CANDU Safety
#5 - Safety Functions - Shutdown Systems

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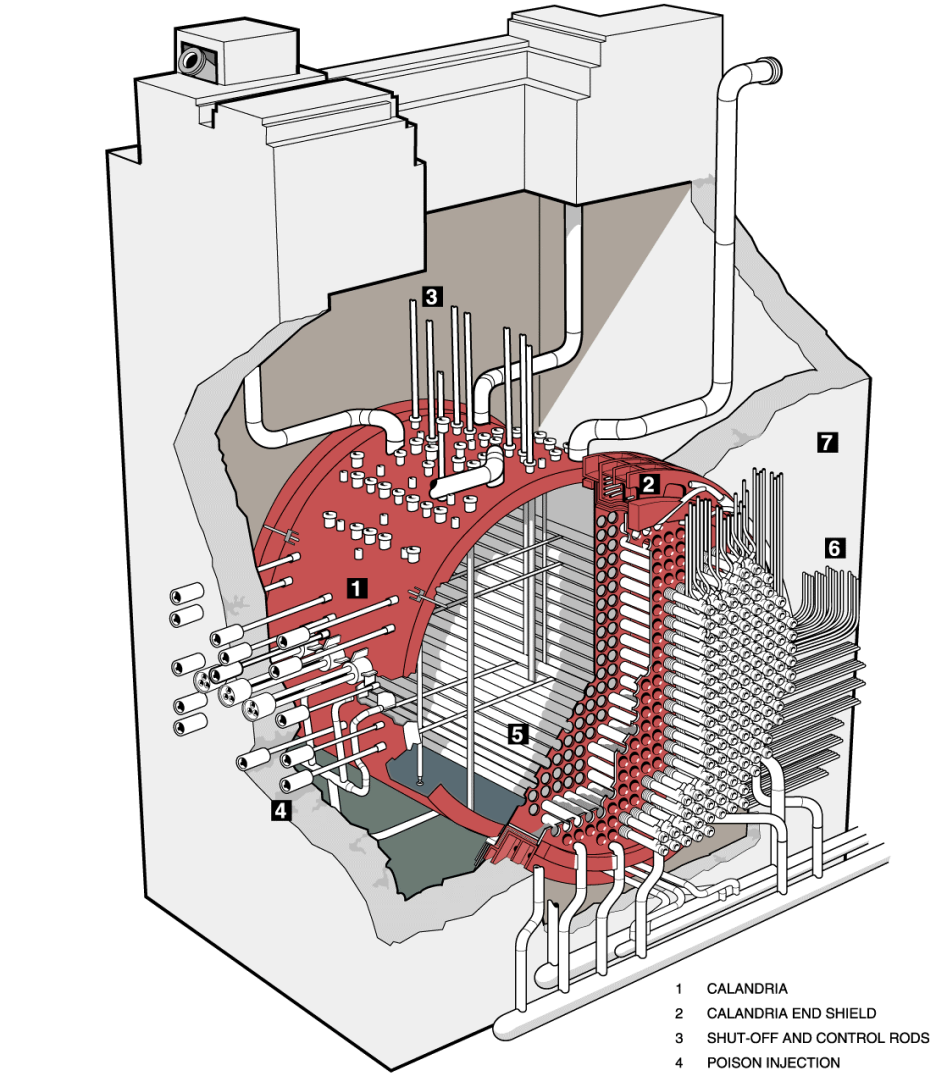
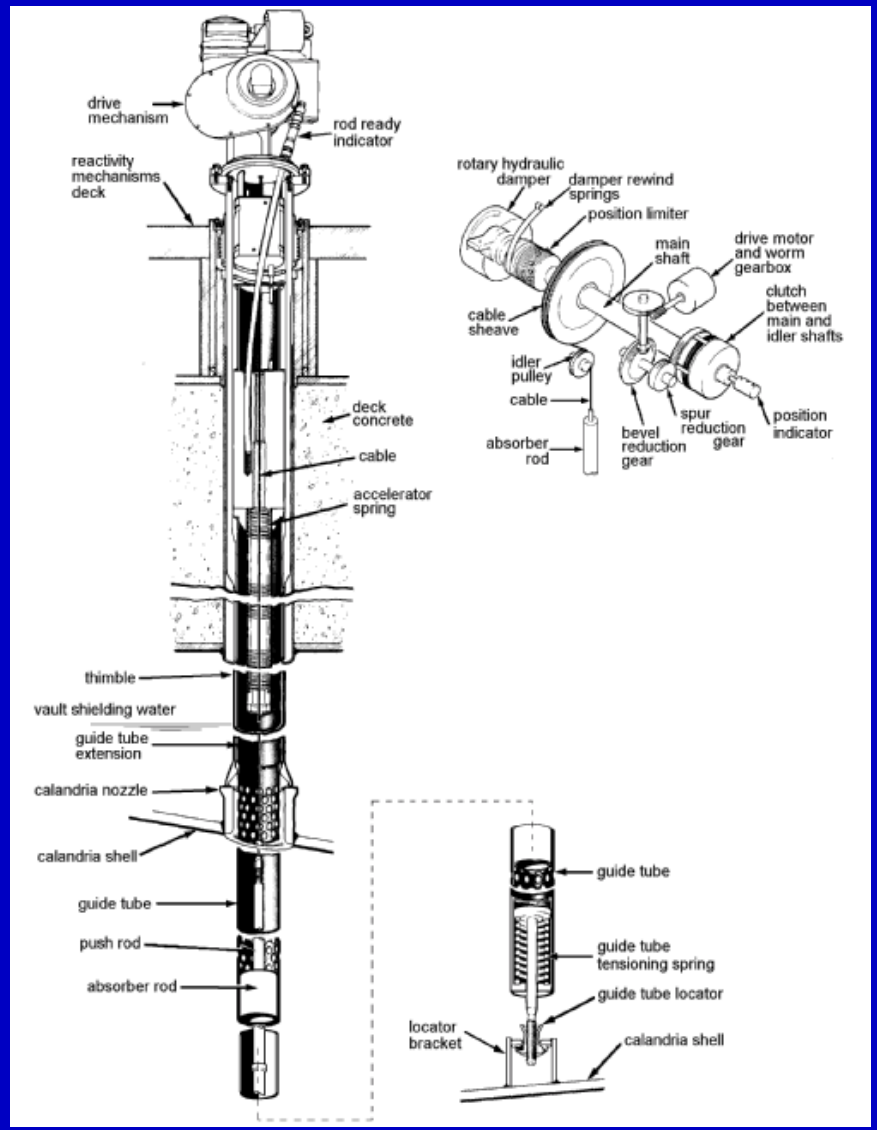
Location of Shutdown Systems Relative to the Reactor and Reactivity Mechanisms



CANDU 6 Reactor Assembly

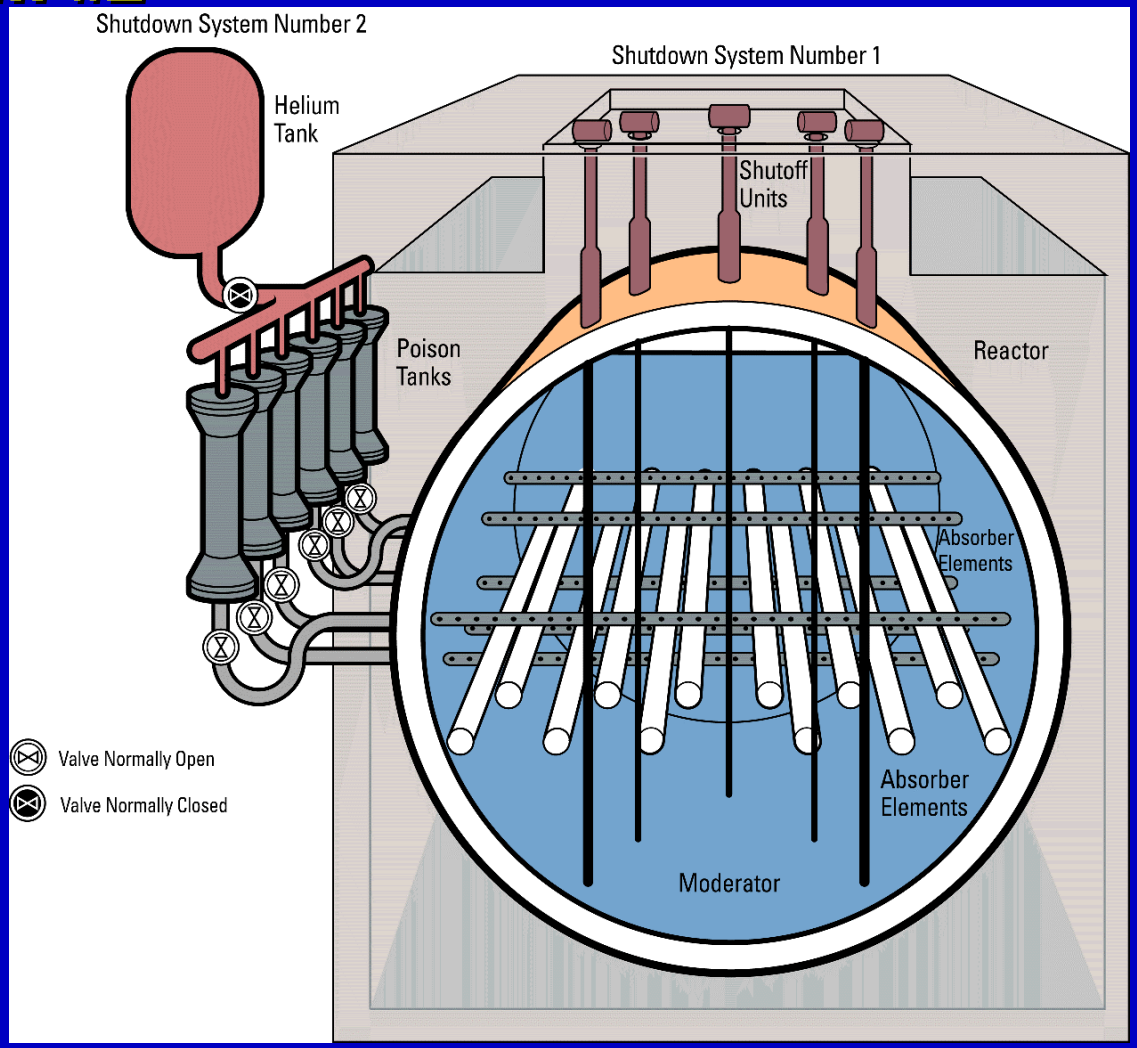
Shutdown System 1

- 28 spring-assisted gravity-drop absorber elements
- poised above core
- supported by cable
- held against spring by clutch; loss of power to clutch causes rods to fall into moderator
- guide tubes guide the absorbers as they fall in
- full insertion in < 2 seconds



Shutdown System #2

- 6 perforated nozzles run horizontally across the moderator
- each nozzle is connected to a liquid tank full of $GdNO_3$
- a high-pressure helium tank forces the "poison" into the moderator in < 2 sec.



Performance Requirements

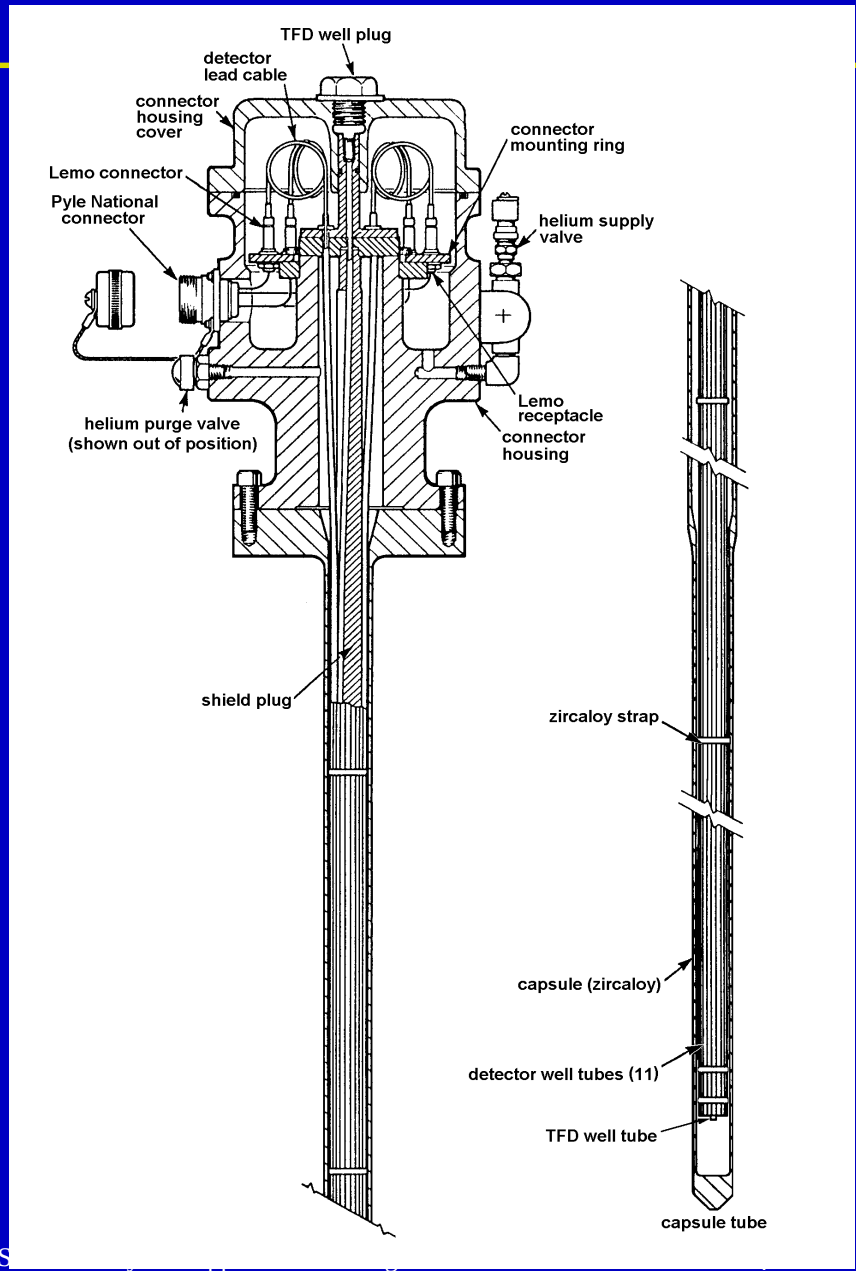
- insertion speed and initial negative reactivity
  - set by the large LOCA
  - turn over the power increase before the fuel or sheath melts
  - significant negative reactivity within 0.6 seconds of trip
- reactivity depth
  - set by a fuel channel rupture (in-core break) on startup after a long shutdown
  - moderator contains boron / gadolinium and after rupture is displaced by “unpoisoned” coolant
  - some shutoff rod guide tubes may be damaged

Reactivity Balance for In-Core Break

Reactivity Change Due to:	*Reactivity (mk) at 15 minutes*
Moderator poison displacement	10.5
Coolant void	13.3
Coolant Temperature	0.3
Fuel Temperature	4.1
Downgrading Moderator Purity	-4.8
Moderator Temperature	-0.1
Total to be compensated by shutdown	23.3

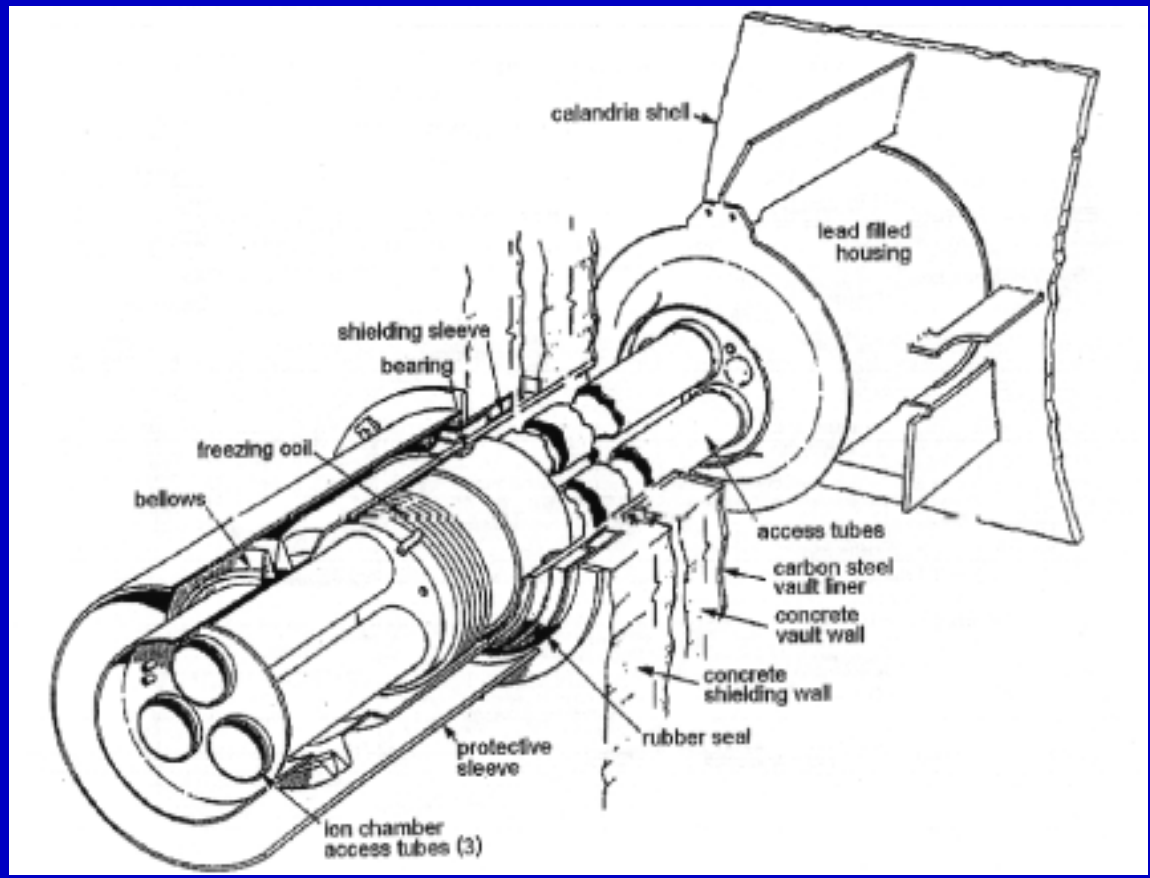
Flux Detectors

- SDS1 uses vertical self-powered fast-response platinum flux detectors in core
- they are not shared with the control system nor with SDS2
- they are used for local overpower protection and for bulk overpower
- SDS2 uses separate horizontal in-core detectors



Ion Chambers

- SDS1 and SDS2 use (separate) ion chambers on the side of the core
- the main purpose is to generate a low-level power signal and a high-rate signal



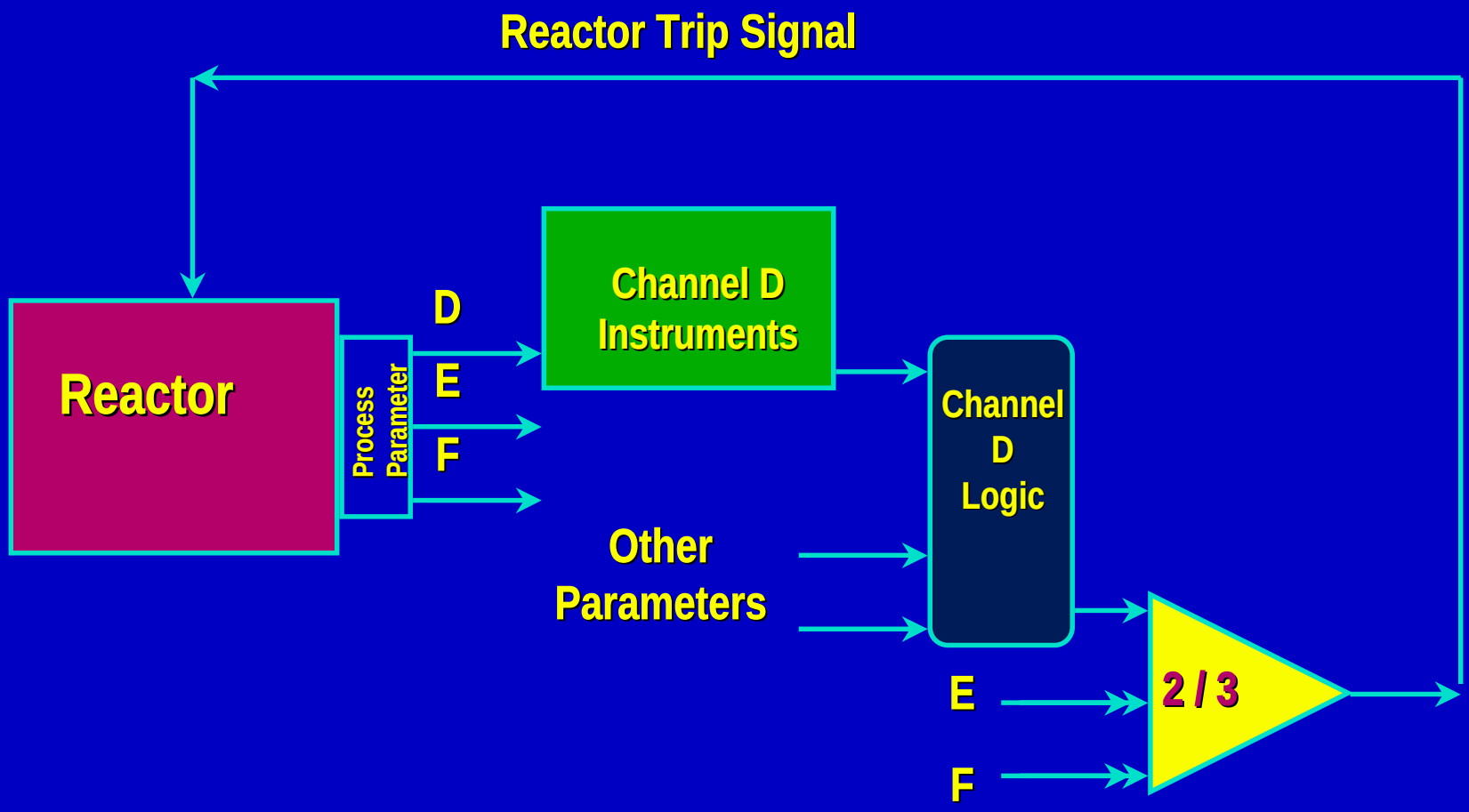
Typical SDS1 Trip Parameters

Parameter	*Purpose - examples*
High Neutron Power	**Loss of reactivity control, LOCA**
High Rate of Rise of Neutron Power	**LOCA, loss of reactivity control from low power**
High Coolant Pressure	**Loss of flow, loss of heat sink**
Low Coolant Pressure	**Small LOCA**
High Building Pressure	**LOCA, steam line break**
Low Steam Generator Level	**Steam and feedwater line breaks**
Low Pressurizer Level	**Small LOCA**
High Moderator Temperature	**Loss of service water**
Low Coolant Flow	**Loss of flow**
Low Steam Generator Pressure	**Steam line break**

Typical SDS2 Trip Parameters

Parameter	*Purpose - examples*
High Neutron Power	Loss of reactivity control, LOCA
High Rate of Rise of Neutron Power	LOCA, loss of reactivity control from low power
High Coolant Pressure	Loss of flow, loss of heat sink
Low Coolant Pressure	Small LOCA
High Building Pressure	LOCA, steam line break
Low Steam Generator Level	Steam and feedwater line breaks
Low Pressurizer Level	Small LOCA
Low Header Δp	Loss of flow
Low Steam Generator Pressure	Steam line break

SDS1 Two- Out-of-Three Logic



2 out of 3 Logic

- allows one channel to be tested without tripping the reactor
- allows one channel, if it is known to be faulty, to be put in a safe (tripped) state without tripping the reactor
- permits comparison of the three signals and alerts the operator if any seem inconsistent

Shutdown System Design Requirements

- each shutdown system is effective for all accidents
- they do not share sensing, logic or actuation devices with each other or with the reactor control system
- the design of the two shutdown systems is diverse
  - solid absorber rods and liquid poison injection
  - logic microprocessors programmed by different groups of people in different languages
- where practical, each shutdown system has two diverse trip parameters which are effective for each accident
- in a few cases SDS1 and SDS2 trips are diverse
  - e.g., low flow and low Δp

Shutdown System Design Requirements - More

- the two shutdown systems are oriented differently
  - vertical rods and horizontal nozzles, also for flux detectors
- the cables and instrumentation are physically separated
- each SDS is controlled from a different control room
- each SDS is designed to meet an unavailability of 1 in 1000
- each SDS is tested during operation to show that this unavailability is met:
  - each channel is testable up to the final 2 / 3 logic
  - any shutoff rod can be partially dropped
  - any poison valve can be opened without firing SDS2

Shutdown System Design Requirements - More

- most process parameters are directly testable: e.g., a shutter can be moved in an ion chamber to test the log rate trip for that channel
- the systems are fail safe as far as possible:
  - loss of power to clutches or poison valves trips the system
  - loss of power to a channel trips the channel
  - loss of power supply trips the channel
  - watchdog timers trip the channel if the logic is not routinely operating
- the operator cannot easily prevent tripping the systems nor change the logic

Lesson Learned from Chernobyl

- the shutdown systems in Chernobyl were adequate according to the safety analysis
- the designers assumed the operator would not operate the plant in an unusual configuration
- he did, and the shutdown systems made the accident worse
- in CANDU:
  - the reactor state does not change much once equilibrium fuelling is reached
  - the shutdown system effectiveness does not depend much on reactor state

Summary

- CANDU Shutdown Systems are:
  - effective, acting alone; therefore they are fully redundant
  - diverse in design
  - designed to numerical reliability target
  - testable during operation to show the reliability target is met
  - separated so that a hazard in a local area will not affect both systems