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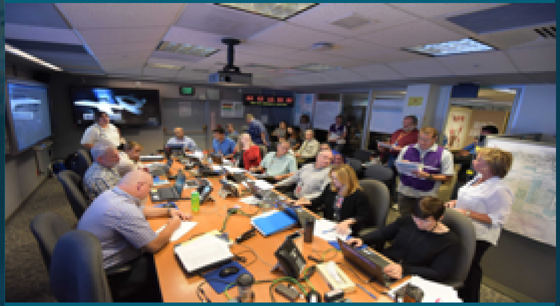
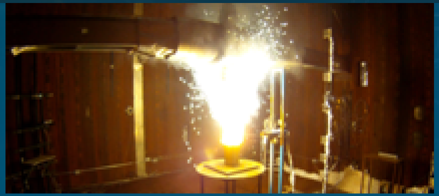
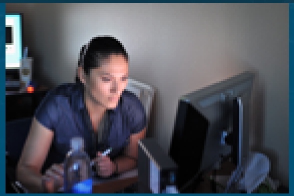
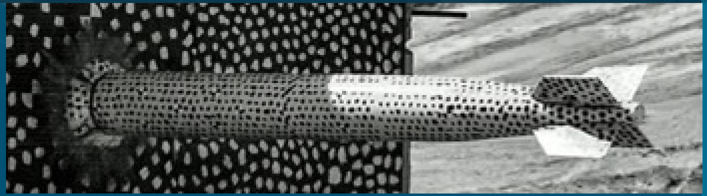


2021 TTUG Virtual Meeting

SNL Modeling/Simulation Update







PRESENTED BY

Brad Beeny, Severe Accident Modeling/Analysis (SNL-08852)

U.S. DEPARTMENT OF ENERGY NNSA

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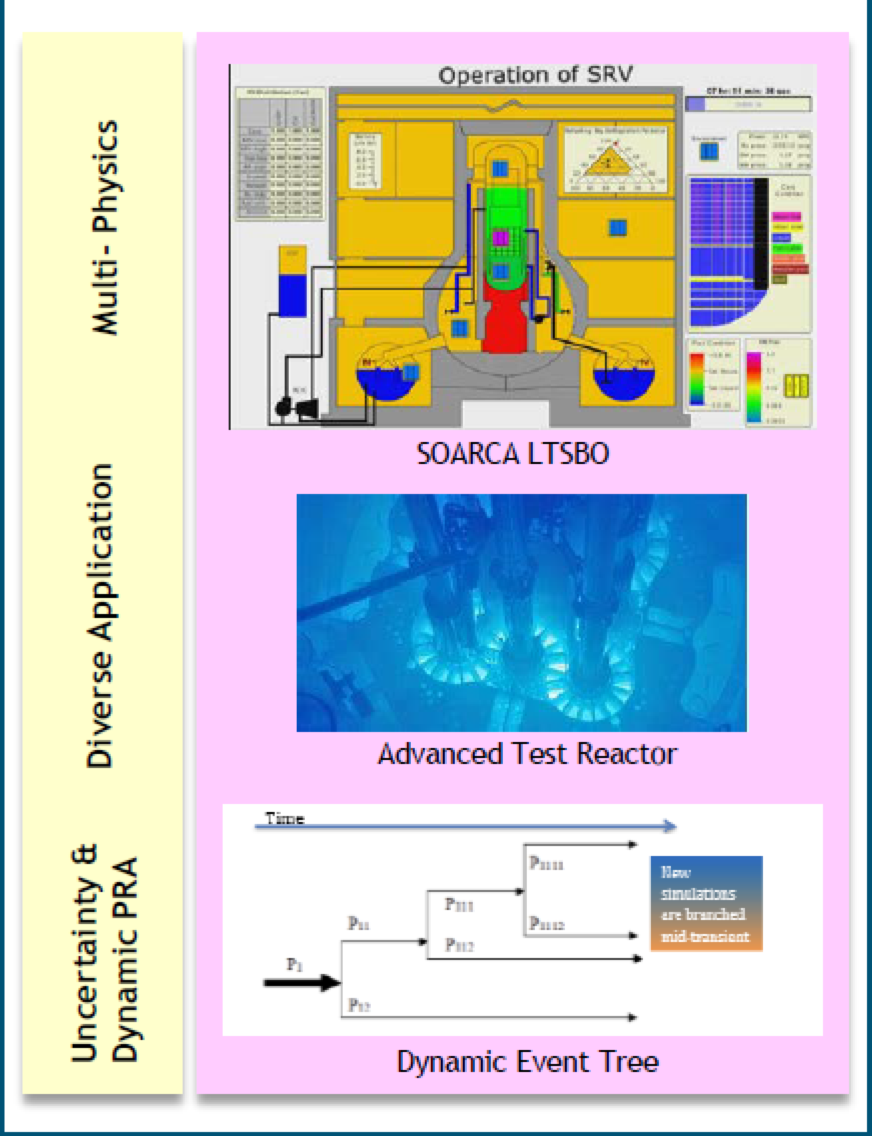
SNL MELCOR Modeling/Simulation Efforts Pursuant to TTEXOB Milestone 7 – FY21

L. Gilkey, M. Solom, B. Beeny (SNL)

MELCOR History and Introduction

- Fully integrated, multi-physics engineering-level code
  - Thermal-hydraulic response in the reactor coolant system, reactor cavity, containment, and confinement buildings
  - Core heat-up, degradation, and relocation
  - Core-concrete attack
  - Hydrogen production, transport, and combustion
  - Fission product release and transport behavior
- Diverse application
  - Multiple core designs
  - Models built from basic code constructs
  - Adaptability to new or non-traditional reactor designs (ATR, Naval, VVER)
- Validated physics models (ISP’s, benchmarks, experiments, accidents)
- Uncertainty analysis & dynamic PRA (fast-running, reliable, access to parameters)
- User convenience
  - Windows/Linux versions
  - User utilities and post-processing/visualization capabilities
  - Extensive code documentation

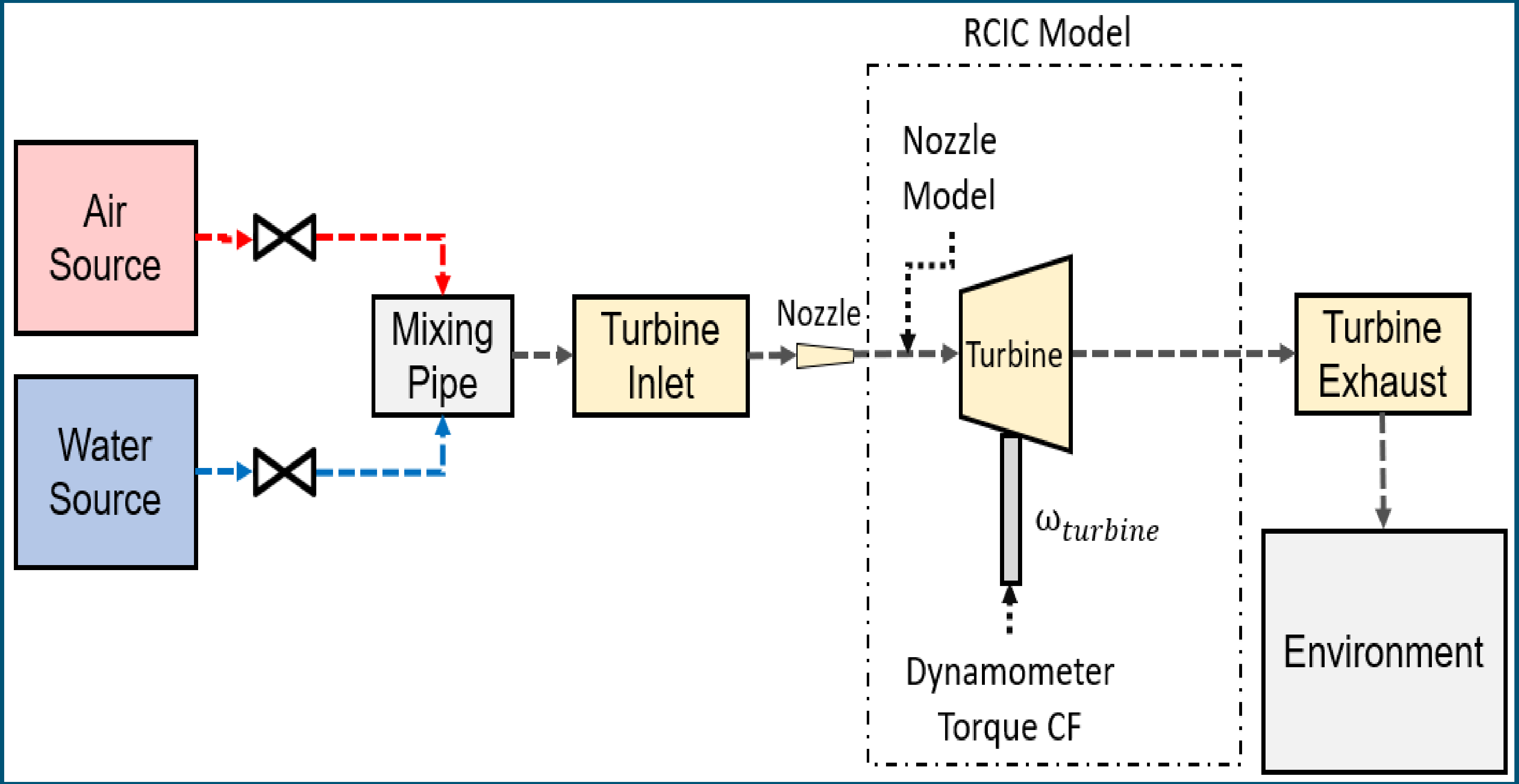


MELCOR RCIC System Modeling & Analysis

- FY21 was an extended period-of-performance (no cost extension)
- Milestone 7 work focused on input model development for the ZS-1, GS-2, and generic BWR
  - ZS-1
    - New experimental data available from TAMU
    - New MELCOR code capabilities employed
    - Inputs configured for uncertainty analysis demonstration with the DAKOTA code
  - GS-2
    - New experimental details available
    - Some of the ZS-1 modeling improvements apply
    - Set up for future comparison with experimental observations/data
  - Generic BWR
    - Revolved around the question of self-regulating behavior
    - Three observed modes of self-regulation
    - Identification of particularly influential parameters and/or modeling choices
  - FY21 summary report has been publicly released

MELCOR RCIC System Modeling & Analysis

- ZS-1 Model



MELCOR RCIC System Modeling & Analysis

- ZS-1 Modeling
  - Temperature and pressure set while air/water mass flow modulated
  - Experiments suggest turbine losses include a linear term:

$$\tau_{loss} = c_{windage}\,\omega^2 + c_{linear}\,\omega + c_{constant}$$

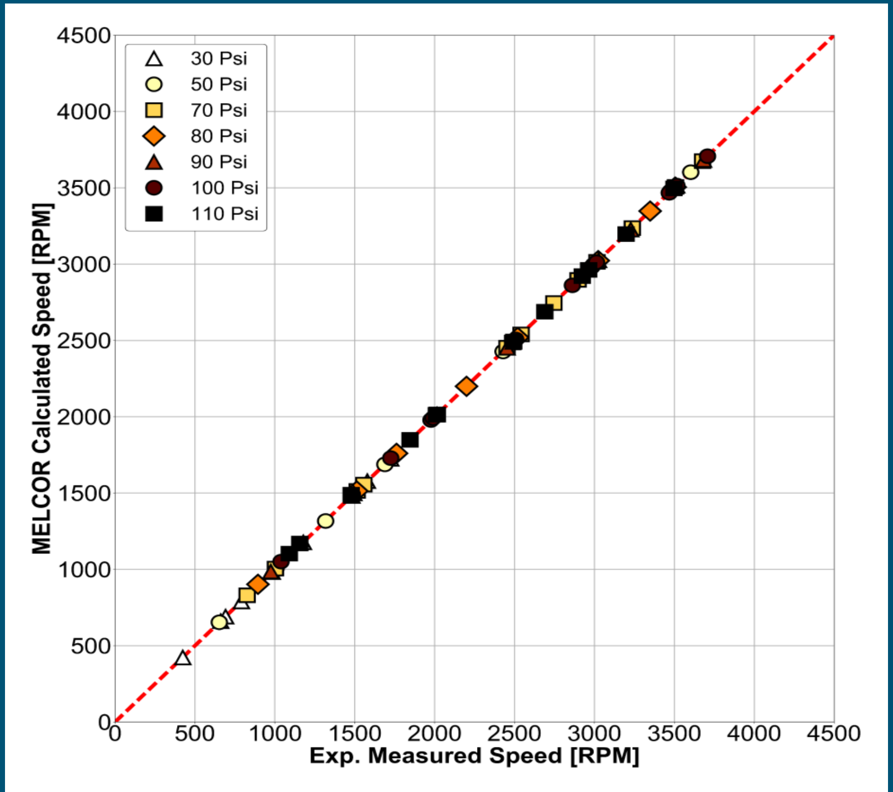
$$\tau_{net} = c_{torque} \times \tau_{turbine} - \tau_{loss}$$

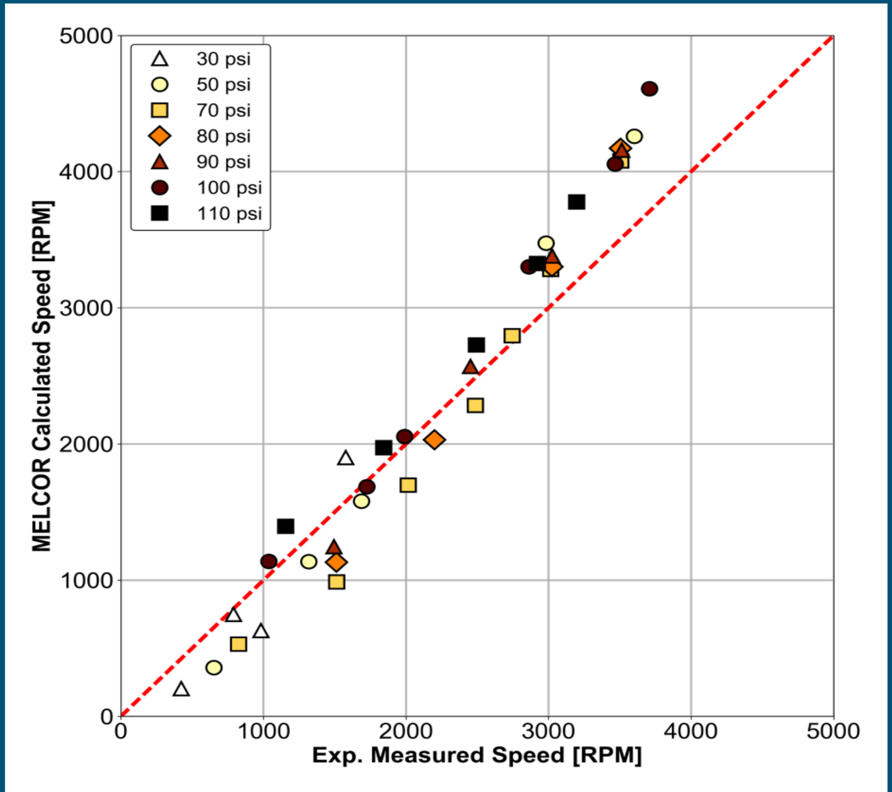
Coefficient/Constant	Value
$c_{windage}$	1.39×10^{-7}
c_{linear}	2.3×10^{-4}
$constant$	3.8×10^{-2}

  - Loss coefficients experimentally determined
  - Ideal gas mixture nozzle flow model employed along with new systems-level RCIC mechanistic models
  - c_{torque} found with MELCOR simulations
    - Deterministic calibration
      - Can do this per experiment
      - Can derive a single value considering all experiments → c_{torque}=0.3453
    - Bayesian calibration
      - MELCOR/DAKOTA coupling
      - Uncertain parameter is c_{torque}
      - Mean value compares well with deterministic value → c_{torque}=0.3467

MELCOR RCIC System Modeling & Analysis

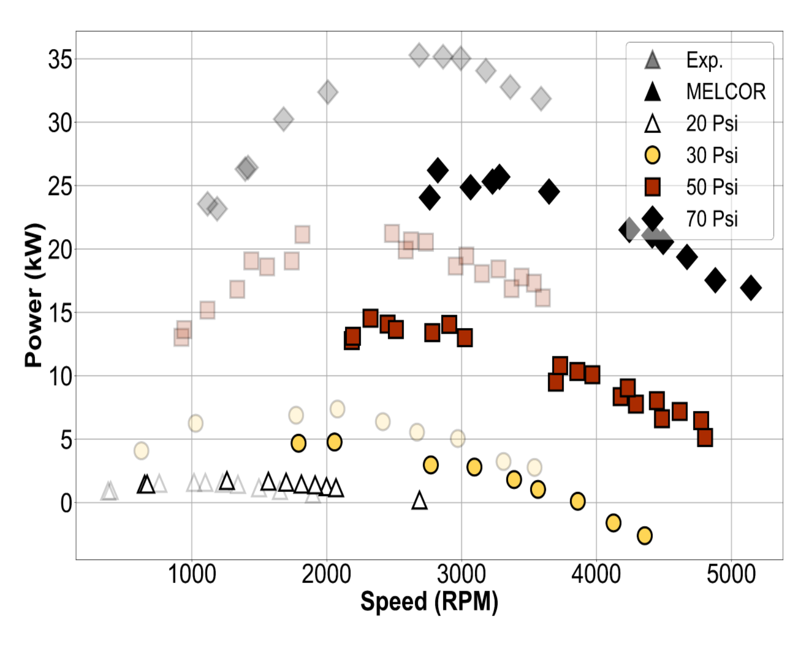
- ZS-1 MELCOR results vs experimental data
  - Left: Per-experiment c_{torque} calibrations (proper speed with proper calibration per experiment)
  - Right: c_{torque} calibrations across all experiments

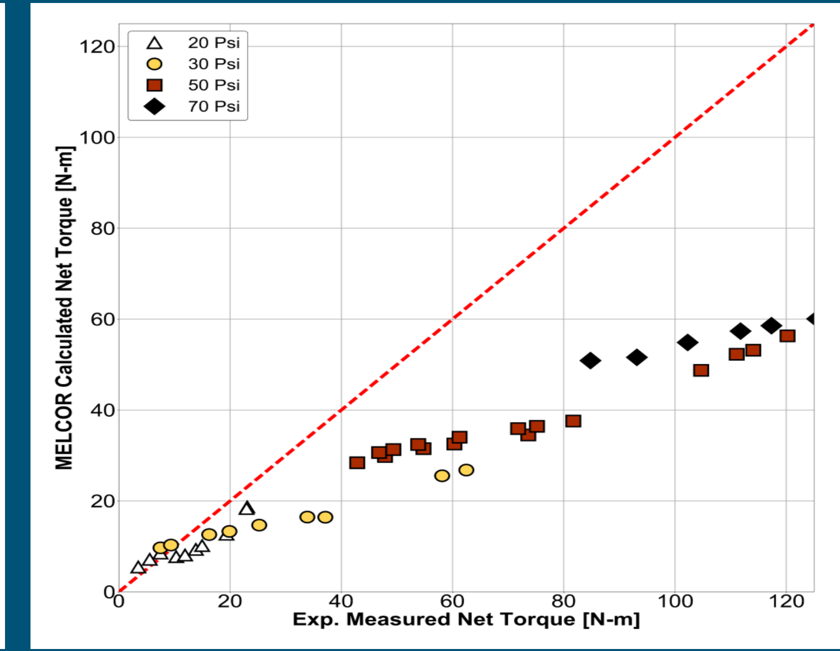


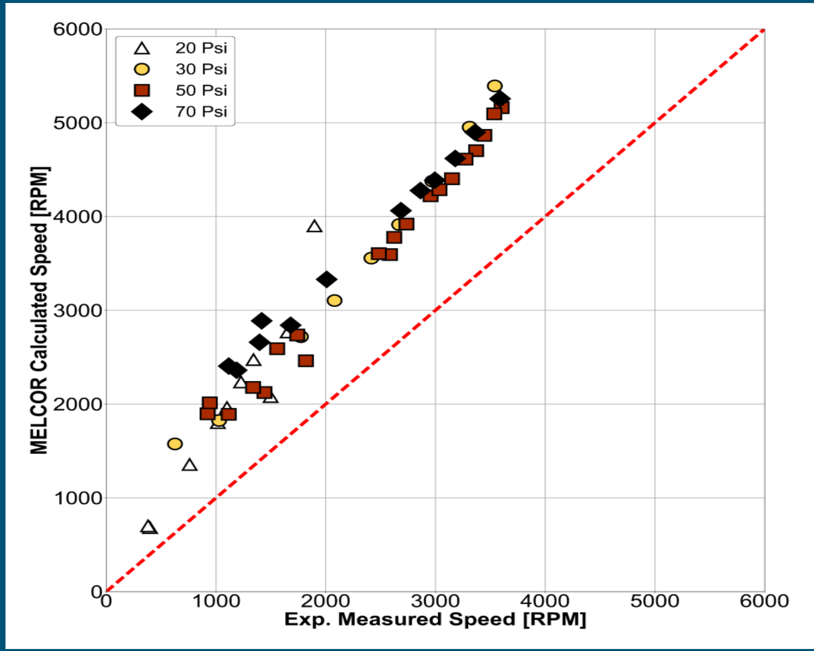


MELCOR RCIC System Modeling & Analysis

- ZS-1 c_{torque} in GS-2 simulations?
  - Loss data not yet available and/or incorporated
  - Using ZS-1 coefficients in GS-2 leads to comparatively poor MELCOR/experiment agreement
    - Repeat ZS-1 analysis on GS-2 with revised loss coefficients to obtain a GS-2 turbine torque multiplier
    - Or…propose some sort of correction to ZS-1 coefficients?







MELCOR RCIC System Modeling & Analysis

- Generic BWR
  - Geared towards RCIC modeling
  - GS-1 type Terry turbine
  - 5 circumferential nozzles around rotor wheel (high and low)
- No overspeed allowed
- Pump NPSH failure allowed
- SBO w/ DC loss at 2 hr

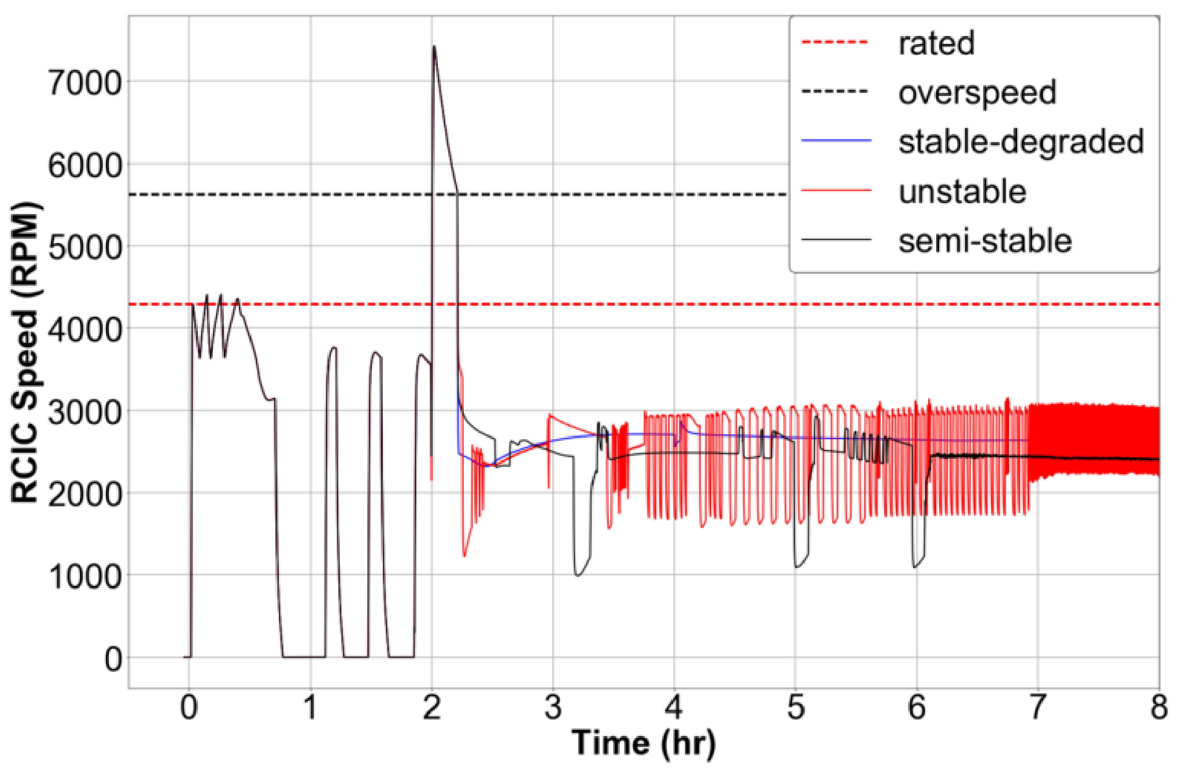
Parameter	Value
RCIC Turbine Specifications	
Turbine Radius	0.3048 m
Turbine CV Volume	0.106 m^3
Turbine Moment of Inertia	10.0 kg-m^2
Turbine Friction Torque	10.0 N-m
Turbine Bucket Exit Angle	30º
Turbine Nozzle Diameter	12.7 mm
Number of Nozzles	5
RCIC Pump Specifications	
Rated Pump Speed	4287.0 RPM
Rated Pump Head	7.59 MPa
Rated Pump Torque	448.8 MPa

Parameter	Value
Rated Pump Power	2.0147×10^5 W
Rated Pump Injection Rate	0.03886 m^3/s
Pump Moment of Inertia	30.0 kg-m^2
Other RCIC Related Specifications	
RCIC CF Target Injection Rate	38.733 kg/s
RCIC CF Target Relative Downcomer Level	2.54 m

- MELCOR mechanistic RCIC models configured and active
  - Turbine - pressure stage and velocity stage(s), friction and losses, etc.
  - Pump - homologous curves, friction and losses, etc.
  - Shaft - torque-inertia equation for synchronous speed considering turbine and pump sides

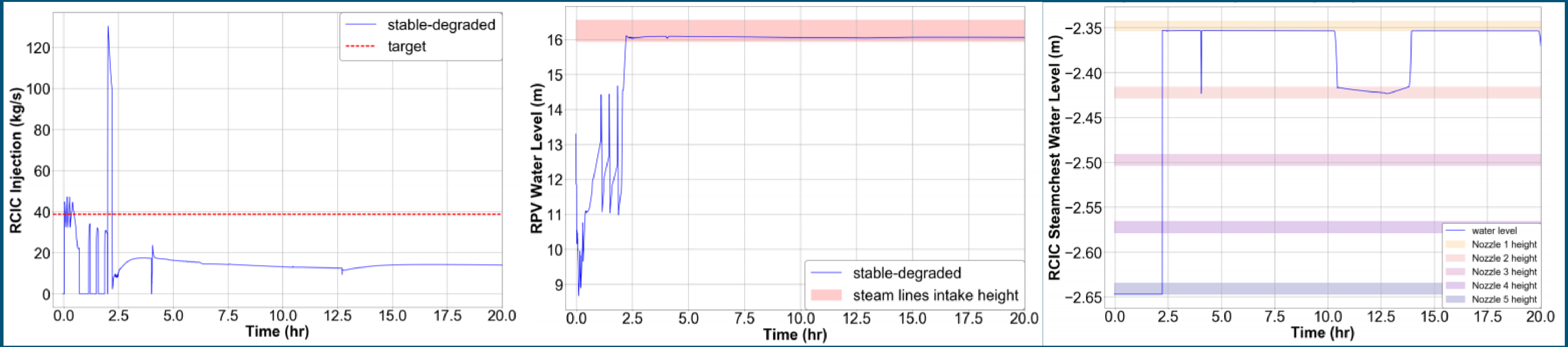
MELCOR RCIC System Modeling & Analysis

- Observe three self-regulating modes of operation (pending model input parameters)
  - Stable, degraded – Constant turbine speed and stable (degraded) water injection to RPV
  - Unstable – Oscillations in turbine speed and RPV injection according to steam line flooding
  - Semi-stable, degraded – Stable, degraded with fluctuations
- Nozzle modeling choices make the difference
  - Single "lumped" flow path
  - Several flow paths at different elevations
  - Steam line and steam chest modeling
  - Experimental insights can help?



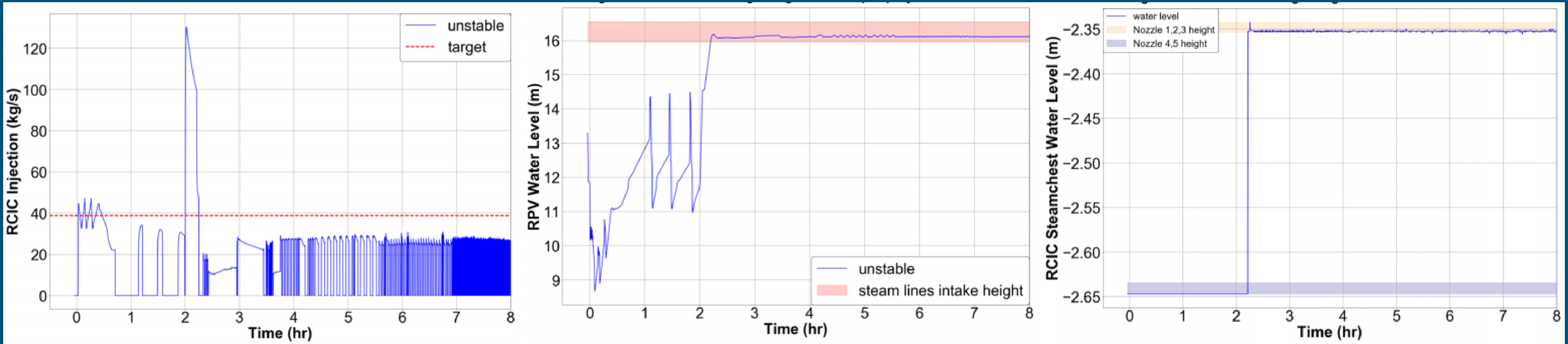
MELCOR RCIC System Modeling & Analysis

- Stable, degraded – Constant turbine speed and stable but degraded water injection to RPV
  - Five nozzles at five distinct locations, circumferentially situated about the rotor wheel
  - Nozzles 3, 4, and 5 (lowest) submerged, nozzle 2 mostly submerged, nozzle 1 always uncovered
  - Top nozzle admits steam, preserves turbine performance, pump flow, and water level



MELCOR RCIC System Modeling & Analysis

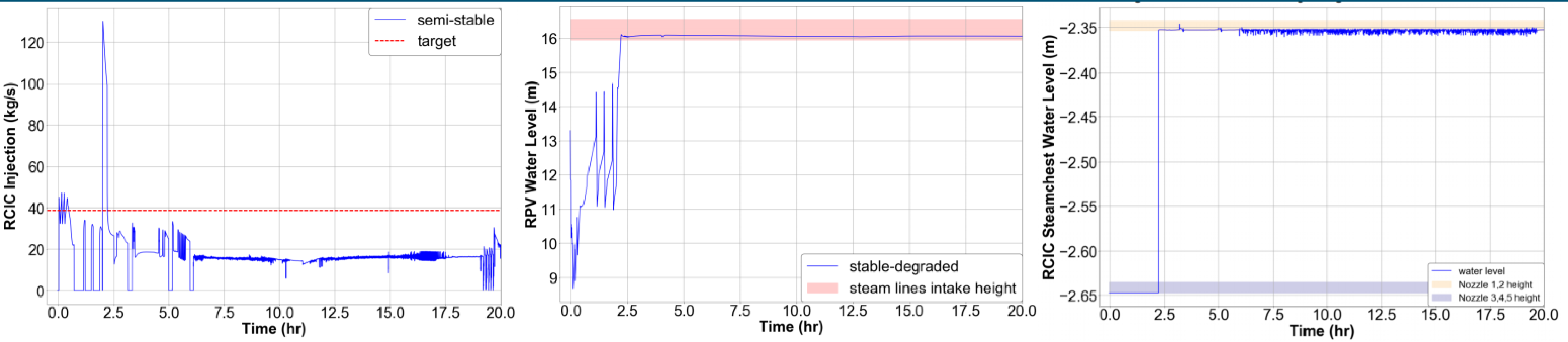
- Unstable – Oscillatory fluctuations in speed/injection according to steam line flooding
  - Three high nozzles at common elevation
  - Two low nozzles at common elevation
  - Same nozzle characteristics otherwise
  - Preferential phasic flow as low nozzles flow water only, high nozzles flow two-phase mixture



MELCOR RCIC System Modeling & Analysis

- Semi-stable, degraded – Stable, degraded with significant speed/injection fluctuations
  - Two high nozzles at common elevation and three low nozzles at common elevation
  - Fewer mixed-phase high nozzles results in a mitigation of oscillatory behavior
  - Extra pool phase low nozzle results in less turbine impulse and more windage loss

→ Small changes in uncertain inputs can have drastic implications for model



MELCOR RCIC System Modeling & Analysis

- Summary
  - FY21 MODSIM work consisted mostly of input development on the ZS-1 and generic BWR input decks
  - ZS-1 loss data and experimental results allows calibration of c_{torque} in MELCOR
  - Demonstrated MELCOR/DAKOTA coupling as an alternative pathway to deterministic calibration
  - GS-2 input model with ZS-1 loss coefficients leads to relatively poor MELCOR/experiment agreement, suggesting an item of future work (characterize GS-2 losses experimentally, repeat c_{torque} calibration)
  - Generic BWR input model can predict Terry turbine self-regulation in one of three modes depending largely on nozzle modeling decisions, e.g. the circumferential orientation of nozzles about the rotor