



CANDU Safety #12: Large Loss of Coolant Accident

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Overview

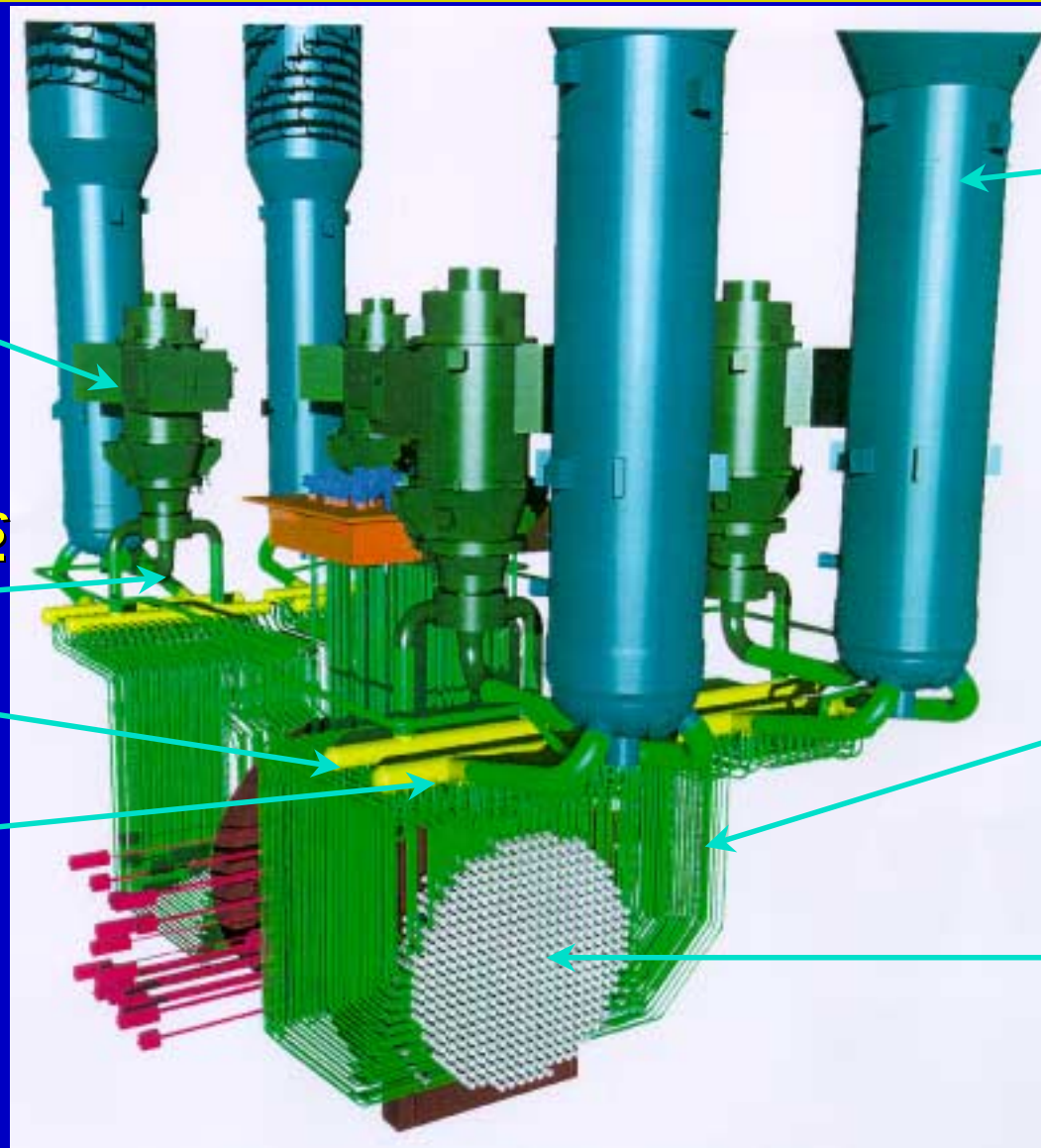
- λ Event sequence for a large break loss-of-coolant accident (LOCA)
- λ Acceptance criteria used to assess the results of the analysis
- λ Normal operating conditions
- λ Fuel and pressure tube behaviour during the transient
- λ Fission product release behaviour
- λ Containment behaviour

★ Large LOCA with ECC Available

λ 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



PHT Pumps

Steam Generators

Postulated Break Locations

1) Pump Suction

2) Inlet Header

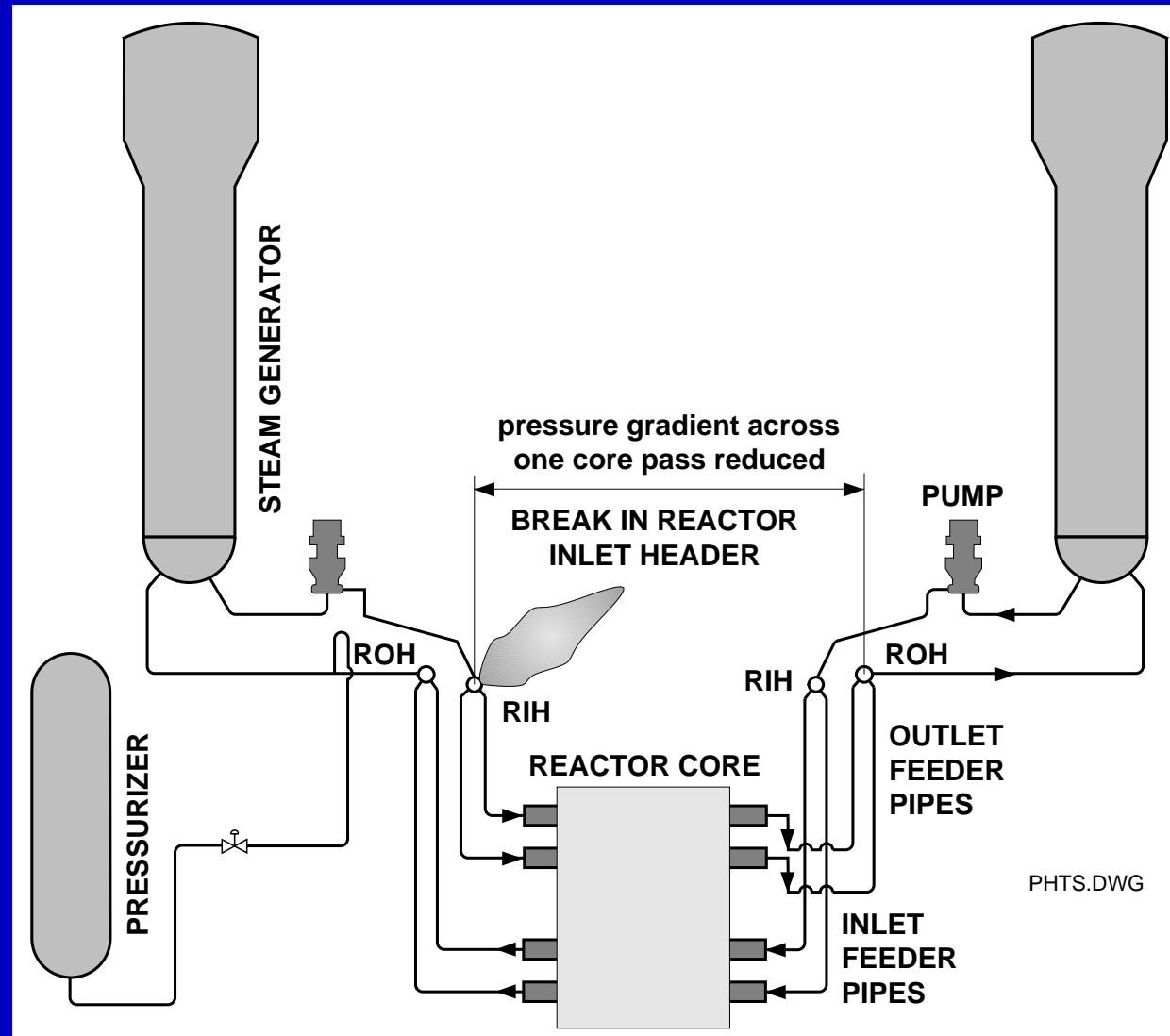
3) Outlet Header

Feeders

Reactor/Fuel Channels

★ Break in Primary Heat Transport System

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





Analysis Acceptance Criteria

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



Large Break LOCA Safety Analysis

- λ 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

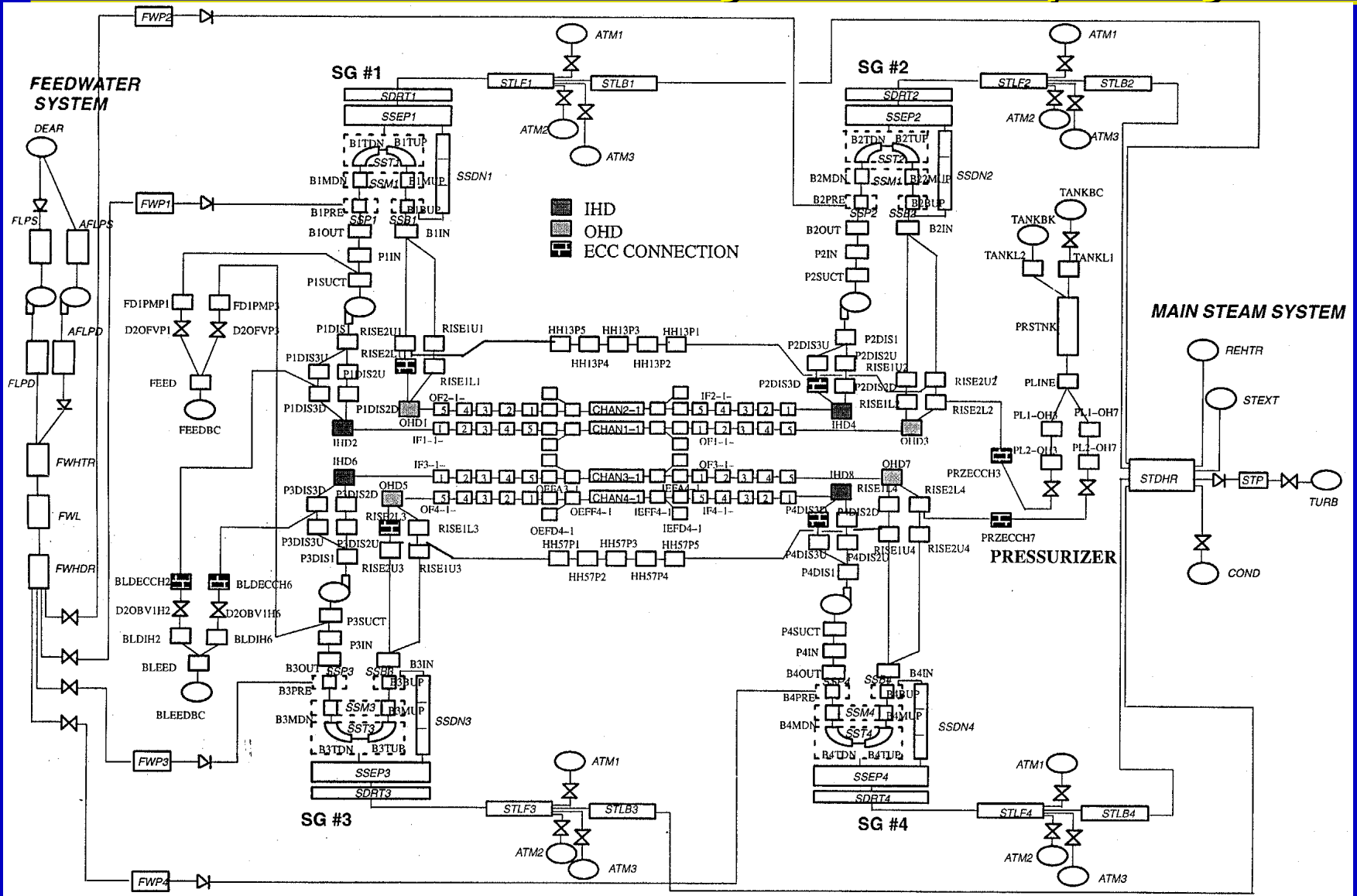
- Normal operating conditions is modelled by the ELESTRES computer code
- Main Input Requirements
 - λ Fuel element (pellet and sheath) dimensions & properties
 - λ Power/burnup history
 - λ Coolant temperature and pressure
- Important Output Parameters
 - λ Fission product distribution (gap, grain boundary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



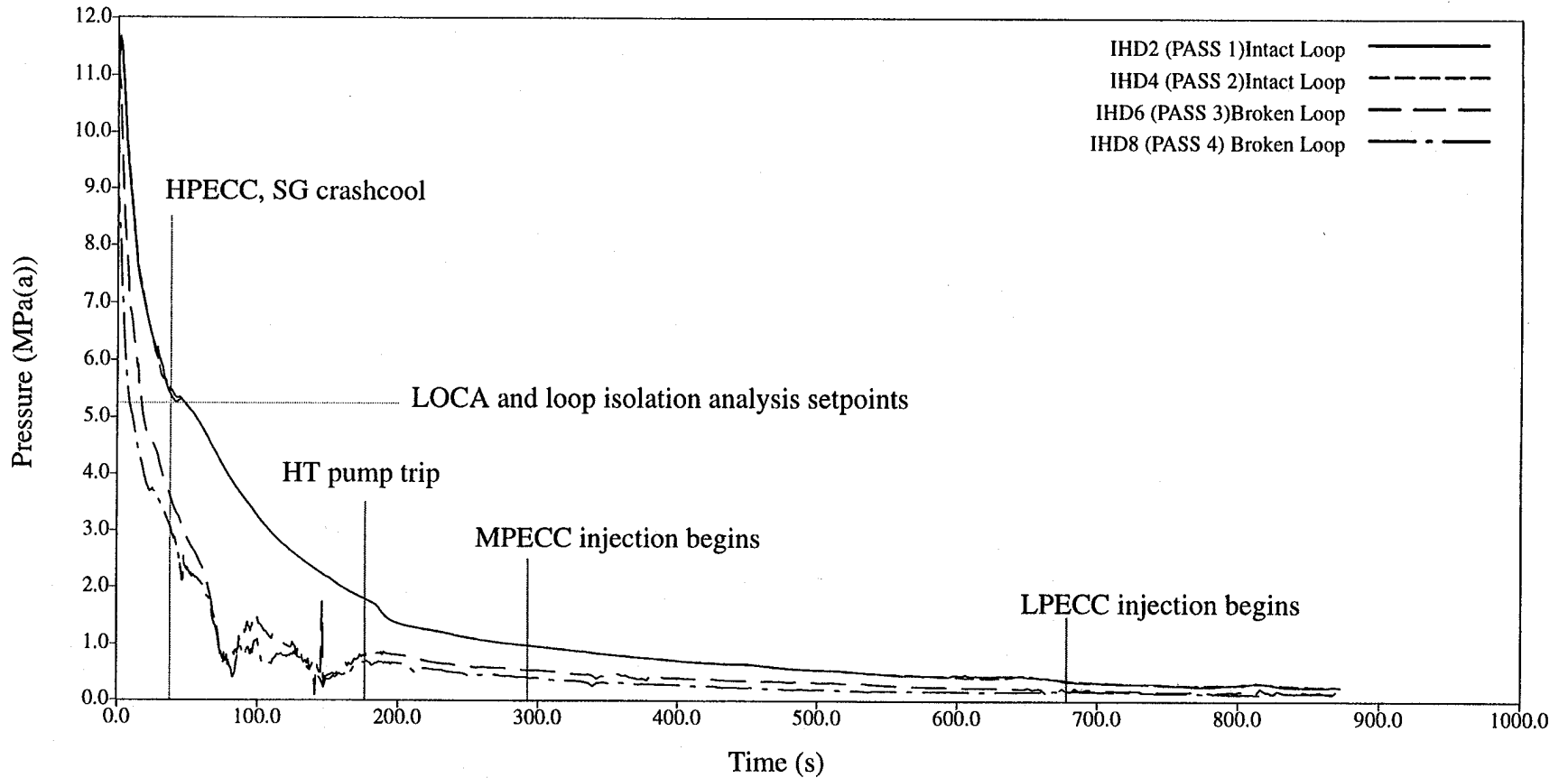
Transient Temperatures

- 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

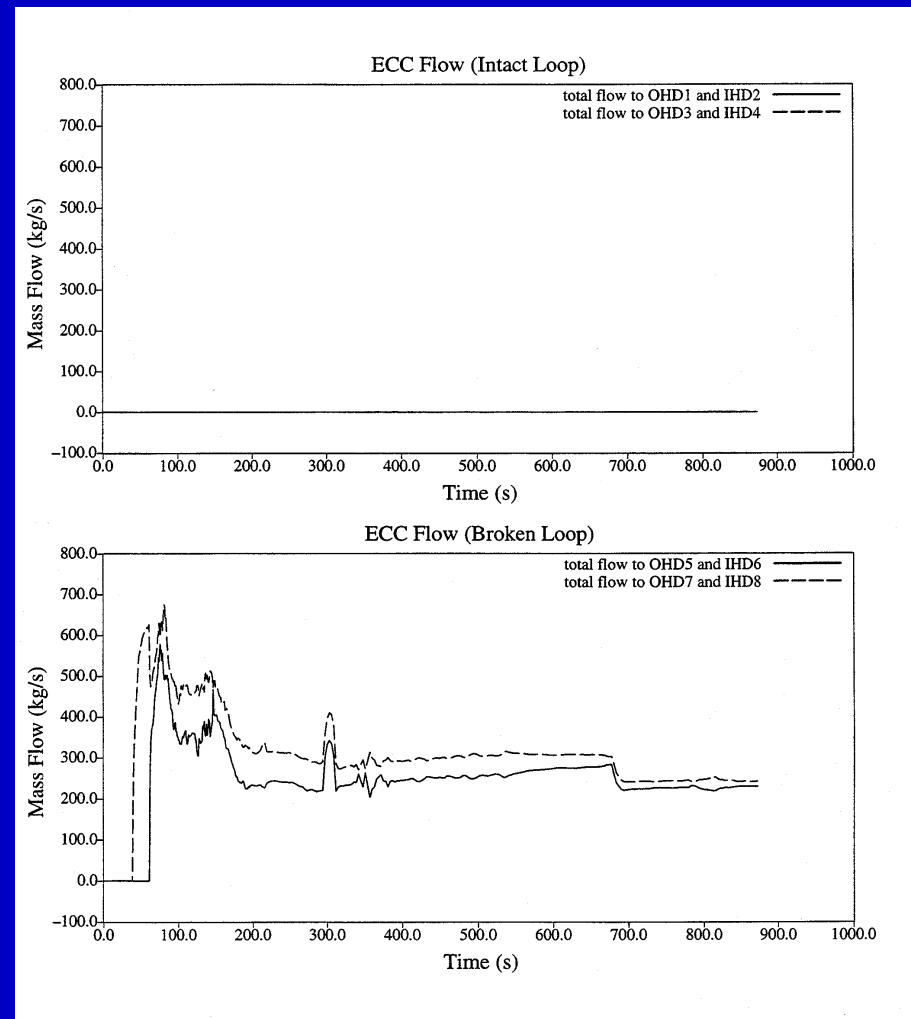


Depressurization in Inlet Headers (35% RIH Break)



ECC Flows

- λ 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
- λ LOCA signal & loop isolation initiated at 9 s after accident
- λ Loop isolation complete by 29 s
- λ ECC flows into the broken loop, 3 stages
 - High-pressure injection initiation (38 s)
 - Medium-pressure injection (293 s)
 - Low-pressure injection (678 s)

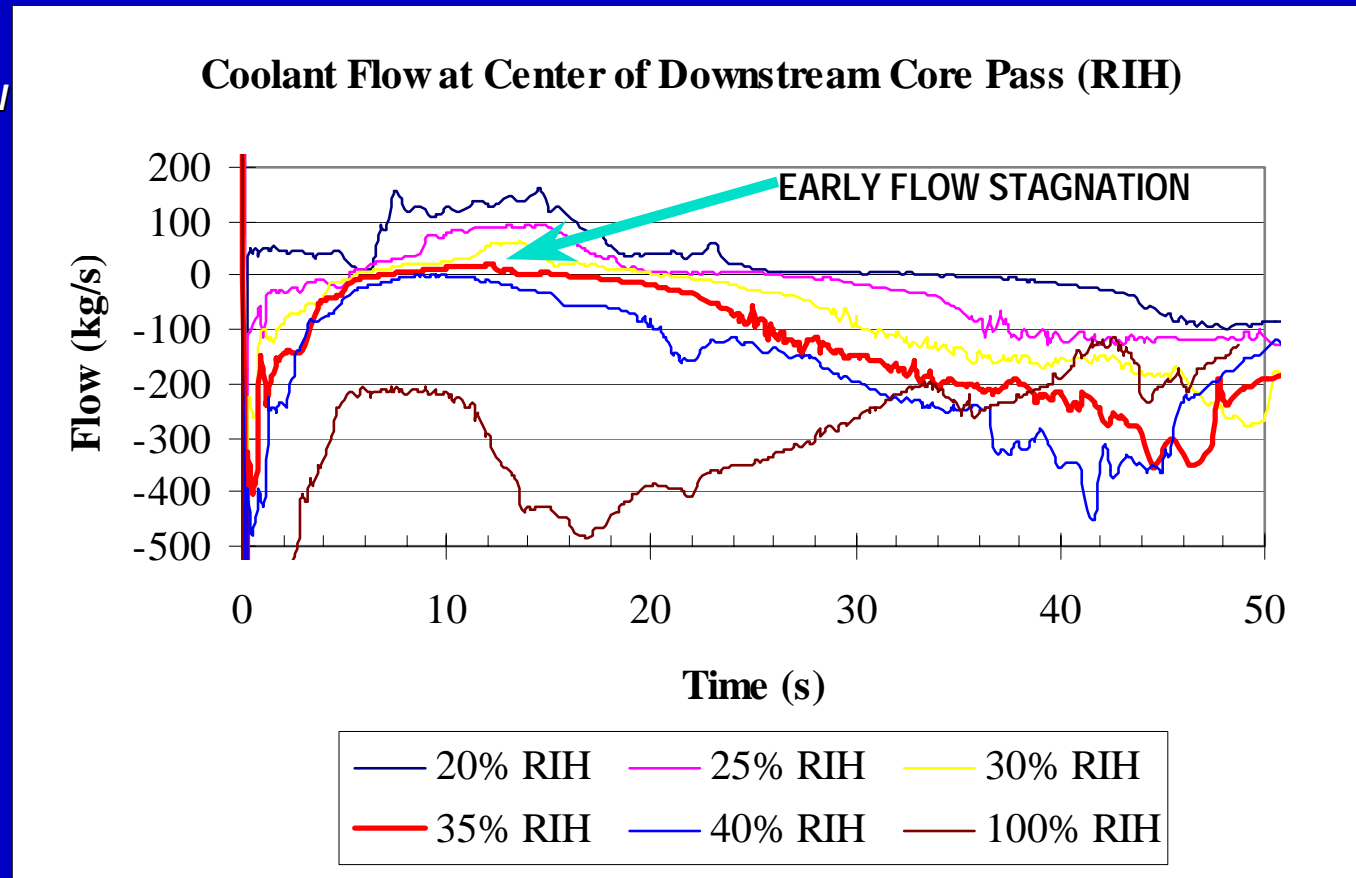




Break Survey for RIH breaks (Flows)

CATHENA Circuit Model

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



Break Survey for RIH breaks (Sheath Temperature)

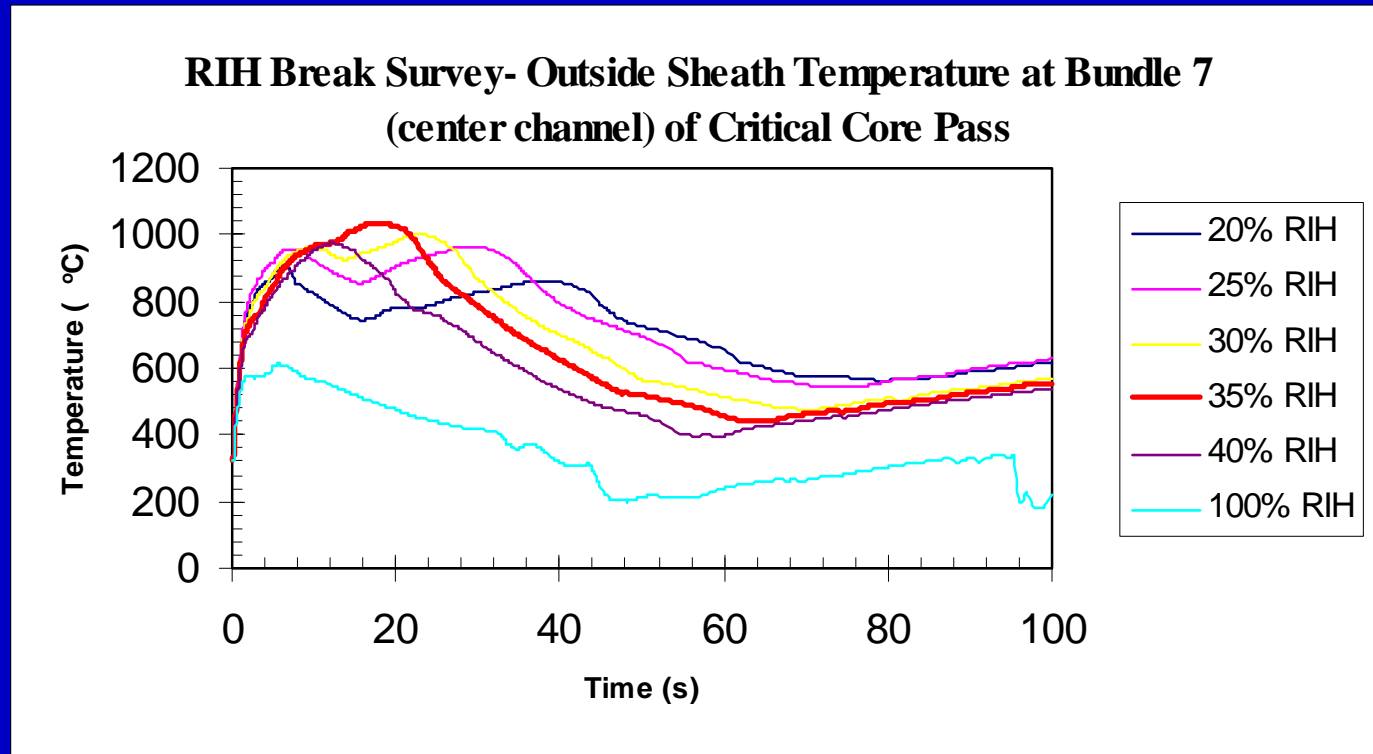
CATHENA Circuit Model

λ Temperature transient corresponds to flow conditions

λ Flow stagnation ==> temperatures increase

λ Break in flow stagnation ==> temperatures drop

λ 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)

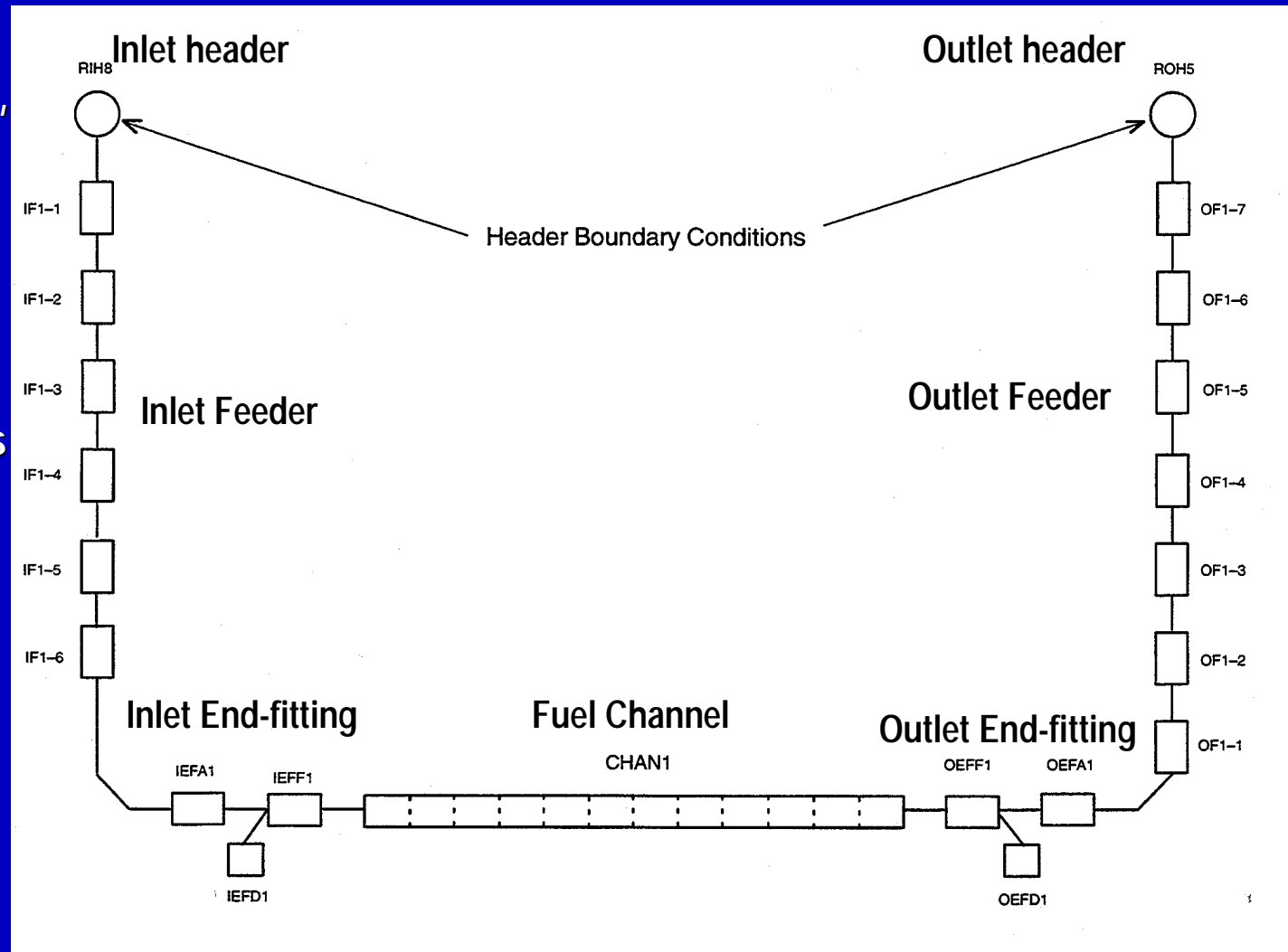
6 inlet feeder segments

Inlet end-fitting model

12 channel segments (for 12 bundles)

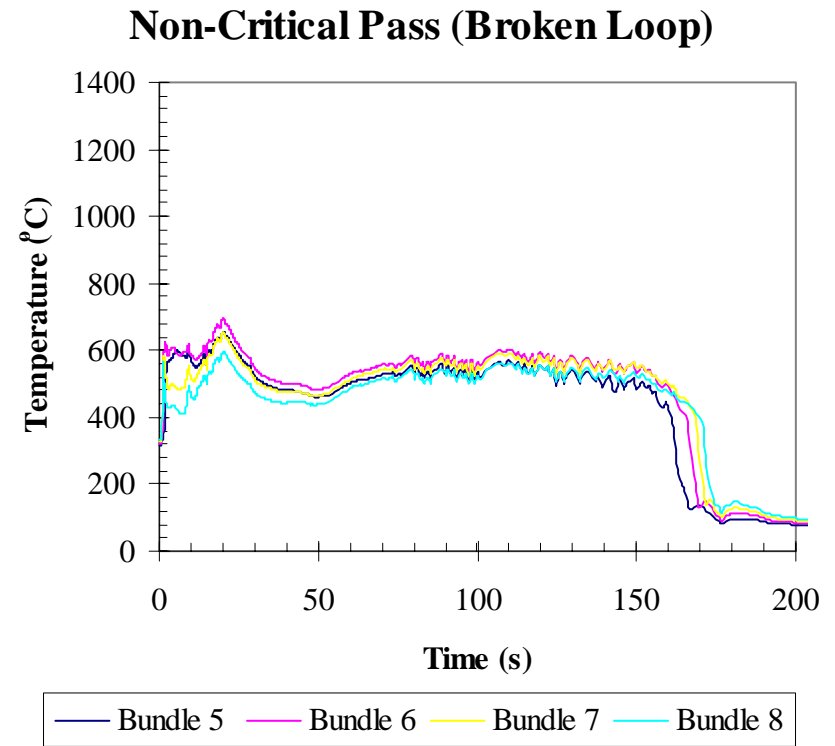
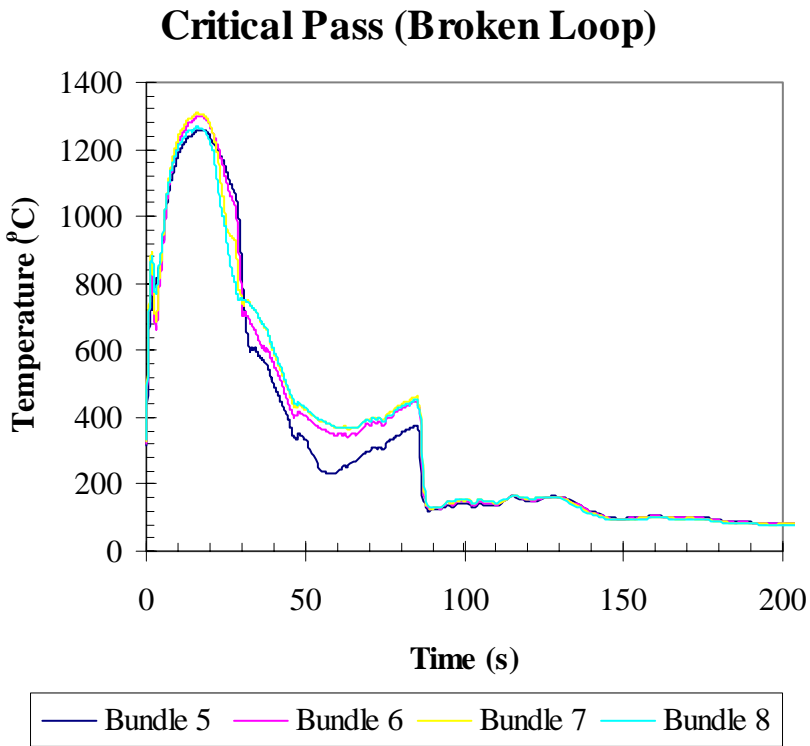
Outlet end-fitting model

7 outlet feeder segments





Single Channel Analysis of 35% RIH Critical Break



Detailed Fuel Element Analysis

- λ Objective of analysis is to predict the potential for sheath failure during the LOCA
- λ 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
- λ 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

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

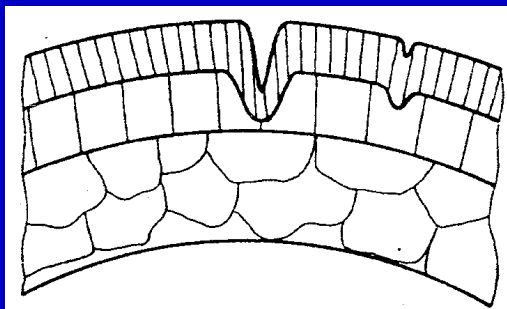
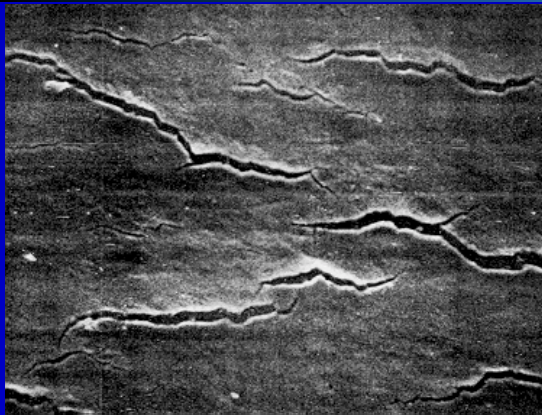
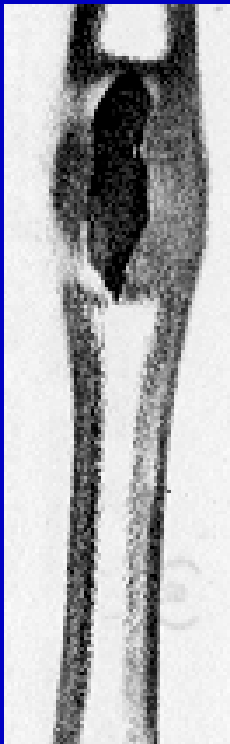
- no excessive straining- 5% strain less than 1000°C

- no-oxide cracking- 2% strain greater than 1000°C

- no beryllium-braze penetration

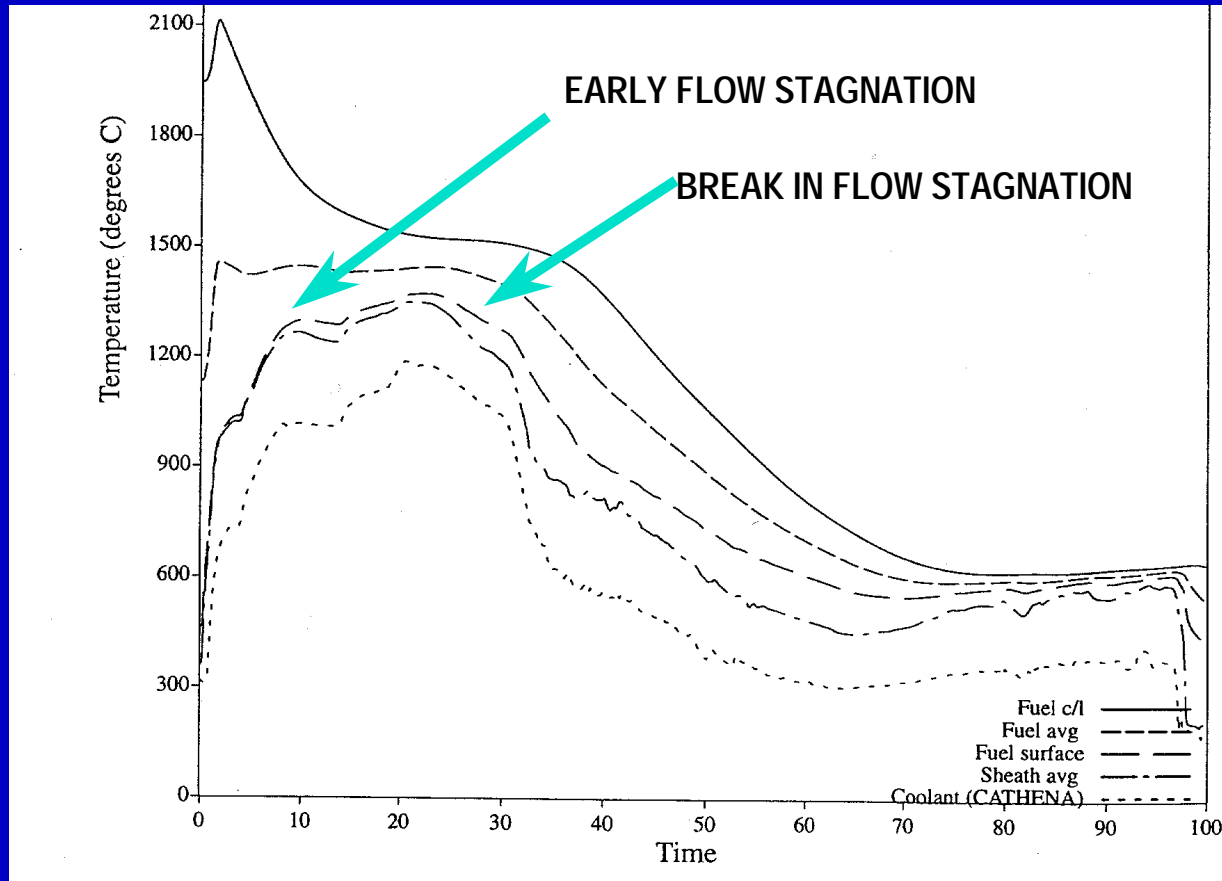
- no oxygen embrittlement

- no fuel melting



★ Detailed Fuel Analysis by ELOCA code

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





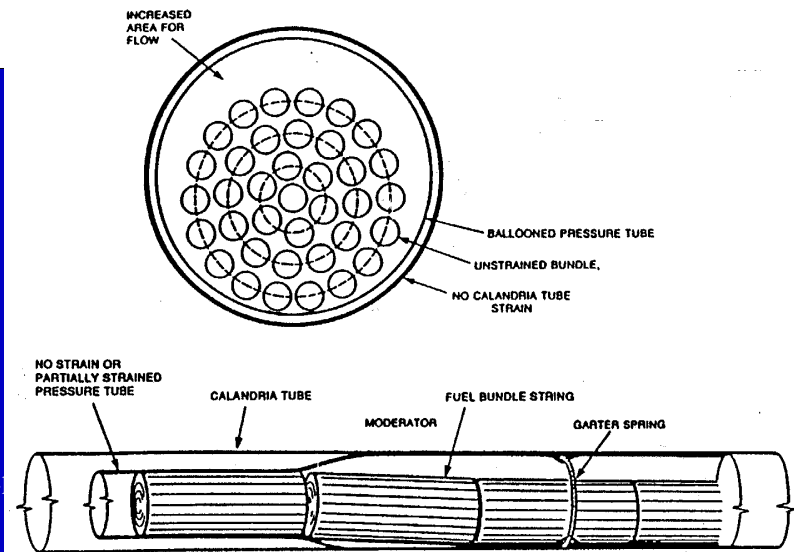
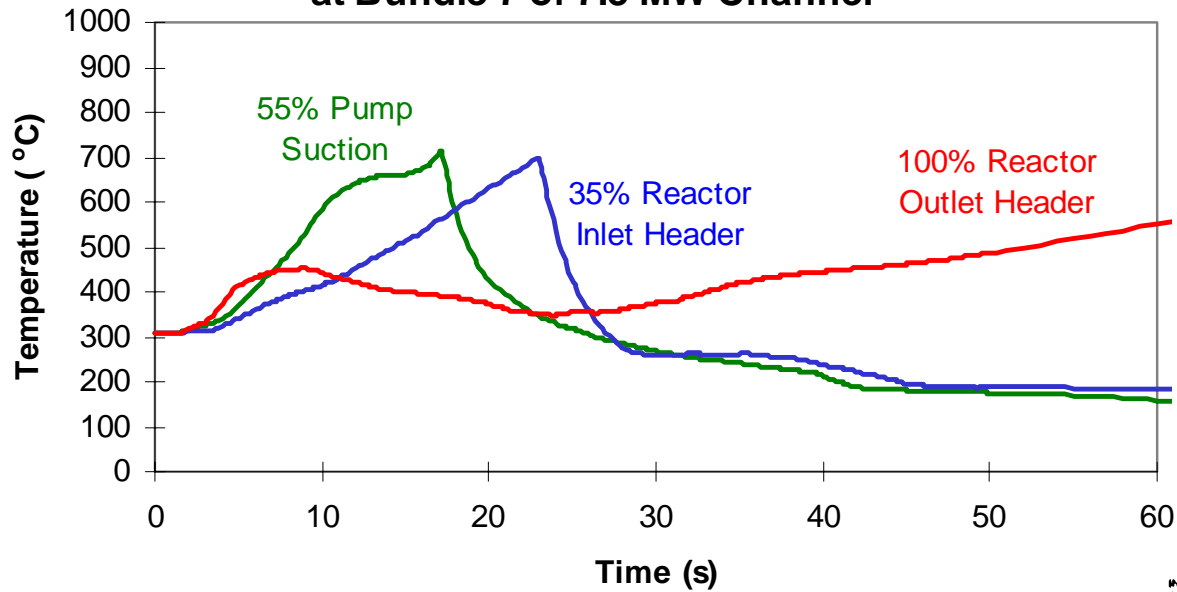
Pressure Tube Behaviour

- λ Pressure tube deformation is expected for LOCA breaks resulting in high pressure tube temperatures at high channel pressures
- λ Objective of analysis is to determine pressure tube temperature at time of contact with its surrounding calandria tube
- λ 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
- λ Localized hotspots on the pressure tube due to bearing-pad/pressure tube contact results in localized deformation of tube

λ 24-11-2011 No channel failures during a large break LOCA

Pressure Tube Temperatures

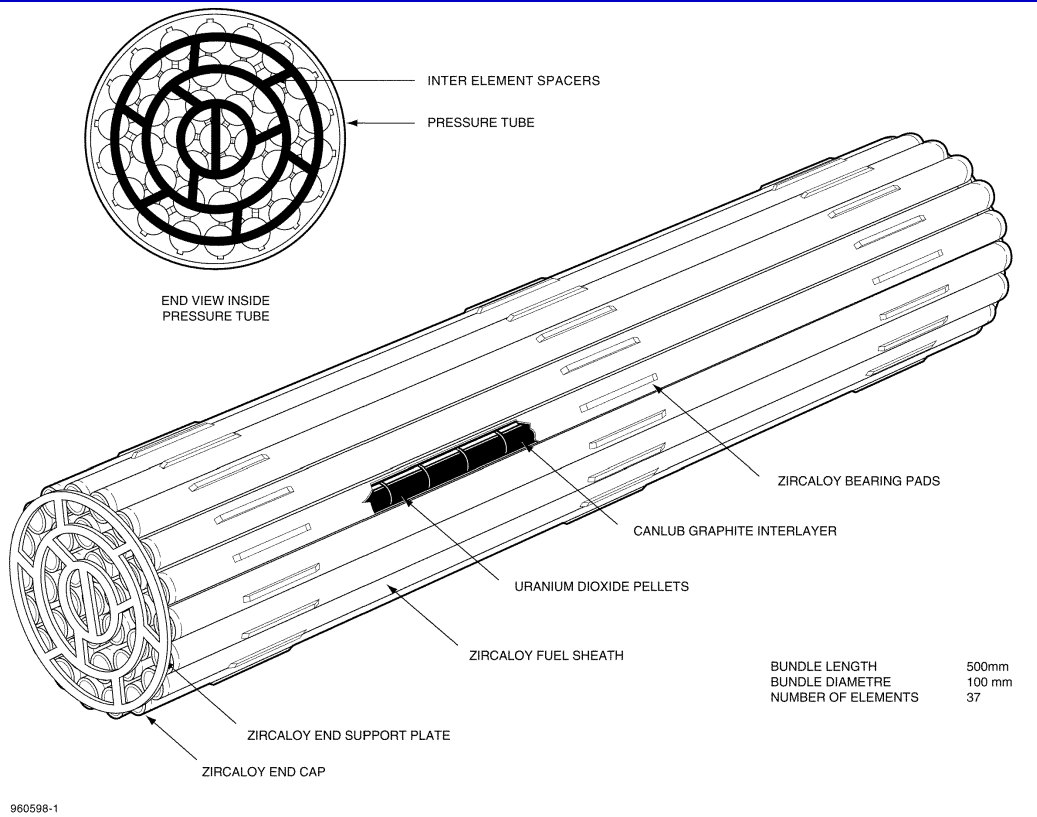
Critical breaks: Pressure Tube Temperature at Bundle 7 of 7.3 MW Channel





Barriers to Fission Product Release

1) Uranium-Dioxide Fuel Matrix & 2) Sheath



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

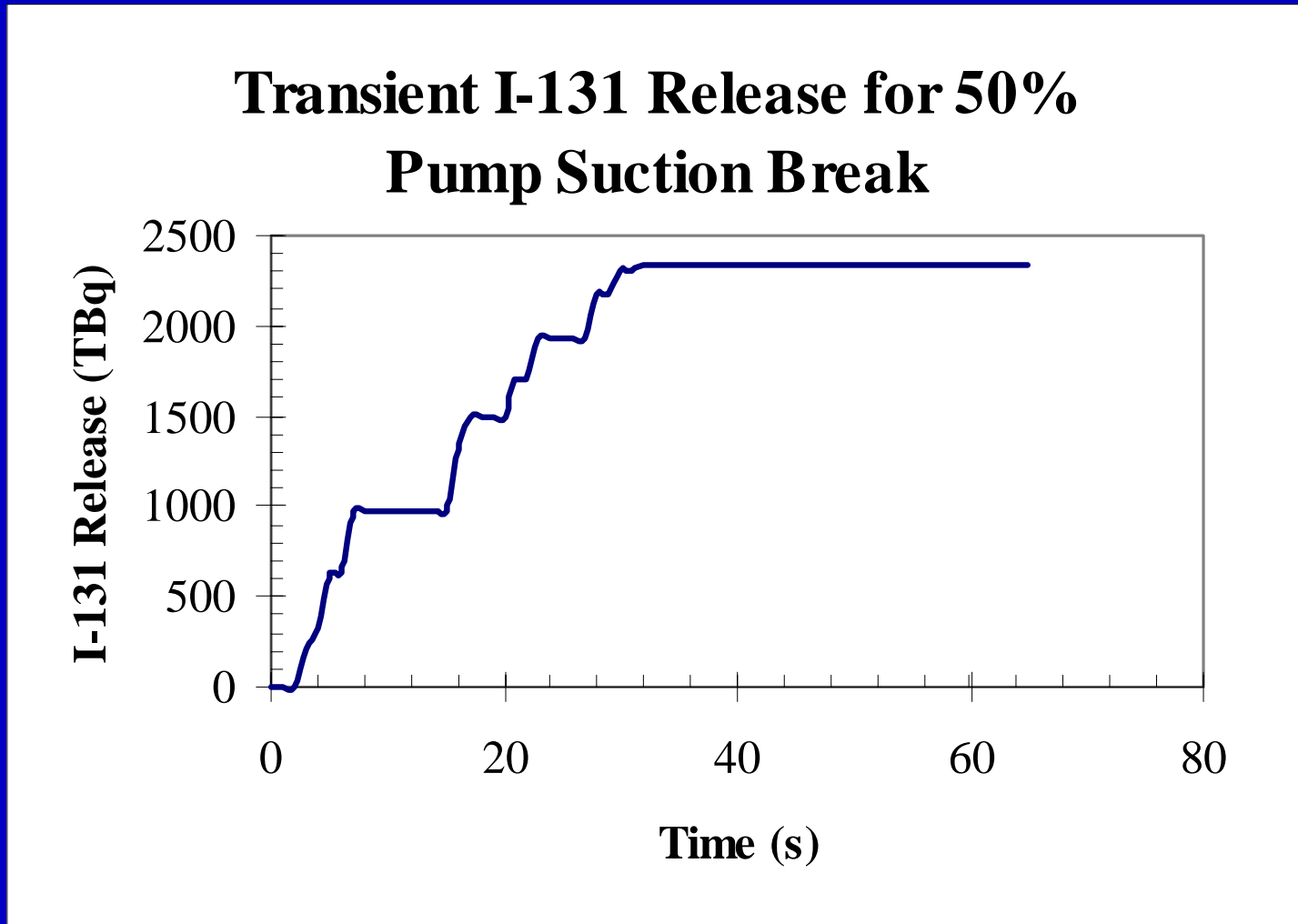


Fission Product Release

- λ 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)
- λ Secondary release phenomena may include diffusion, fuel oxidation, Zircaloy-UO₂ reaction and fuel cracking
- λ 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
- λ 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

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

Containment Pressure Transient for 100% ROH LOCA

