Regulatory Review of GEH Topical Report "BWRX-300 Containment Evaluation Method"

NEDC-33922P, Revision 2

NRC Staff Presentation

BWRX-300 Small Modular Reactor
ACRS Full Committee Meeting

April 6, 2022

NRC Staff Review Team

- NRR Nuclear Systems Performance Branch (SNSB)
  - Syed Haider
- NRR New Reactor Licensing Branch (NRLB)
  - James Shea
- NRR Nuclear Methods, Systems & New Reactors Branch (SNRB)
  - Carl Thurston, Shanlai Lu
- NRR Containment and Plant Systems Branch (SCPB)
  - Chang Li
- RES Code and Reactor Analysis Branch (CRAB)
  - Peter Lien, Joe Staudenmeier, Andrew Ireland
- RES Fuel & Source Term Code Development Branch (FSTCB)
  - Shawn Campbell

Presentation Outline

- Overview of BWRX-300 Containment Evaluation Method (CEM) LTR NEDC-33922P, Revision 2
- BWRX-300 acceptance criteria for containment response
- BWRX-300 containment design background
- BWRX-300 containment evaluation method demonstration analyses
- TRACG mass and energy release calculation methodology review
- GOTHIC containment response calculation methodology review
- Confirmatory analysis approach and results
- Resulting four limitations and conditions
- Conclusions

NRC Staff Review of the LTR

- The purpose of GEH LTR NEDC-33922P, Revision 2, is to obtain NRC staff approval of the BWRX-300 containment evaluation method (CEM) for peak containment pressure and temperature analysis

- The approved methodology will be used to design the BWRX-300 containment, and support a license application for a CP and OL under 10 CFR 50, or a DCA and COL under 10 CFR 52

- BWRX-300 LTR Acceptance Criteria
  - Accident pressure and temperature are less than design pressure and temperature with appropriate margin
  - Containment pressure is reduced to less than 50% of the peak accident pressure for the most limiting LOCA within 24 hours
  - Containment pressure responses after 24 hours for LOCAs that do not produce the peak accident pressure are maintained below 50% of the peak pressure for the most limiting LOCA
  - Containment atmosphere remains sufficiently mixed such that deflagration or detonation does not occur inside containment

BWRX-300 Containment Design Background

- BWRX-300 has a nitrogen-inerted, dry containment
- No suppression pool inside the containment
- RPV isolation valve closure limits M&E release in LBLOCA
- RPV remains unisolated for SBLOCA with continuous break flow
- Passive Containment Cooling System (PCCS)
  - Long-term containment SBLOCA pressure reduction/mitigation
  - Demonstration analyses with specific PCCS units described in the LTR
- Reactor cavity pool for containment heat removal
- Containment dome interfacing with the reactor cavity pool

BWRX-300 Containment Evaluation Method Demonstration Analyses

- Containment analysis method for BWRX-300 thermal-hydraulic performance is used to demonstrate that the containment design satisfies the acceptance criteria for:
  - Large-Break Loss-of-Coolant Accident (LBLOCA)
  - Small-Break Loss-of-Coolant Accident (SBLOCA)

- Analyzed containment DBAs include liquid and steam breaks

- Acceptance criteria were satisfied for the LTR demonstration cases

- Applicant used TRACG code to calculate the mass and energy release, and GOTHIC code to calculate the containment response

- NRC Staff used TRACE and MELCOR to develop models to perform confirmatory analyses

TRACG Code - Overview for BWRX-300

- Overview of TRACG code
  - ➢ Latest TRACG versions used in analysis, no significant changes since ESBWR
  - ➢ RPV model and internal components scaled from ESBWR
  - ➢ De-coupled method assumes containment remains at atmospheric pressure

- Past TRACG approval and relevance to BWRX-300
  - ➢ ESBWR qualification extended to BWRX-300, such that ESBWR PIRT and model biases applied for RPV and internals
  - ➢ BWR/2–6 methods evoked since some events result in core uncovery
  - ➢ IC's safety function changed and modeled in considerably more detail
  - ➢ Modeling deemed adequate for M&E release calculations (w/ L&Cs applied)

TRACG Code – Mass and Energy Release Calculation Methodology

- BWRX-300 unique design features in comparison with ESBWR
  - ➢ LBLOCA isolation (Previous Approved LTR)
  - ➢ No suppression pool
  - ➢ ICs are the primary decay heat removal path
- RPV isolation valves limits break flow and M&E release for large piping but small breaks are un-isolated and continue blowdown for 72 hours
- One ICS train inoperative (due to limiting single failure)
- Conservative inputs for initial power level, power history, scram time, choke flow model, atmospheric pressure break boundary condition and bounding operating conditions

TRACG Code – Mass and Energy Release Calculation Methodology

Significant Issues and Resolution

RAI – Radiolytic gas accumulation and removal in the ICs

L&C 1: total volumetric fraction of radiolytic gases in the IC lower drum limited to a sufficiently low level such that condensation heat transfer in the ICs is not adversely affected and the hydrogen deflagration margin is maintained

RAI – ICs return line steam trap

L&C 2: IC return line layout must include a loop seal, or water trap, that prevents reverse flow from RPV back into the IC return line

GOTHIC Code Overview for BWRX-300

- Overview of GOTHIC code
  - ➢ An established industry code widely used for containment response analysis
  - ➢ 10 CFR Part 50, Appendix B compliant code
  - ➢ Latest GOTHIC version 8.3 used in the BWRX-300 analysis

- Past GOTHIC approval and relevance to BWRX-300
  - ➢ GOTHIC previously approved for containment response analysis
  - ➢ BWRX-300 containment PIRT consistent with GOTHIC functionalities
  - ➢ BWRX-300 relevant GOTHIC benchmarking against CVTR test data reviewed
  - ➢ GOTHIC is qualified for the thermal stratification and 3D effects

BWRX-300 GOTHIC Containment Response Methodology

- Based on Reg Guide 1.203, "Transient and Accident Analysis Methods”
- Decoupled M&E release from the TRACG RPV model with no backpressure as a containment BC for the stand-alone GOTHIC containment model
- 4-component GOTHIC model
  - Containment (nodalized)
  - Dome (nodalized)
  - PCCS (nodalized)
  - Reactor Cavity Pool (lumped)
- Conservative Diffusion Layer Model (DLM) used for condensation
- Thermal stratification inside the containment

Staff Review of the BWRX-300 GOTHIC Containment Response Methodology

- Physical phenomena (GOTHIC PIRT)
- GOTHIC input model (Nominal inputs, assumptions, and correlations)
- Key modeling uncertainties and conservative biases -- Overall GOTHIC model conservatism
- Nodalization sensitivity studies for the containment and PCCS
- GOTHIC benchmarking of the test data
- BWRX-300 containment sensitivity analyses for large/small breaks
- PCCS capacity to mitigate the containment pressure in the long-term
- Containment mixing for combustible gases

Significant Containment-specific Issues & Resolutions

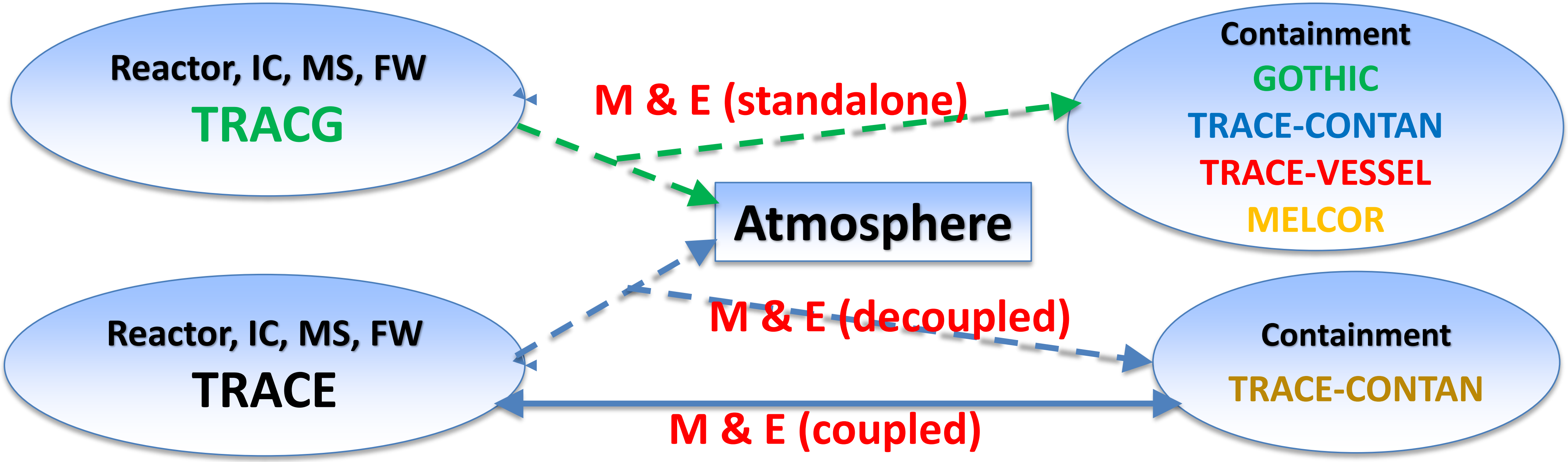
- Break location & and break flow orientation sensitivities
  - Limiting PCP LBLOCA location and orientation modified
  - A liquid, and not steam, SBLOCA is limiting

- Sensitivity to containment nodalization
  - Potential for reverse flow and non-condensable gas return to RPV
  - L&C #3 –No break flow reversal or reversal not safety significant

- Containment heat transfer modeling
  - Differences b/w confirmatory & GOTHIC Dome & PCCS heat transfers
  - Justification for the condensation/natural convection heat transfer correlations
  - An error identified & corrected in GOTHIC PCCS condensation modeling

- PCCS modeling and nodalization sensitivity study
  - Confirmatory sensitivity study performed
  - L&C #4 – Applicability to the final PCCS design for licensing basis

Confirmatory Analysis Approach and Results



- The proposed methodology using TRACG/GOTHIC codes is conservative
- Containment response is sensitive to nodalization, break location/orientation
- The accumulation of radiolytic gases during LOCA is possible (L&C#1)
- The ICs return line water trap is needed (L&C#2)
- Flow reversal from containment to RPV is possible (L&C#3) with insufficient PCCS heat removal capacity (L&C#4)

RPV-specific Limitations and Conditions

- L&C #1

  The use of this CEM is limited to a BWRX-300 design that limits the total volumetric fraction of radiolytic gases in the IC lower drum to a sufficiently low level throughout a 72-hour period following the event such that condensation heat transfer in the ICs is not adversely affected and the hydrogen deflagration margin is maintained.

- L&C #2

  The use of this CEM is limited to a BWRX-300 design that a proper isolation condenser return line layout is chosen, such as a loop seal or a water trap, to prevent reverse flow from RPV into the IC return line throughout a 72-hour period following the event or where an applicant or licensee referencing this report demonstrates that the TRACG code is capable of conservatively modeling the overall ICs heat removal capacity when reverse flow occurs in the IC discharge lines.

Containment-specific Limitations and Conditions

- L&C #3.

  The use of this CEM is limited to a BWRX-300 design in which the PCCS is sized sufficiently large such that a reverse flow from containment back to RPV does not occur during the first 72-hours into the event. The applicant or licensee referencing this report needs to demonstrate that no reverse flow could occur, or any reverse flow that occurs under the most bounding flow reversal conditions resulting in the degradation of IC heat transfer is not safety-significant with respect to the acceptance criteria for the BWRX-300 CEM.

- L&C #4.

  The use of this CEM was demonstrated for a BWRX-300 design with the PCCS described in this LTR. For any alternate PCCS design configuration and placement, the applicability of this method and the PCCS modeling approach must be reviewed and found to be acceptable by the NRC for BWRX-300 licensing-basis analyses.

Conclusions

- The proposed BWRX-300 analytical approach and TRACG/GOTHIC modeling described in the LTR for M&E release and containment response are acceptable, with the appropriate conservative biases and modeling inputs to address the model uncertainties.

- With the four NRC L&Cs specified in the staff SER Section 7.0, the CEM presented in GEH LTR NEDC-33922P, Revision 2, is acceptable for BWRX 300 peak containment pressure and temperature analysis of the containment DBAs.

- The NRC staff will evaluate the regulatory compliance of the final BWRX-300 containment design using the CEM during the future licensing activities, in accordance with 10 CFR Part 50 or 10 CFR Part 52, as applicable.