



Qualification Process for Safety Analysis Computer Codes

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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**

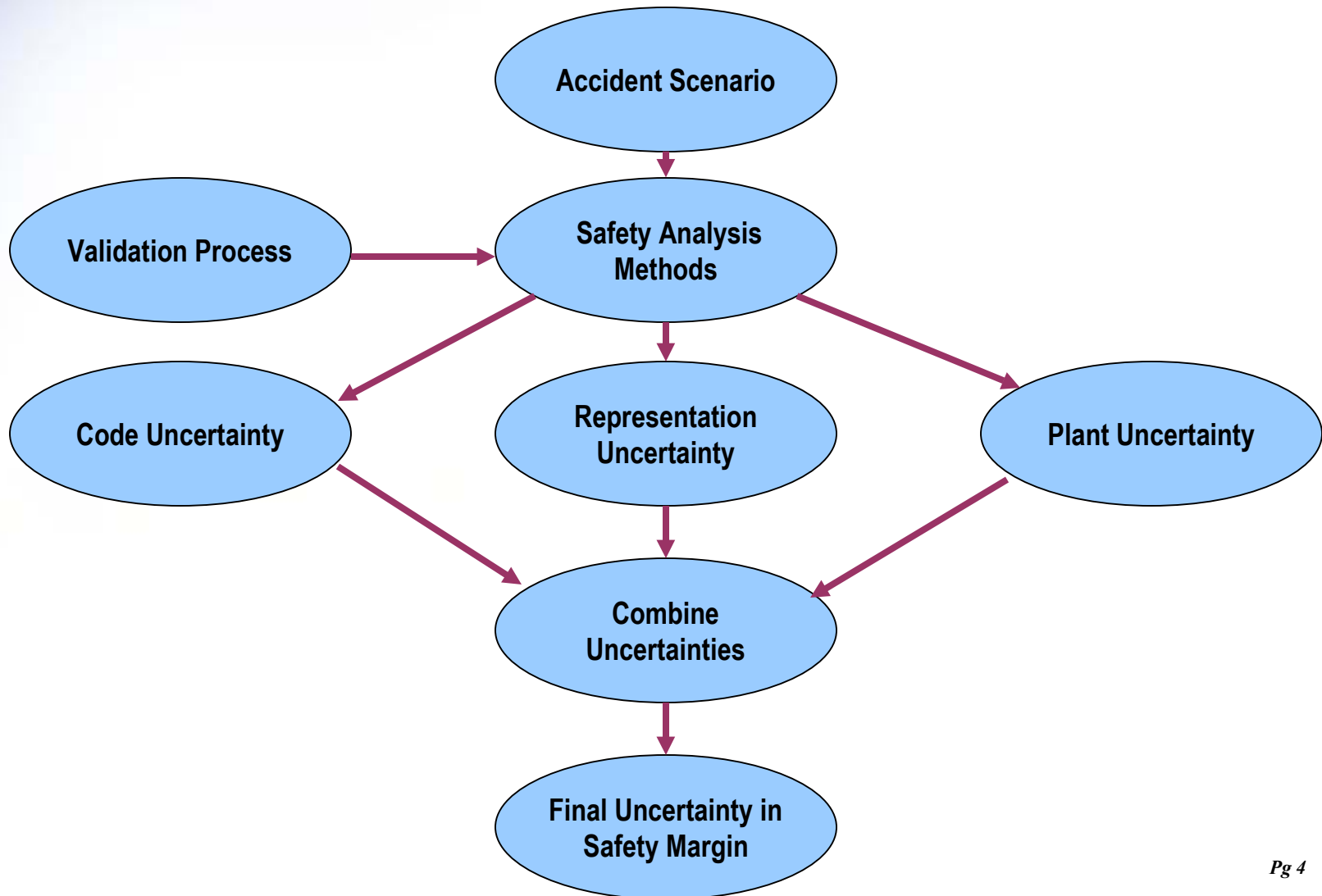


Background

- **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)**



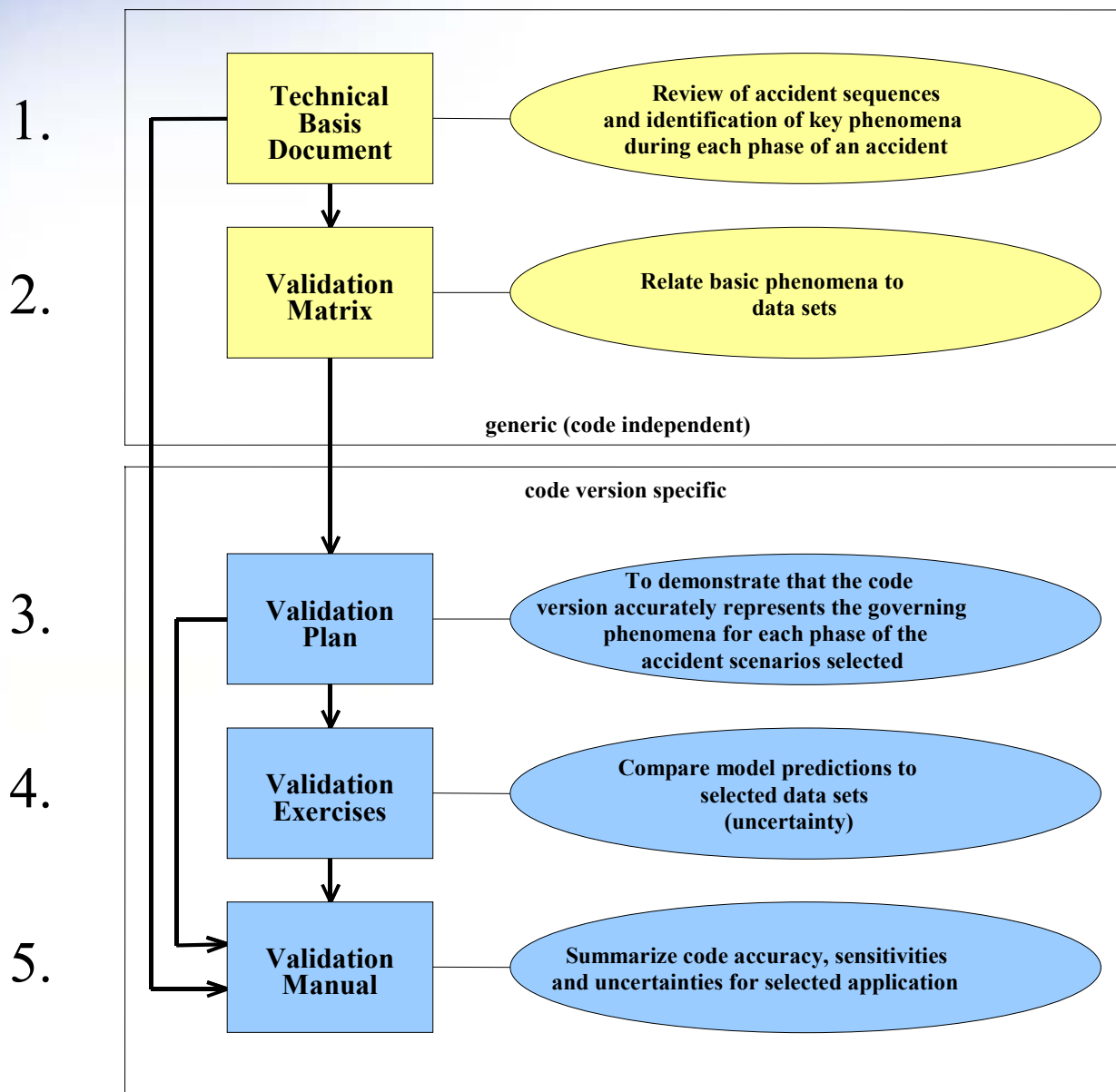
Design Basis Renewal

- **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**





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

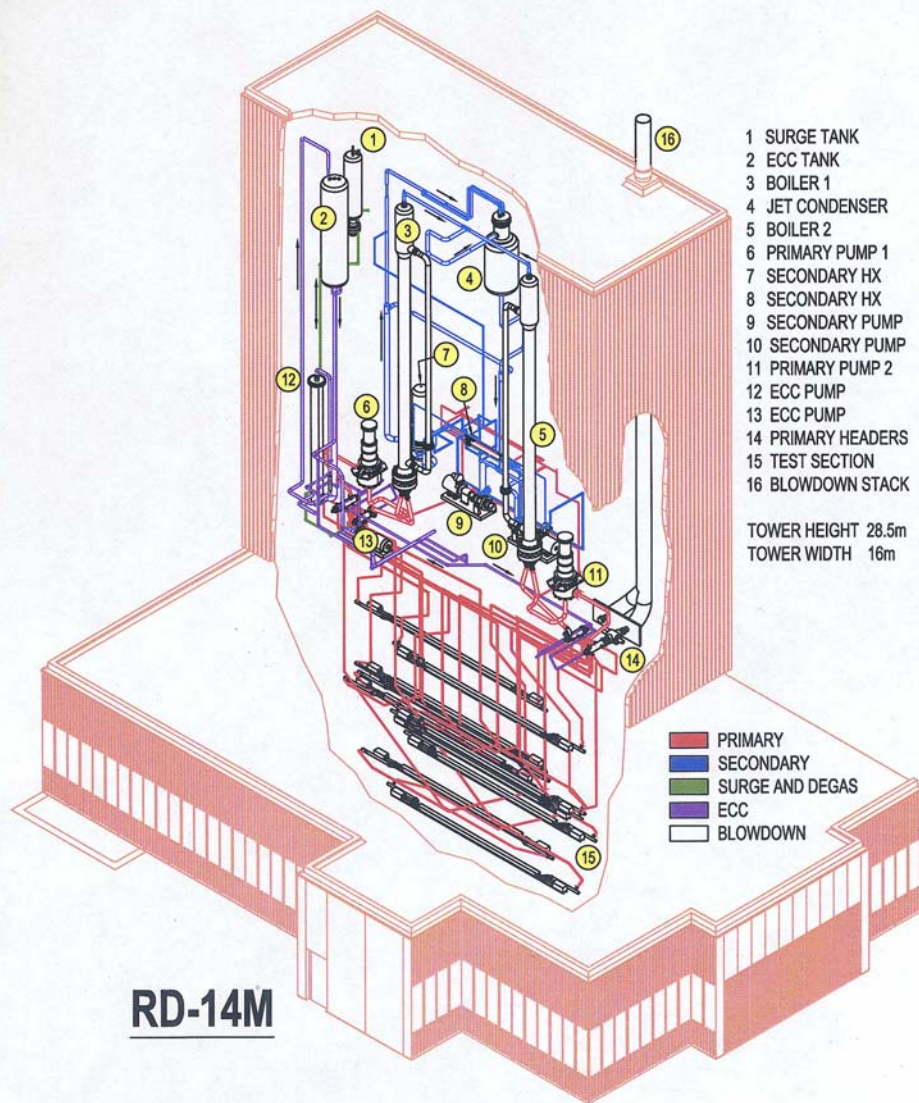


Code Qualification Status

- **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

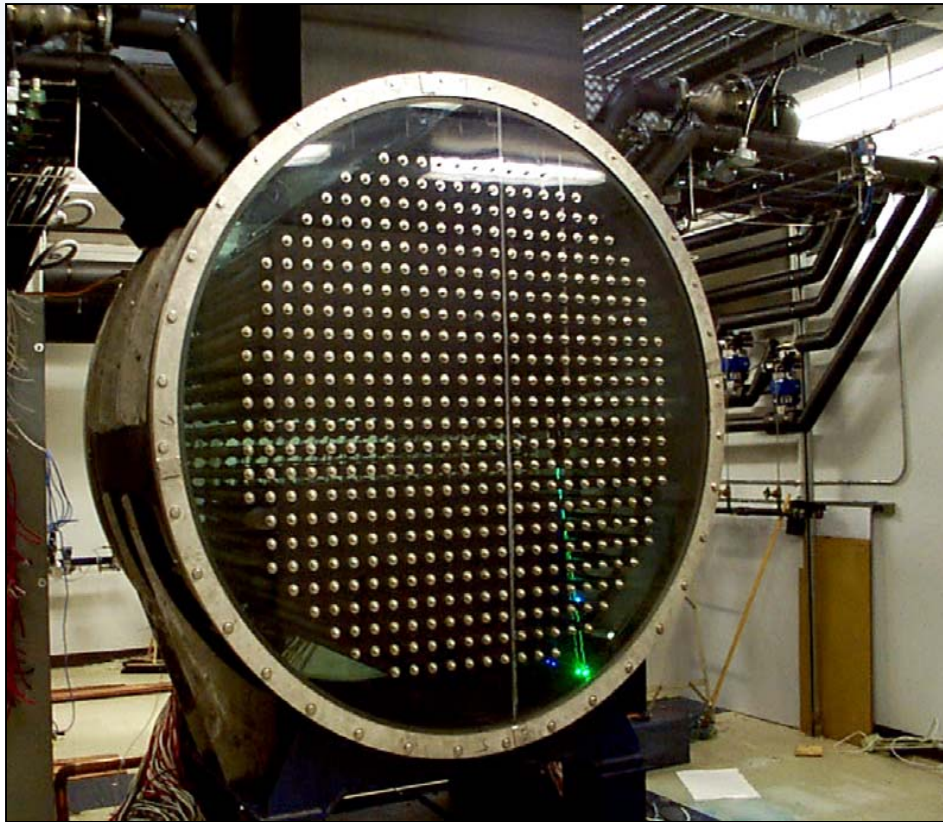


RD-14M

- 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.