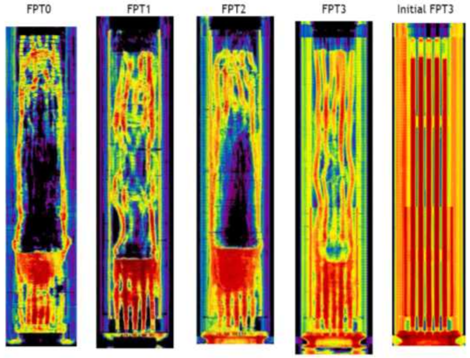
SAND2018-11673C

Source: Tokyo Electric Power Company



Dynamic Modeling of SAMGs

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Dynamic SAMG Modeling

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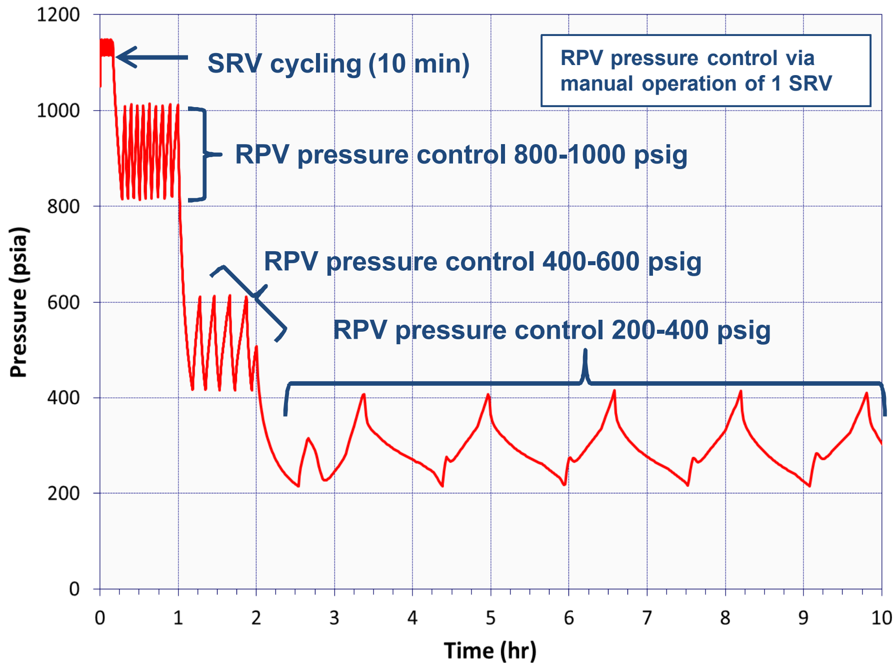
Motivation:

- Develop scenarios that will support training for the MBDBE rule
- Provide a modeling basis for SAMGs: now based on expert judgement
- Investigate known differences in MELCOR/MAAP applied to SAMGs



Objective:

Use severe accident analysis signatures to test SAMG symptom-based approach and confirm that SAMGs can address a wide-range of accident signatures and be successful in accident mitigation strategies

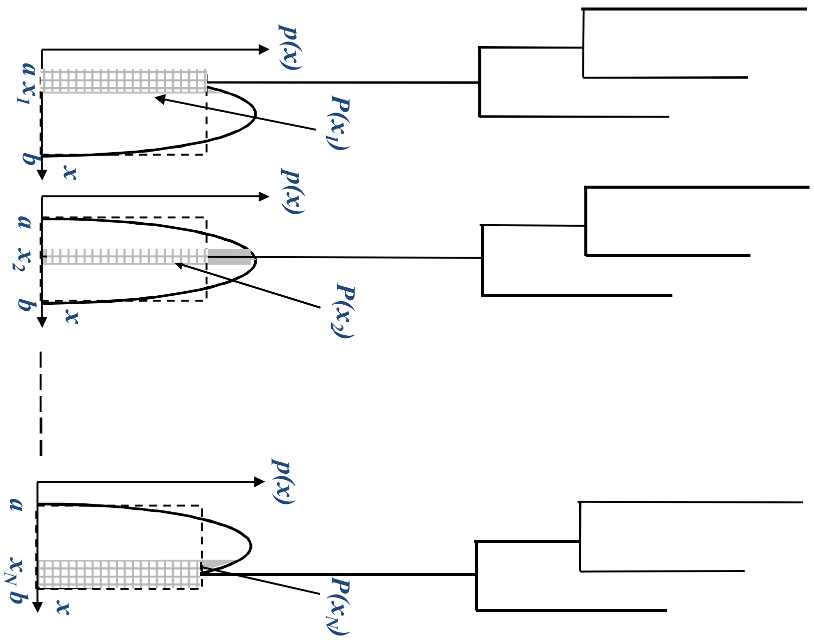
Dynamic SAMG Modeling – Goals

- Event timings
  - Identify and determine the impact of different actions on key event timings
- Long-term water management
  - Explore impact SAWA and SAWM strategies on long-term accident progression
- Impact of different models within MAAP and MELCOR on event scenario
  - Fully characterize possible severe accident event progression pathways
- Provide guidance on possible simplification of SAMG pathways
  - Identify locations where SAMGs could be streamlined
- Provide guidance on SAMG training
  - Based on severe accident signatures from MAAP and MELCOR from working through a SAMG scenario branches

SAMG Modeling Using ADAPT

- Analysis of Dynamic Accident Progression Trees (ADAPT) splits scenario at key times
- Develops visualization tool to focus on parameters of interest
  - Returns portions of tree meeting a set of rules
    - Branches with water level below TAF at $t<40$ min and lower head penetration failure at $t>4$ hr
- Developed dynamic importance measures to determine impact of parameters
  - Events: return ratio of a measure of consequence (e.g. extent of radionuclide release) for event occurrence vs non-occurrence
    - Compatible with non-binary branching
    - Events with both uncertain occurrence and timing
  - Physical parameters: return ratio of consequence measure for each sampled value vs overall

Concept of Dynamic Event Trees



Epistemic Uncertainty Branching (Outer Loop)

Aleatory Uncertainty Branching (Inner Loop)

p(x)*: *pdf* of a≤*x* ≤*b

$$P(x_n) = \int_{x_n-\Delta x}^{x_n+\Delta x} dx\ p(x) \quad \left(n = 1, \cdots, N;\ \Delta x = \frac{b-a}{2N}\right)$$

- - - - **Uniform p(x)**

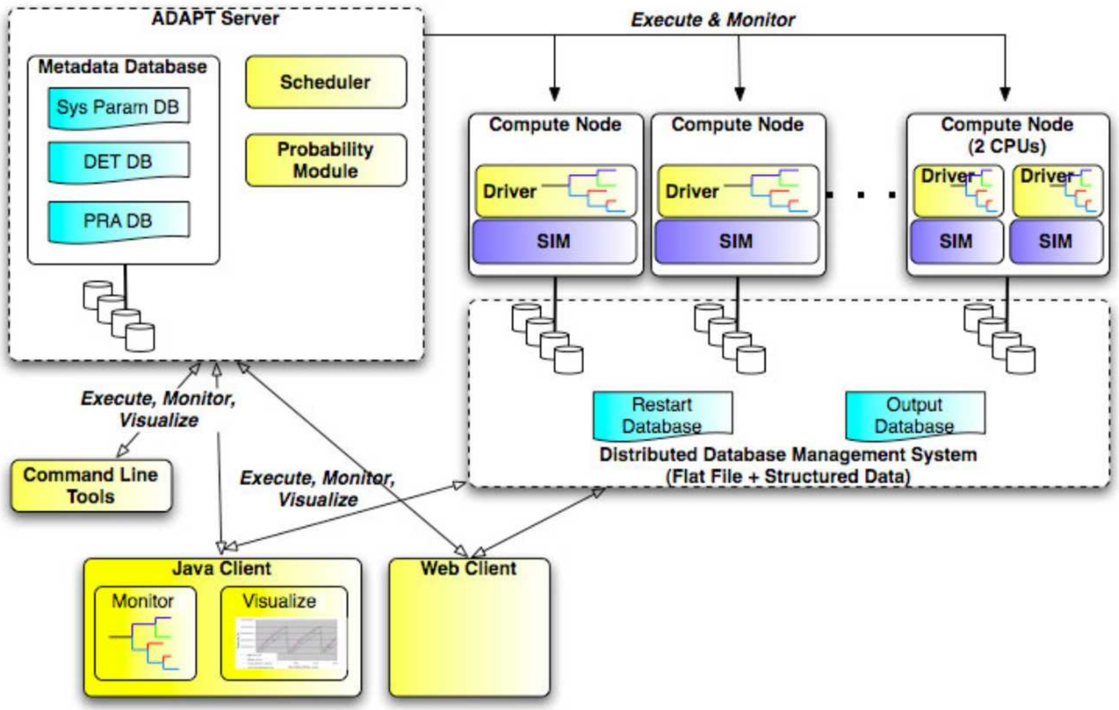
_____ **Non-uniform p(x)**

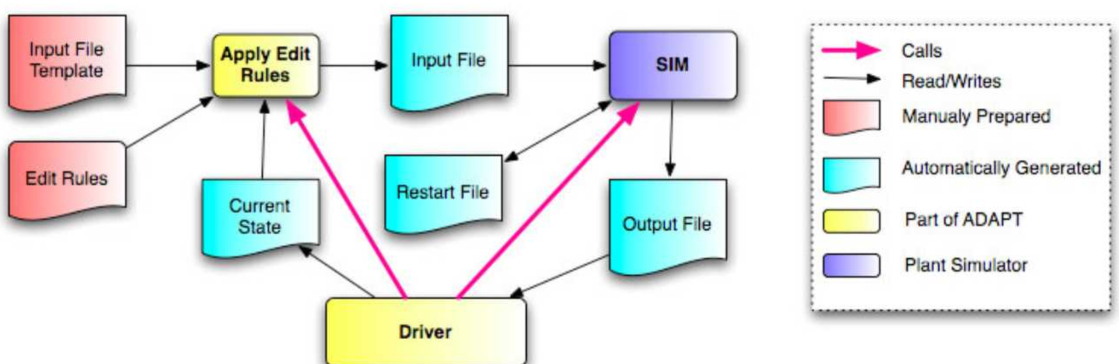
P(x_n)* for uniform *p(x)

P(x_n)* for non-uniform *p(x)

ADAPT Software Framework

- ADAPT is a Job Schedule *ONLY*
- Provide stop & restart commands to system code (MELCOR)
- Creates and tracks branches based on uncertain dynamic events
  - Timing
  - Phenomena





Work to Date

- Run-down of a SAMG scenario with industry representatives
  - Steady State Operation → Initiating Event → EOP → SAMG
- Developed scenario based off of EOPs, TSGs, SAMGs and expert opinion
  - Attended TSG workshop and received BWROG EPC guidance
  - Informed by ex-vessel analysis experts
- ADAPT framework for queuing MELCOR cases
  - Updates and setup of scenario framework
  - Dynamic approach: single run that diverges at key times
    - Pump failure or start-up
    - Different injection rates
    - Water injection timings based on different pressure signatures
- Simulations of scenarios into EOP and SAMG space

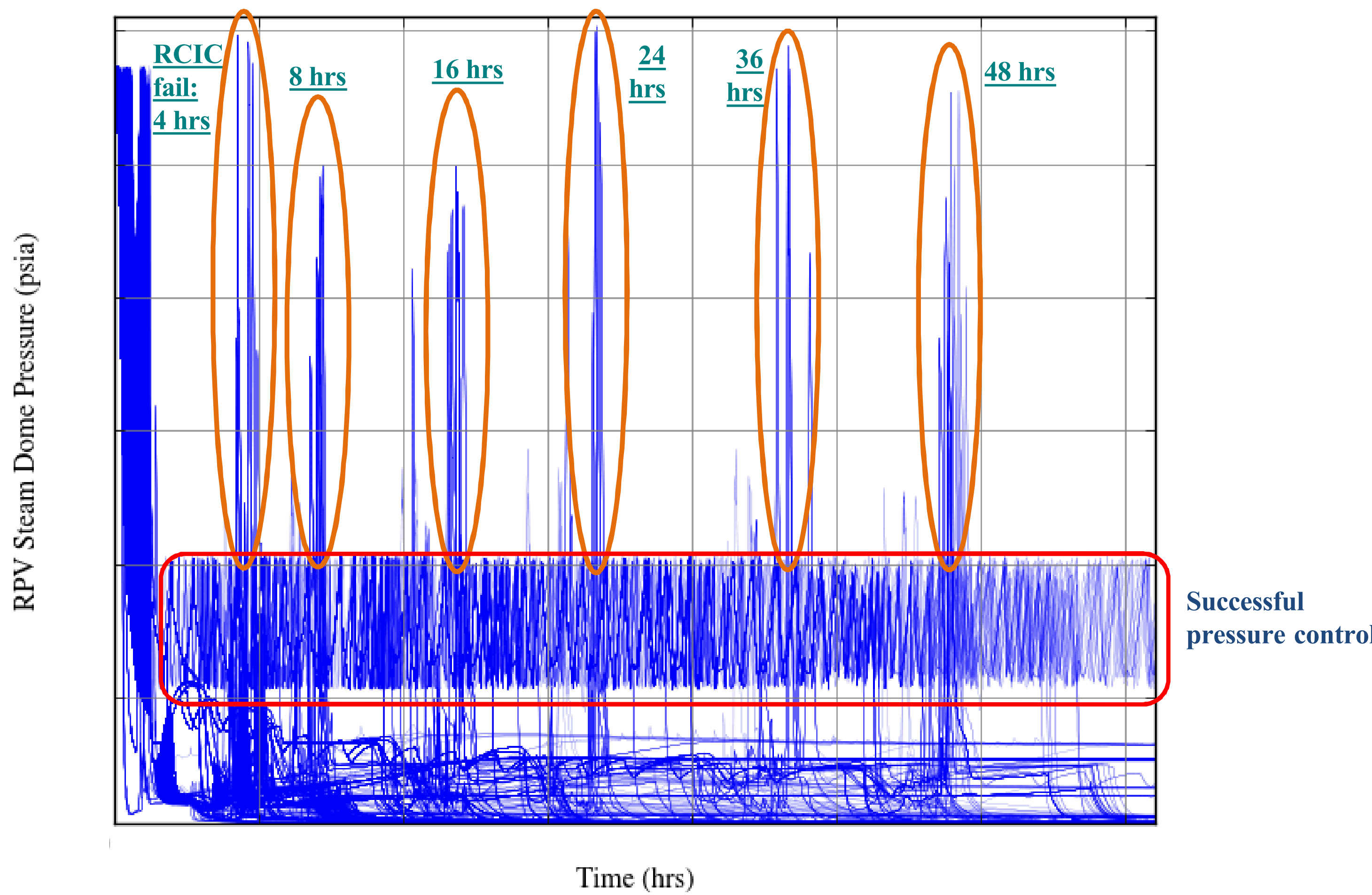
SAMG Modeling - Metrics

- Event timings
  - Water levels: TAF, BAF
  - Zr-oxidation pickup
  - Core plate
  - Lower head failure
  - Ex-vessel signatures
- Long-term water management
  - SAWA
  - SAWM
  - Different long-term injection rates into the PCV
  - Impact on total release (accident source)
- Assess impact of different models within MAAP and MELCOR on event scenario
  - In-vessel treatment of core relocation
  - Core quenching
  - Lower head failure modeling
  - MCCI model impact on long-term PCV behavior
    - Ex-vessel gas generation
    - Debris coolability
  - Environmental release fraction of Cs & I

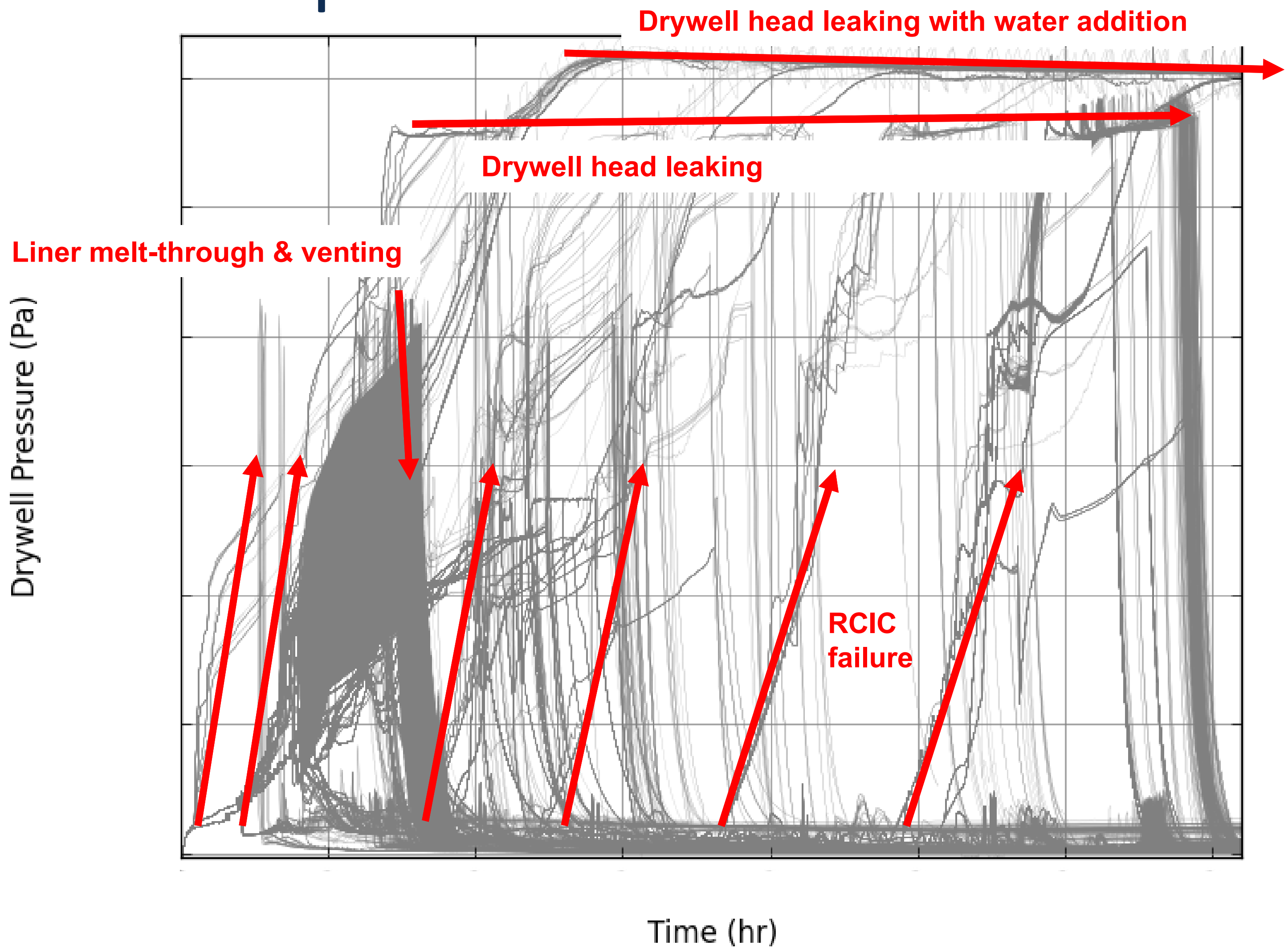
SAMG Scenario Runs

- Base case for ADAPT-MELCOR run
  - Subsequent runs will be horsetail plots showing different operator actions, decisions and bifurcation points
  - Steady State Operation → Initiating Event → EOP → SAMG
- Based on accident scenario that was iterated on by EPRI, Industry, and Sandia
  - SRV cycling
  - RPV pressure control via manual operation of 1 SRV
  - Containment venting
  - RCIC operation
- Analysis past the point of SAMG entry
  - Significant simulation of EOP space
    - RPV Pressure Control
    - RCIC operation
    - Drywell venting
  - Importance of capturing stratification within the wetwell

ADAPT Horsetail Plots for RPV Pressure Response

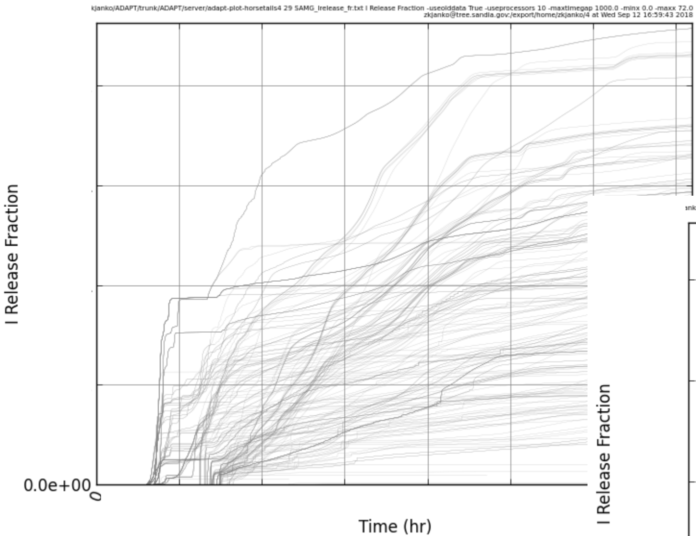


ADAPT Horsetail Plots for RPV Pressure Response

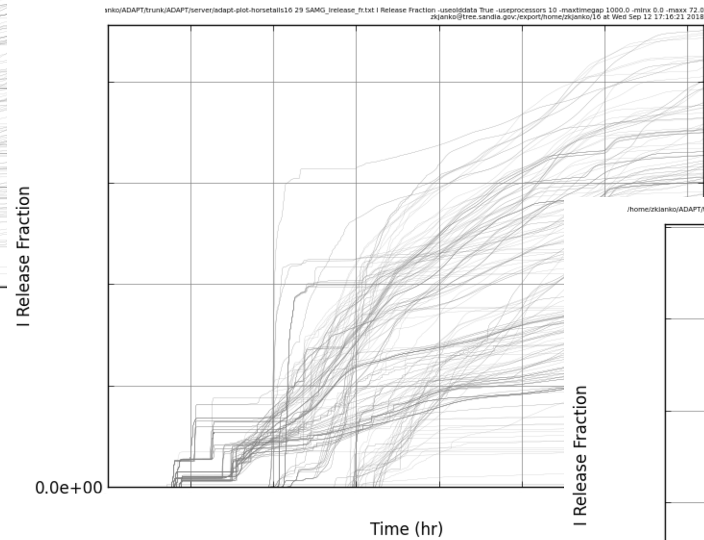


Sample ADAPT Iodine Source Term Plots

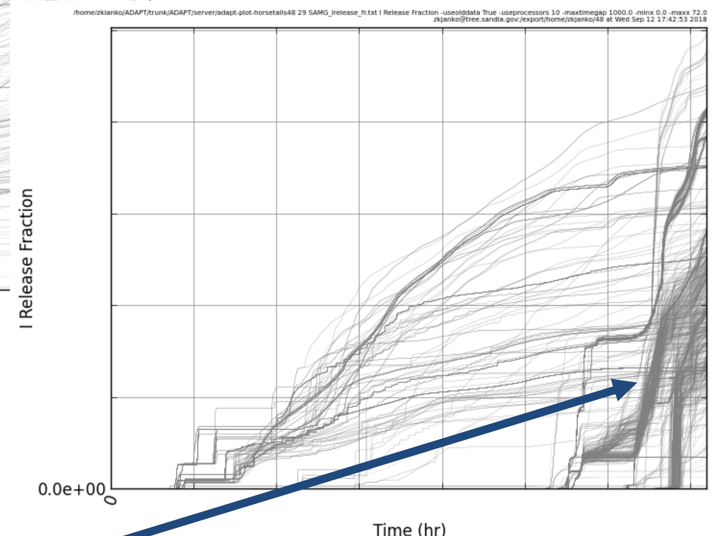
Accident uncertainties can lead to early releases (various RCIC failure mechanisms)



RCIC failure at 4 hr



RCIC failure at 16 hr



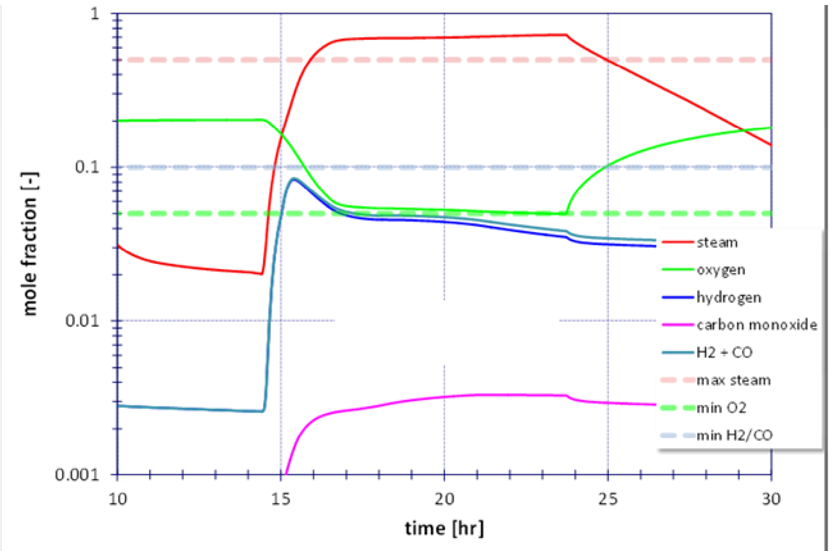
RCIC failure at 48 hr

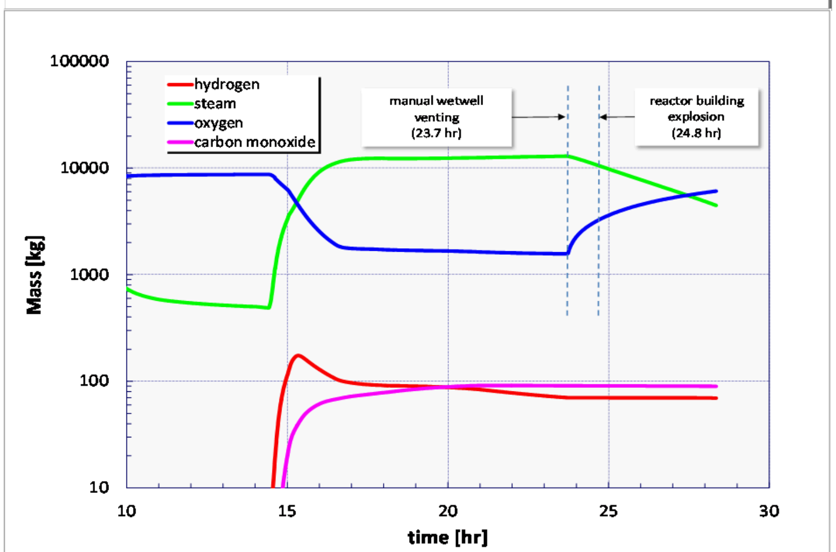
Late releases can be more rapid and larger

1F1 Issues with Uncertainties

- 1F1 is a real-world need for dynamic modeling
  - Investigate the ‘State Space’ of uncertainty
- Amount of hydrogen generated
  - Some variation among codes
- Mode of RPV depressurization
  - SRV seizes open vs. MSL failure
  - SRV gasket failure?
- Lower head failure
  - Currently modeled as low-pressure creep rupture
  - Could an earlier penetration failure occur?
  - Would it release significant core material?

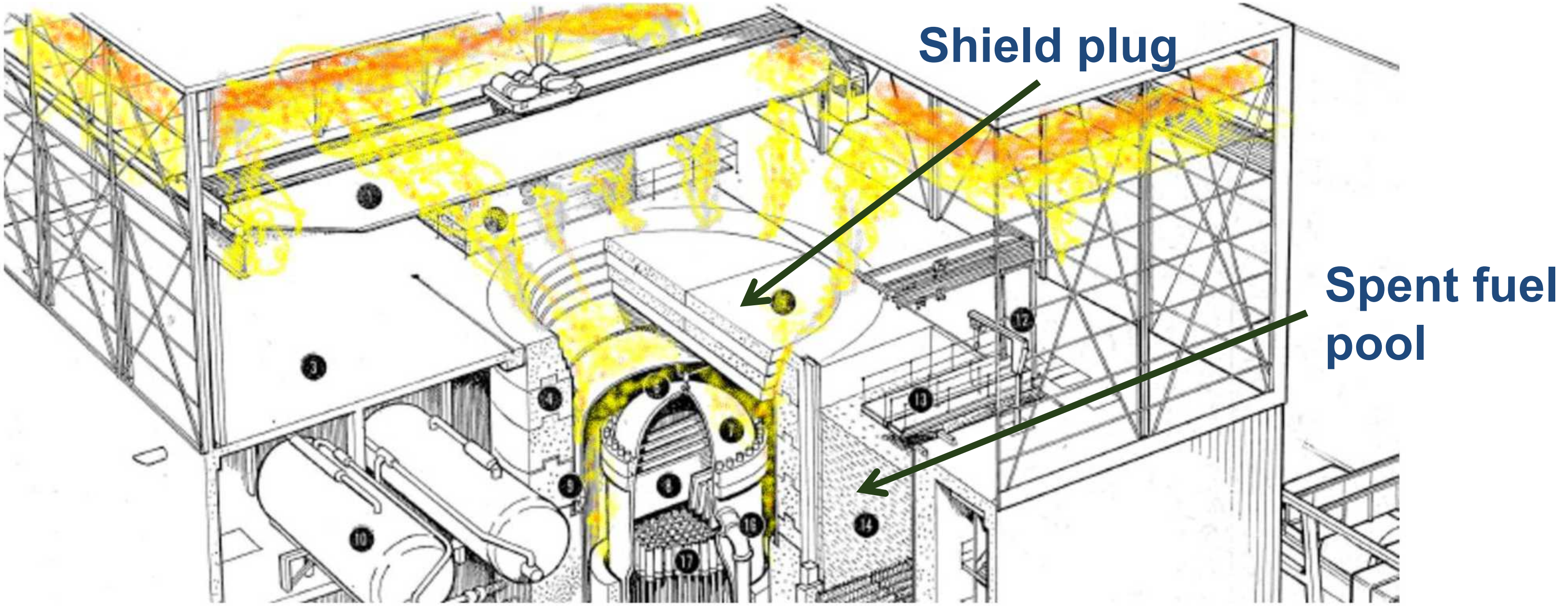
Unit 1 Results - Refueling Bay Vapor/Gas Molar Concentrations





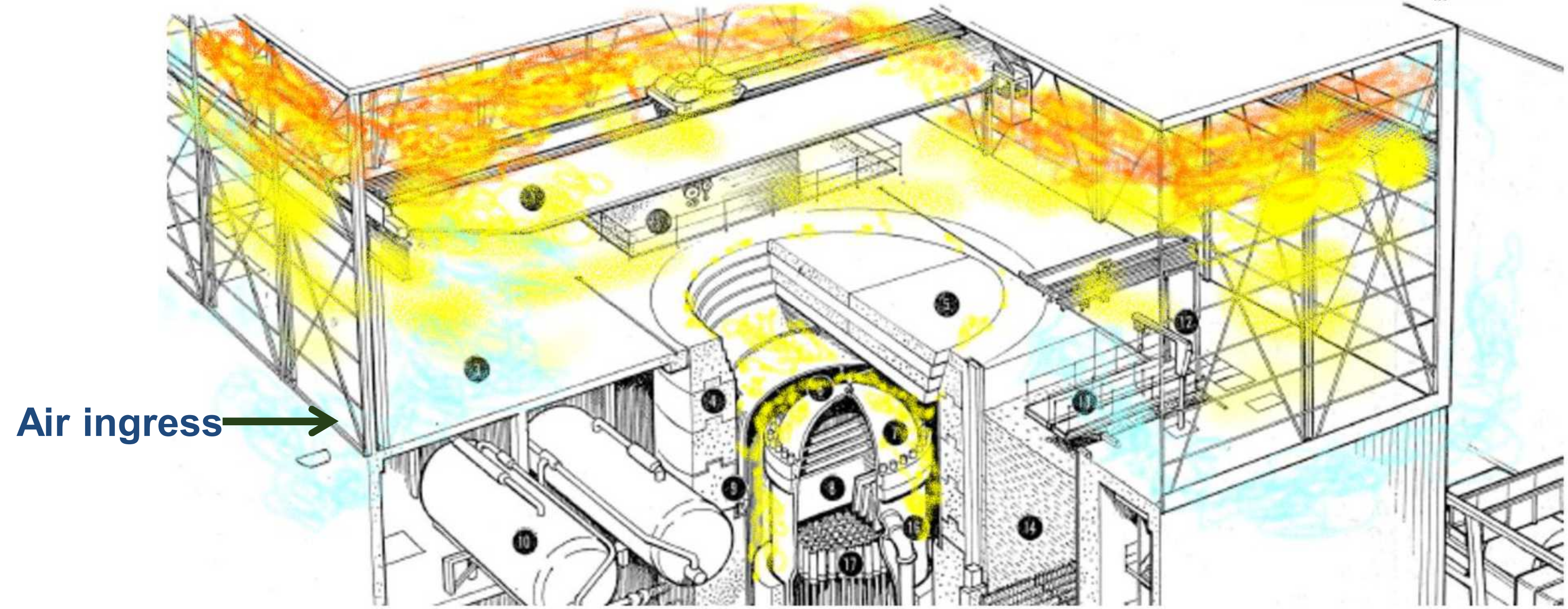
- **Steam, H_2, and CO enter the refueling bay via the drywell head flange leakage (drywell head lifts due to high containment pressure).**
  - **Persists for ~10 hours**
- **O_2 concentration decreases as air is displaced by steam H_2 and CO.**
- **Wetwell is vented at ~24 hr; containment pressure drops and drywell head reseats.**
  - ***Water injection also stopped***
- **Steam concentration decreases and O_2 increases as steam condenses and air ingress commences**
- **Well-mixed volume concentrations are slightly below the minimum H_2/CO flammability limit**
  - **Total of 900 kg vented into the refueling bay, but only 100 to 200 kg resident at any given time.**
- ***Thermally buoyant plume of H_2/steam rising to ceiling not modeled***
- ***Light gas (H_2) stratification not modeled***

Hydrogen Accumulation in 1F1



- Between ~12 hours and ~23 hours, steam and hydrogen leaks from drywell head flange and enters RB via shield plug seams
- Hydrogen, CO and steam rises to roof and spreads laterally
- Steam produced in MCCI and from emergency water injection
- Condensation in refueling bay depletes steam in hot layer and enriches hydrogen
- Mixture displaces air from building
- Steam mole fraction exceeds 50% - inert conditions prevent combustion

Combustible Conditions Follow PCV Venting in 1F1



- At around ~23 hours, steam and hydrogen leakage from PCV greatly reduced
  - Water injection was stopped
  - PCV was depressurized by operator venting action
- Continuing condensation without steam source....
  - Reduces steam molar fraction to below 50% in refueling bay, and
  - Produces partial vacuum that draws in outside air
- Air ingress and steam condensation leads to conditions favoring combustion
- Hydrogen stratification produces flammable or detonable concentrations of H_2/O_2

Damage from Explosions

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Kenji Tetawa