CANDU Safety #19: Safety Analysis Tools

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Overview

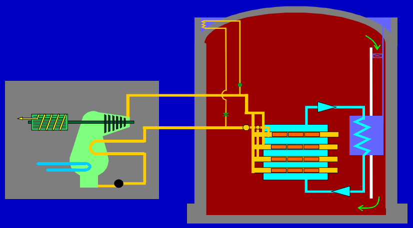
- Computer code application and user requirements
- AECL computers used in Qinshan safety report
- ELESTRES code
- CATHENA code
- CHAN-II code
- ELOCA code
- TUBRUPT code
- PHOENICS code
- Computer code/discipline interaction

Application and User Requirements

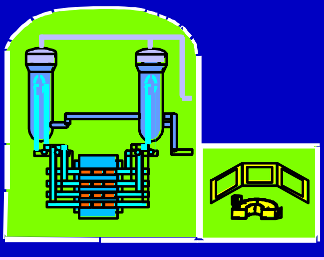
- Various computer codes are used in safety analysis assessments
- These codes allow us to effectively and efficiently meet our objective:
  - evaluation against safety analysis acceptance criteria, and
  - provide an understanding of the system behaviour
  - reactor license
- Codes cover various disciplines from the upstream analysis of reactor physics to the downstream analysis of dose
- The users requirements (i.e., defined by the safety analyst) are feedback to the code developer; therefore, an excellent/strong interface is established

Computer Code Evolution and Application

SAFETY R&D



ADVANCED DESIGNS



REACTOR LICENSING

KNOWLEDGE

SAFETY REPORT

CODES

REPRESENTATIVE MODELS

THEORY

USER REQUIREMENTS

Some of AECL Safety Codes used for Qinshan Safety Report

- Physics: Reactor Fuelling Simulation Program (RFSP)
- Fuel behaviour during normal operating conditions: Element Stress (ELESTRES)
- Thermalhydraulics and fuel/fuel channel: Canadian Algorithm for Thermalhydraulic Network Analysis (CATHENA); CHAN
- Detailed fuel behaviour: Element Loss-of-Coolant Accident (ELOCA)
- Moderator behaviour: Moderator and Steady-State and Transient Boiling (MODSTBOIL); Parabolic Hyperbolic or Elliptic Numerical Integration Series (PHOENICS)
- In-core damage: Tube Rupture (TUBRUPT)

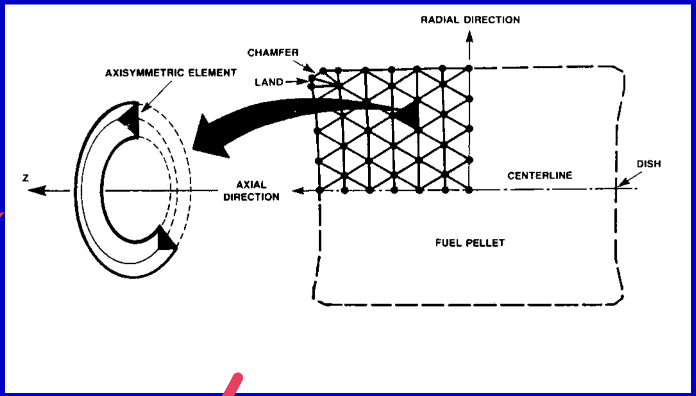
Some of AECL Safety Codes used for Qinshan Safety Report (cont'd)

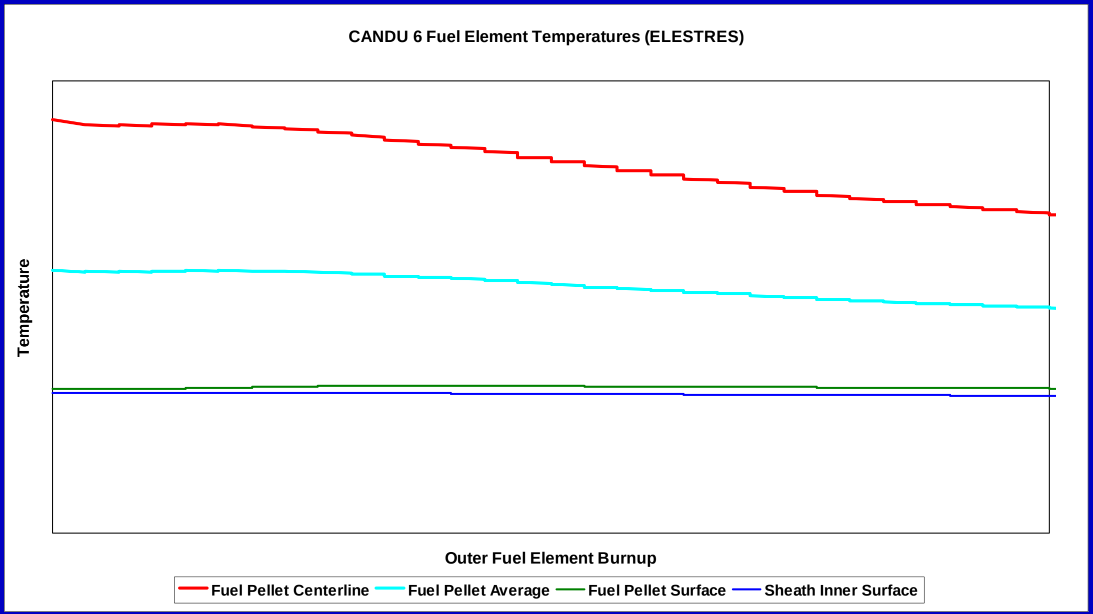
- Fission product release behaviour: various models
- Containment Thermalhydraulic behaviour (pressure): Pressure in Containment (PRESCON)
- Containment radionuclide behaviour: Simple Model for Activity Removal and Transport (SMART)
- Dose analysis: Public Exposure from Atmospheric Releases (PEAR)

ELESTRES

- Models the behaviour of CANDU fuel under normal operating conditions
- Main Input Requirements
  - Fuel element (pellet and sheath) dimensions & properties
  - Power/burnup history
  - Coolant conditions
- Important Output Parameters
  - Fission product distribution (gap, grain boundary and grain bound)
  - Internal gas pressure
  - Fuel temperatures
  - Volumetric heat generation
  - Pellet strain
- Results are passed onto the ELOCA code for a detailed calculation

ELESTRES Application

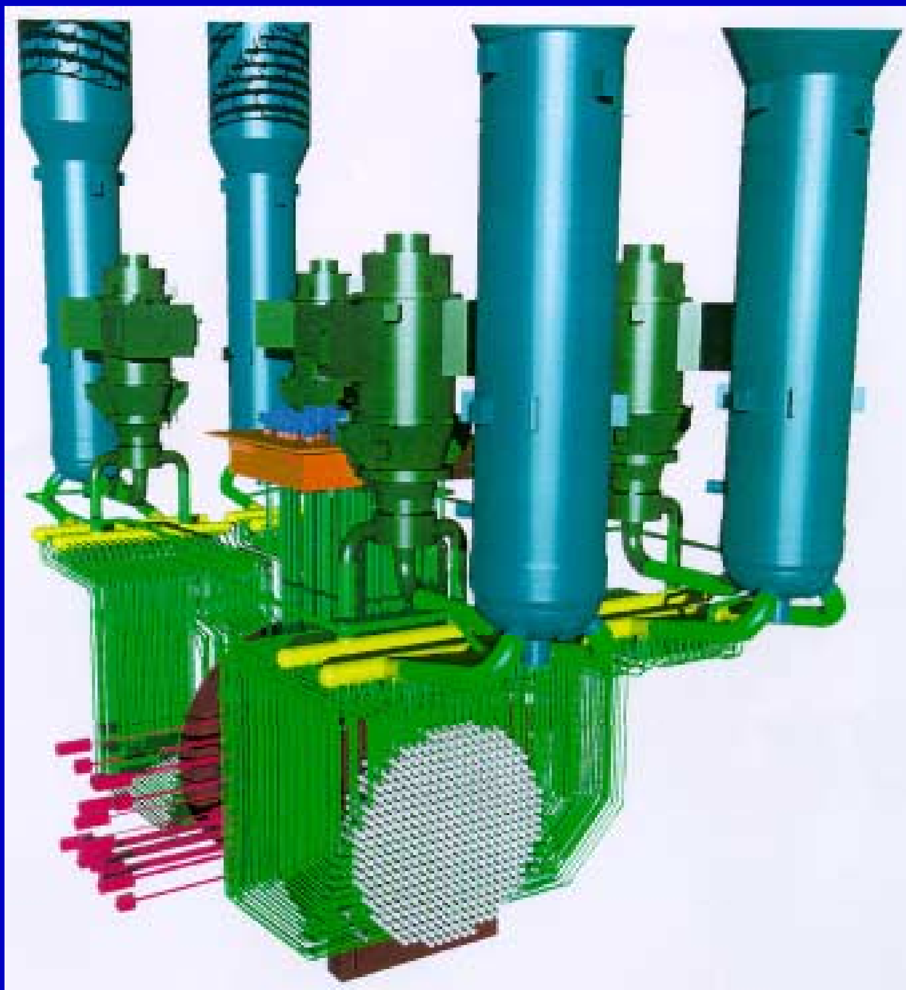


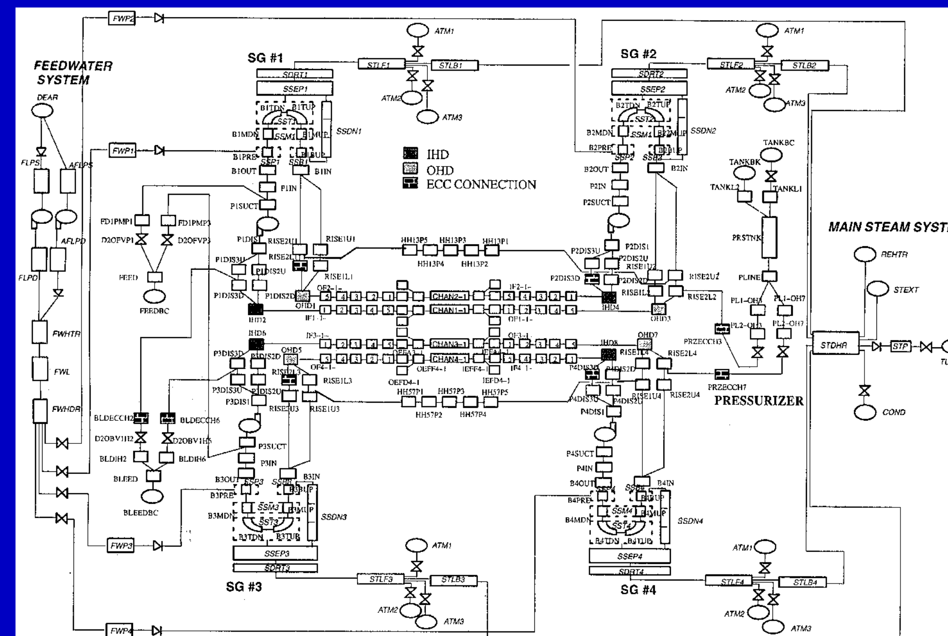


CATHENA

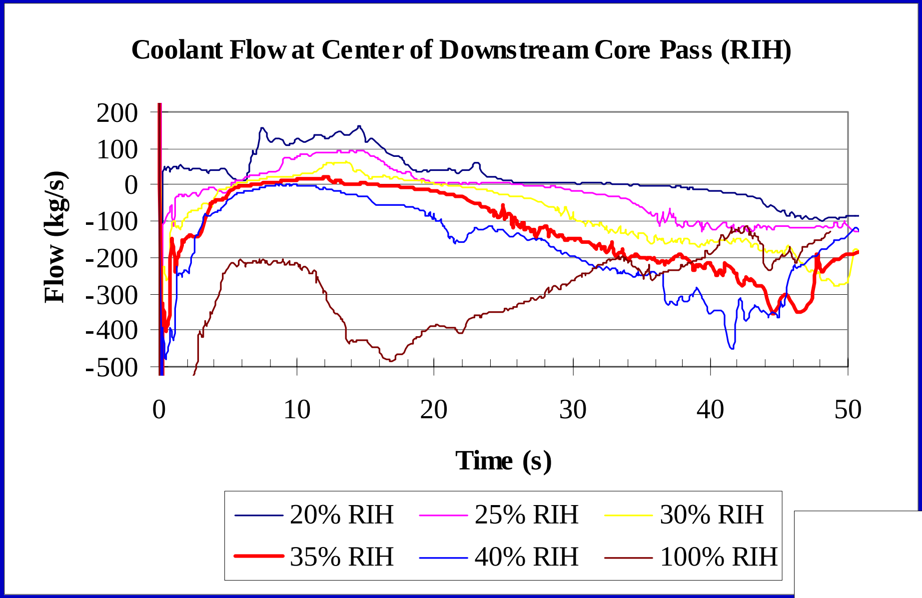
- 1-dimensional, 2 fluid thermalhydraulic computer code
- Capable of analyzing two-phase flow and heat transfer in piping networks
- Heat transfer process models available include:
  - wall and fuel (radial and circumferential) heat conduction,
  - heat generation through the Zirconium metal-water reaction
  - thermal radiation heat transfer (sheath sector to sheath sector, sheath sector to pressure tube sector, pressure tube sector to calandria tube sector)
  - wall-to-fluid heat transfer
  - heat transfer in a horizontal fuel channel under stratified flow conditions

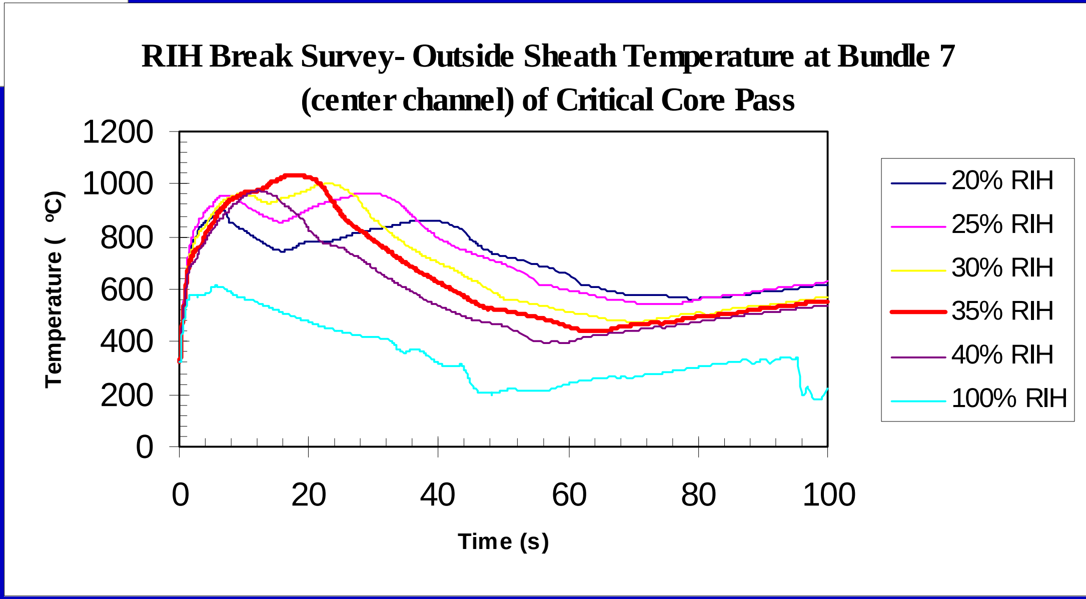
CATHENA Application (Circuit)



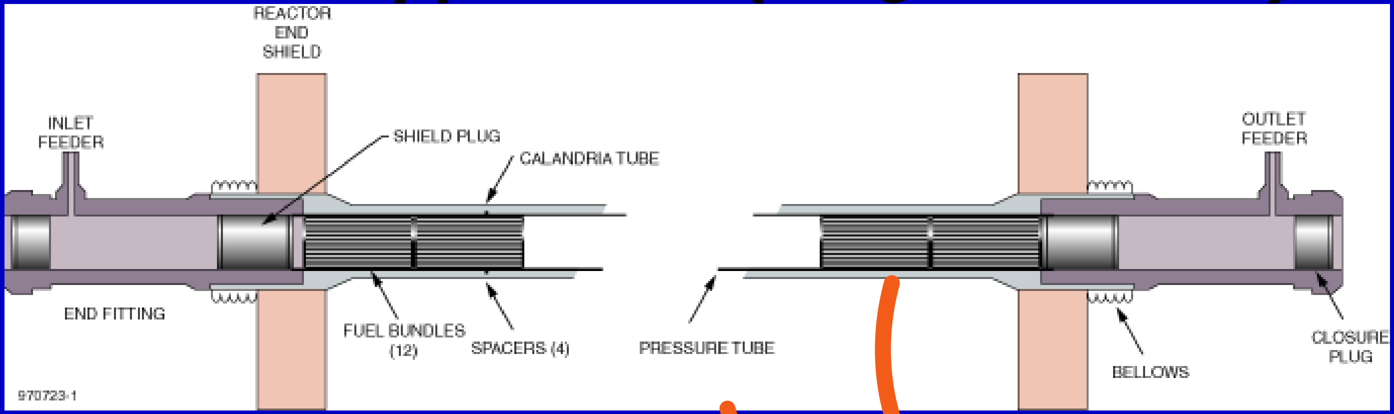


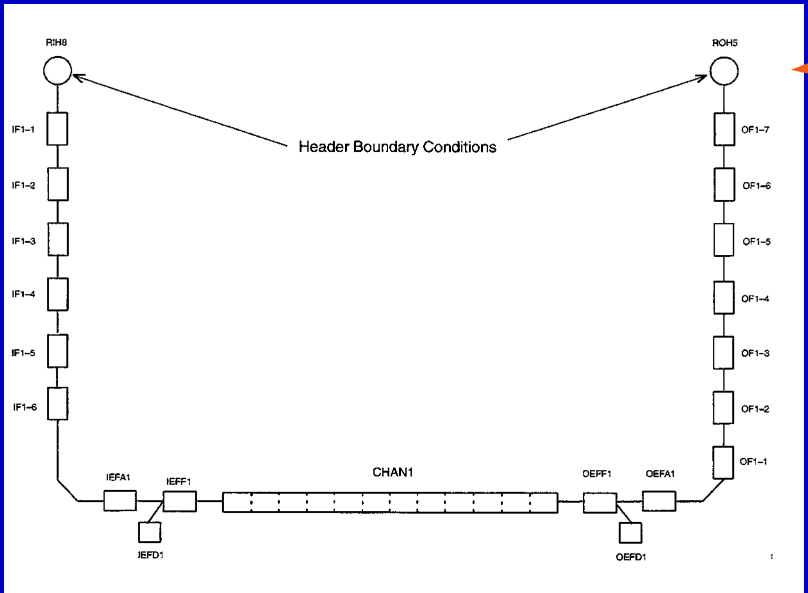
CATHENA Results (Circuit) - 35% RIH Break

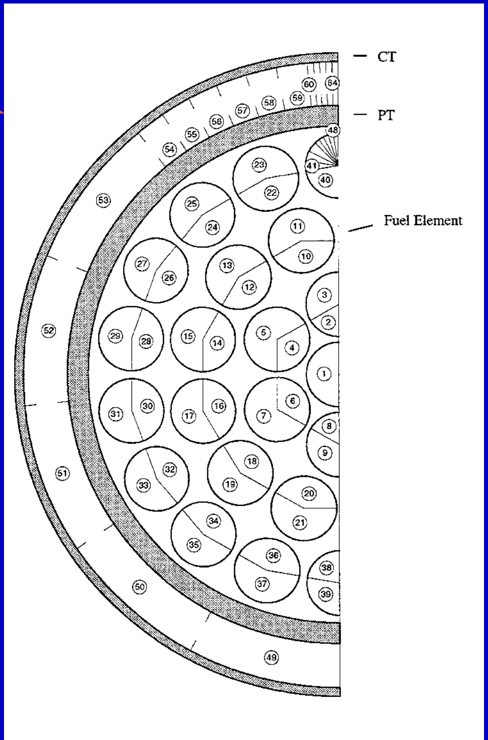




CATHENA Application (Single Channel)

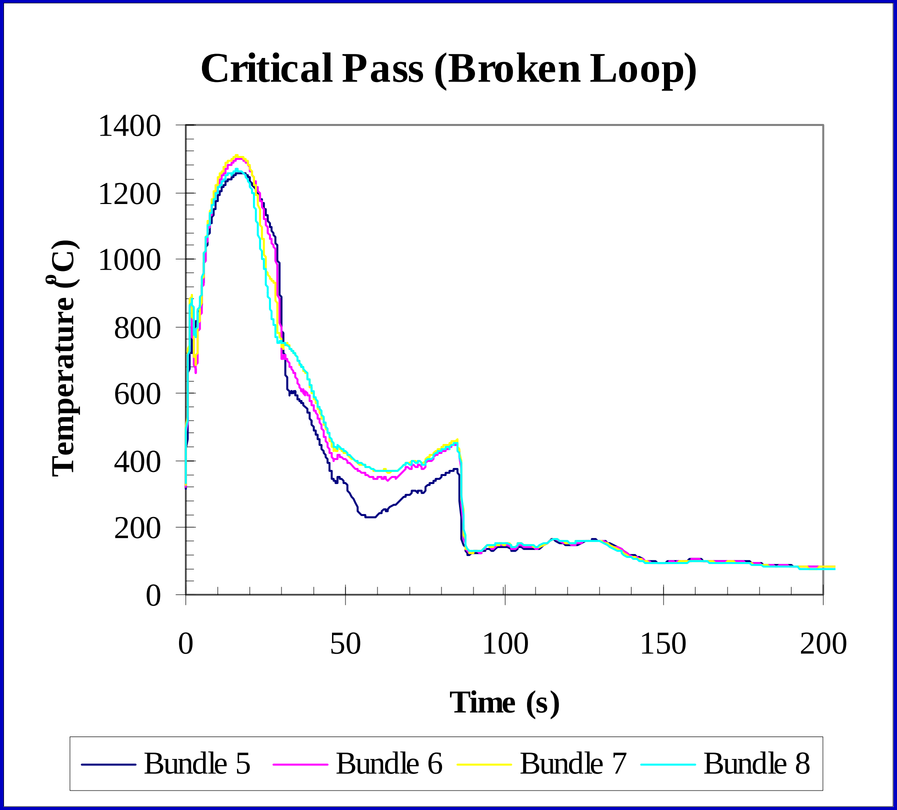


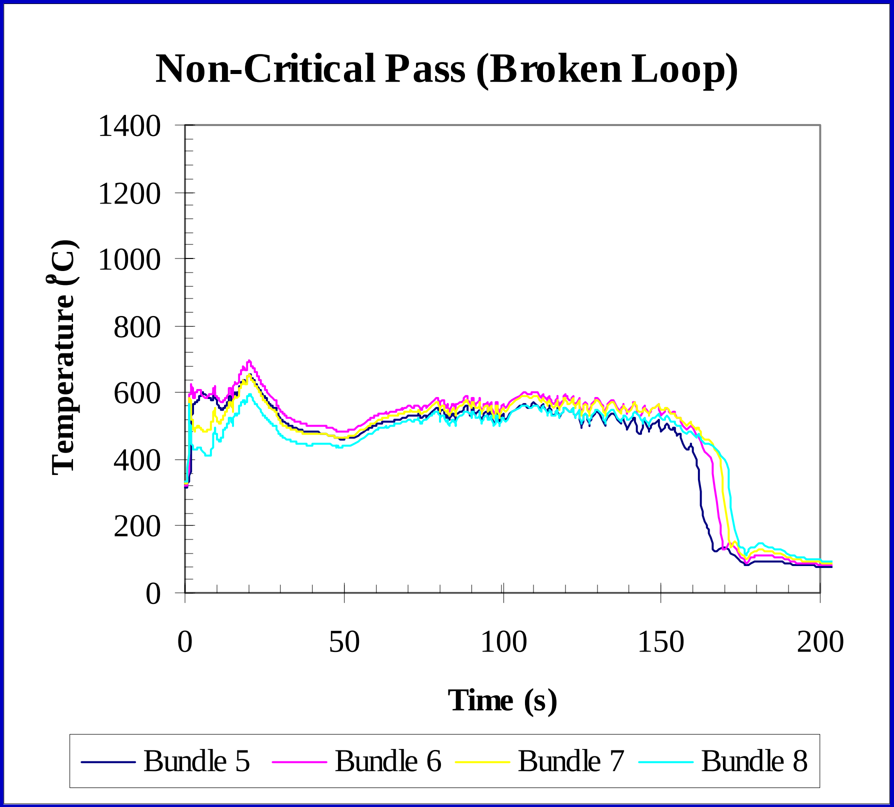




CATHENA Results (Single Channel) - 35% RIH break

- Sheath temperatures in critical pass (i.e., downstream of break location) and non-critical pass of the broken loop (35% RIH LOCA scenario)
- Outer elements of bundle positions 5, 6, 7 and 8
- High-powered Channel O6 (7.3 MW)

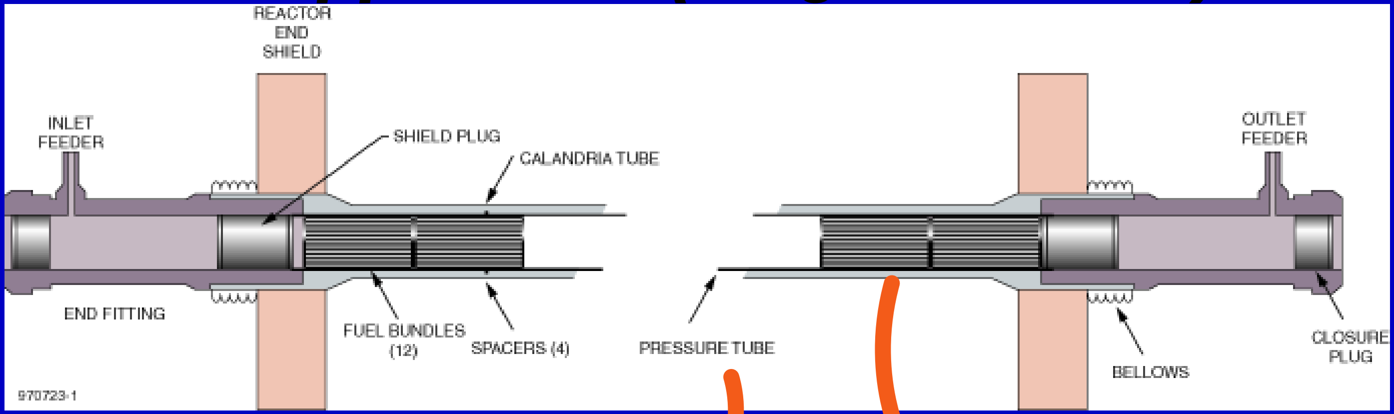


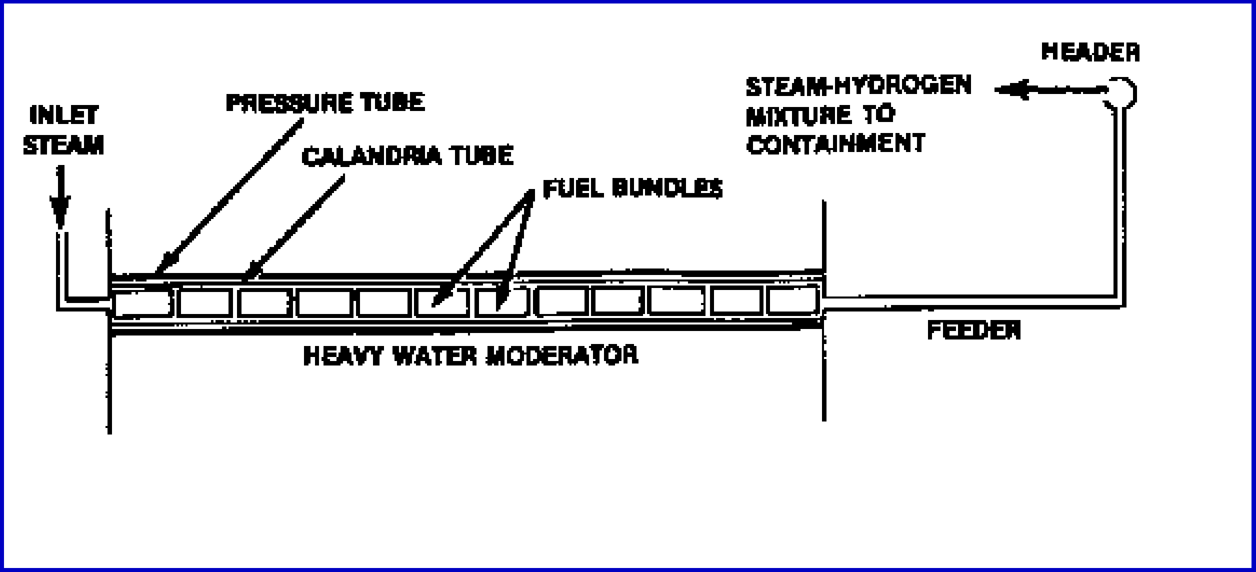


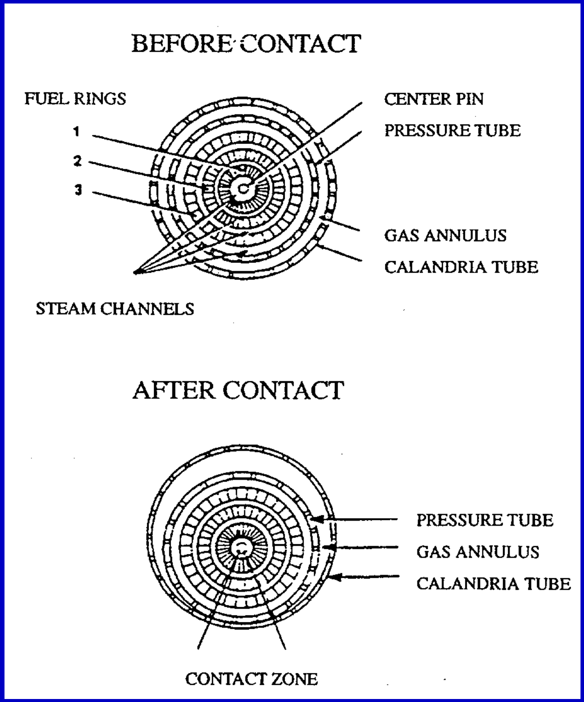
CHAN-II Computer Code

- **Models the thermal and chemical behaviour of a fuel channel under low steam flow conditions**
- **Quantifies the effects of steam flow, metal/water reaction and thermal radiation on fuel temperatures and hydrogen production**
- **A single-channel model divided into 12 axial segments with each bundle segment represented by a lumped parameter ring model**
- **Models pressure tube strain in each channel segment**

CHAN-II Application (Single Channel)

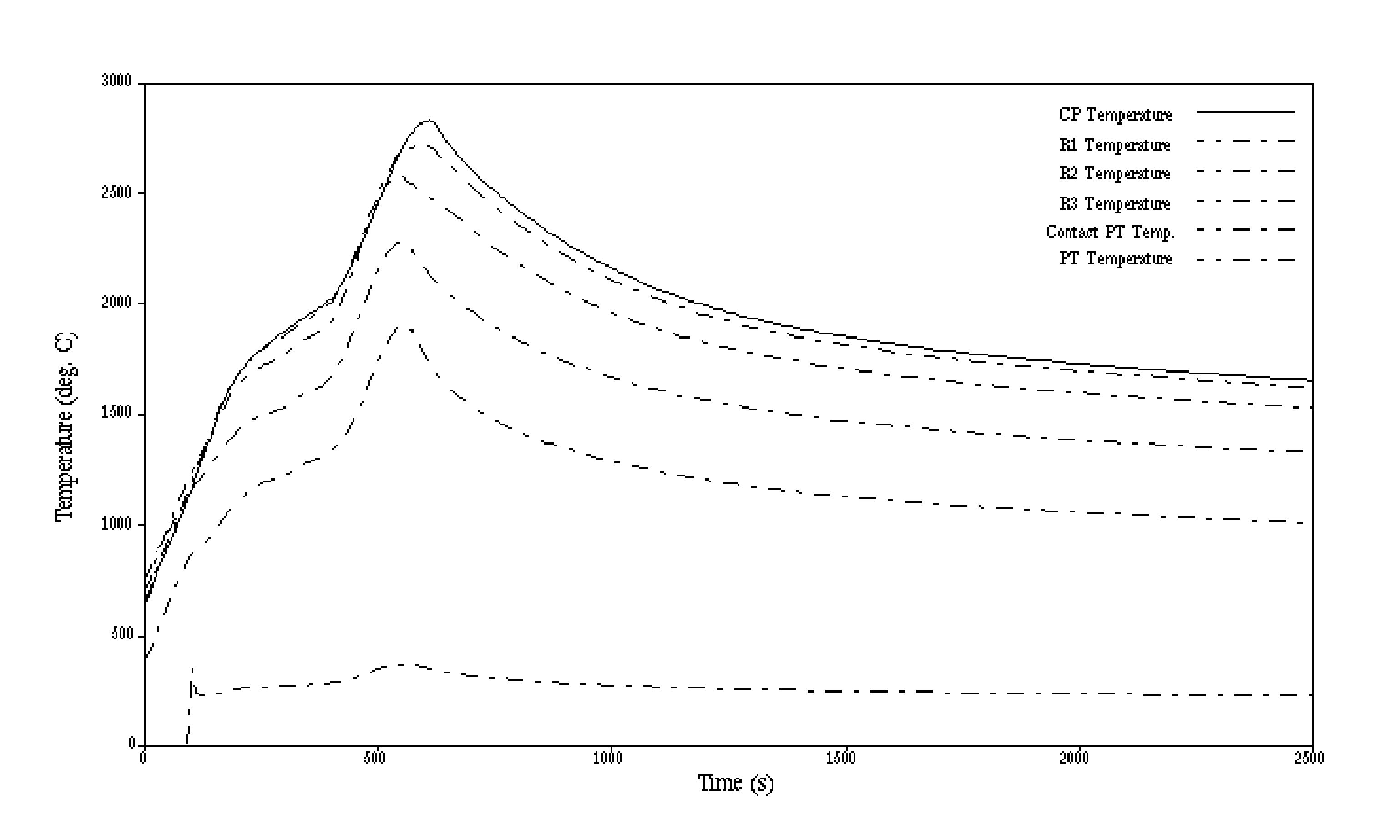






CHAN-II Results (single-channel)

- Fuel temperatures during the late heatup stage of a 35% RIH LOCA/LOECC accident
- Fuel temperatures for different constant steam flows in the channel
- 100% ROH LOCA with LOECC; Channel O6 (7.3 MW); Bundle 8



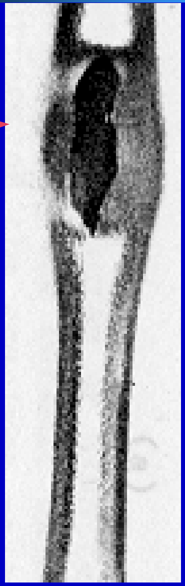
ELOCA

- Models a single fuel element, primarily for the transient thermo-mechanical response following an accident
- Code models:
  - thermal, elastic, and plastic sheath deformation
  - variation of internal gas pressure during the transient
  - variation of the fuel-to-sheath heat transfer coefficient and the fuel-to-sheath radial gap during the transient
  - fuel expansion
  - beryllium-assisted crack penetration of the sheath
  - sheath oxidation rates

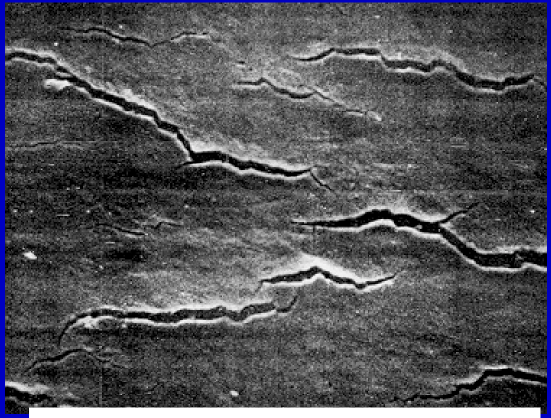
ELOCA Application

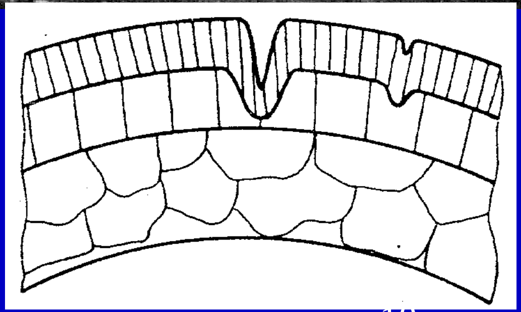
- Some examples applications of the ELOCA code

• Sheath Strain

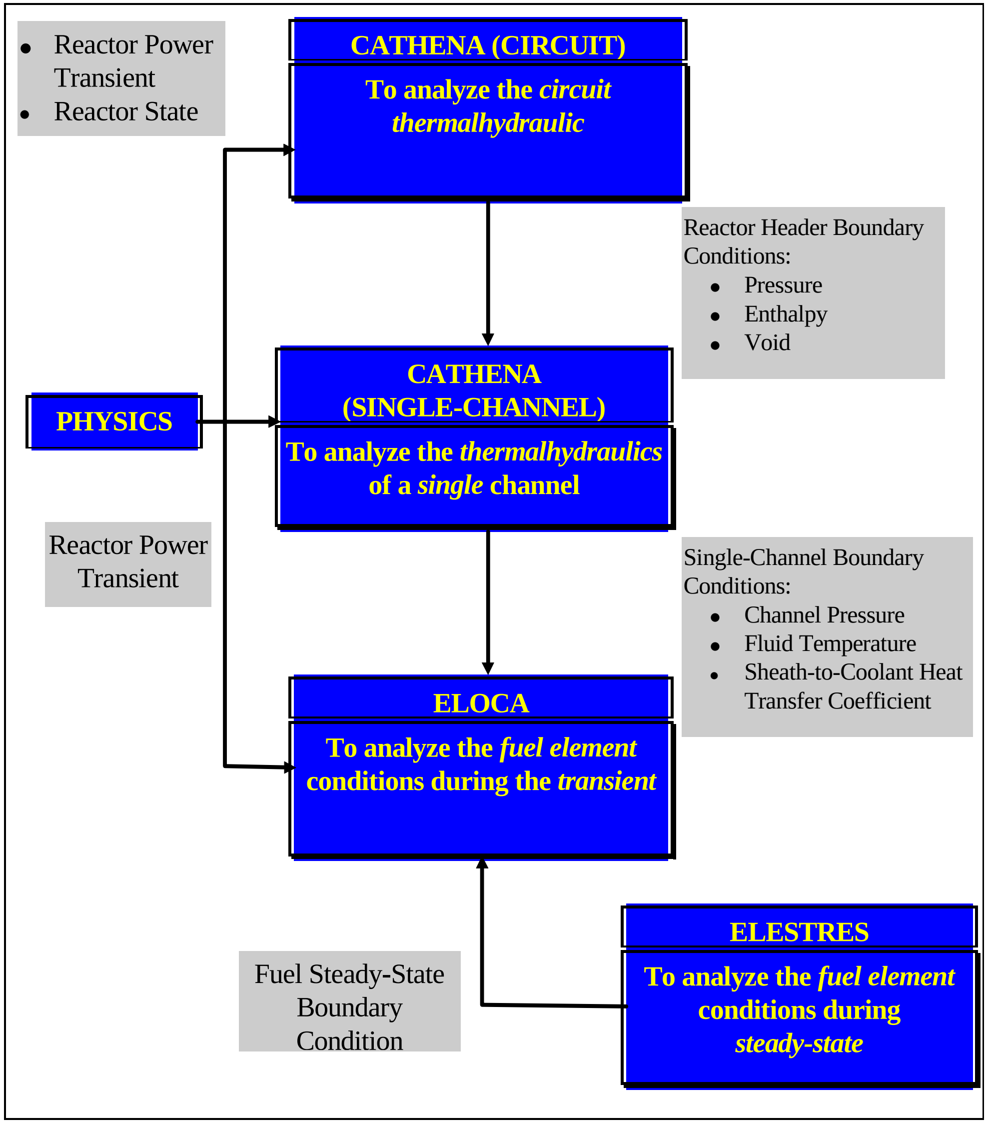


• Sheath Oxide Cracking



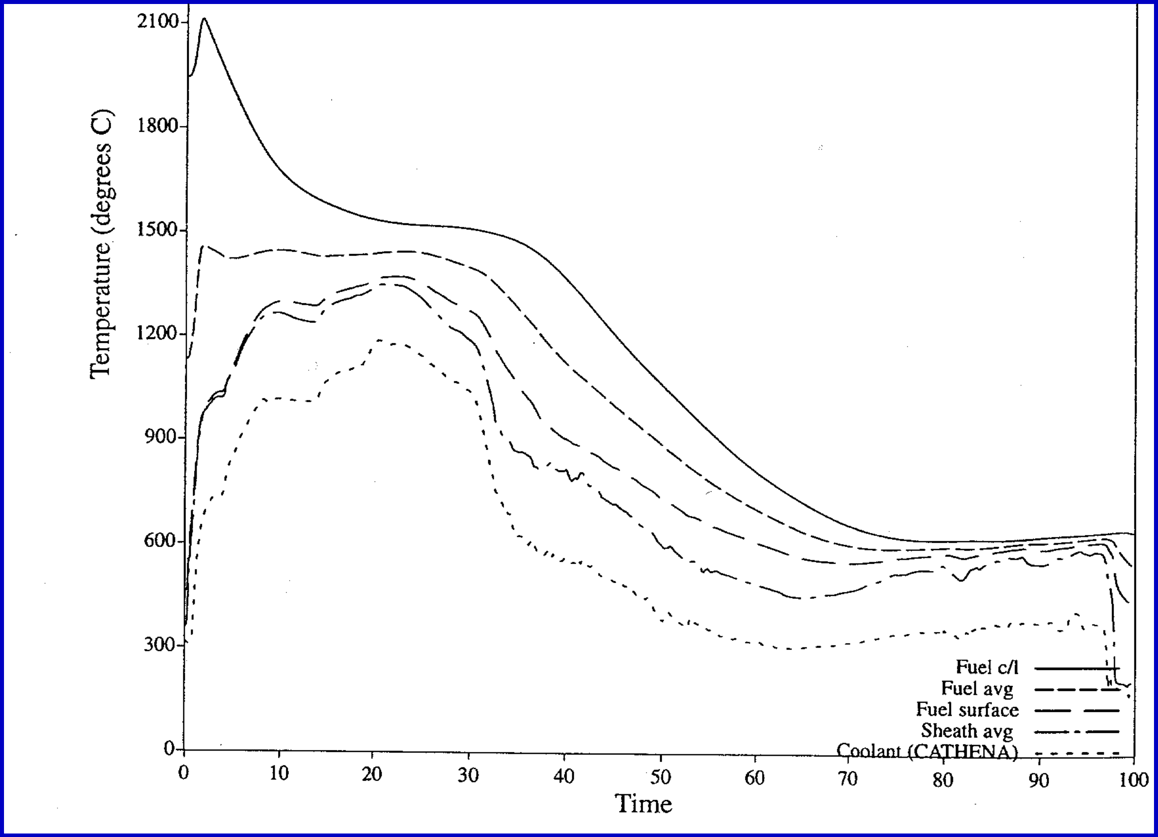


ELOCA Interaction with Other Codes



ELOCA Results - 30% RIH LOCA

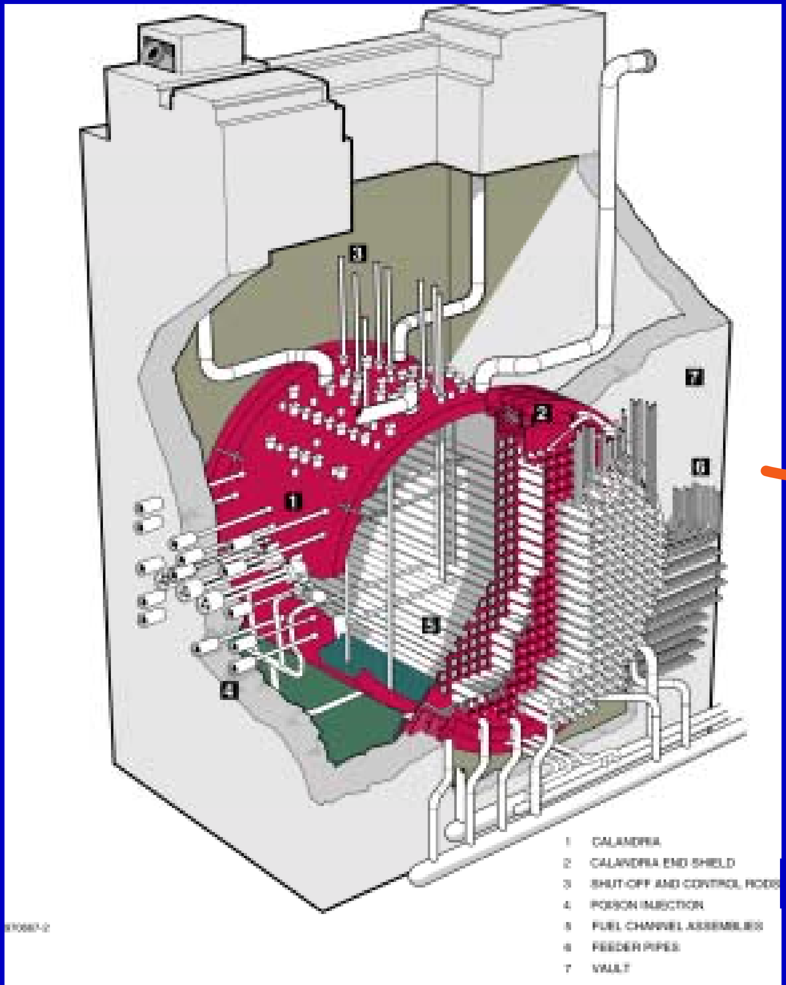
- Sheath temperatures in critical pass (i.e., downstream of break location) of the broken loop (30% RIH LOCA scenario)
- Outer elements of bundle position 6
- High-powered Channel O6 (7.3 MW)



TUBRUPT

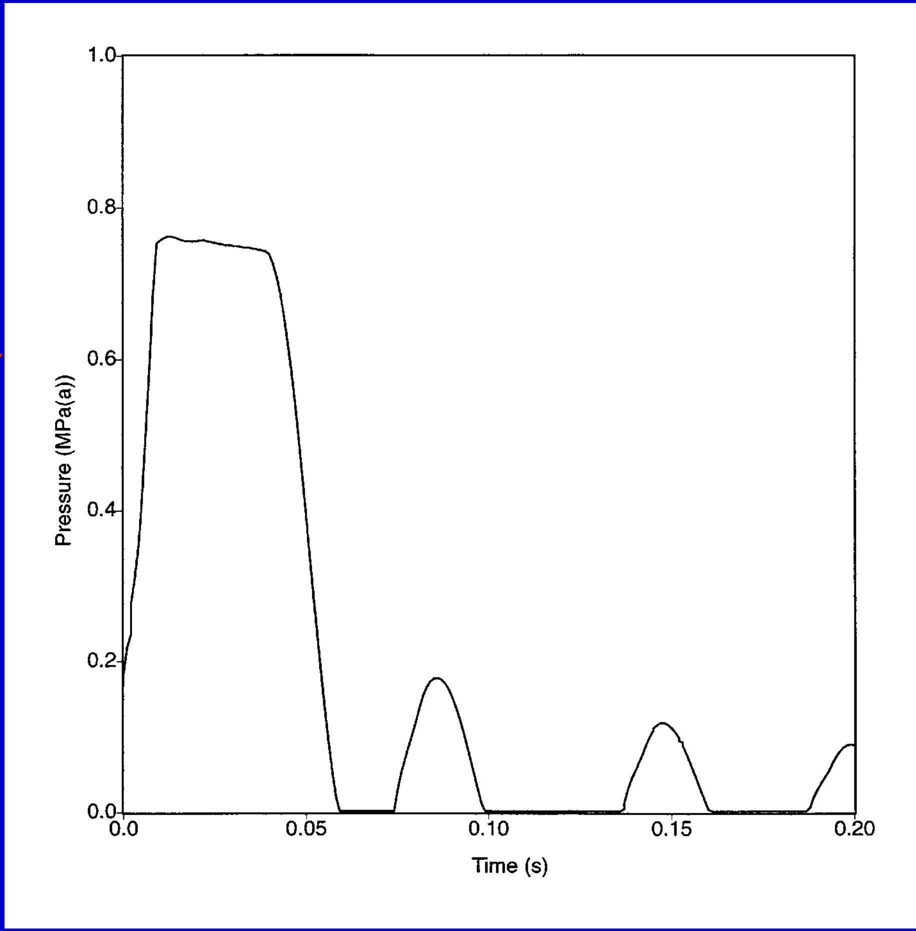
- Used to assess in-core damage following single-channel events (flow blockage/feeder stagnation breaks, pressure tube rupture)
- Models the hydrodynamic transient in the calandria vessel (pressure pulse), shutoff rod damage and potential damage to adjacent channels
- Phenomena modelled includes:
  - bubble dynamics in calandria vessel
  - bubble condensation
  - calandria vessel response
  - relief pipe discharge flow
  - shield tank behaviour
  - damage to shutoff rod guide tube, adjacent channels
  - molten-material interaction for feeder stagnation and flow blockage accidents

TUBRUPT Application



CANDU 6 Reactor Assembly

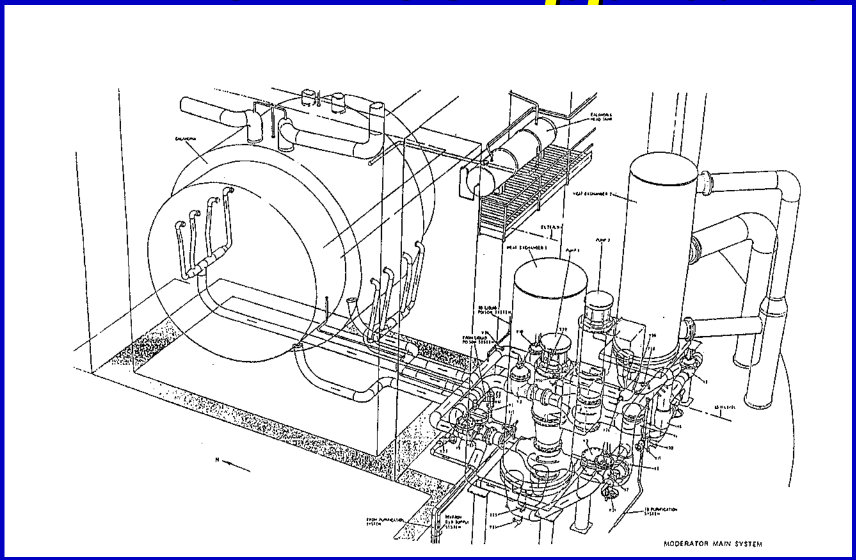
PRESSURE ON INSIDE OF CALANDRIA VESSEL WALL

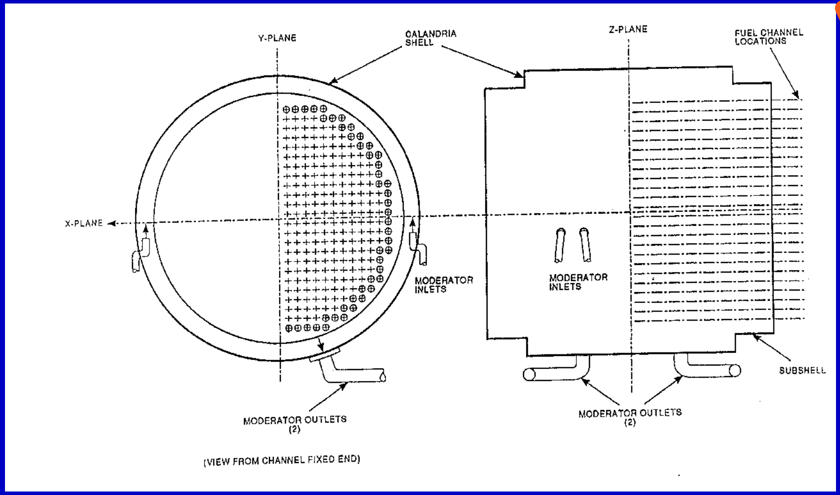


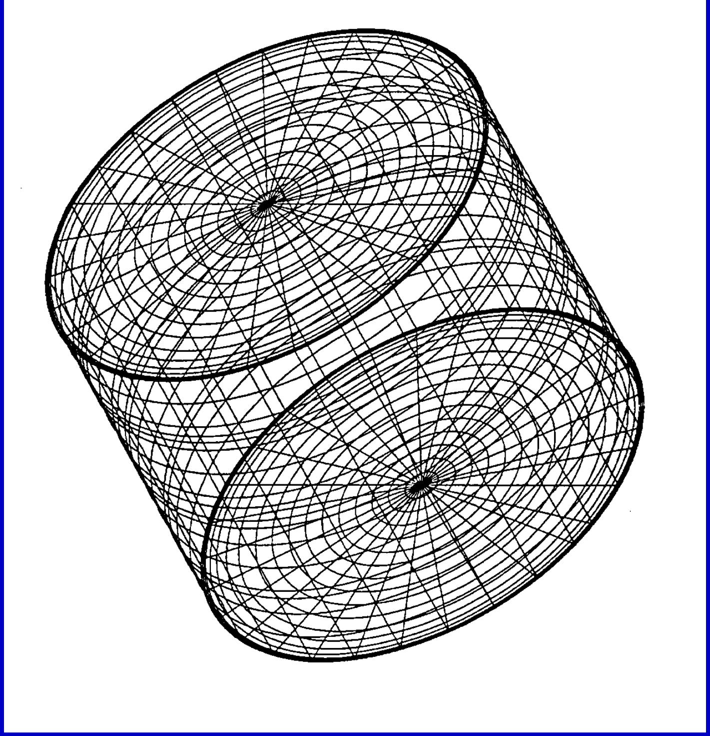
PHOENICS

- Used to determine the local temperatures in the moderator following accident scenarios
- This is important for channel integrity (i.e. during a LOCA and LOCA/LOECC), since the local temperature will determine the amount of subcooling margin
- The subcooling margin is tied in with the contact boiling experiments previously discussed
  - temperature of the pressure tube at the time of contact with the calandria tube
  - subcooling available
  - assessment of whether the calandria tube will go into dryout or no-dryout

PHOENICS Application

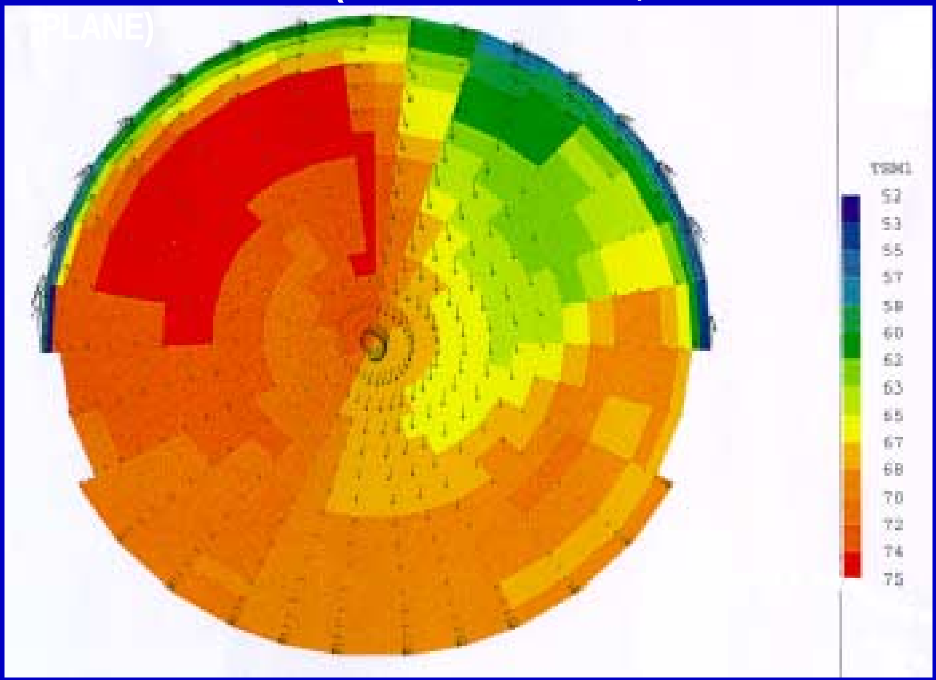




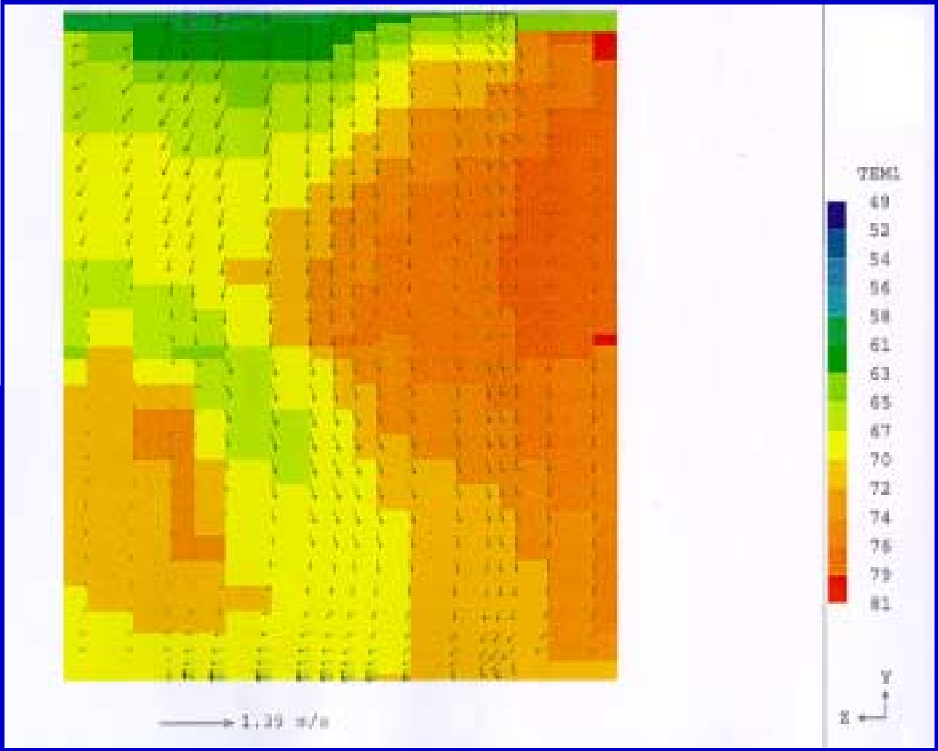


PHOENICS Results

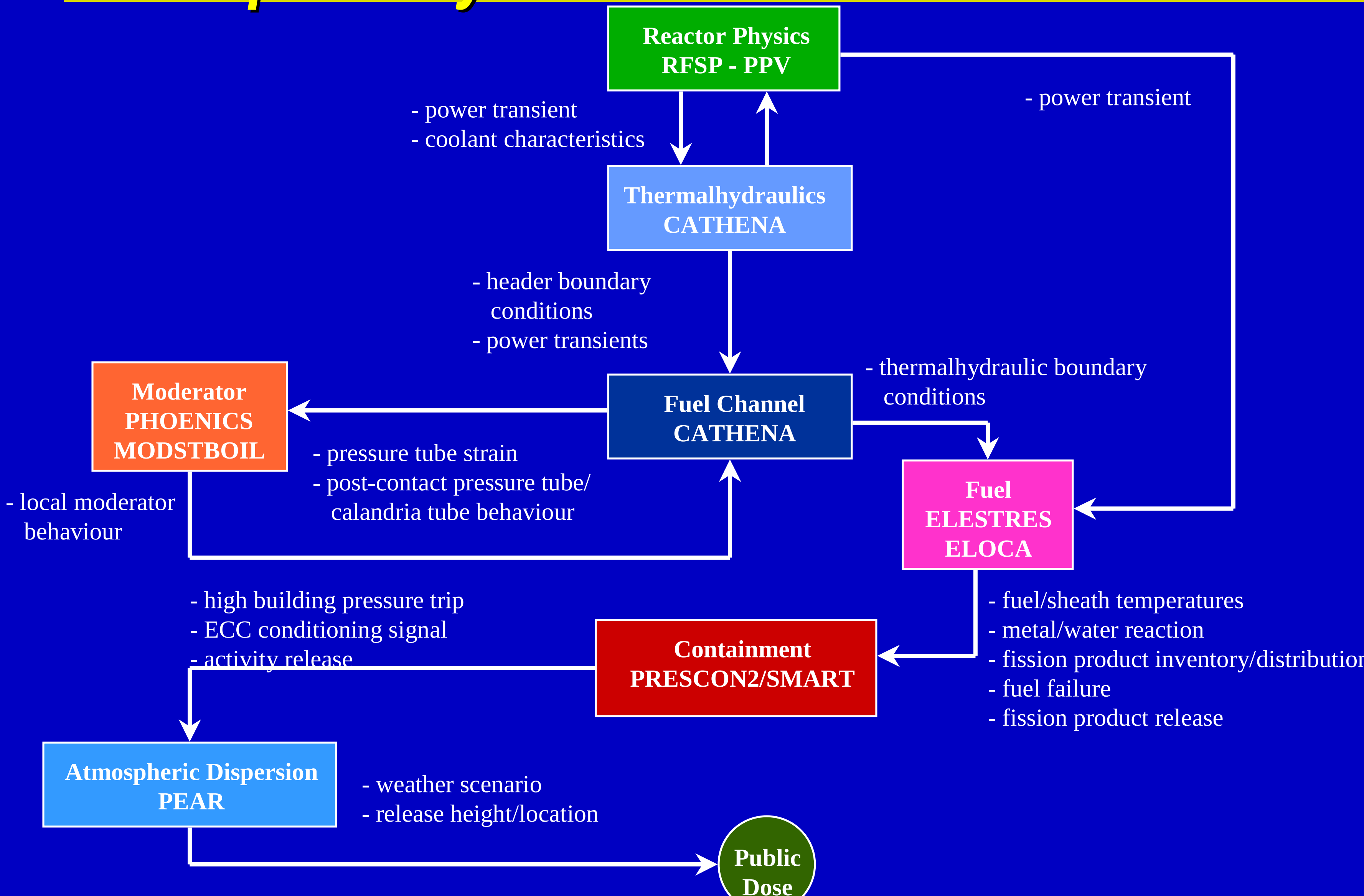
MODERATOR TEMPERATURE DISTRIBUTION AT STEADY-STATE (RADIAL DIRECTION, NEAR MID-PLANE)



MODERATOR TEMPERATURE DISTRIBUTION AT STEADY-STATE (AXIAL DIRECTION)



Sample Analysis Process



Canadian Industry Standard Toolset

- Recently, in Canada, the nuclear industry (AECL, and Canadian nuclear power utilities) have come together and agreed to adopt a single computer code for several different disciplines
- These industry standard toolset (IST) codes will be used by the Canadian nuclear industry for safety analyses
- Under the IST initiative, computer codes are also undergoing extensive validation

Computer Code Validation

- Involves various stages:
  - Phenomena Synopsis Report
    - Provides a detailed discussion of the phenomena for various disciplines such as fission product release, fuel channel etc.
  - Technical Basis Document (TBD):
    - provides a detailed description of the phenomena associated with each stage of the accident (i.e., for 3-stages in LOCA: power pulse stage, blowdown stage, refill stage)
  - Validation Matrix:
    - detailed review of Canadian and international experiments related the various disciplines (i.e., fission product release, fuel and fuel channel thermal-mechanical behaviour etc)
  - Validation Test Plan:
    - identifies scope, objective, cost, resources, QA procedures to follow, test selection criteria etc
  - Validation Exercise Reports:
    - identifies the experiment facility, phenomena, accident scenario, test cases, modelling assumptions, boundary conditions, test results, uncertainties, etc
  - Validation Manual:
    - ties all of the validation exercise reports together