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State-of-the-Art Reactor Consequence Analyses (SOARCA) Project: Summary of Uncertainty Analyses (UAs) for Station Blackout Scenarios

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Outline

- Background on SOARCA and UAs
- Objectives of the project
- Overview of approach
- Examples of results
- Overall conclusions and summary
- Status

Background on SOARCA

- SOARCA was initiated to develop a body of knowledge on the realistic outcomes of severe reactor accidents; three pilot plant analyses complete

Peach Bottom

- Boiling water reactor with Mark I containment
- Located in Pennsylvania
- UA on LTSBO

Surry

- 3-loop Westinghouse pressurized reactor with large, dry containment
- Located in Virginia
- UA on STSBO/ induced SGTR

Sequoyah

- 4-loop Westinghouse pressurized reactor with ice condenser containment
- Located in Tennessee
- UA on STSBO (no SGTR)

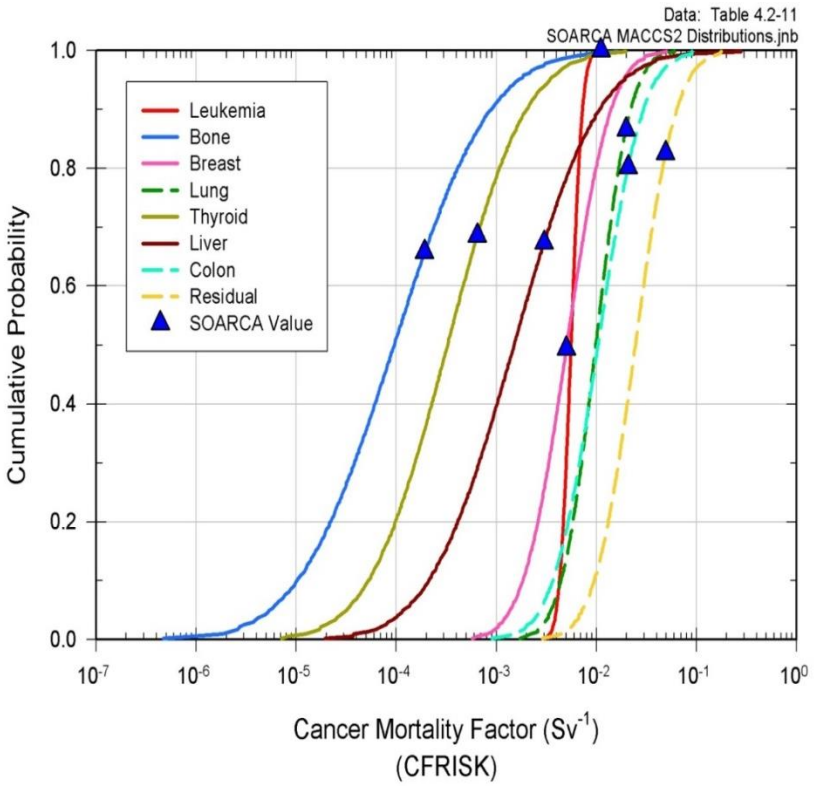
Objectives of the SOARCA Uncertainty Analyses & Summary

- Develop insight into overall sensitivity of results and conclusions from original SOARCA study to uncertainty in model inputs.
- Identify the most influential input parameters contributing to variations in accident progression, source term, and offsite consequence results.
- “Complement and support” the NRC’s Site Level 3 PRA project and post-Fukushima accident regulatory activities.
- Purpose of summary report is to provide a useful reference for future regulatory applications that require the evaluation of offsite consequence risk from severe accidents.

Overview

- Analysis of uncertainty in each of the three SOARCA plant analyses, one unmitigated station blackout (SBO) scenario

- Focus on epistemic (state-of-knowledge) uncertainty in input parameter values, and limited aleatory uncertainty
- Investigate uncertainty in key MELCOR and MACCS inputs
- Propagate uncertainty in these parameters in a two-step Monte Carlo (MC) simulation
  - Generate a set of source terms using MELCOR model
  - Generate distribution of consequence results using MACCS model



Overview (continued)

- >500-1,000 successful MC realizations analyzed
- Results reported with regard to figures of merit:
  - MELCOR: Cesium and Iodine release to the environment by 72 hours, in-vessel hydrogen production, timing of initial fission product release to the environment, and others
  - MACCS: Individual early and latent cancer fatality (LCF) risk
- Results analyzed with statistical regression based methods, scatter plots, and phenomenological investigation of selected individual realizations

Iodine Regression Table for Sequoyah SOARCA

	Rank Regression		Quadratic		Recursive Partitioning		MARS		Main Contribution	Conjoint Contribution
Final R^2	0.75		0.80		0.57		0.77			
Input	R^2 contr.	SRRC	S_I	T_I	S_I	T_I	S_I	T_I		
Cycle	0.67	0.73	0.10	0.15	0.15	0.17	0.33	0.32	0.272	0.017
priSVcyc	0.03	-0.25	0.32	0.79	0.47	0.82	0.36	0.64	0.207	0.265
Rupture	0.03	-0.16	0.02	0.10	0.03	0.36	0.01	0.08	0.016	0.104
Eu_Melt_T	---	---	0.02	0.25	0.00	0.01	0.01	0.23	0.008	0.119
Shape_Fact	0.02	0.13	0.00	0.01	---	---	0.00	0.00	0.004	0.003
Ox_Model	0.00	0.06	0.01	0.13	---	---	0.00	0.00	0.003	0.032
Burn_Dir	0.01	0.07	0.00	0.02	---	---	0.00	0.00	0.002	0.005
Seal_Open_A	---	---	0.00	0.02	---	---	0.00	0.00	0.001	0.005
Ajar	---	---	0.00	0.04	---	---	0.00	0.01	0.000	0.011

** highlighted if main contribution larger than 0.02 or conjoint contribution larger than 0.1*

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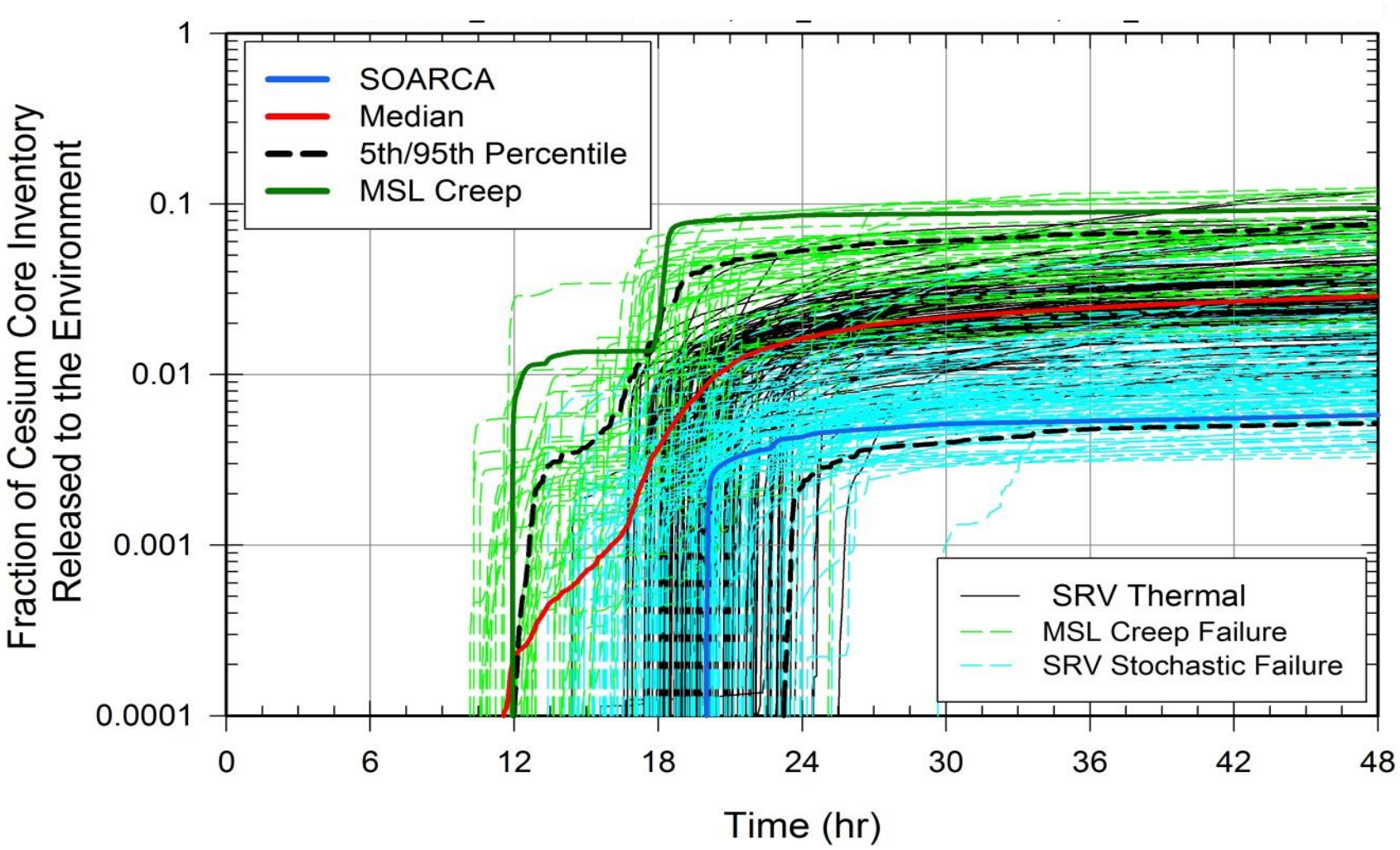
Cesium release for SOARCA Peach Bottom unmitigated LTSBO scenario



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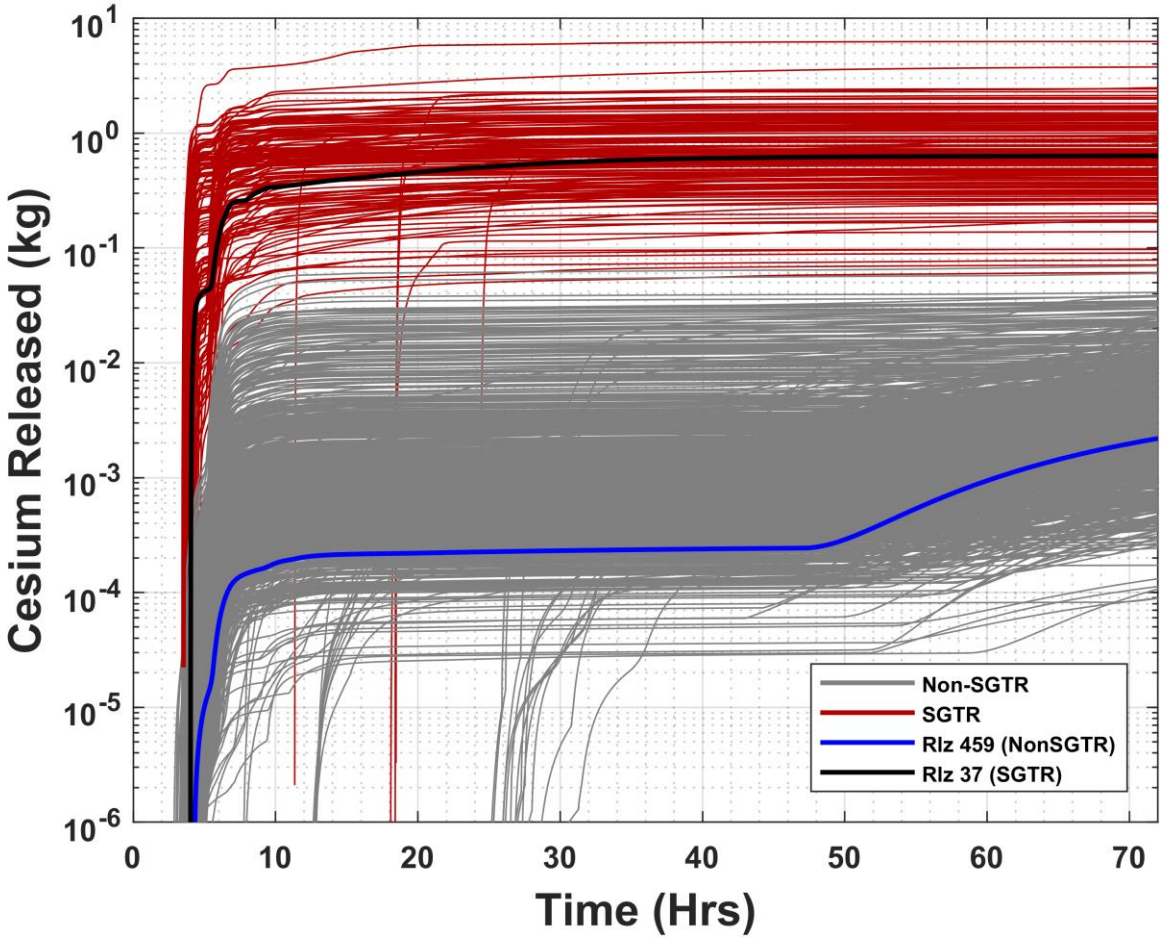
Cesium Release Masses to the Environment in the Surry STSBO UA (with reference cases noted)



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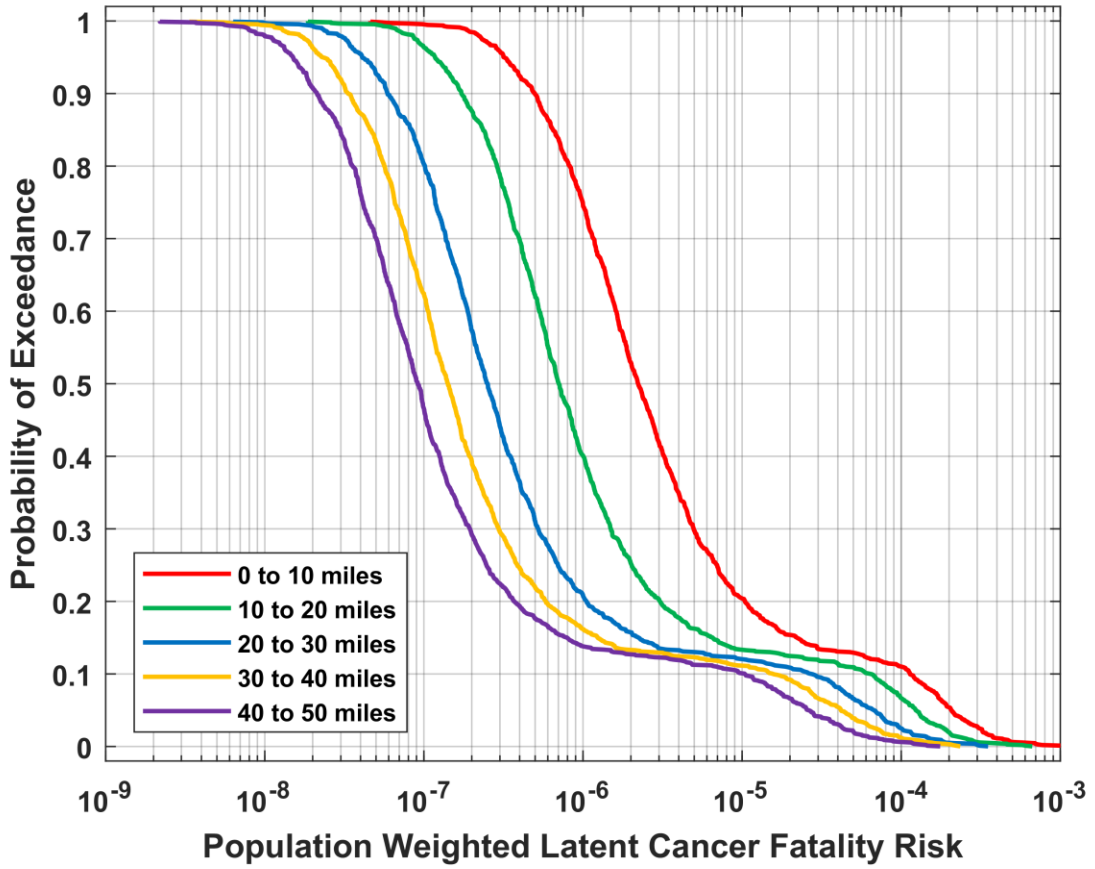
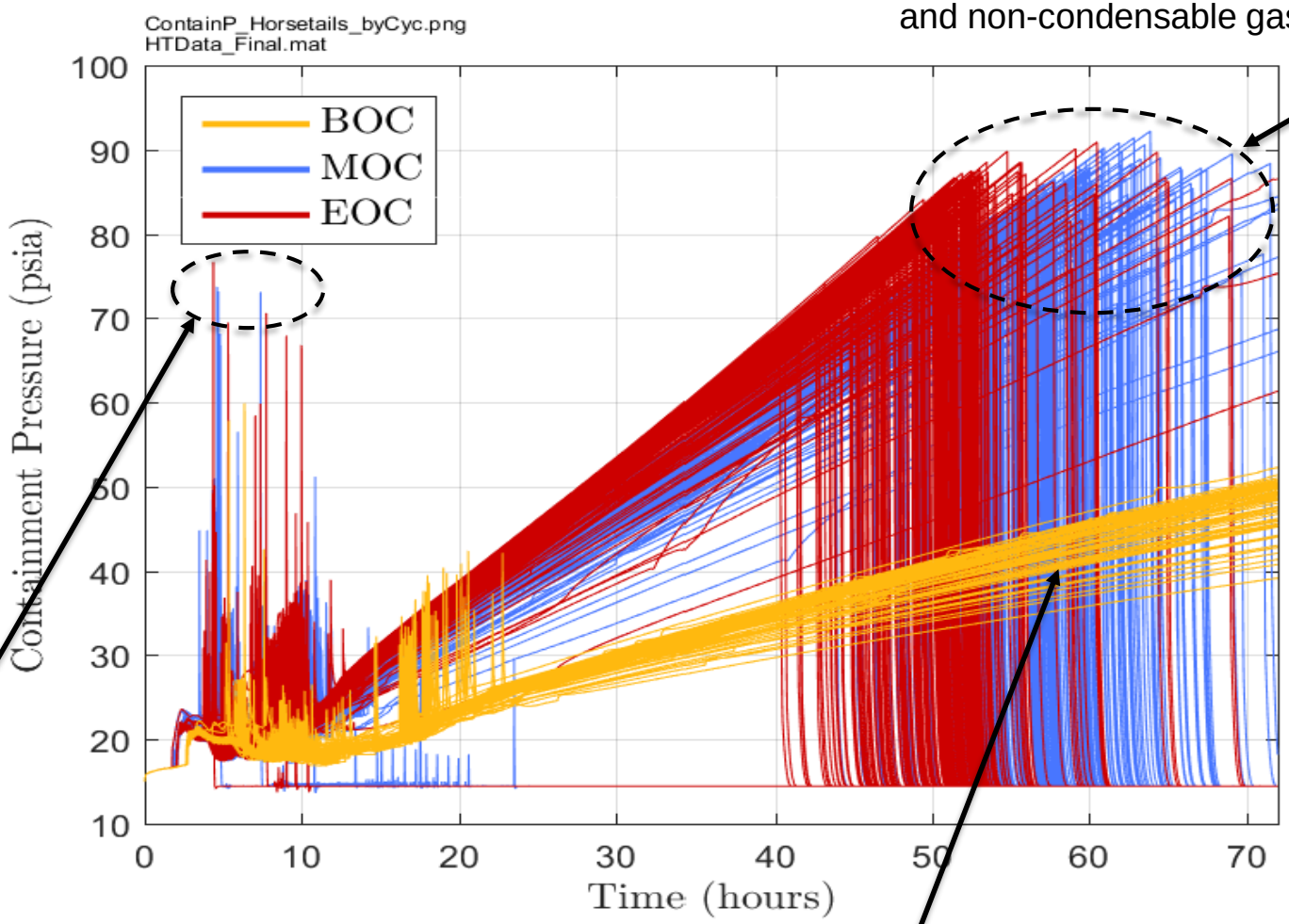
Complementary Cumulative Distribution Functions (CCDF) of Conditional Mean (over weather), LCF Risk (Based on LNT Dose Response) for Annular Areas Centered on Surry



Sequoyah STSBO UA Containment Failure Outcomes

Long-tem containment over-pressurization failure due to prolonged steam production and non-condensable gas generation



Early containment overpressure failures due to sufficiently large burns in containment

No BOC cases exhibit long-term overpressure failure before 72 hours

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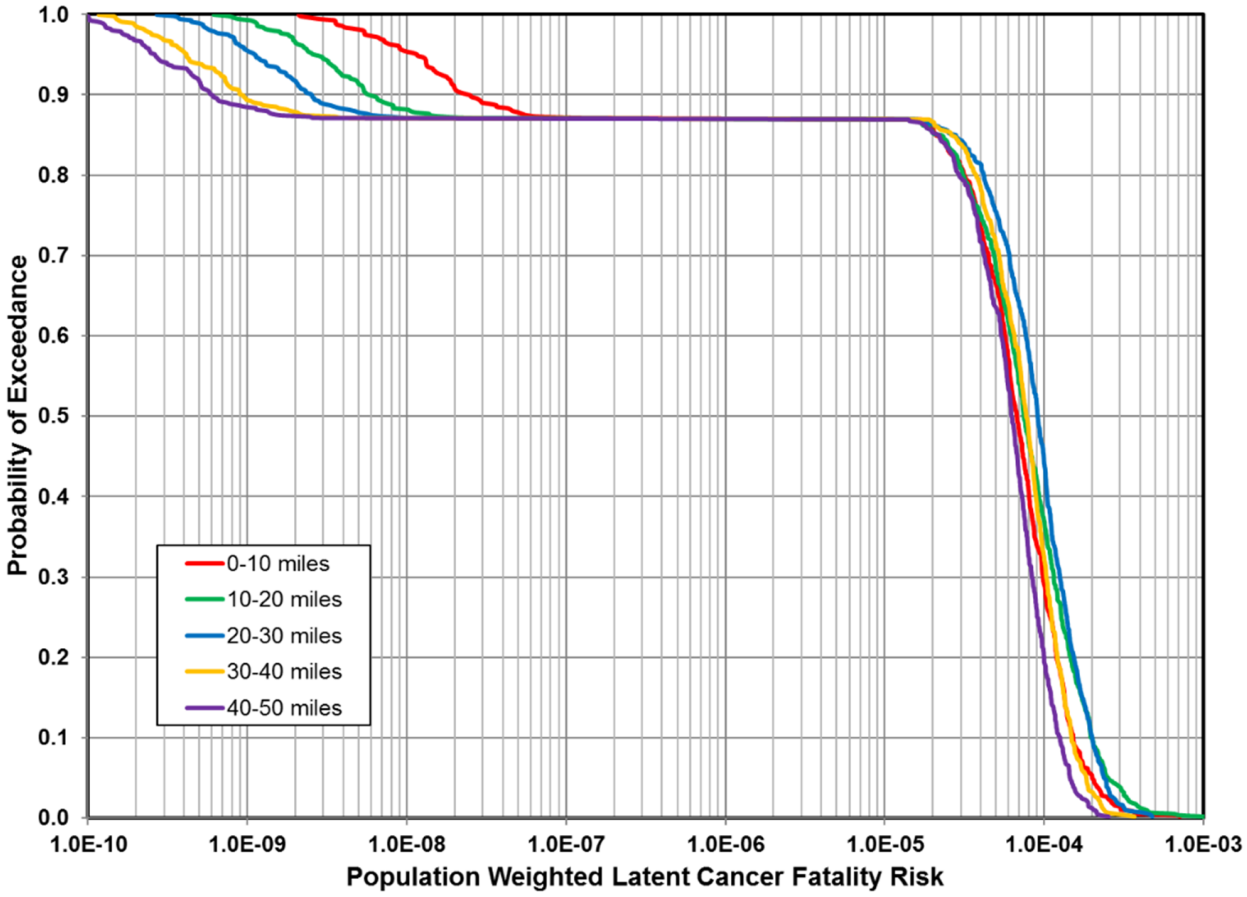
Complementary Cumulative Distribution Functions (CCDF) of Conditional Mean (over weather), LCF Risk (Based on LNT Dose Response) for Annular Areas Centered on Sequoyah



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Mean, individual, LCF risk regression results within 0- to 50-mile for all realizations based on LNT dose response in the Sequoyah UA

	Rank Regression		Quadratic		Recursive Partitioning		MARS		Main Contribution	Conjoint Contribution
Final R^2	0.59		0.86		0.65		0.75			
Input	R^2 contr.	SRRC	S_i	T_i	S_i	T_i	S_i	T_i		
Cycle	0.23	0.52	0.24	0.31	0.36	0.44	0.21	0.21	0.208	0.038
CFRISK(8)	0.06	0.24	0.09	0.13	0.05	0.14	0.09	0.08	0.059	0.029
Rupture	0.05	-0.21	0.06	0.10	0.05	0.22	0.10	0.25	0.052	0.086
CFRISK(4)	0.05	0.23	0.07	0.10	0.04	0.15	0.08	0.09	0.048	0.037
CFRISK(7)	0.04	0.22	0.05	0.07	0.02	0.10	0.08	0.11	0.040	0.028
TIMNRM	0.04	0.22	0.04	0.07	0.06	0.30	0.05	0.06	0.038	0.061
CYSIGA(1)	0.03	0.19	0.03	0.04	0.01	0.05	---	---	0.015	0.013
DDREFA(4)	0.02	-0.13	0.02	0.02	0.00	0.04	0.02	0.02	0.013	0.011
CFRISK(6)	0.01	0.08	0.03	0.12	---	---	0.02	0.08	0.012	0.042

** highlighted if main contribution larger than 0.02 or conjoint contribution larger than 0.1*

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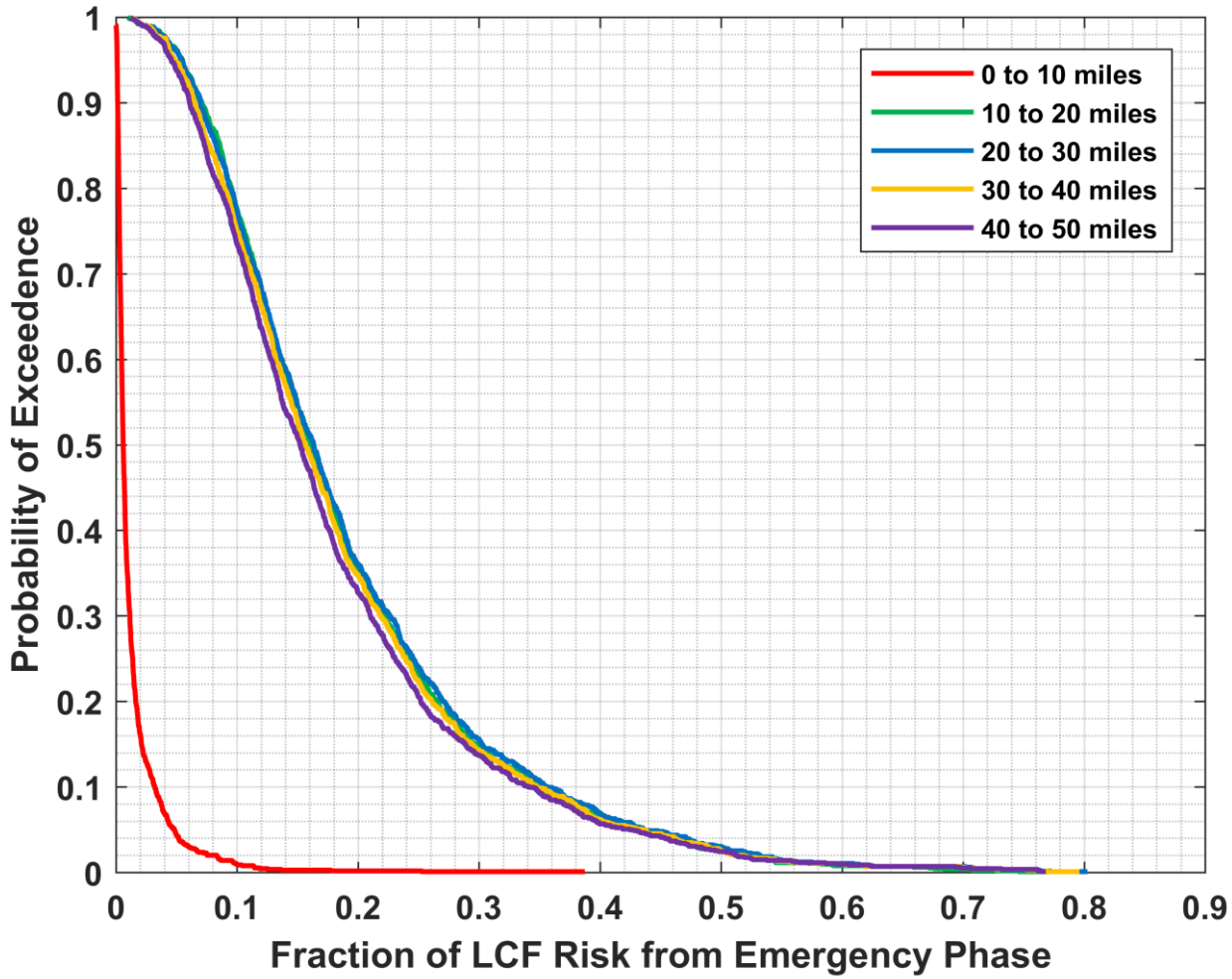
CCDFs of fraction of the LCF risk (based on LNT dose response) from the emergency phase for five annular areas centered on Surry



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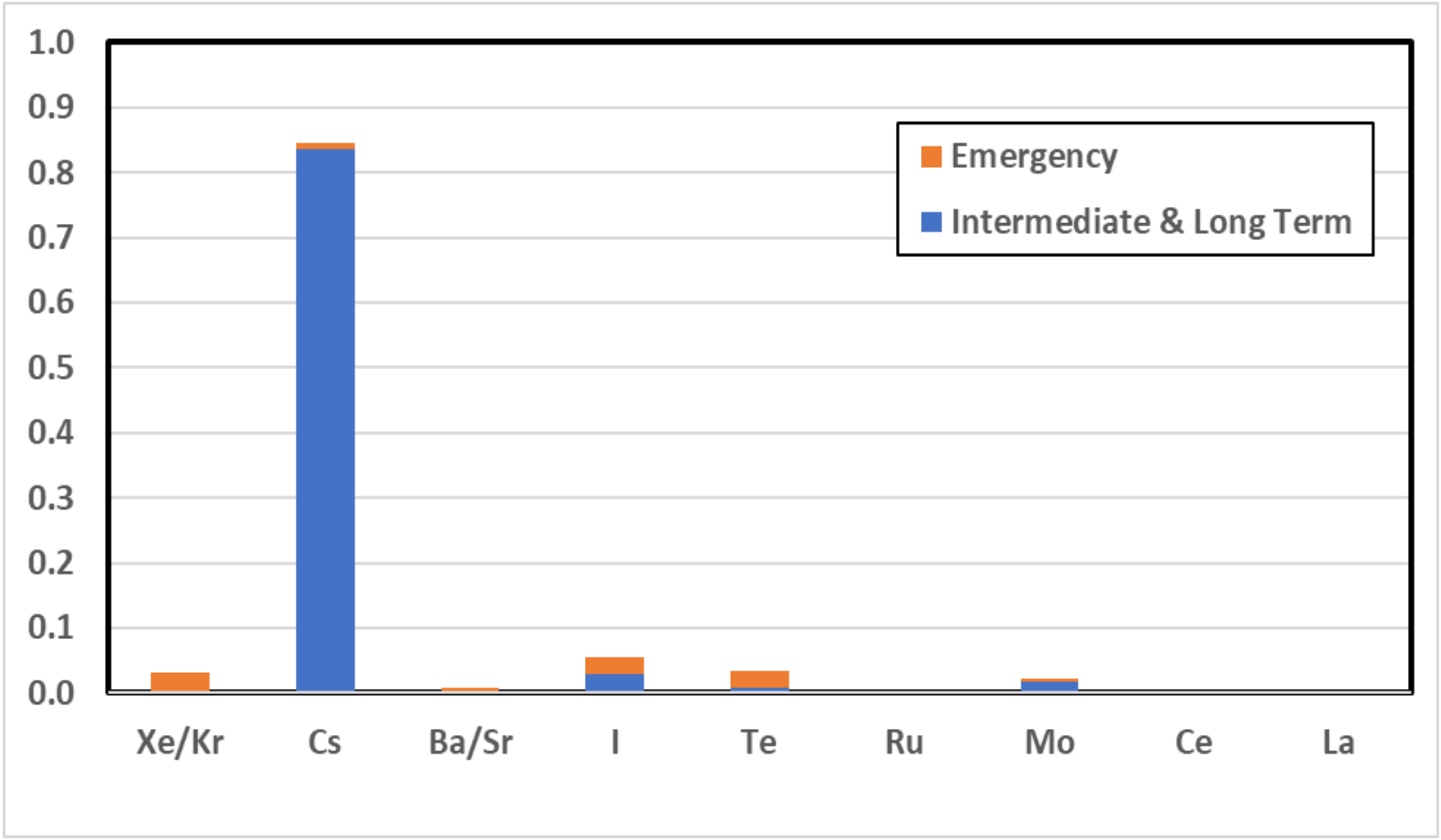
Relative contribution of the chemical groups for LCF risk within 50 miles of the site using the Surry UA reference non-SGTR source term (Realization 459)



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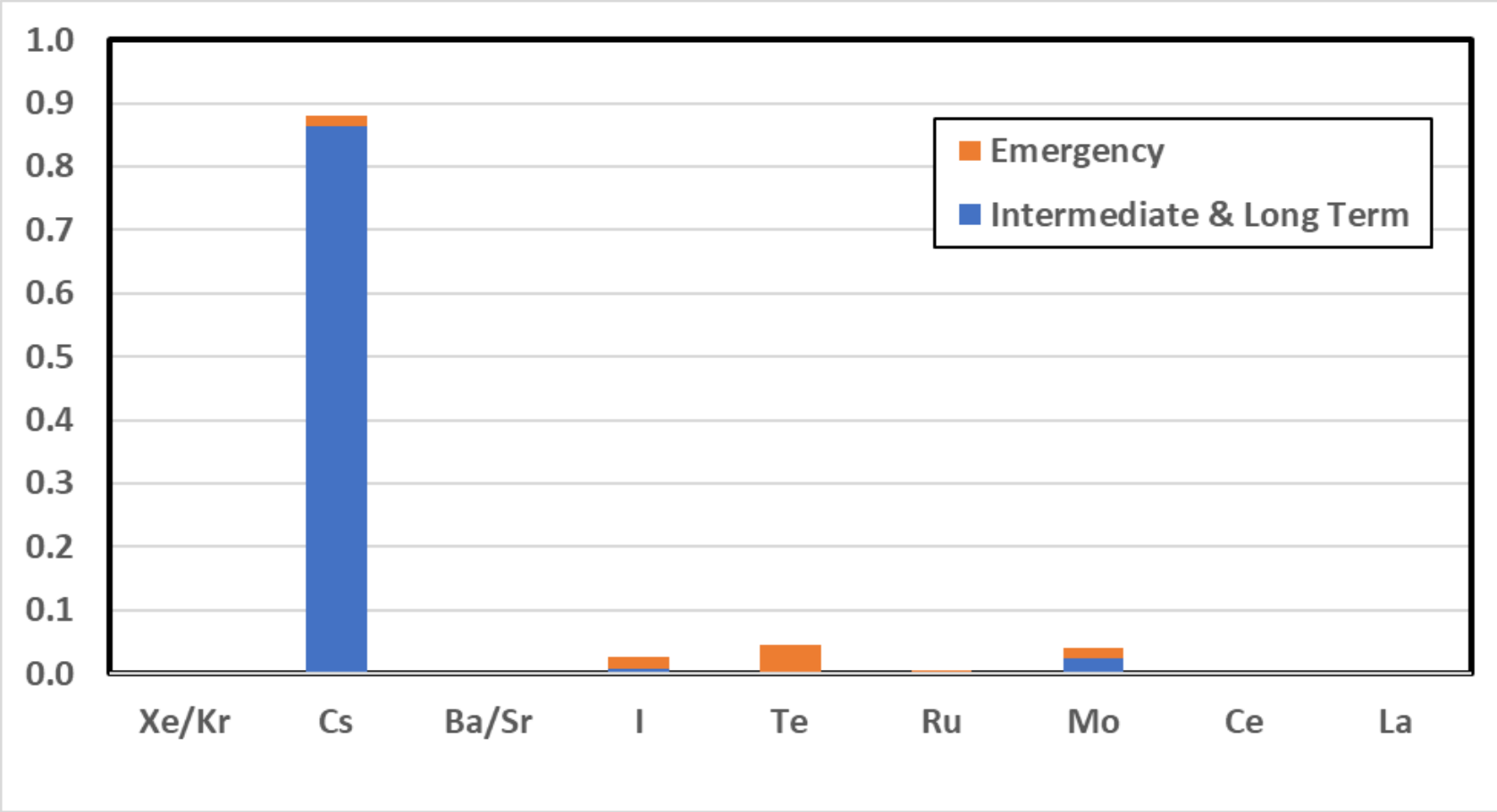
Relative contribution of the chemical groups for LCF risk within 50 miles of the site using the Surry UA reference SGTR source term (Realization 37)



Overall Conclusions and Summary

- SOARCA UAs corroborate conclusions from the original SOARCA project:
  - The public's individual fatality risks from severe nuclear accident scenarios modeled are smaller than those projected in NUREG/CR-2239.
  - Calculated delay in releases provides more time for emergency response actions (such as evacuating or sheltering).
  - "Essentially zero" absolute early fatality risk is projected.

Overall Conclusions and Summary (Continued)

- The three UAs revealed interesting insights with respect to accident progression, radionuclide release, offsite consequences, and which uncertain parameters are most influential on outcomes of interest for the modeled scenarios at the three plants.
- Regarding UA methodologies, the more advanced regression techniques were essential to explain the variations in possible source terms and consequences and use of select single-realization analyses proved useful in validating the results of the statistical regression analyses and providing phenomenological explanations.
- The SOARCA analyses of the three plants have been useful in many ways beyond their original objectives.

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Status

- Revised SOARCA Surry Uncertainty Analysis with updates following Advisory Committee Reactor Safeguards (ACRS) review on the SOARCA Sequoyah Analysis; updated report expected in late 2019.
- Peach Bottom SOARCA UA models (originally completed almost 10 years ago now) have been updated and implemented in the current version of the MELCOR code (version 2.2 versus 1.86) and are being taken out to a 72-hour simulation time.
- Developing summary NUREG report on insights from the SOARCA Peach Bottom, Surry, and Sequoyah Uncertainty Analyses, which should be more user-friendly.

Core Team Members

- MELCOR and severe accident progression: Kyle Ross, Casey Wagner, Troy Haskin, Chris Faucett, Larry Humphries, Randy Gauntt (SNL); Mark Leonard (formerly dycoda); Hossein Esmaili, Salman Haq, Trey Hathaway (NRC)
- MELMACCS: Nathan Bixler, Doug Osborn, Fotini Walton (SNL); Trey Hathaway (NRC)
- MACCS, consequence analysis and emergency response: Nathan Bixler, Doug Osborn, Fotini Walton (SNL); Matt Dennis, Joe Jones (formerly SNL); Jonathan Barr, Keith Compton, Trey Hathaway (NRC)
- UA methodology: Dusty Brooks, Matthew Denman, Aubrey Eckert-Gallup, Patrick Mattie (SNL); Cedric Sallaberry (formerly SNL); Tina Ghosh, Trey Hathaway (NRC)
- NRC management: Patricia Santiago

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References

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- NUREG/BR-0359, Modeling Potential Reactor Accident Consequences, Rev. 1 (December 2012)
- NUREG/CR-7110, Vol. 1, SOARCA Project Peach Bottom Integrated Analysis, Rev. 1, (May 2013)
- NUREG/CR-7110, Vol. 2, SOARCA Project Surry Integrated Analysis, Rev. 1 (August 2013)
- NUREG/CR-7008, MELCOR Best Practices as Applied in the SOARCA Project (August 2014)
- NUREG/CR-7009, MACCS Best Practices as Applied in the SOARCA Project (August 2014)
- NUREG/CR-7155, SOARCA Project Uncertainty Analysis of the Unmitigated Long-Term Station Blackout of the Peach Bottom Atomic Power Station (May 2016)
- NUREG/CR-7245, SOARCA Project Sequoyah Integrated Deterministic and Uncertainty Analyses (forthcoming in 2019)