U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

State-of-the-Art Reactor Consequence Analyses (SOARCA) Surry Uncertainty Analysis (UA)

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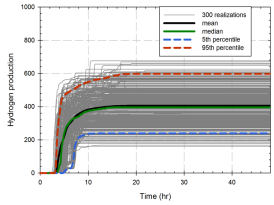
Tina Ghosh, PhD, Accident Analysis Branch
U.S. NRC Office of Nuclear Regulatory Research

Outline

- Background
- Objectives
- Scope and approach
- Parameters
- Sample of results
- Overall conclusions



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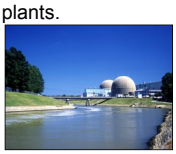
Background on SOARCA

- SOARCA was initiated to develop a body of knowledge on the realistic outcomes of severe reactor accidents; two pilot plants.


Peach Bottom


Surry

- SECY-12-0092, "State-of-the-Art Reactor Consequence Analyses – Recommendation for Limited Additional Analysis"
  - Staff recommended "UA for a severe accident scenario at Surry".

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Objectives of the Surry Uncertainty Analysis

- Develop insight into overall sensitivity of results and conclusions to uncertainty in inputs.
- Identify the most influential input parameters contributing to variations in accident progression, source term, and offsite consequences.
- "Complement and support" the NRC's Site Level 3 PRA project and post-Fukushima activities including Tier 3 items. (SRM SECY-12-0092)

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Scope and Approach

- SOARCA Surry unmitigated short term station blackout (STSBO) scenario chosen.
- Epistemic (state-of-knowledge) uncertainty in key input parameter values described with probability distributions.
- Uncertainty in these parameters propagated in a two-step Monte Carlo process using MELCOR and MACCS.
- Figures of merit investigated: cesium and iodine release, hydrogen production, early and latent cancer fatality risk.
- Results analyzed with statistical regression based methods, scatter plots, and phenomenological investigation of selected individual realizations.

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MELCOR Uncertain Parameters

Sequence

- Primary SV stochastic failure to close (FTC)
- Primary SV stochastic failure to open (FTO)
- Primary SV FTC due to passing water
- Secondary SV stochastic FTC
- SV open area fraction (SVOFRAC)
- Primary SV FTC due to overheating
- Reactor coolant pump seal leakage (RCPSL)
- Normalized temperature of hottest SG tube (TUBETEMP)
- SG tube thickness (mm) (TUBTHICK)

In-Vessel Accident Progression

- Zircaloy melt breakout temperature** (SC1131(2))
- Molten clad drainage rate** (SC1141(2))
- Radial molten debris relocation time constant (RDMTC)
- Radial solid debris relocation time constant (RDSTC)
- Time in the fuel cycle of the accident (BOC, MOC, or EOC) (CYCLE)
- Decay Heat (DEV_DEC_HEAT)
- Melting temperature of the eutectic formed between UO_2 and ZrO_2 (SC1132)

** indicates parameter was uncertain in the Peach Bottom UA

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MELCOR Uncertain Parameters (continued)

Ex-vessel Accident Progression
- Hydrogen ignition criteria (H_2 LFL)
- Steam Generator Tube Rupture (SGTR) location (for decontamination factor per ARTIST) (SGTRLOC)

Containment Behavior
- Containment design leakage rate (DLEAK)
- Containment fragility curve (CFC)
- Containment convection heat transfer coefficient (XHTFCL)

Chemical Forms of Iodine and Cesium
- CHEMFORM iodine** (CHEMFORMI2)
- CHEMFORM cesium** (CHEMORMCS)

Aerosol Transport and Deposition
- Dynamic Shape Factor (PARTSHAPE)

** indicates parameter was uncertain in the Peach Bottom UA

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MACCS Uncertain Parameter Groups

Deposition
- Wet Deposition (CWASH1)
- Dry Deposition Velocities (VDEPOS, m/s)

Dispersion
- Crosswind Dispersion Linear Coefficient (CYSIGA)
- Vertical Dispersion Linear Coefficient (CZSIGA)

Shielding factors
- Groundshine Shielding Factors (GSHFAC)
- Inhalation Protection Factors (PROTIN)

Latent Health Effects
- Dose and dose rate effectiveness factor (DDREFA)
- Lifetime Cancer Fatality Risk Factors (CFRISK)
- Long Term Inhalation Dose Coefficients

Early Health Effects
- Early Health Effects LD_{50} Parameter (EFFACA)
- Early Health Effects Exponential Parameter (EFFACB)
- Early Health Effects Threshold Dose (EFFTHR)

All of these parameters were uncertain in the SOARCA Peach Bottom UA too

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MACCS Uncertain Parameters (continued)

Emergency Response
- Evacuation Delay (DLTEVA)
- Evacuation Speed (ESPEED)
- Hotspot Relocation Time (TIMHOT)
- Normal Relocation Time (TIMNRM)
- Hotspot Relocation Dose (DOSHOT)
- Normal Relocation Dose (DOSNRM)

Aleatory Uncertainty
- Weather trials

All of these parameters were uncertain in the SOARCA Peach Bottom UA too

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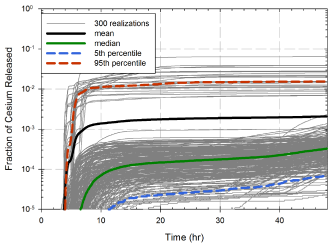
Cesium Release Fraction to Environment

- There is a clear bifurcation in the results, with the higher release fractions representing SGTR realizations, and the remainder of the realizations having much lower releases.
- The release fractions for non-SGTR realizations are almost all below 0.001 at 48 hours, while the SGTR realizations are in the 0.01 range.



Cesium release fractions over 48 hours with mean, median, 5th and 95th percentiles

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Mean, individual, LCF risk (based on LNT) regression results within a 10-mile circular area for all realizations

	Rank Regression		Quadratic		Recursive Partitioning		MARS		Main Contr.*	Conjoint Contr. *
Final R^2	0.54		0.60		0.86		0.74			
Input	R^2 contr.	SRRC	S_i	T_i	S_i	T_i	S_i	T_i		
TUBTHICK	0.04	-0.20	0.33	0.53	0.30	0.86	0.35	0.80	0.189	0.309
SVOAFRAC	0.03	-0.18	0.23	0.40	0.09	0.55	0.11	0.45	0.082	0.250
CYCLE	0.18	0.44	0.01	0.02	0.01	0.01	0.02	0.02	0.050	0.005
GSHFAC.2	0.13	0.35	0.02	0.05	0.00	0.00	0.01	0.03	0.038	0.011
DLEAK	0.08	0.26	0.01	0.04	0.01	0.01	0.00	0.01	0.022	0.010
CFRISK.8	0.02	0.15	0.02	0.05	0.00	0.06	0.02	0.08	0.011	0.037
SV_STATUS	---	---	0.04	0.04	---	---	---	---	0.006	0.000
DDREFA.8	0.01	-0.12	0.00	0.02	0.00	0.05	0.00	0.03	0.004	0.025
CYSIGA.1	0.02	-0.13	---	---	---	---	---	---	0.004	0.000
TUBETEMP	---	---	0.02	0.02	0.00	0.00	0.01	0.03	0.004	0.006
DEV_DEC_HEAT	0.01	-0.09	0.00	0.03	0.00	0.03	0.01	0.02	0.004	0.015
VDEPOS.1	0.01	0.09	0.01	0.01	0.00	0.04	---	---	0.003	0.011
CFRISK.7	0.01	0.09	---	---	---	---	---	---	0.002	0.000
CFC	0.01	-0.09	---	---	---	---	0.00	0.01	0.002	0.001
CFRISK.6	0.01	0.07	---	---	---	---	0.00	0.02	0.002	0.003
PROTIN.2	---	---	---	---	0.01	0.09	---	---	0.001	0.023
CHEMFORMCS	0.01	-0.06	---	---	---	---	---	---	0.001	0.000
SGTRLOC	0.00	0.06	0.00	0.01	---	---	---	---	0.001	0.002
CFRISK.2	---	---	0.00	0.03	---	---	---	---	0.001	0.005
LA.140_ICH.9	---	---	0.00	0.04	0.00	0.03	0.00	0.01	0.000	0.018
PARTSHAPE	---	---	0.00	0.01	0.00	0.01	---	---	0.000	0.004
CHEMFORMI2	---	---	---	---	0.00	0.02	0.00	0.01	0.000	0.009

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

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Mean, individual, LCF risk (based on LNT) regression results within a 10-mile circular area for realizations that do not involve SGTR.

	Rank Regression		Quadratic		Recursive Partitioning		MARS		Main Contr.*	Conjoint Contr. *
Final R^2	0.73		0.83		0.84		0.89			
Input	R^2 contr.	SRRC	S_i	T_i	S_i	T_i	S_i	T_i		
CYCLE	0.27	0.52	0.14	0.23	0.18	0.55	0.30	0.30	0.179	0.128
GSHFAC.2	0.19	0.44	0.22	0.38	0.18	0.54	0.25	0.27	0.166	0.152
DLEAK	0.12	-0.33	0.06	0.20	0.03	0.16	0.09	0.09	0.062	0.077
CFRISK.8	0.03	0.16	0.04	0.07	0.02	0.14	0.07	0.07	0.030	0.040
CYSIGA.1	0.03	-0.18	0.02	0.02	0.01	0.04	0.04	0.05	0.019	0.012
VDEPOS.1	0.02	0.12	0.02	0.06	0.01	0.24	0.03	0.07	0.017	0.081
PARTSHAPE	0.01	0.09	0.01	0.03	0.00	0.04	0.05	0.06	0.012	0.018
CFRISK.7	0.01	0.12	0.02	0.03	0.00	0.02	0.03	0.03	0.012	0.007
CFC	0.02	-0.13	0.02	0.03	0.00	0.02	0.02	0.02	0.010	0.009
DEV_DEC_HEAT	0.01	-0.08	0.02	0.04	0.00	0.04	0.02	0.04	0.010	0.021
CFRISK.6	0.01	0.09	0.02	0.07	0.00	0.04	0.01	0.01	0.009	0.023
DDREFA.8	0.01	-0.11	0.01	0.03	0.01	0.03	---	---	0.006	0.014
CHEMFORMCS	0.01	-0.09	---	---	---	---	0.02	0.03	0.005	0.001
GSHFAC.3	---	---	0.02	0.07	---	---	---	---	0.005	0.014
CFRISK.4	0.01	0.09	---	---	---	---	---	---	0.002	0.000
CFRISK.3	---	---	---	---	---	---	0.01	0.02	0.001	0.003
SV_NBCYC	---	---	0.00	0.02	---	---	0.00	0.00	0.001	0.005
SGTRLOC	0.00	0.04	0.00	0.03	---	---	0.00	0.00	0.000	0.009
CFRISK.1	---	---	---	---	0.00	0.12	---	---	0.000	0.033
DLTEVA_5.12	---	---	---	---	0.00	0.04	---	---	0.000	0.011
ZR.95_ICH.9	---	---	---	---	0.00	0.03	---	---	0.000	0.008

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

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Overall Conclusions

- Surry UA corroborates SOARCA study conclusions:
  - Public health consequences from severe nuclear accident scenarios modeled are smaller than previously calculated, and very small in absolute terms.
  - Delayed releases calculated provide time for emergency response actions such as evacuating or sheltering; long-term phase dominates health effect risks because emergency response is faster than progression to release.
  - "Essentially zero" early fatality risk projected.

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Overall Conclusions (2)

- A major determinant of source term magnitude and health consequences is whether or not an SGTR occurs.
- Mean, individual, LCF risks assuming LNT dose response, conditional on an the occurrence of an accident, estimated in this uncertainty analysis of the Surry STSBO are very low, approximately 3×10^{-5} within 10 miles and lower at longer distances.
- Use of multiple techniques to post-process Monte Carlo results provided better explanatory power with regard to which input parameters are most important to uncertainty in results.

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Core Team Members and Advisors

- MELCOR and severe accident progression: Randy Gauntt, Kyle Ross, Scott Weber, Jeff Cardoni (SNL); KC Wagner (dycoda); Ed Fuller, Hossein Esmaili, Don Helton (NRC)
- MELMACCS: Nate Bixler, Doug Osborn (SNL)
- MACCS, consequence analysis and emergency response: Nate Bixler, Joe Jones, Doug Osborn (SNL)
- Uncertainty Analysis (UA) methodology and glossary: Cedric Sallaberry, Aubrey Eckert, Dusty Brooks, Jon Helton, Matthew Denman (SNL); Tina Ghosh, Trey Hathaway (NRC)

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SOARCA References

- NUREG-1935, State-of-the-Art Reactor Consequence Analyses (SOARCA) Report (November 2012)
- 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
- Draft report on SOARCA Uncertainty Analysis of the Unmitigated Short-Term Station Blackout of the Surry Power Station available in ADAMS, accession number ML15224A002

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Acronyms

CCDF	Complementary cumulative distribution function
LCF	Latent cancer fatality
LNT	Linear no threshold
MACCS	MELCOR Accident Consequence Code System
SGTR	Steam generator tube rupture
SNL	Sandia National Laboratories
SOARCA	State-of-the-Art Reactor Consequence Analyses
SRM	Staff Requirements Memorandum
STSBO	Short term station blackout
UA	Uncertainty Analysis

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