CANDU Safety #4: Thermalhydraulic Safety Characteristics Of CANDU Reactors

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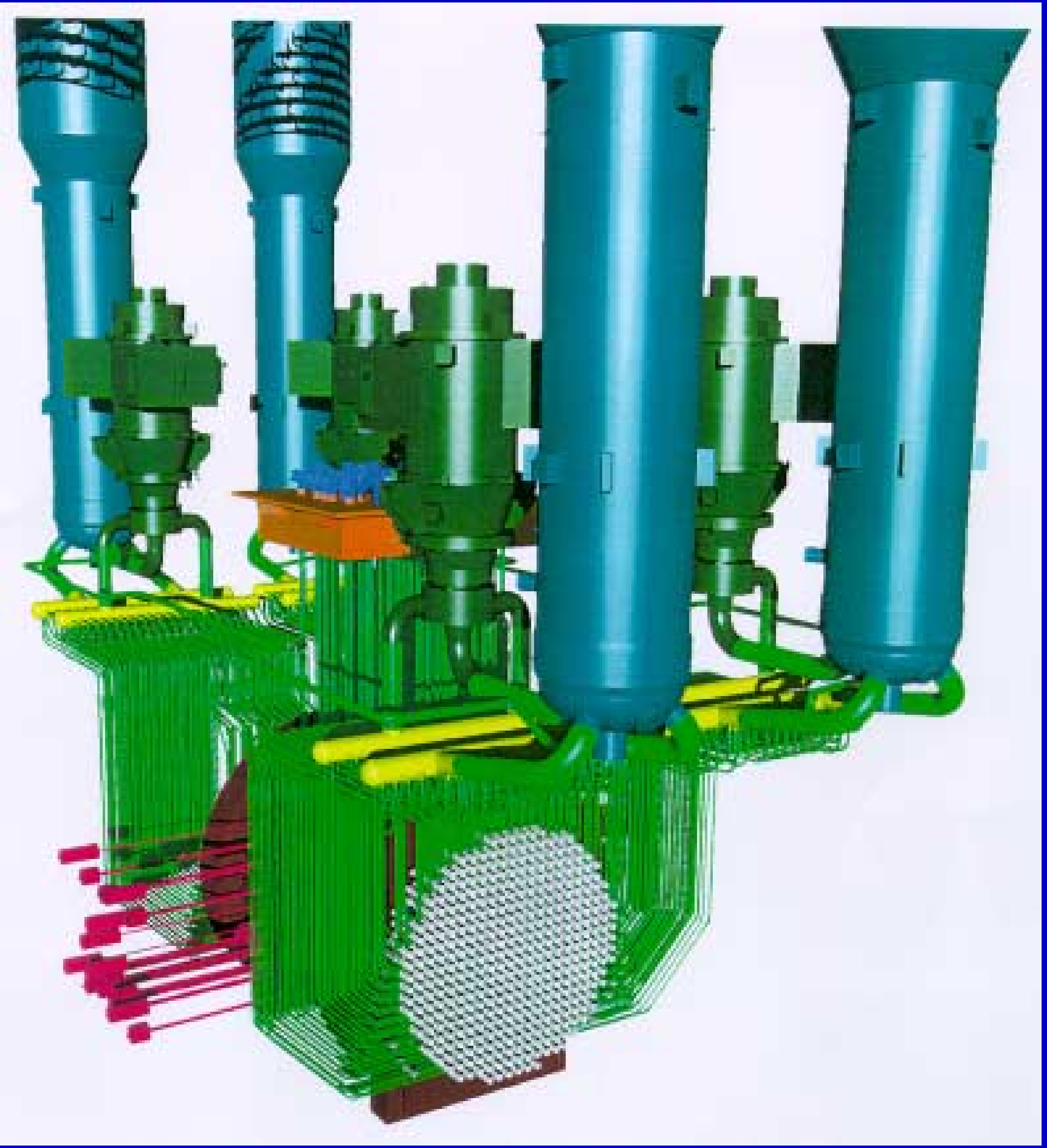
Overview

- 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)

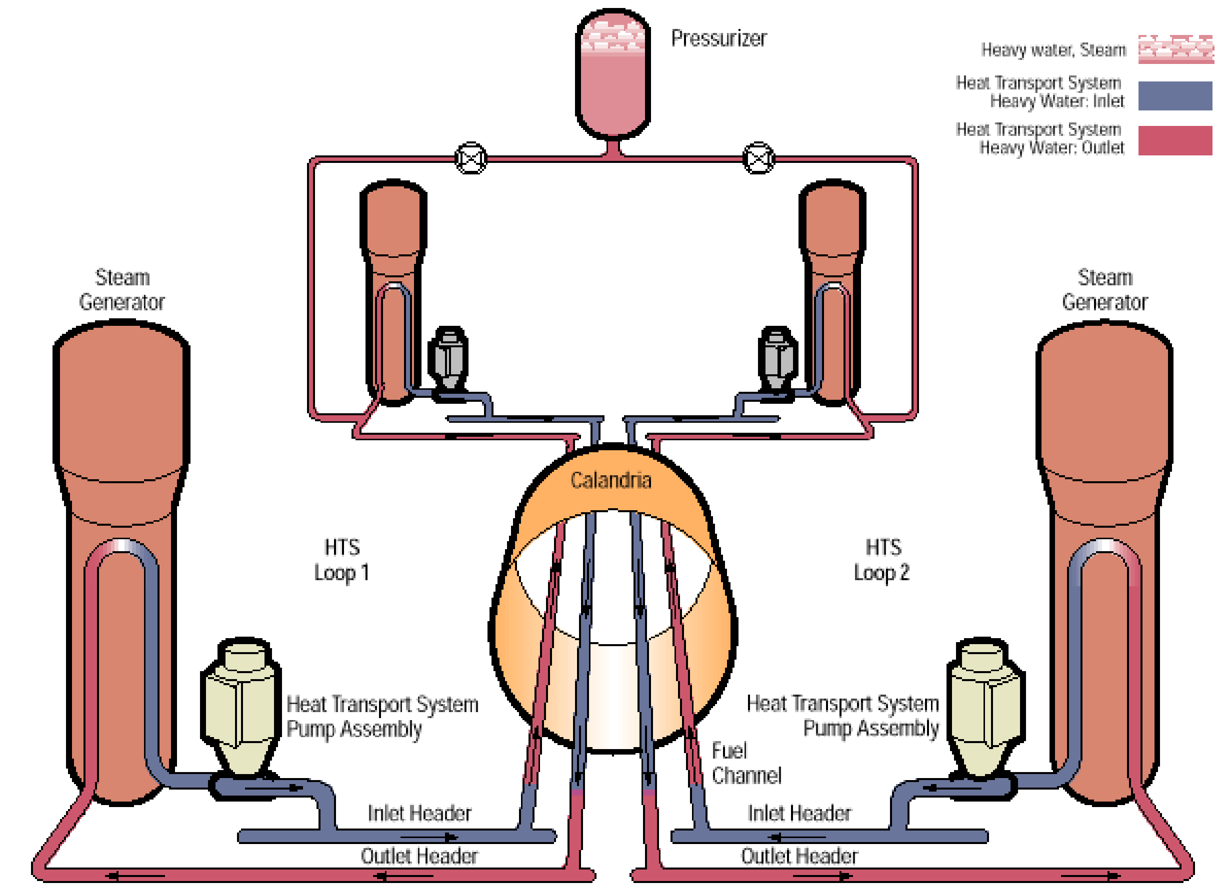
- 2 separate loops
- 4 steam generators
- 4 primary heat transport system pumps
- Pressurized heavy water in loops
- 380 horizontal fuel channels
- 380 inlet feeders; 380 outlet feeders
- 4 inlet headers; 4 outlet headers



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

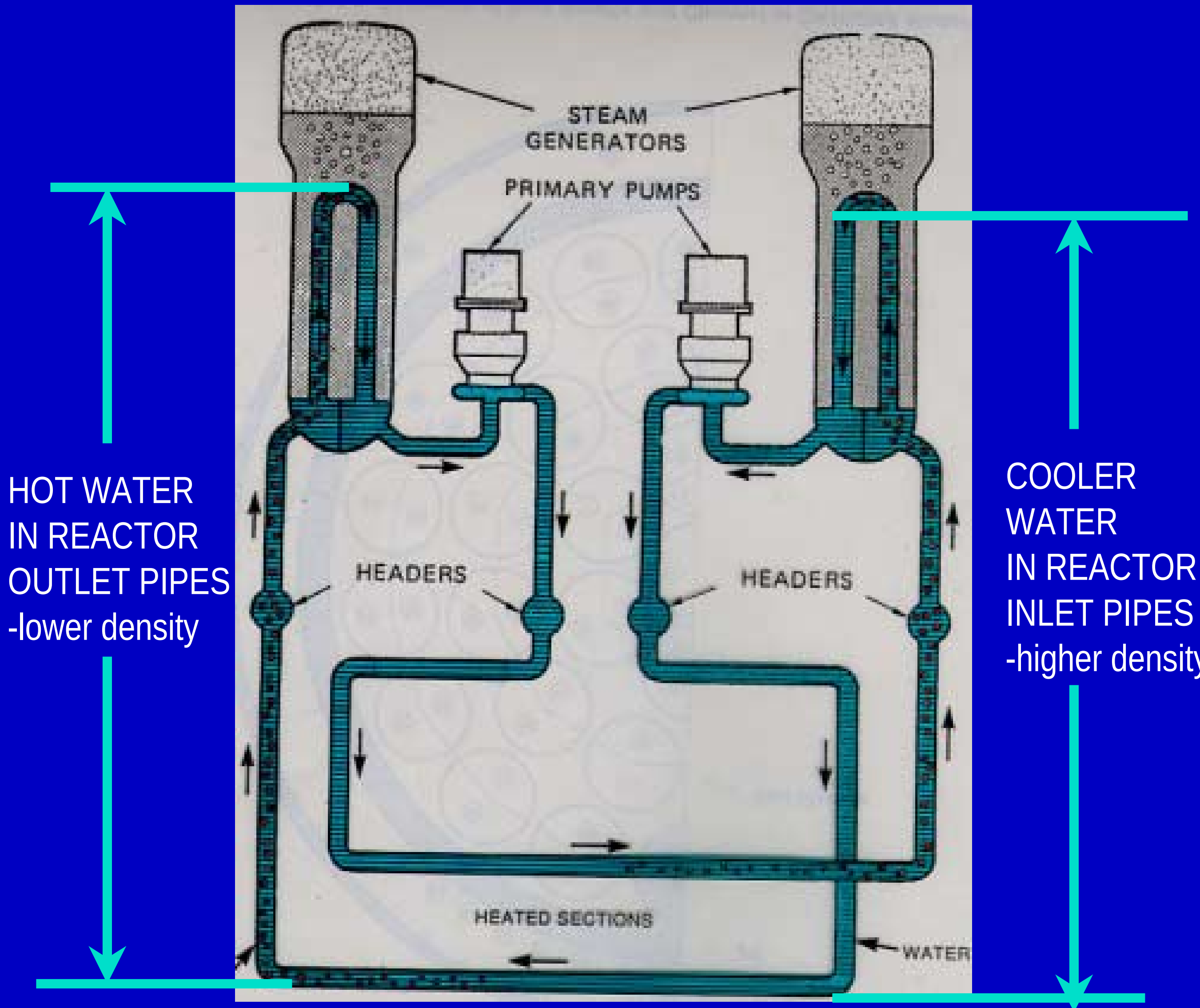
- In the event where the PHT system boundary fails, must limit the fuel damage to satisfy dose limits, in conjunction with the mitigating systems such as reactor shutdown: SDS1, SDS2; and emergency core cooling system
- Promote decay heat removal by natural circulation (thermosyphoning) after the total 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

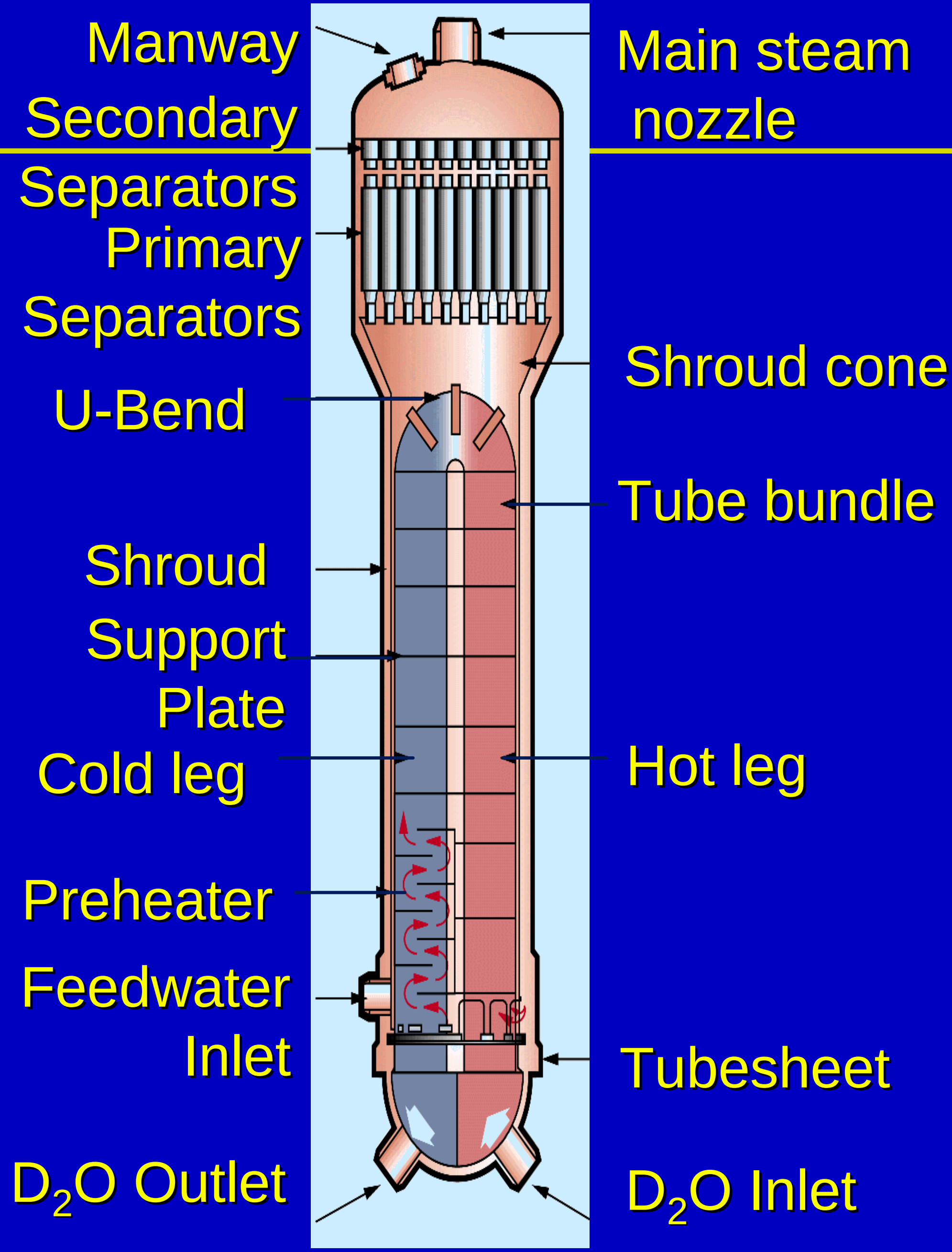
- Effective heat removal process for scenarios involving loss of forced circulation
- For example,
  - For LOCA: following PHT trip, the thermosyphoning process provides cooling in the intact loop
  - loss of Class IV power



Steam Generator

Operating Specifications

- Tube side (primary side)
  - Fluid is heavy water
  - Flow rate: 7.7 Mg/s (for 4 steam generators)
  - Inlet temperature: 309ºC
  - Outlet temperature: 266ºC
- 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



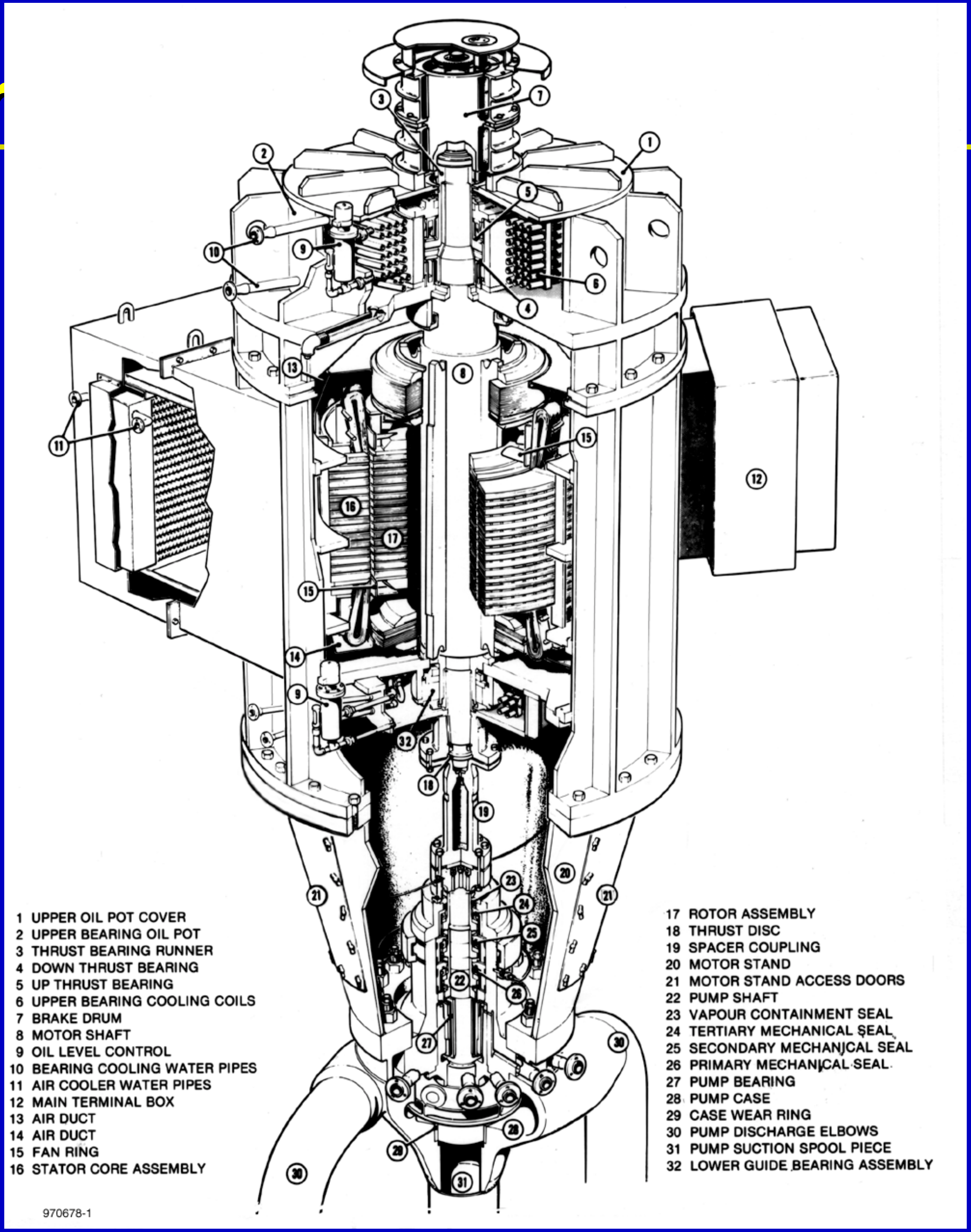
Some Functional Requirements Related to Safety for Steam Generator

- **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: 266ºC
  - Head: 215 m
- Motor
  - Power supply is Class IV



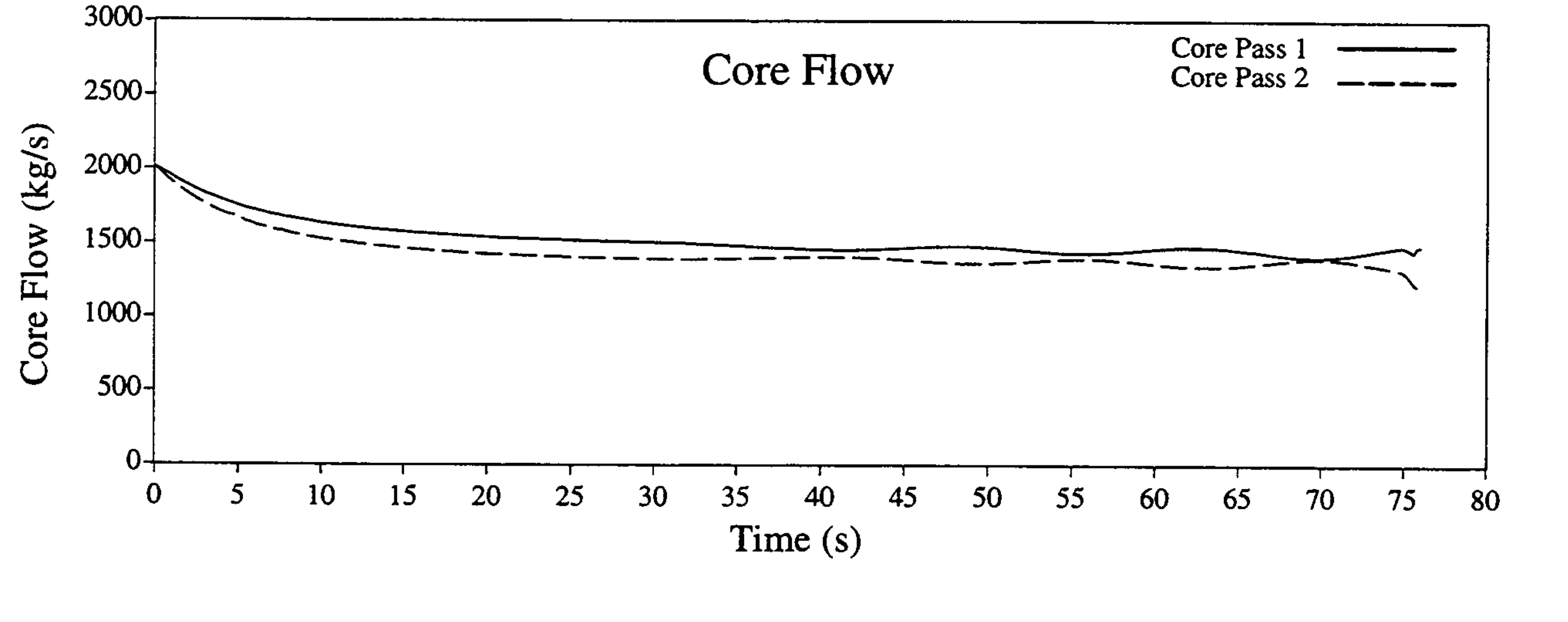
Some Functional Requirements Related to Safety for PHT Pump

- 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

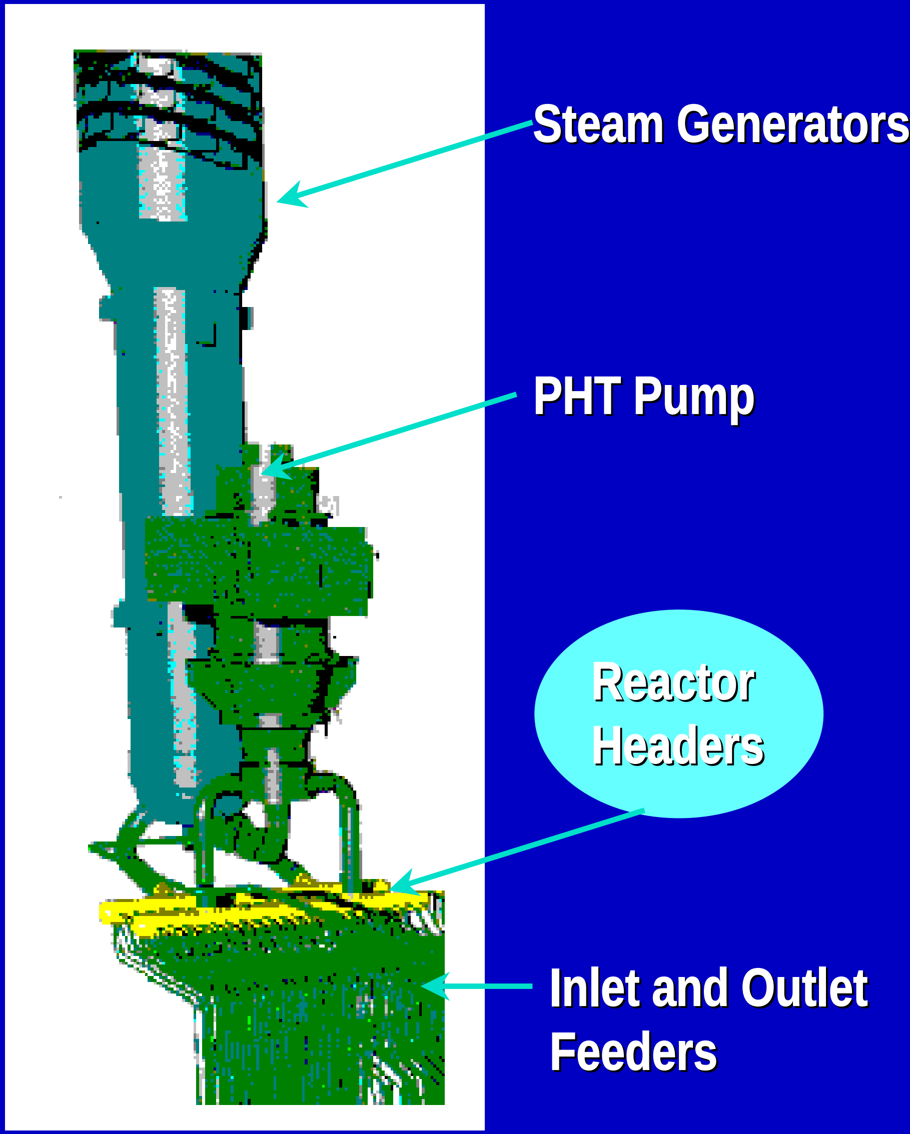
CORE FLOW FOR SINGLE PUMP TRIP; 80% Full-Power



Headers

Specifications

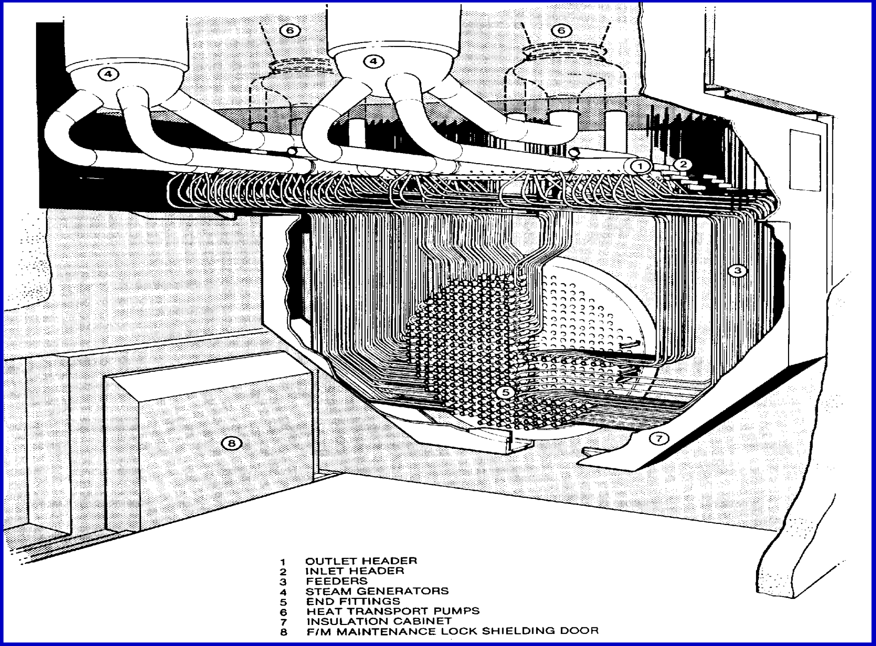
- Inlet Headers
  - 4 inlet headers
  - 0.37 m inside diameter
  - Operating pressure: 11.25 MPa (g)
  - Operating temperature: 266ºC
- Outlet Headers
  - 4 outlet headers
  - 0.406 m inside diameter
  - Operating pressure: 9.89 MPa (g)
  - Operating temperature: 310ºC



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

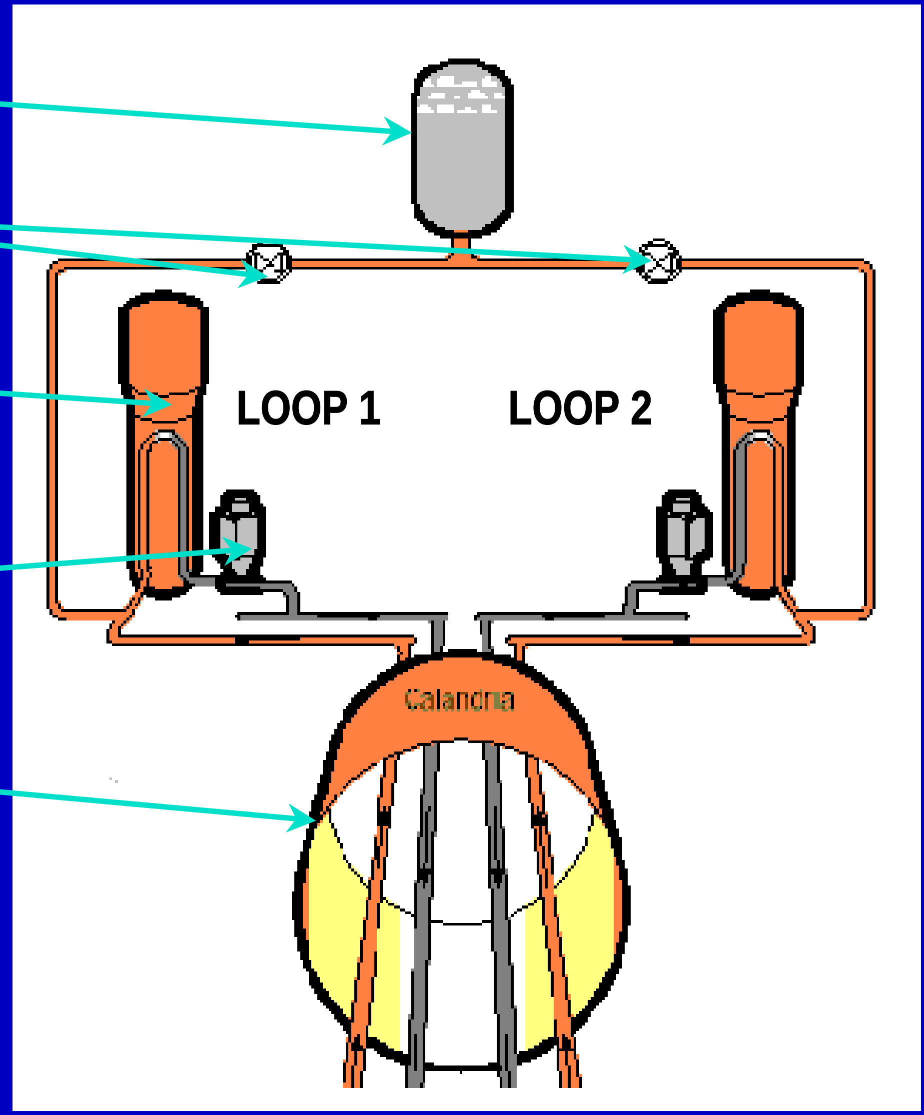
PRESSURIZER

LOOP ISOLATION VALVES

STEAM GENERATORS

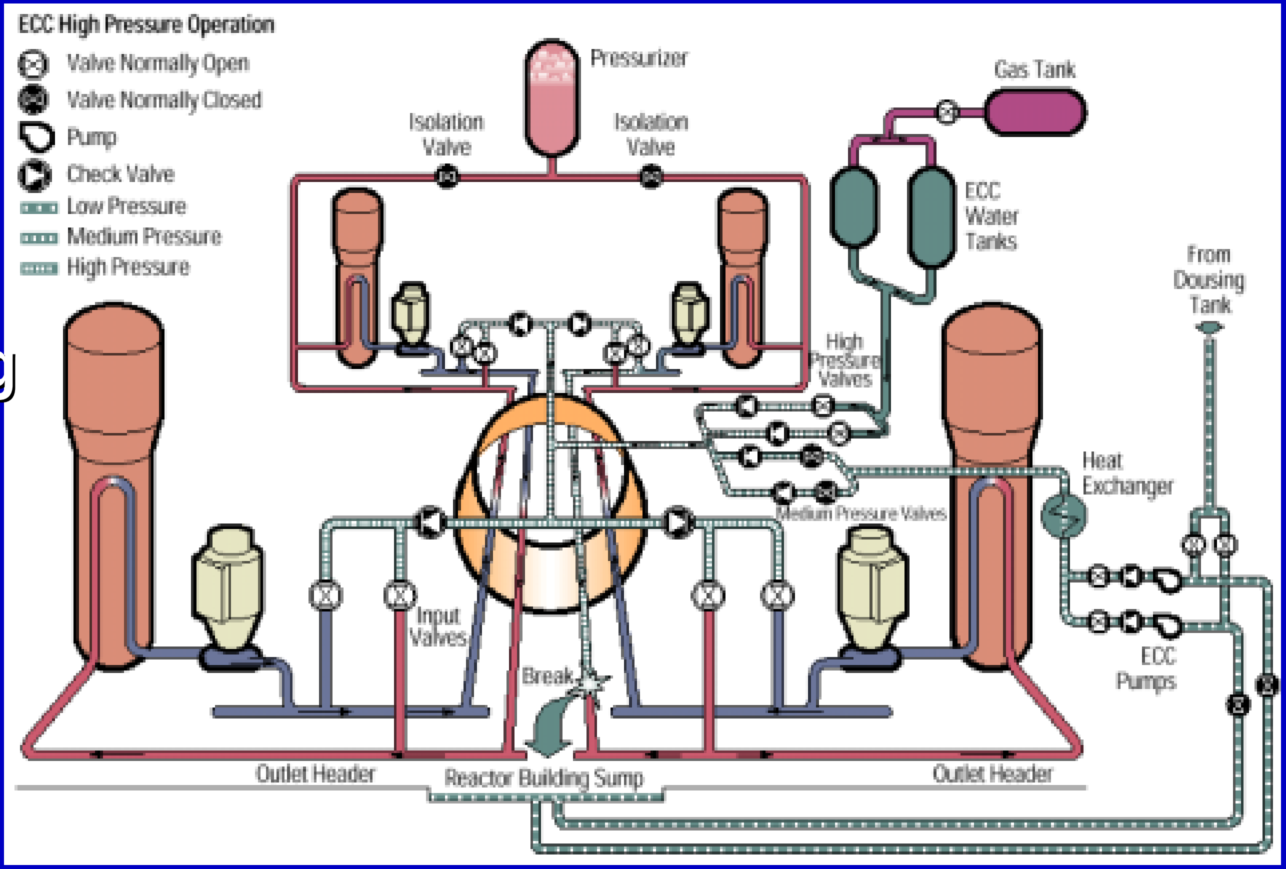
PHT PUMPS

REACTOR



Thermalhydraulics of Emergency Core Cooling (ECC) System

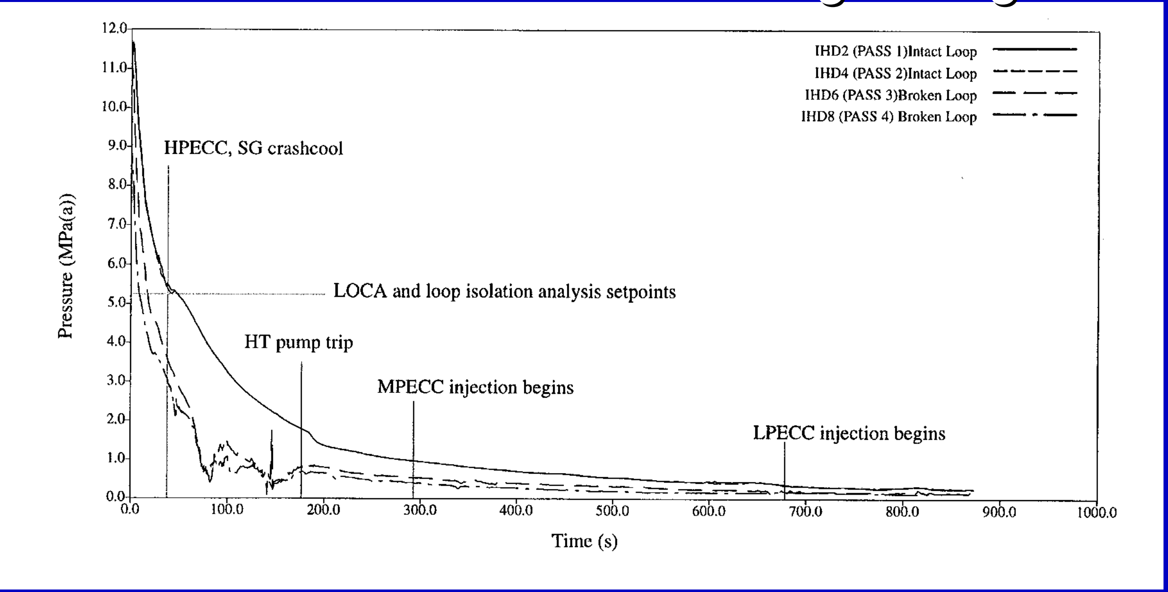
- **High** pressure injection by gas
- **Medium** pressure injection by ECC pumps and dousing tank water supply
- **Low** pressure injection by ECC pumps and reactor building sump
- Injection into reactor headers



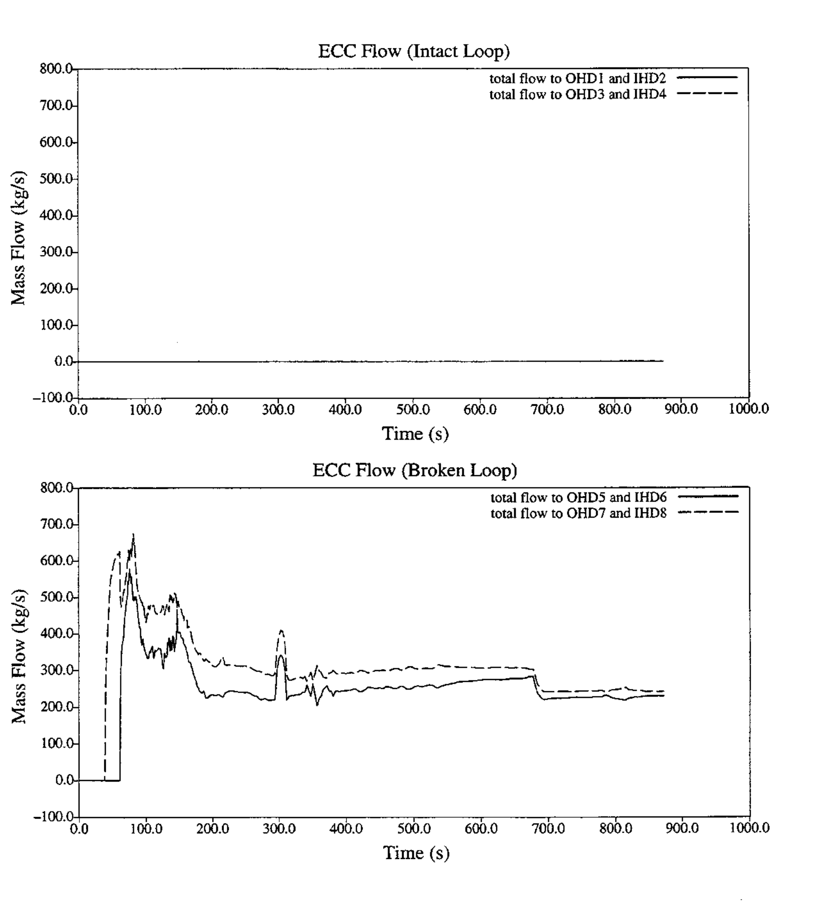
Some Safety Requirements of ECC

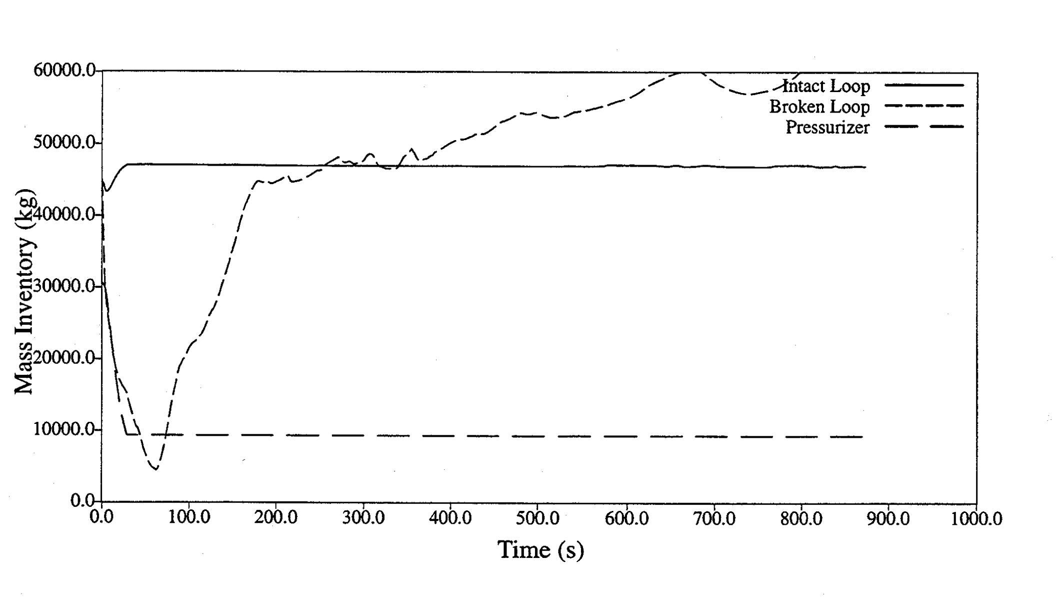
- To prevent any fuel sheath failures during small LOCAs
- To limit the number of fuel sheath failures for large LOCA such that the acceptable dose limits are satisfied
- To maintain a coolable fuel bundle geometry for large LOCA

Depressurization of Inlet Headers during a Large 35% RIH LOCA



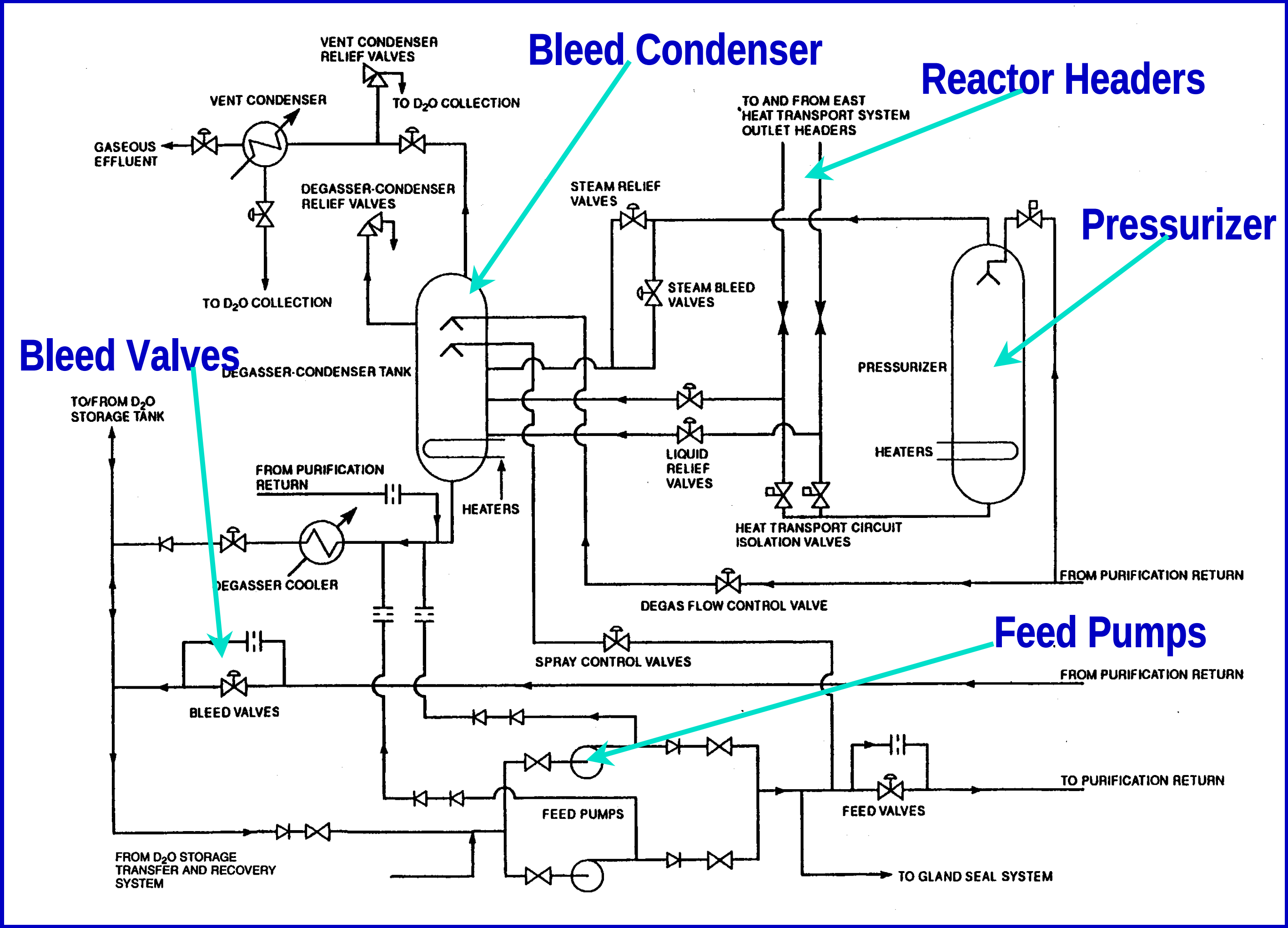
Emergency Core Cooling & PHT Refill of Broken Loop





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

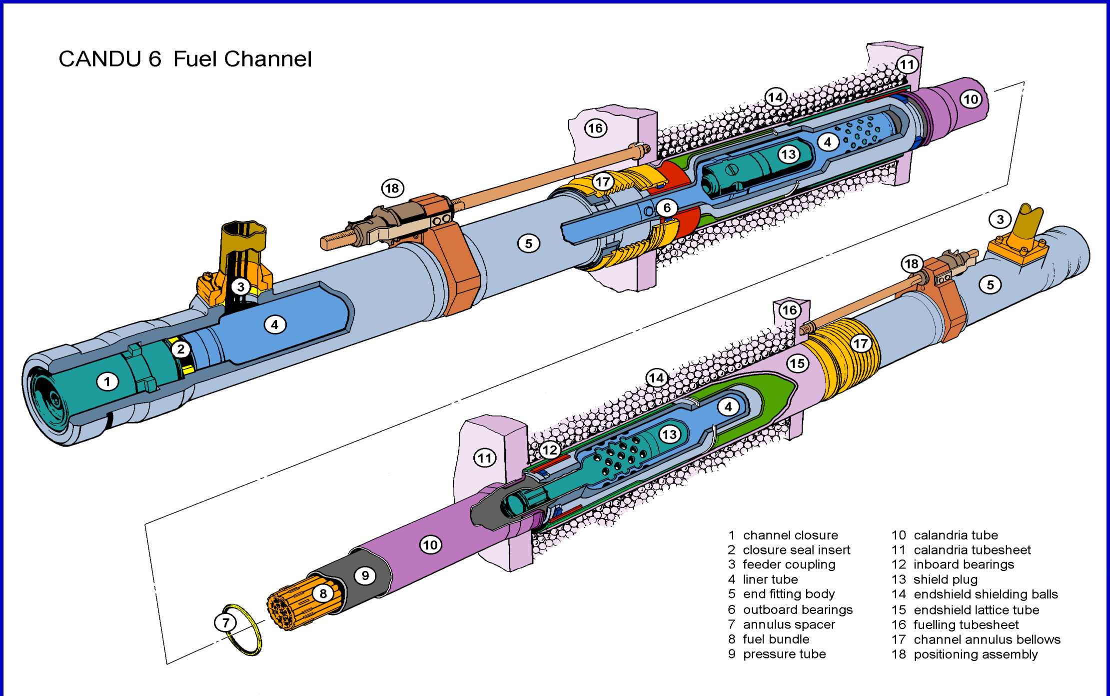


Some Requirements of Pressure & Inventory Control

- 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)