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
- CODES
- SAFETY REPORT

- THEORY
- REPRESENTATIVE MODELS
- 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

CANDU 6 Fuel Element Temperatures (ELESTRES)

Temperature

Outer Fuel Element Burnup

- Fuel Pellet Centerline
- Fuel Pellet Average
- Fuel Pellet Surface
- Sheath Inner Surface
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

Coolant Flow at Center of Downstream Core Pass (RIH)

Flow (kg/s)

0 100 200 300 400 500

Time (s)

0 10 20 30 40 50

-500

20% RIH 25% RIH 30% RIH

35% RIH 40% RIH 100% RIH

RIH Break Survey - Outside Sheath Temperature at Bundle 7 (center channel) of Critical Core Pass

Temperature (°C)

0 200 400 600 800 1000 1200

Time (s)

0 20 40 60 80 100

20% RIH 25% RIH 30% RIH 35% RIH

40% RIH 100% RIH
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)**

Diagram of a single channel with components labeled:
- Reactor End Shield
- Inlet Feeder
- End Fitting
- Fuel Bundles (12)
- Spacers (4)
- Calandria Tube
- Shield Plug
- Pressure Tube
- Outlet Feeder
- Bellows
- Closure Plug

Diagram showing a cross-section of the channel with:
- Inlet Steam
- Pressure Tube
- Calandria Tube
- Fuel Bundles
- Steam-Hydrogen Mixture to Containment
- Header
- Heavy Water Moderator
- Feeder

**BEFORE CONTACT**
- Fuel Rings
- Center Pin
- Pressure Tube
- Gas Annulus
- Calandria Tube

**AFTER CONTACT**
- Pressure Tube
- Gas Annulus
- Calandria Tube
- Contact Zone
**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
Some examples applications of the ELOCA code

- Sheath Strain
- Sheath Oxide Cracking
ELOCA Interaction with Other Codes

- **CATHENA (CIRCUIT)**
  To analyze the circuit thermalhydraulic

- **CATHENA (SINGLE-CHANNEL)**
  To analyze the thermohydraulics of a single channel

- **PHYSICS**
  Reactor Power Transient

- **ELOCA**
  To analyze the fuel element conditions during the transient

- **ELESTRES**
  To analyze the fuel element conditions during steady-state

**Reactor Header Boundary Conditions:**
- Pressure
- Enthalpy
- Void

**Single-Channel Boundary Conditions:**
- Channel Pressure
- Fluid Temperature
- Sheath-to-Coolant Heat Transfer Coefficient

**Fuel Steady-State Boundary Condition**
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

PRESSURE ON INSIDE OF CALANDRIA VESSEL WALL

Diagram of CANDU 6 Reactor Assembly with a graph showing pressure over time.
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

- Header boundary conditions
- Power transients

Reactor Physics
RFSP - PPV
- Power transient
- Coolant characteristics

Thermalhydraulics
CATHENA
- Header boundary conditions
- Power transients

Fuel Channel
CATHENA
- Thermalhydraulic boundary conditions

Moderator
PHOENICS MODSTBOIL
- Local moderator behaviour
- Pressure tube strain
- Post-contact pressure tube/calandria tube behaviour
- High building pressure trip
- ECC conditioning signal
- Activity release

Fuel Channel
CATHENA
- Fuel/sheath temperatures
- Metal/water reaction
- Fission product inventory/distribution
- Fuel failure
- Fission product release

Containment
PRESCON2/SMART
- Weather scenario
- Release height/location

Atmospheric Dispersion
PEAR
- Power transient

Fuel
ELESTRES ELOCA

Public Dose
- Weather scenario
- Release height/location
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