



# *CANDU Safety*

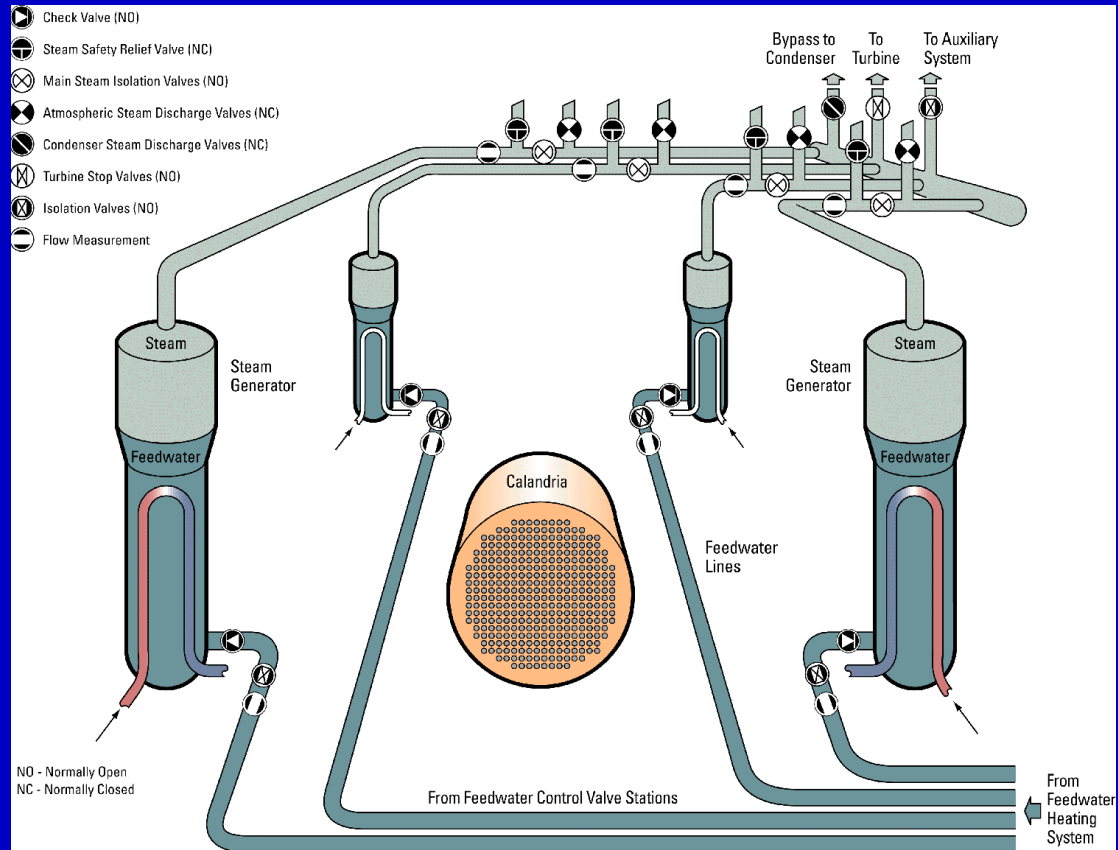
## *#14 - Loss of Heat Sink*

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# Steam and Feedwater System

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





# *Safety Requirements*

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



## *Defences*

- $\lambda$  trip reactor
  - regulating system, shutdown system 1, shutdown system 2
- $\lambda$  protect containment
  - dousing, air coolers, main steam safety valves
  - long-term alternate heat sink
- $\lambda$  protect turbine hall
  - barrier wall and relief panels
- $\lambda$  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?*

- λ secondary side breaks in CANDU are not a reactivity concern
- λ 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
- λ the steam generators are large, allowing ~30 minutes operator action time after a loss of all feedwater
- λ 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
- λ containment must remain intact but not necessarily leak-tight



## *Acceptance Criteria*

- λ Class 3 Dose Limits set by AECB
- λ two effective trips on each shutdown system where practical
  - prevent fuel sheath failures
  - prevent heat transport system boundary failures
- λ 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)
- λ turbine hall wall structural integrity

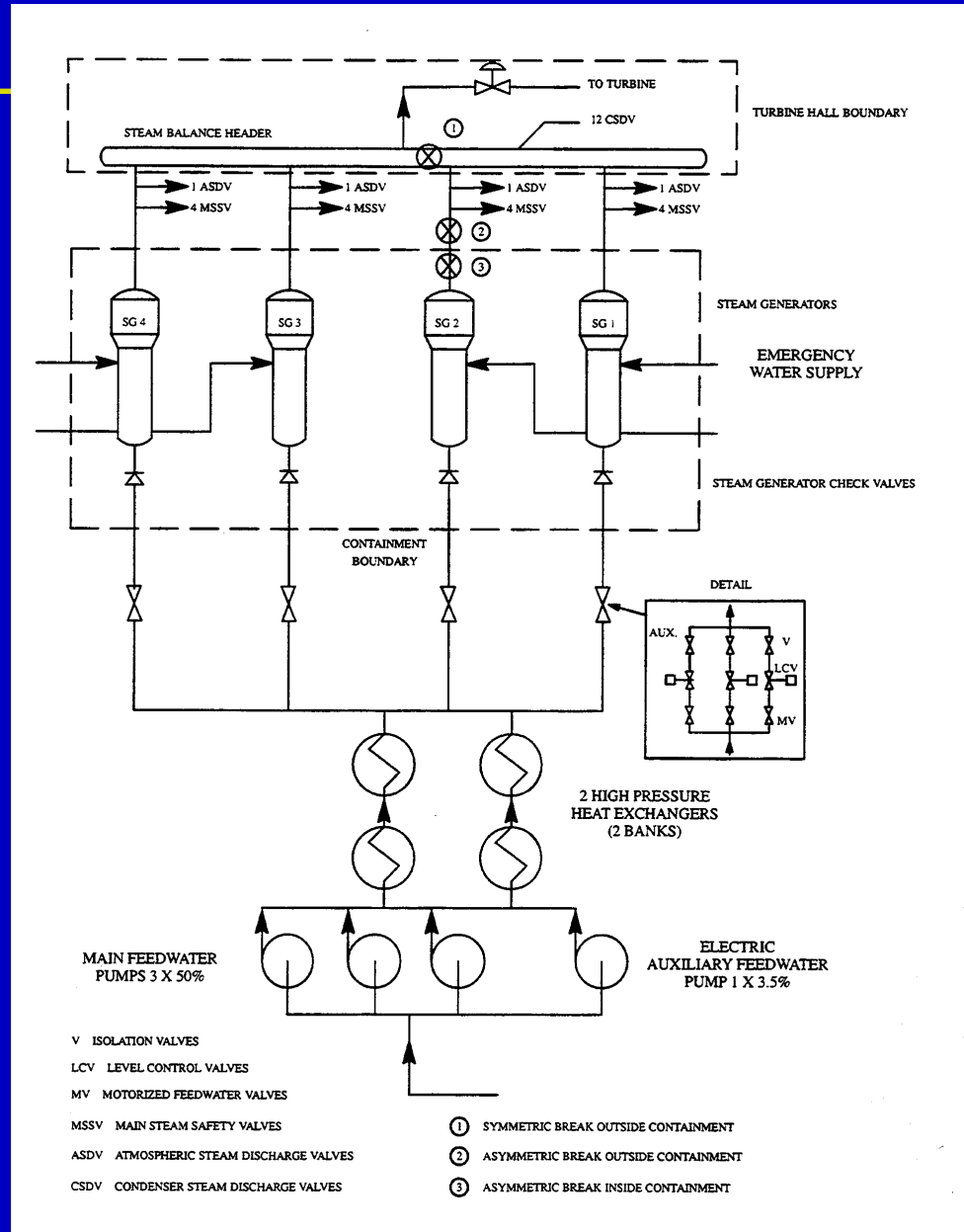


## *Cases Analyzed*

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



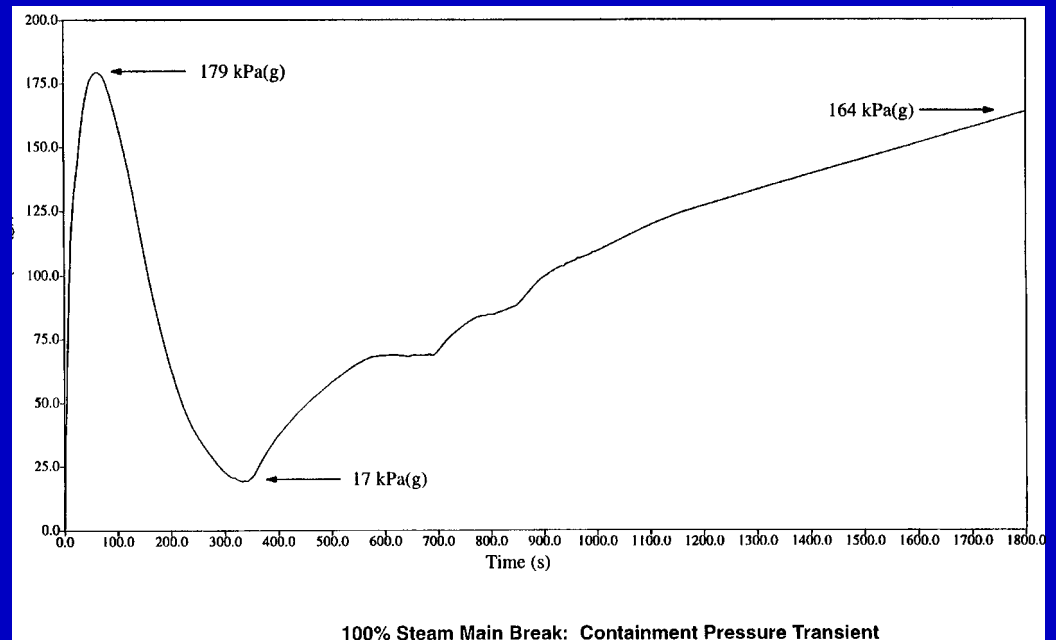
# *Large Steam Line Break Inside Containment*

<i>Time</i>	<i>Event</i>
<b>0</b>	Break
<b>1-9</b>	Several reactor trip and stepback signals shut down reactor. Dousing begins
<b>25</b>	Feedwater flow exceeds steam discharge, steam generators start to refill
<b>60</b>	Containment pressure peaks at 179 kPa(g)
<b>225</b>	Heat transport pump trip (low pressure)
<b>340</b>	Dousing water exhausted. Containment pressure begins to rise again. Some heat removed by air coolers and condensation
<b>1800</b>	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

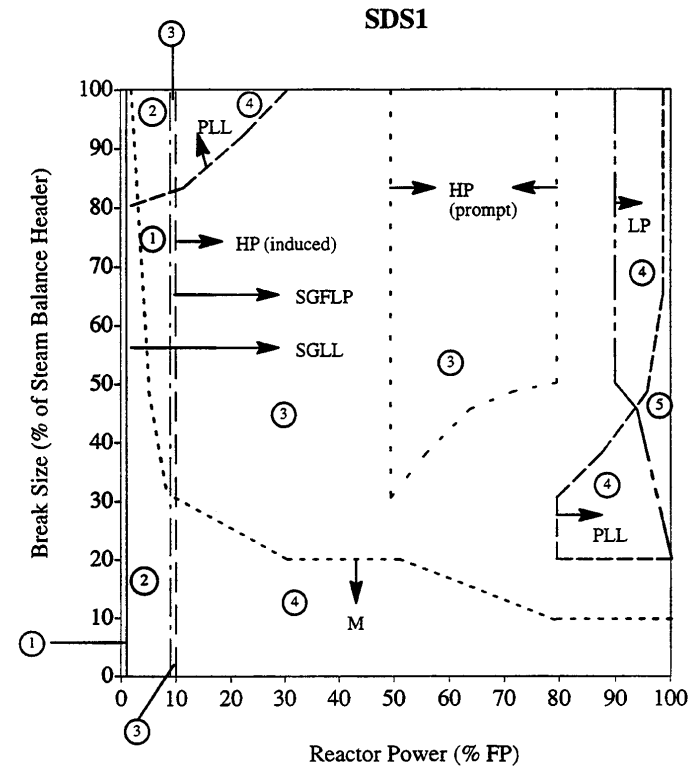
- λ pressure suppressed initially by dousing
- λ air coolers slow rate of rise after dousing is exhausted
- λ requires operator action in long term:
  - open main steam safety valves
  - add dousing water to steam generators
  - add EWS water to steam generators





# Trip Coverage Map for Shutdown System 1

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



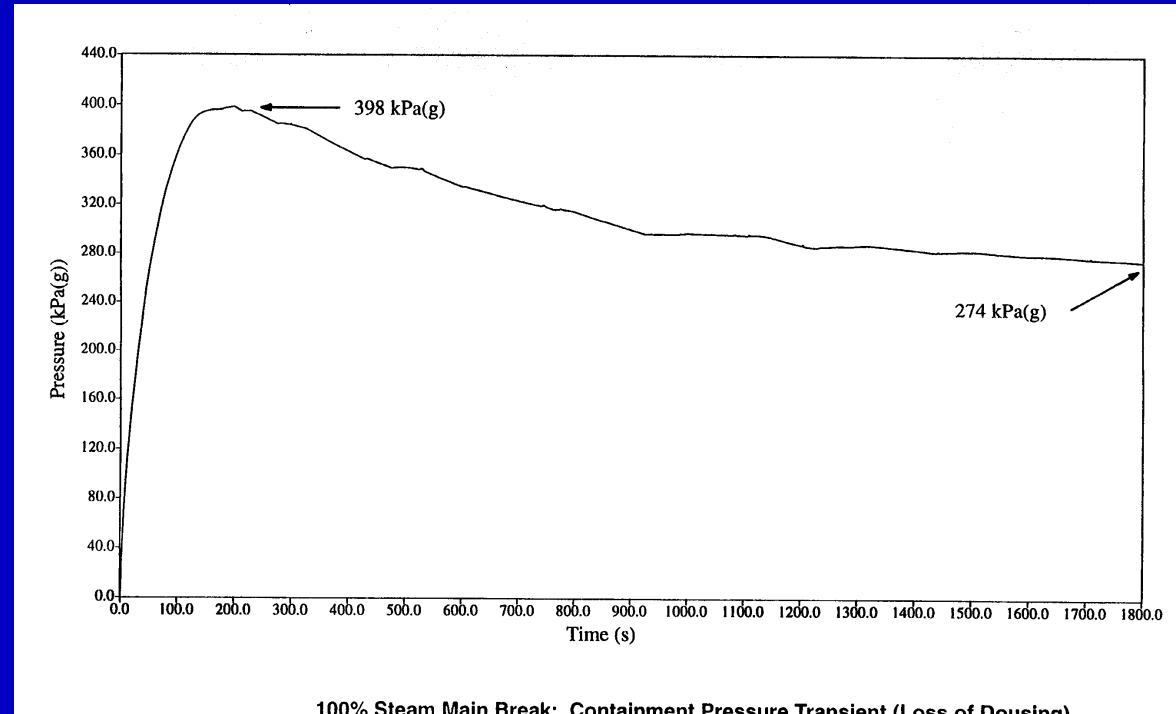
- SGLL Steam Generator Low Level (conditioned out at 1% FP)
- SGFLP Steam Generator Feedline Low Pressure (conditioned out at 9% FP)
- HP High Heat Transport System Pressure
- LP Low Heat Transport System Pressure (conditioned out at 0.1% FP)
- PLL Pressurizer Low Level (conditioned out at 1% FP)
- M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

**SDS1 Trip Coverage Map for Symmetric Steam Balance Header Breaks**



# Loss of Dousing - Containment Pressure

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





## *Summary*

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