CANDU Safety
#15 - Loss of Forced Circulation

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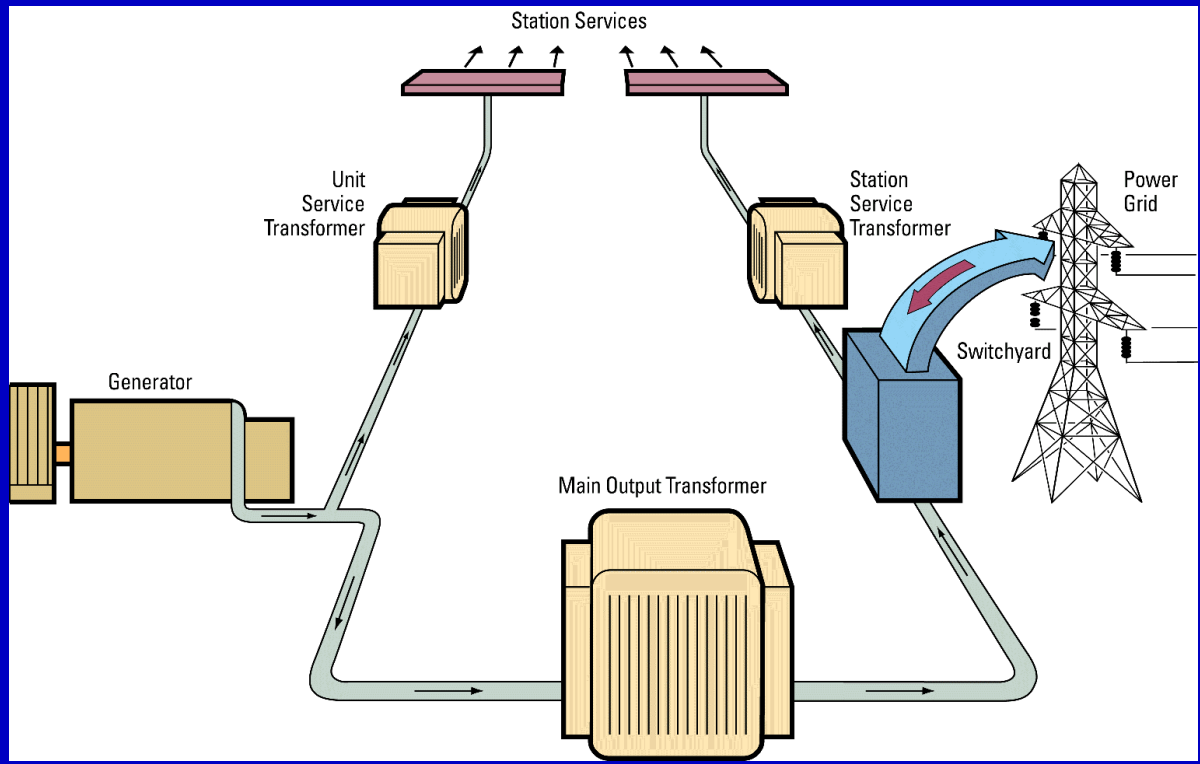
Station Electrical Diagram

- half the station load goes directly from the unit service transformer; the other half comes from the station service transformer
- either can provide the total service load



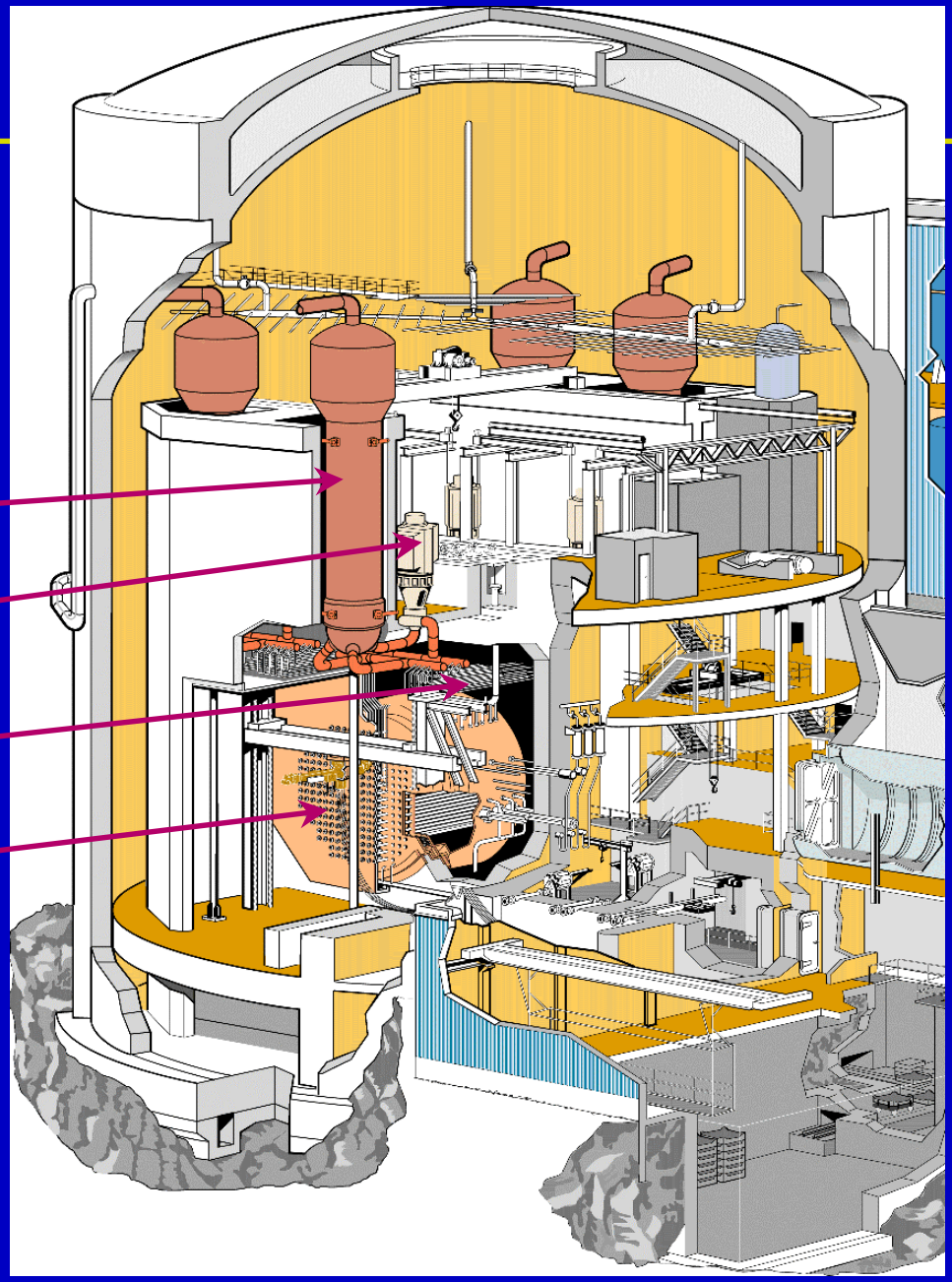
Heat Transport System Layout

Steam generators

Main pumps

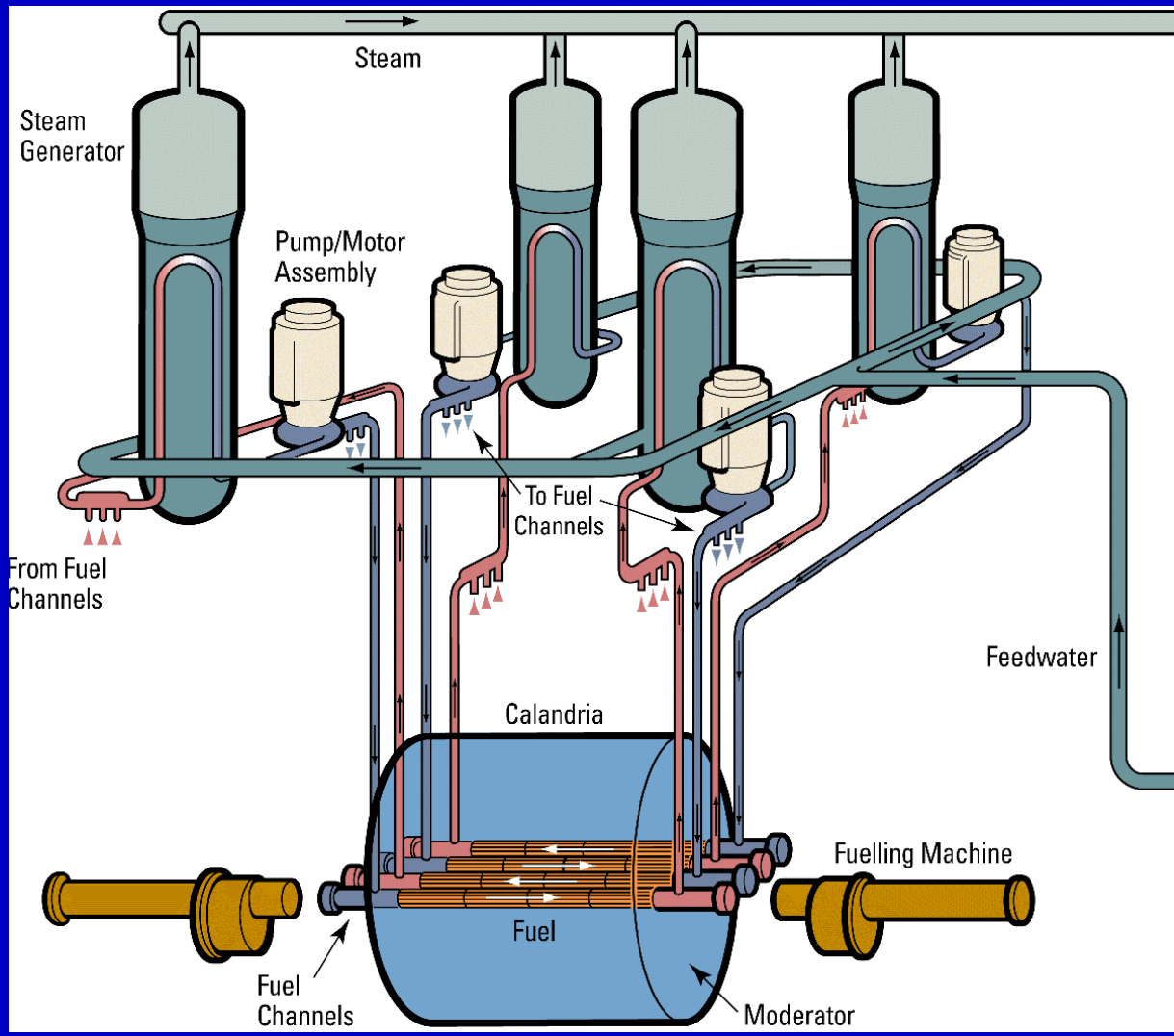
Feeder pipes

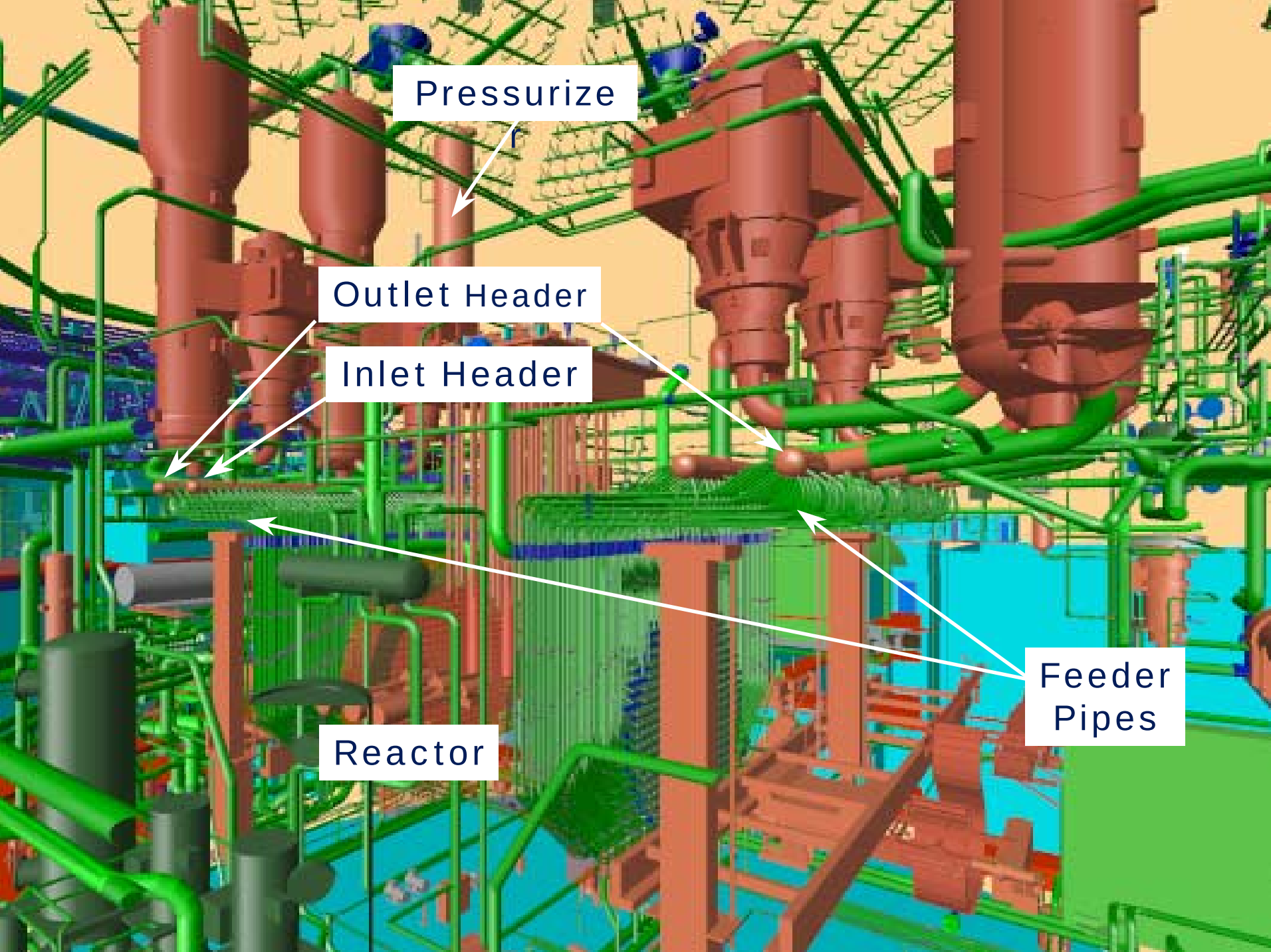
Reactor



Heat Transport System Schematic

- two separate heat transport system loops
- each has two circulating pumps *in series*
- steam generators located high above the core to allow for thermosyphoning if forced circulation is lost




Pressurize
r
Outlet Header
Inlet Header
Feeder
Pipes
Reactor

Some Differences from LWRs

- small power increase due to boiling in reactor core
- no preferred flow direction in the core
  - flow kept in “normal” direction as the pumps rundown and thermosyphoning forces take over
- flow is through 2 pumps and 2 steam generators in series
- *two* high-pressure long term heat sinks:
  - steam generators (auxiliary feedwater, Class III power)
  - shutdown cooling system

Accident Analysis - Loss of Forced Circulation

- defences
  - stepback
  - Shutdown System 1
  - Shutdown System 2
  - thermosyphoning to steam generators
  - shutdown cooling system
- since this is an event expected one or more times in the station lifetime, stepback should be effective and prevent a trip in most cases

Acceptance Criteria

- Class 1 Dose Limits set by AECB
- two effective trips on each shutdown system where practical
  - overpressure trip *only* is allowed if it is the first trip
  - prevent fuel sheath failures
  - prevent heat transport system boundary failure

Cases Analyzed

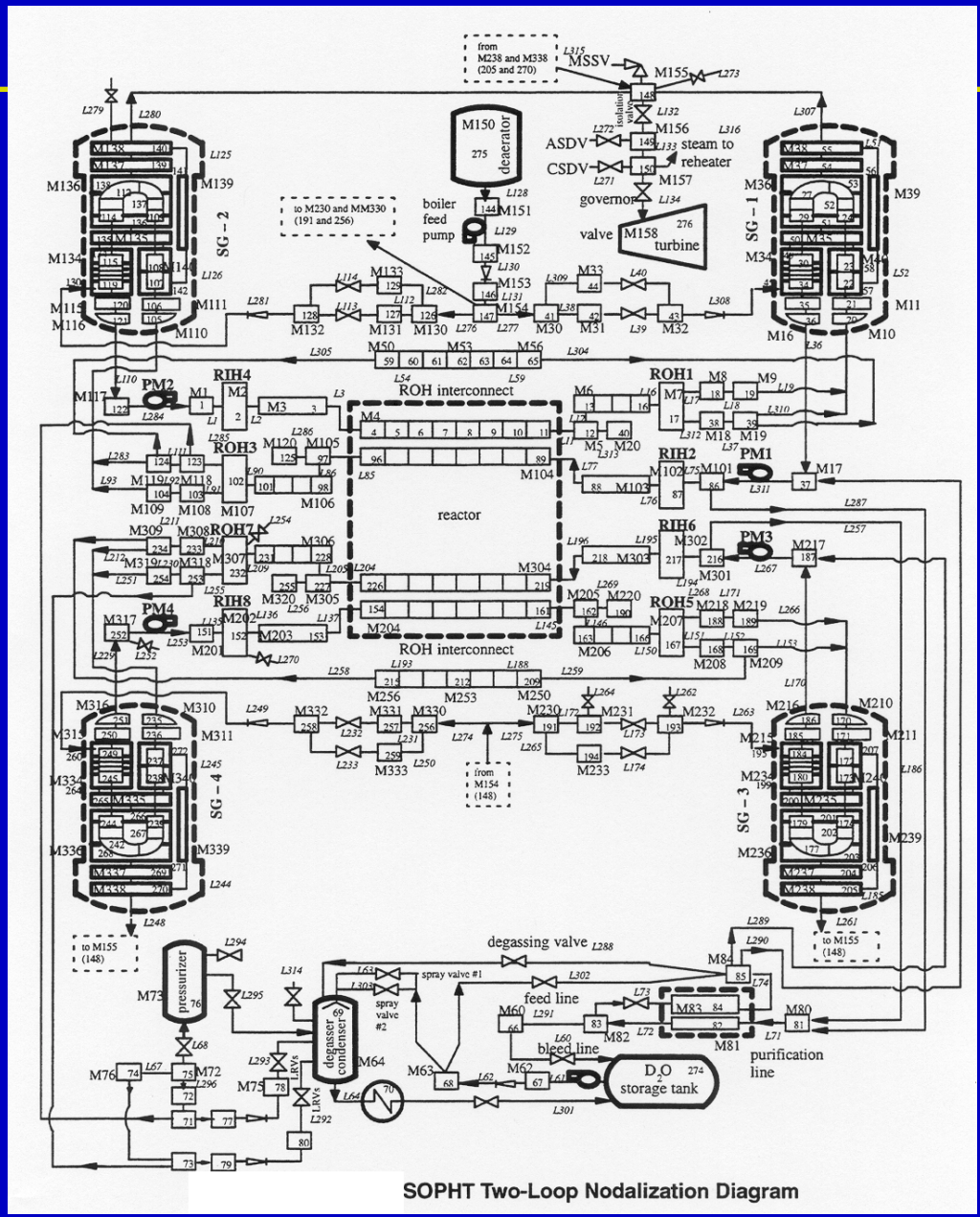
- loss of Class IV power to the heat transport pumps
  - complete loss of power (4 pumps)
  - partial loss of power (2 pumps)
  - single pump trip
- mechanical failure resulting in single pump seizure
- various initial power levels

Relevant Trips

High neutron power	115% full power	
Low coolant flow (SDS1)	80%	
High heat transport system pressure (immediate)	10.55 MPa	11.72 MPa
High heat transport system pressure (delayed)	10.34 MPa	
Low core pressure drop (SDS2)	450 kPa	immediate
	950 kPa	delayed

Circuit Model

- the (illegible) picture at right shows the complexity of the circuit model required for trip coverage analysis
- the model has been compared to operating plant transients

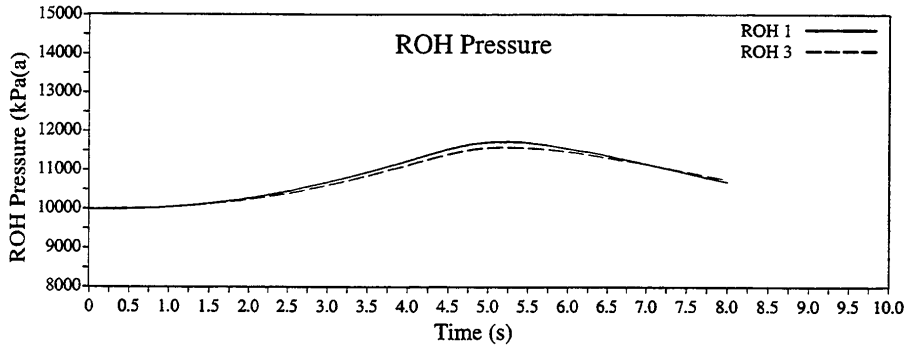


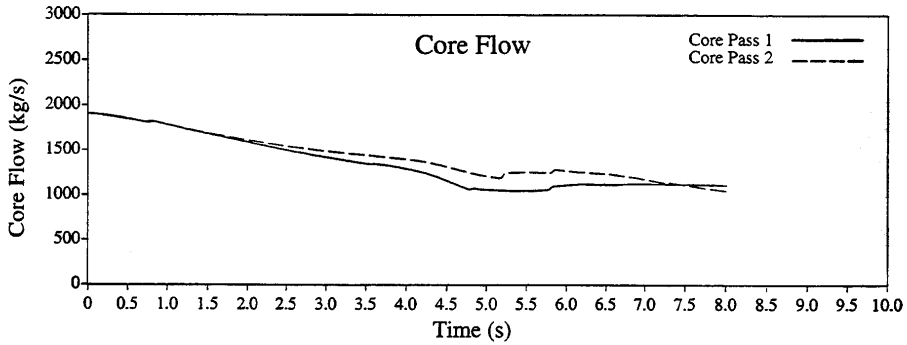
Event Sequence

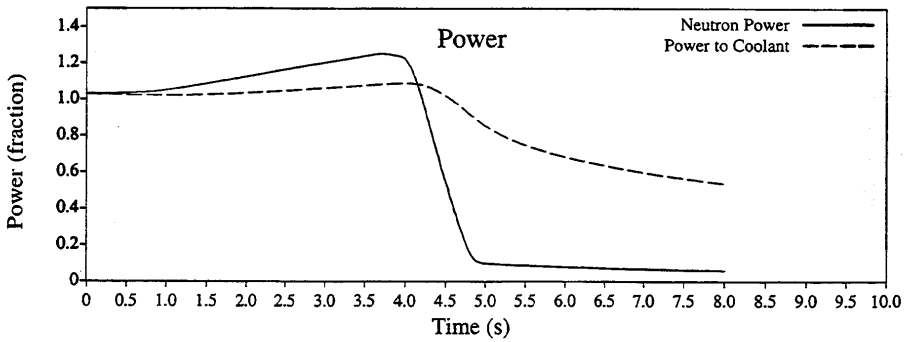
- loss of Class IV power, all pumps run down
- turbine trip due to loss of condenser vacuum
- coolant pressure increases, relief valves open, then re-close
- small amount of void in the core, power rises
- reactor shut down by stepback (not credited)
- reactor shut down by trip on shutdown system (s)
- boiler steam relief valves open, if needed, to control pressure
- flow matches power and heat transport system thermosyphons with heat being rejected to steam generators
- long term: use of shutdown cooling system

Loss of Class IV from Full Power

- power rise due to increase in boiling in the channels, terminated by stepback or trip
- slow flow rundown due to high rotational inertia of the pumps



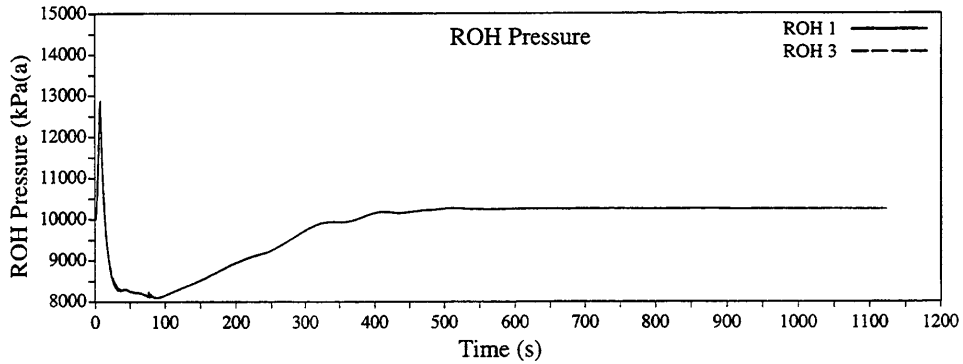


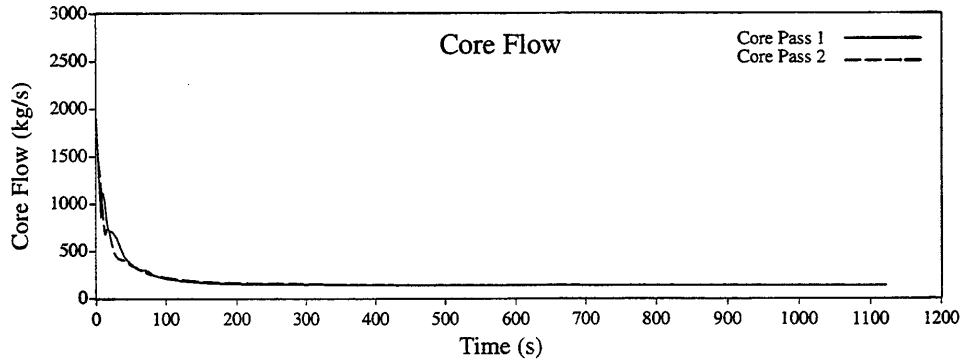


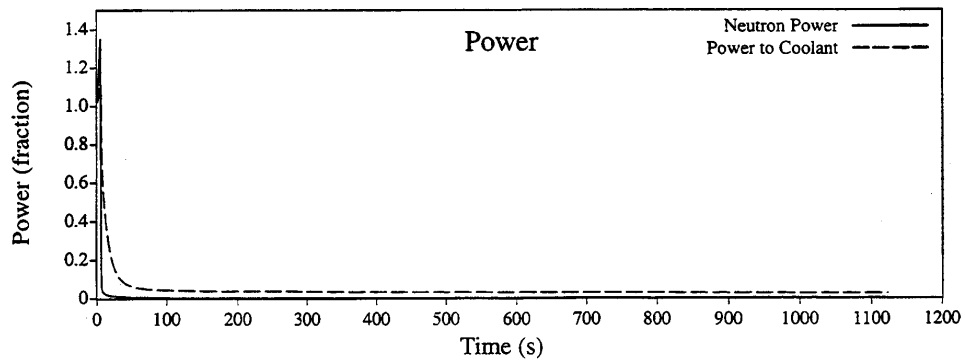
Complete Loss of Class IV Power from 103% FP, SDS1 High Pressure Trip

Long Term Behaviour

- flow rundown to match reactor decay power
- reactor outlet header pressure rises to reject heat to steam generators



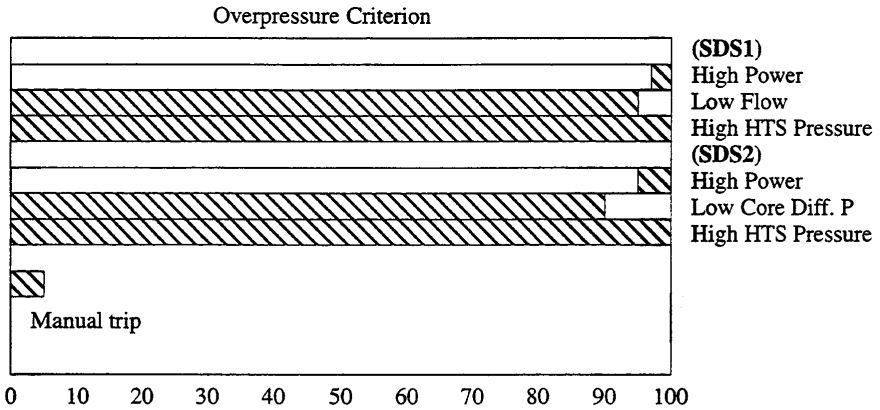


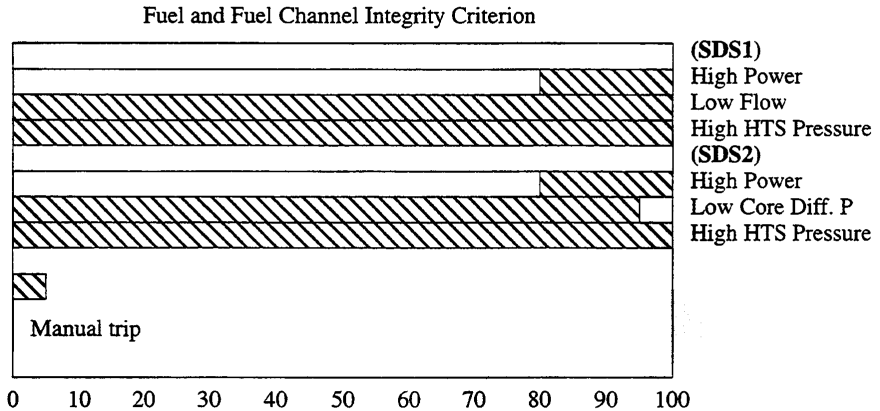


Complete Loss of Class IV Power from 103% FP, Trip on SDS2
High Pressure, Long Term Thermosyphoning

Trip Coverage Maps

- at least 2 effective trips for fuel protection
- two effective trips in most cases to meet acceptance criteria for overpressure
- limited area of single trip coverage on *each* shutdown system
  - sometimes only a high pressure signal is effective in detecting high pressure





Note: SDS1 Low Flow conditioned out below 0.1 % FP
SDS2 Low Core Differential Pressure conditioned out below 5% FP

Trip Coverage Map for Complete Loss of Class IV Power (Fresh or Equilibrium Fuel and Fouled Steam Generators) RRS Frozen

Other Events - Moderator Pipe Rupture

- low pressure piping
- issues
  - release of tritium
  - increase in deuterium gas concentration in cover gas
- power reduction on Regional Overpower Protection System trip (high local powers) or “naturally” as moderator level falls

Other Events - Fuel Handling Failures

- can affect at most one channel plus fuel in fuelling machine
- separate D_2O cooling system when off-reactor
- examples:
  - loss of cooling to fuelling machine off-reactor
  - fueling machine detaches from channel without replacing closure plug
- safety case bounded by single channel events
- large heat capacity in fuelling machine slows down the heat-up of the fuel

Summary

- geometrical layout of CANDU is favourable to thermosyphoning
- slow power rise stopped by regulating or shutdown systems
- flow direction stays the same
- two high-pressure heat sinks
- can reject heat to feeders in the very long term, with no preferred flow direction in the channels