Outline

- Qualification program for safety and licensing codes for current CANDU reactors
  - Description of Canadian industry initiative to formally qualify codes
  - Overview of qualification process
    - Renewal of design basis
    - Computer code validation
- Validation underway for ACR
Background

- Computer codes are important tools for design support and safety analysis of CANDU reactors
- Codes were verified and validated against experiment as they were developed and used, but the methods were not formal
- Since 1995, the Canadian industry has carried out a formal program for qualifying design and analysis software
  - Quantify biases and uncertainties
  - Consistent with modern quality standards, CSA-N286.7-99
Uncertainty Assessment Process

Accident Scenario

Safety Analysis Methods

Validation Process

Code Uncertainty

Representation Uncertainty

Combine Uncertainties

Plant Uncertainty

Final Uncertainty in Safety Margin
Qualification

- A qualified computer program is one that is:
  - Properly specified: documented requirements, accuracy targets and quality attributes
  - Shown to meet all requirements (verification)
  - Demonstrated to meet intended application (validation)
  - Is under configuration management and version control
Industry Standard Toolset (IST)

- Formal qualification of safety and licensing codes was recognized as requiring significant investment, and resulting in redundancies and inconsistencies if undertaken separately

- Canadian utilities and AECL worked together to qualify a standard set of computer programs (IST)
  - Consolidated on single versions of computer programs (with the exception of thermalhydraulics)
  - Agreed to common processes to meet CSA-N286.7-99
  - Shared effort on code development, qualification and support
Qualification Process

- Renewal of design basis: demonstration that “legacy” safety analysis codes comply with software quality assurance (SQA) standards
- Validation: quantification of the range of applicability, and associated accuracy of computer codes
New Code Development

- Development of new codes would follow a process of:
  - Setting requirements (problem definition and requirements specification)
  - Establishing the design: theoretical and conceptual model development (theory manual)
  - Implementing the design: coding (programmers manual)
  - Verification applied at completion of each stage

- A Users Manual provides appropriate instruction on code usage

- The computer program is put under version control and configuration management (AECL Procedure 00-552.1)
Design Basis Renewal

- Review legacy computer programs for compliance with process for new code development
- Ensure appropriate documentation is in place:
- Verify:
  - Theory is appropriate for intended application
  - Coding has correctly captured theory
- Ensure program is under version control and configuration management
- Address any remaining gaps
Validation Process

- Common approach to validation was developed by Canadian industry, based on use of validation matrices
- Recognizes need to address Code Scaling, Applicability and Uncertainty, consistent with CSAU
1. Technical Basis Document
   - Review of accident sequences and identification of key phenomena during each phase of an accident

2. Validation Matrix
   - Relate basic phenomena to data sets
   - generic (code independent)

3. Validation Plan
   - To demonstrate that the code version accurately represents the governing phenomena for each phase of the accident scenarios selected

4. Validation Exercises
   - Compare model predictions to selected data sets (uncertainty)

5. Validation Manual
   - Summarize code accuracy, sensitivities and uncertainties for selected application
For a given accident category, the TBD identifies:

- The key safety concerns
- The expected phenomena governing the behavior that evolves with time during identifiable phases of an accident

The TBD establishes a relationship between technical disciplines, the safety concerns associated with a phase of an accident, the governing physical phenomena, and the relevant validation matrices.

Example:
- Early in a LOCA, “Break discharge characteristics and critical flow” is a primary phenomenon
- During ECC injection, “Quench/rewet characteristics” becomes a primary phenomenon
Validation Matrices

- Identify and describe phenomena relevant to a discipline
- Rank the phenomena according to their importance in accident phases (consistent with PIRT)
- Identify data sets and cross-reference to phenomena
  - Separate effects experiments, integral and/or scaled experiments, analytical solutions, inter-code comparisons
  - Includes CANDU-specific and otherwise
Safety Analysis Disciplines

- Reactor Physics: WIMS-AECL, RFSP and DRAGON
- Thermalhydraulics: CATHENA and NUCIRC
- Moderator system behavior: MODTURC_CLAS
- Fuel behavior: ELESTRES and ELOCA
- Fission Product behavior: SOURCE, SOPHAEROS, SMART and ADDAM
- Containment behavior: GOTHIC
- Severe accident phenomenology: MAAP4-CANDU
## Thermalhydraulic Phenomena

<table>
<thead>
<tr>
<th>ID Number</th>
<th>PHENOMENA</th>
</tr>
</thead>
<tbody>
<tr>
<td>TH1</td>
<td>Break Discharge Characteristics and Critical Flow</td>
</tr>
<tr>
<td>TH2</td>
<td>Coolant Voiding</td>
</tr>
<tr>
<td>TH3</td>
<td>Phase Separation</td>
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<tr>
<td>TH4</td>
<td>Level Swell and Void Hold-up</td>
</tr>
<tr>
<td>TH5</td>
<td>HT Pump Characteristics (Single &amp; 2-Phase)</td>
</tr>
<tr>
<td>TH6</td>
<td>Thermal Conduction</td>
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<tr>
<td>TH7</td>
<td>Convective Heat Transfer</td>
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<tr>
<td>TH8</td>
<td>Nucleate Boiling</td>
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<tr>
<td>TH9</td>
<td>CHF &amp; Post Dryout Heat Transfer</td>
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<tr>
<td>TH10</td>
<td>Condensation Heat Transfer</td>
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<tr>
<td>TH11</td>
<td>Radiative Heat Transfer</td>
</tr>
<tr>
<td>TH12</td>
<td>Quench/rewet Characteristics</td>
</tr>
<tr>
<td>TH13</td>
<td>Zirc/water Thermal-Chemical Reaction</td>
</tr>
<tr>
<td>TH14</td>
<td>Reflux Condensation</td>
</tr>
<tr>
<td>TH15</td>
<td>Counter Current Flow</td>
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<tr>
<td>TH16</td>
<td>Flow Oscillations</td>
</tr>
<tr>
<td>TH17</td>
<td>Density Driven Flows: Natural Circulation</td>
</tr>
<tr>
<td>TH18</td>
<td>Fuel Channel Deformation</td>
</tr>
<tr>
<td>TH19</td>
<td>Waterhammer</td>
</tr>
<tr>
<td>TH20</td>
<td>Waterhammer: Steam Condensation Induced</td>
</tr>
<tr>
<td>TH21</td>
<td>Noncondensable Gas Effect</td>
</tr>
</tbody>
</table>
# Ranking of Phenomena: Large LOCA in current CANDU

## Time Period (seconds)
- **0 - 5**: Reactor Trip
- **5 - 30**: Early Blowdown Cooling
- **30 - 200**: Late Blowdown Cooling/ECIS Injection
- **> 200**: Refill

## Phenomena

<table>
<thead>
<tr>
<th>Phenomena</th>
<th>Primary</th>
<th>Early Blowdown Cooling</th>
<th>Late Blowdown Cooling/ECIS Injection</th>
<th>Refill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coolant Voiding</td>
<td>Convective Heat Transfer</td>
<td>Convective Heat Transfer</td>
<td>Phase Separation</td>
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<td>Fuel Channel Deformation</td>
<td>Quench Rewet Characteristics</td>
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<td>Zirc/Water Thermal Chemical Reaction</td>
<td>Radiative Heat Transfer</td>
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<td></td>
<td>Thermal Conduction</td>
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<tr>
<td>Secondary</td>
<td>CHF &amp; Post Dryout Heat Transfer</td>
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<td>Phase Separation</td>
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<td></td>
<td></td>
<td></td>
<td>Waterhammer steam</td>
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</tbody>
</table>
## Test Data for Thermalhydraulic Phenomena

<table>
<thead>
<tr>
<th></th>
<th>TH2 Coolant Voiding</th>
<th>TH6 Thermal Conduction</th>
<th>TH16 Flow Oscillations</th>
</tr>
</thead>
<tbody>
<tr>
<td>SE1: Edwards Pipe Blowdown</td>
<td>⬤</td>
<td></td>
<td></td>
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<tr>
<td>SE5: Marviken Bottom Blowdown</td>
<td>0</td>
<td></td>
<td></td>
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<tr>
<td>SE13: PT/CT contact heat transfer tests</td>
<td></td>
<td>⬤</td>
<td></td>
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<tr>
<td>CO1: End Fitting Characterization Tests</td>
<td>0</td>
<td>⬤</td>
<td></td>
</tr>
<tr>
<td>INT5: RD-12 Natural Circulation Tests</td>
<td></td>
<td></td>
<td>⬤</td>
</tr>
<tr>
<td>INT14: Station Transients</td>
<td></td>
<td></td>
<td>⬤</td>
</tr>
<tr>
<td>NUM6: Radial Conduction Test</td>
<td></td>
<td></td>
<td>⬤</td>
</tr>
</tbody>
</table>

- Suitable for direct validation
- o Suitable for indirect validation
Validation Plan and Exercises

Validation Plan:

- Based on appropriate validation matrix, specifies datasets to be used in validation exercises
  - excludes datasets used for model development
- Consideration given to scaling and feedback effects
- Specifies key parameters, and accuracy requirements

Validation Exercises:

- Comparison of code predictions to datasets
- Establishes biases and uncertainties in key parameters over desired ranges of application
Validation Manual

- Summary of results of validation exercises
- Description of range of applicability
Code Qualification Status

- Codes have been qualified for use in safety analysis for current CANDU reactors – a few codes are still in process
- Qualification status will be extended to cover ACR conditions
  - Examples provided on the next slides
RD-14M Experiments for ACR

• RD-14M has been reconfigured for ACR conditions

• Tests are underway to provide validation data for the system thermalhydraulics code CATHENA
MTF Experiments for ACR

- The Moderator Test Facility will be reconfigured for ACR geometry (1/3 scale)
- Tests will be performed to validate the moderator thermalhydraulics code, MODTURC_CLAS
Conclusion

• A formal process has been established for qualifying safety and licensing codes for CANDU reactors

• Codes have been qualified for use with current reactors – remaining gaps to be addressed over next couple of years

• An initial assessment by AECL has identified necessary extensions for ACR

• Work is underway to generate the necessary data, and complete code qualification