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UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

State-of-the-Art Reactor Consequence Analyses (SOARCA) Project: Sequoyah Uncertainty Analysis Methods and Insights

PSAM 14
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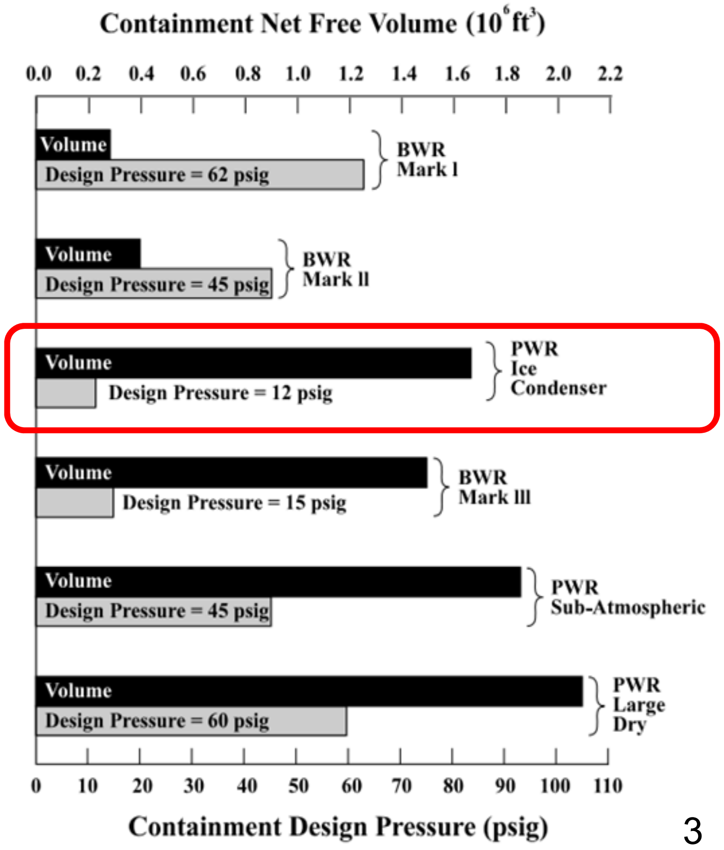
Outline

- Objectives and Overview of Short-Term Station Blackout (STSBO) Uncertainty Analysis (UA) for Sequoyah Nuclear Plant
- Uncertain Parameters Included in Study
- Severe Accident Progression and Release Results and Observations
- Summary and Next Steps

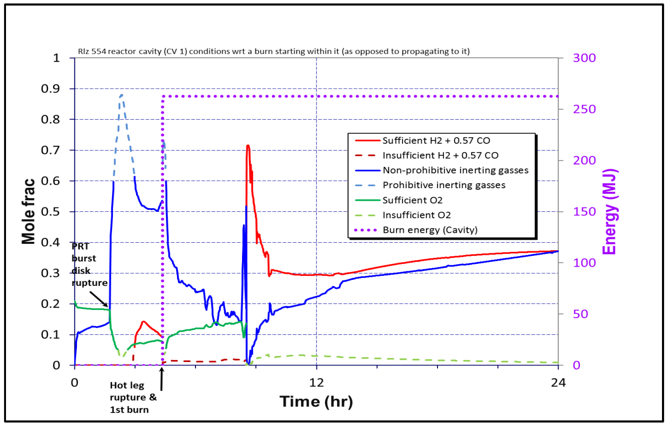
Objectives and Scope

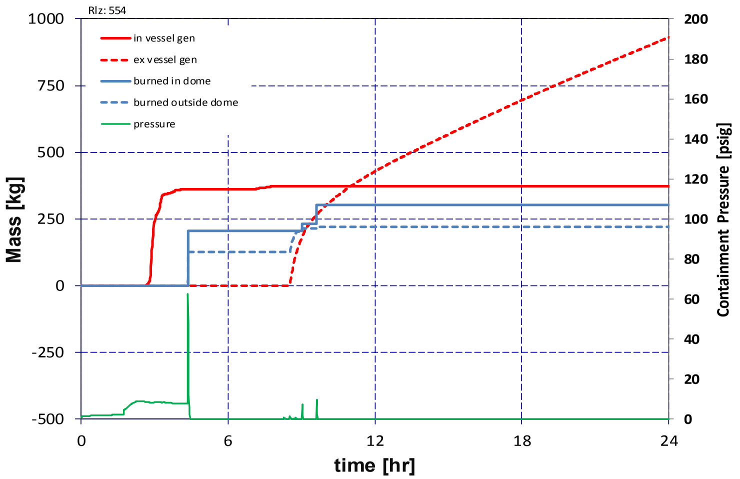
- SOARCA goals and objectives
  - Develop body of knowledge on the realistic outcomes of severe reactor accidents
  - Incorporate state of the art modeling (MELCOR/MACCS)
- Scope of Sequoyah analyses
  - Limited to station blackouts (SBOs)
  - Focused on issues unique to ice condenser containment and hydrogen challenges
    - ➢ Relatively low design pressure and smaller volume leads to potential susceptibility to early failure from hydrogen combustion in a station blackout



Overview of Sequoyah STSBO UA

- Integrated UA focused on unmitigated STSBO scenario
- Input parameter uncertainty propagated in a two-step Monte Carlo process, using 567 (out of 600) samples
- The UA results were examined in detail using both quantitative and qualitative approaches, such as phenomenological analysis of individual realizations.



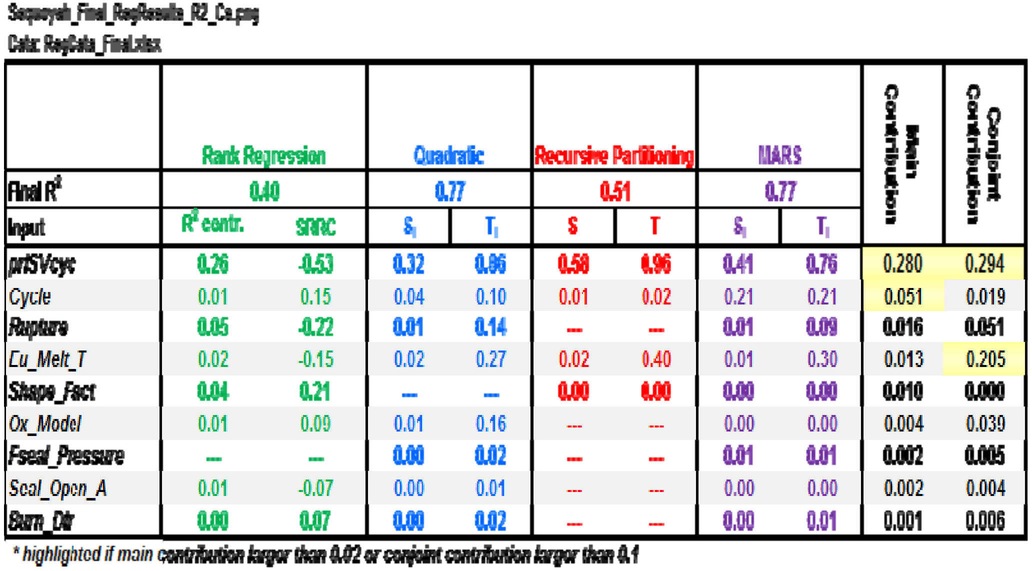


The case with earliest containment rupture – RLZ 554

Overview (continued)

- Four regression techniques were used to identify input parameters contributing to key accident progression characteristics and public health impacts.

Cesium Regression Table



Sequoyah_Final_RegResults_R2_Cs.png
Data: RegData_Final.xlsx

	Rank Regression		Quadratic		Recursive Partitioning		MARS		Main Contribution	Conjoint Contribution
Final R^2	0.40		0.77		0.51		0.77			
Input	R^2 contr.	SRRC	S_i	T_i	S	T	S_i	T_i		
prtSVcyc	**0.26**	**-0.53**	**0.32**	**0.86**	**0.58**	**0.96**	**0.41**	**0.76**	0.280	0.294
Cycle	0.01	0.15	0.04	0.10	0.01	0.02	0.21	0.21	0.051	0.019
Rupture	**0.05**	**-0.22**	**0.01**	**0.14**	---	---	**0.01**	**0.09**	**0.016**	**0.051**
Cu_Melt_T	0.02	-0.15	0.02	0.27	0.02	0.40	0.01	0.30	0.013	0.205
Shape_Fact	**0.04**	**0.21**	---	---	**0.00**	**0.00**	**0.00**	**0.00**	**0.010**	**0.000**
Ox_Model	0.01	0.09	0.01	0.16	---	---	0.00	0.00	0.004	0.039
Fseal_Pressure	---	---	**0.00**	**0.02**	---	---	**0.01**	**0.01**	**0.002**	**0.005**
Seal_Open_A	0.01	-0.07	0.00	0.01	---	---	0.00	0.00	0.002	0.004
Burn_Dir	**0.00**	**0.07**	**0.00**	**0.02**	---	---	**0.00**	0.01	0.001	0.006

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

- A stability analysis was performed for the result metrics of interest (e.g., cesium and iodine release to the environment) using a bootstrapping method, to gain an understanding of the level of convergence in the statistical results

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MELCOR Model Parameters

Sequence Related Parameters

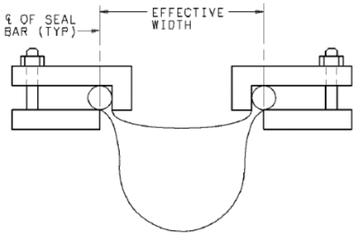
Primary safety valve stochastic number of cycles until failure-to-close
Primary safety valve open area fraction after failure
Secondary safety valve stochastic number of cycles until failure-to-close
Secondary safety valve open area fraction after failure

In-Vessel Accident Progression

Melting temperature of the eutectic formed from fuel and zirconium oxides
Oxidation kinetics model

Ex-Vessel Accident Progression

Lower flammability limit hydrogen ignition criterion for an ignition source in lower containment
Containment rupture pressure
Barrier seal open area
Barrier seal failure pressure
Ice chest door open fraction
Particle dynamic shape factor



Barrier seal

Time within the Fuel Cycle

Time-in-cycle (Beginning, Middle, End-of-Cycle: BOC, MOC, EOC)

MACCS
Uncertain Parameter Groups

Deposition

- Wet Deposition
- Dry Deposition Velocities

Dispersion

- Crosswind Dispersion Linear Coefficient
- Vertical Dispersion Linear Coefficient
- Time-Based Crosswind Dispersion Coefficient

Latent Health Effects

- Dose and Dose Rate Effectiveness Factor
- Lifetime Cancer Fatality Risk Factors
- Long Term Inhalation Dose Coefficients

Early Health Effects

- Threshold Dose
- Lethal Dose to 50% of population
- Hazard Function Shape Factor

Shielding Factors

- Groundshine Shielding Factors*
- Inhalation Protection Factors*

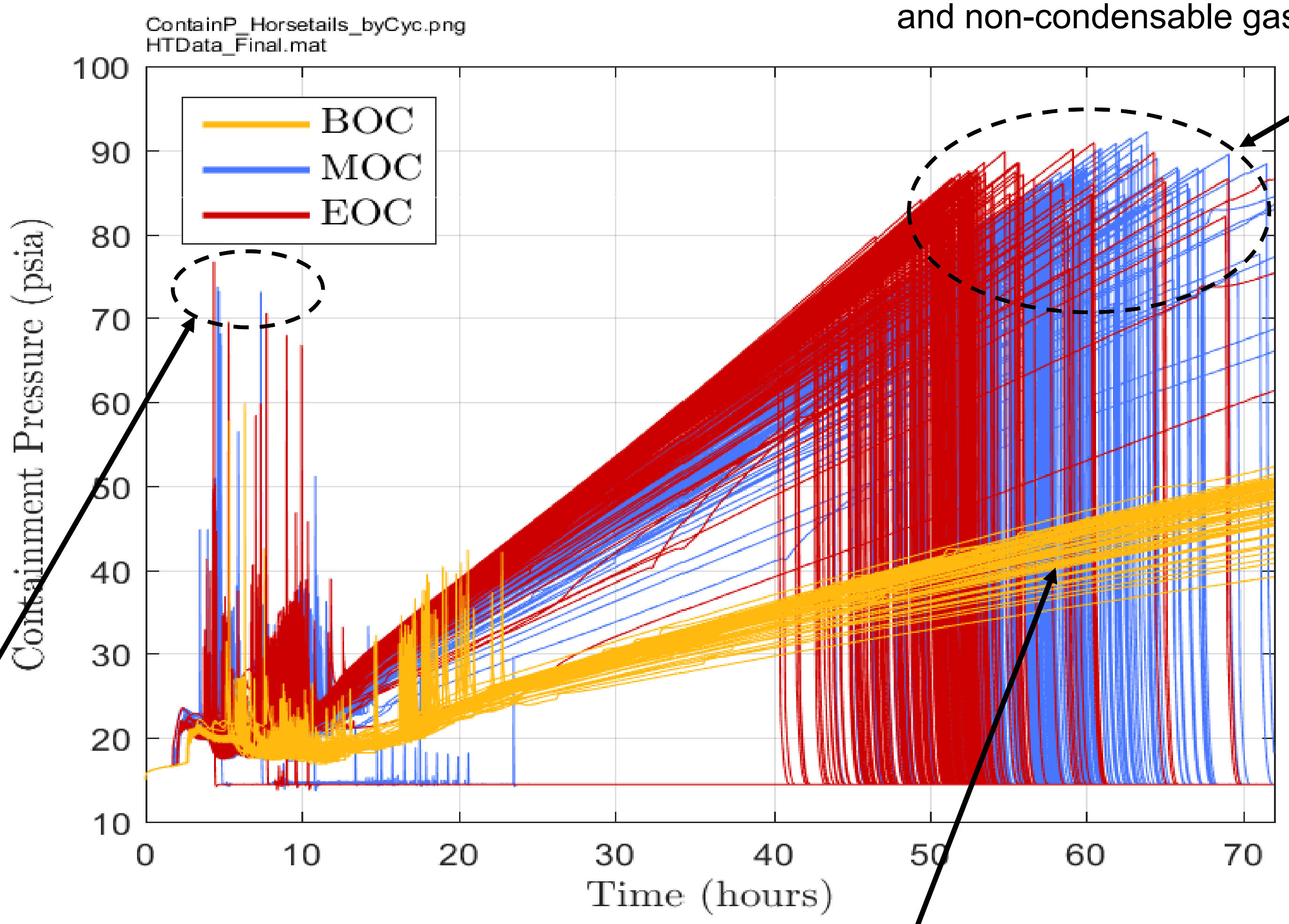
Emergency Response

- Evacuation Delay*
- Evacuation Speed*
- Hotspot Relocation Time and Dose Criteria
- Normal Relocation Time and Dose Criteria
- Keyhole Forecast Time

Aleatory Uncertainty

- Weather Trials

Containment Failure Outcomes

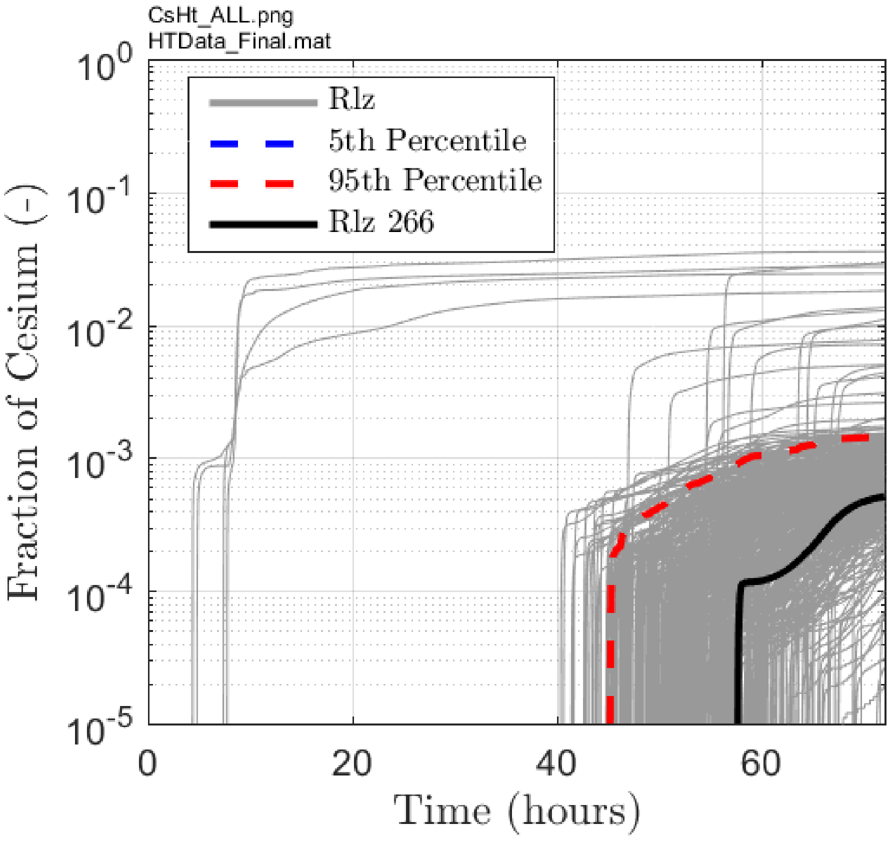


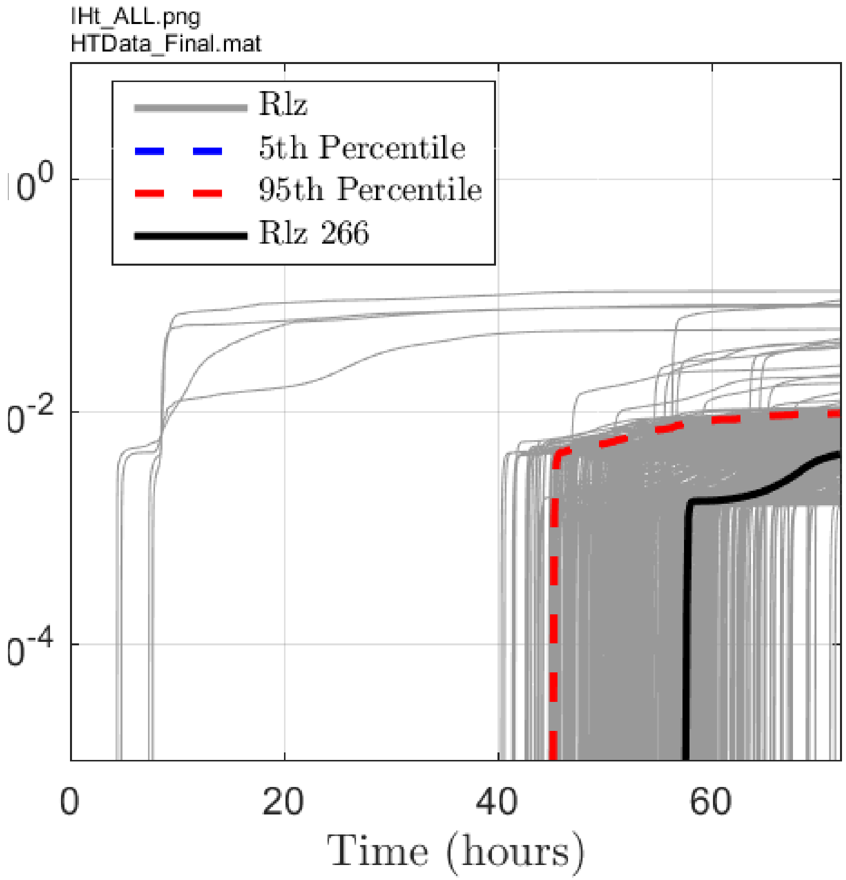
Long-tem containment over-pressurization failure due to prolonged steam production and non-condensable gas generation

Early containment overpressure failures due to sufficiently large burns in containment

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

Cesium (left) and Iodine (right) Environmental Release Fraction Horsetails from STSBO UA





Severe Accident Progression
STSBO High Level General Observations

- Consequences strongly (and intuitively) affected by *early vs. late* containment failure. Early containment failure dominated by hydrogen combustion, and late containment failure results mainly from ex-vessel phenomena (e.g., CCI)
- Early containment failures occur *only on the first hydrogen burn* (subsequent burns do not challenge containment integrity)
- Protracted safety valve (SV) cycling produces *lower in-vessel hydrogen* by the time of first burn
- Pressurizer SV failure to close (with large open area) results in greater hydrogen production and transport to the containment prior to the first burn, which increases the potential for early containment failure
- Late containment failures generally have reduced source term release benefiting from gravitational settling

Summary and Next Steps

- SOARCA Sequoyah analysis confirmed insights from previous analyses and yielded some new insights too
  - MACCS offsite consequence analyses will be discussed in session Th14, Paper 211
- Will be published as NUREG/CR-7245 within the next month, and available through NRC's website www.nrc.gov
- NRC is developing a NUREG report that will summarize the insights from all three SOARCA UAs completed