CANDU Safety
#14 - Loss of Heat Sink

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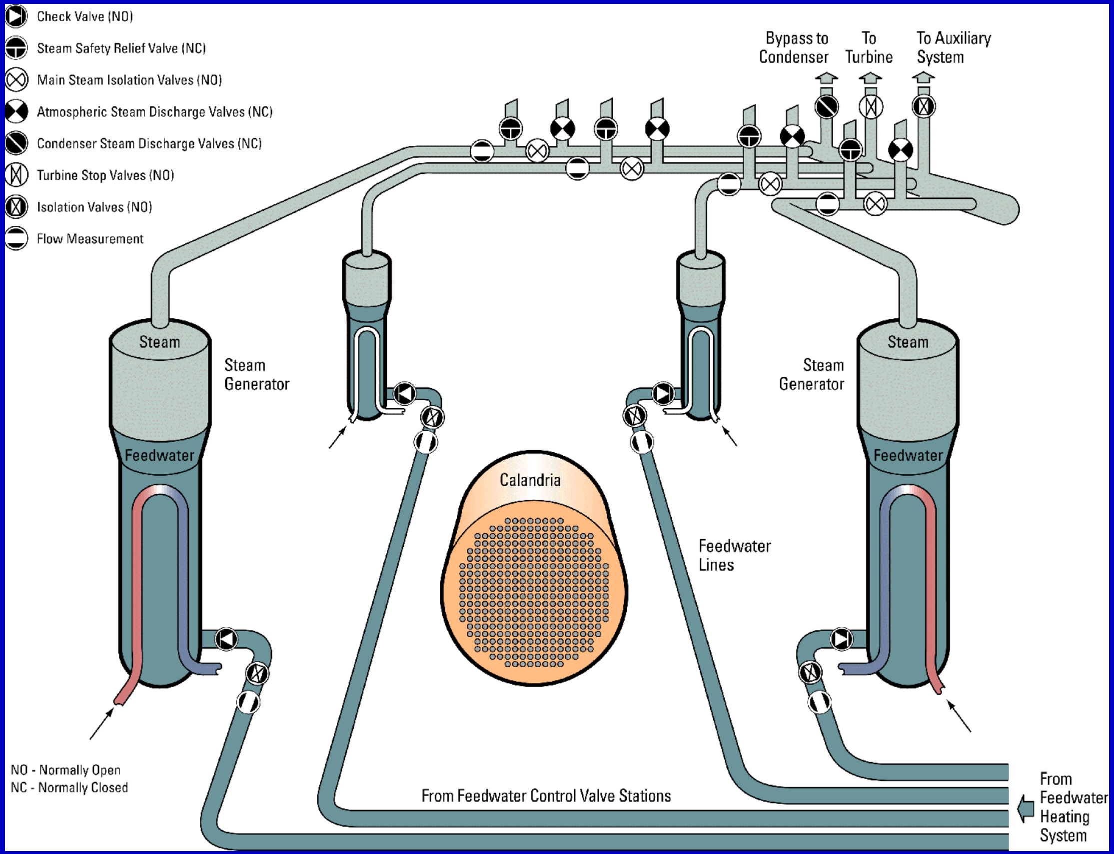
Steam and Feedwater System

- steam lines have isolation valves which are remote manual closure - they do not close automatically
- thus the steam generators are preserved as a heat sink wherever practical
- the steam generator tubes are designed to withstand the forces due to a main steam line break
- an individual steam generator can be isolated in the long term



Safety Requirements

- safety issues:
  - preserve or restore the heat sink for the reactor
- and, for breaks inside containment:
  - preserve structural integrity of containment
  - preserve internal structural walls of containment
- and, for breaks in turbine hall
  - preserve environmental protection of key equipment in turbine hall

Defences

- trip reactor
  - regulating system, shutdown system 1, shutdown system 2
- protect containment
  - dousing, air coolers, main steam safety valves
  - long-term alternate heat sink
- protect turbine hall
  - barrier wall and relief panels
- restore alternate heat sink
  - shutdown cooling system (breaks outside containment)
  - steam generator makeup from dousing tank
  - steam generator makeup from Emergency Water System

What's Different?

- secondary side breaks in CANDU are not a reactivity concern
- the inventory of radionuclides in a CANDU coolant is small because defective fuel can be removed on power, so there is less concern with discharge of secondary side water to atmosphere, even with a leaking boiler tube
- the steam generators are large, allowing ~30 minutes operator action time after a loss of all feedwater
- as with other accidents, the initiating event must be combined with failures of the safety systems - e.g., Main Steam Line break inside containment plus loss of dousing
- containment must remain intact but not necessarily leak-tight

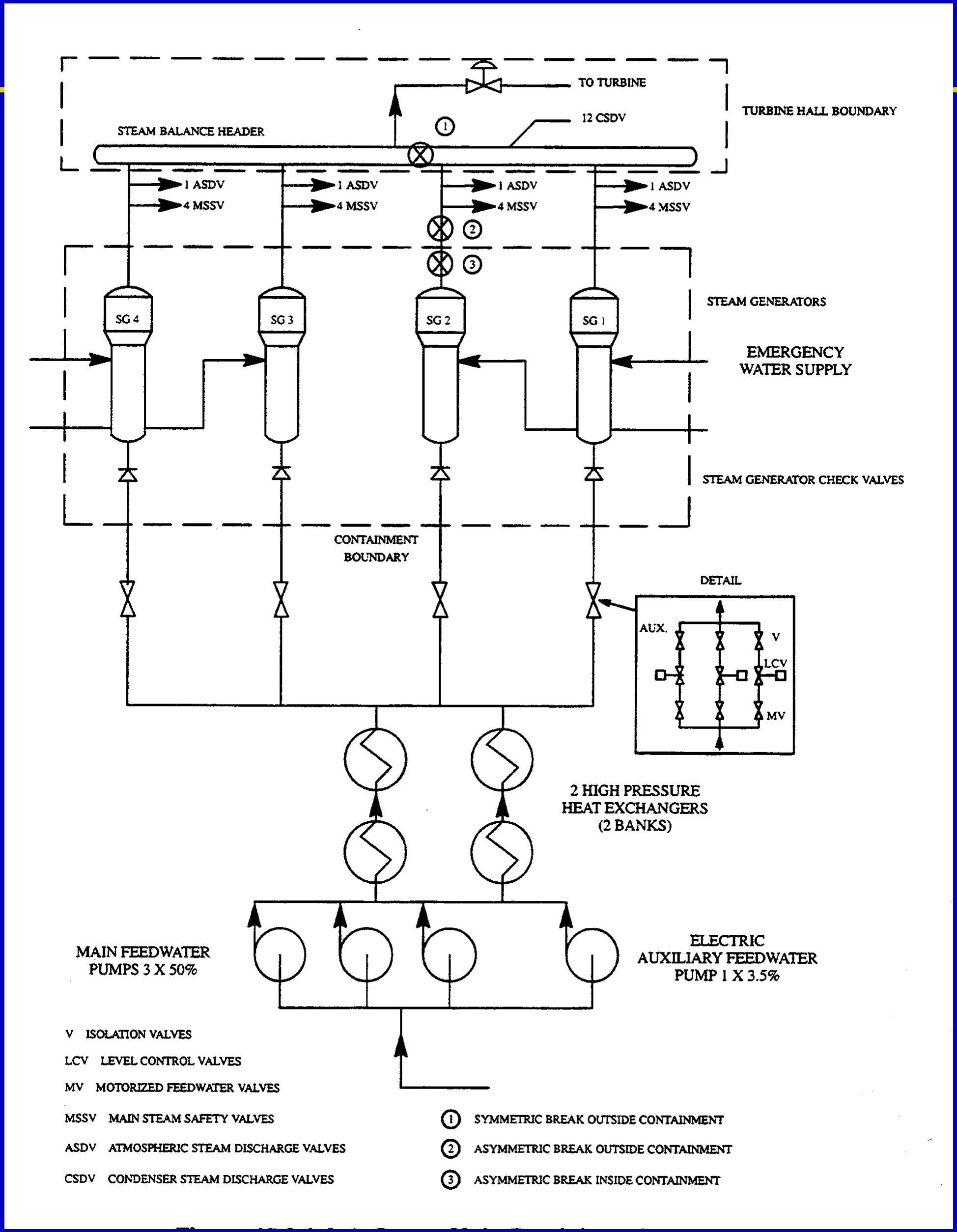
Acceptance Criteria

- Class 3 Dose Limits set by AECB
- two effective trips on each shutdown system where practical
  - prevent fuel sheath failures
  - prevent heat transport system boundary failures
- no damage to the containment structure
  - design pressure is 124 kPa(g)
  - threshold pressure for through-wall cracking ~330 kPa(g)
  - structural failure ~530 kPa(g) (for loss of dousing)
- turbine hall wall structural integrity

Cases Analyzed

- steam line breaks inside containment
  - plus containment impairments (loss of dousing)
  - plus loss of Class IV power
- steam line breaks outside containment
- feedwater line breaks
- loss of feedwater pumps
- feedwater valve closure
- loss of secondary side pressure control

Steam and Feedwater Schematic Diagram



Relevant Trips - both Shutdown Systems

Low feedwater pressure	4.0 MPa(a)
Low steam generator level (SDS2 only)	1.74-1.59m*
High heat transport system pressure	10.34-11.72 MPa(a)
Low pressurizer level	7.26m*
Low heat transport system pressure	8.8 MPa(a)*
Reactor building high pressure	3.45 kPa(g)

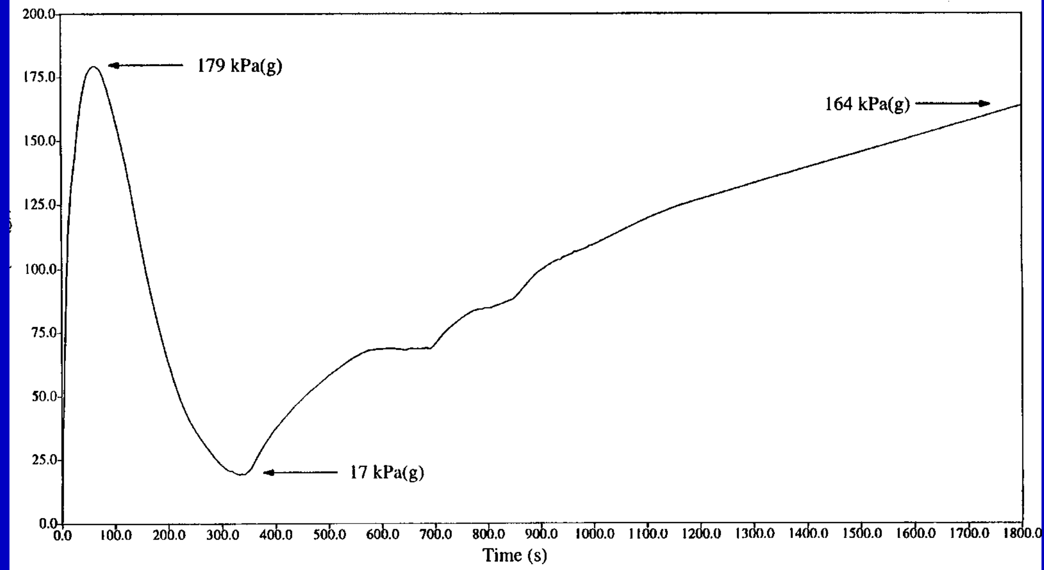
*function of power

Large Steam Line Break Inside Containment

Time	*Event*
0	Break
1-9	Several reactor trip and stepback signals shut down reactor. Dousing begins
25	Feedwater flow exceeds steam discharge, steam generators start to refill
60	Containment pressure peaks at 179 kPa(g)
225	Heat transport pump trip (low pressure)
340	Dousing water exhausted. Containment pressure begins to rise again. Some heat removed by air coolers and condensation
1800	Pressure has reached 164 kPa(g). Operator reduces containment pressure (e.g., opens Main Steam Safety Valves) & brings in long-term heat sink.

Containment Pressure

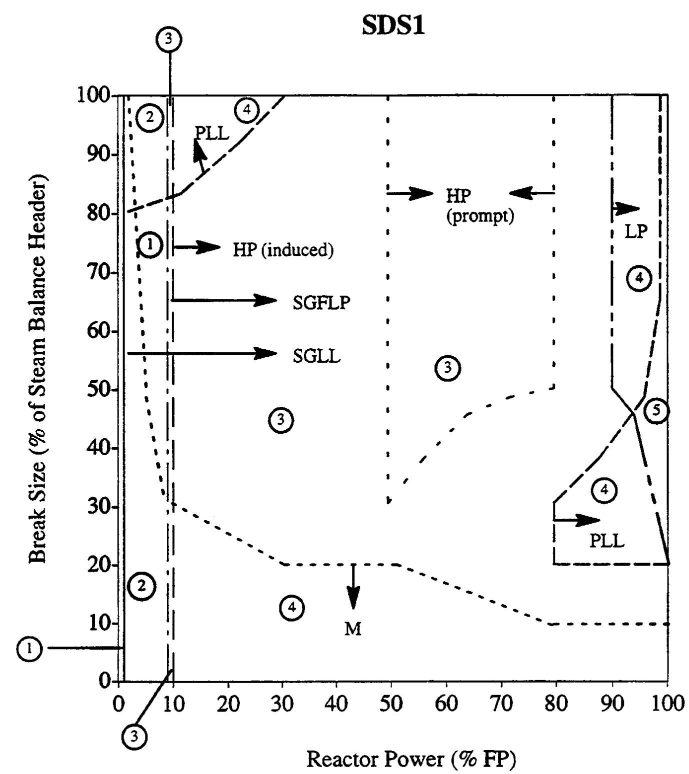
- pressure suppressed initially by dousing
- air coolers slow rate of rise after dousing is exhausted
- requires operator action in long term:
  - open main steam safety valves
  - add dousing water to steam generators
  - add EWS water to steam generators



100% Steam Main Break: Containment Pressure Transient

Trip Coverage Map for Shutdown System 1

- 2 or more trips in this example in all areas except very low power
- steam generator low level and low feedwater pressure effective across almost all the range
- trip coverage map for Shutdown System 2 very similar

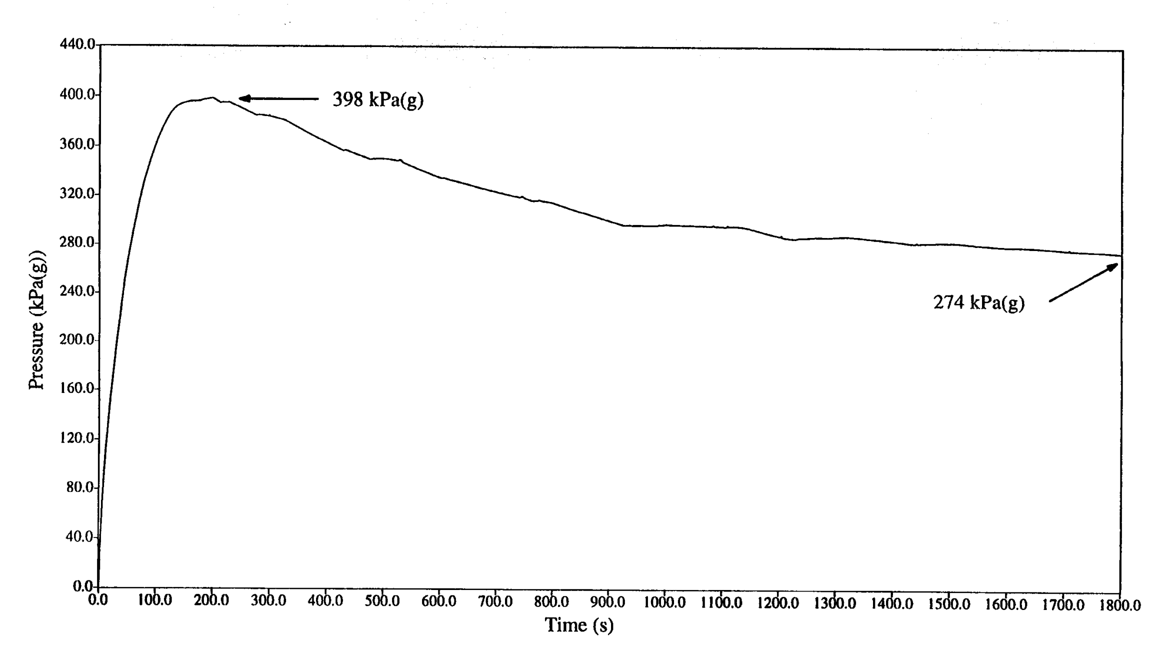


SGLL	Steam Generator Low Level (conditioned out at 1% FP)
SGFLP	Steam Generator Feedline Low Pressure (conditioned out at 9% FP)
HP	High Heat Transport System Pressure
LP	Low Heat Transport System Pressure (conditioned out at 0.1% FP)
PLL	Pressurizer Low Level (conditioned out at 1% FP)
M	Manual
(n)	Number of effective trips

SDS1 Trip Coverage Map for Symmetric Steam Balance Header Breaks

Loss of Dousing - Containment Pressure

- initial peak turned over due to decrease in steaming rate, effect of local air coolers and wall condensation
- longer term pressure below cracking pressure (acceptance criteria is to be below structural failure pressure)



100% Steam Main Break: Containment Pressure Transient (Loss of Dousing)

Summary

- continued feedwater flow after a steam main break provides a heat sink for at least half an hour (feedwater not isolated)
- operator has two sources of low pressure makeup water: from dousing tank and from Emergency Water System
- less concern on containment leakage than in other designs as the radioactive inventory in the coolant is low
- acceptance criteria for containment pressure allow leakage but not structural failure