SAND2018-6625PE

Uncertainty Analysis of Consequence Management (CM) Data Products

AMS International Technical Exchange on Uncertainty in Radiological Aerial Measurements

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Project Background

Initial Analysis

- DOE NNSA Consequence Management (CM) has been asked for many years to quantify how good (certain) our data products are
- This project is a first attempt at **quantifying uncertainty** of the Derived Response Level (DRL) values that are used for CM data products
  - DRL = a level of radioactivity in the environment that would be expected to produce a dose equal to the corresponding Environmental Protection Agency (EPA) Protective Action Guide (PAG)
- Ultimate goal is to quantify the **confidence** in the values used for **CM data products** to ensure that appropriate public and worker protection decisions are supported by defensible analysis
- Uncertainty analyses can help CM **identify major sources of uncertainty** and motivate additional studies to **minimize** these sources of uncertainty

Demonstration Scenario

- Detonation of **Cesium-137 or Americium-241 radiological dispersal device (RDD)** on level terrain with stable wind class
- Idealized particle size distribution (particles created by detonation and atmospherically dispersed are all 1 μm diameter)
- Source term of sufficient quantity to create an activity per area equal to the DRL at a hypothetical location downwind
- **Public Protection DRL** calculation was performed for the **Early Phase (Total Dose), Early Phase (Avoidable Dose), and First Year** time phases and used all FRMAC defaults, as specified in FRMAC Assessment Manual, Vol. 1

Scenario	Deposition DRL (μCi/m^2)			
	Single Radionuclides		1:1 Mixture	
	Cs-137	Am-241	Cs-137	Am-241
Early Phase (TD)	3.30E+02	4.64E-02	4.64E-02	4.64E-02
Early Phase (AD)	1.70E+03	8.66	8.62	8.62
First Year	42.0	4.15	3.78	3.78

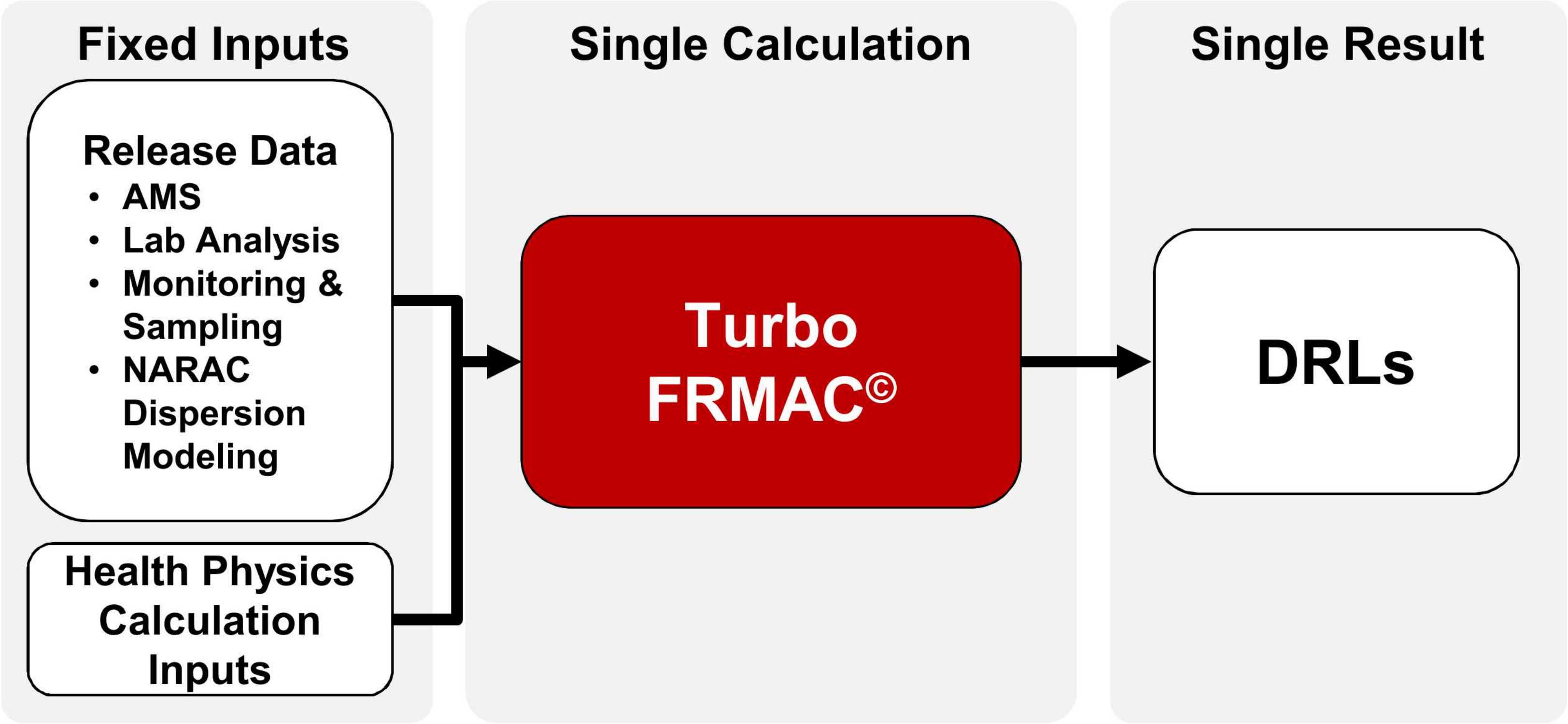
Uncertainty Quantification Methods

Uncertainty Quantification Methods

- Uncertainty in context of CM
  - **Variation (error) of a measurement** from the exact value being measured; termed **uncertainty** in the fixed value of a measurement
  - **Input uncertainty leads to output uncertainty**, meaning that final DRL results are estimates of the true DRL value
- For example, suppose that the **actual** activity per area is 330 µCi/m^2
  - Suppose that the laboratory measures the activity per area from a sample. **How much will this measurement differ from the actual value?**
  - Uncertainty in this estimate contributes to uncertainty in the final DRL estimate. **How close is this estimate to the actual DRL value?**
- **Monte Carlo analysis** used to characterize uncertainty

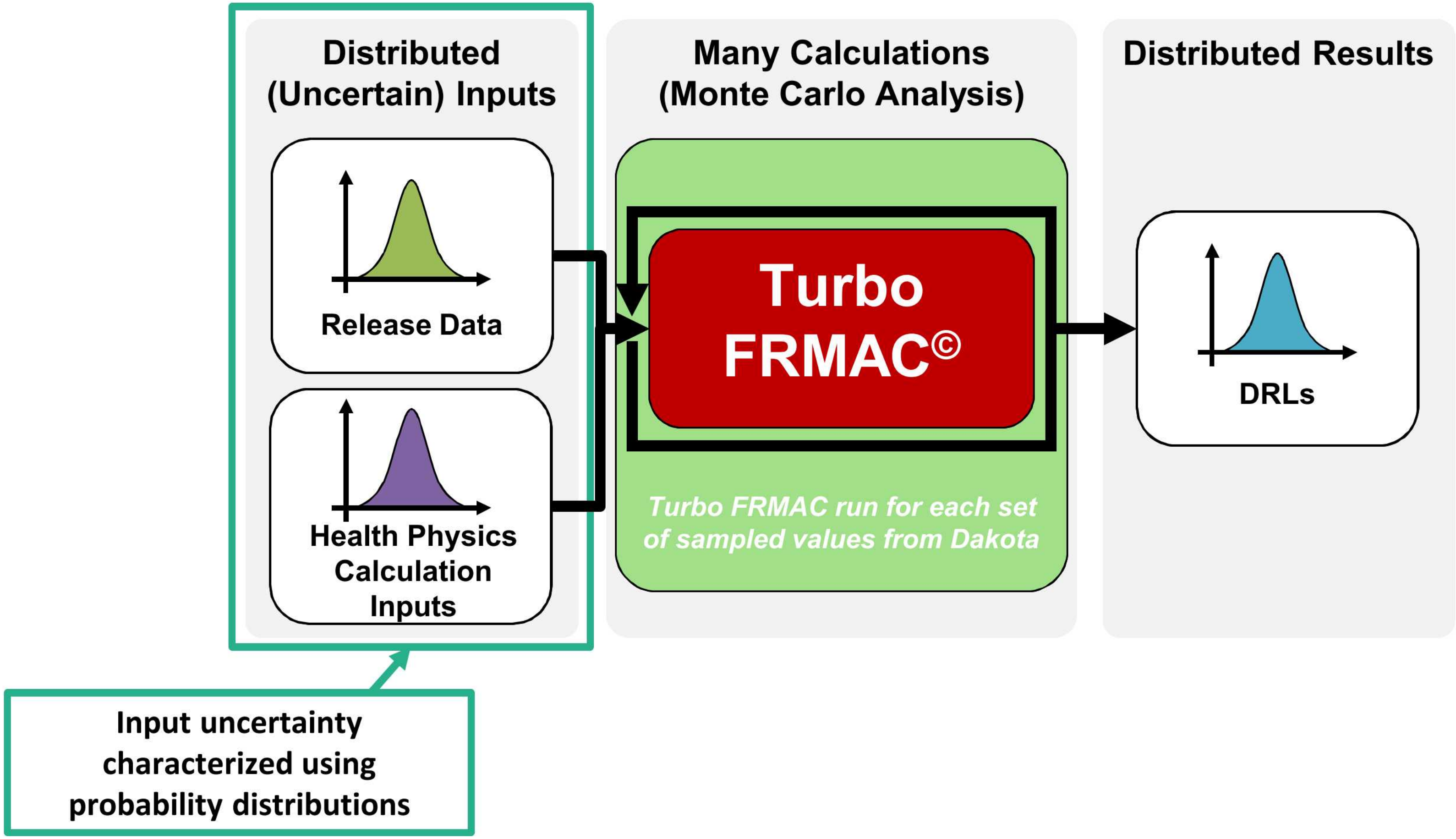
Current Response Process

- **Response calculations** use **fixed inputs** to run a single calculation with a **single result**



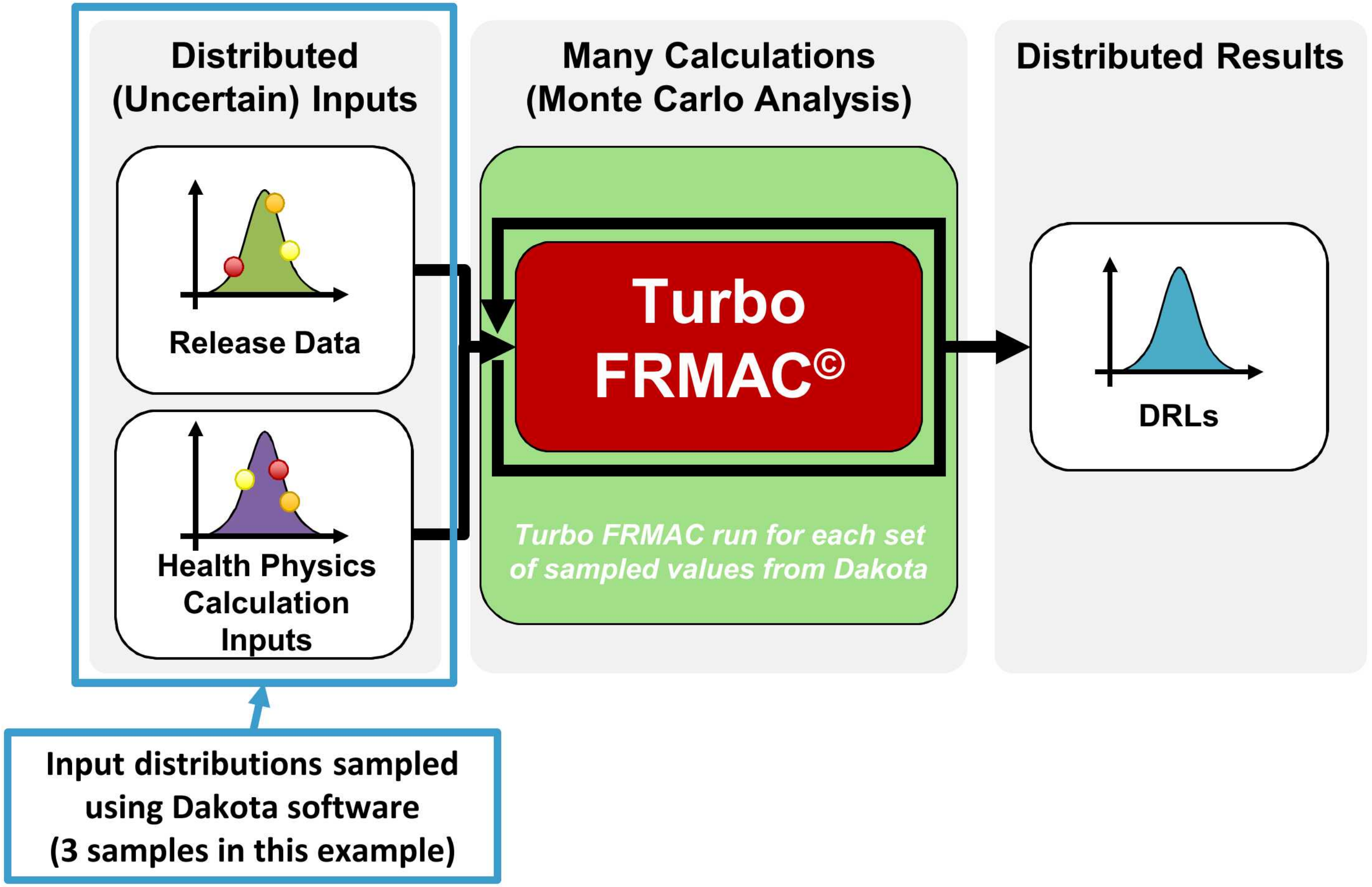
Uncertainty Propagation

- **Monte Carlo analysis** used to **propagate uncertainty** from inputs through the model to the outputs



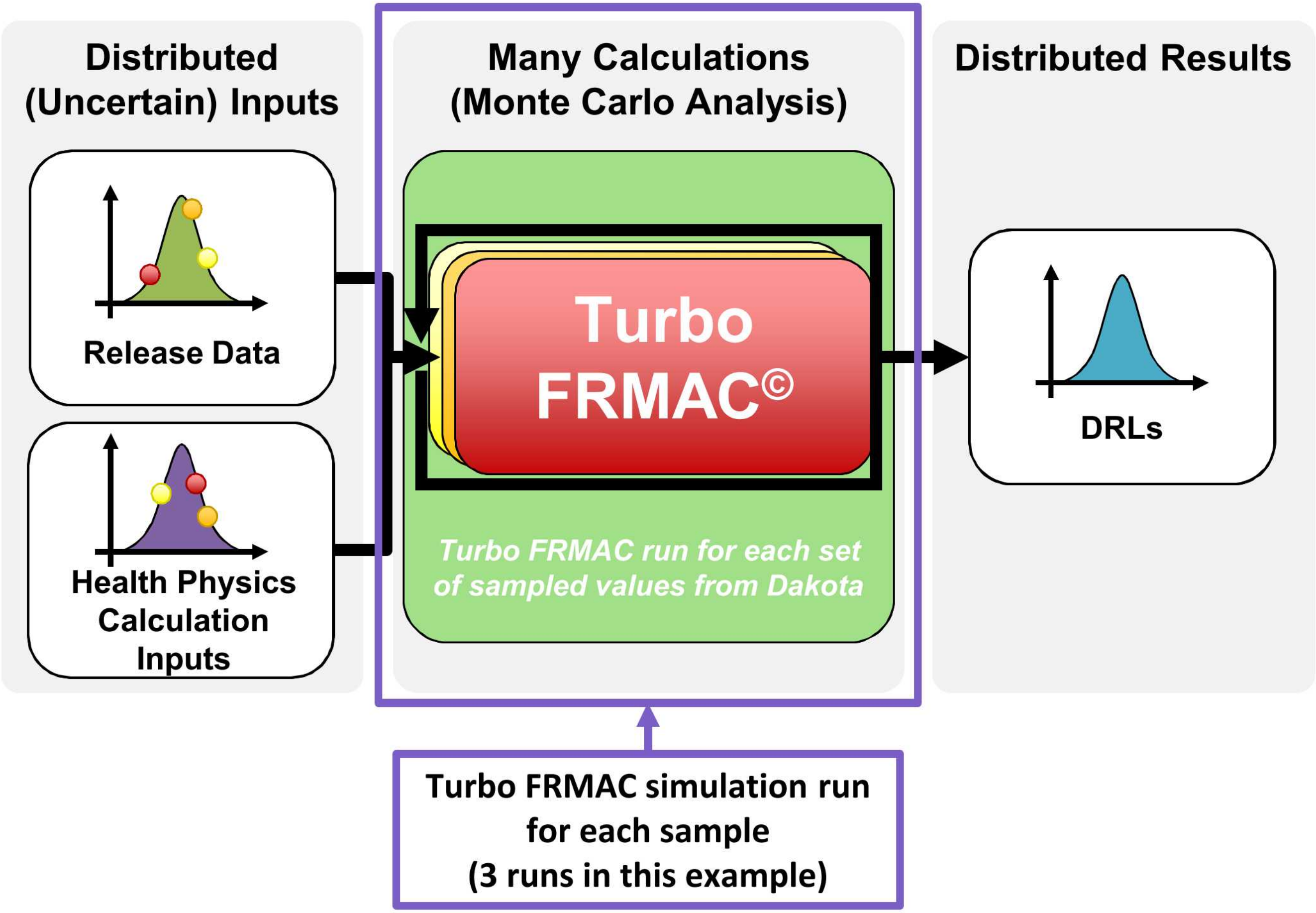
Uncertainty Propagation

- **Input probability distributions** characterize uncertain inputs and are **sampled** using Sandia's Dakota software



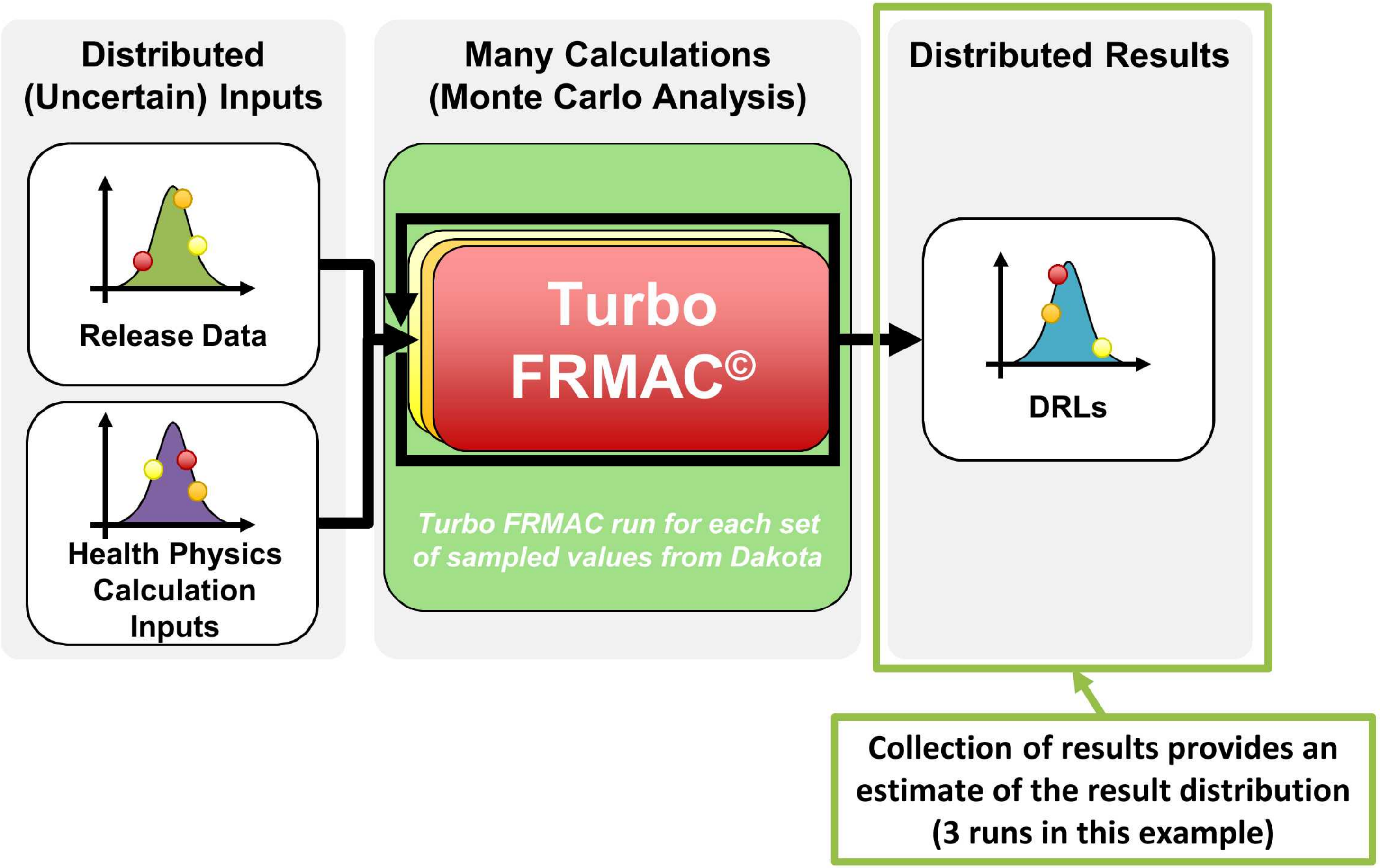
Uncertainty Propagation

- **Turbo FRMAC** simulation run for **each sample** taken from input distributions



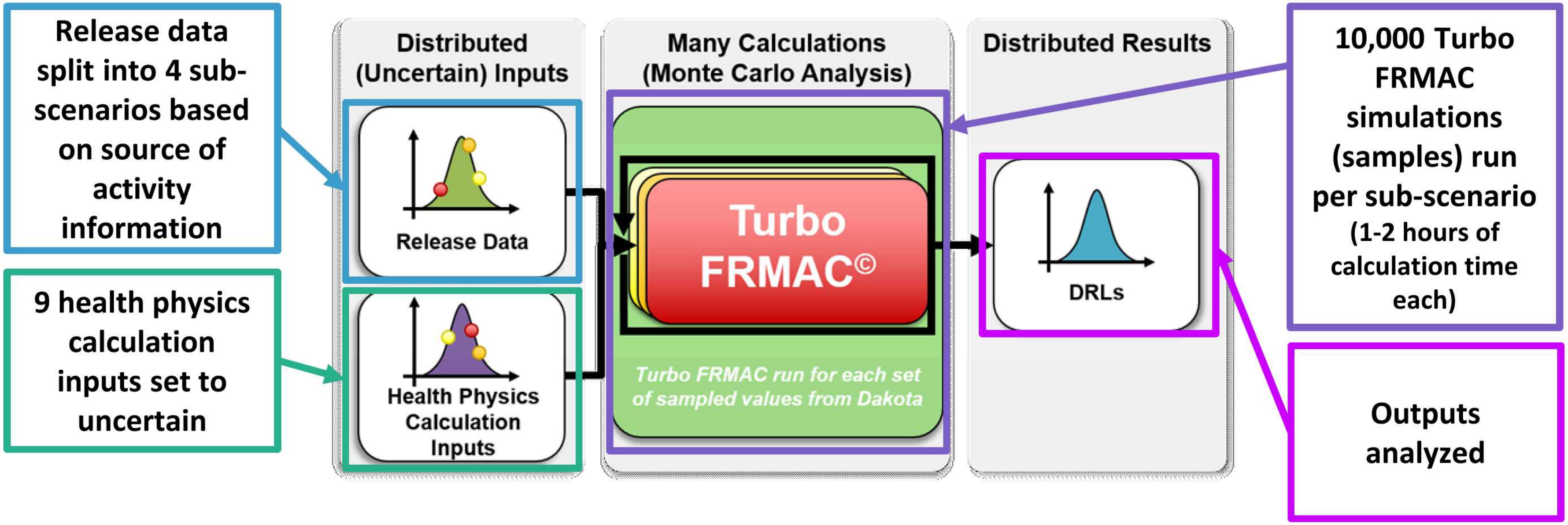
Uncertainty Propagation

- **Collection of results** from each simulation provides an **estimate of the distribution** of the result of interest (DRL)



Uncertainty Propagation Details

- Samples from input distributions taken using **Latin hypercube sampling (LHS)**
- A **large sample size** is needed to create a precise estimate of the output distribution
- **Turbo FRMAC updated** to read in and run each set of input samples and save all outputs for each simulation



Sources of Uncertainty

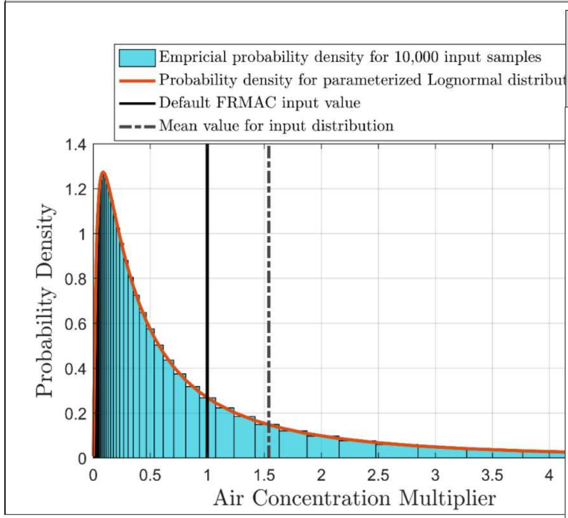
Sources of Uncertainty

- **DRLs** are calculated based on **measured or projected** concentrations of **radionuclides** in the environment
- The **concentration sources** considered in this analysis include:
  - NARAC plume projections
  - Laboratory Analysis
  - In Situ Deposition
  - AMS measurements
- **Nine uncertain inputs** that contribute to uncertainty in the health physics calculations of Public Protection DRLs were assigned probability distributions
- **Input distributions** were **selected** based on uncertainty information from **published data and/or expert opinion**

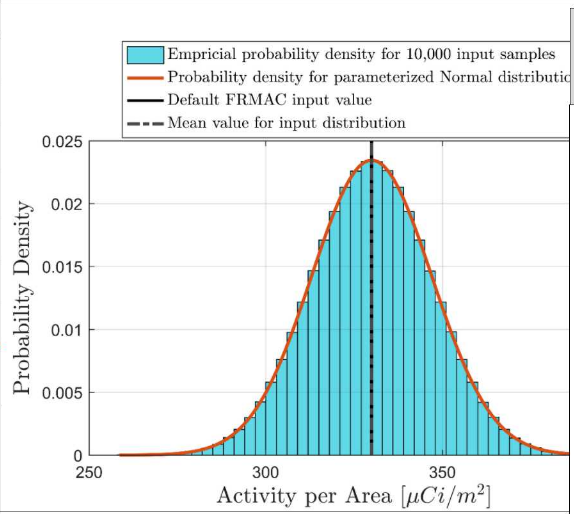
Input Distribution Examples

- Distribution forms and parameters describe the **possible values** for an input and are **sampled** for each simulation
- Figures below show **examples** of assigned distributions

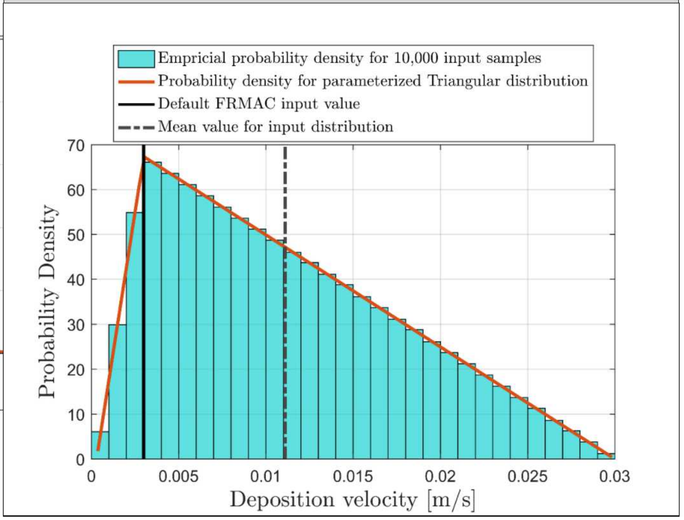
Lognormal distribution for Air Concentration Multiplier



Normal distribution for Activity per Area



Triangular distribution for Deposition Velocity



AMS Measurement Uncertainty

AMS Measurement Uncertainty – Cs-137

- Initial processing of the data **converts the gross count rate** in the detector to a corrected equivalent net count rate at a nominal altitude:

$$N = K\left(N_g - N_0\right)e^{B(z-z_o)}$$

K: Conversion factor for count rate

N_g: Gross count rate in the detector during the measurement

N_0: Mean count rate estimate due to airborne background radiation

B: Effective attenuation coefficient

z: Altitude above ground level

z_0: Nominal altitude

- The uncertainty for the coefficient to convert a net count rate in the aerial system to a ground-level quantity (exposure rate, or deposition concentration) depends upon the ground and aerial measurements along a calibration line

AMS Measurement Uncertainty – Cs-137

- The **aerial components of the uncertainty** are related to the knowledge of the height above ground level (AGL) while performing the measurements at multiple altitudes (altitude spiral)
  - Radar altimeter uncertainty = ±0.7 m
  - GPS uncertainty = ±3 m
- The **uncertainty in the effective attenuation coefficient** results from atmospheric conditions as well as the variability of the actual flight altitudes during passes over the calibration line
  - Attenuation coefficient = 1.674×10^{-3} ft^{-1} with an SD of 4.58×10^{-5} ft^{-1} (2.74%)
- The **uncertainty in the raw counts in the detector**, either from the ground contamination or from the aircraft background, follow **normal statistics**

Platform	Nominal Altitude AGL	Estimated Count Rate cps/(330 µCi/m^2)	Background (cps)
Fixed-wing	50 m	7.85×10^5	870
	150 m	4.72×10^5	870
Helicopter	50 m	3.14×10^6	3500
	150 m	1.89×10^6	3500

AMS Measurement Uncertainty – Cs-137

- To calculate the **total uncertainty** for the aerial measurements, the contributions from the different components must be propagated:

$$\sigma_N^2 = \sigma_K^2 \left(N_g - N_0\right)^2 e^{2B(z-z_0)} + \left(\sigma_{N_g}^2 + \sigma_{N_0}^2\right) K^2 e^{2B(z-z_0)} + \sigma_B^2 K^2 \left(N_g - N_0\right)^2 e^{2B(z-z_0)} (z - z_0)^2 + \sigma_z^2 K^2 \left(N_g - N_0\right)^2 e^{2B(z-z_0)} B^2$$

- A **simplifying assumption** is made that the aircraft is flown precisely at the nominal altitude ($z = z_0$)

AMS Measurement Uncertainty – Am-241

- For extraction of a low-level Am-241 signal from the data collected with an aerial platform, a **3-window extraction process** is likely to be used
- In this process, the spectrum is broken down into three components: Am-241 signal region (36-72 keV) and two background regions (21-36 and 72-87 keV)
- A ratio, R, of the counts in the signal region ($N_{a,0}$) to the counts in the background region ($N_{b,0}, N_{c,0}$) is determined by data collected over an uncontaminated area:

$$R = \frac{N_{a,0}}{N_{b,0} + N_{c,0}}$$

- The ratio is used to calculate the expected counts in the signal region, in the absence of contamination. The **excess counts** in the signal region are taken to be from the contamination:

$$N_{\text{Am}} = N_a - R \times (N_b + N_c)$$

AMS Measurement Uncertainty – Am-241

- The **extracted counts must be corrected** for the measurement altitude, and a scale factor to convert the result to an activity concentration on the ground:

$$A = K \times \left(N_a - R \times (N_b + N_c)\right) \times e^{\mu(z - z_0)}$$

A: Deposited activity

K: Conversion factor for the count rate at altitude z_0

μ: Effective attenuation coefficient

z: Altitude above ground level

z_0: Nominal altitude

Platform	Nominal Altitude AGL	ROI a0 (36-72 keV)	ROI b0 (21-36 keV)	ROI c0 (72-87 keV)	Ratio	Ratio Uncertainty
Fixed-wing	50 m	841.4	140	503.2	1.31	0.069
	150 m	617.3	103.8	289.4	1.57	0.101
Helicopter	50 m	3365.7	559.9	2012.8	1.31	0.034
	150 m	3341	557.5	1827.3	1.40	0.038

AMS Measurement Uncertainty – Am-241

- If the uncertainties are propagated in the normal manner, the variance is:

$$
\begin{aligned}
&\sigma_A^2 \\
&= \sigma_K^2\left(N_a - R\times(N_b+N_c)\right)^2 \times e^{2\mu(z-z_0)} \\
&+ \sigma_\mu^2 K^2\left(N_a - R\times(N_b+N_c)\right)^2 e^{2\mu(z-z_0)}(z-z_0)^2 \\
&+ \sigma_z^2 K^2\left(N_a - R\times(N_b+N_c)\right)^2 e^{2\mu(z-z_0)}\mu^2 \\
&+ \left(\sigma_a^2 + R^2\times\left(\sigma_b^2+\sigma_c^2\right) + (N_b+N_c)^2\times\sigma_R^2\right)K^2 e^{2\mu(z-z_0)},
\end{aligned}
$$

- The correction of only the count rate and its uncertainty is considered first. If the conversion factor is set to 1 and it is assumed that the mission is flown at nominal altitude ($z = z_0$), the uncertainty reduces:

$$
\begin{aligned}
&\sigma_A^2 \\
&= \sigma_z^2 {N_{Am}}^2\mu^2 \\
&+ \left(\left(N_{\mathrm{Am}} + N_{a,0}\right) + R^2\times\left(N_{b,0}+N_{c,0}\right) + \left(N_{b,0}+N_{c,0}\right)^2\times\sigma_R^2\right)
\end{aligned}
$$

Converting from Air to Ground

- Uncertainties calculated using the previously described methods must then be **propagated to a ground contamination value** that includes calibration uncertainty for use in Turbo FRMAC© calculations
- K is a scaling factor determined by a combination of aerial and ground measurements at a calibration area

$$K = \frac{A'}{N'} \qquad \sigma_K = \frac{A'}{N'} * \sqrt{\left(\frac{\sigma_{A'}}{A'}\right)^2 + \left(\frac{\sigma_{N'}}{N'}\right)^2}$$

- Ground contamination, A, is then calculated:

$$A = K * N \qquad \sigma_A = (K * N) * \sqrt{\left(\frac{\sigma_K}{K}\right)^2 + \left(\frac{\sigma_N}{N}\right)^2}$$

Cs-137 and Am-241 AMS Uncertainties

Assuming Fixed Wing at 150 m AGL

Single Radionuclide

Scenario	Cs-137			Am-241		
	Mean (µCi/m²)	Standard Deviation (µCi/m²)	Relative Error	Mean (µCi/m²)	Standard Deviation (µCi/m²)	Relative Error
Early Phase (TD)	3.30E+02	9.31	3%	4.64E-02	1.46	3148%
Early Phase (AD)	1.70E+03	47.9	3%	8.66	1.71	20%
First Year	42.0	1.27	3%	4.15	1.54	37%

1:1 Mixture

Scenario	Cs-137			Am-241		
	Mean (µCi/m²)	Standard Deviation (µCi/m²)	Relative Error	Mean (µCi/m²)	Standard Deviation (µCi/m²)	Relative Error
Early Phase (TD)	4.64E-02	4.81E-01	1037%	4.64E-02	1.46	3148%
Early Phase (AD)	8.62	5.34E-01	6%	8.62	1.71	20%
First Year	3.78	4.90E-01	13%	3.78	1.53	40%

Uncertainty Analysis Results

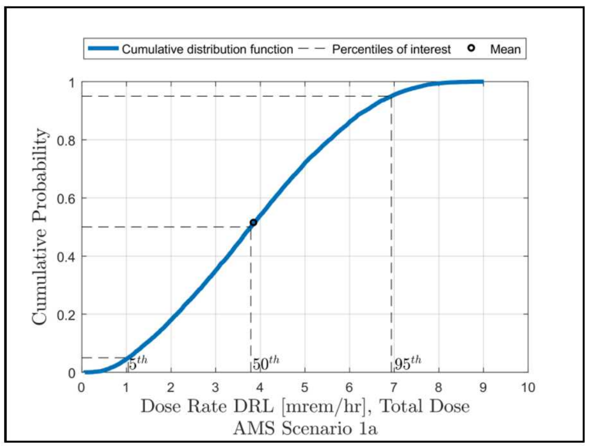
Uncertainty Analysis Results

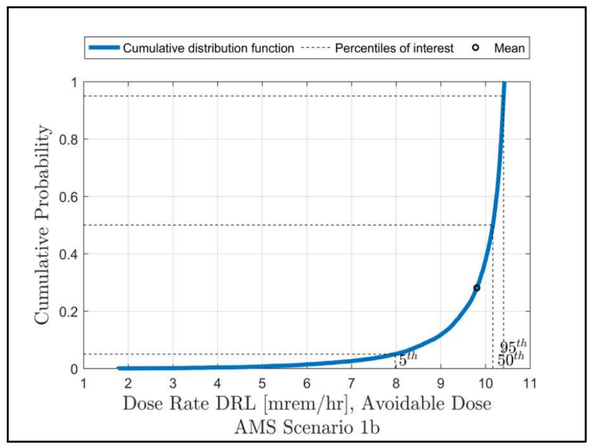
- Performed **10,000 simulations** to generate a set of results for each output of interest
- **Sensitivity analysis methods** tell us how much of the **uncertainty in the output** is explained by the **uncertainty in the input**
- Linear rank regression technique applied for the purposes of this project
  - **Inputs ranked in terms of importance** by standardized rank regression coefficient (SRRC) value
- **Preliminary FY18 results** using AMS measurement uncertainty are presented

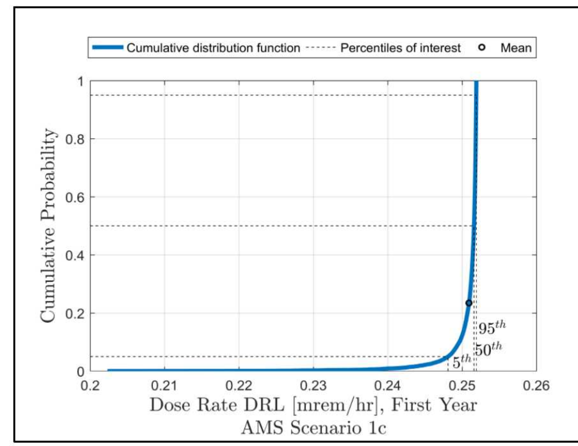
Cs-137 Scenario Results

Dose Rate DRL (mrem/hr)

Scenario	Default	Mean	5th	50th	95th	Mean/ Default	95th/ 5th
Early Phase (TD)	1.98	3.857	1.043	3.786	6.934	1.94	6.65
Early Phase (AD)	10.2	9.808	7.979	10.165	10.407	0.96	1.30
First Year	0.2516	0.2509	0.2481	0.2516	0.2519	1.00	1.02







- Mean and Default DRLs are at most about a factor of 2 different
- Appears that there is little uncertainty in the Dose Rate DRL for the Early Phase (AD) and First Year time phases

Cs-137 Scenario Results

- Sensitivity results show that **Deposition Velocity** is the important input when the dose includes plume inhalation
- When plume dose is not included, **groundshine** drives the dose, but the inputs are not important because they are cancelled out in the DRL ratio
- AMS measurement uncertainty associated with Cs-137 at these activity levels is **not important** to the DRL uncertainty

Early Phase (TD) Dose Rate DRL, R^2 = 0.942		
Variable Name	**R^2**	**SRRC**
Deposition Velocity	0.621	0.788
Cs-137 Inhalation Dose Coefficient Multiplier	0.752	-0.360
Breathing Rate, Light Exercise, Adult Male	0.820	-0.259
Deposition External Dose Coefficient Multiplier	0.886	0.258
Weathering Coefficient Multiplier	0.926	0.199
Ground Roughness Factor	0.938	0.108
Resuspension Coefficient Multiplier	0.942	-0.065
Breathing Rate, Activity Averaged, Adult Male	0.942	-0.010
Plume External Dose Coefficient Multiplier	0.942	-0.004
Cs-137 Activity per Area	0.942	0.000

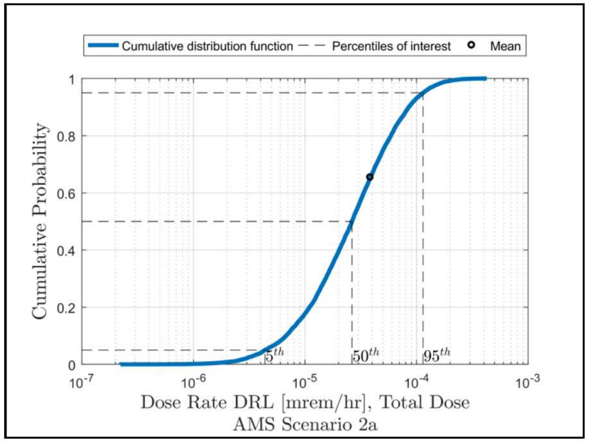
Early Phase (AD) Dose Rate DRL, R^2 = 0.984		
Variable Name	**R^2**	**SRRC**
Resuspension Coefficient Multiplier	0.888	-0.941
Cs-137 Inhalation Dose Coefficient Multiplier	0.930	-0.205
Deposition External Dose Coefficient Multiplier	0.951	0.143
Breathing Rate, Activity Averaged, Adult Male	0.967	-0.129
Weathering Coefficient Multiplier	0.981	0.115
Breathing Rate, Light Exercise, Adult Male	0.984	0.000
Cs-137 Activity per Area	0.984	0.000
Deposition Velocity	0.984	0.000
Plume External Dose Coefficient Multiplier	0.984	0.000
Ground Roughness Factor	0.985	0.061

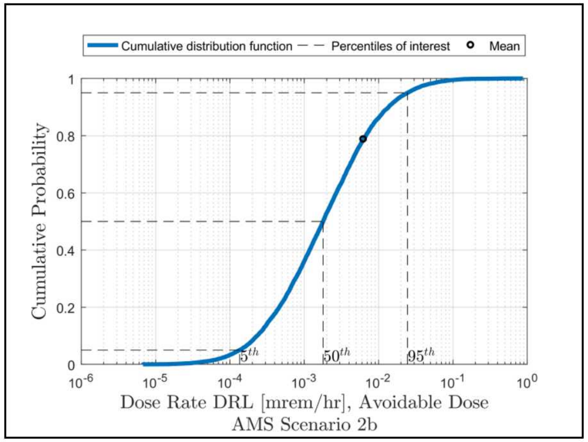
First Year results similar to Early Phase (AD)

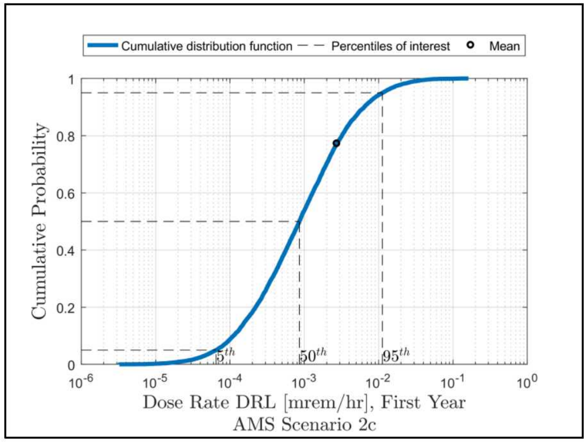
Am-241 Scenario Results

Dose Rate DRL (mrem/hr)

Scenario	Default	Mean	5th	50th	95th	Mean/ Default	95th/ 5th
Early Phase (TD)	1.10E-05	3.85E-05	4.38E-06	2.63E-05	1.14E-04	3.49	26.06
Early Phase (AD)	2.06E-03	6.26E-03	1.35E-04	1.79E-03	2.44E-02	3.04	180.16
First Year	9.89E-04	2.75E-03	6.52E-05	8.59E-04	1.12E-02	2.78	172.48







- Mean and Default DRLs are at most about a factor of 3.5 different
- The spread of the DRL distribution increases for the Early Phase (AD) and First Year time phases

Am-241 Scenario Results

- Sensitivity results show that **Deposition Velocity** is the important input when the dose includes plume inhalation
- When plume dose is not included, **resuspension inhalation** drives the dose, so those inputs become important
- AMS measurement uncertainty associated with Am-241 at these activity levels is **not important** to the DRL uncertainty

Early Phase (TD) Dose Rate DRL, R^2 = 0.940		
Variable Name	**R^2**	**SRRC**
Deposition Velocity	0.481	0.693
Am-241 Inhalation Dose Coefficient Multiplier	0.791	-0.556
Breathing Rate, Light Exercise, Adult Male	0.845	-0.230
Deposition External Dose Coefficient Multiplier	0.897	0.228
Weathering Coefficient Multiplier	0.928	0.176
Ground Roughness Factor	0.937	0.096
Resuspension Coefficient Multiplier	0.940	-0.058
Am-241 Activity per Area	0.940	0.000
Plume External Dose Coefficient Multiplier	0.940	0.000
Breathing Rate, Activity Averaged, Adult Male	0.940	-0.009

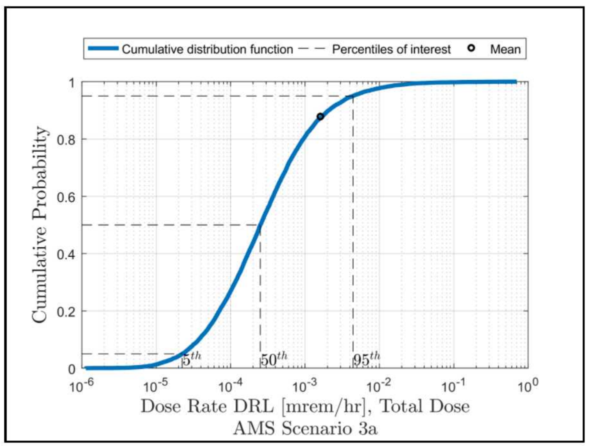
Early Phase (AD) Dose Rate DRL, R^2 = 0.977		
Variable Name	**R^2**	**SRRC**
Resuspension Coefficient Multiplier	0.812	-0.900
Am-241 Inhalation Dose Coefficient Multiplier	0.927	-0.338
Deposition External Dose Coefficient Multiplier	0.945	0.137
Breathing Rate, Activity Averaged, Adult Male	0.961	-0.123
Weathering Coefficient Multiplier	0.973	0.111
Ground Roughness Factor	0.977	0.059
Breathing Rate, Light Exercise, Adult Male	0.977	0.000
Am-241 Activity per Area	0.977	0.000
Deposition Velocity	0.977	0.000
Plume External Dose Coefficient Multiplier	0.977	0.000

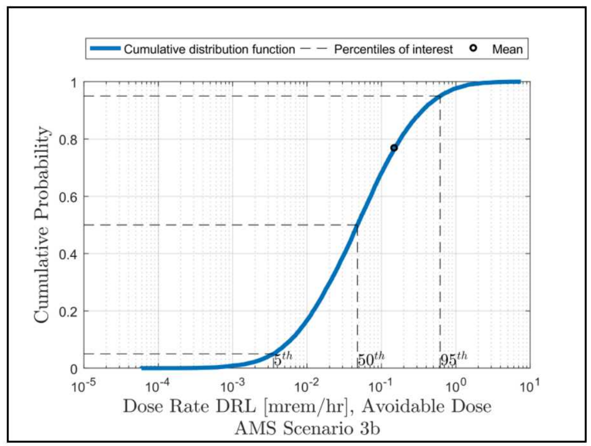
First Year results similar to Early Phase (AD)

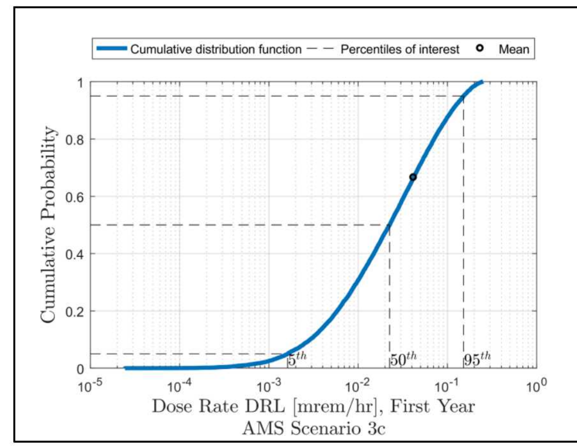
1:1 Mixture Scenario Results

Dose Rate DRL (mrem/hr)

Scenario	Default	Mean	5th	50th	95th	Mean/ Default	95th/ 5th
Early Phase (TD)	2.89E-04	1.64E-03	2.23E-05	2.51E-04	4.42E-03	5.67	197.90
Early Phase (AD)	5.37E-02	1.50E-01	3.54E-03	4.75E-02	6.15E-01	2.79	173.71
First Year	2.36E-02	4.17E-02	1.62E-03	2.25E-02	1.52E-01	1.77	93.46



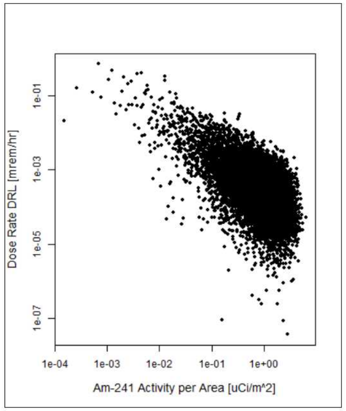


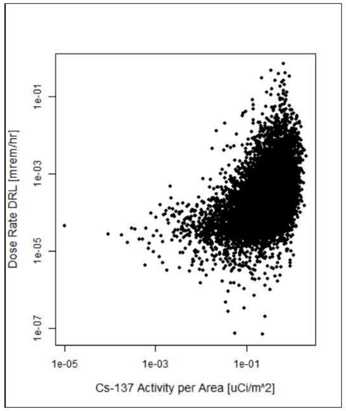


- Mean and Default DRLs are at most about a factor of 6 different
- Greatest spread of this DRL is associated with the Early Phase (TD) scenario using the 1:1 mixture of Cs-137:Am-241

1:1 Mixture Scenario Results

- Sensitivity results show that Am-241 and Cs-137 measurement uncertainty is **very important** for the Early Phase (TD) scenario





- When plume dose is not included, Am-241 **resuspension inhalation** drives the dose, so those inputs become important

Early Phase (TD) Dose Rate DRL, R^2 = 0.892		
Variable Name	**R^2**	**SRRC**
Am-241 Activity per Area	0.274	-0.524
Cs-137 Activity per Area	0.521	0.499
Deposition Velocity	0.715	0.439
Am-241 Inhalation Dose Coefficient Multiplier	0.835	-0.346
Breathing Rate, Light Exercise, Adult Male	0.856	-0.144
Deposition External Dose Coefficient Multiplier	0.874	0.137
Weathering Coefficient Multiplier	0.888	0.116
Ground Roughness Factor	0.891	0.057
Cs-137 Inhalation Dose Coefficient Multiplier	0.892	0.007
Resuspension Coefficient Multiplier	0.892	-0.035

Early Phase (AD) Dose Rate DRL, R^2 = 0.974		
Variable Name	**R^2**	**SRRC**
Resuspension Coefficient Multiplier	0.798	-0.892
Am-241 Inhalation Dose Coefficient Multiplier	0.910	-0.336
Deposition External Dose Coefficient Multiplier	0.929	0.137
Breathing Rate, Activity Averaged, Adult Male	0.944	-0.122
Am-241 Activity per Area	0.957	-0.116
Weathering Coefficient Multiplier	0.969	0.110
Ground Roughness Factor	0.972	0.055
Breathing Rate, Light Exercise, Adult Male	0.974	0.000
Cs-137 Inhalation Dose Coefficient Multiplier	0.974	0.000
Deposition Velocity	0.974	0.000

First Year results similar to Early Phase (AD)

Conclusions

- FY17-18 accomplishments:
  - Developed a **comprehensive method** to assess overall uncertainty of the values used for CM data products
  - **Identified uncertainty distributions** for Public Protection DRL inputs
  - Developed an **automated process** that utilizes **Turbo FRMAC and Dakota** software to perform uncertainty analyses for Assessment calculations
- **Uncertainty analyses** for study scenarios using the developed framework are currently underway
  - Preliminary results indicate that measurement uncertainty is important to DRL results when there is more than one radionuclide in the mixture and the associated uncertainty is large enough
- Need to determine if/how uncertainty analysis results can be used to **inform protective action decisions**

Thank you!

Questions?

Additional Slides

Input Distribution Summary

Input	Default Value	Distribution Type	Mean	SD	Mode	Lower Bound	Upper Bound	Units
Deposition Velocity	3.00E-3	Triangular			3.00E-3	3.00E-4	3.00E-2	m/s
Breathing Rate – Light Exercise, Adult Male	1.50	Normal	1.75	0.42		0.54	3.00	m^3/hr
Breathing Rate – Activity-Averaged, Adult Male	0.92	Triangular			0.92	0.54	1.50	m^3/hr
Ground Roughness Factor	0.82	Normal	0.82	0.082		0	1	--
Resuspension Coefficient Multiplier‡	1	Lognormal+	1	4.2				--
Weathering Coefficient Multiplier‡	1	Lognormal+	1	1.2				--
Deposition External Dose Coefficient Multiplier	1	Triangular			0.8	0.5	1.5	--
Inhalation Dose Coefficient Multiplier – Cs-137§	1	Lognormal+	1	1.5				--
Inhalation Dose Coefficient Multiplier – Am-241	1	Lognormal+	1	2.0				--
Plume External Dose Coefficient Multiplier	1	Triangular			0.8	0.5	1.5	--

* This uncertainty multiplier is multiplied by a user-defined air concentration value to sample air concentration with uncertainty. This distribution is calculated from the comparison of NARAC predictions to experimental data.

+ The means and standard deviations (SD) listed for lognormal distributions on this table are the geometric mean and geometric standard deviation, respectively. The lognormal distribution is defined by parameters μ, the mean of the natural logarithm of the data, and σ, the standard deviation of the natural logarithm of the data. Then, the geometric mean (GM) is given by $GM = e^{\mu}$ and the geometric standard deviation (GSD) is given by $GSD = e^{\sigma}$.

‡ These multipliers are to be applied only to the coefficients outside the exponentials in the Resuspension and Weathering Factors

§ This multiplier is specifically for Cs-137, Type F, Effective (Whole Body). Ba-137m is present at equilibrium with Cs-137 at the start of the time phase. The uncertainty in the Ba-137m inhalation dose coefficient is neglected because its ingrowth from Cs-137 over the dose commitment period dominates the delivered dose. The Cs-137 inhalation dose coefficient accounts for dose and uncertainty from the ingrowth of Ba-137m. (per communication with Keith Eckerman on May 10, 2017)

Input Distribution References

Input	Reference
Air Concentration Uncertainty Multiplier – NARAC	Developed in collaboration with FRMAC scientists at RSL and NARAC
Activity per Area – In Situ	
Activity per Area – AMS	
Activity per Area – Laboratory Analysis	
Deposition Velocity	*Evaluation of Severe Accident Risks: Quantification of Major Input Parameters*, NUREG/CR-4551, Vol. 2, Rev. 1, Part 7, U.S. Nuclear Regulatory Commission, Washington, DC, 1990
Breathing Rate – Light Exercise, Adult Male	Developed using information from 2011 EPA Exposure Factors Handbook
Breathing Rate – Activity-Averaged, Adult Male	Based on approach used by RESRAD for a similar parameter - *Development of Probabilistic RESRAD 6.0 and RESRAD-BUILD 3.0 Computer Codes*, NUREG/CR-6697, ANL/EAD/TM-98, Argonne National Laboratory, Argonne, IL, 2000
Ground Roughness Factor	No uncertainty information available. Developed based on 10% measurement uncertainty described in Beck, H.L., *Exposure Rate Conversion Factors for Radionuclides Deposited on the Ground*, EML-378, U.S. Department of Energy Environmental Measurements Laboratory, New York, NY, 1980
Resuspension Coefficient Multiplier	Maxwell, R. and Anspaugh, L., “An Improved Model for Prediction of Resuspension” in *Health Physics*, Vol. 101, pp. 722-730, December 2011
Weathering Coefficient Multiplier	No uncertainty information available. Developed based on information in Anspaugh reference: Golikov, V.Y., Balonov, M.I., Jacob, P., “External Exposure of the Population Living in Areas of Russia Contaminated Due to the Chernobyl Accident” in *Radiat Environ Biophys*, Vol. 41, pp. 185-193, 2002
Deposition External Dose Coefficient Multiplier	Eckerman, K., *Radiation Dose and Health Risk Estimation: Technical Basis for the State-of-the-Art Reactor Consequence Analysis Project*, Oak Ridge National Laboratory, Oak Ridge, TN, 2012
Inhalation Dose Coefficient Multiplier	
Plume External Dose Coefficient Multiplier	Assigned per conversation with Keith Eckerman on March 20, 2017

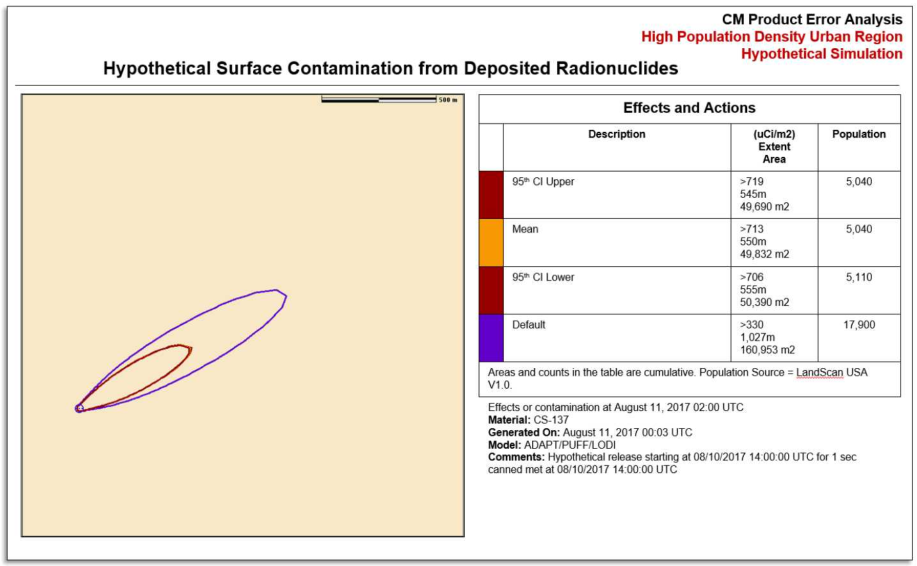
Convergence Results for Dose Rate DRL

Scenario	Lower Bound of 95% CI	Mean	Upper Bound of 95% CI
Early Phase (TD) – Cs-137	3.82	3.86	3.89
Early Phase (AD) – Cs-137	9.79	9.81	9.83
First Year – Cs-137	0.25088	0.25093	0.25097
Early Phase (TD) – Am-241	3.78E-05	3.85E-05	3.93E-05
Early Phase (AD) – Am-241	5.87E-03	6.26E-03	6.67E-03
First Year – Am-241	2.62E-03	2.75E-03	2.89E-03
Early Phase (TD) – 1:1	1.38E-03	1.64E-03	1.91E-03
Early Phase (AD) – 1:1	0.143	0.150	0.157
First Year – 1:1	4.08E-02	4.17E-02	4.27E-02

- **95% Confidence Intervals (CI)** are interpreted as follows: ‘there is a 95% confidence that the true value of the mean falls within this interval.’

Example Data Products

- The following **example data products** use the **uncertainty analysis results** for the Cs-137 Deposition DRL from the FY17 NARAC simulations



CM Product Error Analysis
High Population Density Urban Region
Hypothetical Simulation

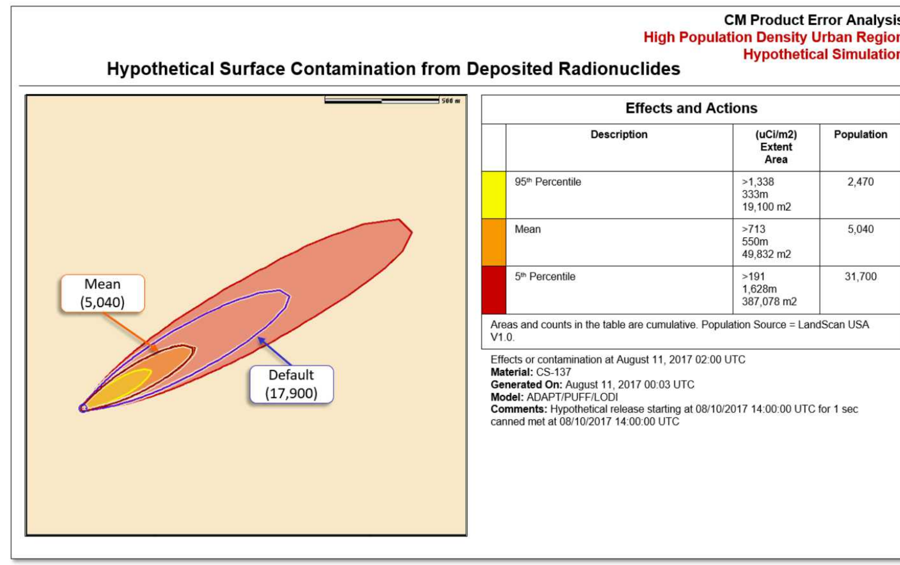
Hypothetical Surface Contamination from Deposited Radionuclides

Effects and Actions

	Description	(uCi/m2) Extent Area	Population
	95th CI Upper	>719 545m 49,690 m2	5,040
	Mean	>713 550m 49,832 m2	5,040
	95th CI Lower	>706 555m 50,390 m2	5,110
	Default	>330 1,027m 160,953 m2	17,900

Areas and counts in the table are cumulative. Population Source = LandScan USA V1.0.

Effects or contamination at August 11, 2017 02:00 UTC
Material: CS-137
Generated On: August 11, 2017 00:03 UTC
Model: ADAPT/PUFF/LODI
Comments: Hypothetical release starting at 08/10/2017 14:00:00 UTC for 1 sec canned met at 08/10/2017 14:00:00 UTC



CM Product Error Analysis
High Population Density Urban Region
Hypothetical Simulation

Hypothetical Surface Contamination from Deposited Radionuclides

Effects and Actions

	Description	(uCi/m2) Extent Area	Population
	95th Percentile	>1,338 333m 19,100 m2	2,470
	Mean	>713 550m 49,832 m2	5,040
	5th Percentile	>191 1,628m 387,078 m2	31,700

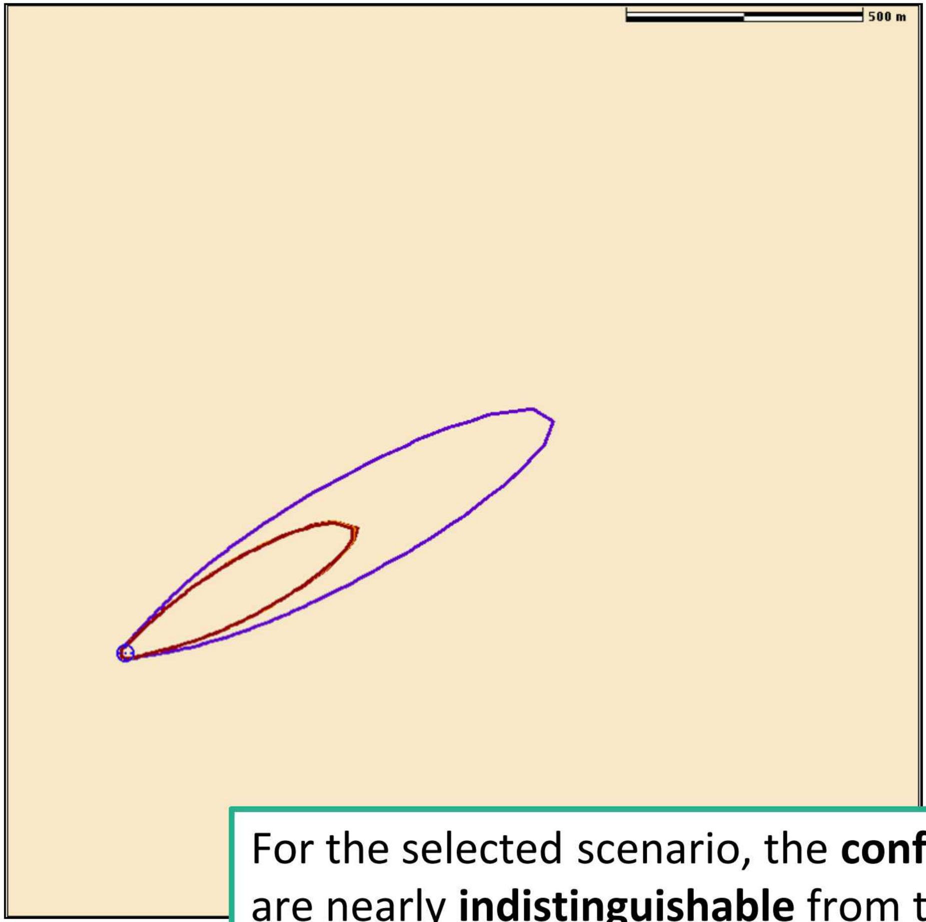
Areas and counts in the table are cumulative. Population Source = LandScan USA V1.0.

Effects or contamination at August 11, 2017 02:00 UTC
Material: CS-137
Generated On: August 11, 2017 00:03 UTC
Model: ADAPT/PUFF/LODI
Comments: Hypothetical release starting at 08/10/2017 14:00:00 UTC for 1 sec canned met at 08/10/2017 14:00:00 UTC

Confidence intervals
characterize sampling uncertainty

5th and 95th percentiles
describe uncertainty in result of interest

Hypothetical Surface Contamination from Deposited Radionuclides



Effects and Actions

	Description	(uCi/m2) Extent Area	Population
	95th CI Upper	>719 545m 49,690 m2	5,040
	Mean	>713 550m 49,832 m2	5,040
	95th CI Lower	>706 555m 50,390 m2	5,110
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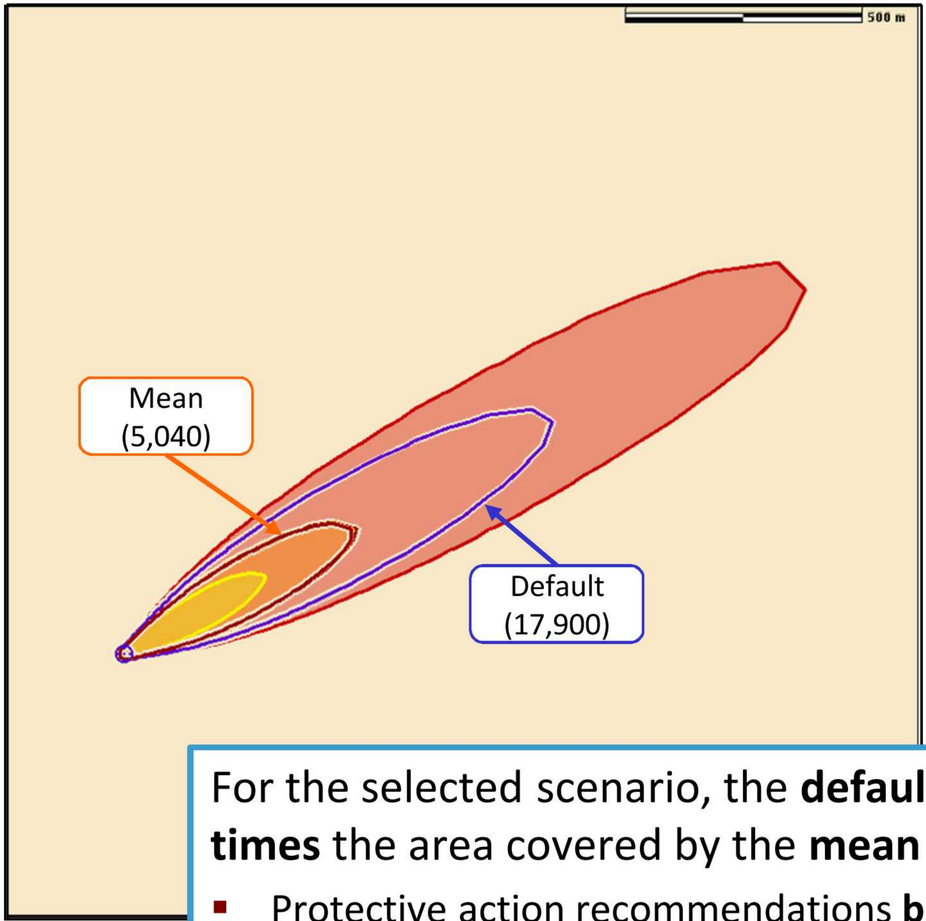
For the selected scenario, the **confidence interval (CI) contours** are nearly **indistinguishable** from the mean contour

- CIs calculated using non-parametric bootstrap approach
- CI results demonstrate that the sampling method and sample size used for this analysis **adequately capture the uncertainty in the mean**

Hypothetical Surface Contamination from Deposited Radionuclides



Effects and Actions

	Description	(uCi/m2) Extent Area	Population
(yellow)	95th Percentile	>1,338 333m 19,100 m2	2,470
(orange)	Mean	>713 550m 49,832 m2	5,040
(red)	5th Percentile	>191 1,628m 387,078 m2	31,700

Areas and counts in the table are cumulative. Population Source = LandScan USA V1.0.

Effects or contamination at August 11, 2017 02:00 UTC
Material: CS-137
Generated On: August 11, 2017 00:03 UTC
Model: ADAPT/PUFF/LODI
Comments: Hypothetical release starting at 08/10/2017 14:00:00 UTC for 1 sec canned met at 08/10/2017 14:00:00 UTC

For the selected scenario, the **default DRL** contour covers **nearly three times** the area covered by the **mean DRL** contour

- Protective action recommendations **based on default method** would result in a **significantly larger impacted population** when compared to the mean
- **Distribution of DRL values** represented by **5th and 95th percentiles** shows that **extreme values** encompassing areas that are **much larger and much smaller** than the default, respectively, are possible