AURORA-B Pre-Submittal Meeting

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Presentation Outline

- Introduction to AURORA-B and the planned submittal
- Summary of the evaluation model development
- Description of the assessment base and selected results
- Presentation of selected demonstration analysis results
- Submittal schedule and requested review scope

Introduction to AURORA-B

Introduction to AURORA-B

- The AURORA-B evaluation model (EM) consists of a best-estimate multi-physics code system for simulating the coupled fuel, neutronic, and thermal hydraulic BWR system response
  - RODEX4 best estimate fuel performance predictions
  - MB2-K 3D kinetics based on MICROBURN-B2
  - S-RELAP5 modern two-fluid T/H system code
- S-RELAP5 is the host code in which relevant kernels of RODEX4 and MB2-K have been incorporated

Introduction to AURORA-B

- **The AURORA-B EM is structured as a comprehensive tool for BWR analysis**
  - **The present submittal qualifies the EM for analyzing "core wide" transients and accidents based on a deterministic application methodology**
  - **The present submittal does not address**
    - Loss of coolant accidents
    - Late stages of the anticipated transients without scram (after initiation of Boron injection)
    - Instability events
    - BWR control rod drop & control rod withdraw error
  - **Future submittals are planned to expand the EM qualification to other applications, including statistical analysis of limiting anticipated operational occurrences**

Introduction to AURORA-B

EM Development Summary

EM Development Summary

- Principles of Regulatory Guide 1.203 were used to drive the development process
  - The LTR outline follows the evaluation model development and assessment process (EMDAP) steps
  - Phenomena identification and ranking is performed
- AURORA-B builds upon the same S-RELAP5 code as used in PWR Realistic LBLOCA, but with some improvements in physical models
  - limited reliance on prior S-RELAP5 LTRs within the AURORA-B LTR and supporting documentation but reference to the general S-RELAP5 code qualification and extensive source code reviews supporting earlier LTRs is made

EM Development Summary

More on these documents later in the presentation

EM Development Summary

- S-RELAP5 physical models have been improved
  - Interfacial drag for rod bundles and large volumes
  - Reynolds dependent form losses for spacer grids
  - Single and two phase friction models consistent with MICROBURN-B2 for the fuel
- S-RELAP5 component models have been added or improved
  - Jet-pump model
  - Mechanistic separator model
  - Critical power correlations, AURORA-B is used to predict the transient MCPR response

Assessment of these models is summarized later in the presentation

EM Development Summary

Contents of the LTR and Supporting Documentation

LTR and Supporting Documentation

- **The LTR demonstrates the qualification and capabilities of the evaluation model for the target plant and event applications**
  - **The LTR outline follows the evaluation model development and assessment process (EMDAP) steps**
    - Key information and important aspects are addressed within the LTR (e.g. summary of the PIRT)
    - Reference to supporting documents is made for background information (e.g. detailed sequence of events, detailed PIRT development, etc.)
    - Reference is made to the MICROBURN-B2, and RODEX4 LTRs, their theoretical manuals, and their qualifications.
- **The LTR describes the "application methodology" within which the EM will be used describes how initial conditions and plant parameters are addressed in analyses**

LTR and Supporting Documentation

LTR and Supporting Documentation

LTR and Supporting Documentation

Assessment Base and Presentation of Selected Results

Assessment Base

- **A database has been constructed to assess all the improved physical models and new/revised component models**
  - **Includes updated results from prior S-RELAP5 verification & validation efforts that are applicable**
  - **Expanded to include more rod bundle void fraction assessments and ATRIUM-10 void tests**
  - **Void assessments for large diameter geometries**
    2.9 inch, 18 inch, and 36 inch round pipes at high pressure
  - **Pressure drop assessments for 7x7 through 10x10 fuel**
  - **Assesses the jet-pump model versus reduced scale and full scale jet-pump test results**
  - **Assesses the mechanistic separator model versus full scale two- and three-stage steam separator test results carry under, carry over, and pressure drop**

Assessment Base

- Transient critical power tests were performed to support CPR correlations
  - Demonstrates the S-RELAP5 ability to predict time of boiling transition
  - Selected tests are used to demonstrate conservative prediction of transient cladding temperature after boiling transition occurs
- Full Integral Simulation Test (FIST) 4PTT1 simulation to assess the integral system response to a simulated turbine trip
  - Peach Bottom TT3 simulation with an electrically heated bundle
  - Comparisons to transient flow response, void response to transient pressurization, etc.

Assessment Base

- MB2-K Numerical benchmarks include three different problems TWIGL 2D, LMW PWR, and LRA numerical benchmarks
- Assessments of the EM compared to Peach Bottom Turbine Trip 1, 2, & 3 tests are provided
  - Baseline results show overall capability of the EM to predict a relevant plant transient
  - Sensitivity studies demonstrate the overall EM behavior, the impact of model uncertainties, etc.

Selected Assessment Results
Peach Bottom

- Peach Bottom Unit 2 is GE BWR/4 licensed at 3293 MW at time of tests
  - 764 fuel assemblies
  - 185 control rods
  - 211 2-stage separators
  - 20 jet pumps, 10 per recirculation loop
  - 2 feedwater loops
  - 4 steam lines ≈470 ft long
- Peach Bottom TT2 has become the reference BWR transient since it's inclusion in an International Standard Problem
  - AURORA-B analysis is independent of the ISP e.g. the AREVA CASMO4/MICROBURN-B2 process was used for cross section generation
  - Selected results for TT2 are provided on the following pages to demonstrate the AURORA-B capability, followed by TT3 and TT1 results

Selected Assessment Results
Peach Bottom – Test Description

- Three tests (TT1, TT2, and TT3) performed in late 1970s at 47, 62 and 69% of rated power, respectively
  - TSVs close in ≈0.1 s, causing sudden pressure increase at the valve
  - Pressure increase felt in steam dome about 0.24 s later, and in upper and lower plenums about 0.30 s later
  - Geometric flow path to upper plenum is short, but through two-phase region
  - Geometric flow path to lower plenum is long, but through single-phase region
  - Result: lower plenum feels the disturbance more severely than the upper plenum
  - Core ΔP increases → core flow increases → void collapse → power excursion
  - Power increases to APRM setpoint → scram (standard TTNB scrams on TSV motion)
  - Power turn-around due to scram

Turbine Trip 2 Results

Turbine Trip 2 Results

Turbine Trip 2 Results

Turbine Trip 3 Results

Turbine Trip 1 Results

Presentation of Selected Demonstration Analysis Results

Demonstration Analyses

- Demonstration analyses for three plants are included
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- Baseline analyses for typically limiting scenarios are shown in the LTR
  - Turbine trip or load reject without bypass operation
  - Feedwater controller failure – maximum demand
  - MSIV closure with scram on valve motion disabled – typical limiting "ASME over pressure" event
  - MSIV closure no scram – typical limiting "ATWS over pressure" event
  - Baseline analyses are used as the reference point for sensitivity studies

Demonstration Analysis Results

- Sensitivity analyses are provided in the LTR to demonstrate the impact of phenomena and model parameters
  - Sensitivity studies for several plants/events shown the sensitivity behavior may change depending on the scenario
- Combined, the baseline analyses and sensitivities;
  - Exercise and demonstrate code model capabilities
  - Confirm control system model behaviors
  - Confirm trip system model functionality
  - Confirm steam line valve model behaviors
- Selected results for the BWR/4 are shown on the following slides for a 100% EPU power and 100% flow statepoint

Generator Load Rejection W/O Bypass (LRNB)

- **Objective:**
  - **Determine core wide response and hot channel MCPR**
  - **Actions:**
    - GLR Event is initiated by TCV Fast Closure
    - Scram on TCV Fast Closure
    - RPT on TCV Fast Closure
    - Turbine bypass operation is disabled
    - Safety/Relief Valves open in Safety Mode on Pressure

LRNB Results

LRNB Results

Feedwater Controller Failure (FWCF)

Objective:

- **Determine core wide response and hot channel MCPR**
- **Actions:**
  - FWCF To Maximum Demand Initiates Event
  - Feedwater Pump Trip on High Water Level
  - Turbine Stop Valve Closure on High Water Level
  - Reactor Scram on TSV Closure
  - RPT on TSV Closure
  - Turbine Bypass Valve Fast Open on TSV Closure
  - Safety/Relief Valves open in Safety Mode on Pressure

FWCF Results

FWCF Results

MSIV Closure With Flux Scram (MSIVF)

Objective:

- **Determine Peak Vessel Pressure After Steam Line Valve Closure (ASME Overpressure Analysis)**
- **Actions:**
  - MSIV Closure Initiates Event
  - Reactor Scram on High Flux
  - RPT on High Dome Pressure
  - Safety/Relief Valves open in Safety Mode

MSIVF Results

MSIVF Results

MSIV Closure Without Scram (ATWSP)

Objective:

- ◇ **Determine Peak Vessel Pressure After Steam Line Valve Closure**
- ◇ **Actions:**
  - MSIV Closure Initiates Event
  - RPT on High Dome Pressure
  - Safety/Relief Valves open in Relief Mode

ATWSP Results

ATWSP Results

Submittal Schedule and Requested Review Scope

Schedule and Review Scope

Schedule and Review Scope