ACR Design Overview

Stephen Yu

Program Manager, ACR Product Development

ACRS Subcommittee on Future Plant Designs

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AECL TECHNOLOGIES INC.

Outline

- Introduction
- ACR Design Features
  - Fuel
  - Fuel channels
  - Core design
  - Reactor Coolant System
  - On-power Fueling
- Engineered Safety Features
  - Shutdown System 1
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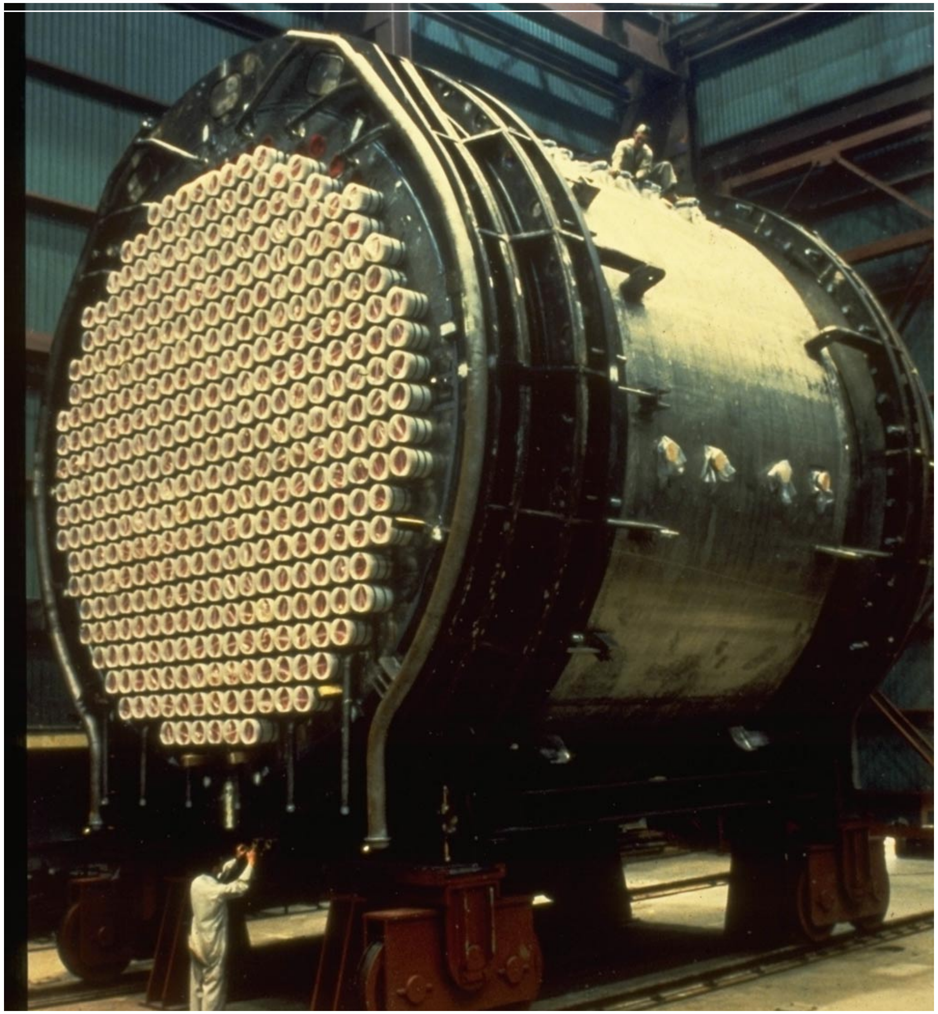
  - ECC
  - Containment
- Severe Accident Resistance and Mitigation
- Operational Features

- **Introduction**
- ACR Design Features
- Engineered Safety Features
- Severe Accident Resistance and Mitigation
- Operational Features

ACR

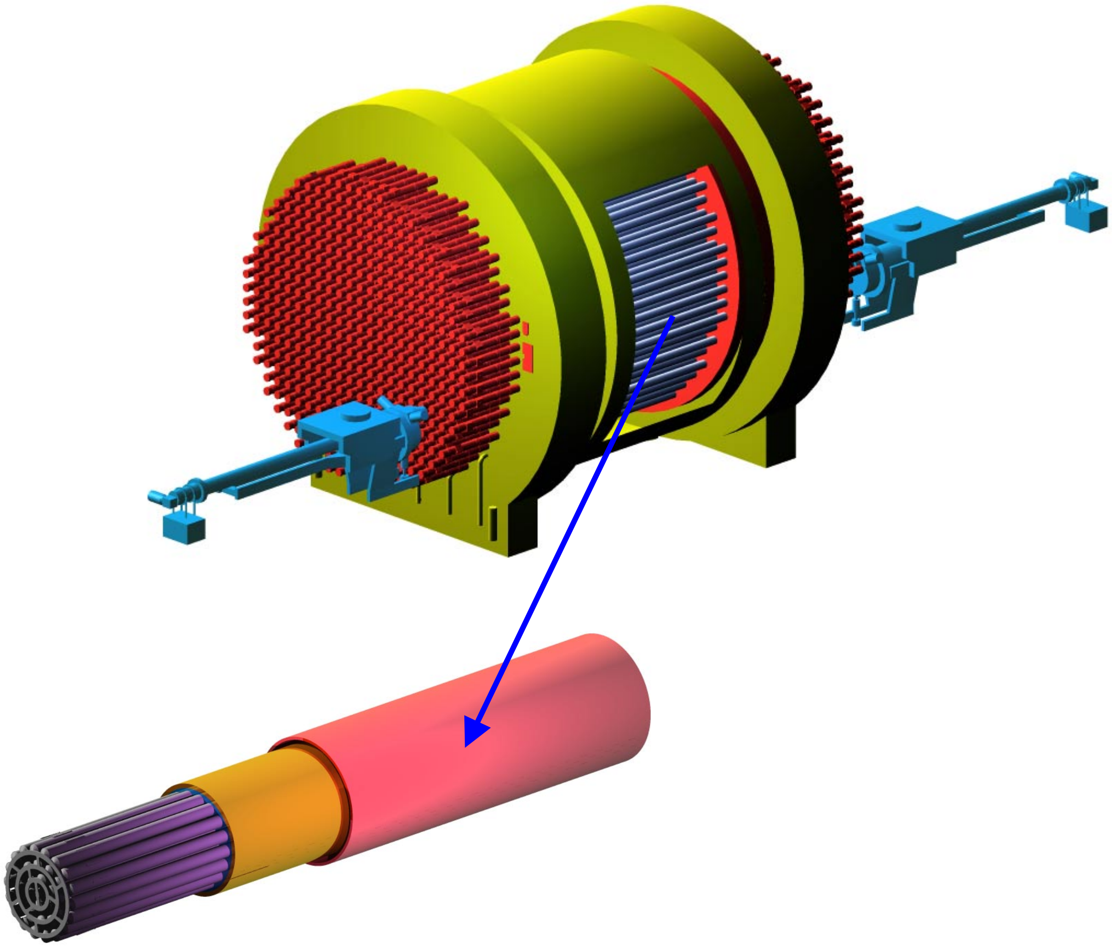
- **The ACR is an evolutionary extension of the CANDU 6 plant, which has ten units in operation on four continents, and one unit currently under construction**

CANDU 6 Reactor



CANDU Intrinsic Features

- Channel reactor
  - Horizontal channels
  - Pressure tube as core pressure boundary
  - Water cooled
  - Water moderated
- Separate coolant and moderator
- Short fuel bundles replaceable on-line



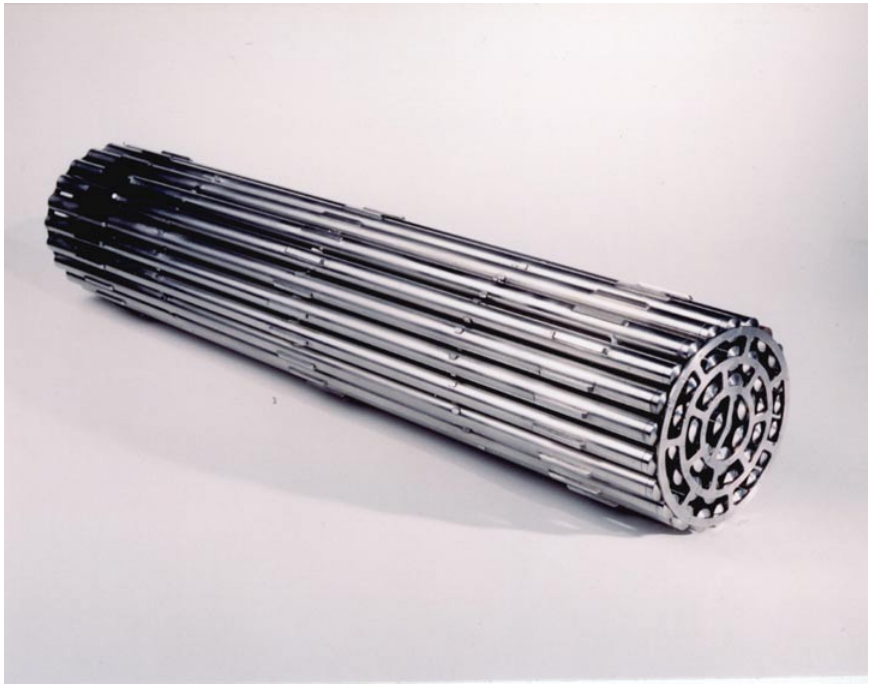
ACR Optimizes the Channel Concept

- Current operating CANDU reactors
  - Natural Uranium (NU) fuel
  - Heavy water (D_2O) coolant
  - Heavy water (D_2O) moderator
- ACR – relax constraint of Natural Uranium Fuel and –
  - Use Slightly Enriched Uranium (SEU) fuel
  - Use light water coolant
  - Reduce core size and reduce amount of heavy water moderator
    - Increase reactor coolant system (RCS) pressure
    - Increase thermal efficiency
- Retain intrinsic proven CANDU features

- Introduction
- **ACR Design Features**
- Engineered Safety Features
- Severe Accident Resistance and Mitigation
- Operations

Fuel

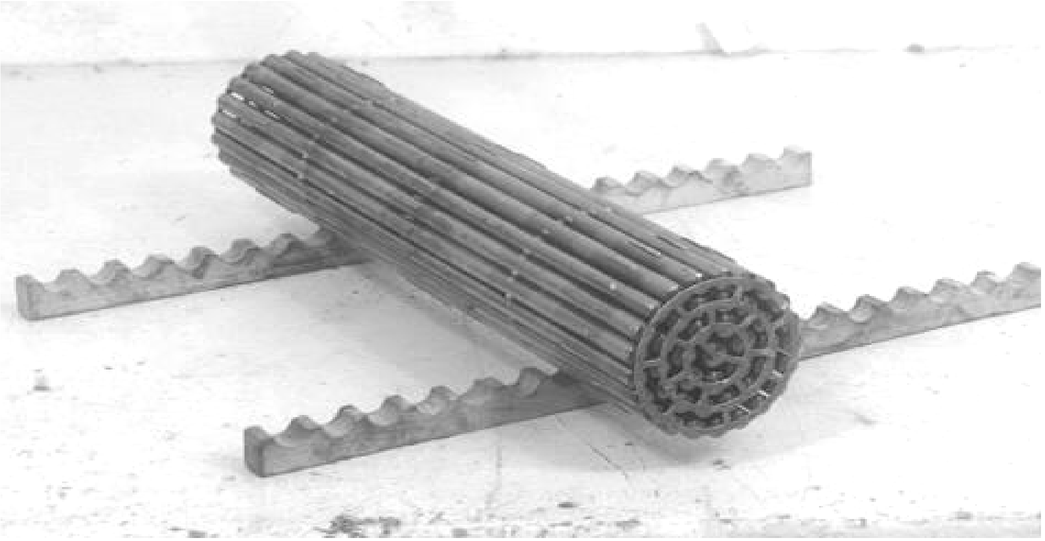
- 0.5m (1.6 foot) long CANFLEX fuel bundle
- On-power refueling
- 43 fuel rods in each bundle
  - 2.1 wt% ^{235}U SEU in 42 rods, in the form of UO_2 pellets
  - NU + 7.5% dysprosium in central rod
- Fuel burn-up 21,000 MWd/MT (U)
  - Higher than NU CANDU average
  - Modest vs. LWRs
- Higher bundle power, lower rod rating than current CANDU



Fuel

- **Short fuel bundles limit radioactivity release from defects or in accidents**
  - **Defected fuel removable during operation**
- **Collapsible clad – good fuel/clad heat transfer**
- **Low internal pressure – small amount of strain relieves internal pressure and reduces likelihood of flow blockage**

CANFLEX-NU fuel bundle removed from Point Lepreau

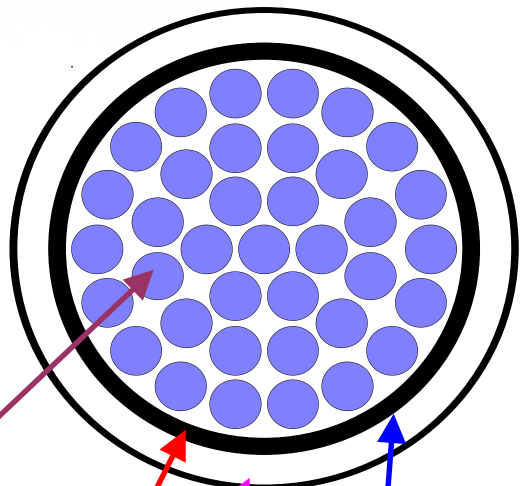


ACR Fuel Channel Design

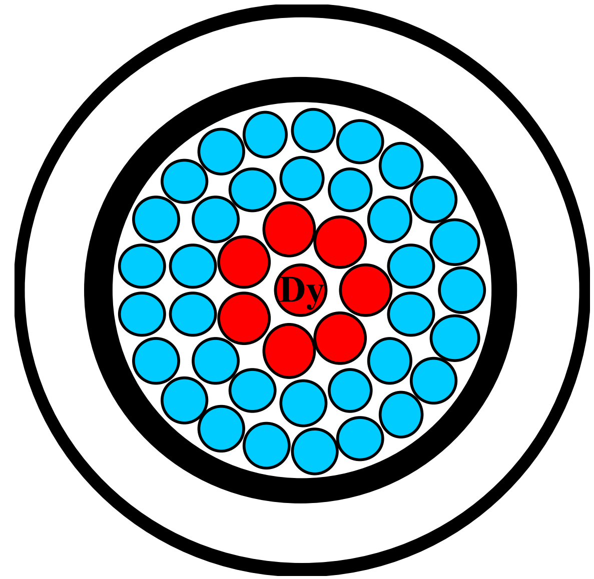
- **Pressure Tube**
  - Thicker to reduce stresses during normal operation
  - Chemistry specification optimized to reduce deformation and corrosion
  - Only the outlet end of the pressure tube experiences temperatures greater than in CANDU 6
- **Calandria Tube**
  - Zr-4 has materials properties equivalent to Zr-2
  - Thicker tube to withstand spontaneous pressure tube failure

Fuel Channel (End View)

CANDU 6



ACR



- 37-rod NU fuel
- Zr – 2.5% Nb pressure tube
- Zr-2 calandria tube
- Insulating gap between pressure tube and calandria tube

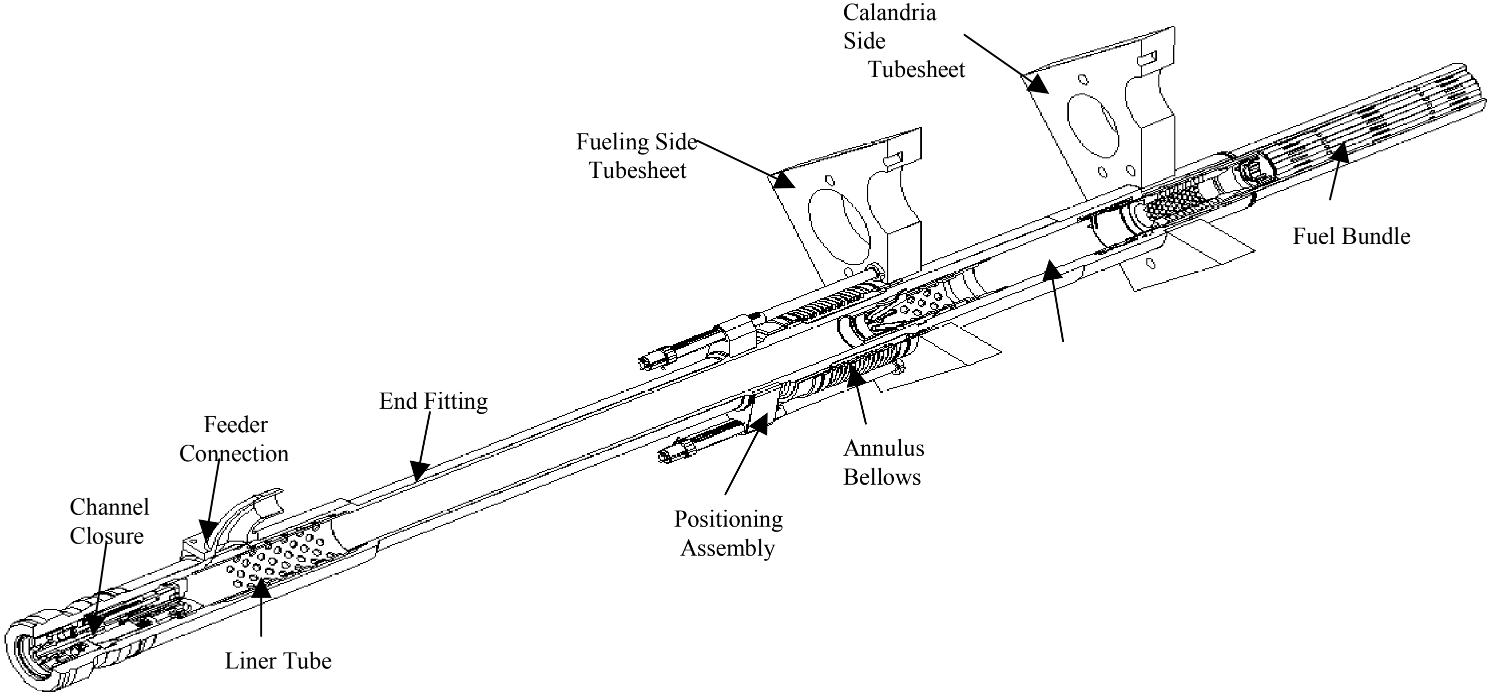
- 43-rod SEU fuel
- Thicker Zr – 2.5% Nb pressure tube
- Stronger Zr-4 calandria tube
- Larger gap between pressure tube and calandria tube

ACR Fuel Channel

Design Feature	ACR	CANDU 6
Pressure Tube	Zr-2.5%Nb	Zr-2.5%Nb
Thickness	6.5 mm	4.2 mm
Fast flux	same	same
Temperature	279-325^{o}C	266-311^{o}C
Pressure	13.2-12 MPa	11.2-10MPa
Calandria Tube	Zr-4	Zr-2
Thickness	2.5 mm	1.4 mm
O.D.	156 mm	132 mm

Fuel Channels

- **Pressure tube defects will leak allowing time for operator action before rupture. Leakage into annulus is detectable.**
- **Pressure tube failure contained within calandria tube**
- **Channel failures will not propagate to other channels, will not fail calandria, nor incapacitate shutdown systems**



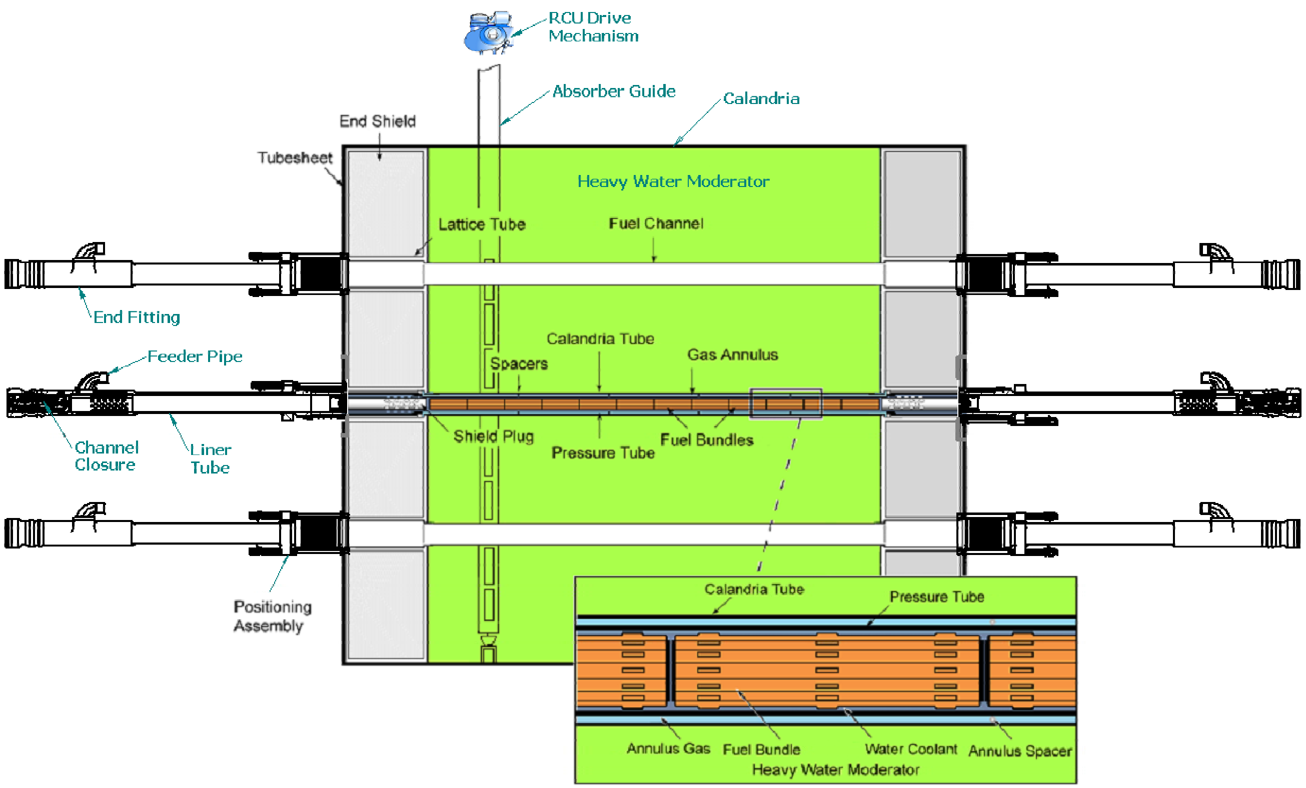
ACR Reactor

• **Horizontal fuel channels surrounded by low temperature, low pressure moderator**

• **Steel calandria contains moderator and supports fuel channels**

• **All reactivity devices in moderator**

• **Shielding water (H_2O) surrounds calandria for thermal and biological shielding**

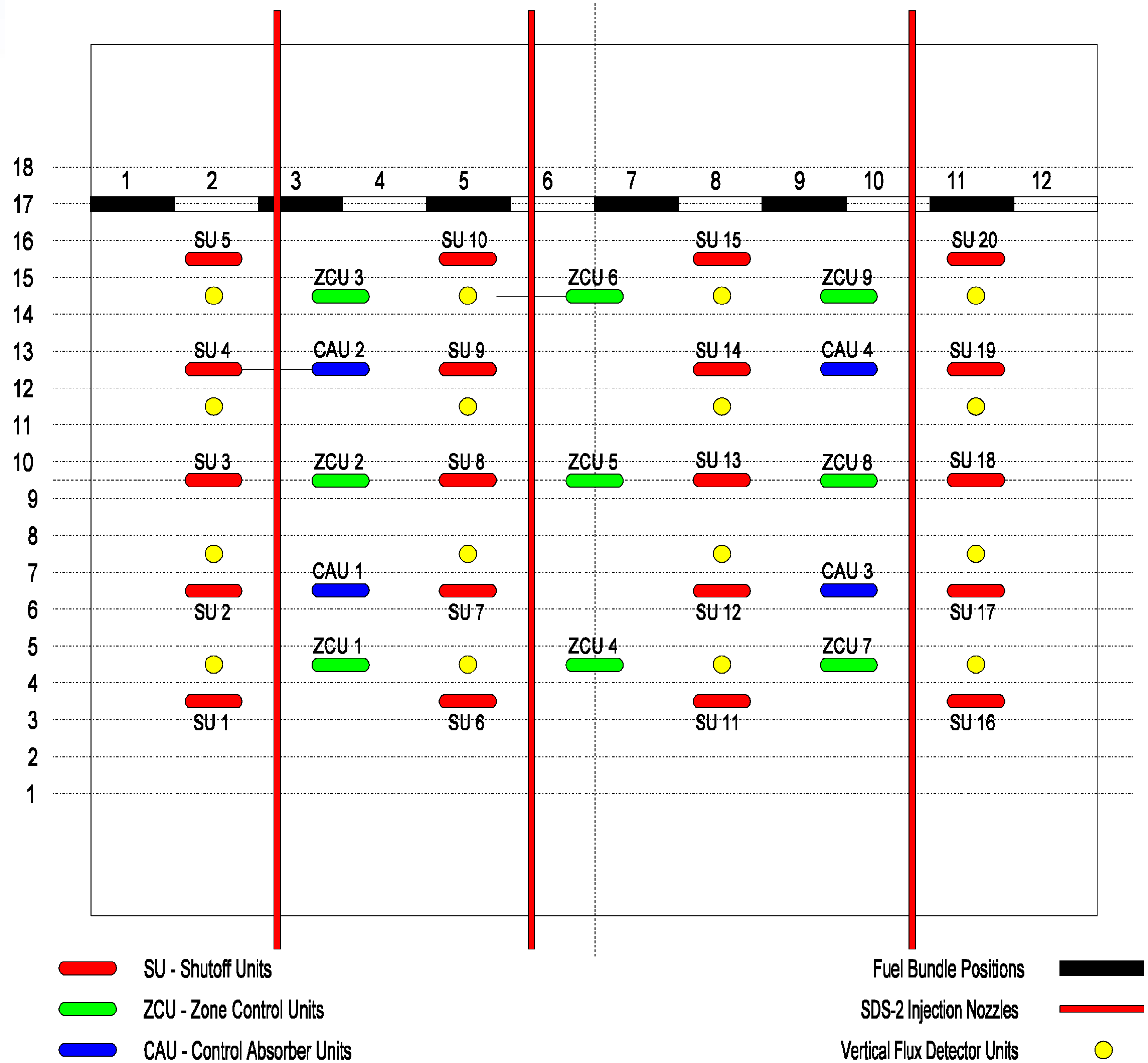


Core Design

- Long prompt neutron lifetime (0.33 ms.) relative to LWRs
  - Due to D_2O moderation (neutron economy)
- Low reactivity hold-up in the control system
  - Due to on-power refueling for long-term reactivity control
  - Typically total of ~9 mk in movable control devices
  - Additional –12mk in Control Absorbers (normally out of core)
  - No need for boron in the coolant to hold down reactivity
  - Limits extent of reactivity accident
- Control rod ejection physically impossible
  - Reactivity control mechanisms penetrate the low-pressure moderator, not the coolant pressure boundary; do not interact with the fuel

Core Design – cont'd

- Low reactivity worth of a reactivity control device
- Short-term and spatial reactivity control by zone controllers in 9 assemblies
- Each controller assembly worth ~1 mk



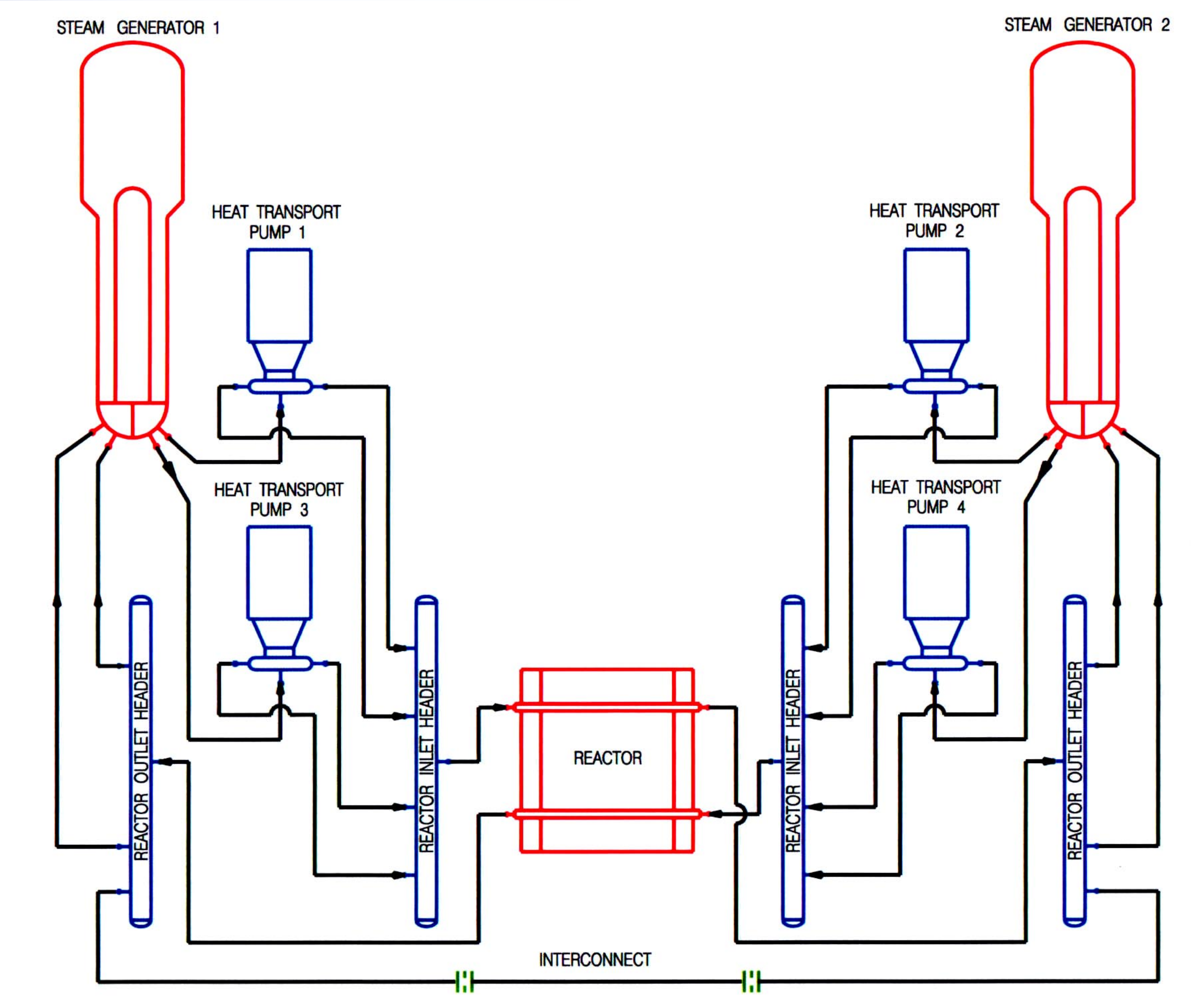
Safety and Control Parameters

Total Delayed Neutron Fraction (ß)	0.0056
Prompt Neutron Lifetime (millisecond)	0.33
Bulk and Spatial Control	Zone Controllers in 9 Assemblies No Adjuster Rods
Fast Power Reduction	4 Control Absorber Units
Shutdown System (SDS1)	20 Shutoff Units
Shutdown System (SDS2)	6 Injection Nozzles (reflector region)

Core Design – cont'd

- Coolant void reactivity coefficient
  - Use of SEU fuel allows flexibility in choice of CVR
  - Chosen small to increase operating margins related to safety
- Total coolant void reactivity is about –7 mk
- Gives negative power coefficient and more stable control
- Inherent reactivity decrease on LOCA, loss of electrical power
- Very small reactivity increase after main steam line break (due to limited boiling in normal operation to about 2% outlet quality)
- Reactivity is reduced should a single channel (pressure tube + calandria tube) fail resulting in H_2O mixing with heavy water moderator

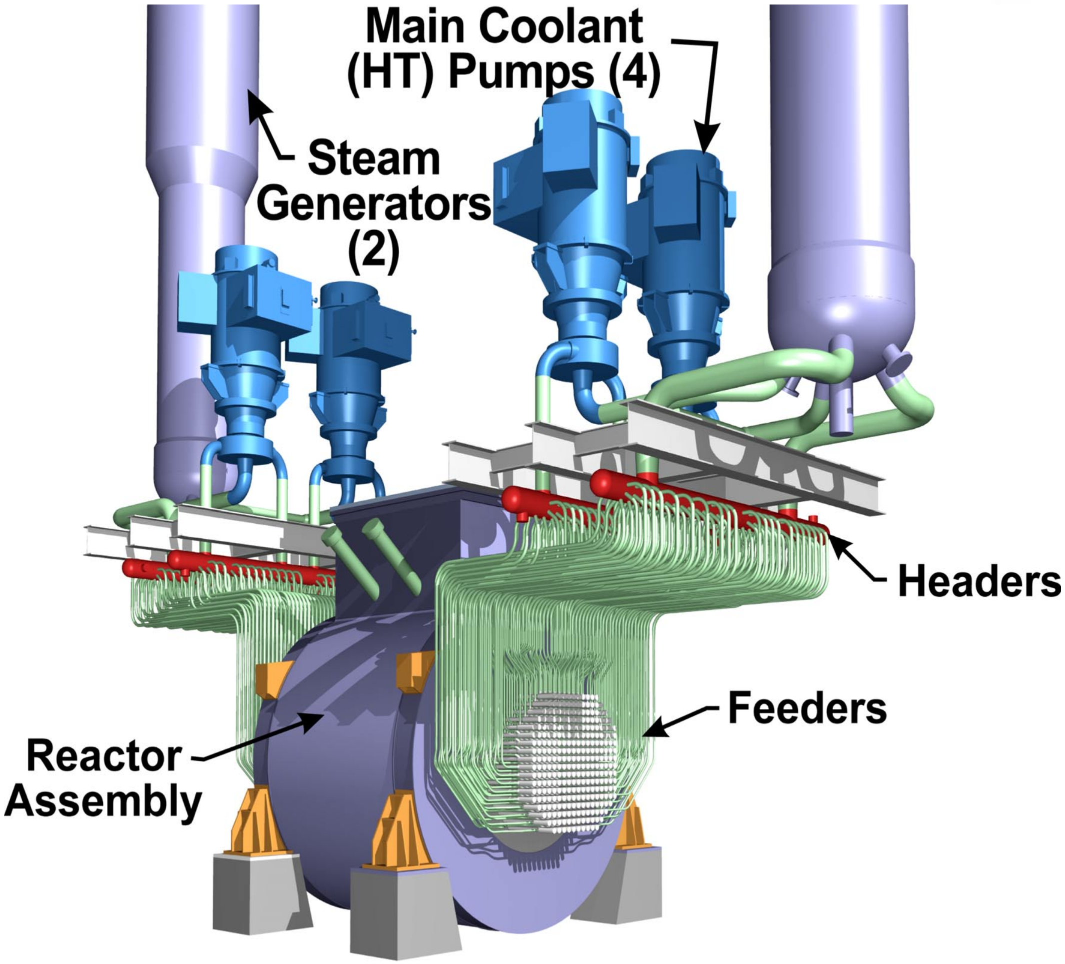
Reactor Coolant System – cont'd



Note "figure-eight" layout

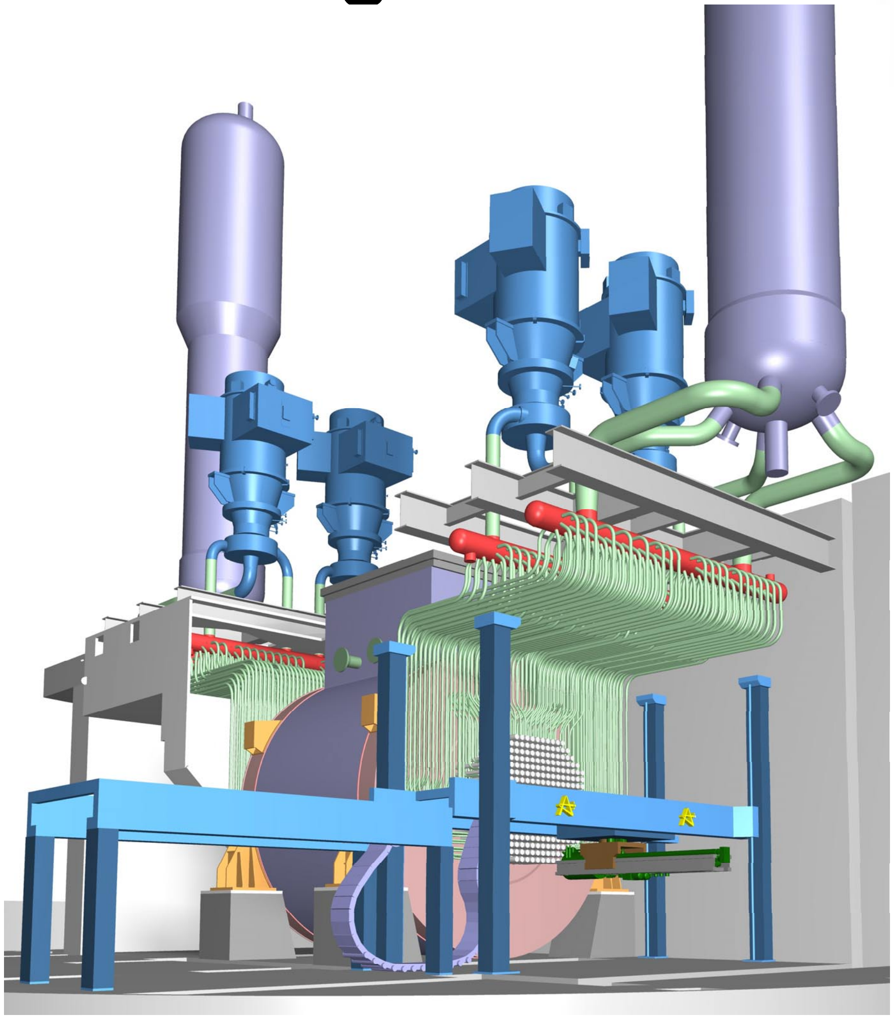
Reactor Coolant System

- Each channel is connected at its inlet and outlet by small diameter (<3.5 inch) feeder pipes to headers above reactor
- No large pipes at or below core level
- Parallel / series pumps – pump seizure mitigation
- Heat sinks above the core - natural circulation, even with some void
  - No preferred flow direction in the channels in the long term

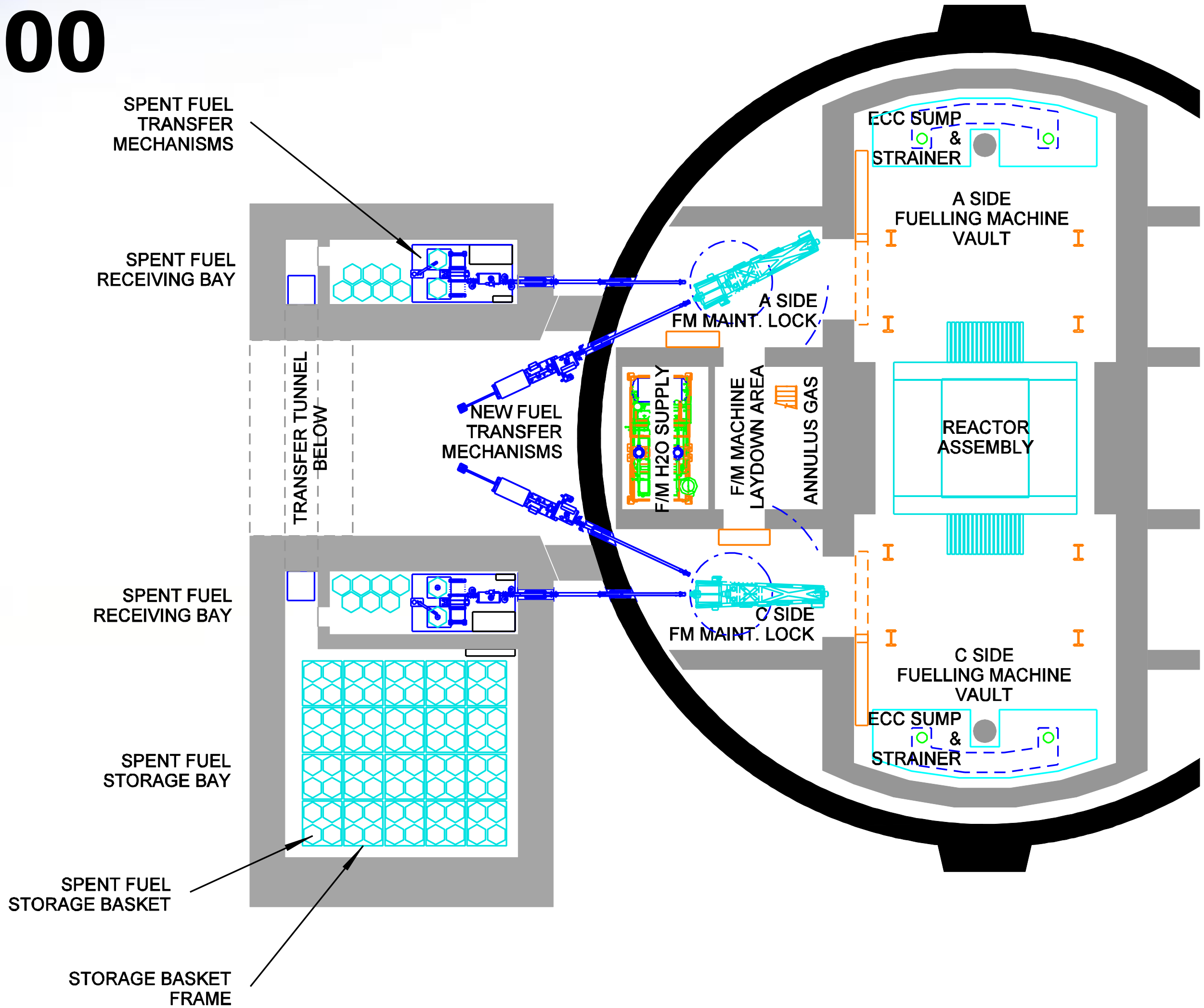


On-Power Fueling

- Each fuel channel contains 12 fuel bundles
- 2 bundles of irradiated fuel are removed and 2 bundles of fresh fuel are inserted using two fueling machines connected to each end of a channel
- The fueling machine has a movable Class 1 pressure vessel that connects to the new and irradiated fuel ports and fuel channels in sequence to move the fuel



ACR 700 Building plan view



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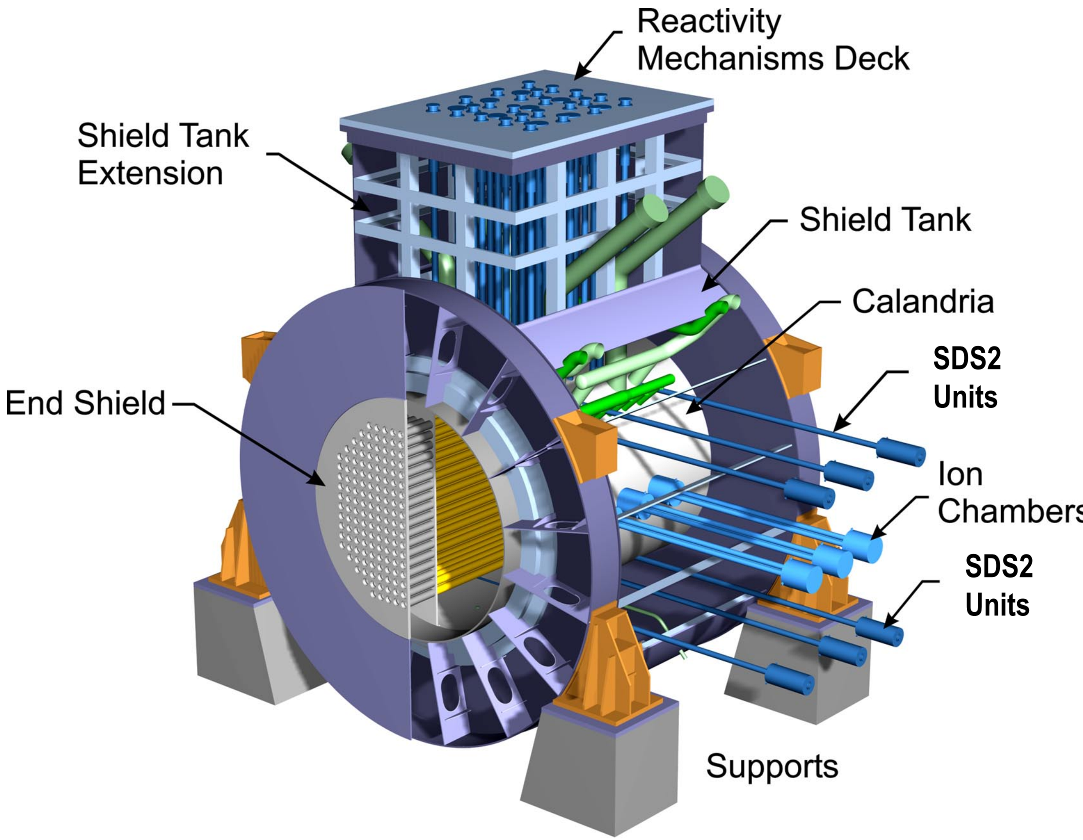
Shutdown Systems

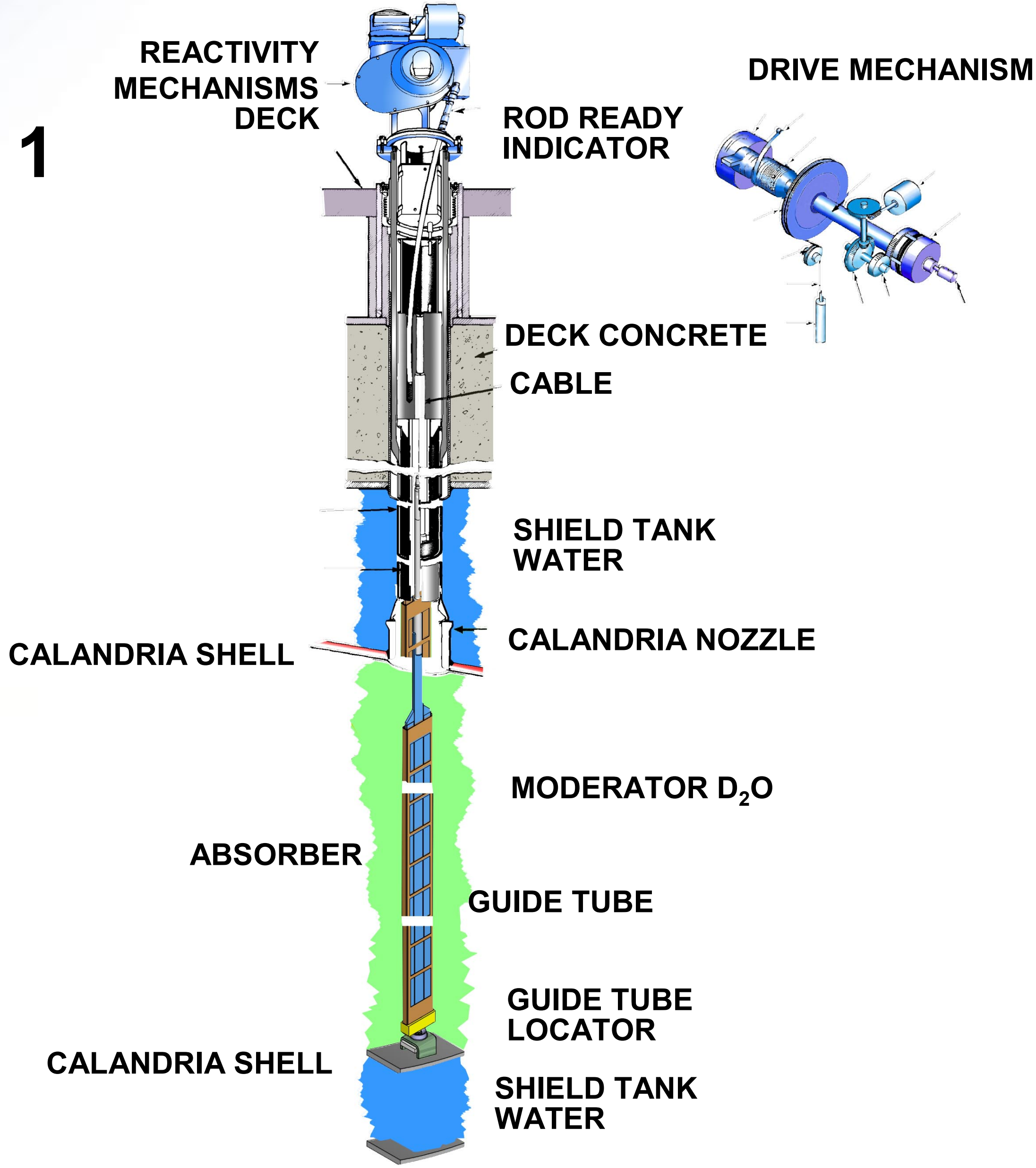
Two fully independent passive shutdown systems:

- SDS1 – rods drop by gravity into moderator
- SDS2 – liquid absorber injected into reflector / moderator by pressurized gas

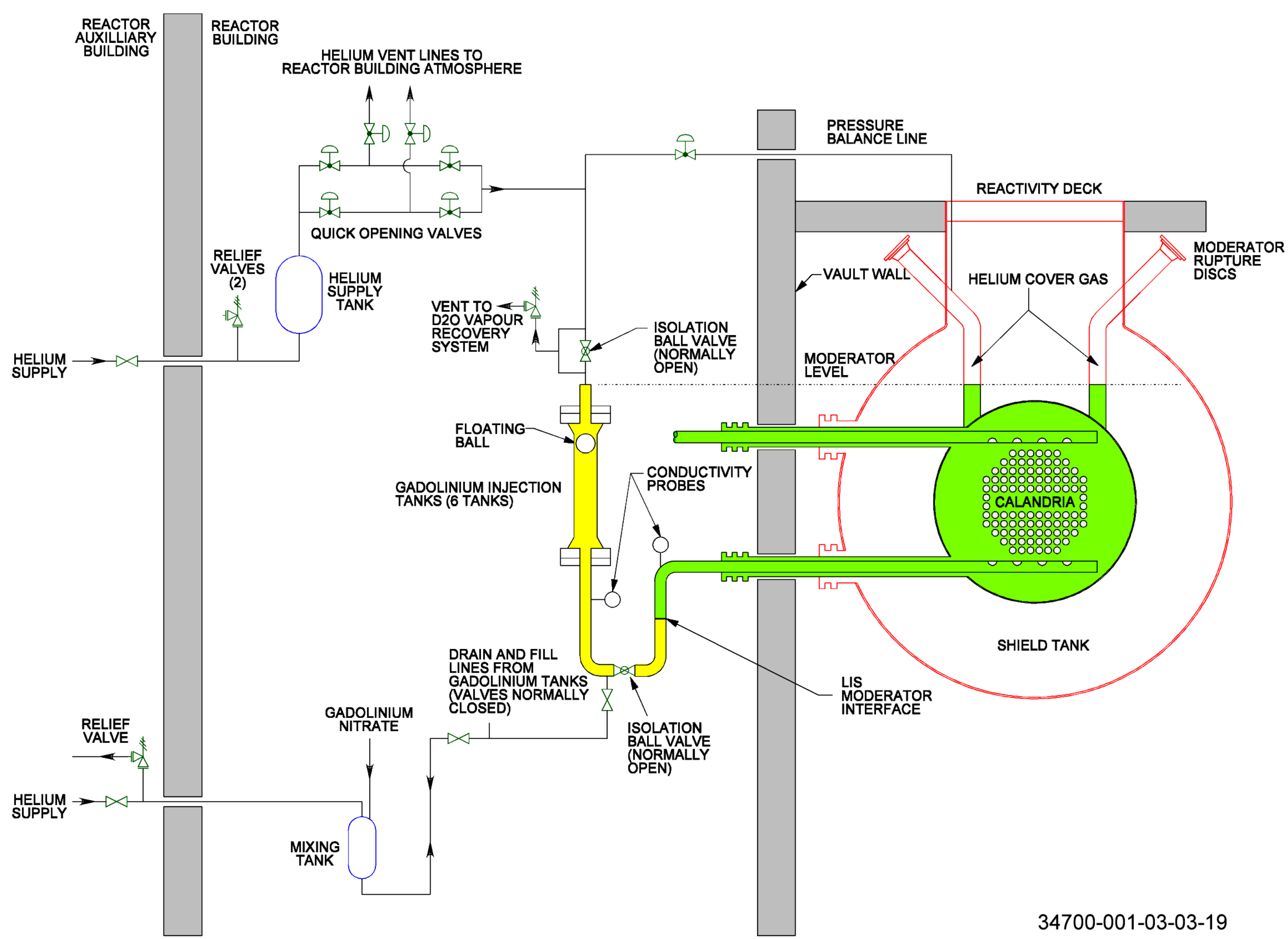


Shutdown System 1 – Mechanical Shutoff Units

- Drive mechanism same as CANDU 6 design
- Passive shutoff unit insertion into core by gravity
- Smaller ACR-700 core achieves approx. same drop time as CANDU 6



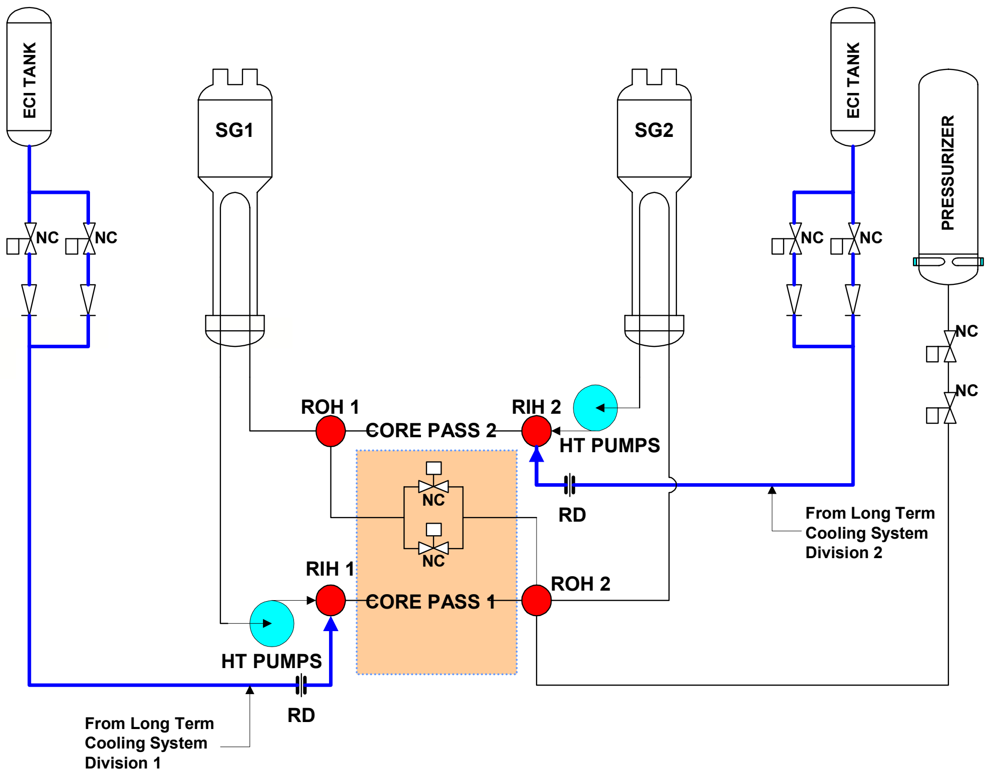
Shutdown System 2 – Liquid Injection Shutdown System



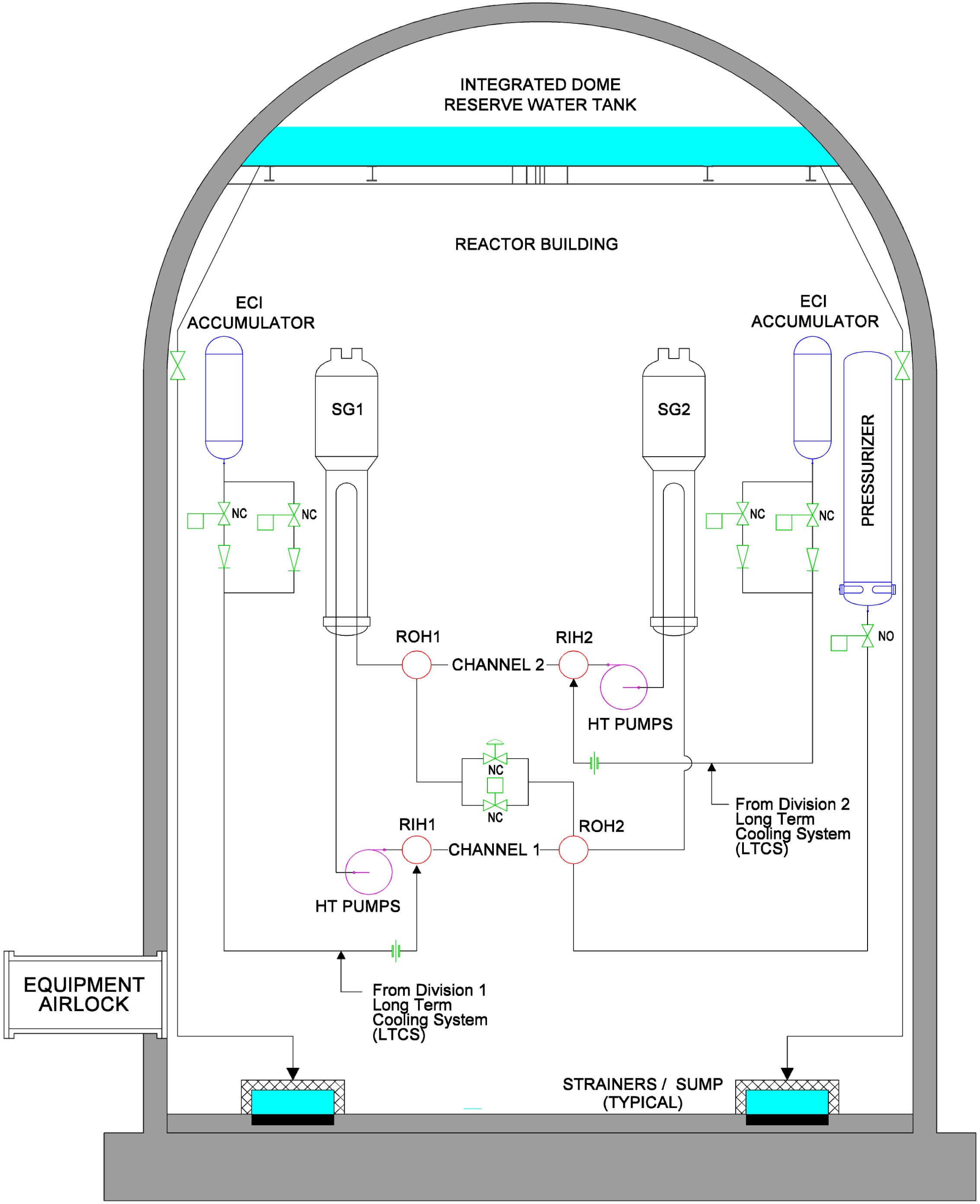
ECC System

Two stage Emergency Core Cooling System

- Initial injection from pressurized tanks in containment
- Long term pumped recovery



Emergency Coolant Injection (ECI)

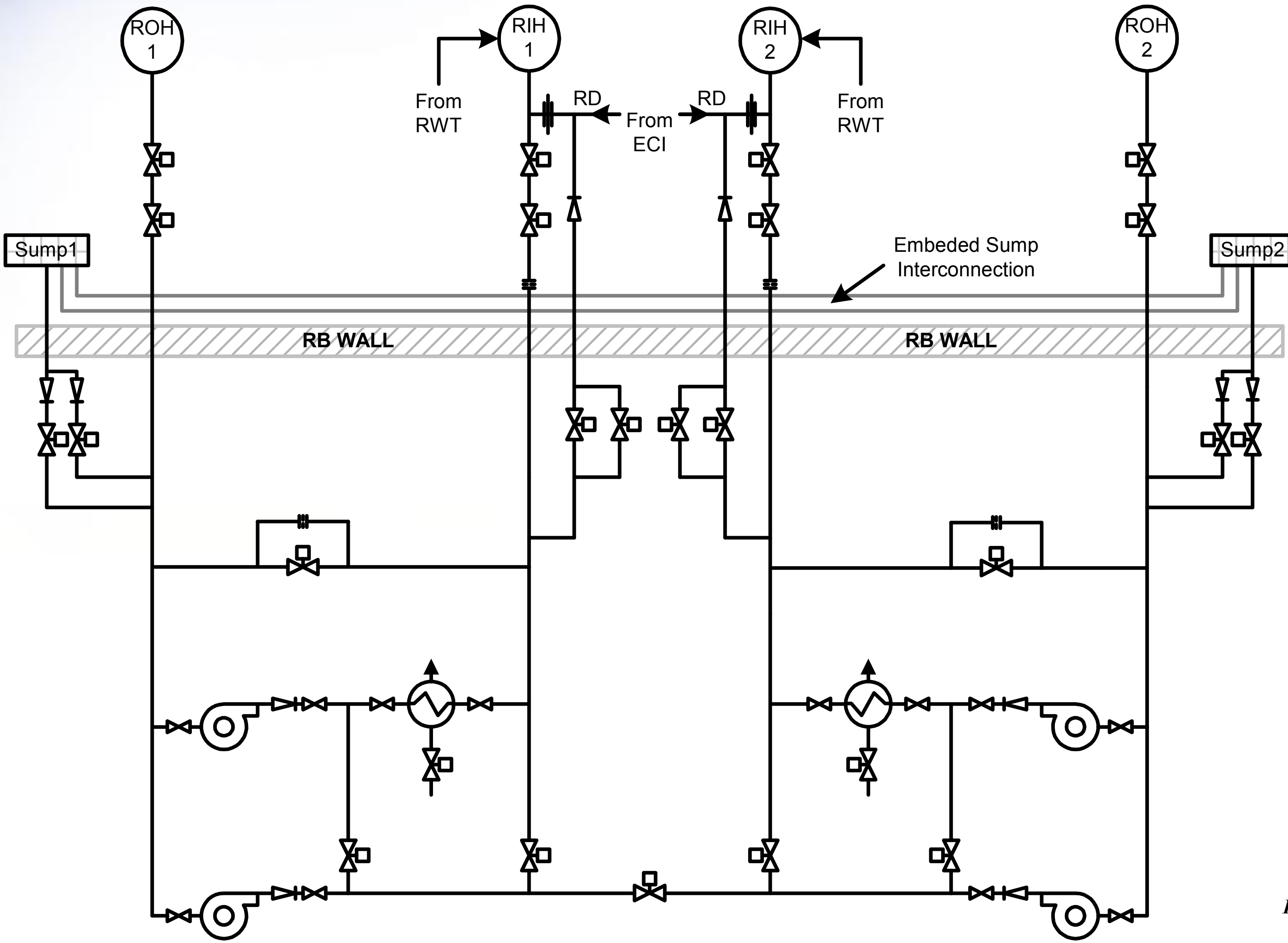


Passive ECI Design Features

- **Pressurized Accumulators**
  - ECI Accumulators are pressurized by nitrogen gas
- **One-Way Rupture Disks**
  - One-way rupture disks isolate the ECI system from the RCS
  - Support a large differential pressure in the RCS to ECI direction
  - Burst at a relatively small differential pressure in the ECI to RCS direction
- **Floating Ball Shutoffs**
  - Seal against a seat at the bottom of the accumulators when the water level becomes low, terminating injection and passively preventing injection of nitrogen gas into the Reactor Coolant System

LTC

- **Long term cooling (LTC) with pumped recovery from sumps**

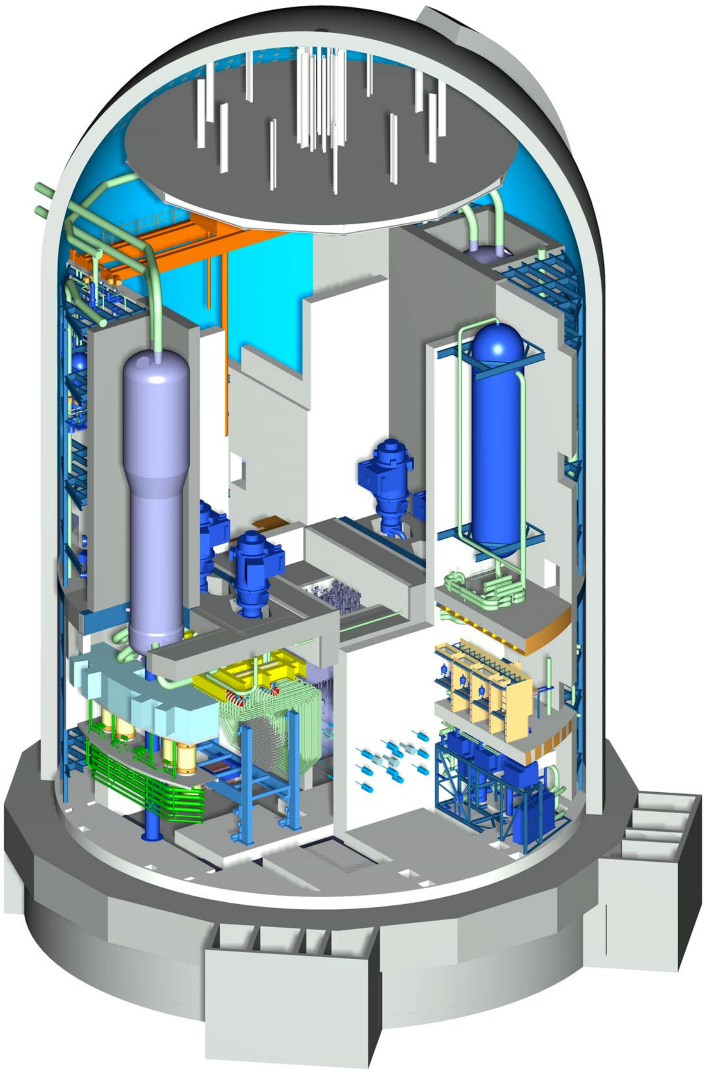


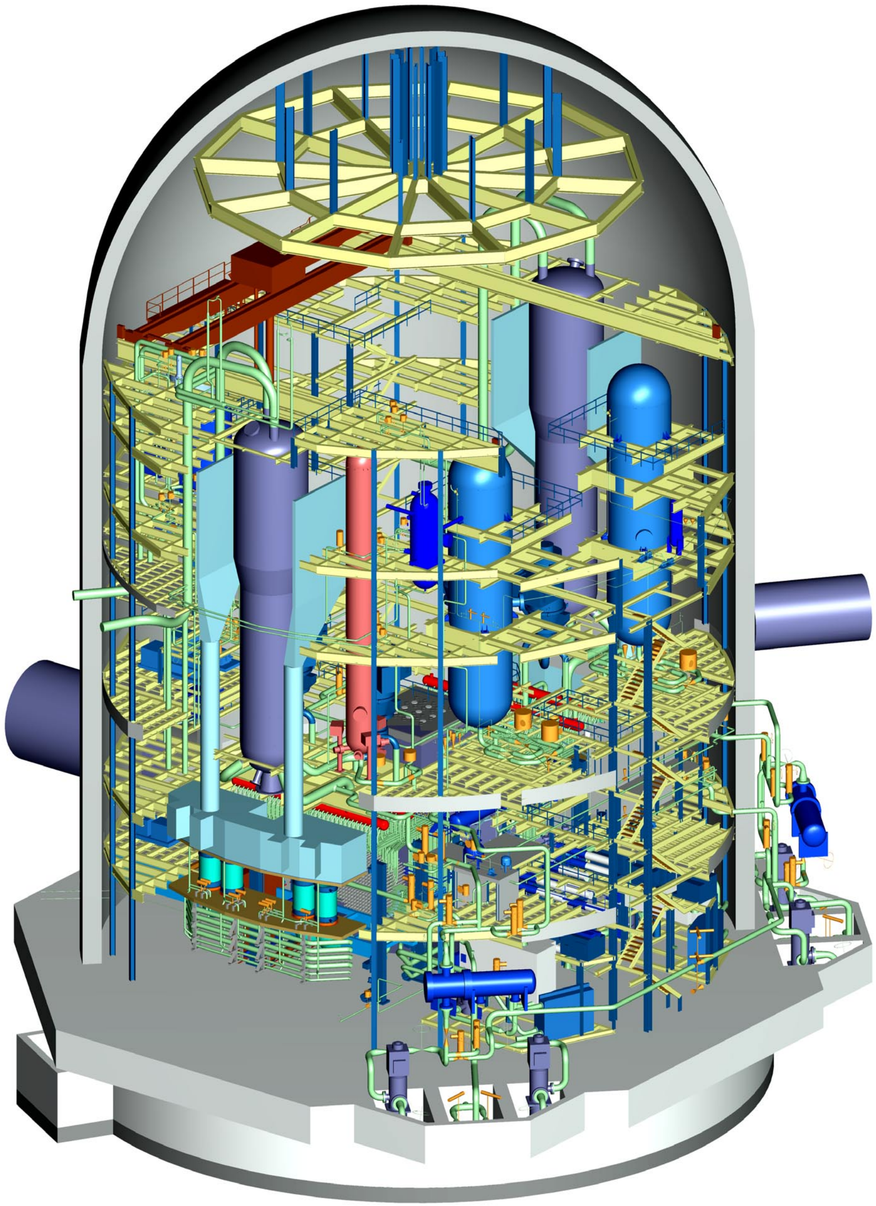
ECC System Parameters

Normal RCS pressure	12 MPa(a)
Normal RCS volume	~120 m^3
ECC Water Tanks	2 (Pressurized with gas)
ECC Water Tank Volume (each)	170 m^3
ECC Working Pressure	5.0 MPa(a)
Injection Lines	2
Major Valves	4
Major Check Valves	2
Rupture Disks	2 (one-way)

Containment

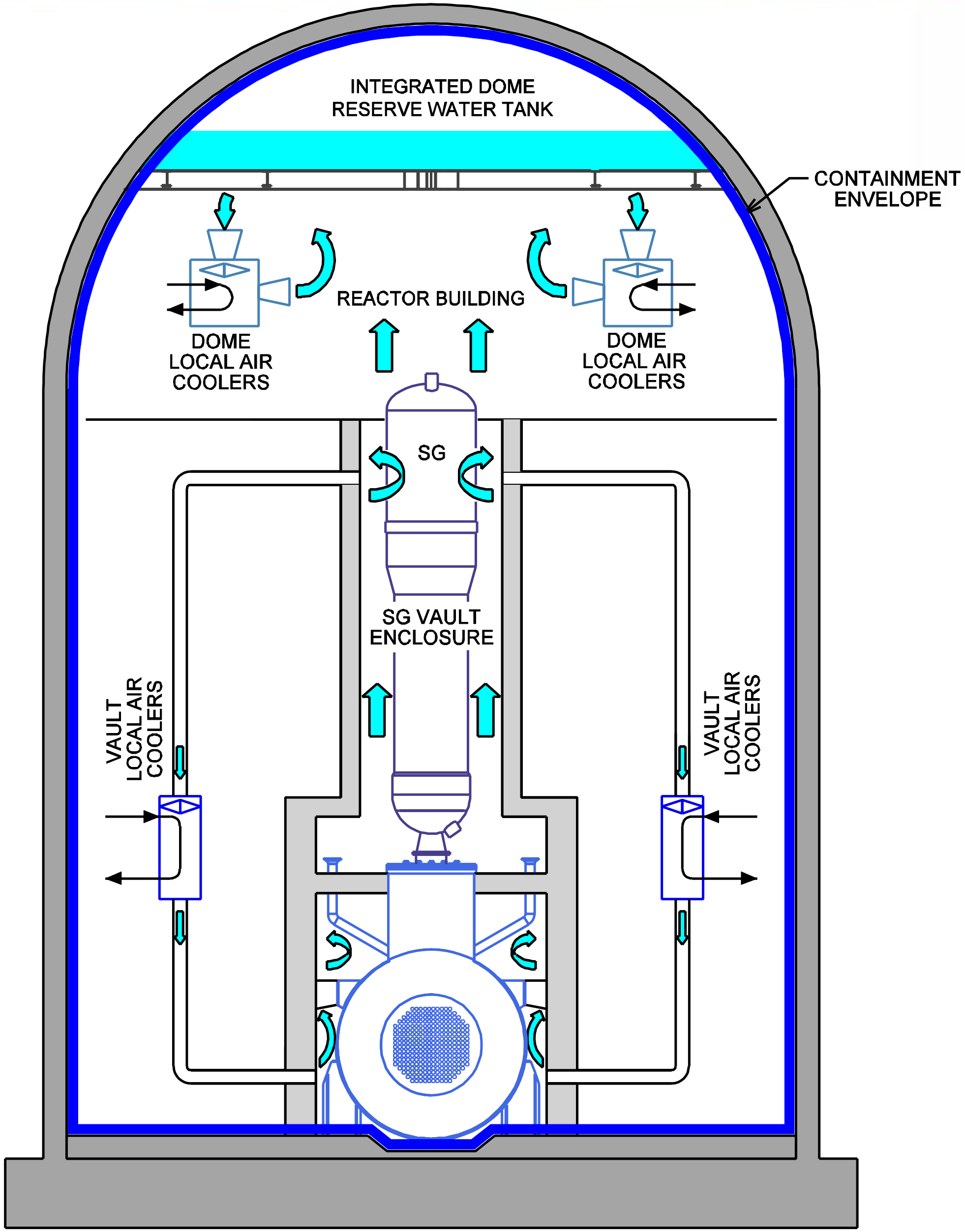
- Steel-lined dry containment similar to conventional PWR
- Elevated Reserve Water Tank for ECC and core damage accident prevention / mitigation
- Air coolers for heat removal
- Passive autocatalytic hydrogen recombiners for core damage accidents





Containment Layout - Detail

Containment Air Flows



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- **Severe Accident Resistance and Mitigation**
- Operational Features

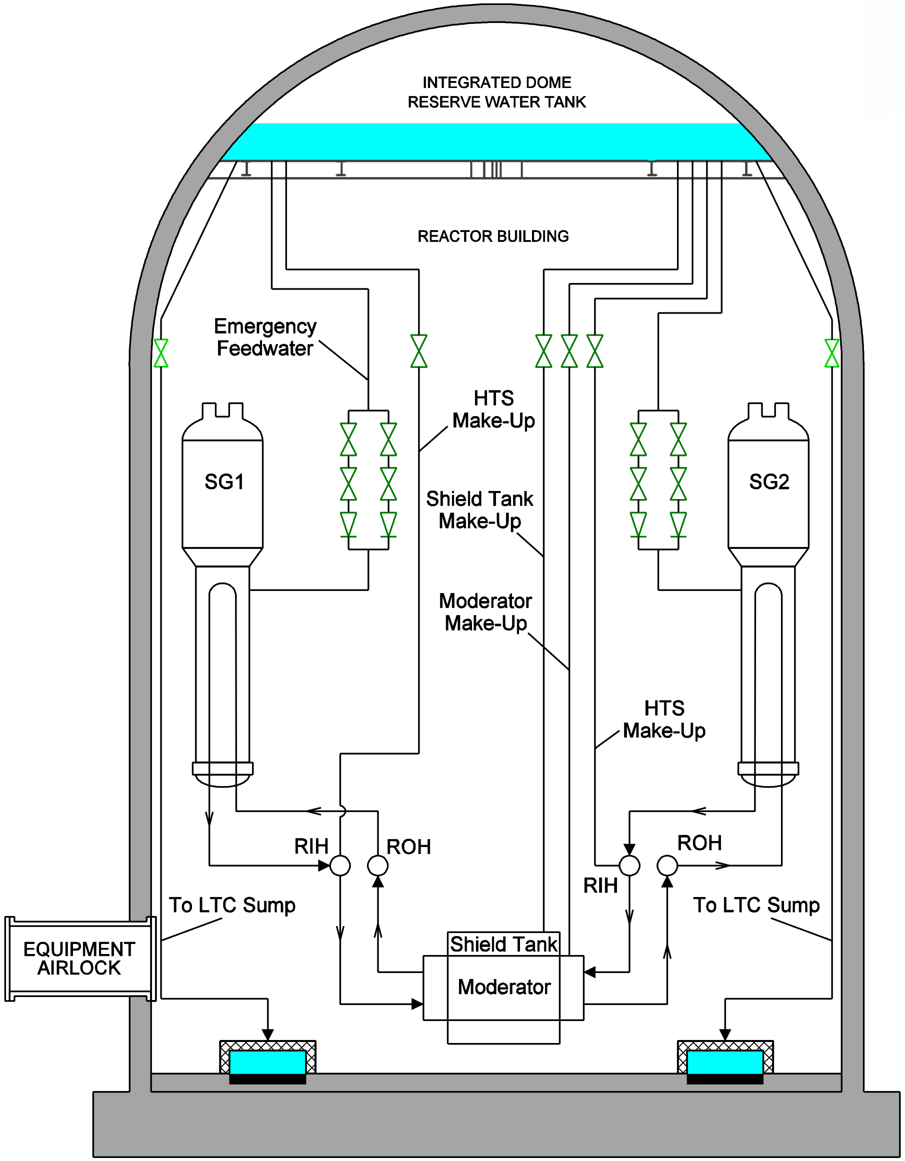
Severe Accident Resistance

Elevated Reserve Water Tank can provide passive makeup by gravity to:

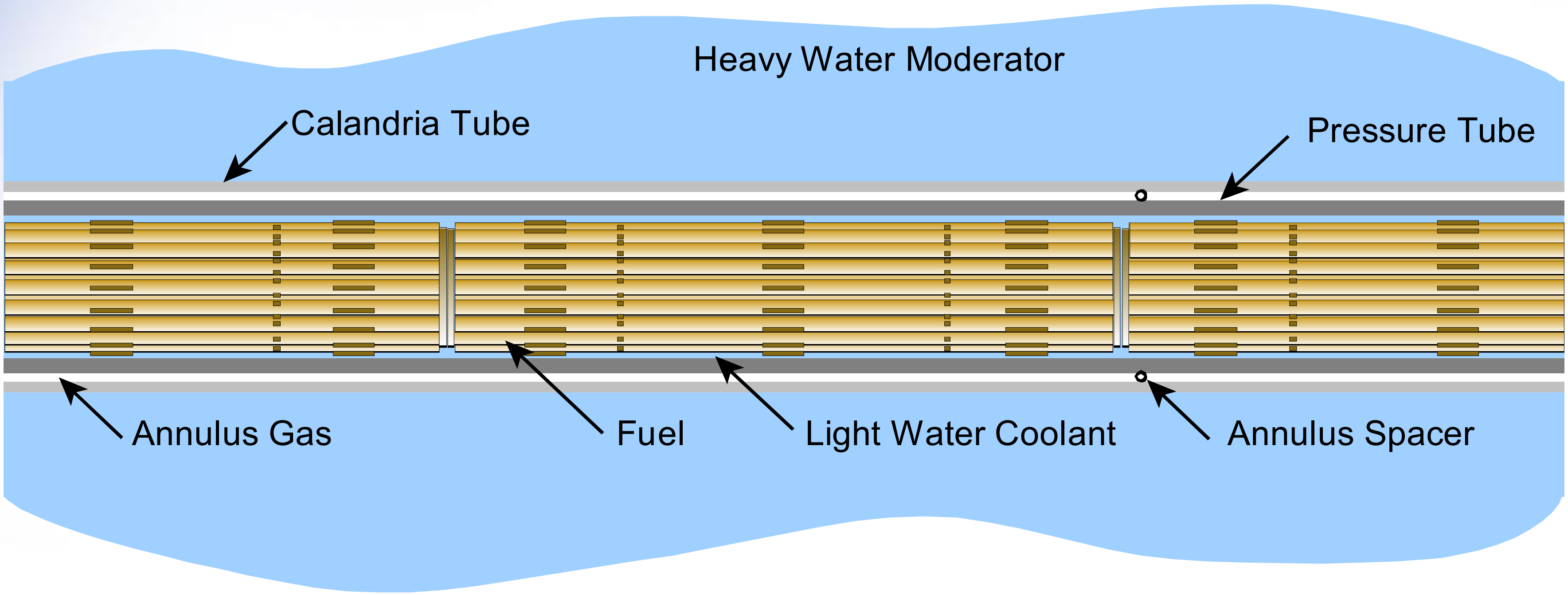
- Reactor coolant system
- Steam generators
- Moderator
- Shield tank

Moderator can remove decay heat from fuel channels without UO_2 melting

Shield tank water can slow down or arrest graceful severe core damage progression



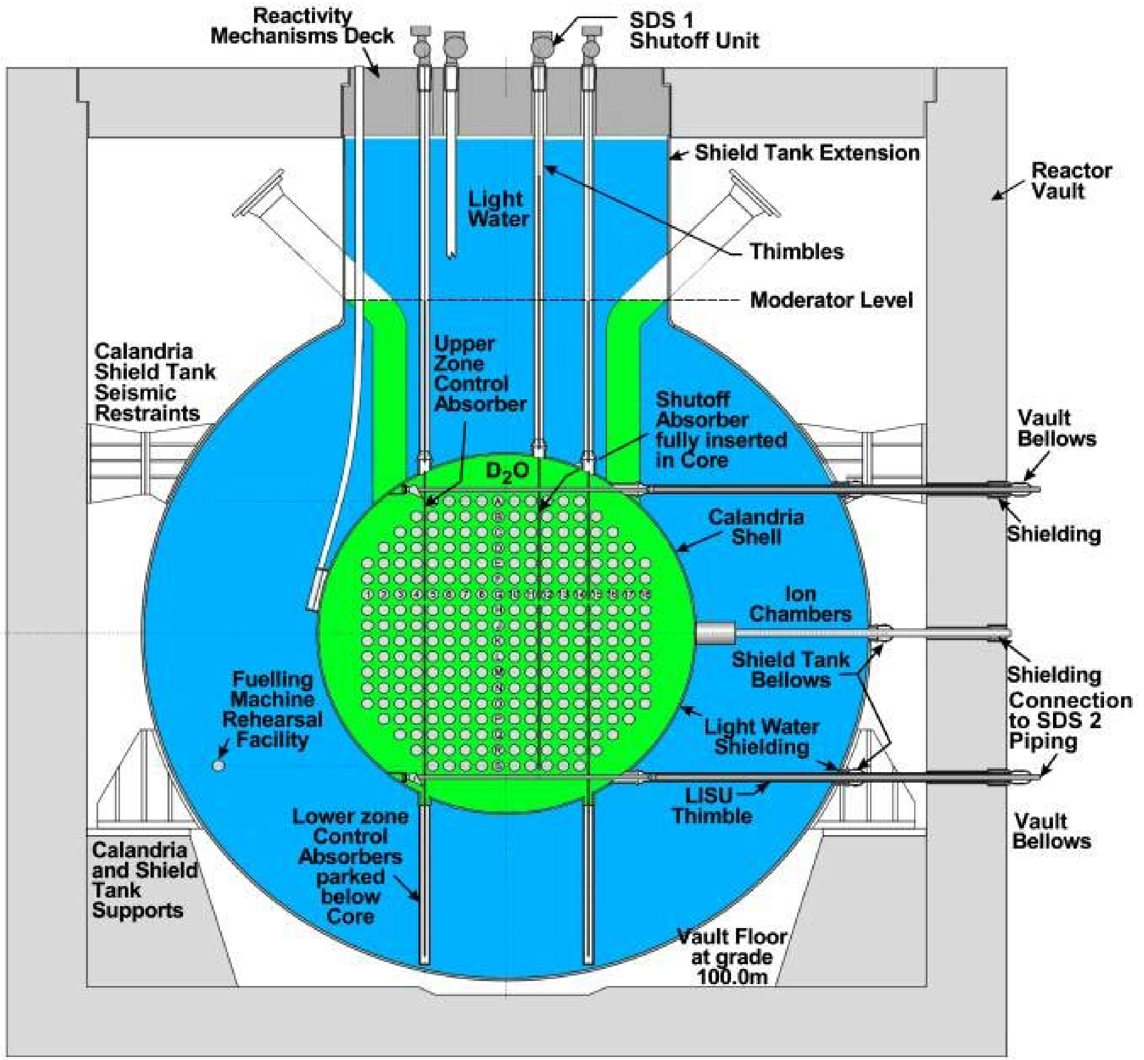
Fuel Channel Surrounded by Water



Fuel is UO_2 clad with Zircaloy-4, in short bundles

Moderator is unpressurized heavy water below 100°C

Moderator Surrounded by Shield Tank

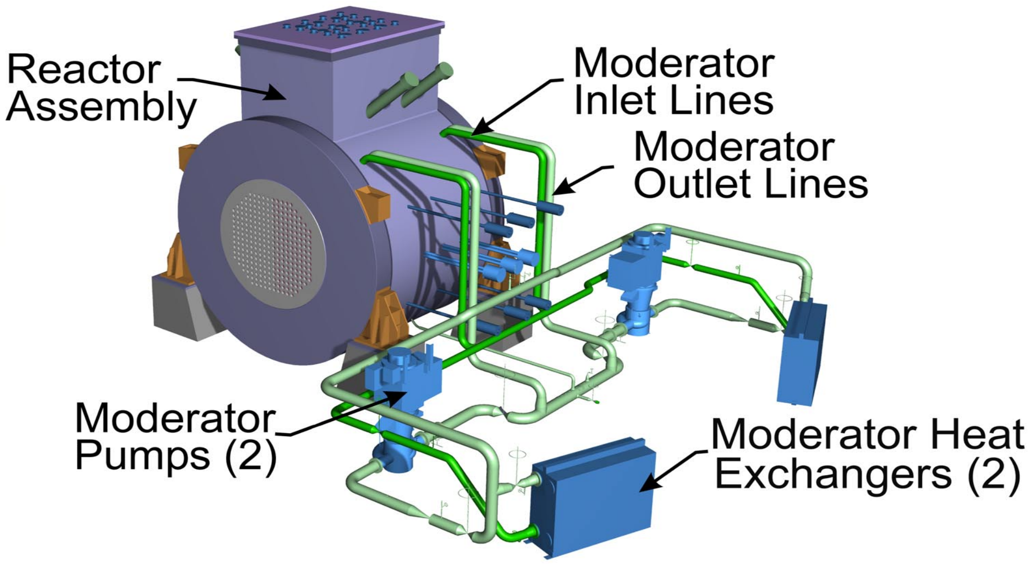


Calandria tank contains 102 m^3 of heavy water

Shield tank contains 456 m^3 of light water

Moderator System

- The moderator is a separately cooled heavy-water tank surrounding the fuel channels
- In normal operation it removes about 5% of the reactor thermal power which is approximately the same as the decay heat shortly after shutdown…



Limited Core Damage Accidents

- Moderator system removes 5% of thermal power in normal operation
- Can therefore provide an emergency heat sink which maintains core coolability and channel geometry even with no water in the fuel channels (e.g., Loss of Coolant plus Loss of Emergency Core Cooling (ECC))
- Fuel will be damaged but no UO_2 melting
- Design facilitates moderator as emergency heat sink via choice of moderator subcooling
- Active moderator heat removal backed up by passive makeup from Reserve Water Tank

Severe Core Damage Accidents

- **Control system and two independent shut-down systems are each capable of safely shutting down the reactor**
  - **Anticipated Transients Without Scram is not risk-significant**
- **Severe core damage sequence would result only from multiple failures such as:**
  - **LOCA *plus* LOECC *plus* Loss of moderator cooling *plus* Loss of Reserve Water Tank makeup to the moderator**
- **In severe core damage sequence, core geometry is lost but shield tank water can delay progression or contain debris within calandria**

Severe Core Damage Delay and Containment

- Severe core damage can be *delayed* for hours due to passive boil-off of moderator and shield tank inventory
- Severe core damage can be *contained* within the calandria vessel if the Reserve Water System is used to make up the shield tank

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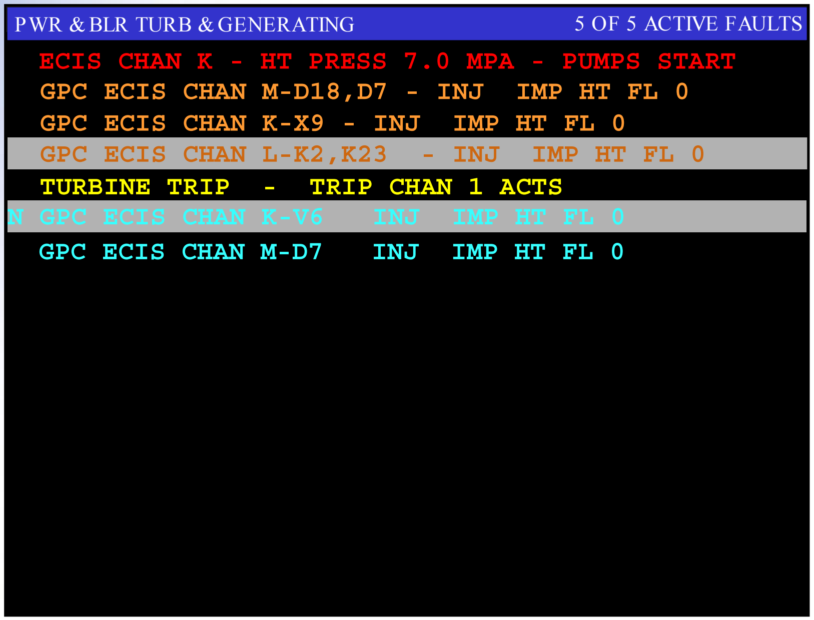
- **Operational Features**

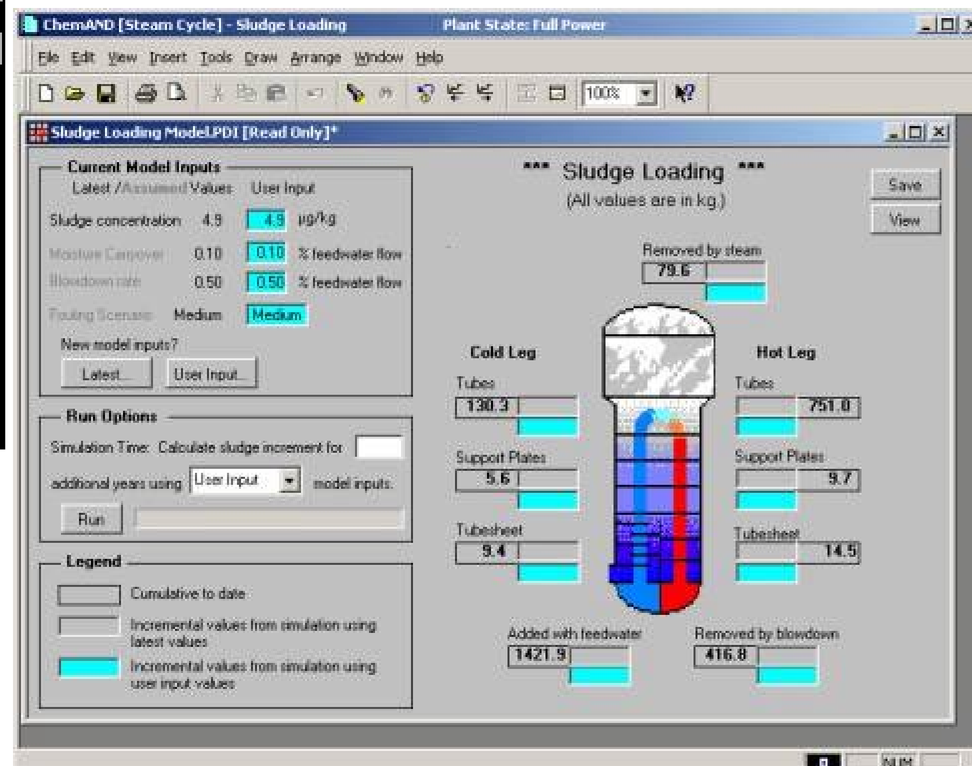
Outage Reduction

- **Reducing running failures of essential equipment**
  - System / equipment health monitoring: on-line data, readily accessible to all for trend analysis
  - Design and operation connected via Reliability Centered Maintenance (proven from application to existing CANDU reactors)
- **Reducing Operator Error**
  - Improved Control Room Design
  - Comprehensive plant status available via large-screen display
  - Improved alarm recognition system

Advanced Control and Monitoring Capabilities

Advanced control room technology and alarm monitoring capability





Advanced plant performance monitoring and diagnostic capability

ChemAND System Health Monitor

Installed at some CANDU Plants

<u>Features</u>

- **Real time monitoring of all chemically controlled systems**
- **Alarms**
- **Diagnostics**
- **Predictions**

Qinshan Main Control Room

The ACR

- Evolutionary product from >50 years of R&D
- Design optimized
- Enhanced safety including passive features
- Enhanced operability

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