Qualification Process for Safety Analysis Computer Codes

by Andrew White, Director, Reactor Safety

Presented to US Nuclear Regulatory Commission
Office of Nuclear Reactor Regulation
September 26, 2002

AECL
TECHNOLOGIES INC.

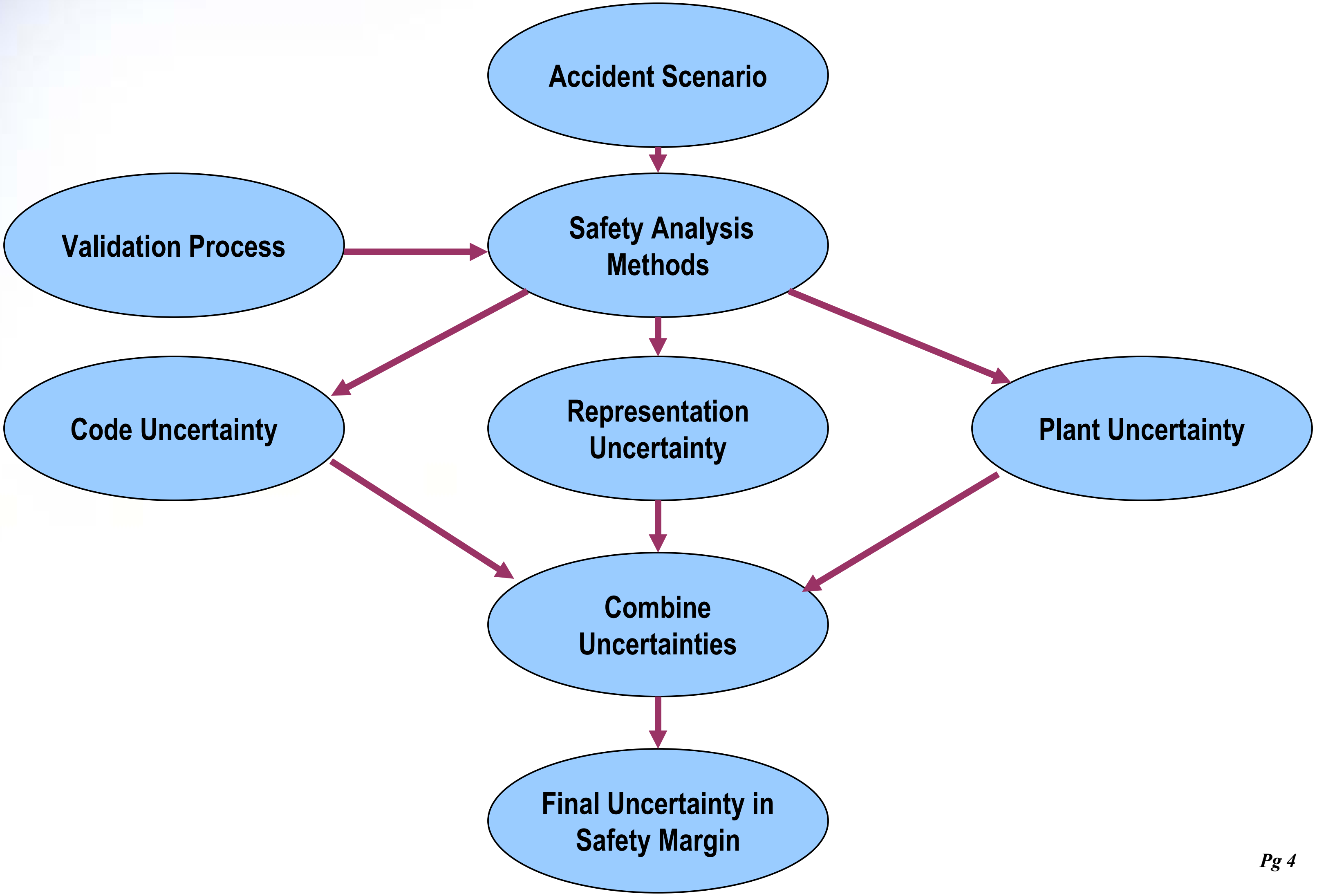
Outline

- 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



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

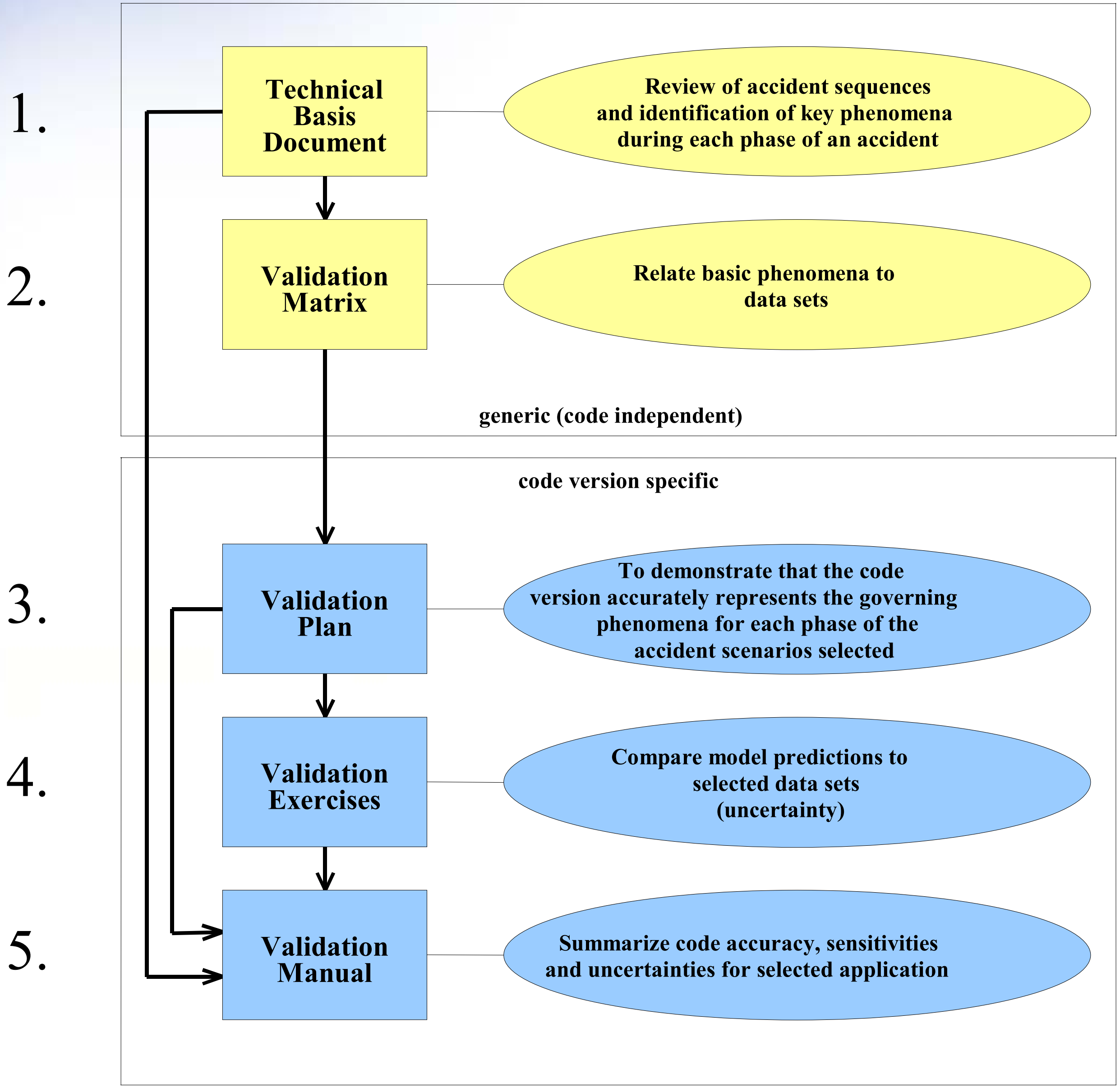
- Development of new codes would follow a process of:
  - Setting requirements (problem definition and requirements specification)
  - Establishing the design: theoretical and conceptual model development (theory manual)
  - Implementing the design: coding (programmers manual)
  - Verification applied 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:
  - Theory Manual, Programmers Manual, Users Manual
- 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)
code version specific
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

Technical Basis Document (TBD)

- 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

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

Ranking of Phenomena: Large LOCA in current CANDU

Phase	Reactor Trip	Early Blowdown Cooling	Late Blowdown Cooling/ECIS Injection	Refill
Time Period (seconds)	0 - 5	5 - 30	30 - 200	> 200
Phenomena				
Primary	Break Discharge Characteristics and Critical Flow	Break Discharge Characteristics and Critical Flow	Break Discharge Characteristics and Critical Flow	Counter-current Flow
	Coolant Voiding	Convective Heat Transfer	Convective Heat Transfer	Phase Separation
	Fuel String Mechanical-Hydraulic Interaction	HT Pump Characteristics (Single & 2-phase)	Condensation Heat Transfer	Thermal Conduction
		Fuel Channel Deformation	Quench Rewet Characteristics	Quench Rewet Characteristics
		Zirc/Water Thermal Chemical Reaction		
		Radiative Heat Transfer		
		Thermal Conduction		
Secondary	CHF & Post Dryout Heat Transfer	CHF & Post Dryout Heat transfer	Phase Separation	Waterhammer steam

Test Data for Thermalhydraulic Phenomena

	TH2 Coolant Voiding	TH6 Thermal Conduction	TH16 Flow Oscillations
SE1: Edwards Pipe Blowdown	•		
SE5: Marviken Bottom Blowdown	o		
SE13: PT/CT contact heat transfer tests		•	
CO1: End Fitting Characterization Tests	o	•	
INT5: RD-12 Natural Circulation Tests			•
INT14: Station Transients			•
NUM6: Radial Conduction Test		•	

• 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

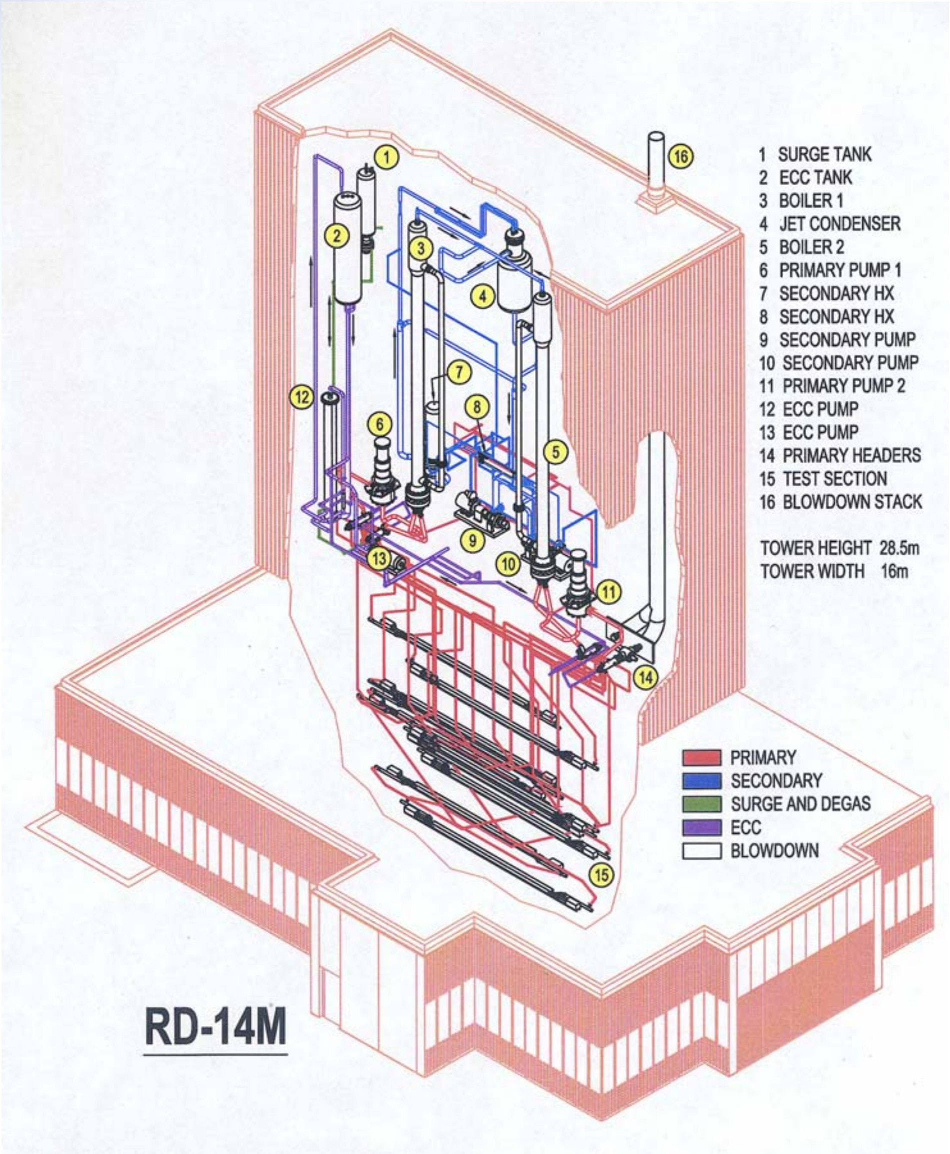
- Summary of results of validation exercises
- Description of range of applicability

A few of the hundreds of reports that have been generated in support of computer code qualification

Code Qualification Status

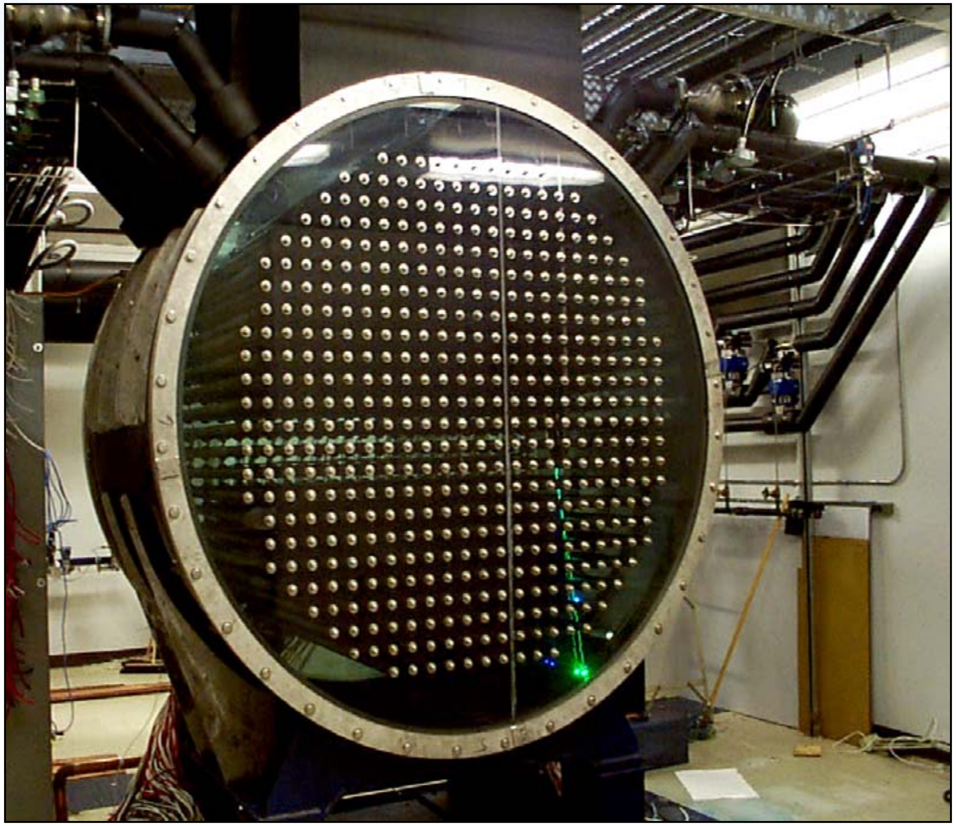
- Codes have been qualified for use in safety analysis for current CANDU reactors – a few codes are still in process
- Qualification status will be extended to cover ACR conditions
  - Examples provided on the next slides

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

AECL

TECHNOLOGIES INC.