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

NEDC-33922P, Revision 2

NRC Staff Presentation-Open Session

BWRX-300 Small Modular Reactor
ACRS Subcommittee Meeting

March 18, 2021

GEH BWRX-300 Pre-Application Status

- September 26, 2019 – BWRX-300 Pre-Application Kick of Meeting
- 3 LTRs have been approved

  Reactivity Control LTR (NEDC-33912P) (04/01/21)
  Reactor Pressure Vessel Isolation and Overpressure Protection LTR (NEDC-33910P) (08/16/21)
  Containment Performance LTR (NEDC-33911P) (01/07/22)

- 2 LTRs currently under review

  Containment Evaluation Method LTR (NEDC-33922P) (AFSE 2/18/22)
  Advanced Civil Construction and Design Approach LTR (NEDC-33914P) (AFSE 2/18/22)

- 3 LTRs expected in 2022

  Safety Strategy (NEDC-33934P) 2Q22
  Severe Accident Management and Source Term Methodology (NEDC-33913P) 3Q22
  Instrumentation and Controls Architecture (NEDC-33925P) 3Q22

NRC Staff Review Team

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Presentation Outline

- Overview of BWRX-300 Containment Evaluation Method (CEM) LTR NEDC-33922P, Revision 2
- BWRX-300 containment design background
- Regulatory requirements & BWRX-300 acceptance criteria for containment response
- BWRX-300 containment evaluation method demonstration analyses
- TRACG mass and energy release calculation methodology review
- GOTHIC containment response calculation methodology review
- 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 peak pressure and temperature analysis methodology.

- The NRC regulations and acceptance criteria dealing with the BWRX-300 containment thermal hydraulics performance are referenced in GEH LTR NEDC-33911P, BWRX-300 Containment Performance.

- 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 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 break flow
- Passive Containment Cooling System (PCCS)
  - ➢ Long-term containment SBLOCA pressure mitigation
  - ➢ Demo with specific LTR described units
- Reactor cavity pool for containment heat removal
- Containment dome interfacing with the reactor cavity pool

Regulatory Requirements & BWRX-300 Acceptance Criteria for Containment Response

- Key Regulatory Requirements
  - Short term peak containment pressure/temperature
  - Long term pressure/temperature
- 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 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 DBEs include liquid and steam breaks

- TRACG code is to calculate the mass and energy release and GOTHIC code to calculate the containment response

- Acceptance criteria were satisfied for the LTR demonstration cases

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 uncover
  - 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 in the 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 and species stratification and 3D effects

GOTHIC Code - Containment Response Calculation 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
- Benchmark predictions of test data
- BWRX-300 containment response analyses for large/small breaks
- PCCS capacity to mitigate the containment pressure in the long-term.
- Containment mixing for combustible gases
- Staff confirmatory analyses

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 for SBLOCA and non-condensable gas return to RPV
  - L&C #3 – No break flow reversal
- Containment heat transfer modeling
  - Identification of the PCCS condensation modeling error.
- PCCS modeling and nodalization sensitivity study
  - L&C #4 – Applicability to the final PCCS design for licensing basis

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 prevents 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 Limitations and Conditions specified in the staff SER Section 7.0, the NRC staff concludes that the evaluation methodology presented in GEH LTR NEDC-33922P, Revision 2, is acceptable for BWRX 300 containment peak containment pressure and temperature analysis of the containment design basis accidents.

- 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.