70	1.69
I-133	0.00544	0.0147	0.0114	2.70	2.10
I-134	0.000207	0.000543	0.000186	2.62	0.90
I-135	0.00120	0.00341	0.00251	2.84	2.09

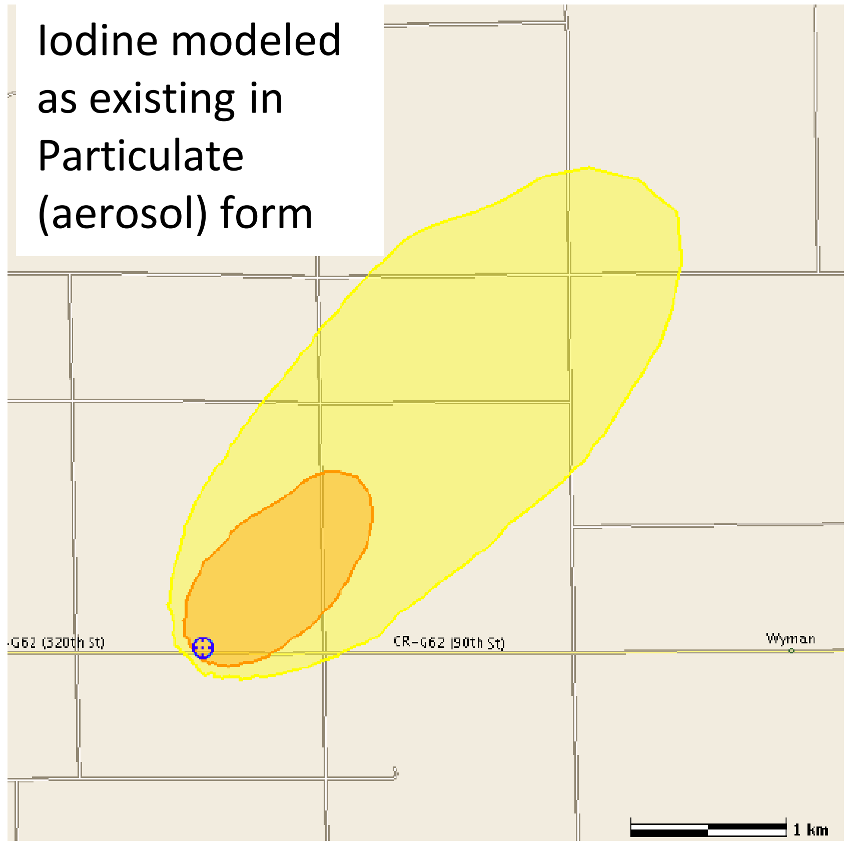
- Adult, Committed Effective Inhalation DCs for Reactive form of iodine are significantly greater (~2.7) than that for the particulate form.
- Adult, Committed Effective Inhalation DCs for Non-reactive form of iodine are significantly greater (~0.9 – 2.1) than that for the particulate form.

Dose Implications of Partitioned Iodine

- Airborne Iodine Dose Implications
  - Although the Non-reactive (organic) form of iodine does not deposit on the ground in the local area, it is assumed to exist in the breathing zone, and therefore, contributes to the plume inhalation dose.
  - The inhalation dose to the thyroid is approximately 2 time larger for the partitioned iodine, compared to the all-particulate iodine because the reactive and non-reactive forms of iodine have larger committed equivalent dose coefficients for the thyroid
- Ground-Deposited Iodine Dose Implications
  - Only approximately 55% of the airborne iodine is deposited because the non-reactive gas is not considered to be deposited in the local area.
  - Partitioned iodine has lower ingestion pathway (e.g., milk, fresh produce) impacts because less is deposited on the crops and fodder.

Comparing Early Phase Contours

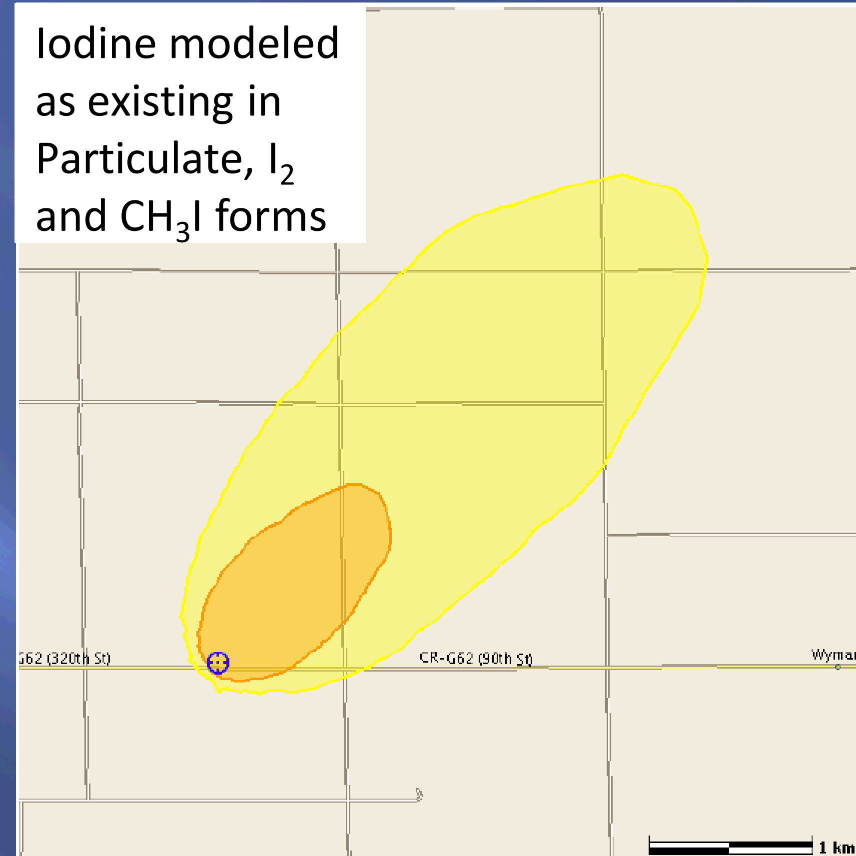
Iodine modeled as existing in Particulate (aerosol) form



	Description	(rem) Extent Area
	Exceeds 5 rem total effective dose (upper limit early phase PAG for evacuation/sheltering).	>5 1.5 km 0.9 km2
	Exceeds 1 rem total effective dose (lower limit early phase PAG for evacuation/sheltering.	>1 4.1 km 5.9 km2

1 rem Impacted Area = 5.9 km^2

Iodine modeled as existing in Particulate, I_2 and CH_3I forms

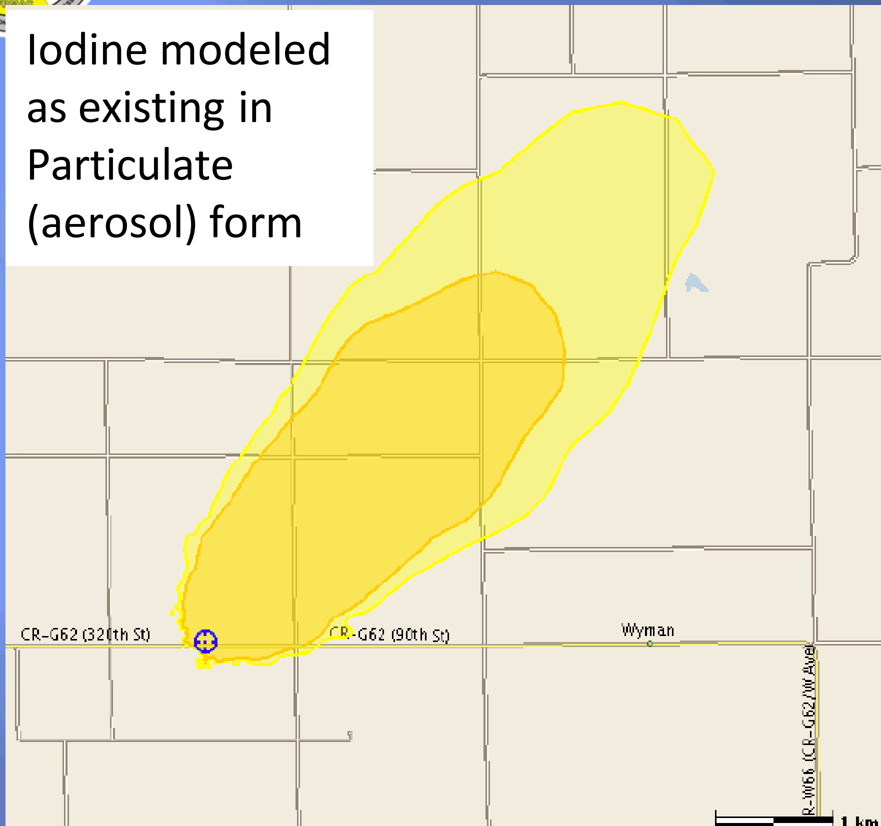


	Description	(rem) Extent Area
	Exceeds 5 rem total effective dose (upper limit early phase PAG for evacuation/sheltering).	>5 1.4 km 0.9 km2
	Exceeds 1 rem total effective dose (lower limit early phase PAG for evacuation/sheltering.	>1 4.0 km 5.7 km2

1 rem Impacted Area = 5.7 km^2

Comparing 1st & 2nd Year Contours

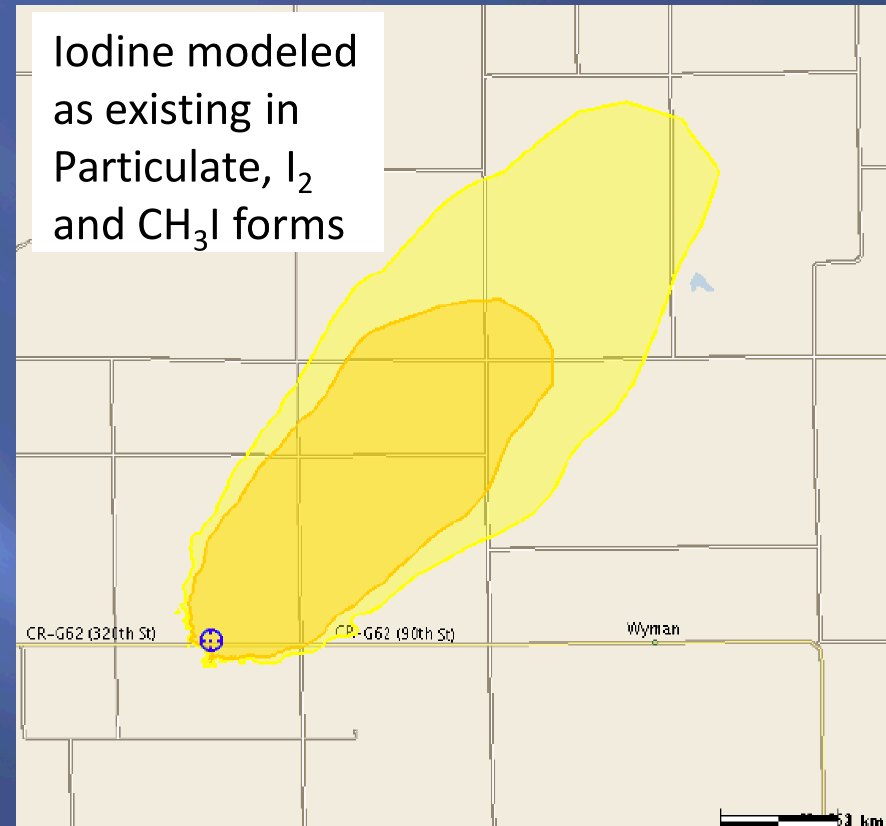
Iodine modeled as existing in Particulate (aerosol) form



	Description	(rem) Extent Area
	Exceeds first-year relocation PAG (12 hrs to 1 yr 12 hrs).	>2 4.1 km 5.6 km2
	Exceeds second-year relocation PAG.	>0.5 6.0 km 10.5 km2

2 rem Impacted Area = 5.6 km^2

Iodine modeled as existing in Particulate, I_2 and CH_3I forms

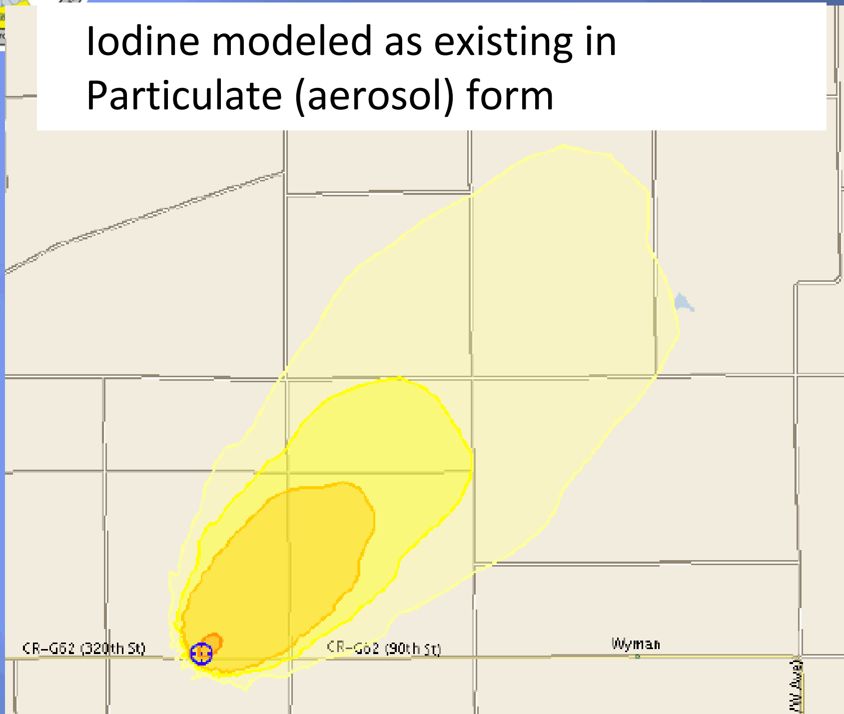


	Description	(rem) Extent Area
	Exceeds first-year relocation PAG (12 hrs to 1 yr 12 hrs).	>2 3.9 km 5.1 km2
	Exceeds second-year relocation PAG.	>0.5 6.0 km 10.5 km2

2 rem Impacted Area = 5.1 km^2

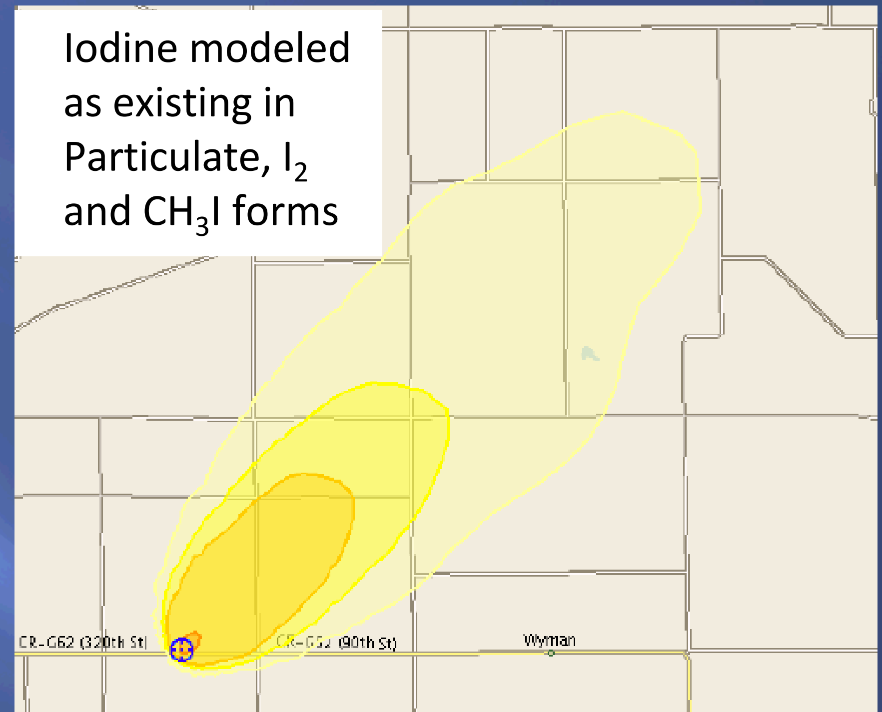
Potassium Iodide Administration

Iodine modeled as existing in Particulate (aerosol) form



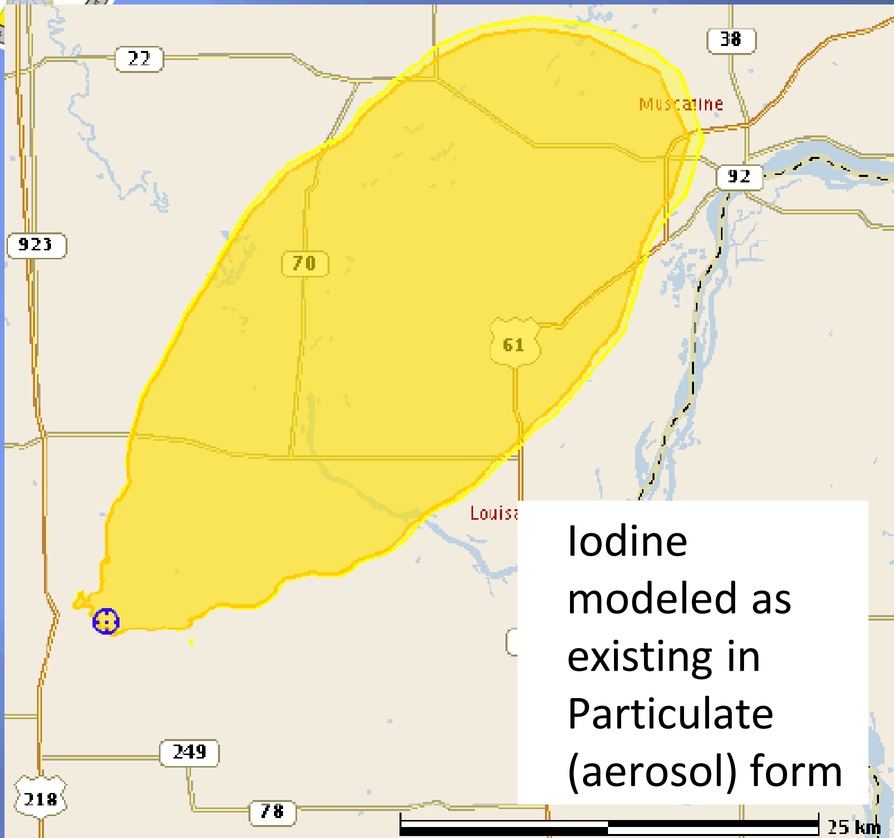
	Description	(rem) Extent Area
	Adult thyroid Committed Equivalent Dose - Early Phase FDA Guidance for KI administration to adults over 40.	>500 0.2 km 0.03 km2
	Adult thyroid Committed Equivalent Dose - Early Phase FDA Guidance for KI administration to adults under 40.	>10 2.0 km 1.7 km2
	Adult thyroid Committed Equivalent Dose - Early Phase FDA Guidance for KI administration to pregnant or lactating females.	>5 3.0 km 3.9 km2
	Child thyroid Committed Equivalent Dose - Early Phase PAG for KI administration to children under 18. (Prediction based on dose factors and breathing rates for 1-year old.)	>5 5.6 km 11.5 km2

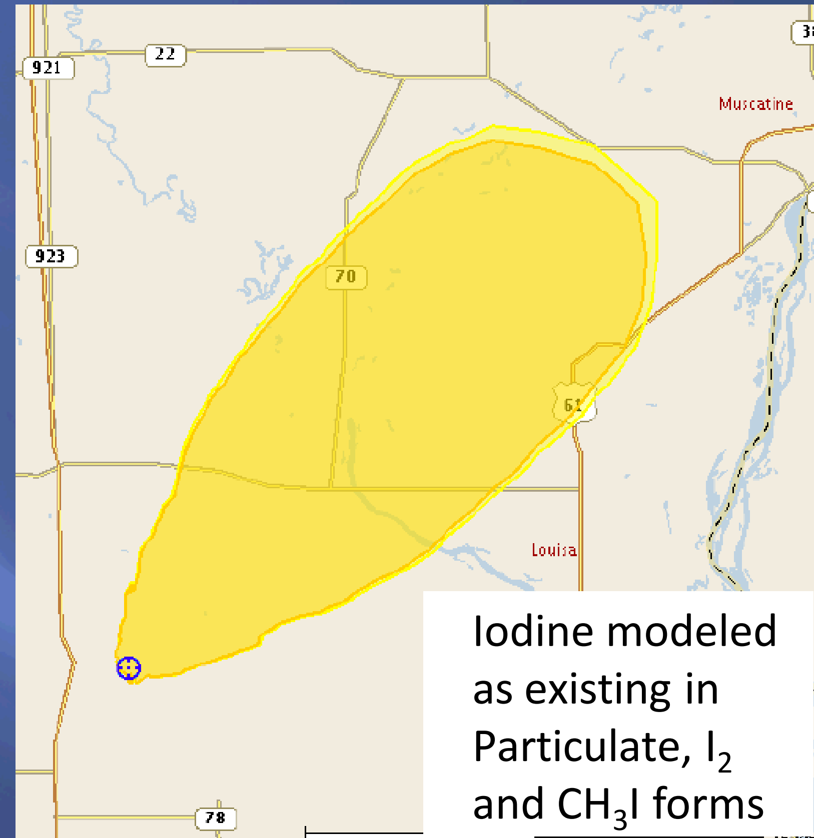
Iodine modeled as existing in Particulate, I_2 and CH_3I forms



	Description	(rem) Extent Area
	Adult thyroid Committed Equivalent Dose - Early Phase FDA Guidance for KI administration to adults over 40.	>500 0.2 km 0.03 km2
	Adult thyroid Committed Equivalent Dose - Early Phase FDA Guidance for KI administration to adults under 40.	>10 2.4 km 2.3 km2
	Adult thyroid Committed Equivalent Dose - Early Phase FDA Guidance for KI administration to pregnant or lactating females.	>5 3.7 km 4.8 km2
	Child thyroid Committed Equivalent Dose - Early Phase PAG for KI administration to children under 18. (Prediction based on dose factors and breathing rates for 1-year old.)	>5 7.4 km 16.3 km2

Ingestion Pathway (Milk, Produce)





	Description	(pCi/m2) Extent Area
	Potentially exceeds FDA Derived Intervention Level for fresh produce ready for harvest. Further analysis recommended to determine if any embargo is required.	>10,000 46.6 km 720 km2
	Potentially exceeds FDA Derived Intervention Level for milk (grass-cow-infant). Further analysis recommended to determine if any embargo is required.	>8,800 47.5 km 738 km2

	Description	(pCi/m2) Extent Area
	Potentially exceeds FDA Derived Intervention Level for fresh produce ready for harvest. Further analysis recommended to determine if any embargo is required.	>10,000 37.8 km 420 km2
	Potentially exceeds FDA Derived Intervention Level for milk (grass-cow-infant). Further analysis recommended to determine if any embargo is required.	>8,800 38.7 km 493 km2

Comparison Summary

Protective Action	Impacts when Iodine modeled as all in **particulate form**		Impacts when Iodine modeled as **multiple forms**	
	Area (km^2)	Extent (km)	Area (km^2)	Extent (km)
Early Phase- Sheltering, Evacuation (1 rem)	5.9	4.1	5.7	4.0
1st Year- Relocation (2 rem)	5.6	4.1	5.1	3.9
KI Administration (5 rem to 1 year old thyroid)	**11.5**	**5.6**	**16.3**	**7.4**
Milk Pathway	**738**	**47.5**	**493**	**38.7**

Note the differences in the KI Administration and Milk Pathway results!

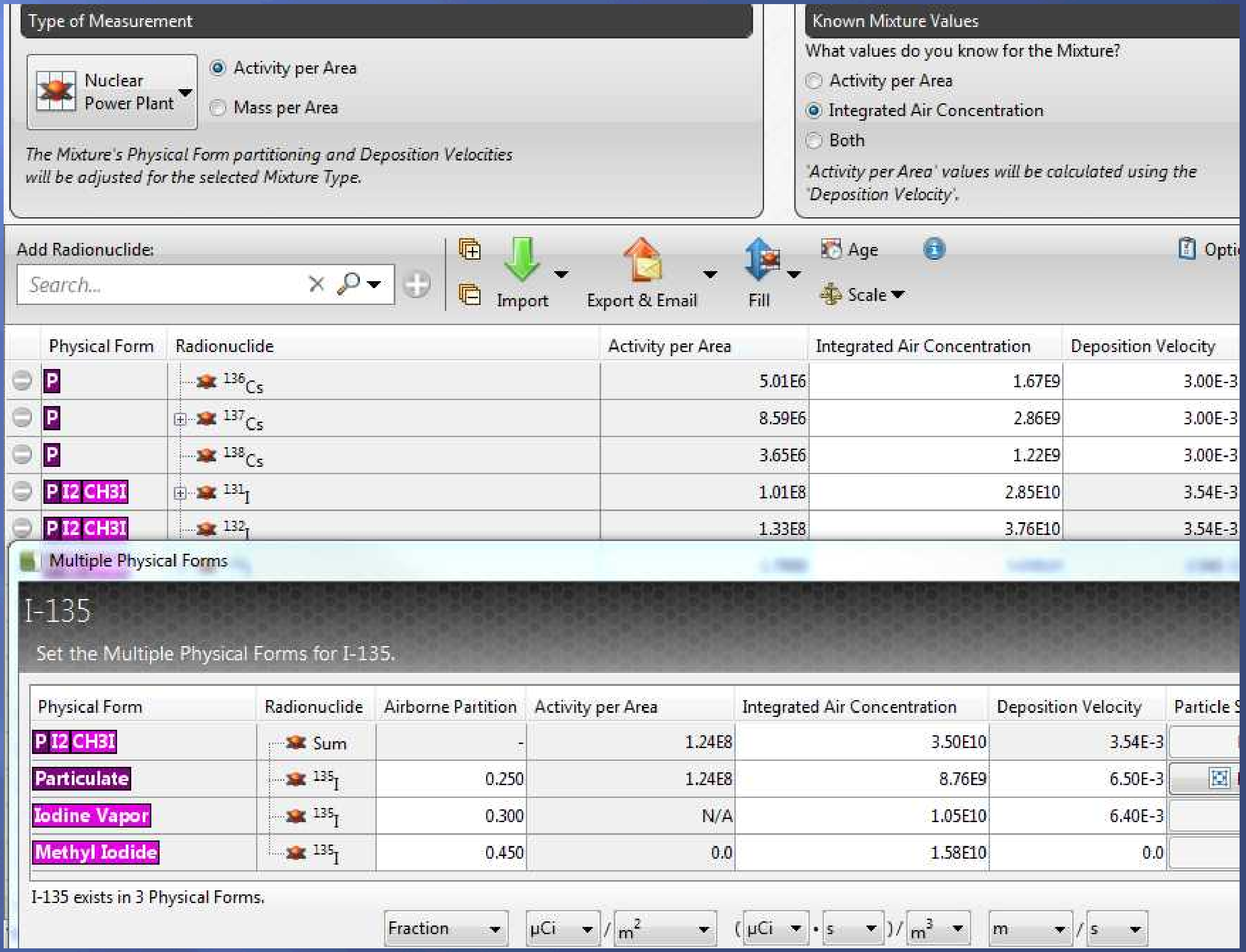
Turbo FRMAC© (TF) Software

Turbo FRMAC© (TF) Software (SNL, 2015a)

- Automates the methods in the FRMAC Assessment Manual, Volume 1, *Overview and Methods* (SNL, 2015b)
- Turbo FRMAC eliminates *most* human errors
- Greatly speeds up calculations and eliminates the need to make simplifying assumptions
- Turbo FRMAC© runs on a laptop
- Latest Version is TF 2015
- Publically accessible at: http://nirp.sandia.gov

NPP Assessments using the Turbo FRMAC Software

- Turbo FRMAC automatically partitions the iodine into the different forms using the default assumptions when “Nuclear Power Plant” mixture is selected
- Partitioning between the different forms can be user defined



Conclusions

- The partitioning of iodine **DOES NOT** have a significant impact on Early Phase (sheltering, relocation) decisions.
- The partitioning of iodine **DOES NOT** have a significant impact on Intermediate Phase (relocation) decisions.
- The partitioning of iodine MAY have a significant impact on KI Administration decisions.
- The partitioning of iodine MAY have a significant impact on ingestion pathway (e.g., milk, fresh produce) decisions.

Conclusions

- It is important to account for the partitioning of iodine when perform radiological assessments.
- There is no one iodine partitioning assumption that is perfect for all iodine releases.
- NRC’s assumptions implemented in RASCAL 4 seem to be a good starting point for modeling.
- Goal should be to have all modelers implement similar default model input assumptions to ensure consistency between predictions and radiological dose assessments.

Questions?