ACR Technology Base
RCS Thermalhydraulics

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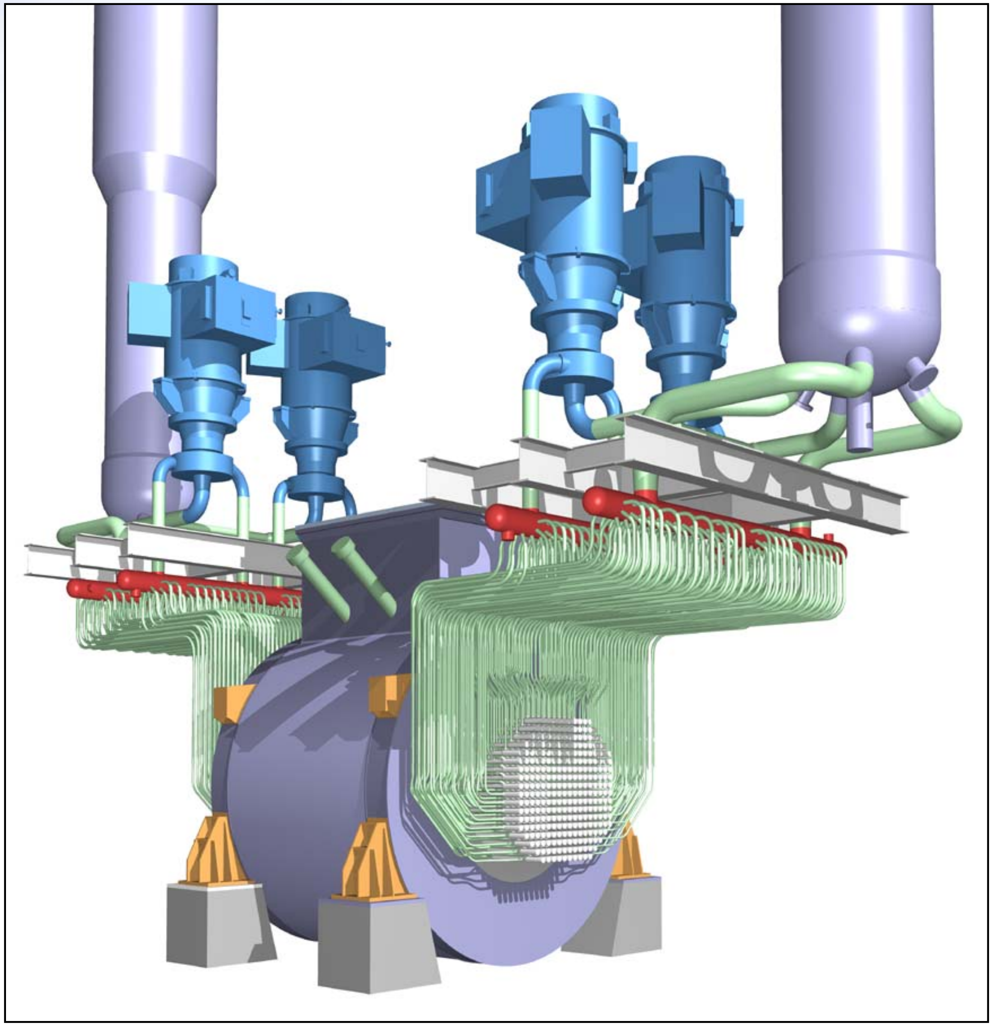
Outline
ACR Technology Base
RCS Thermalhydraulics

- **Distinguishing Features of CANDU**
- **Experimental Programs**
- **CATHENA Thermalhydraulic Code**
- **Validation Methodology and Selected Results**

ACR Reactor Coolant System Layout



Showing piping above and below headers

-All large reactor coolant piping above headers

CANDU System

- **Below "Header", Unique Features:**
  - Horizontal Fuel Channels, Pressure Tube, Calandria Tube
  - 43-Element Fuel Bundle
  - Individual Fuel Channels supplied by Feeder Pipes from a Header
  - End Fittings allow on-power refueling
  - Moderator Heat Sink
- **Above "Header", Common Features (with other reactors):**
  - Vertical U-Tube Steam Generators
  - Centrifugal Pumps

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

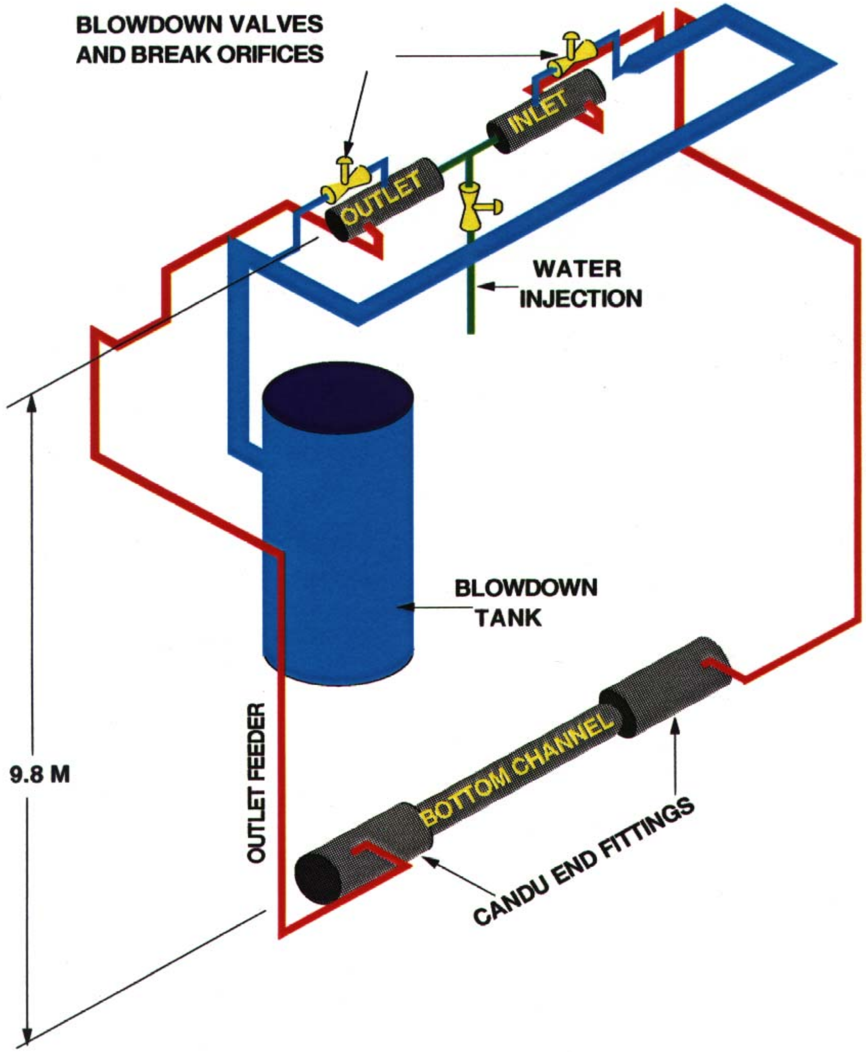
- Small Scale Experiments, Examples:
  - Flooding – downstream of an elbow (relevant to feeder)
  - Pressure Tube / Calandria Tube Heat Transfer Experiments
  - Horizontal Tube Rewetting / Refilling Experiments
  - Pressure Tube Circumferential Temperature Distribution

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



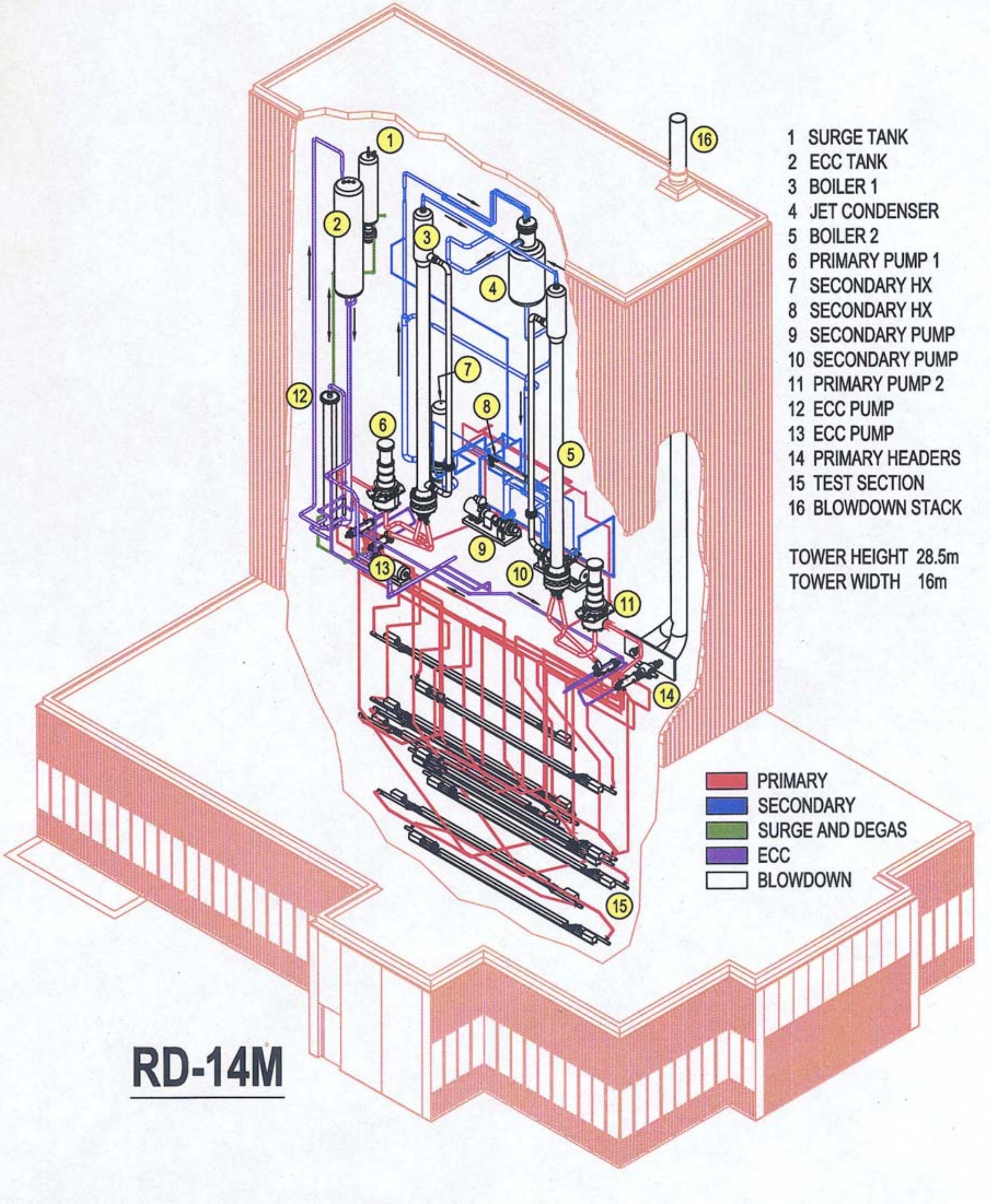
CWIT Test Facility

Experimental Data Base – CANDU Specific

- History of AECL Integral Test Facilities
  - RD-4 - (1974) - small scale
  - RD-12 - (1976 to 83) - half scale
  - RD-14 - (1985 to 87) - full elevation, one channel per pass
  - RD-14M - (1988 to present) - full elevation, five channels per pass
  - RD-14M – (2002 to present) – re-configured to simulate ACR conditions (higher temperature / pressure)
- Integral Experiments:
  - LOCA,
    - Small, Large, Critical
    - With and Without Emergency Core Cooling (ECC)
  - Natural Circulation
    - Single- and Two-Phase
  - Loop Stability
  - Shutdown Cooling Experiments

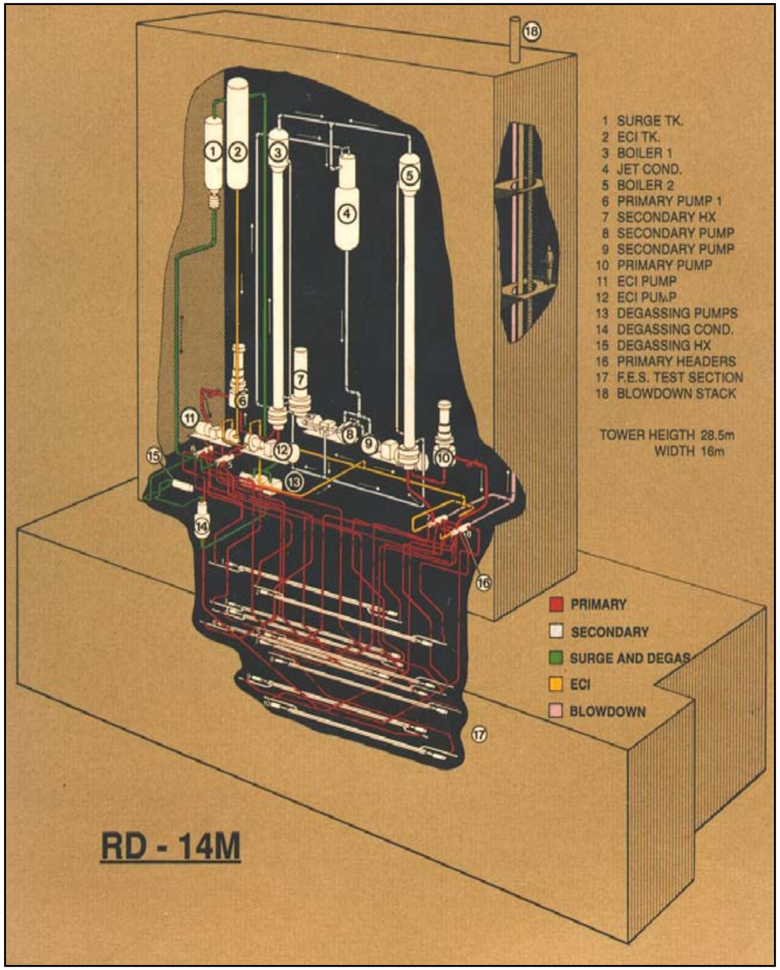
RD-14M

Full elevation, scaled CANDU loop for safety thermalhydraulic code validation

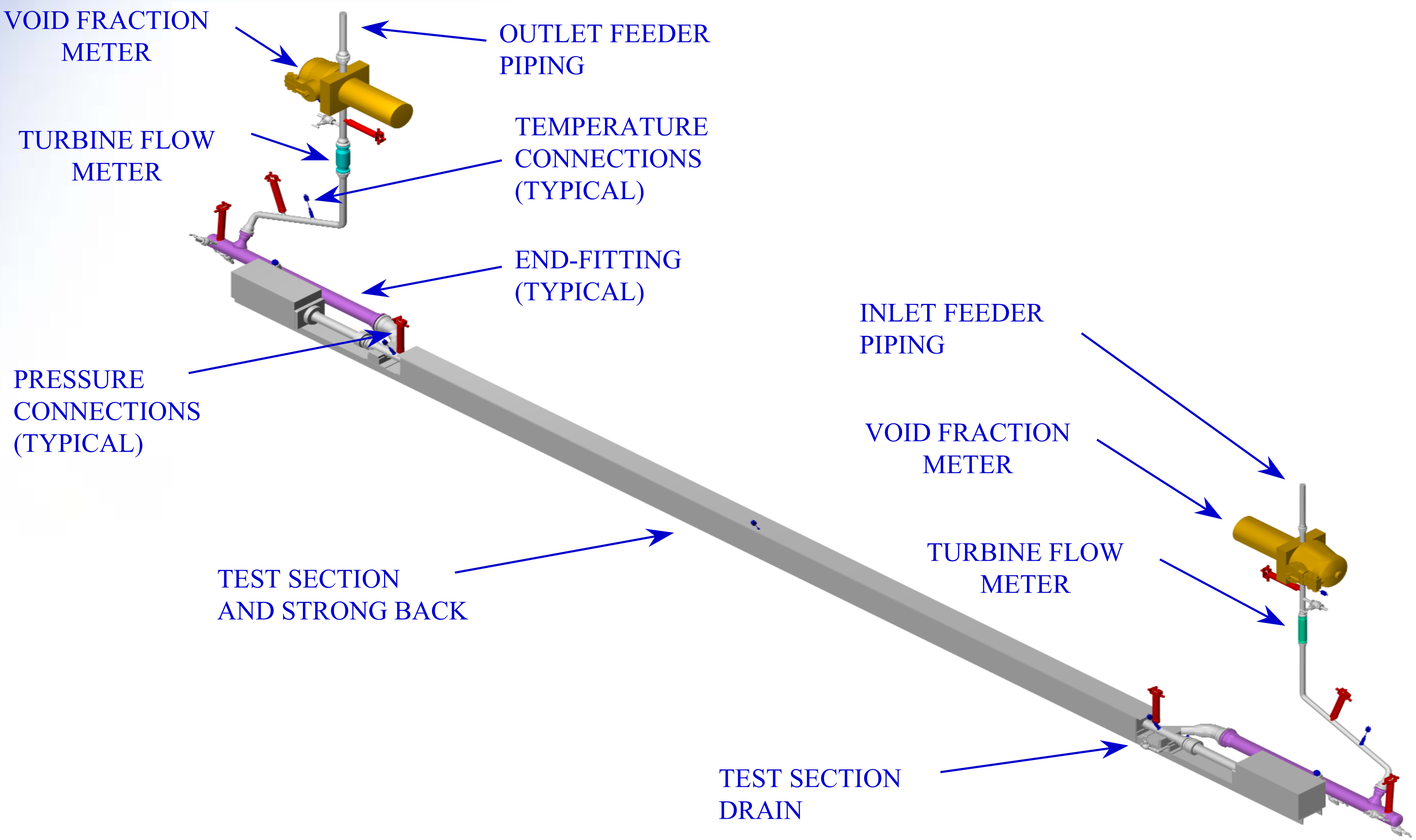


Thermal Hydraulics of RD-14M Heat Transport System

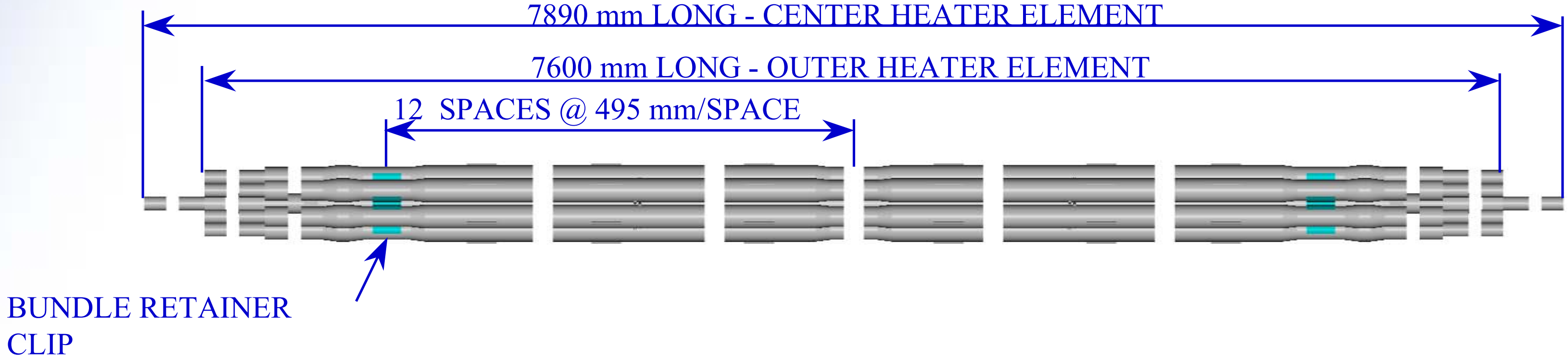
- Full elevation changes between major components and full linear dimensions.
- Reactor typical heat- and mass-transfer rates
- Ten full length electrically heated channels.
- Simulation of all primary-side components - channels, end-fittings, feeders, headers, and steam generators.
- Full pressure and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

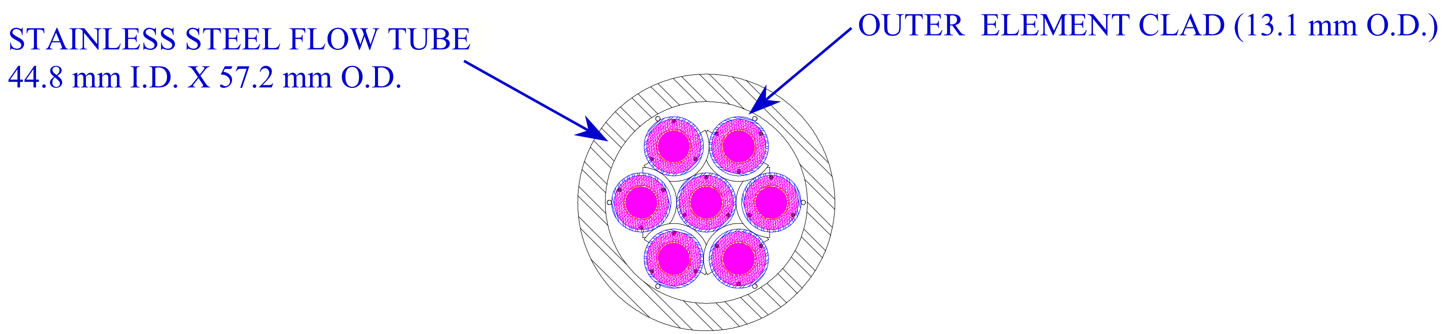


RD-14M Test Sections



RD-14M Heated Sections - Fuel Element Simulators

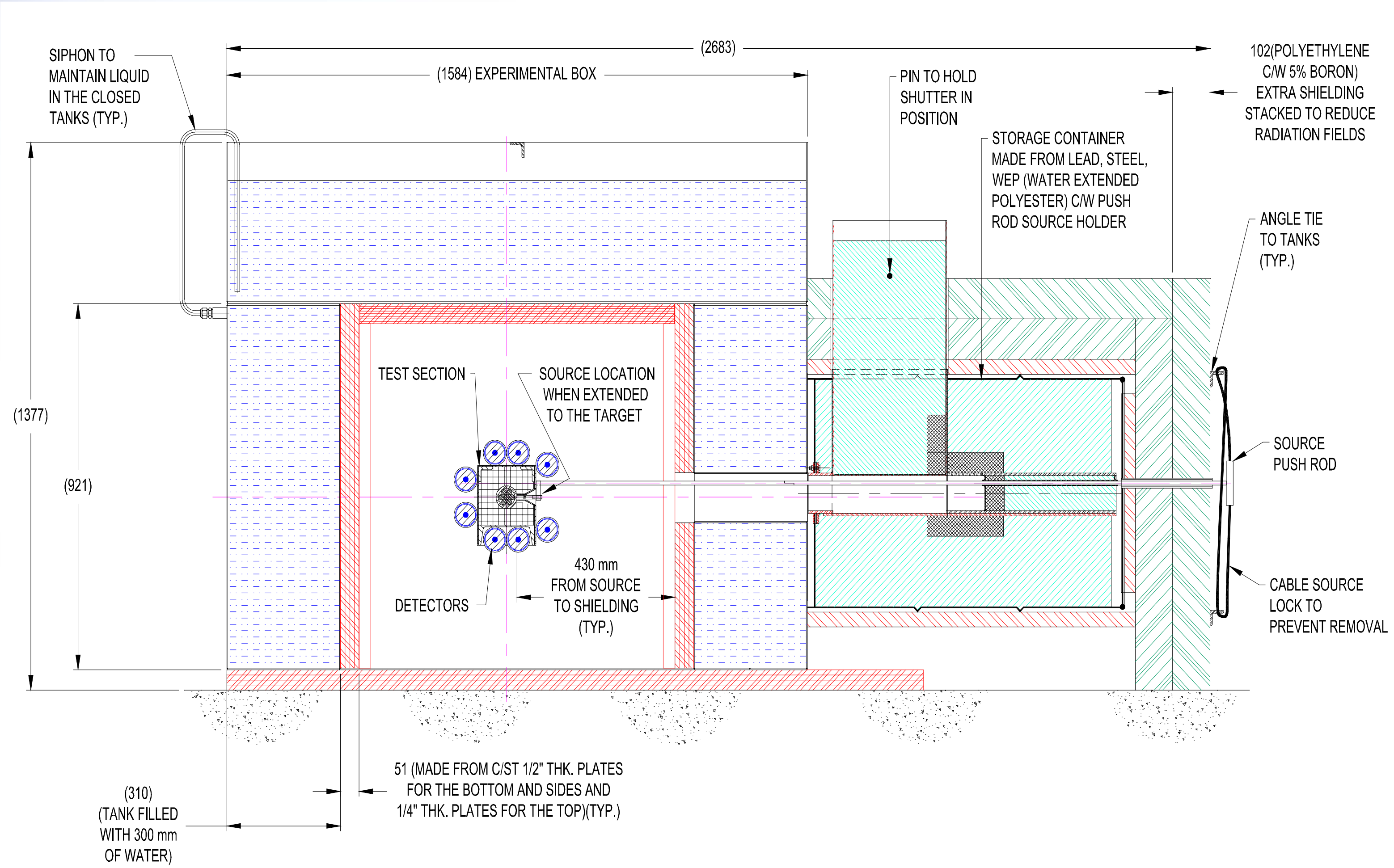




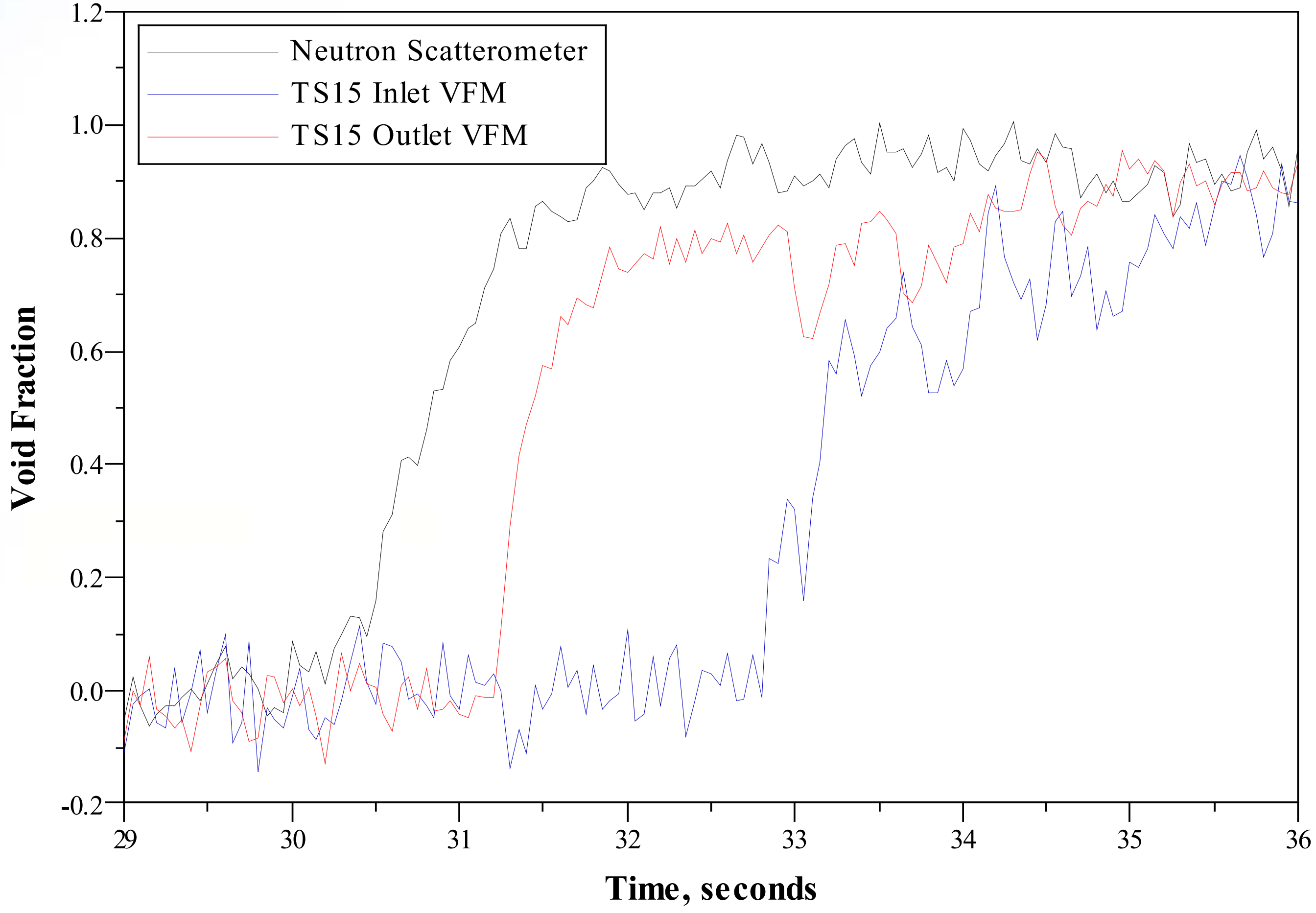
Measuring Void in a RD-14M Channel

- Complex because ratio of metal to fluid volume in the RD-14M channel (1.5) limits the sensitivity to changes in void fraction
- Also, high sampling speed (10 Hz) and uncertainty requirements (10%) required for fast transients
- Neutron Scatterometer was recently developed:
  - Neutron source, 100 μg ^{252}Cf (54 mCi)
  - Optimized counting system for detecting scattered (thermal) neutrons
  - Meets set sampling and accuracy targets

Side View - Source Deployed



TS14 Void Fractions Test B0101

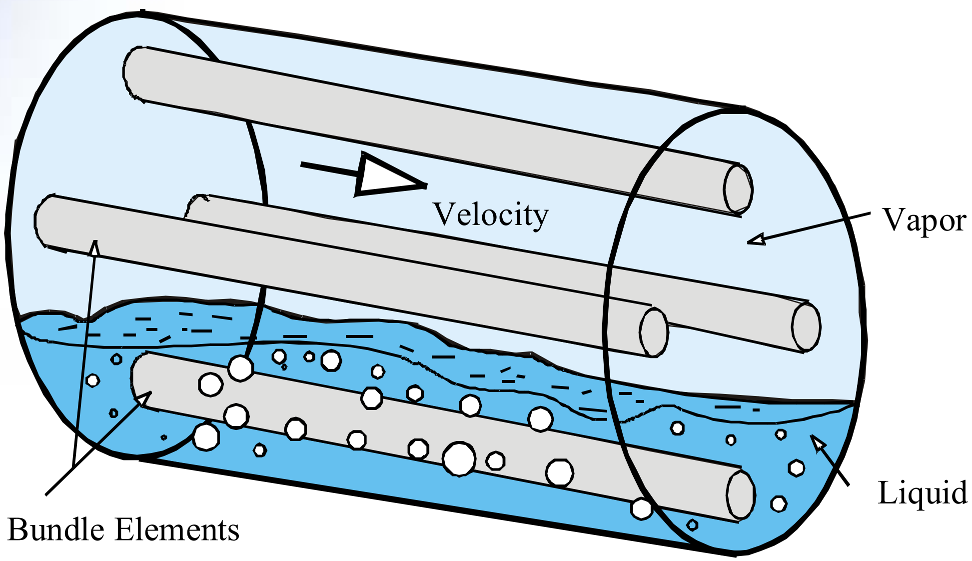


CATHENA

- Code Evolution at AECL
  - RAMA - EVET (~1977)
  - RAMA - EVUT (~1983)
  - RAMA - UVUT (~1984)
  - CATHENA (~1986)
- <u>C</u>anadian <u>A</u>lgorithm for <u>THE</u>rmalhydraulic <u>N</u>etwork <u>A</u>nalysis
- One-dimensional, two-fluid system thermalhydraulics code
- Developed by AECL primarily for analysis of postulated LOCA events in CANDU reactors

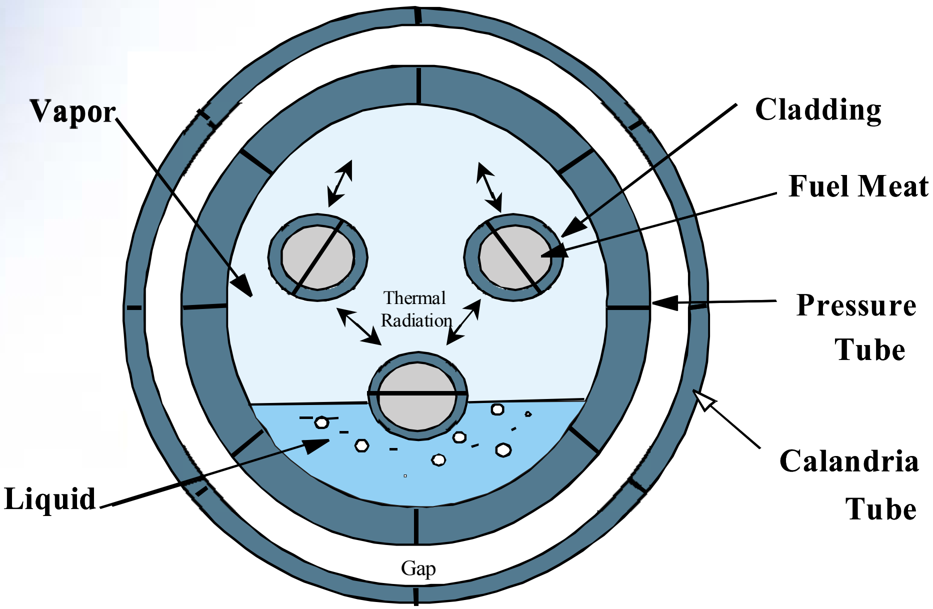
CATHENA THERMALHYDRAULIC MODEL

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:
  - Fuel Behavior: CATHENA / ELOCA
  - Plant Control: CATHENA / LEPCON
  - Physics: CATHENA / RFSP

CATHENA's Solid Heat Transfer Model

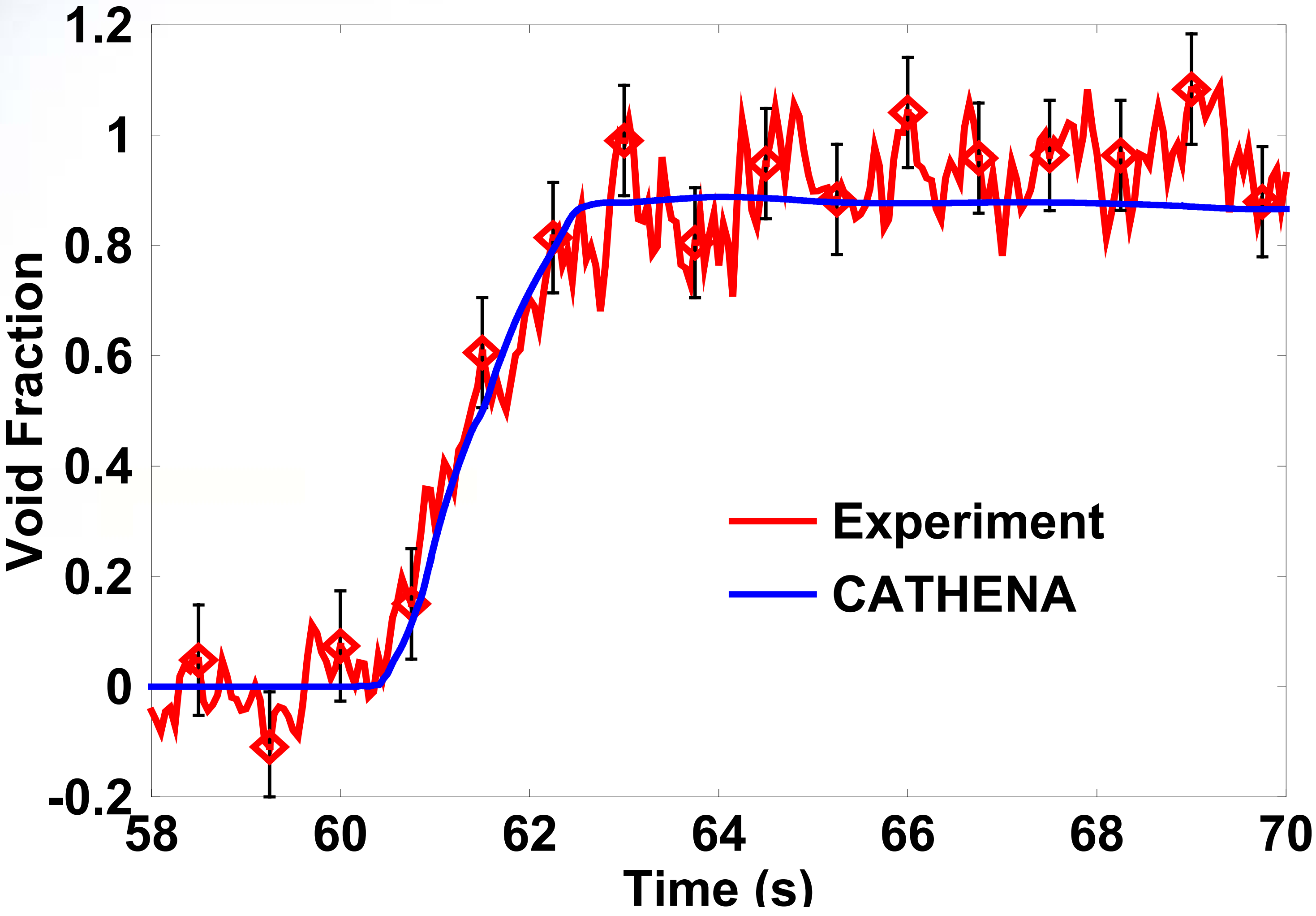


- Multiple surfaces per thermalhydraulic node
- Radial and circumferential conduction modeled
- Models heat transfer within bundles subjected to stratified flow
- Radiation heat transfer calculated
- Built-in temperature dependent material property tables
- Models deformed geometry and pressure/ calandria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

CATHENA VALIDATION

- Described later in a separate generic presentation
- Brief Summary:
  - Validation has proceeded on a phenomenon-by-phenomenon basis
  - Standardized and documented models of facilities used where they exist
  - Default code settings used throughout unless otherwise specified and justified
  - Data selected in validation process includes numerical tests, separate effects, component and integral tests, as well as transients in CANDU plants
  - Sensitivity analysis conducted to identify impact on simulations of experimental errors used as boundary conditions (e.g., power) and nodalization
  - Uncertainty analysis conducted to identify impact on code results (e.g., uncertainty in heat transfer correlations)

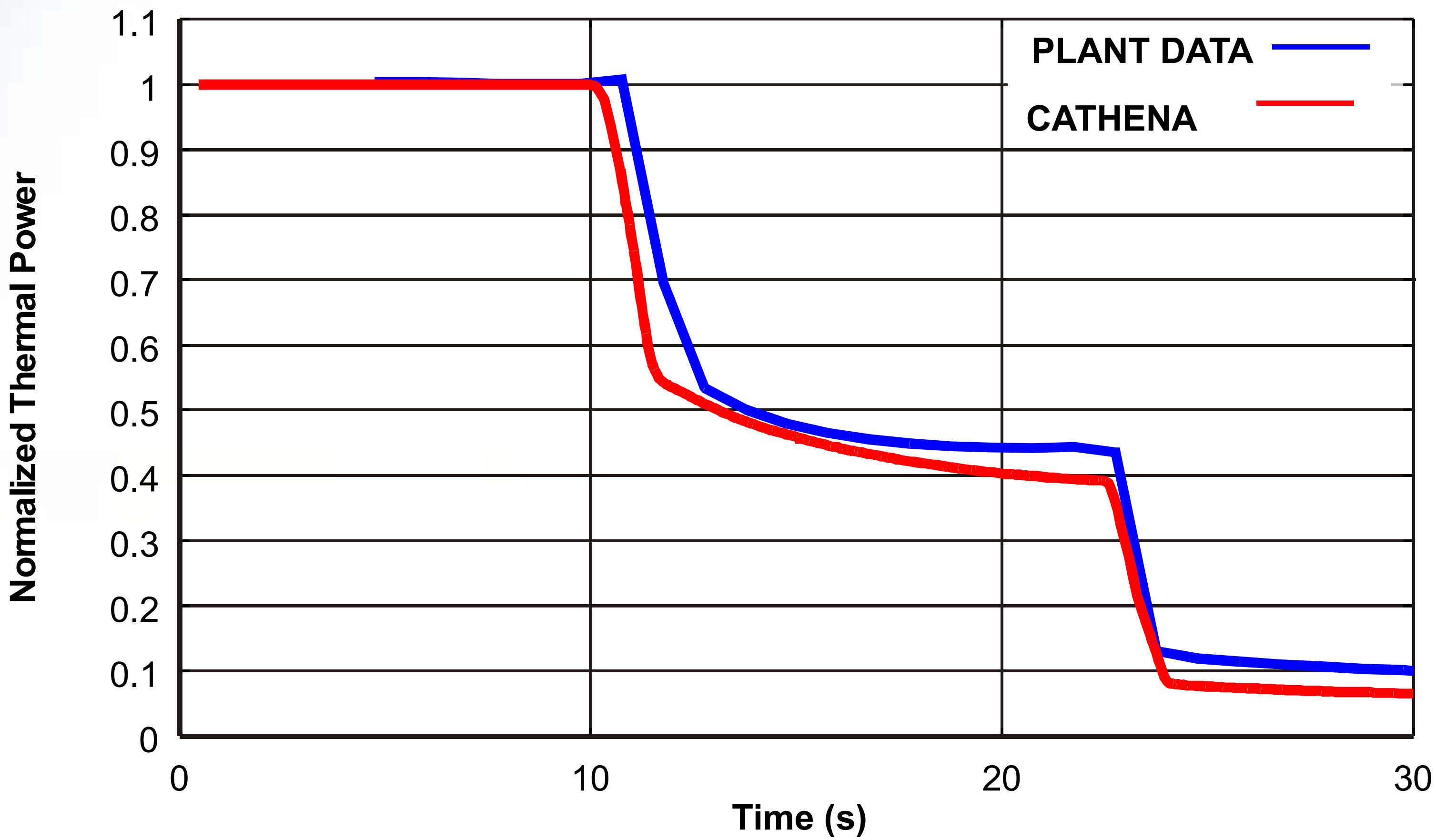
CATHENA Validation, Example of Prediction of Channel Void During LOCA



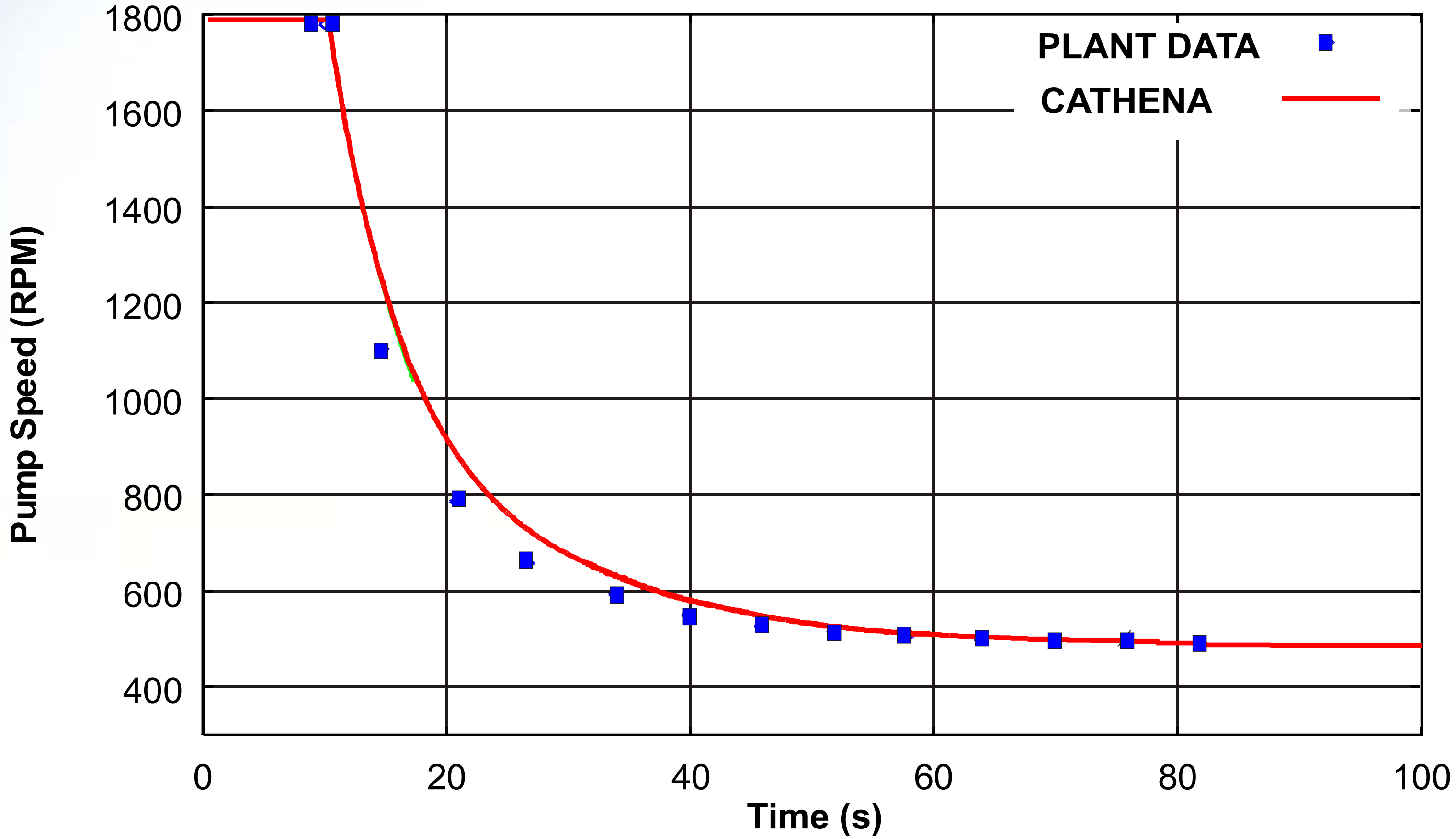
CATHENA Validation, CANDU 6 Plant Transient, Single-Pump Trip

- **CATHENA CANDU-6 (Pt. Lepreau) integrated model includes 28 channels in 4 passes, 4 steam generators, emergency coolant injection system, inventory control system, and reactor regulation system (3775 nodes)**
- **Sequence of events**
  - **primary pump 4 switched off at t=0 s**
  - **pump trip initiates a reactor step back to 60% of full power (step back endpoint)**
  - **reactor trips at approx 13 s on Shutdown System 1 (SDS1) low pressure signal from Reactor Outlet Header 5**

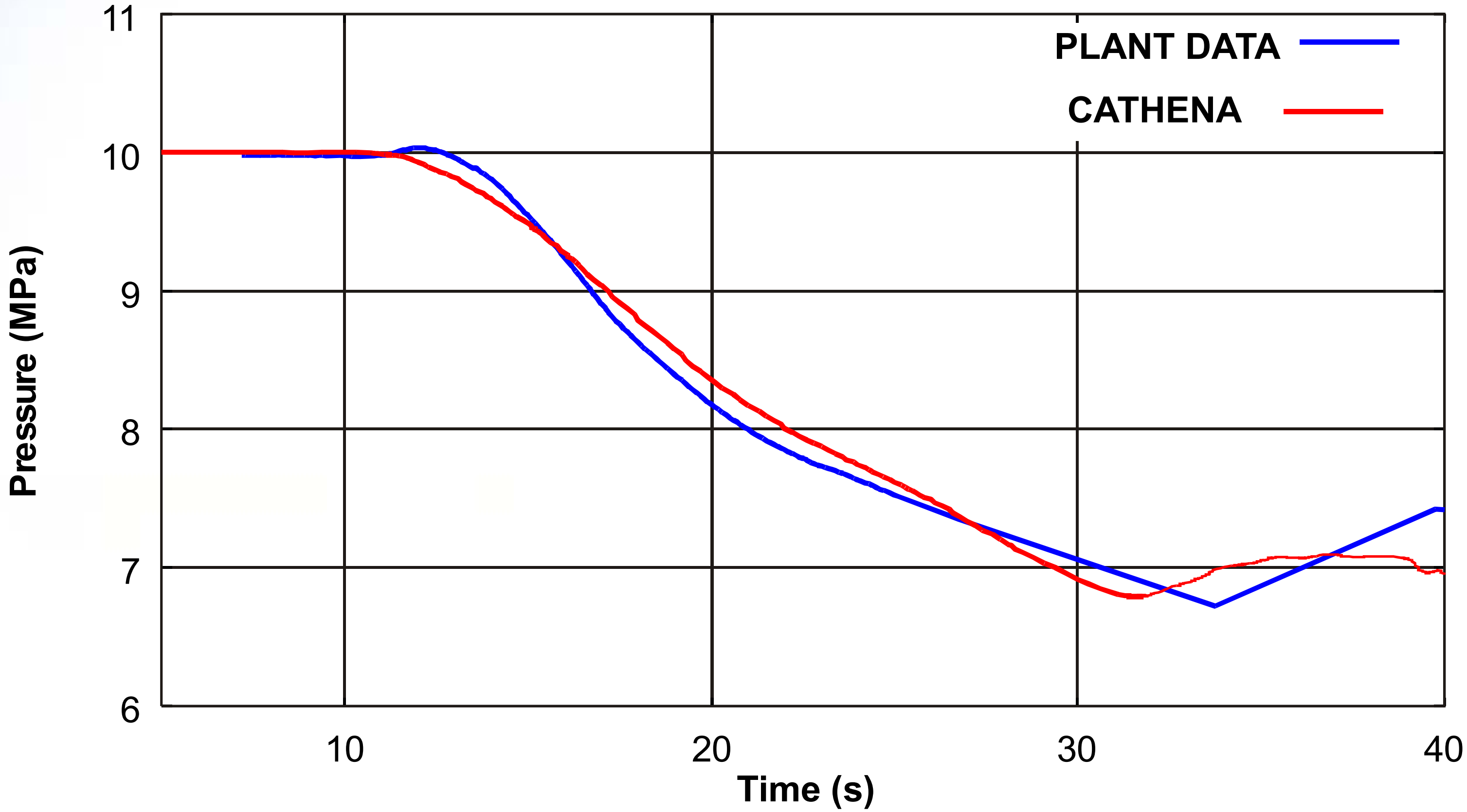
Thermal Power Transients



Pump Run-down Speed



Outlet Header 5 Pressure



Summary

- System Thermalhydraulic Technology Base consists of:
  - Experimental Programs (International & CANDU Specific)
  - CATHENA Thermalhydraulic Code
  - Validation Results
- CATHENA has been validated, in a formal process, for safety and licensing analysis of CANDU Reactors
- This validation is in the process of being extended to ACR conditions

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