CANDU Safety #12: Large Loss of Coolant Accident

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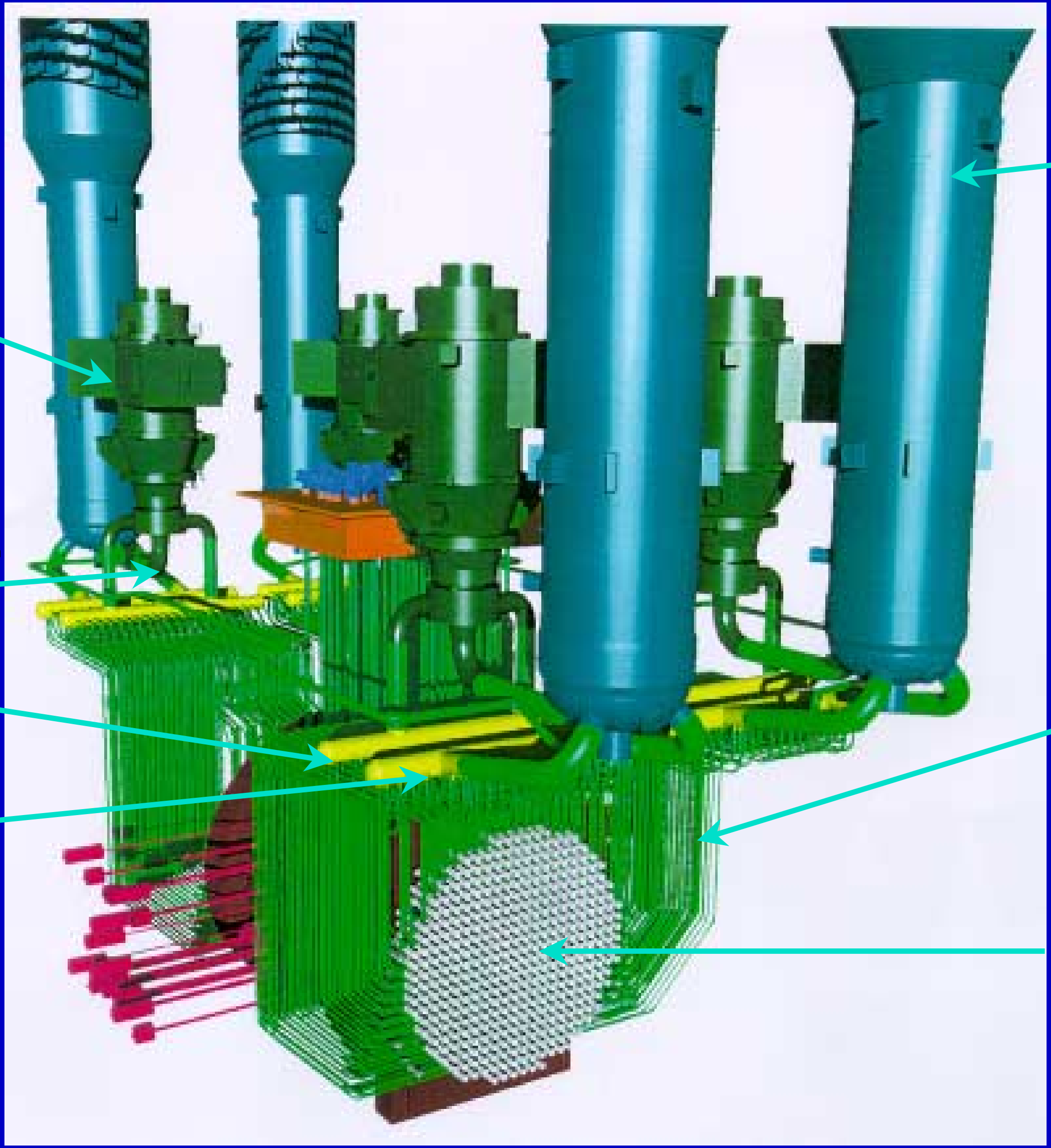
Overview

- Event sequence for a large break loss-of-coolant accident (LOCA)
- Acceptance criteria used to assess the results of the analysis
- Normal operating conditions
- Fuel and pressure tube behaviour during the transient
- Fission product release behaviour
- Containment behaviour

Large LOCA with ECC Available

- Event Sequence
  - A large break occurs in a large diameter pipe in PHT, discharging coolant into containment
  - PHT depressurizes causing coolant voiding and an increase in reactivity
  - Reactor power increases until the reactor is shutdown on a neutronic trip (i.e., high power, high-rate power) or process trip (i.e., low PHT pressure, low pressurizer level, high containment pressure etc.)
  - The PHT flow decreases fastest in the core pass downstream of the break; and coolant stagnation occurs
  - Onset of fuel dryout results in an increase in fuel temperature
  - Once the PHT pressure is reduced to the ECC activation setpoint, ECC is activated; the two loops are isolated from each other

Primary Heat Transport System



Steam Generators

PHT Pumps

Feeders

Reactor/Fuel Channels

Postulated Break Locations

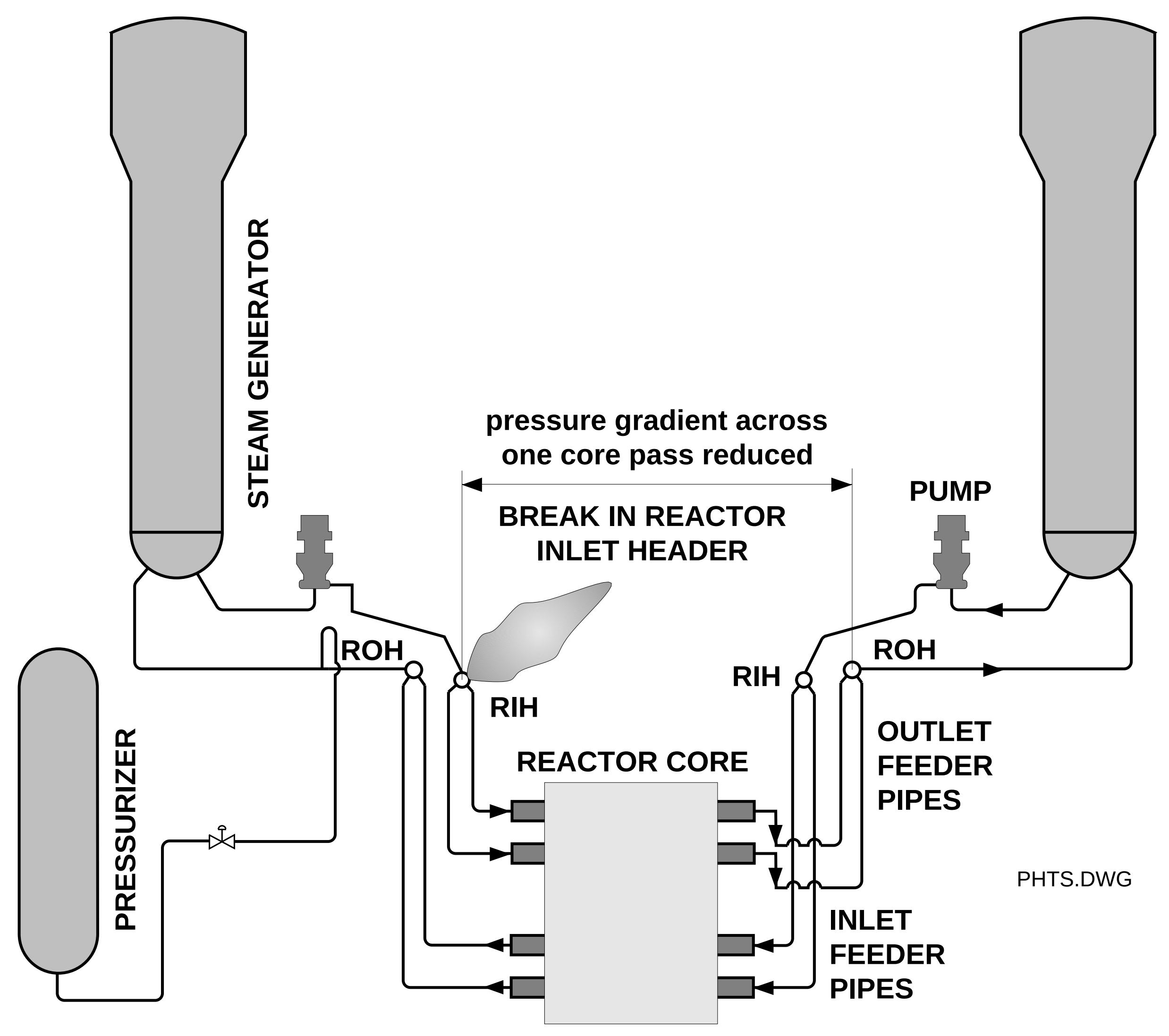
1) Pump Suction

2) Inlet Header

3) Outlet Header

Break in Primary Heat Transport System

- Critical pass is the pass downstream of the break location
- Key of analysis is to stagnate the flow in the channel



Analysis Acceptance Criteria

- **Dose limits are not exceeded**
- **Two independent shutdown systems will arrest the reactivity and power excursion, and will maintain the reactor in a shutdown state**
- **Fuel channel integrity is not compromised**
- **The structural integrity of the containment must be maintained**

Large Break LOCA Safety Analysis

- **Involves determining:**
  - **Fuel normal operating conditions**
  - **Fuel and fuel channel temperatures during LOCA transient**
  - **Fission product release during transient**
  - **Containment analysis**
  - **Dose analysis**

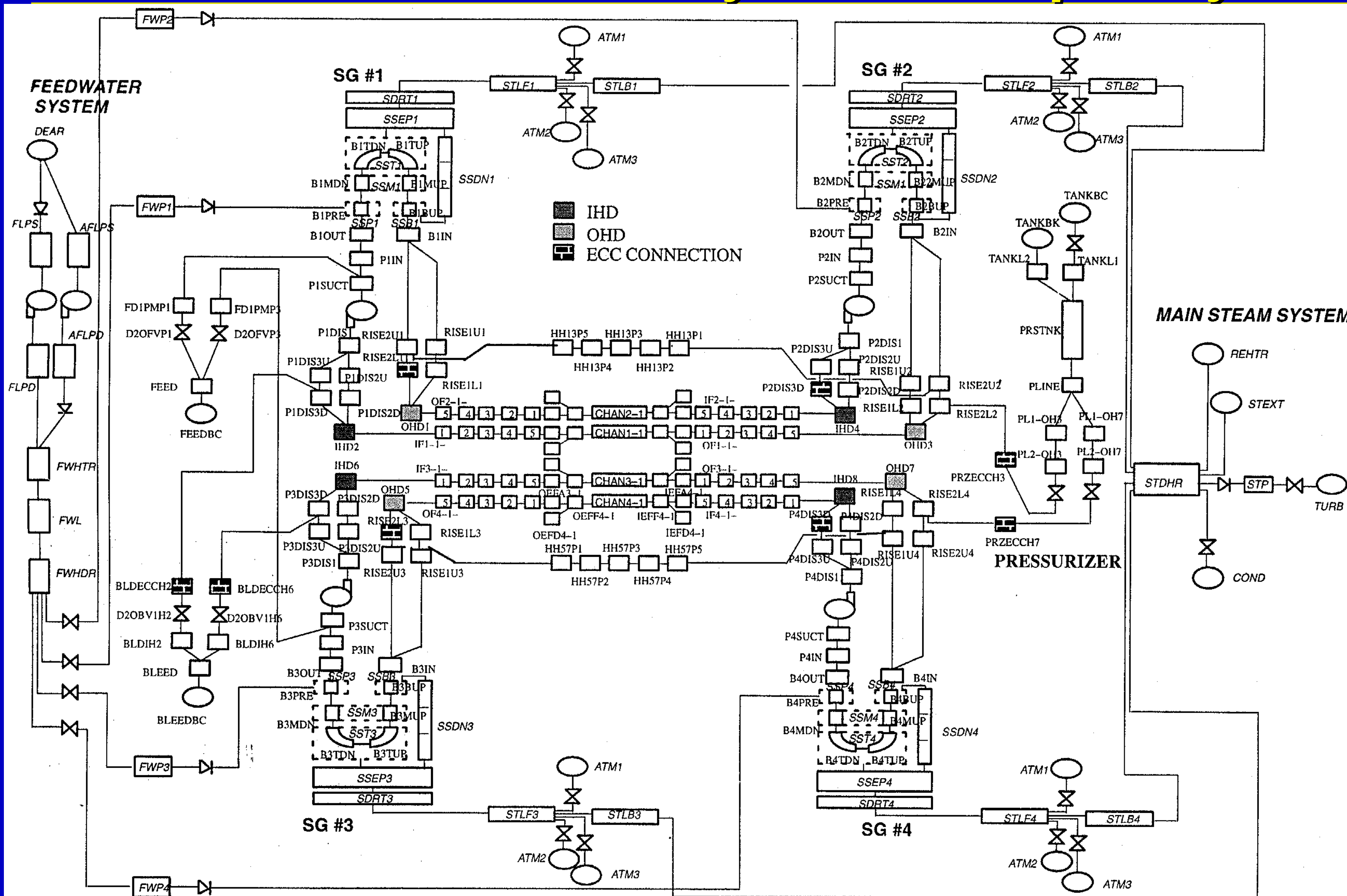
Fuel conditions prior to the onset of the accident

- Normal operating conditions is modelled by the ELESTRES computer code
- Main Input Requirements
  - Fuel element (pellet and sheath) dimensions & properties
  - Power/burnup history
  - Coolant temperature and pressure
- Important Output Parameters
  - Fission product distribution (gap, grain boundary and grain bound)
  - Internal gas pressure
  - Fuel temperatures
  - Pellet strain

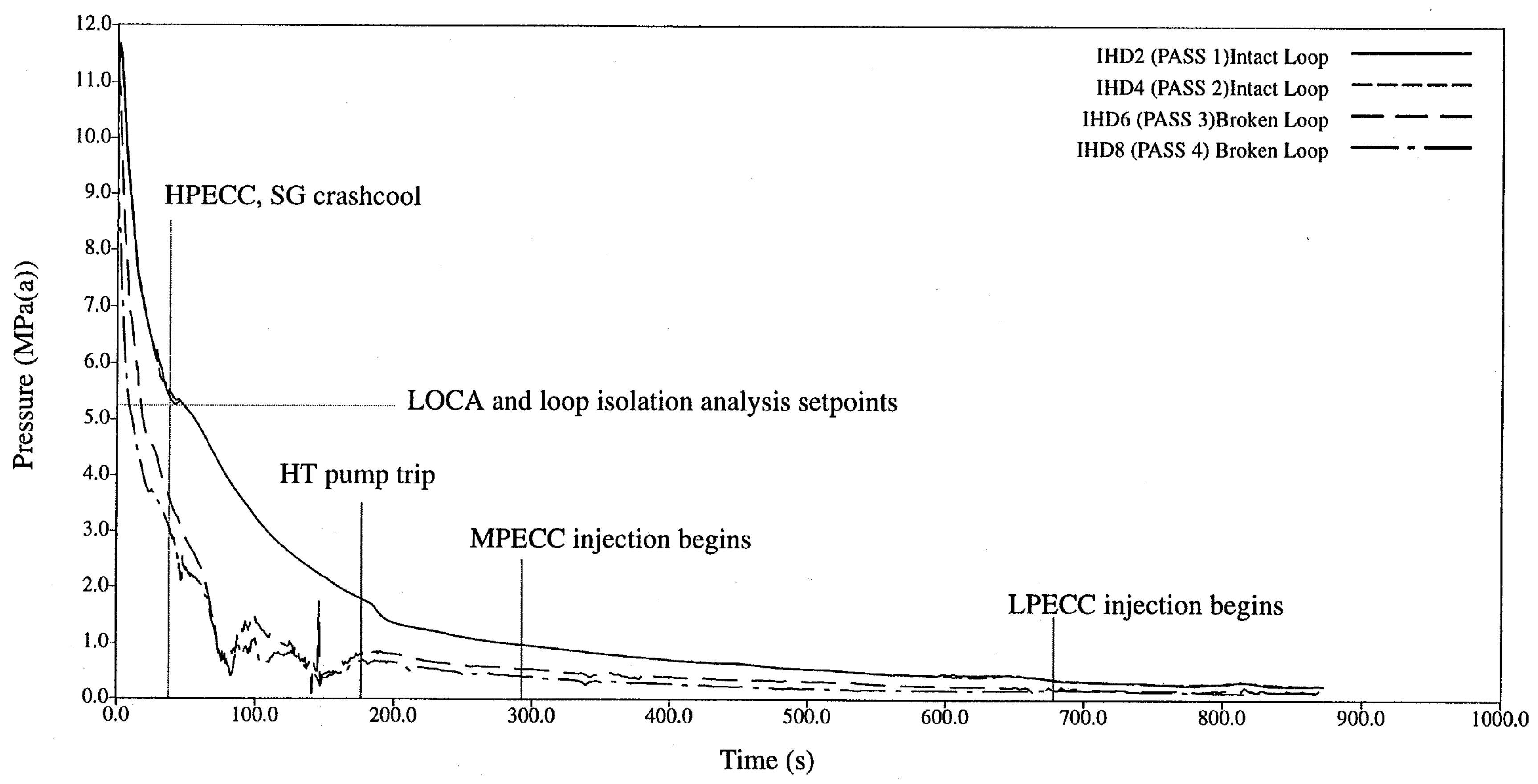
Transient Temperatures

- Thermalhydraulic behaviour is calculated by the CATHENA circuit model
  - λ Reactor Inlet Header Break (RIH)
    - 20%, 25%, 30%, 35%, 40% & 100%
  - λ Pump Suction Pipe Break (PS)
    - 40%, 45%, 50%, 55%, 60%, 70% & 100%
  - λ Reactor Outlet Header Break (ROH)
    - 80%, 90%, 95% & 100%
- A critical break size is identified for each break location and a detailed CATHENA single-channel analysis is performed:
  - λ 35% RIH , 55% PS & 100% ROH

Circuit Model of Primary Heat Transport System

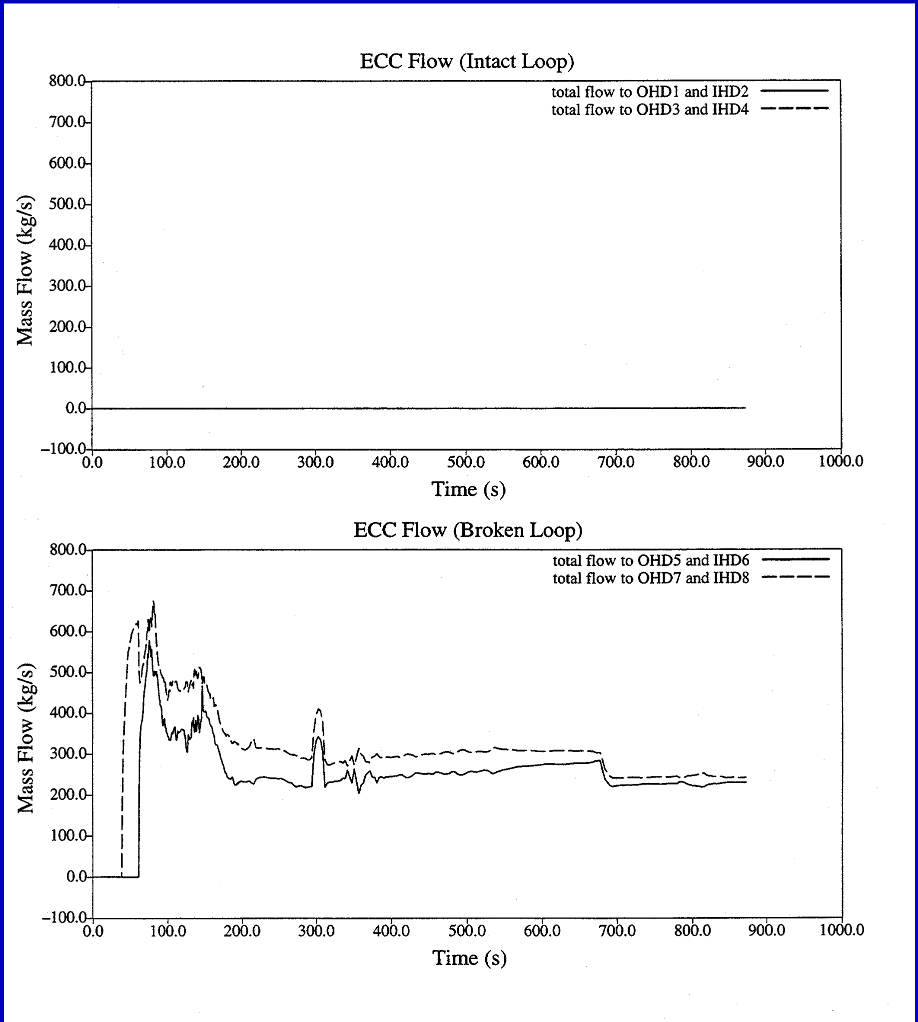


Depressurization in Inlet Headers (35% RIH Break)



ECC Flows

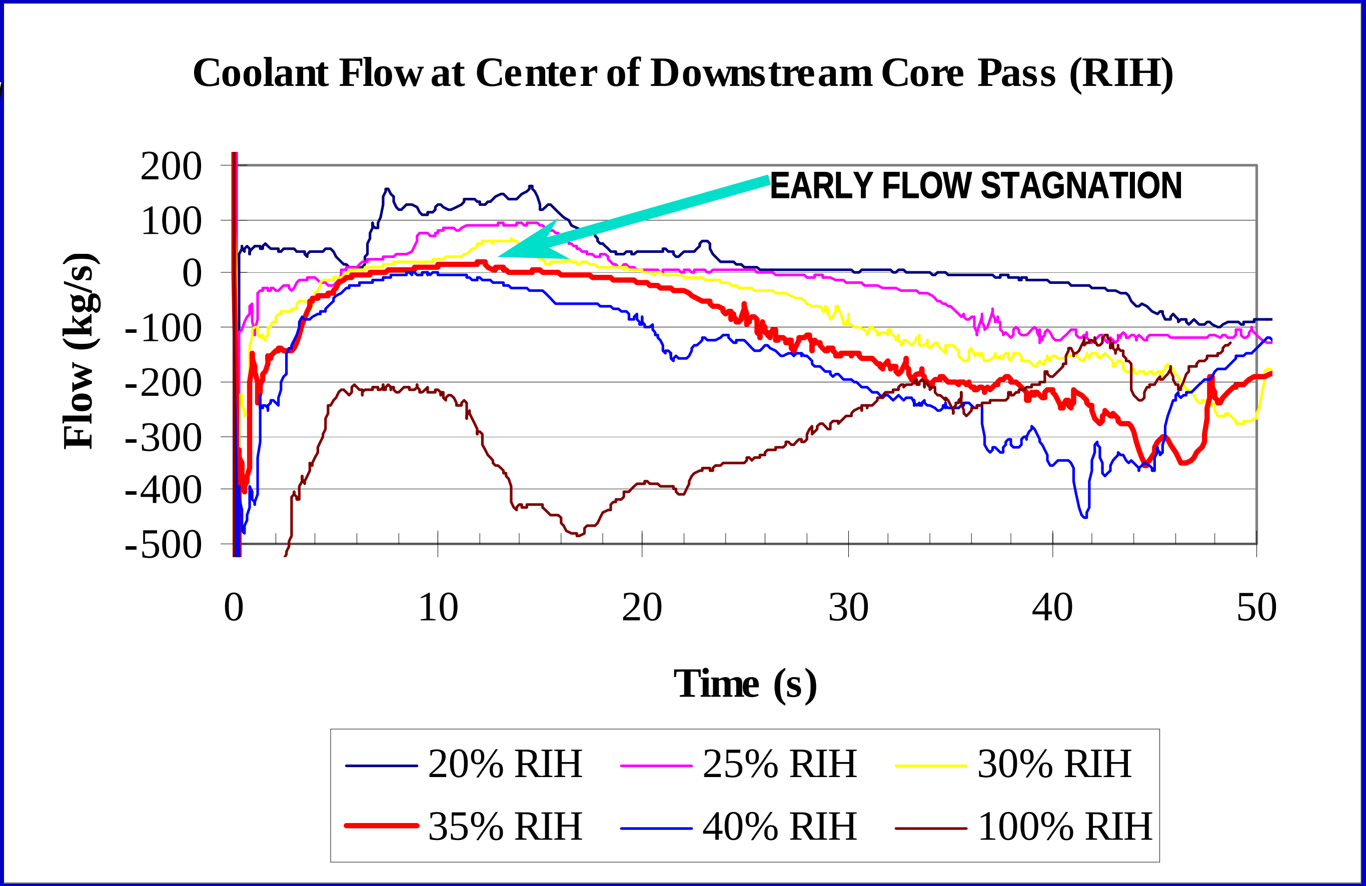
- No ECC flow into the intact loop, since
  - intact loop pressure > broken loop pressure (intact loop was isolated from the broken loop)
  - Intact loop pressure > ECC supply pressure
- LOCA signal & loop isolation initiated at 9 s after accident
- Loop isolation complete by 29 s
- ECC flows into the broken loop, 3 stages
  - High-pressure injection initiation (38 s)
  - Medium-pressure injection (293 s)
  - Low-pressure injection (678 s)



Break Survey for RIH breaks (Flows)

CATHENA Circuit Model

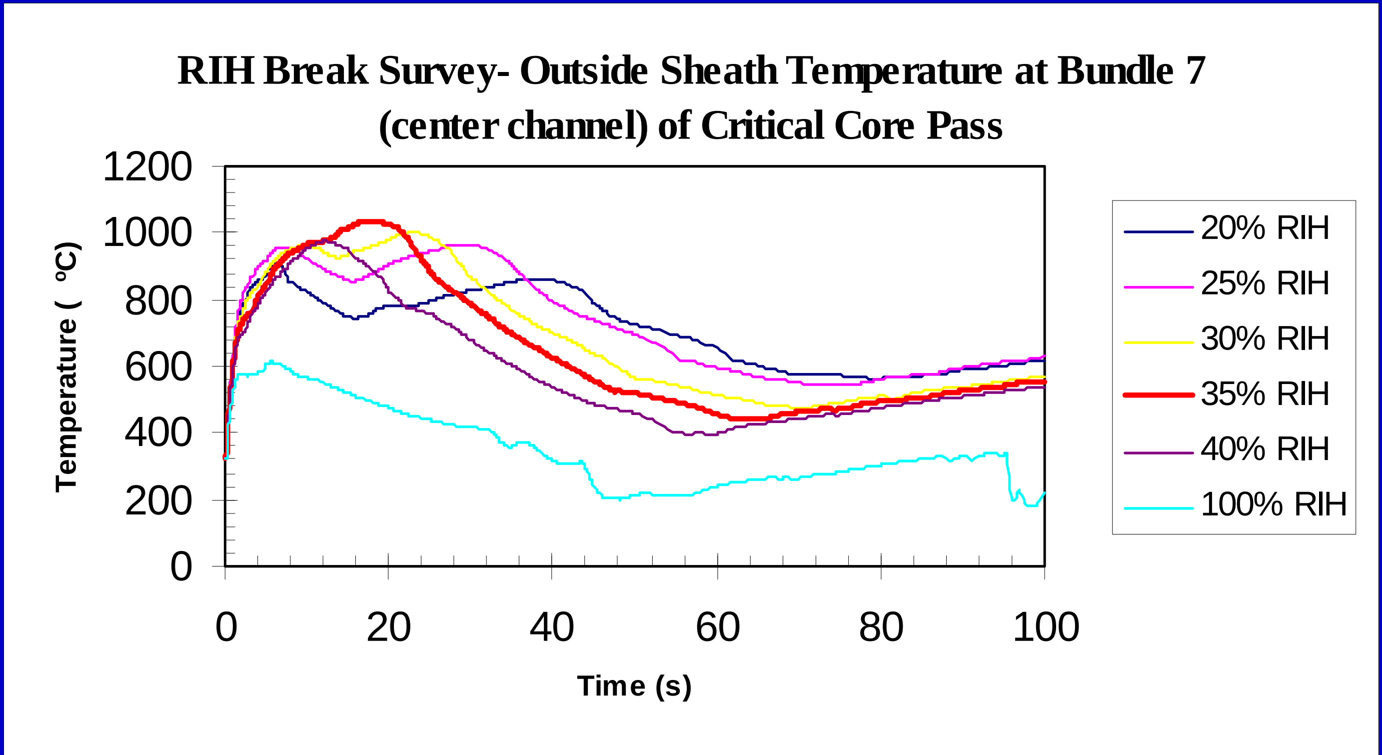
- **large breaks ==> sustained reverse flow**
- **small breaks ==> forward flow**
- **medium breaks ==> stagnation**
- **Critical break is 35% RIH**



Break Survey for RIH breaks (Sheath Temperature)

CATHENA Circuit Model

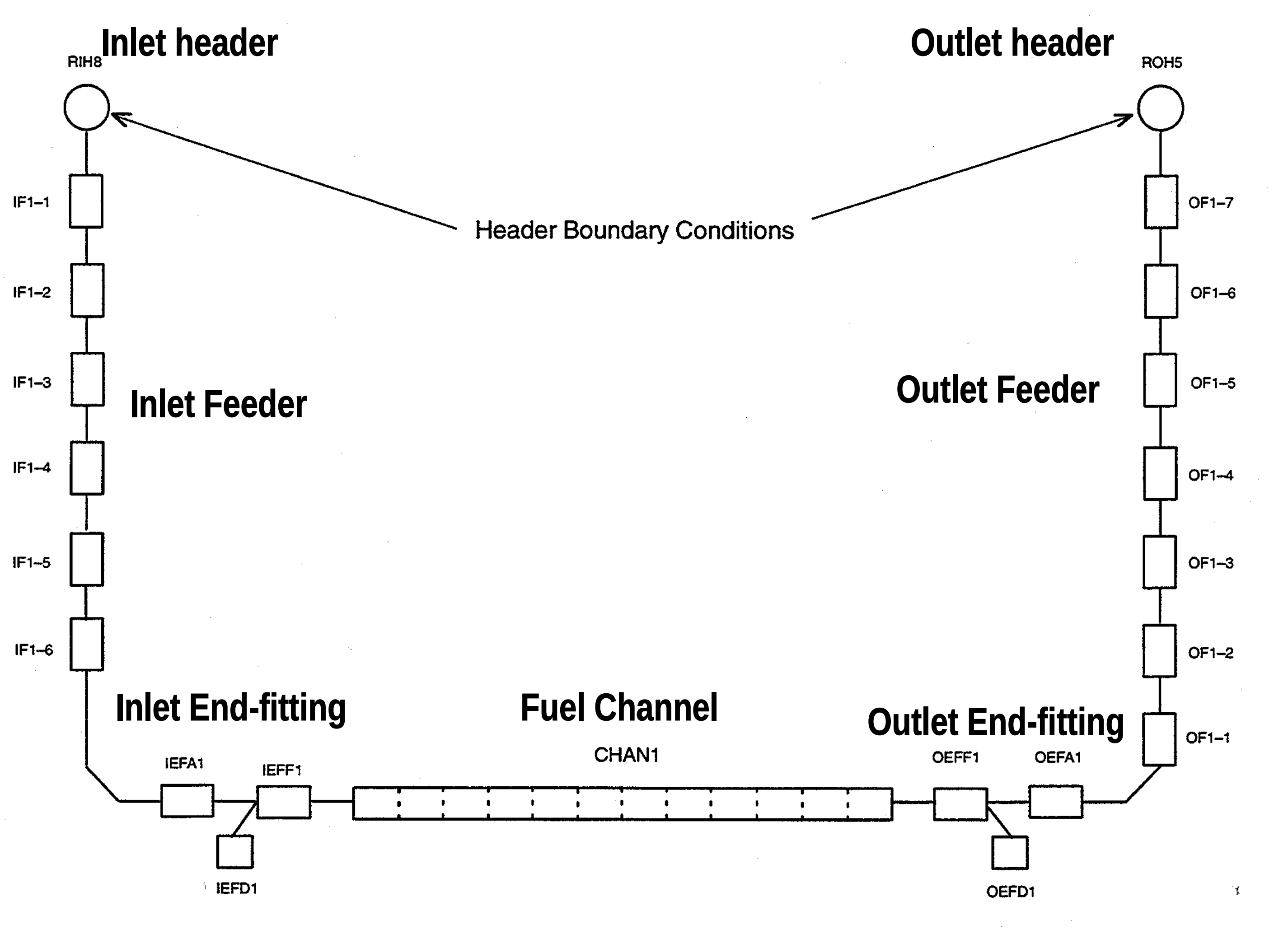
- Temperature transient corresponds to flow conditions
- Flow stagnation ==> temperatures increase
- Break in flow stagnation ==> temperatures drop
- Critical break is 35% RIH



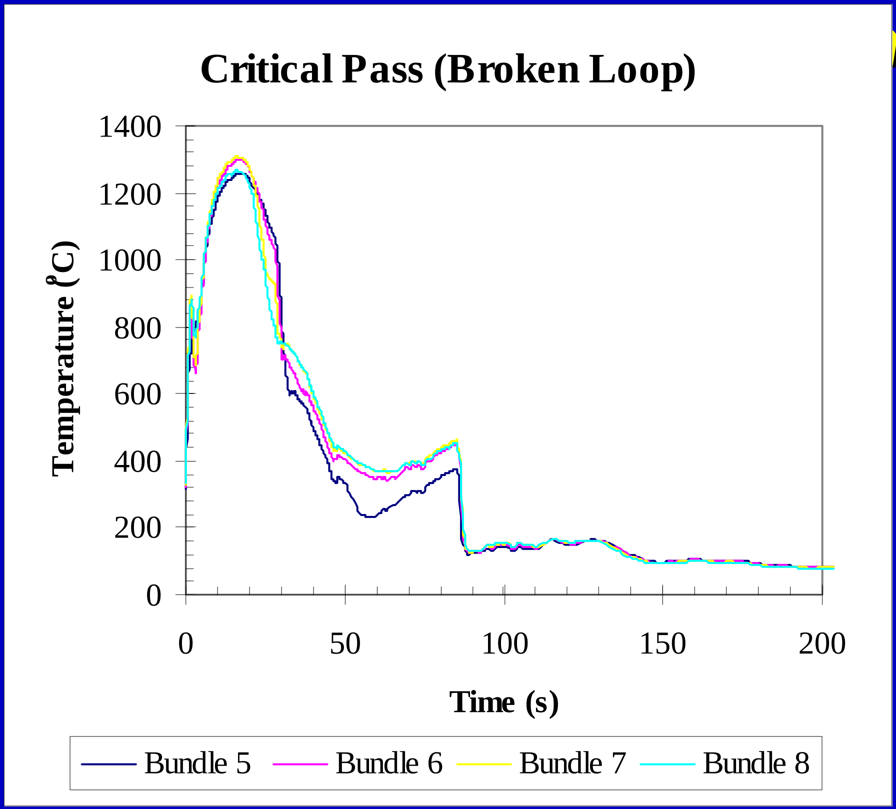
Single Channel Model for 35% RIH Critical Break

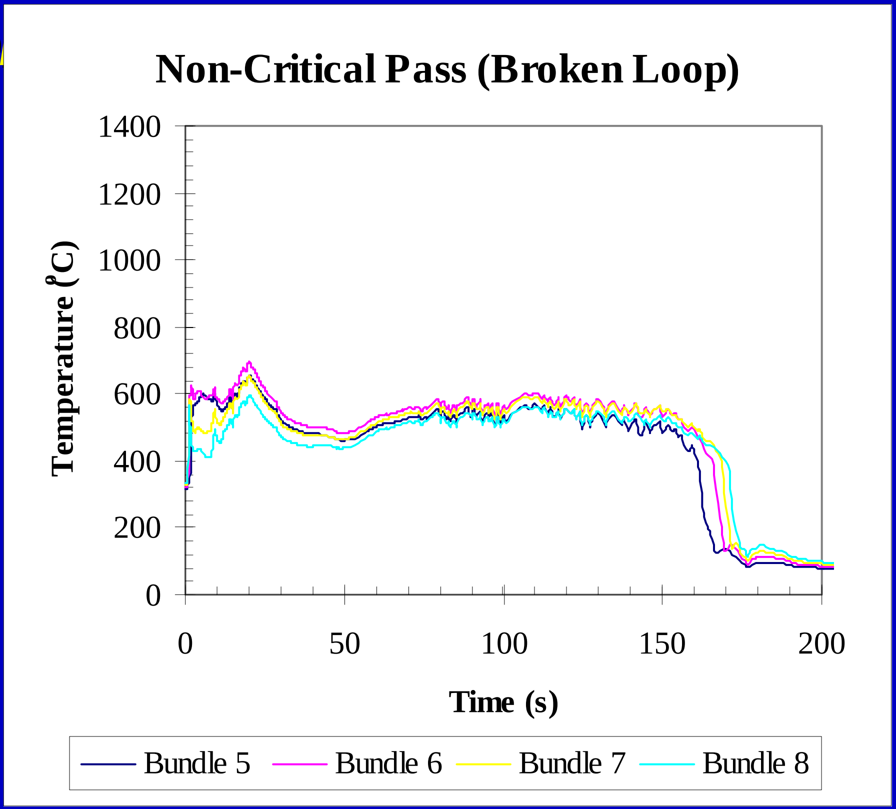
Boundary Conditions from Circuit Analysis Applied

- Header boundary conditions (pressure, enthalpy, void)
- 6 inlet feeder segments
- Inlet end-fitting model
- 12 channel segments (for 12 bundles)
- Outlet end-fitting model
- 7 outlet feeder segments



Single Channel Analysis of 35% RIH Critical Break





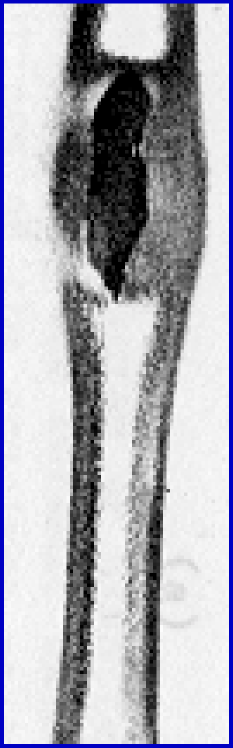
Detailed Fuel Element Analysis

- Objective of analysis is to predict the potential for sheath failure during the LOCA
- Boundary conditions from single-channel CATHENA analysis is provided to ELOCA code
  - coolant temperature,
  - coolant pressure,
  - sheath-to-coolant heat transfer coefficient,
  - ELESTRES normal operating conditions, and
  - power pulse
- For excessive straining: the increase in sheath temperature and high internal gas pressure in conjunction with low coolant pressure may result in sheath failure

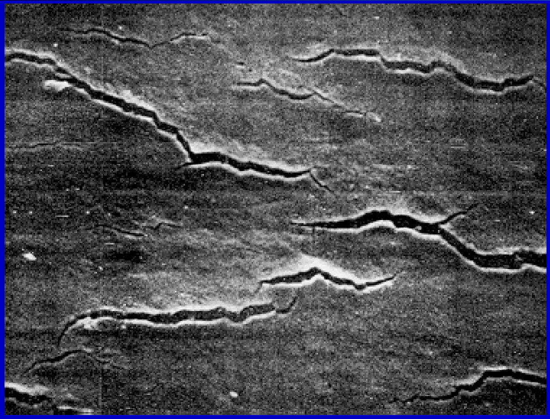
Fuel Element Failure Mechanisms

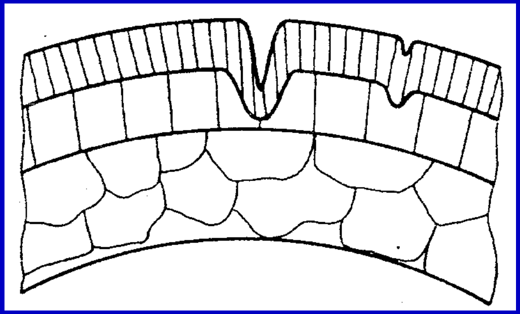
- The ELOCA code is used to generate a sheath failure map (threshold map) in conjunction with failure criteria, for

• no excessive straining- 5% strain less than 1000^{o}C



• no-oxide cracking- 2% strain greater than 1000^{o}C





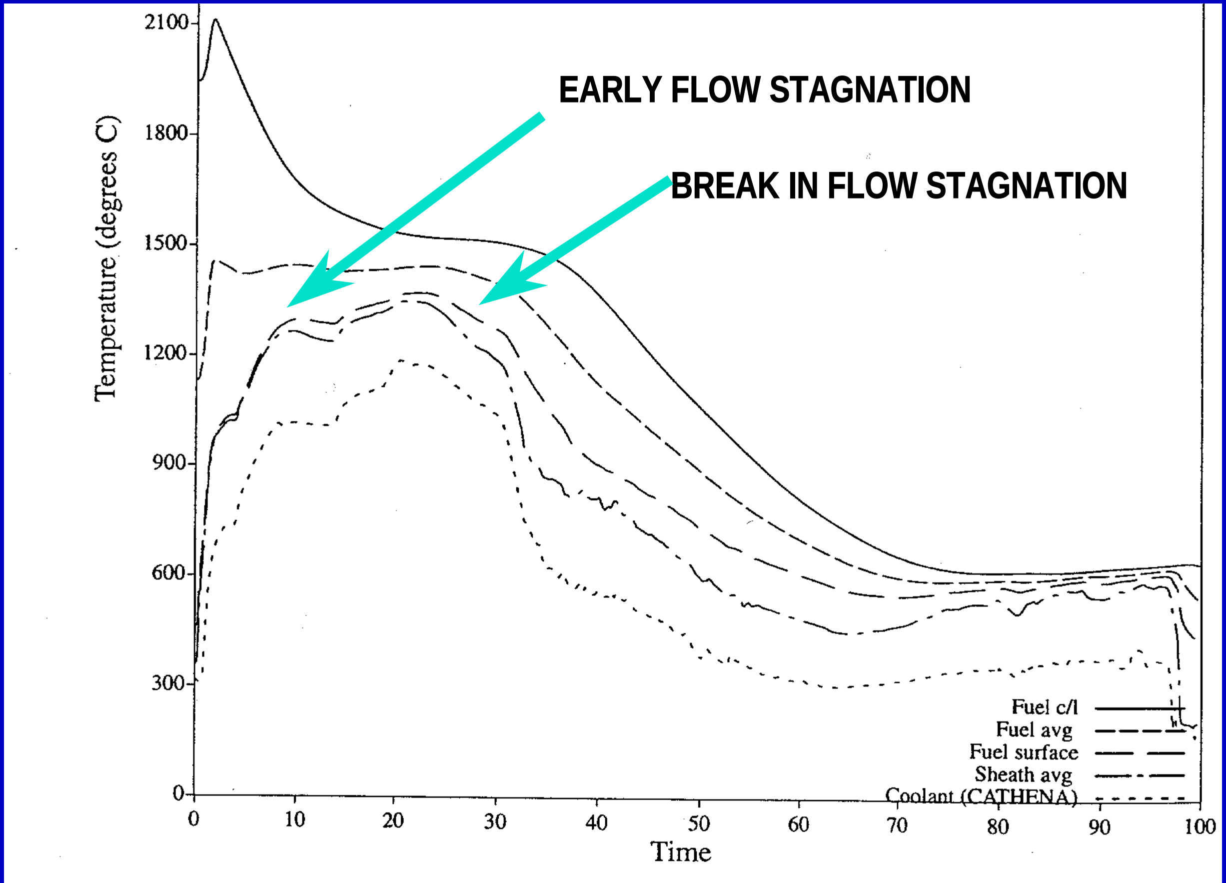
• no beryllium-braze penetration

• no oxygen embrittlement

• no fuel melting

Detailed Fuel Analysis by ELOCA code

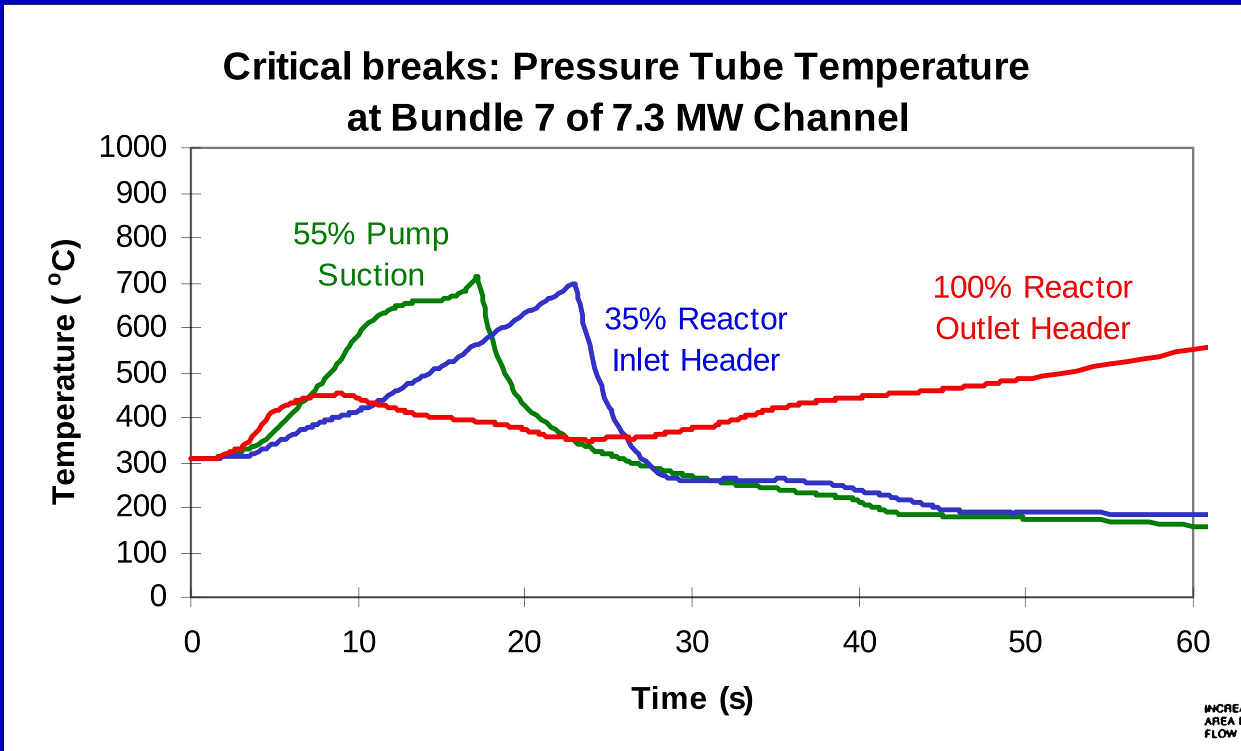
- Sheath temperatures for a 30% RIH LOCA scenario
- Outer elements of bundle position 6
- High-powered Channel O6 (7.3 MW)

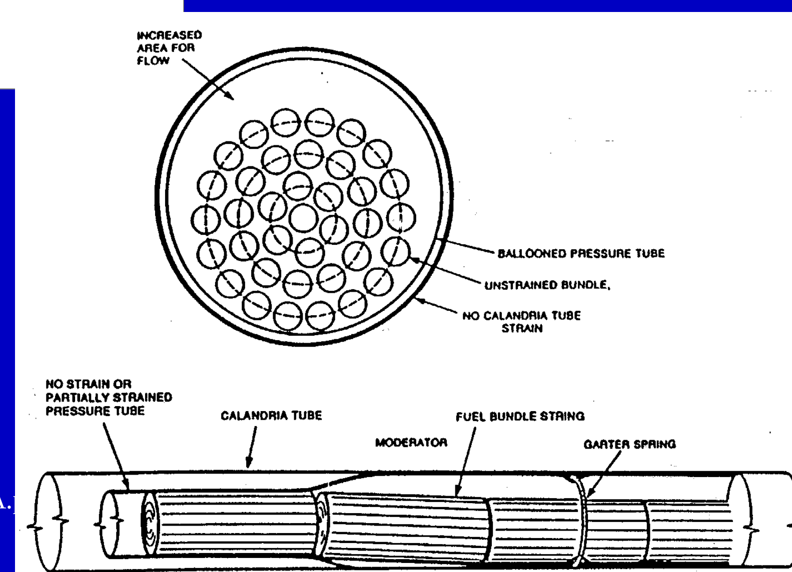


Pressure Tube Behaviour

- **Pressure tube deformation is expected for LOCA breaks resulting in high pressure tube temperatures at high channel pressures**
- **Objective of analysis is to determine pressure tube temperature at time of contact with its surrounding calandria tube**
- **Moderator temperatures are sufficiently low enough to prevent film boiling (dryout) on the outer surface of the calandria tube after the pressure tube-calandria tube contact**
- **Localized hotspots on the pressure tube due to bearing-pad/pressure tube contact results in localized deformation of tube**
- **No channel failures during a large break LOCA**

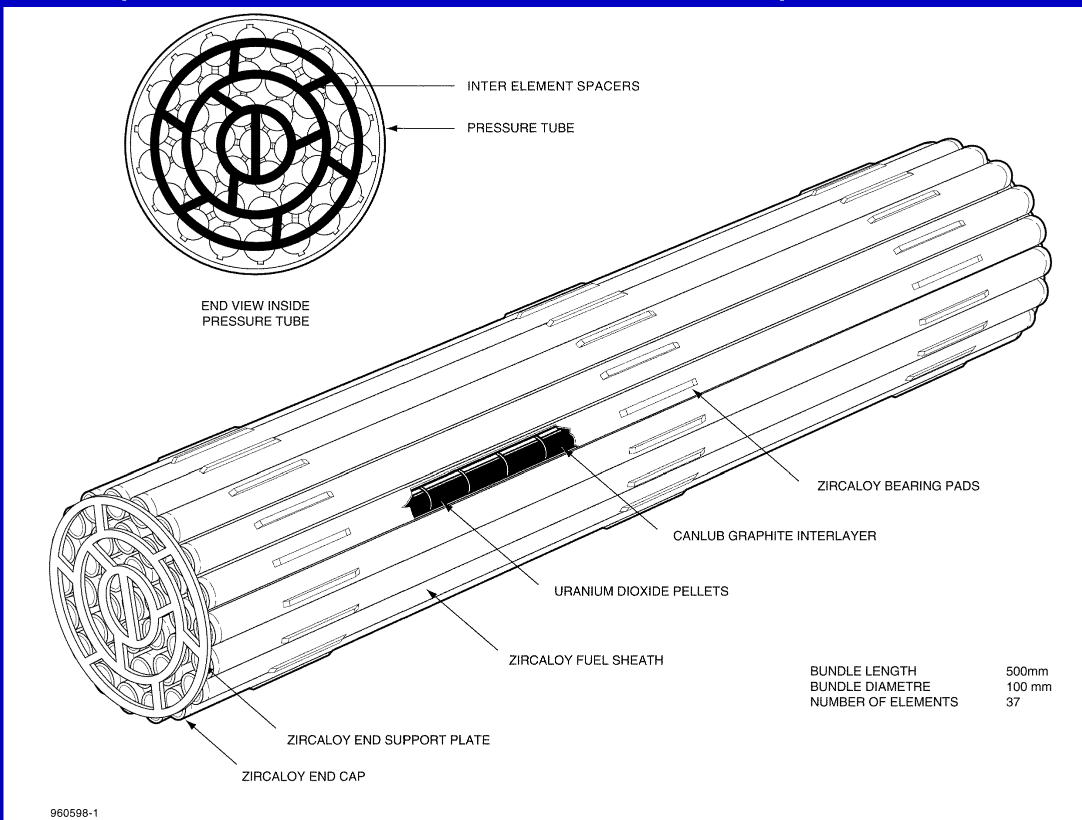
Pressure Tube Temperatures





Barriers to Fission Product Release

1) Uranium-Dioxide Fuel Matrix & 2) Sheath

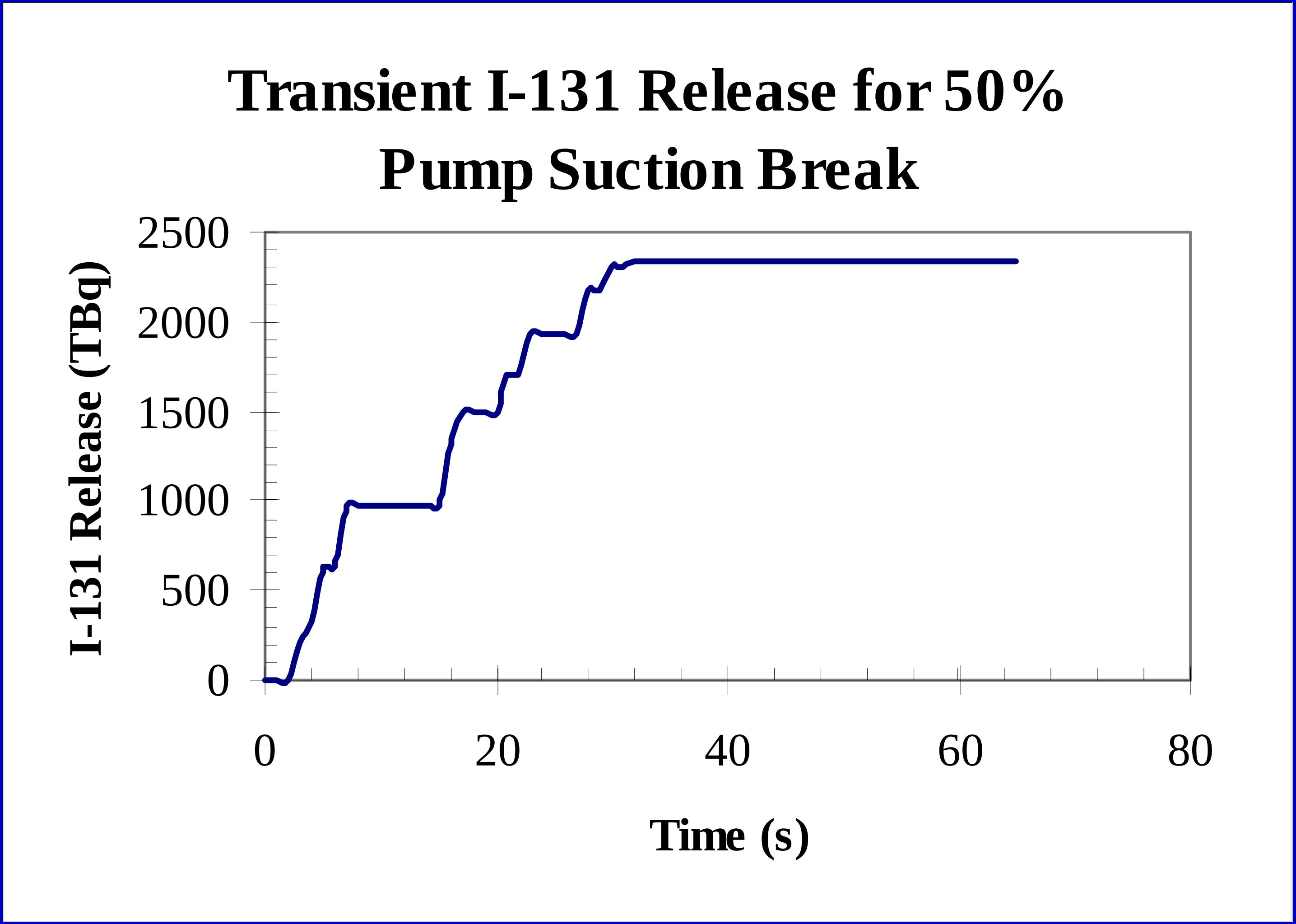


3) Primary Heat Transport System, 4) Containment & 5) Boundary

Fission Product Release

- The gap inventory plays a key role in the fission products released during the transient (i.e., sheath failure ==> retention & transport of fission products in the gap ==> released to heat transport system)
- Secondary release phenomena may include diffusion, fuel oxidation, Zircaloy-UO_2 reaction and fuel cracking
- LOCA Methodology
  - Entire gap inventory is assumed to be released upon sheath failure
  - 1% of fission products residing on grains and grain boundary is assumed to be released: to account for the possibility of secondary release mechanisms
- Fission Product Retention in Heat Transport System
  - large surface area in primary heat transport system (for example, endfitting, feeders) for fission product deposition
  - The retention of fission products in the system are currently not credited in the analysis; however, plan to credit in the future

Example of Fission Product Release Transient



Containment Behaviour

- Pressure increases rapidly due to large amount of heat rejected to the containment atmosphere
- Peak Pressure is below design pressure of 124 kPa (g)
- Dousing system limits peak pressure