CANDU Safety #4: Thermalhydraulic Safety Characteristics Of CANDU Reactors

F. J. Doria

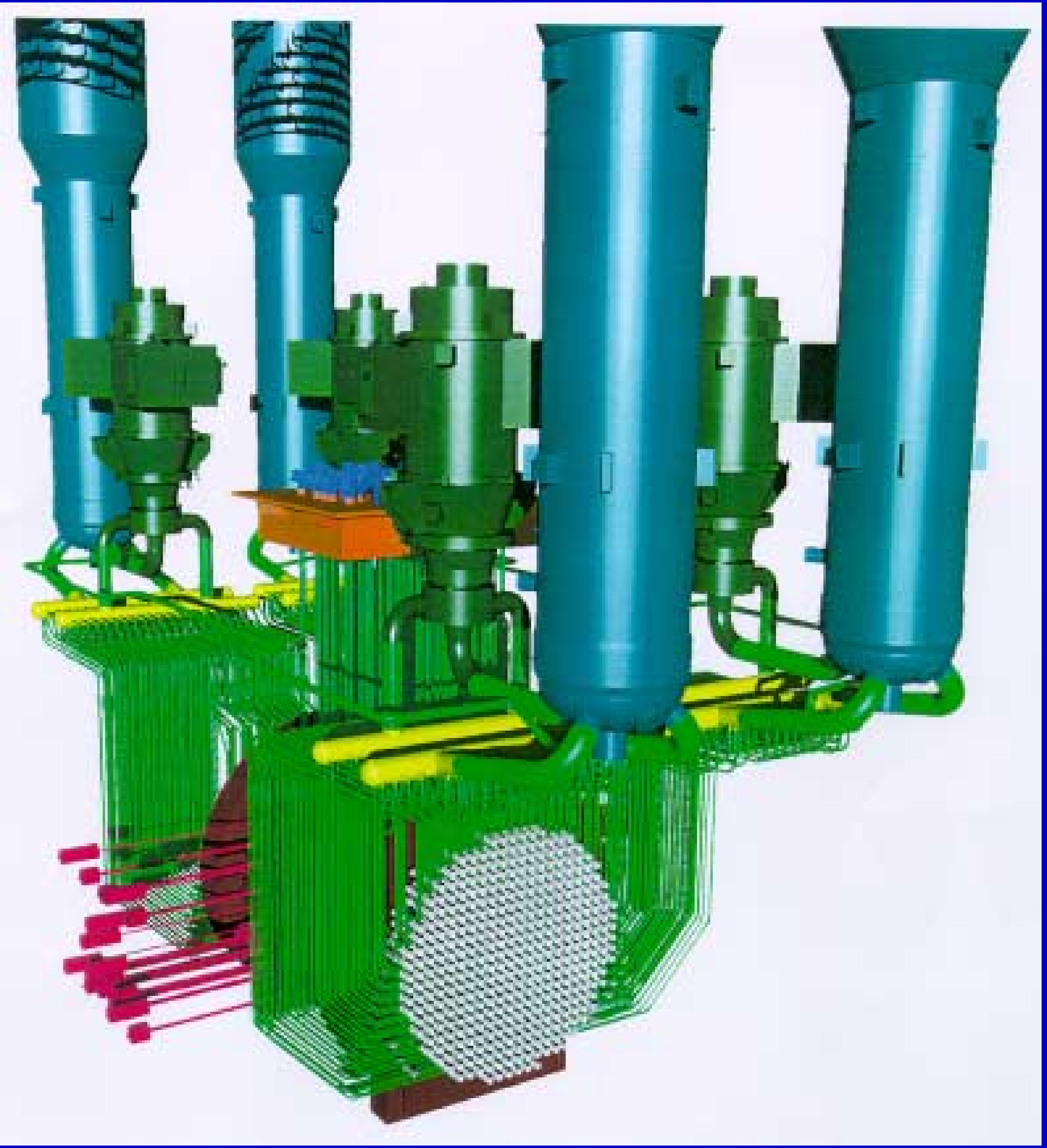
Atomic Energy of Canada Limited

Overview

- Description of the primary heat transport system and safety requirements
- Natural circulation after loss of forced flow in the primary heat transport system
- Description of steam generators, primary heat transport pumps and safety requirements
- Description of reactor headers, feeders
- Loop isolation, emergency core cooling

Primary Heat Transport System (PHT)

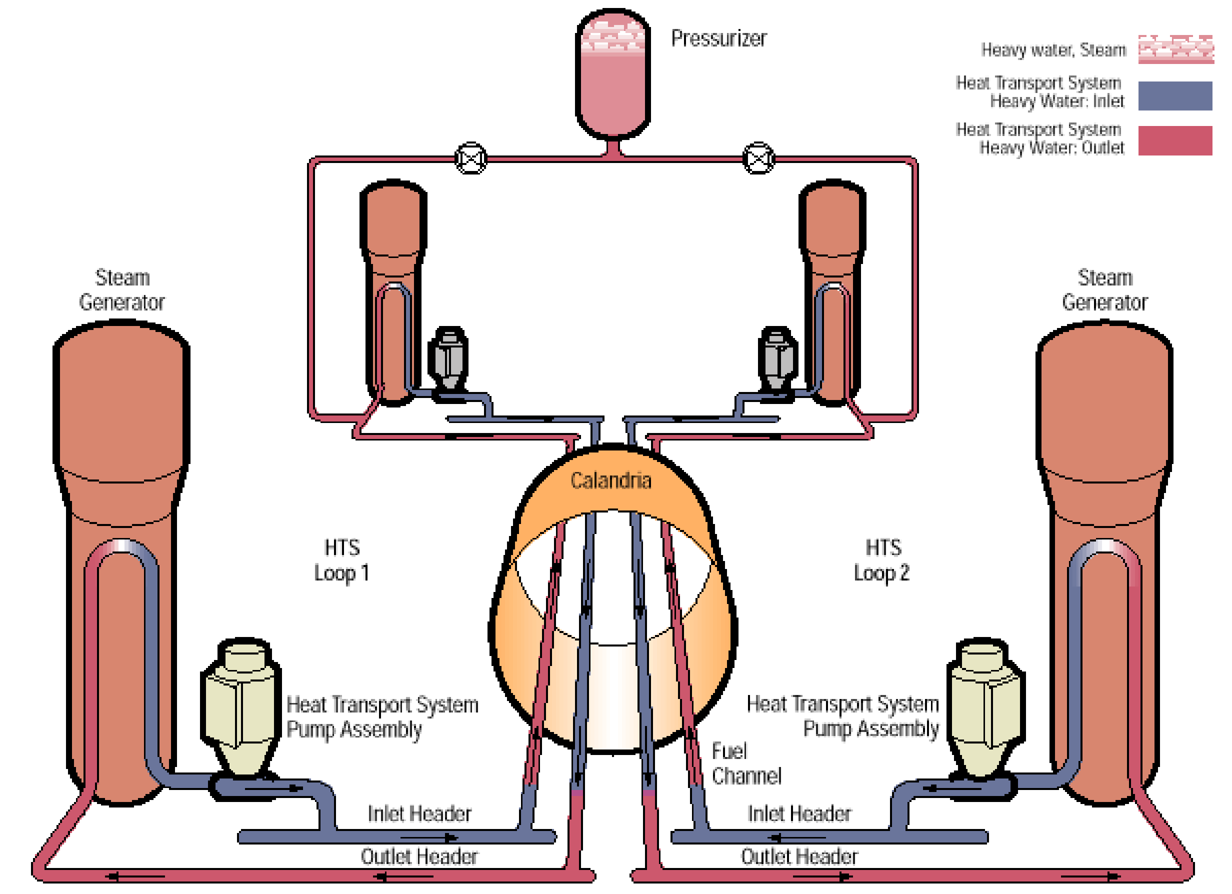
- 2 separate loops
- 4 steam generators
- 4 primary heat transport system pumps
- Pressurized heavy water in loops
- 380 horizontal fuel channels
- 380 inlet feeders; 380 outlet feeders
- 4 inlet headers; 4 outlet headers



Circulation in Primary Heat Transport System

Figure 8 layout

- Flow from inlet header-1 through core to outlet header-1
- Then through steam generator-1 to pump-1
- Then to inlet header-2 on the other side of reactor face
- Back through the core to the outlet header-2
- Then through the steam generator-2 to pump-2
- This constitutes one complete pass in one of the loops



Some Safety Requirements of the PHT

- **In the event where the PHT system boundary fails, must limit the fuel damage to satisfy dose limits, in conjunction with the mitigating systems such as reactor shutdown: SDS1, SDS2; and emergency core cooling system**
- **Promote decay heat removal by natural circulation (thermosyphoning) after the total loss of PHT pumping power**
- **Provide a rotational inertia to each PHT pump so that coolant flow prevents overheating of the fuel, if power is lost to the pump motor**
- **Provide process measurements for tripping and shutting down the reactor to ensure that system pressure is within allowable limits**
- **Provide process measurements for detecting LOCA's and the initiation of ECC injection into the core**

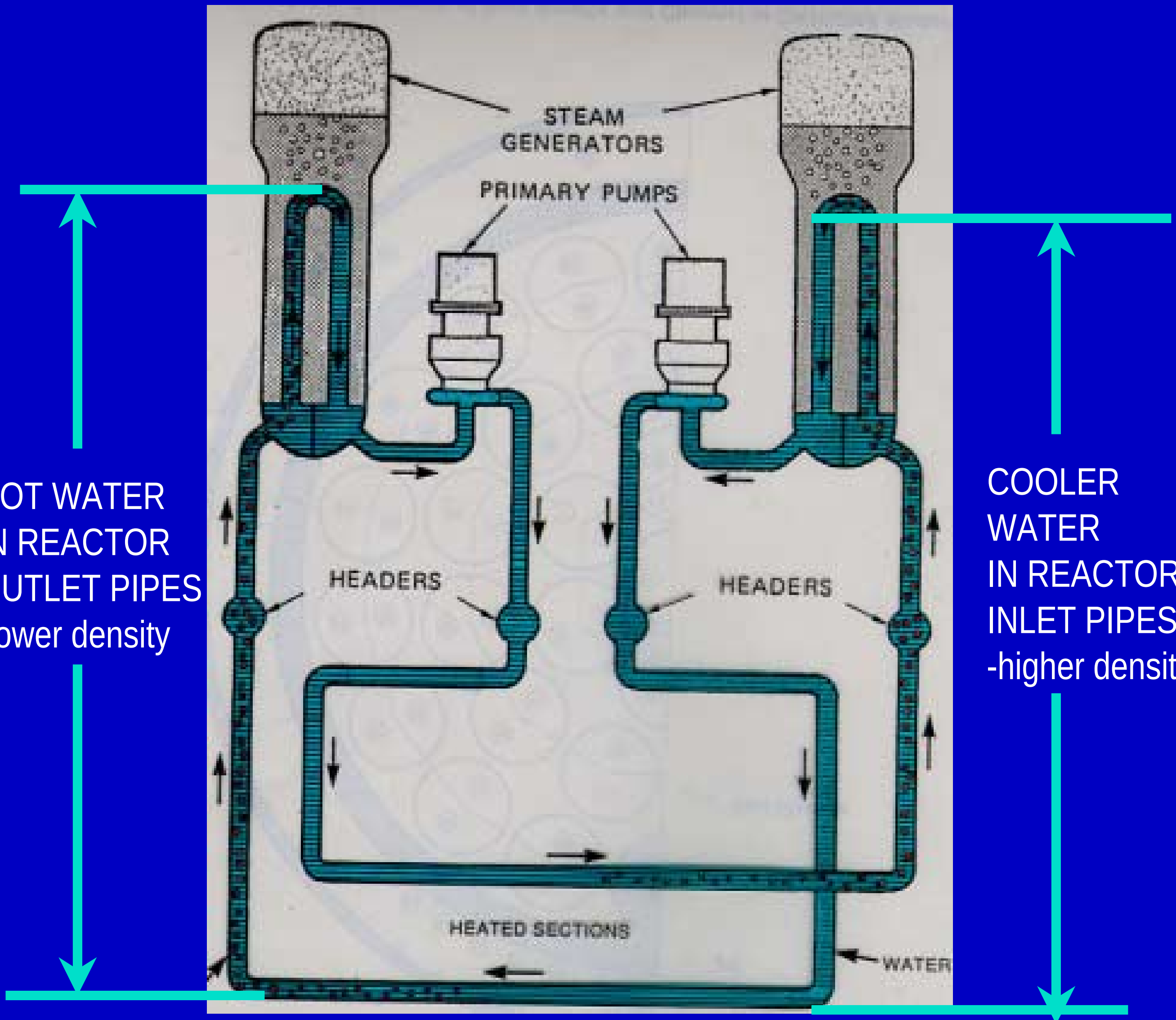
Thermosyphoning Phenomena

- Occurs in the absence of forced flow in the primary heat transport system (i.e., loss of PHT pumps due to loss of Class IV power)
- Decay heat generated by the fuel is transported to the steam generators by natural circulation (thermosyphoning phenomena)
- Thermosyphoning is defined as the natural circulation in the PHT induced by the difference in coolant densities in the vertical sections of the:
  - reactor inlet pipes and
  - reactor outlet pipes
- The thermosyphoning flow through the core is sufficient to cool the fuel

Thermosyphoning Process

- Effective heat removal process for scenarios involving loss of forced circulation
- For example,
  - For LOCA: following PHT trip, the thermosyphoning process provides cooling in the intact loop
  - loss of Class IV power

HOT WATER
IN REACTOR
OUTLET PIPES
-lower density

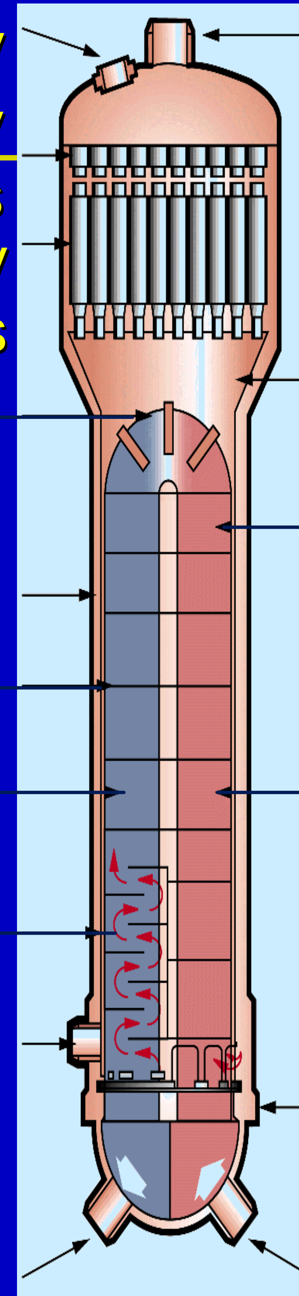


COOLER
WATER
IN REACTOR
INLET PIPES
-higher density

Steam Generator

Operating Specifications

- Tube side (primary side)
  - Fluid is heavy water
  - Flow rate: 7.7 Mg/s (for 4 steam generators)
  - Inlet temperature: 309°C
  - Outlet temperature: 266°C
- Shell side (secondary side)
  - Fluid is light water
  - Steam outflow and feed water inflow: 1 Mg/s (for 4 steam generators)
  - Steam pressure: 4.7 MPa



Some Functional Requirements Related to Safety for Steam Generator

- **To permit thermosyphon cooling of the primary fluid (D_2O) when the reactor is at decay power levels**

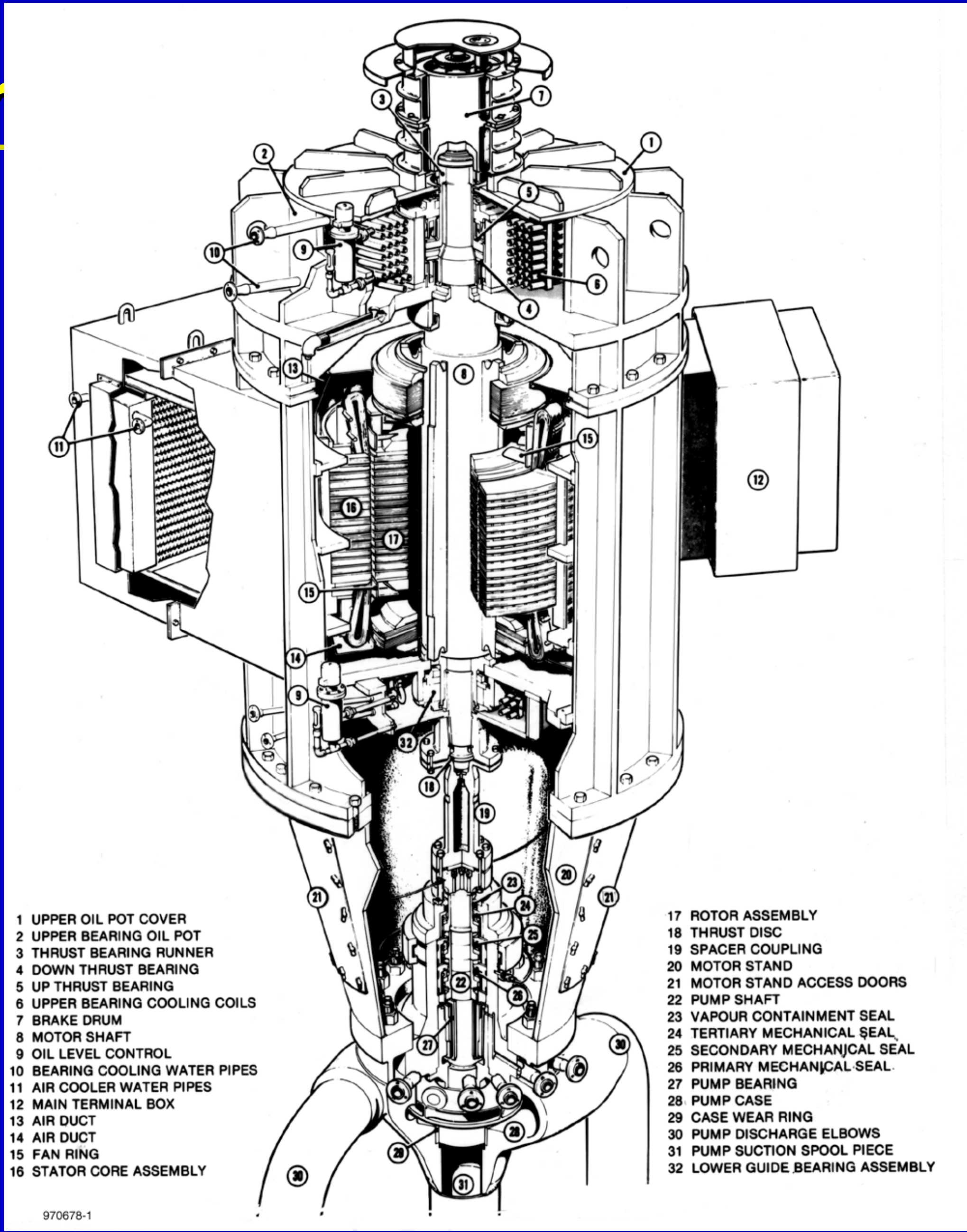
- **To maintain both primary and secondary pressure boundaries and heat sink requirements during a design basis earthquake**

- **To maintain primary pressure boundary integrity during postulated pipe break accidents (i.e., PHT breaks, steam line breaks)**

PHT Pump & Motor

Specifications

- Pump
  - Vertical-type, centrifugal
  - Single suction; double discharge
  - Flow rate: 2228 L/s
  - Operating Temperature: $266^{o}C$
  - Head: 215 m
- Motor
  - Power supply is Class IV



Some Functional Requirements Related to Safety for PHT Pump

- To maintain the pressure boundary integrity during the entire range of normal operating conditions, during all postulated pipe breaks, LOCA, and during a design basis earthquake

- To retain operational capabilities for a short period of time under 2-phase flow conditions resulting from a LOCA

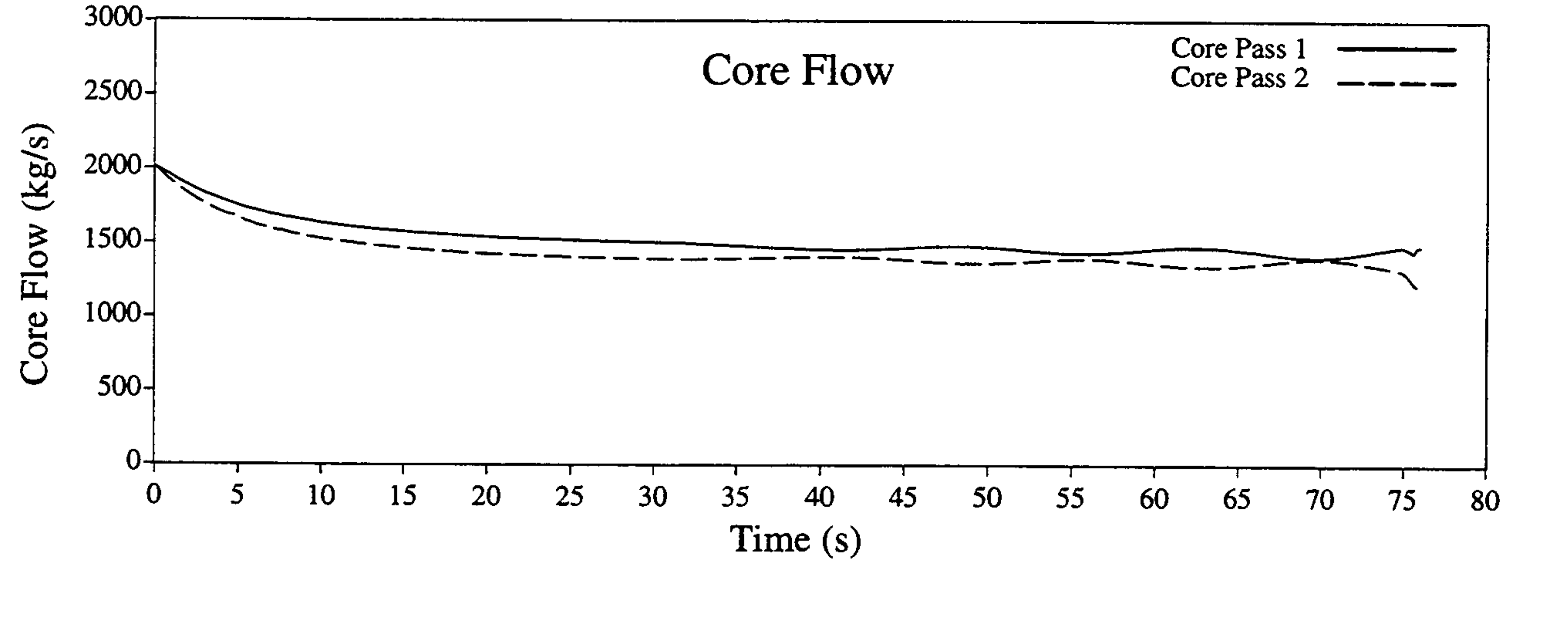
- To continue to remove decay heat from the reactor core during a loss of Class IV power by extended run-down time

- To retain its structural integrity and operational capability during and after a design basis earthquake

Single PHT Pump Trip

- For each loop in the PHT system, there are 2 PHT pumps
- Following a single PHT Pump Trip, the other pump will still provide forced circulation through the system

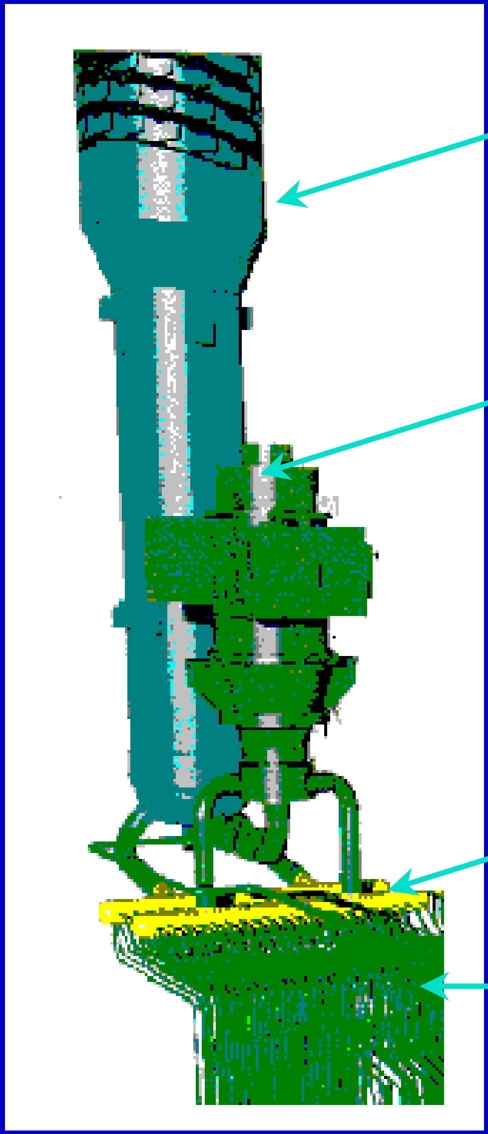
CORE FLOW FOR SINGLE PUMP TRIP; 80% Full-Power



Headers

Specifications

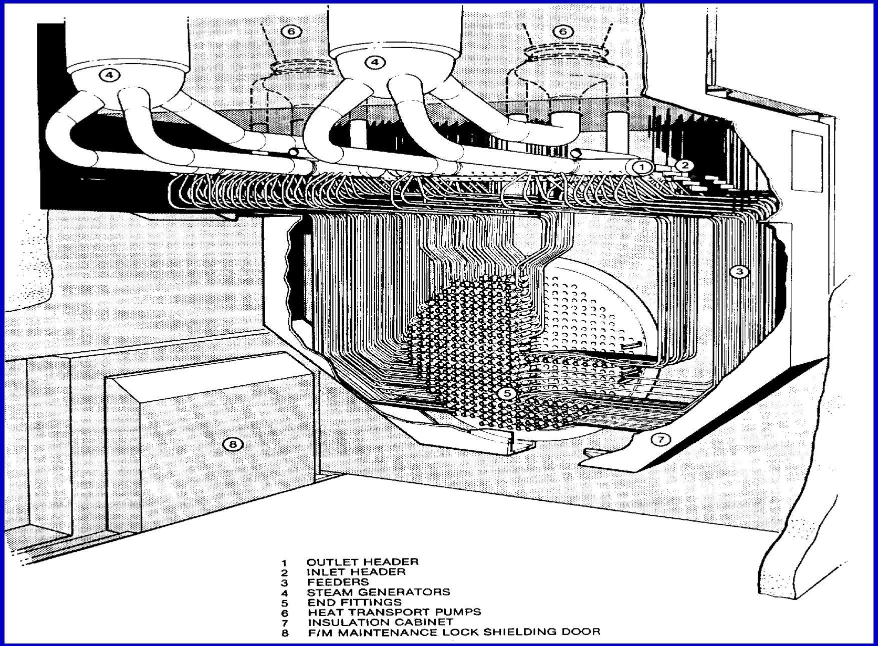
- Inlet Headers
  - 4 inlet headers
  - 0.37 m inside diameter
  - Operating pressure: 11.25 MPa (g)
  - Operating temperature: 266ºC
- Outlet Headers
  - 4 outlet headers
  - 0.406 m inside diameter
  - Operating pressure: 9.89 MPa (g)
  - Operating temperature: 310ºC



Feeders

Specifications

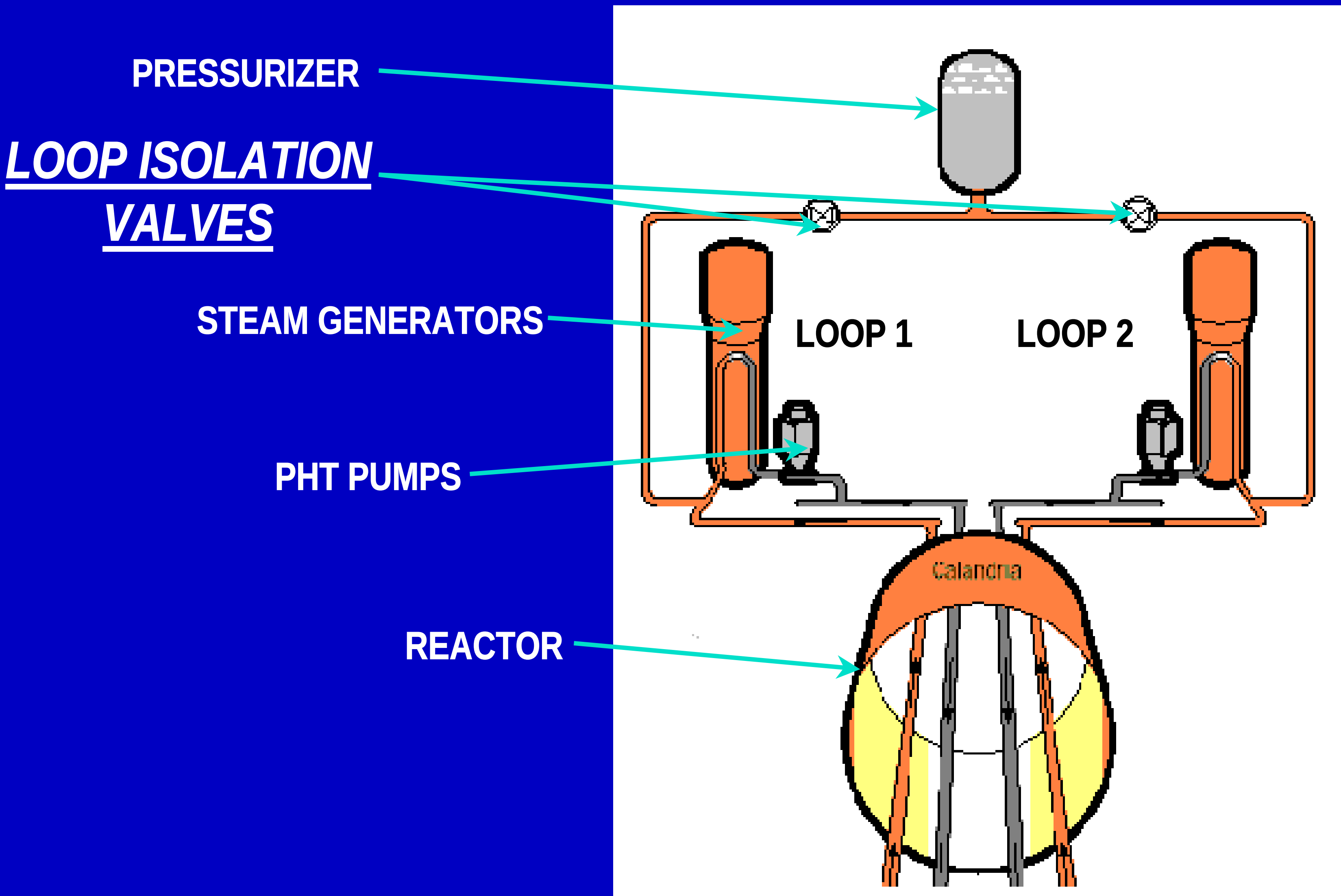
- 380 inlet feeders; 380 outlet feeders
- Connects fuel channel to headers
- The flow in each feeder is set according to the fuel channel power (high channel power ==> high feeder flow)
- Inside diameter ranges from 38.1 mm to 85.4 mm
- Maximum channel flow: 26.5 kg/s



Loop Isolation for LOCA events

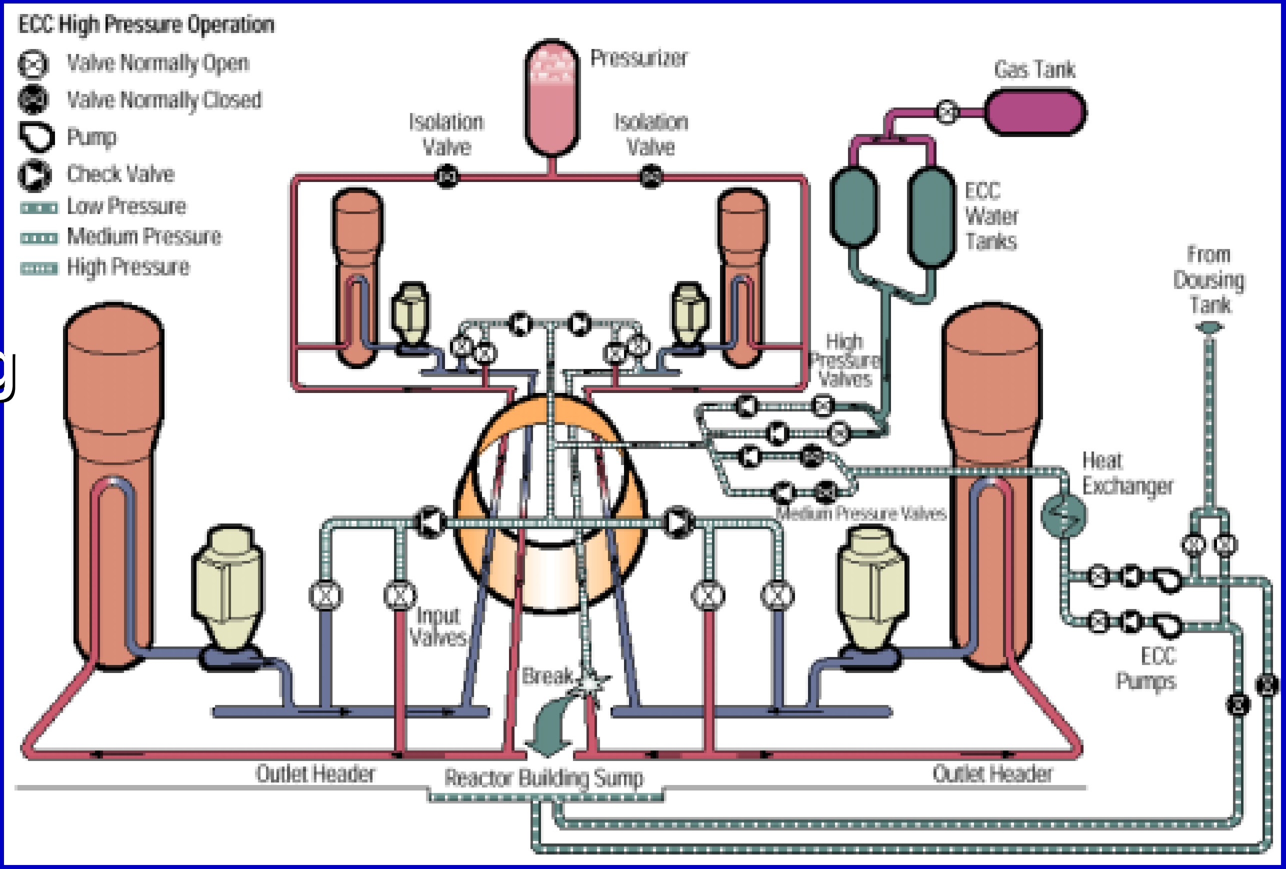
- During some accident scenarios, loop isolation is initiated (for example in LOCA events were a break occurs in the reactor headers)
- Isolation of the two separate loops occurs after the loop isolation signal is received (i.e., detection of a LOCA)
- By separating the two loops from each other, then only half the core is affected by the break
- Forced circulation before the pump trips and thermosyphoning after the pumps trip provide adequate fuel cooling in the intact loop

Loop Isolation



Thermalhydraulics of Emergency Core Cooling (ECC) System

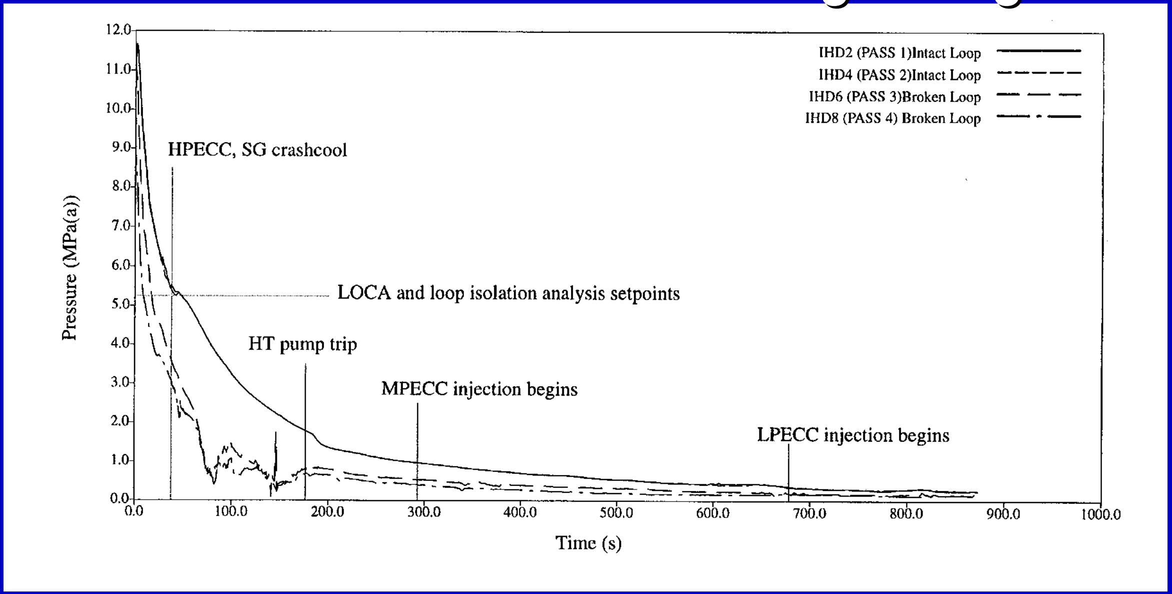
- <u>High</u> pressure injection by gas
- <u>Medium</u> pressure injection by ECC pumps and dousing tank water supply
- <u>Low</u> pressure injection by ECC pumps and reactor building sump
- Injection into reactor headers



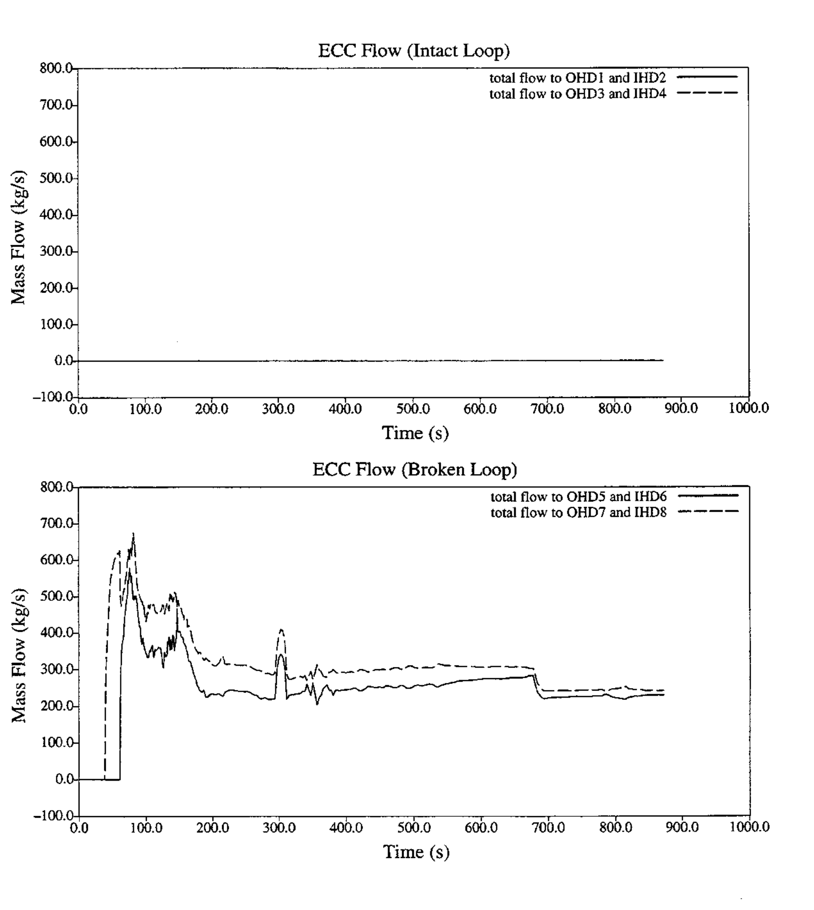
Some Safety Requirements of ECC

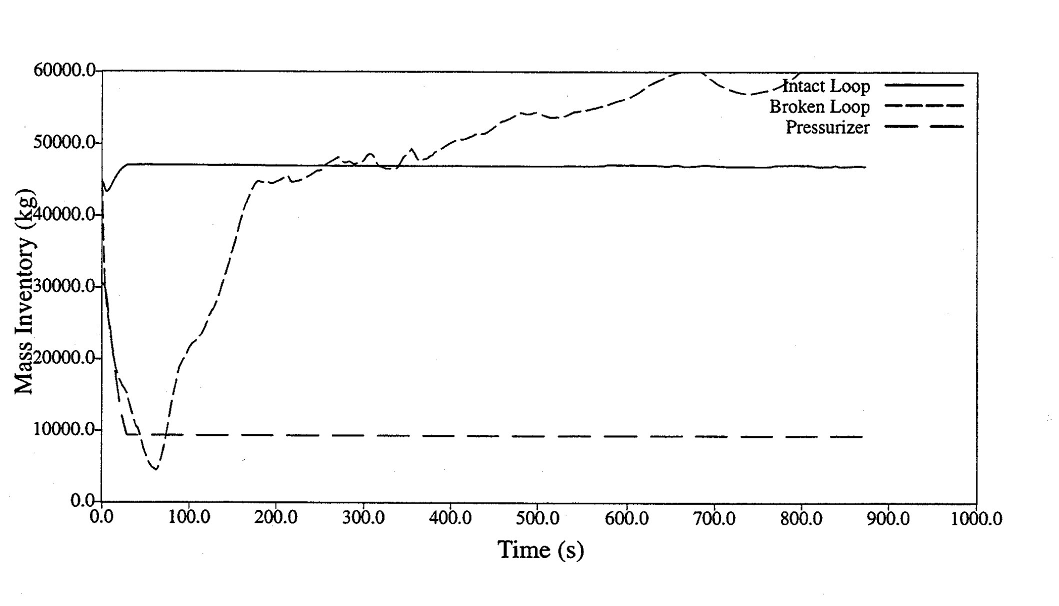
- To prevent any fuel sheath failures during small LOCAs
- To limit the number of fuel sheath failures for large LOCA such that the acceptable dose limits are satisfied
- To maintain a coolable fuel bundle geometry for large LOCA

Depressurization of Inlet Headers during a Large 35% RIH LOCA



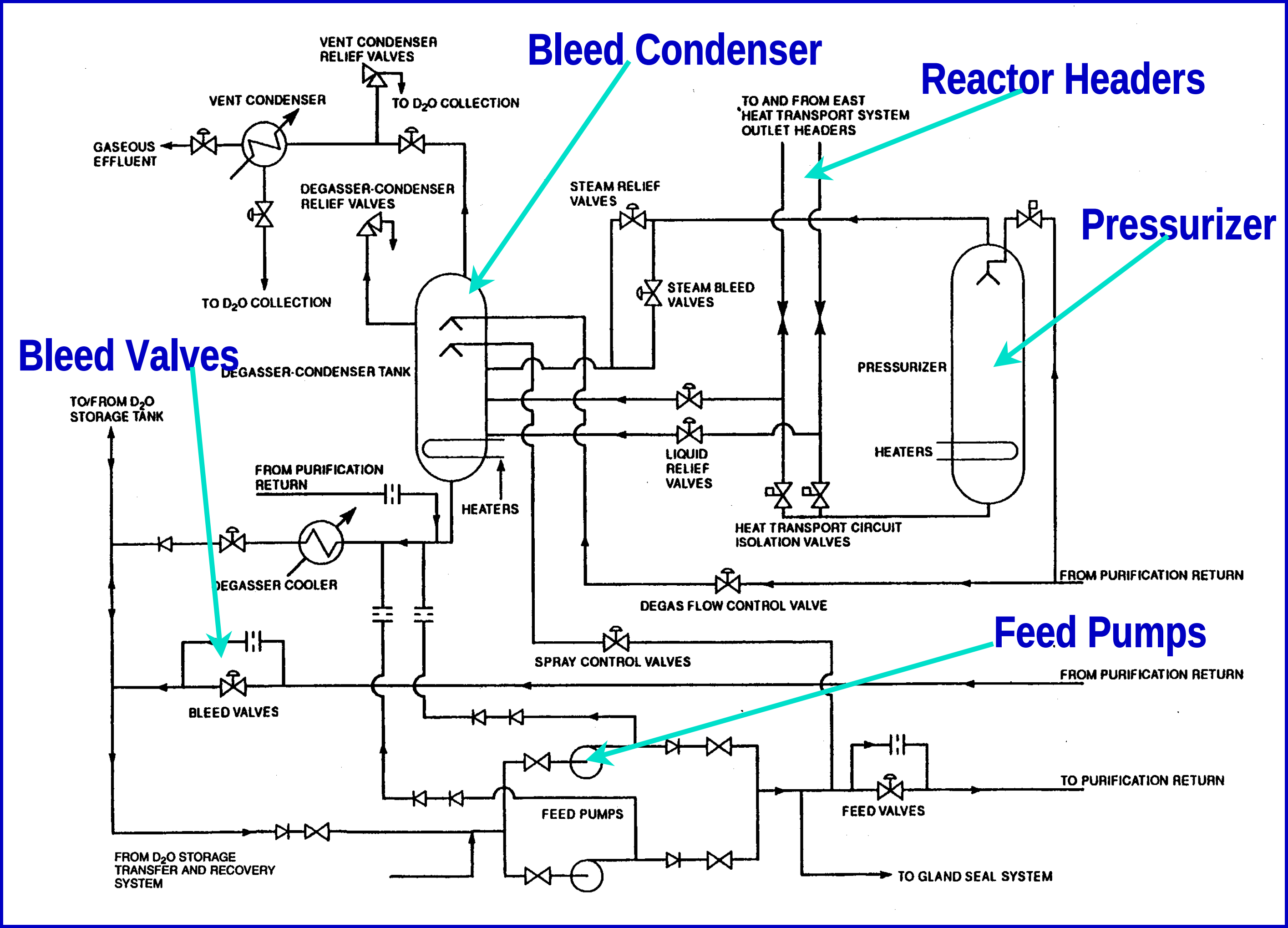
Emergency Core Cooling & PHT Refill of Broken Loop





Pressure and Inventory Control

- Consists of:
  - pressurizer
  - bleed condenser
  - feed pumps
  - feed and bleed valves
  - storage tank
- Functions:
  - pressure and inventory control for each PHT loop

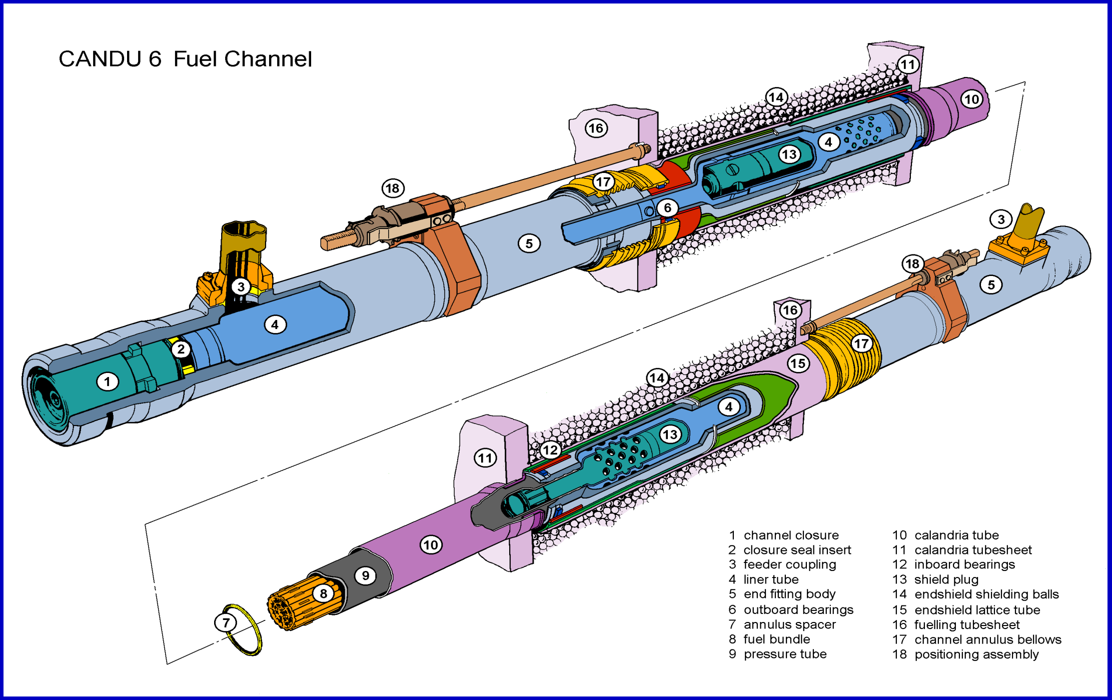


Some Requirements of Pressure & Inventory Control

- To accommodate the PHT coolant swell (cool water to hot water) and shrink (hot water to cool water) associated with warm-up, cooldown and power maneuvering (feed and bleed system)
- Provide relief for over-pressure protection of PHT system (liquid relief valves) and contain the relief from PHT (bleed condenser)
- Control the PHT system pressure (by pressurizer or feed and bleed system)
- Minimize rapid pressure reduction in PHT system for accident scenarios and prevent PHT pump suction pressure from dropping to a value that would cause PHT pump cavitation
- Isolate loops following LOCA
- Provide a low-level trip signal to the reactor shutdown system

CANDU Fuel Channel

- 380 horizontally-oriented fuel channels in core
- Zircaloy-2.5wt%Nb pressure tubes
  - 103.4 mm inside diameter
  - 4.2 mm wall thickness
- Zircaloy-2 calandria tubes
  - 129 mm inside diameter
  - 1.4 mm wall thickness
- Fuel Bundles
  - 37 fuel elements
  - Natural UO_2 with Zircaloy sheaths
  - Centre pin, 6 elements in inner ring, 12 elements in intermediate ring, 18 elements in outer ring
- 380 inlet end fittings and 380 outlet end fittings
  - links the feeders and channels



Some T/H Safety Features of Channels

- Permits the PHT coolant to efficiently remove heat from the fuel with a low pressure drop across the channel and minimize vibration in channel
- During single-channel accidents such as flow blockage and feeder stagnation break, the accident only affects the single-channel (i.e., degraded cooling conditions in 1 channel out of 380 channels, severe fuel temperatures in 1 channel). The unaffected channels behave similar to a small loss-of-coolant accident (i.e., no fuel failures)