Computer Codes and Validation Adequacy

David Richards
Manager, AECL Code Centre and Software Performance

ACRS Subcommittee on Future Plant Designs

Washington D.C.

January 13, 2004

AECL
TECHNOLOGIES INC.

Outline

- AECL Computer Code Software Quality Assurance (SQA) Program
- Validation Methodology
- Industry Standard Toolset and Key ACR Computer Codes
- Experimental Data for Thermal Hydraulics Validation
- Examples of CATHENA Validation

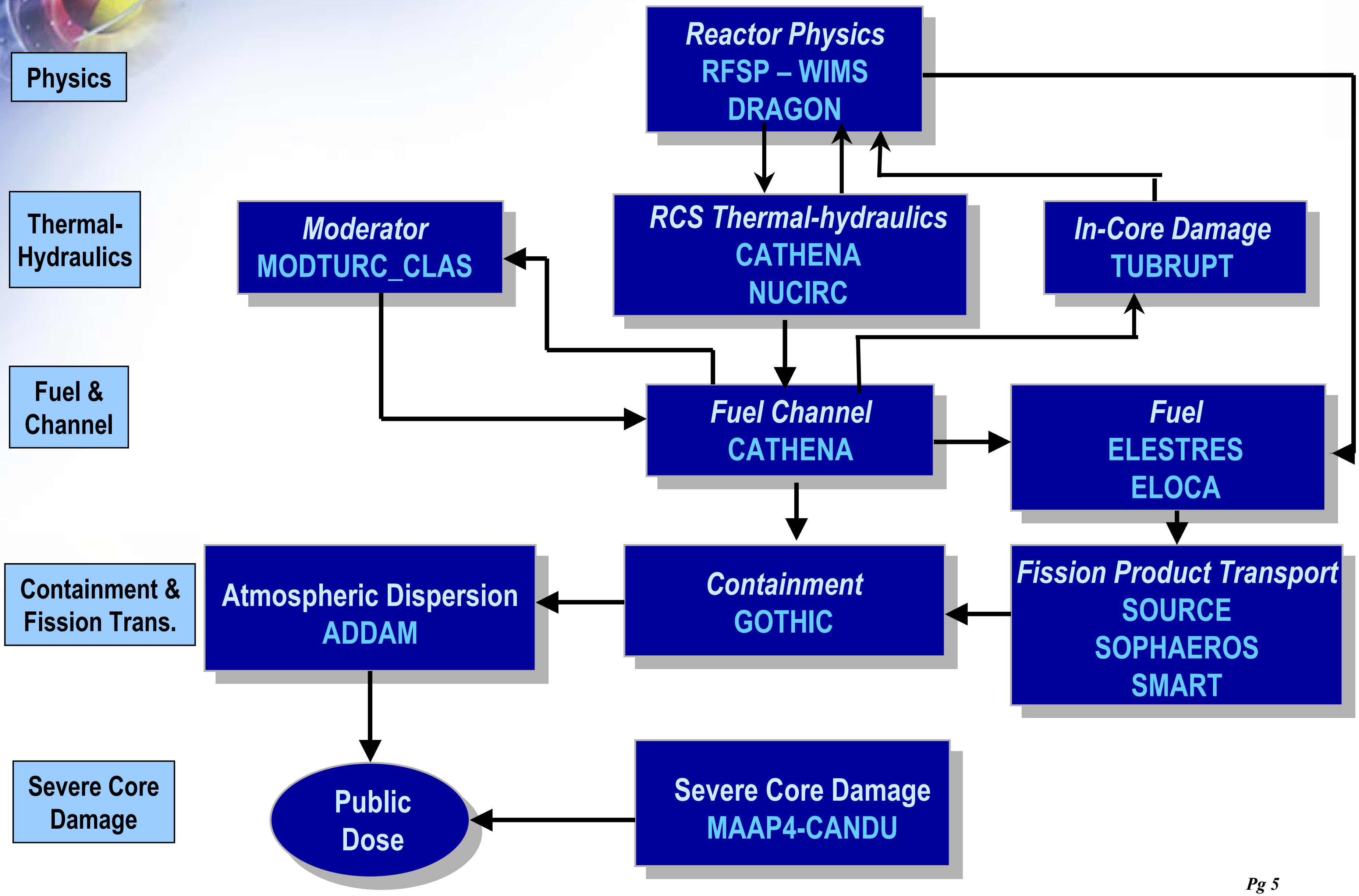
Computer Program
Software Quality Assurance (SQA)

- Code Development and Qualification are conducted according to pre-defined QA procedures:
  - The Canadian Standards Association (CSA) published “Quality Assurance of Analytical, Scientific, and Design Computer Programs for Nuclear Power Plants”, N286.7-99 in March 1999
  - AECL published 00-01913-QAM-003, “Quality Assurance Manual for Analytical Scientific and Design Computer Programs in September 1999, and revised the document in March 2001
- Compliance is verified through internal, 3rd-party and regulatory audits

Industry Standard Toolset (IST)

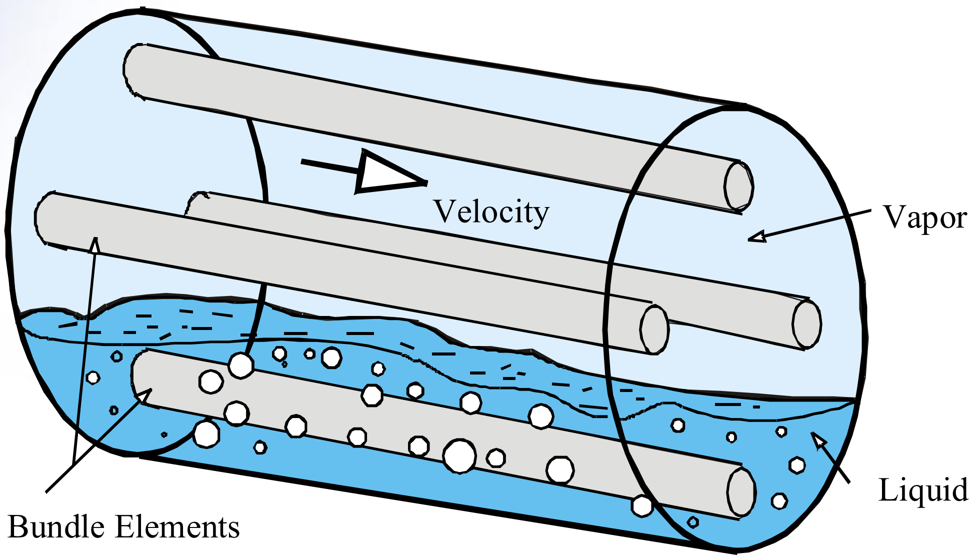
- **Formal qualification of safety and licensing codes was recognized as requiring significant investment, and resulting in redundancies and inconsistencies if undertaken separately**
- **Canadian utilities and AECL worked together to qualify a standard set of computer programs (IST)**
  - **Agreed to common processes to meet CSA-N286.7-99**
  - **Shared effort on code development, qualification and support**

Key ACR Computer Codes



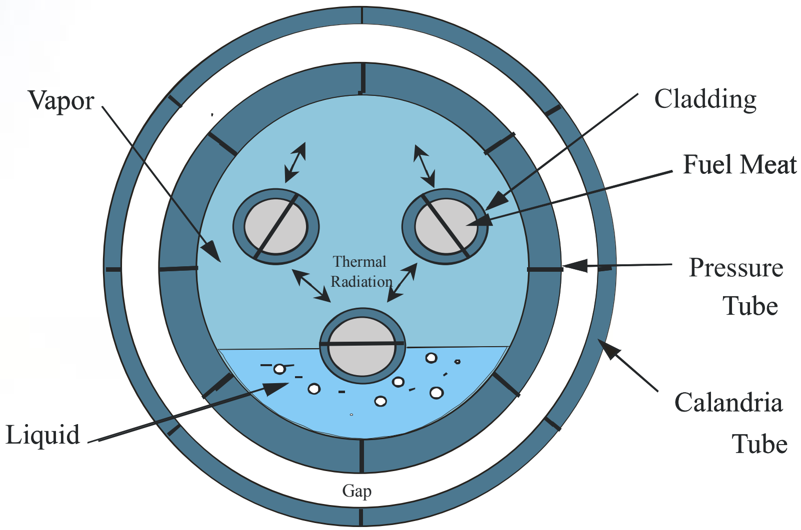
CATHENA THERMALHYDRAULIC MODEL

Axial Segment (node)



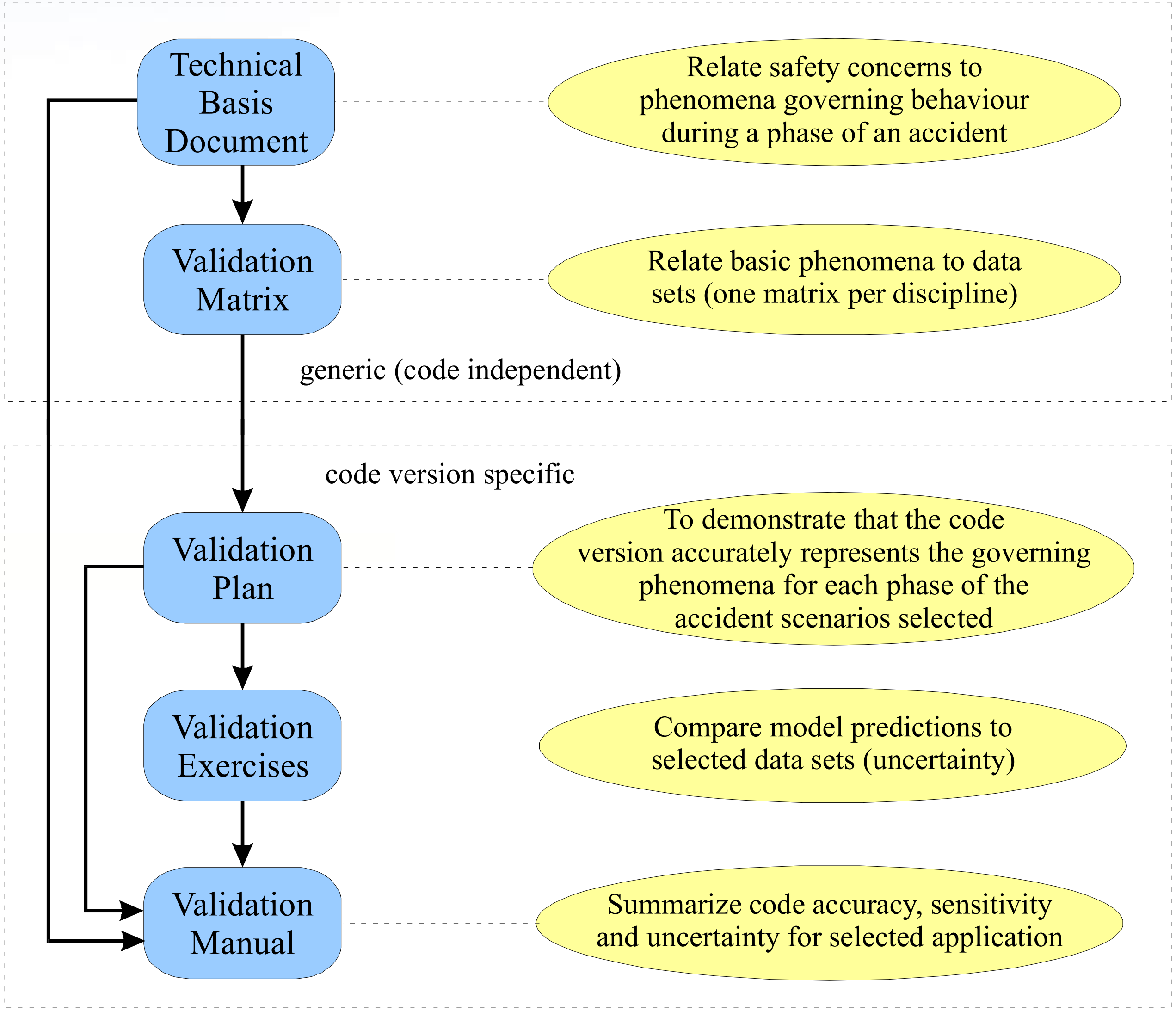
- Non-equilibrium model
  - 2-velocities,
  - 2-temperatures
  - 2-pressures
  - plus noncondensables
- Flow regime dependent constitutive relations couple two-phase model
- CATHENA "interfaces" to other codes:
  - i.e, Fuel Behavior, Plant Control, Physics

CATHENA's Solid Heat Transfer Model



- Multiple surfaces per thermal hydraulic node
- Radial and circumferential conduction modeled
- Models heat transfer within bundles subjected to stratified flow
- Radiation heat transfer calculated
- Built-in temperature dependent material property tables
- Models deformed geometry and pressure / calandria tube contact

Code Validation Methodology



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 (high ranking of importance) 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-like process)
- 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

Thermal Hydraulics Phenomena, (first 10 of 23)

ID No.	Phenomenon	Large LOCA	LOCA/ LOECC	Small LOCA	LOF	LOR	Loss of Feed-water	Steam Line Break
TH1	Break Discharge Characteristics and Critical Flow	✓	✓	✓			✓	✓
TH2	Coolant Voiding	✓	✓	✓	×	×		
TH3	Phase Separation	✓	✓	✓	✓		✓	✓
TH4	Level Swell and Void Holdup	×	×	✓				✓
TH5	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	✓		✓	✓		✓	✓

✓ primary phenomena

× secondary phenomena

Test Data for Thermal Hydraulics Phenomena (sample)

ID#	Data Set Name	TH2 Coolant Voiding	TH3 Phase Separat.	TH6 Thermal Conduct.	TH7 Convect. Heat Tran.	TH16 Flow Oscillation
SE1	Edwards Pipe Blowdown	■				
SE5	Marviken Bottom Blowdown	○				
SE13	PT/CT Contact Heat Transfer Tests			■		
SE21	CWIT Flow Stratification Tests		■		■	
CO1	End Fitting Characterization Tests	○	○	■		
INT9	RD-14 Natural Circulation Tests		○		■	■
INT14	Station Transients		■			■
NUM6	Radial Conduction Test			■		

■ Suitable for direct validation

○ Suitable for indirect validation

Experimental Data Base

- **CANDU System Makes Use of International Data Sets:**
  - **Edwards Pipe Blowdown (Break Discharge)**
  - **Marviken Blowdown Tests (Break Discharge)**
  - **Dartmouth Air/Water Flooding in Straight Pipe (Counter Current Flow)**
  - **GE Large Vessel Blowdown Tests (Level Swell)**
  - **Christensen Power Void Tests (Coolant Voiding)**
  - ***….. and others***

Experimental Data Base – CANDU Specific

- Can by subdivided into:
  - Small Scale Experiments
  - Component Experiments
  - Integral Experiments
  - CANDU Plant Transients
- The majority of existing data (supporting current CANDUs) can be used for validation of the ACR
- Where “gaps” exist (i.e., higher pressure and temperatures of the ACR), new experiments have been completed and others have been planned

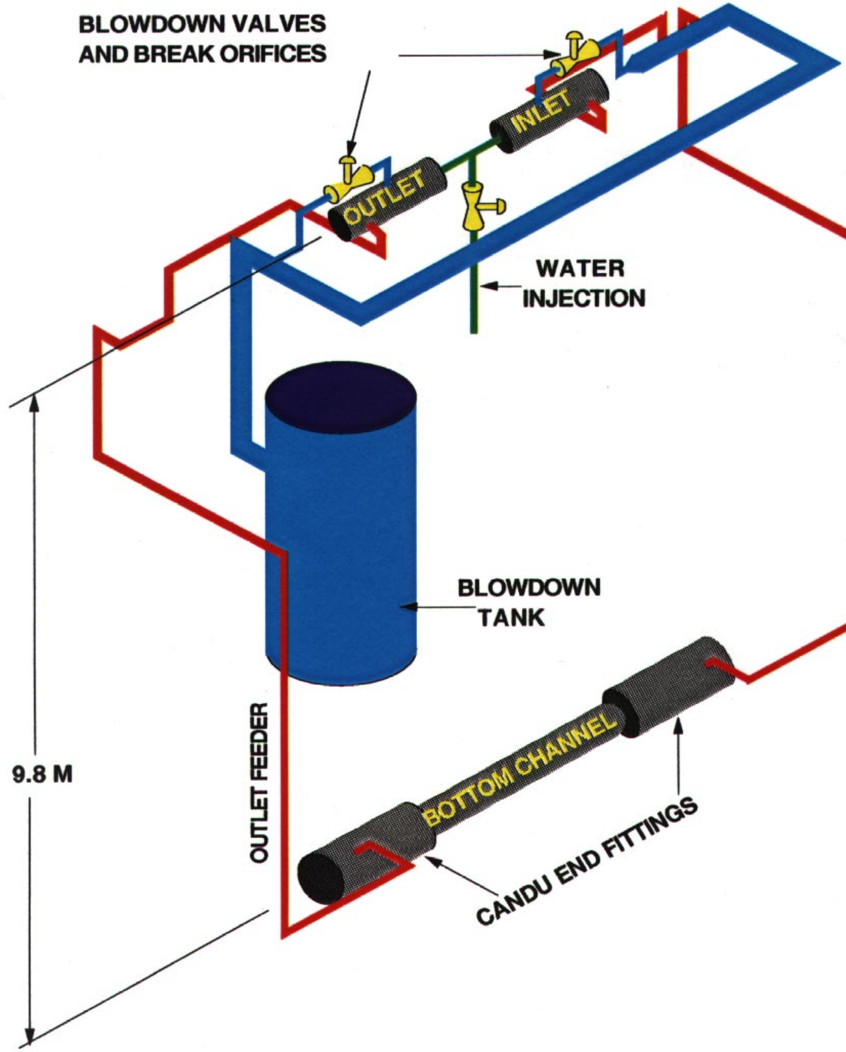
- Small Scale Experiments, Examples:
  - Flooding – downstream of an elbow (relevant to feeder)
  - Pressure Tube / Calandria Tube Heat Transfer Experiments
  - Horizontal Tube Rewetting / Refilling Experiments
  - Pressure Tube Circumferential Temperature Distribution

Experimental Data Base – CANDU Specific

- **Full-Scale Component Experiments:**
  - Feeder Refilling, Cold Water Injection Test Facility
  - Channel Stratification Studies, Cold Water Injection Test Facility
  - Header Studies, Large Scale Header Facility
  - Header Studies, Header Visualization Facility
  - Pump Characterization, CANDU Pump Facility
  - End Fitting Studies, End Fitting Characterization Facility

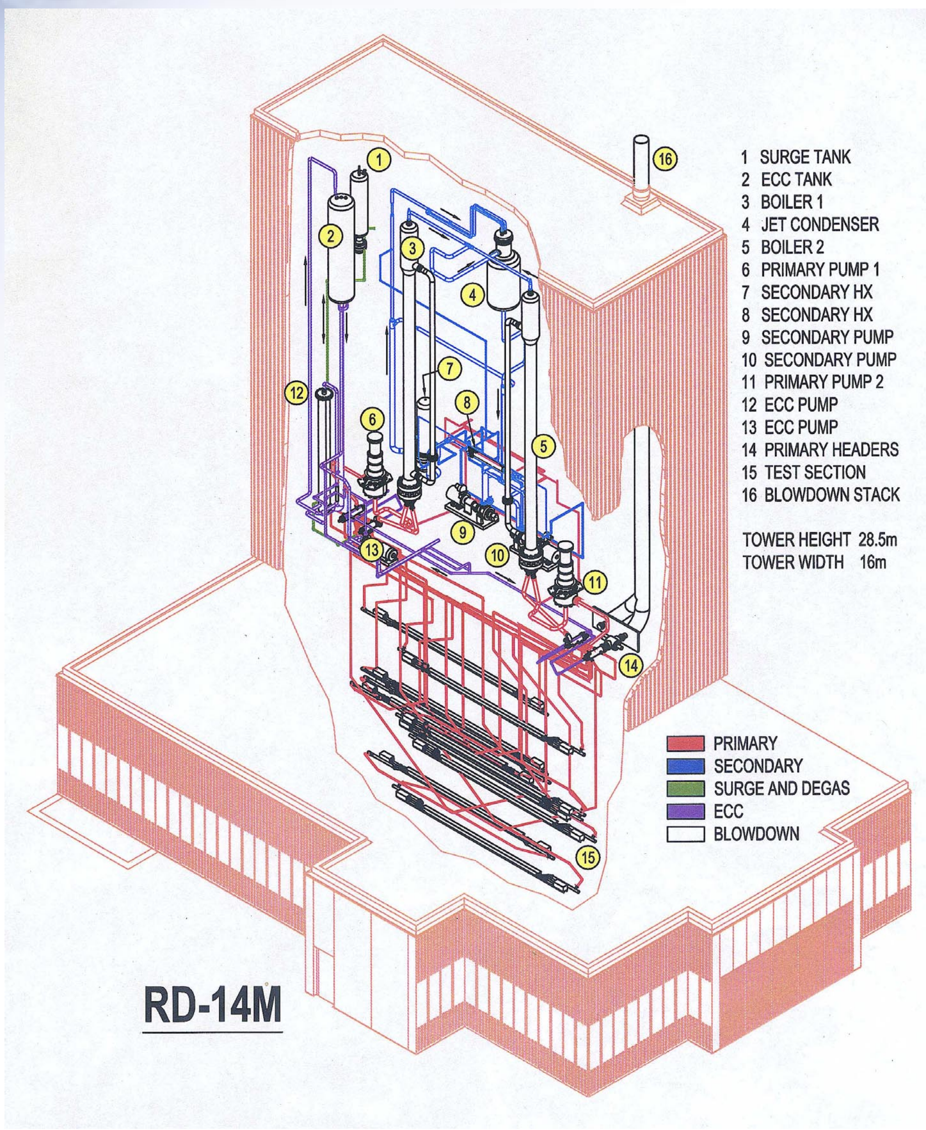
Cold Water Injection Facility (CWIT)

- Full-scale heated fuel channel with simulated fuel string
- CANDU representative feeders and End Fittings
- Designed to investigate feeder/channel refill performance, as well as flow stratification within CANDU bundle



CWIT Test Facility

RD-14M Integral Test Facility

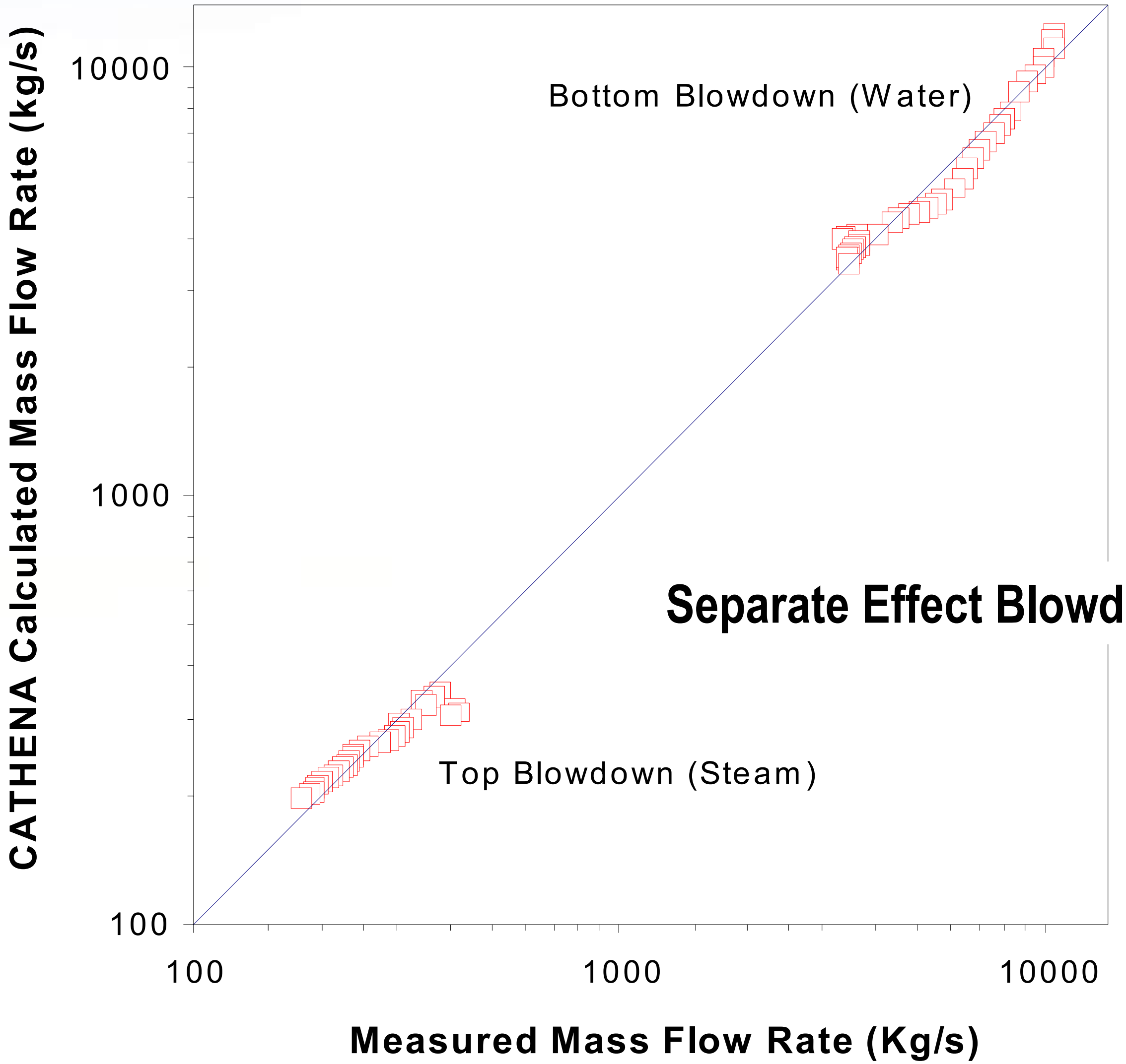


- Full elevation changes between major components and full linear dimensions
- Reactor typical heat- and mass-transfer rates
- Ten full length electrically heated channels (maximum of 11 MW)
- Simulation of all primary-side components - channels, end-fittings, feeders, headers, and steam generators
- Full pressure and temperature conditions (current CANDUs and ACR)

Examples of Validation for CATHENA

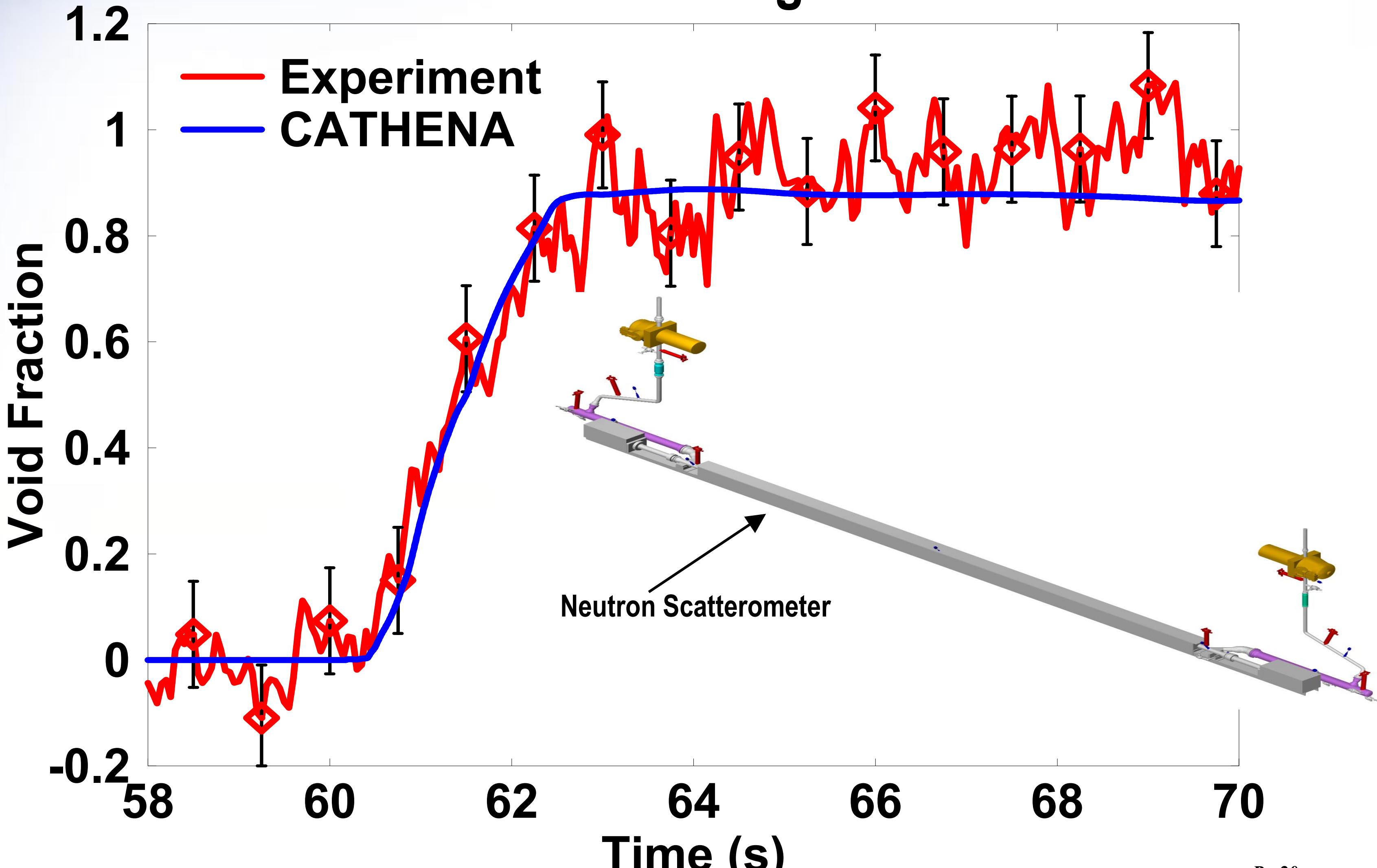
- Component
  - Marviken tests, discharge characteristics
- RD-14M
  - Channel voiding
- CANDU Plant transient
  - Single-pump trip

TH1: Break Discharge Characteristics – 3

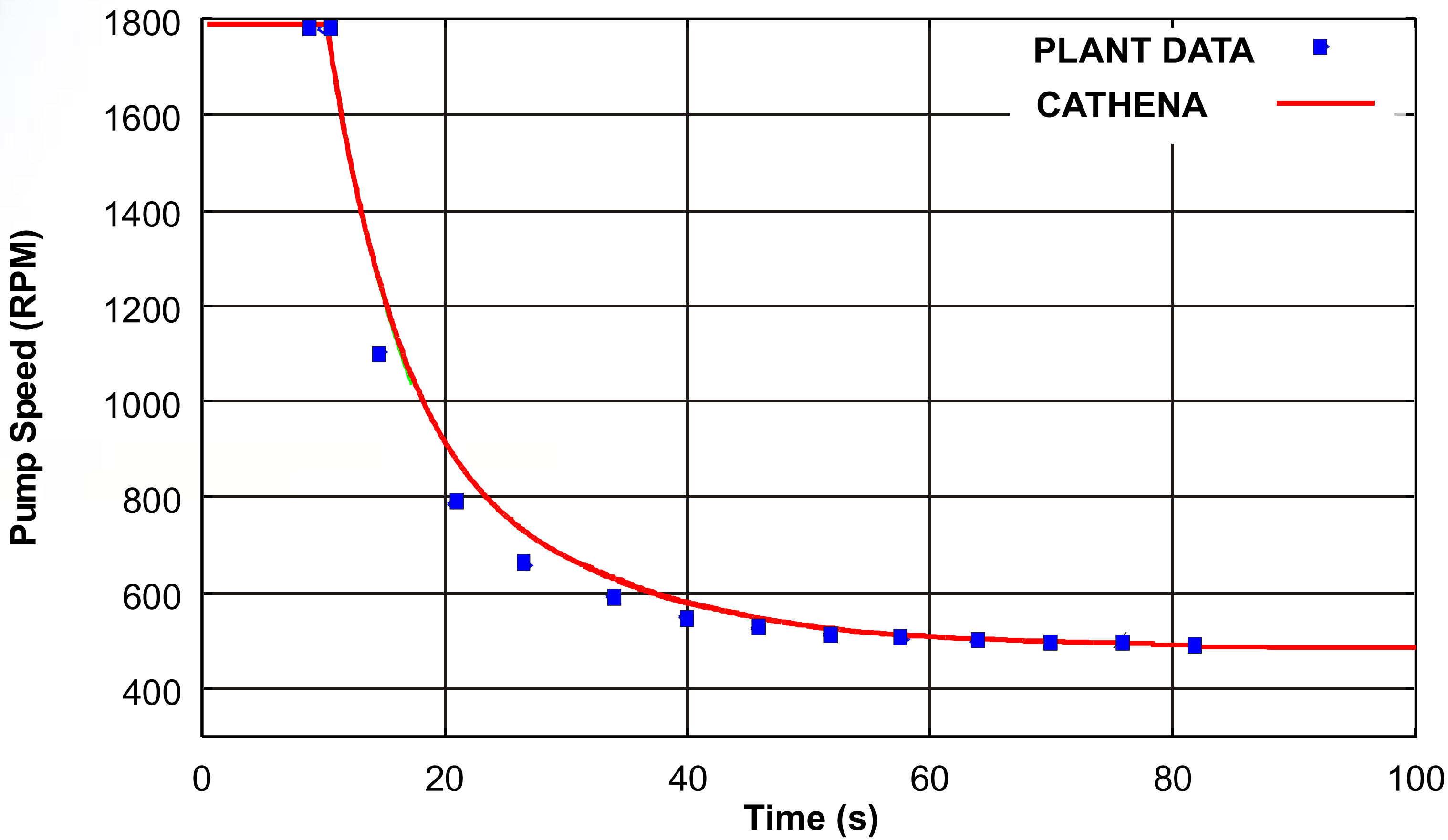


Separate Effect Blowdown Tests

CATHENA Validation, Example of Prediction of Channel Void During LOCA



Single Pump Trip in a CANDU 6 Pump Run-down Speed



Conclusion

- ACR analysis codes are developed and qualified under a formal SQA program
- Validation methodology has been demonstrated, using thermal hydraulics as an example, and the CATHENA code
- A wide range of experimental databases is used in the validation process
- Examples of CATHENA validation are provided

AECL

TECHNOLOGIES INC.