# *CANDU Safety*
# *#15 - Loss of Forced Circulation*

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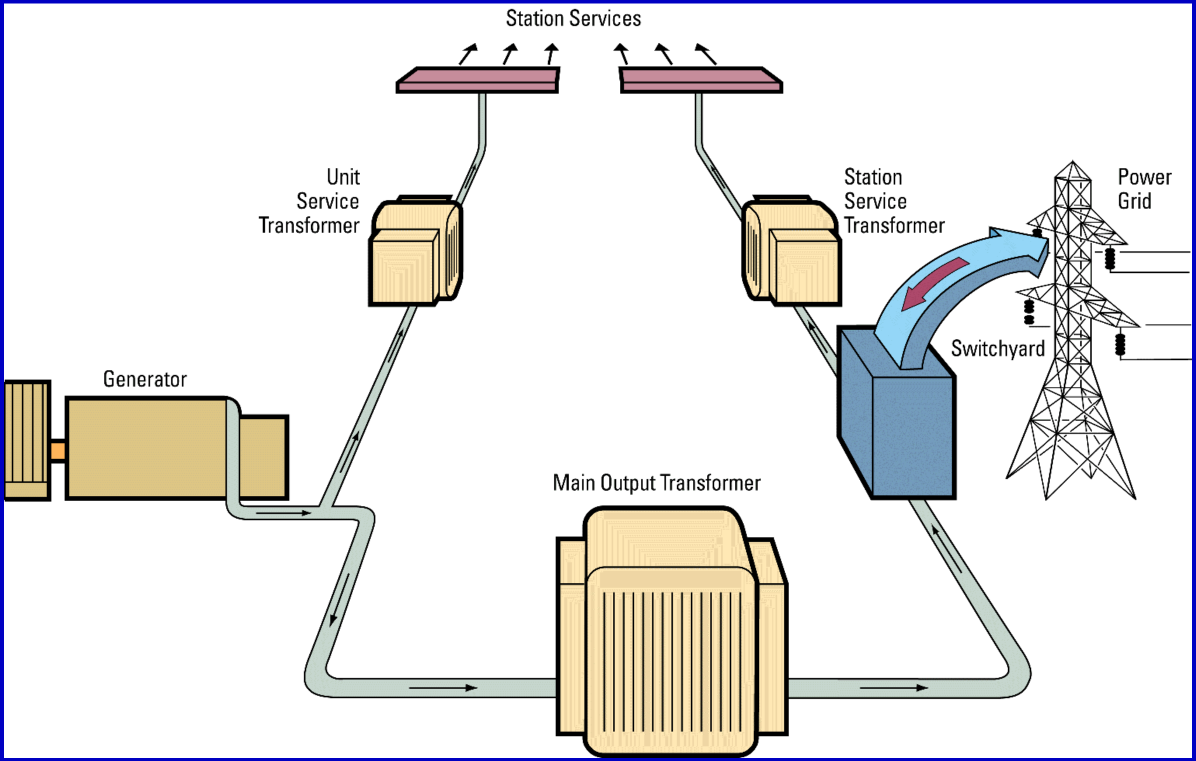
# Station Electrical Diagram

- 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



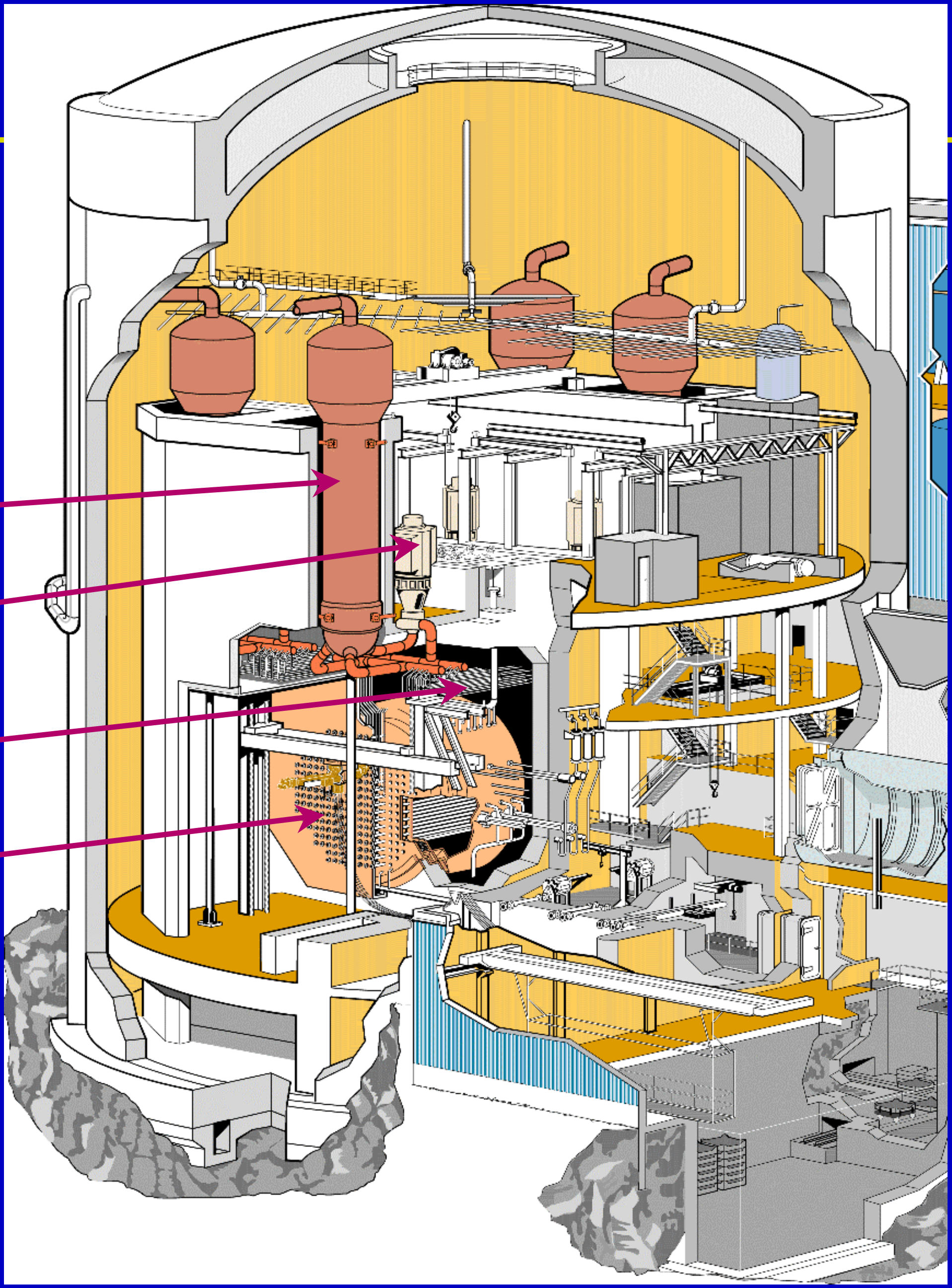
# Heat Transport System Layout

Steam generators

Main pumps

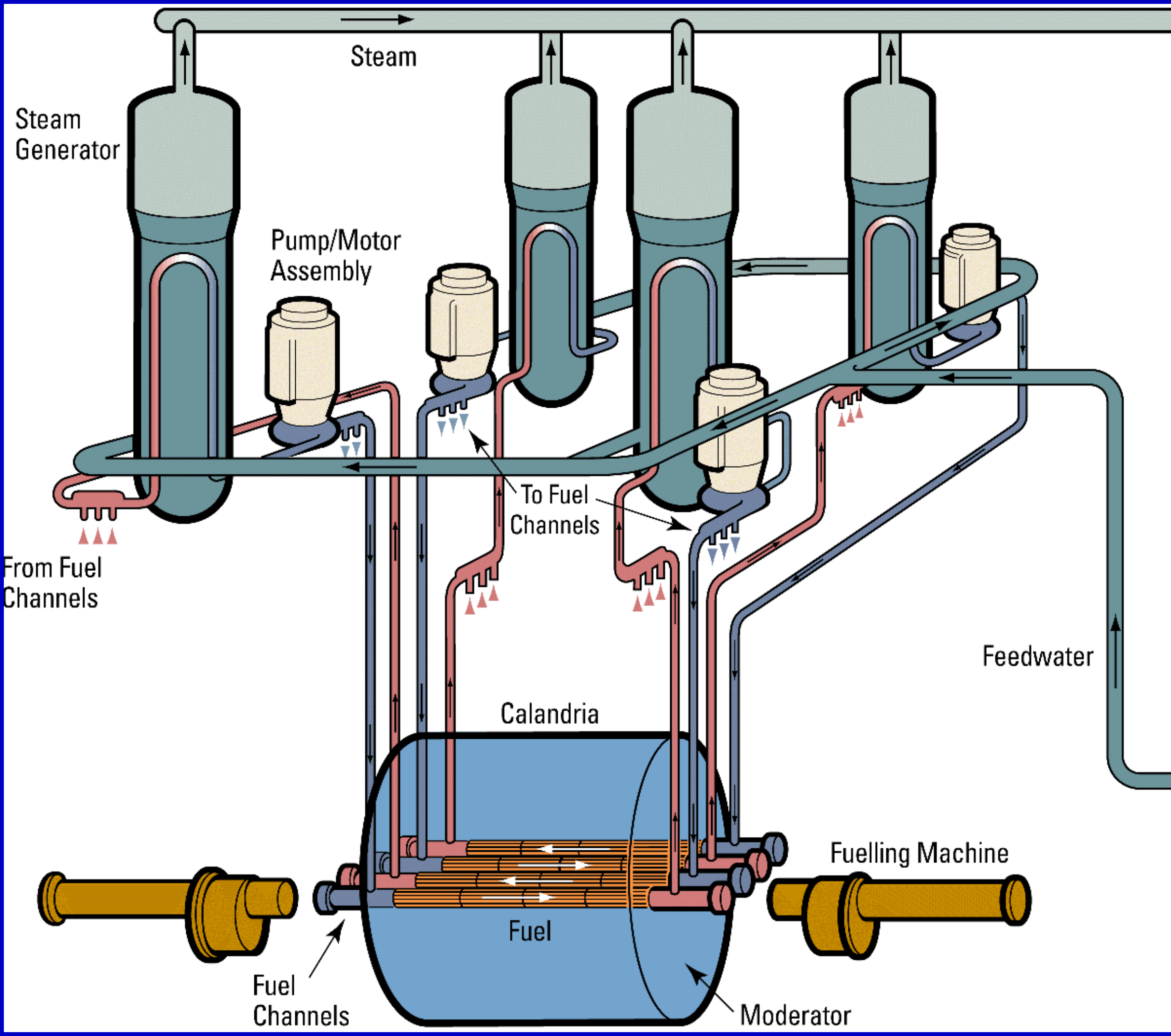
Feeder pipes

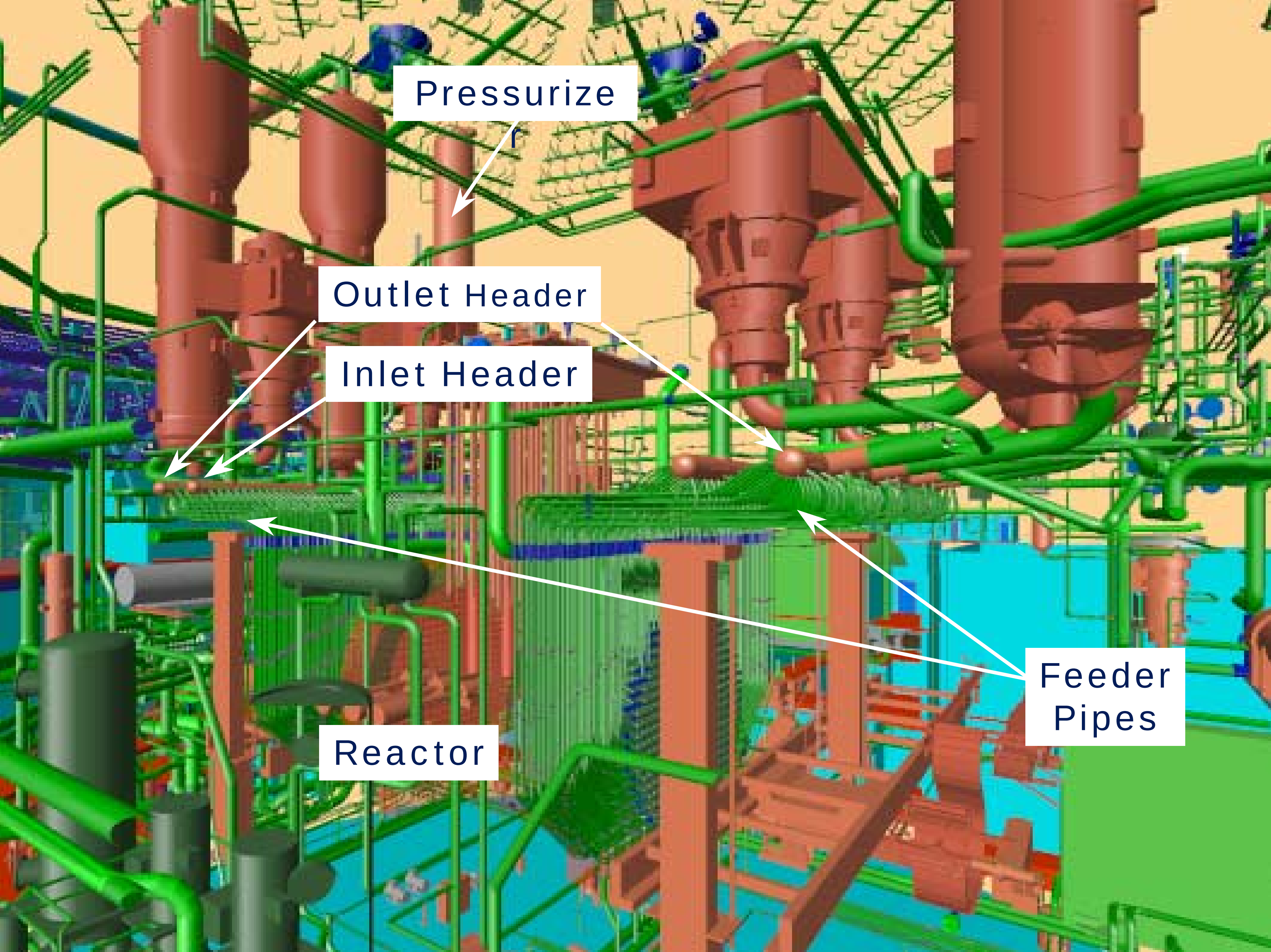
Reactor



# 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*

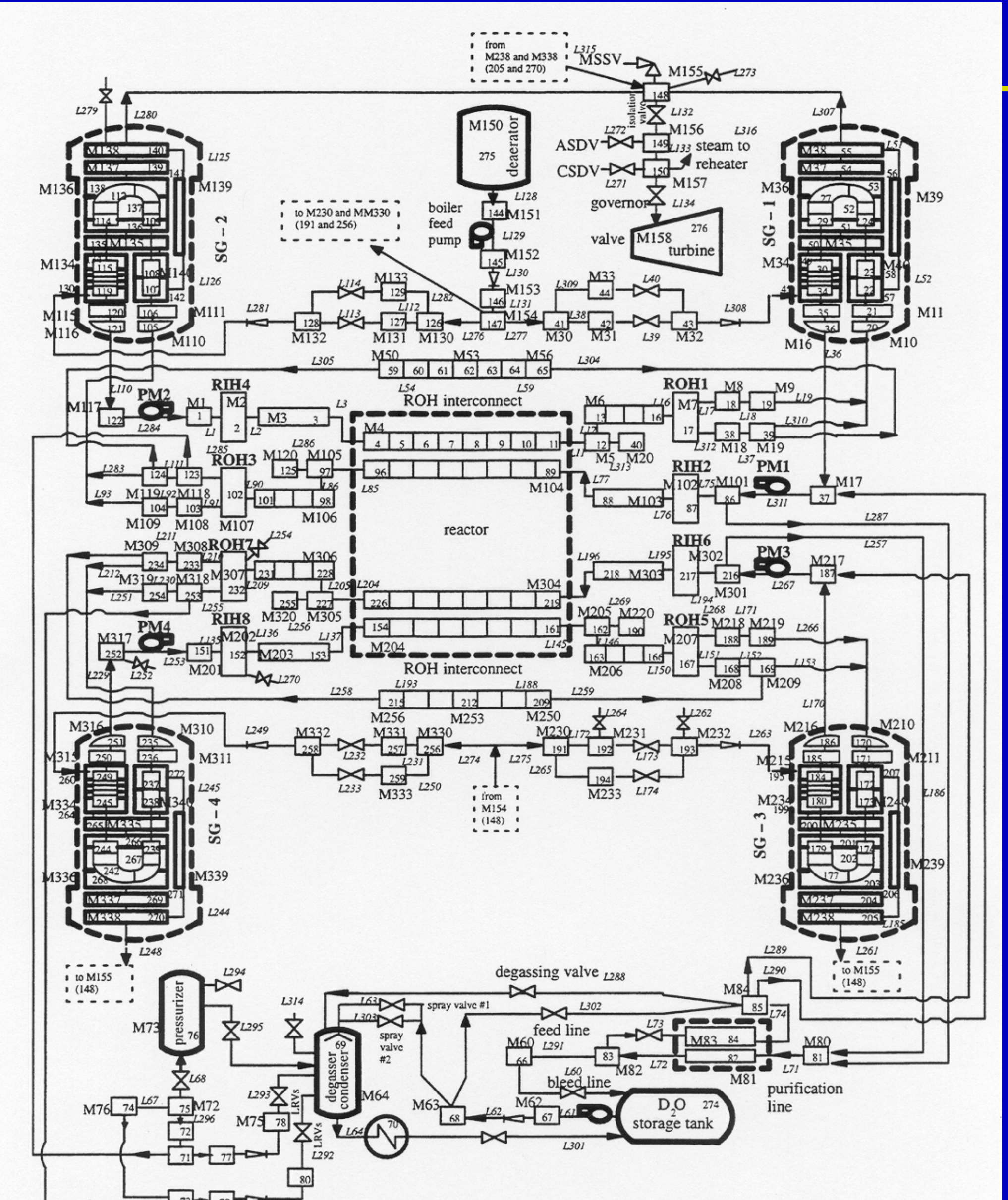
- loss of Class IV power to the heat transport pumps
  - complete loss of power (4 pumps)
  - partial loss of power (2 pumps)
  - single pump trip
- mechanical failure resulting in single pump seizure
- various initial power levels

# *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



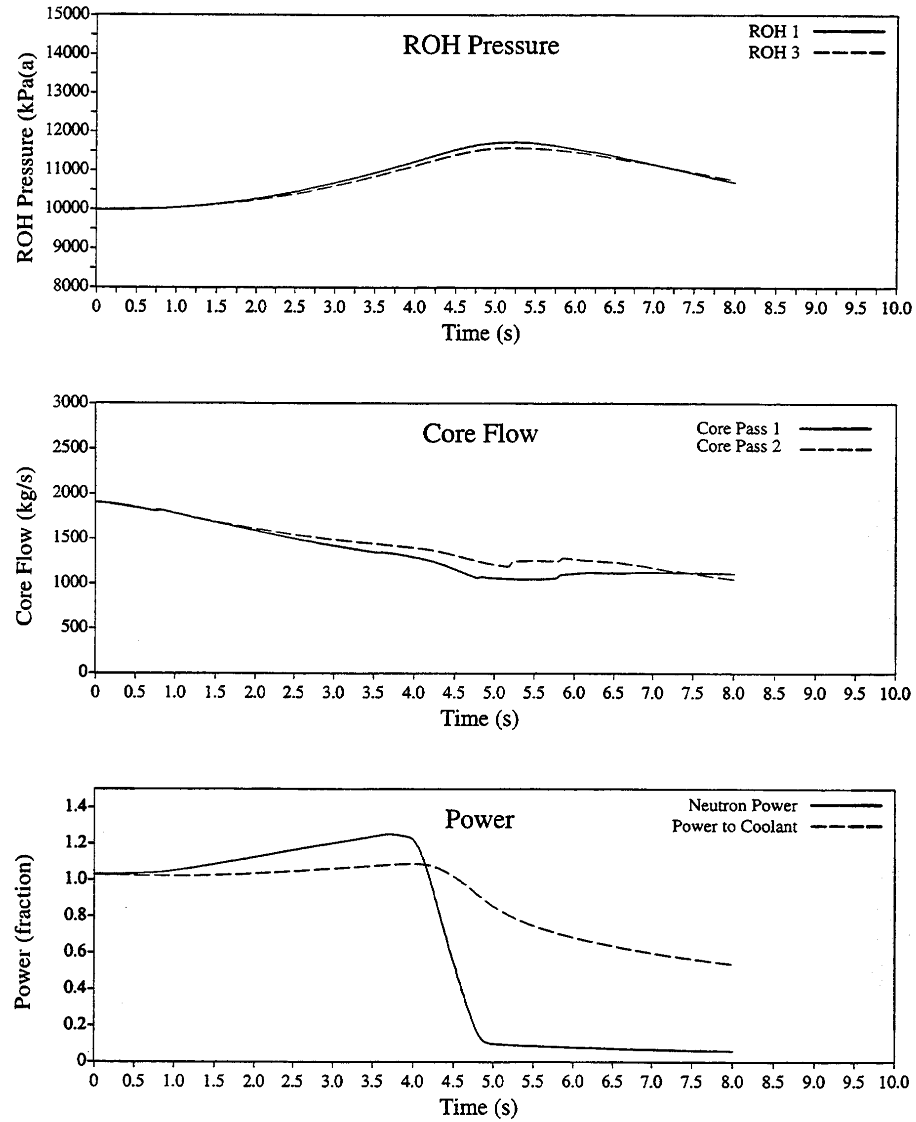

SOPHT Two-Loop Nodalization Diagram

# 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

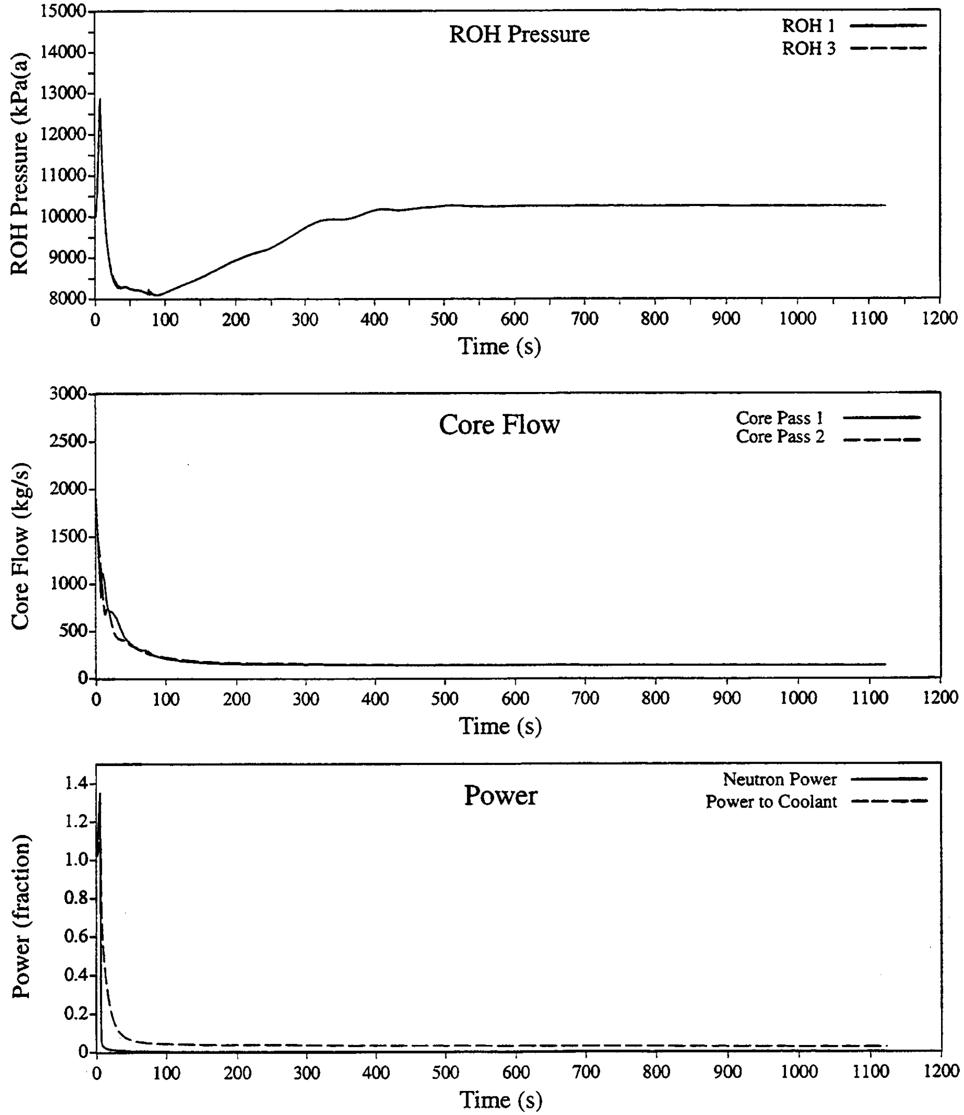
- power rise due to increase in boiling in the channels, terminated by stepback or trip
- slow flow rundown due to high rotational inertia of the pumps




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

# Long Term Behaviour

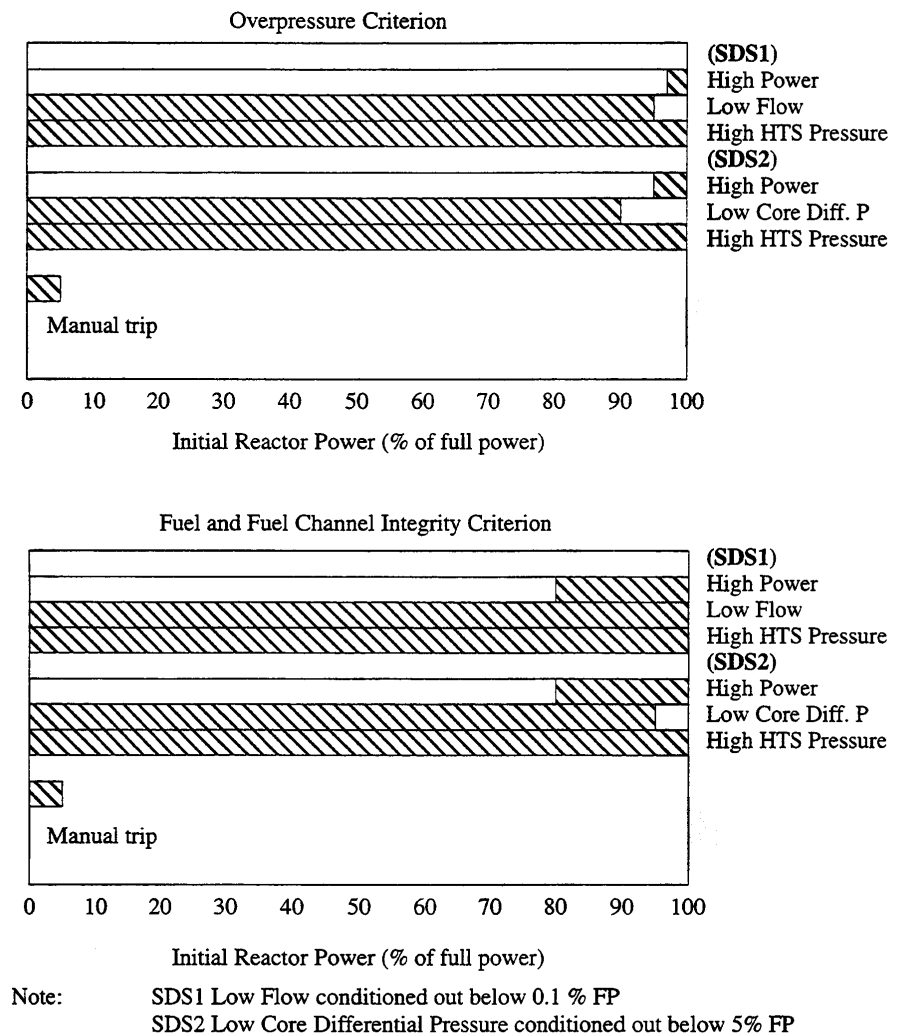
- flow rundown to match reactor decay power
- reactor outlet header pressure rises to reject heat to steam generators




**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




**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