Instrumentation and Control Concepts
CNS Reactor Safety Course

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Canada

AECL
Atomic Energy of Canada Limited

EACL
Énergie atomique du Canada limitée

Opening Notes

- Course discusses a broad range of topics, many in general terms, to provide a good introductory understanding of the principles.
  - Certain systems and features may be different from station to station and, and station specific material should always be studied
- Resource material and related standards are listed at the end of the presentation for further reference/study

Three “C”s

- <u>C</u>ool
- <u>C</u>ontrol
- <u>C</u>ontain

- Sometimes M for monitor

Presentation Overview

- **Overview of the two categories of plant systems to ensure safety:**
  - **Process Systems - used during normal operation of the plant**
  - **Special Safety Systems - used to mitigate failures in process systems**
- **Neutronic Instrumentation**
- **I&C General Concepts**

Safety Objectives

These are met by the process and safety systems as follows:

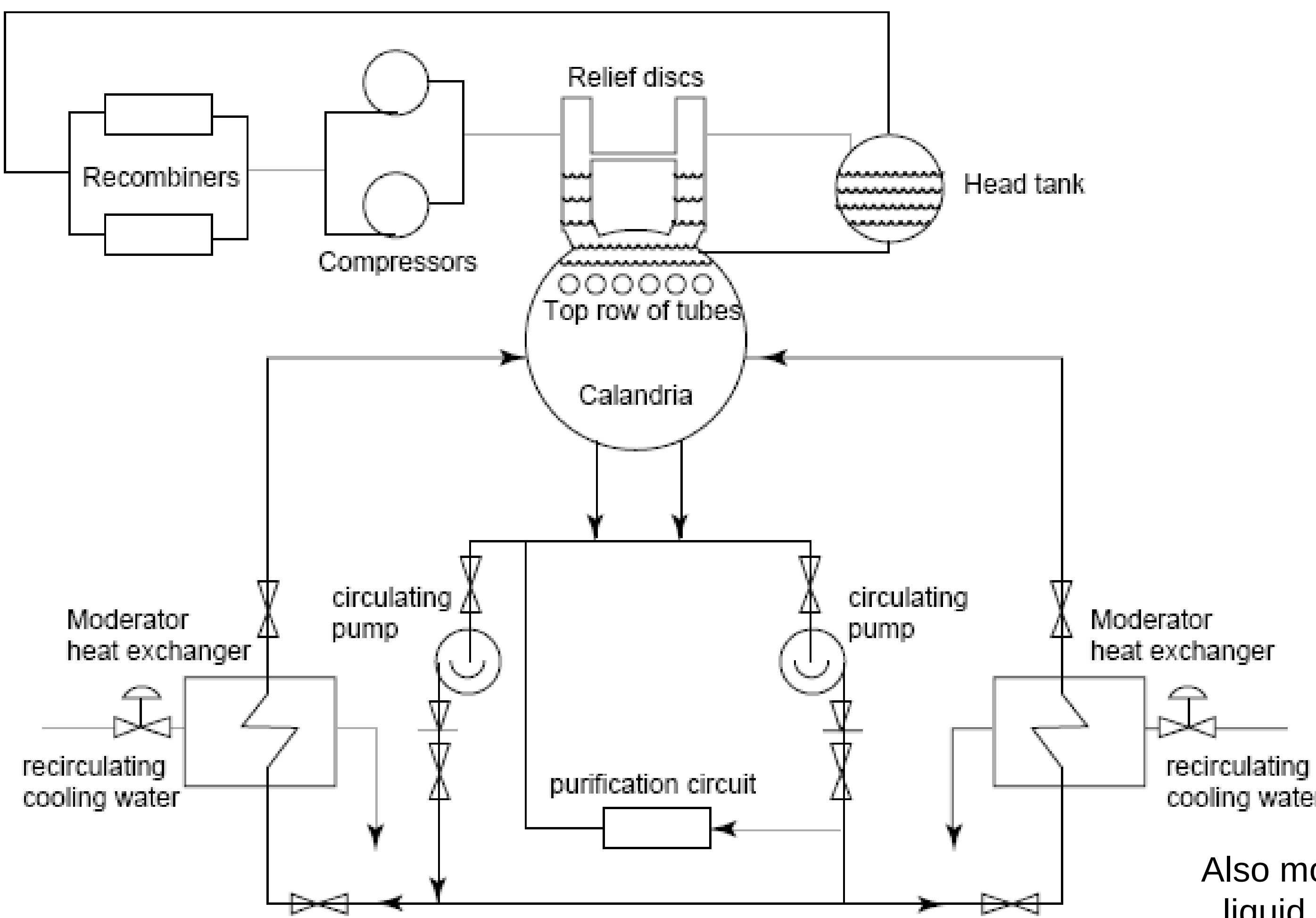
Safety objective	Process System(s)	Special Safety System(s)
Cool the fuel	HTS, Steam & Feedwater Sys	ECC
Control reactor power	RRS	SDS1, SDS2
Contain the radioactivity	Fuel sheath, HTS boundary	Containment

CANDU Process Control Systems

Major CANDU process control Loops:

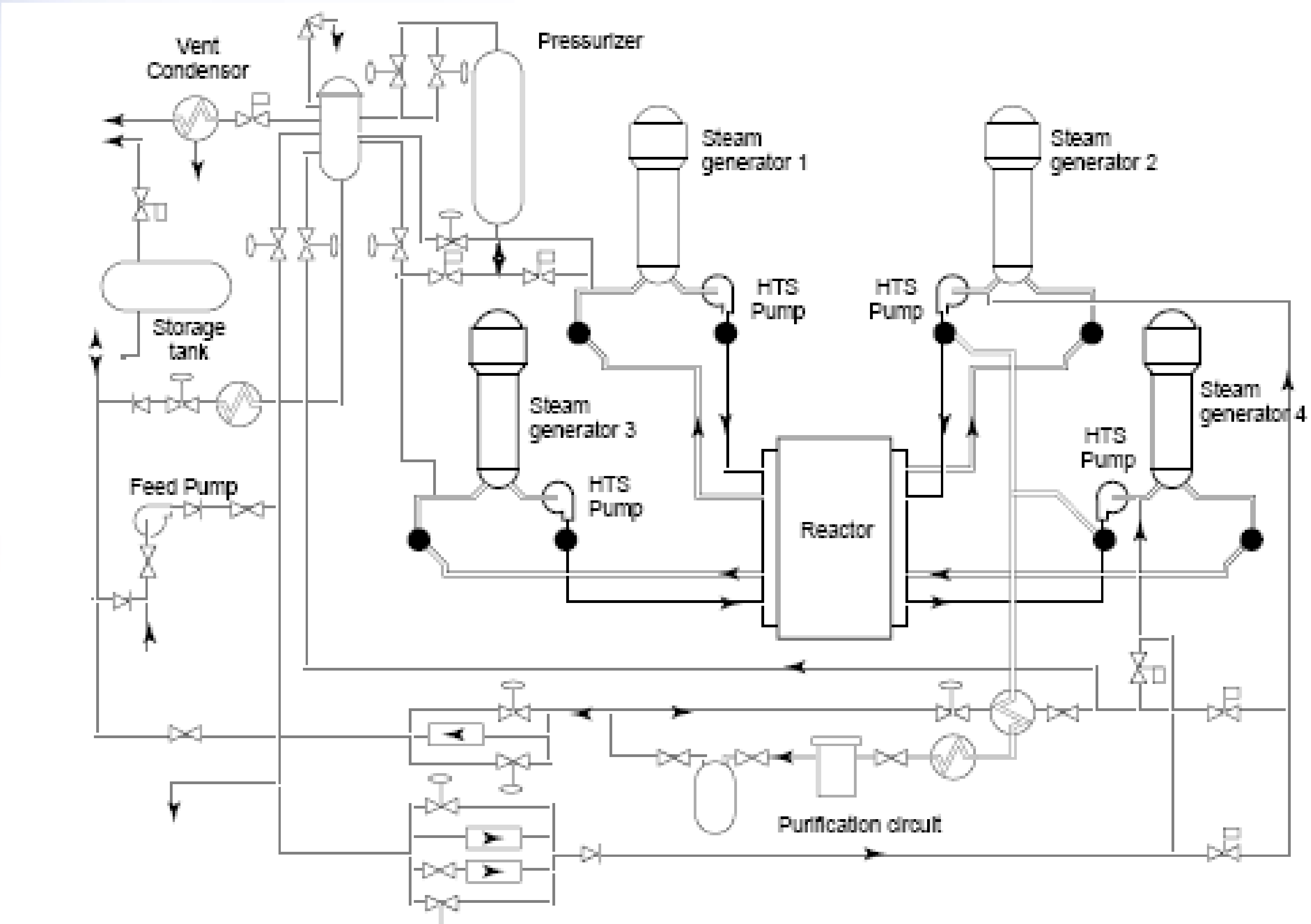
- **Moderator Temperature Control**
- **Heat Transport Pressure and Inventory Control**
- **Steam Generator Level Control**
- **Overall Plant Control (OPC)**
  - **OPC is a co-ordination of 3 major control programs to achieve the desired electrical/thermal output:**
- **Turbine Control System**
- **Steam Generator Pressure Control**
- **Reactor Regulating System**

Moderator and Auxiliaries



Also moderator liquid poison

Overall HTS and Auxiliaries



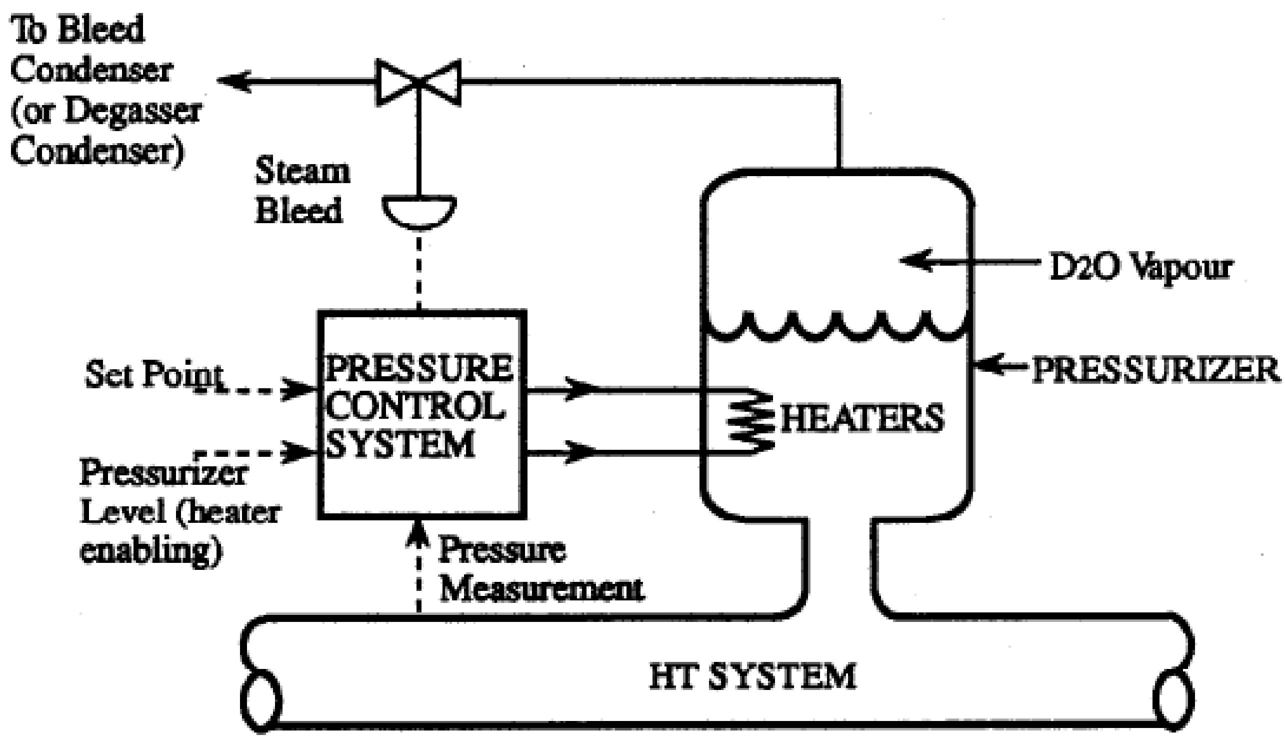
HTS and Auxiliary Controls

- HTS Pressure and Inventory Control
  - Pressure Control
    - Normal Mode (pressurizer connected)
    - Solid Mode (pressurizer isolated or not there)
  - Inventory Control
    - Normal mode (pressurizer level)
- HT Purification
  - High pressure purification (CANDU 6)
  - Low pressure purification (Bruce/Darlington)
- HT Pump Trips (some plants)
  - Low suction pressure
  - High bearing temperature

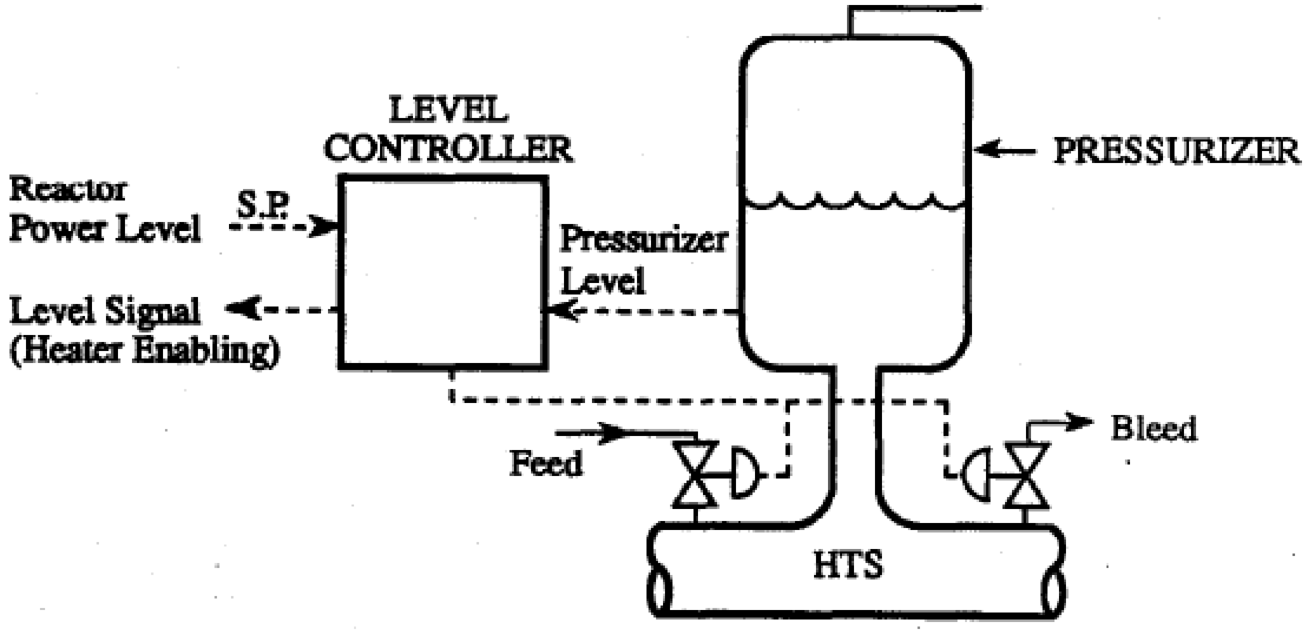
HTS P&IC Control Modes

- SOLID mode control (isolated pressurizer, for warmup /cooldown/shutdown/maintenance) is mixture of manual and analogue controller external to the control computers
    - Pressure of HTS is controlled by feeding and bleeding HTS coolant to/from HTS
- NORMAL mode control (pressurizer connected) is automatic via control computers.
    - Pressure of HTS is controlled by controlling the pressure in the Pressurizer using heaters or steam bleed valves
    - Inventory of HTS is controlled by feeding and bleeding HTS coolant to/from HTS
    - Normal mode of P&IC is not related to normal mode of reactor control (i.e., turbine leading mode)

HTS Pressure Control



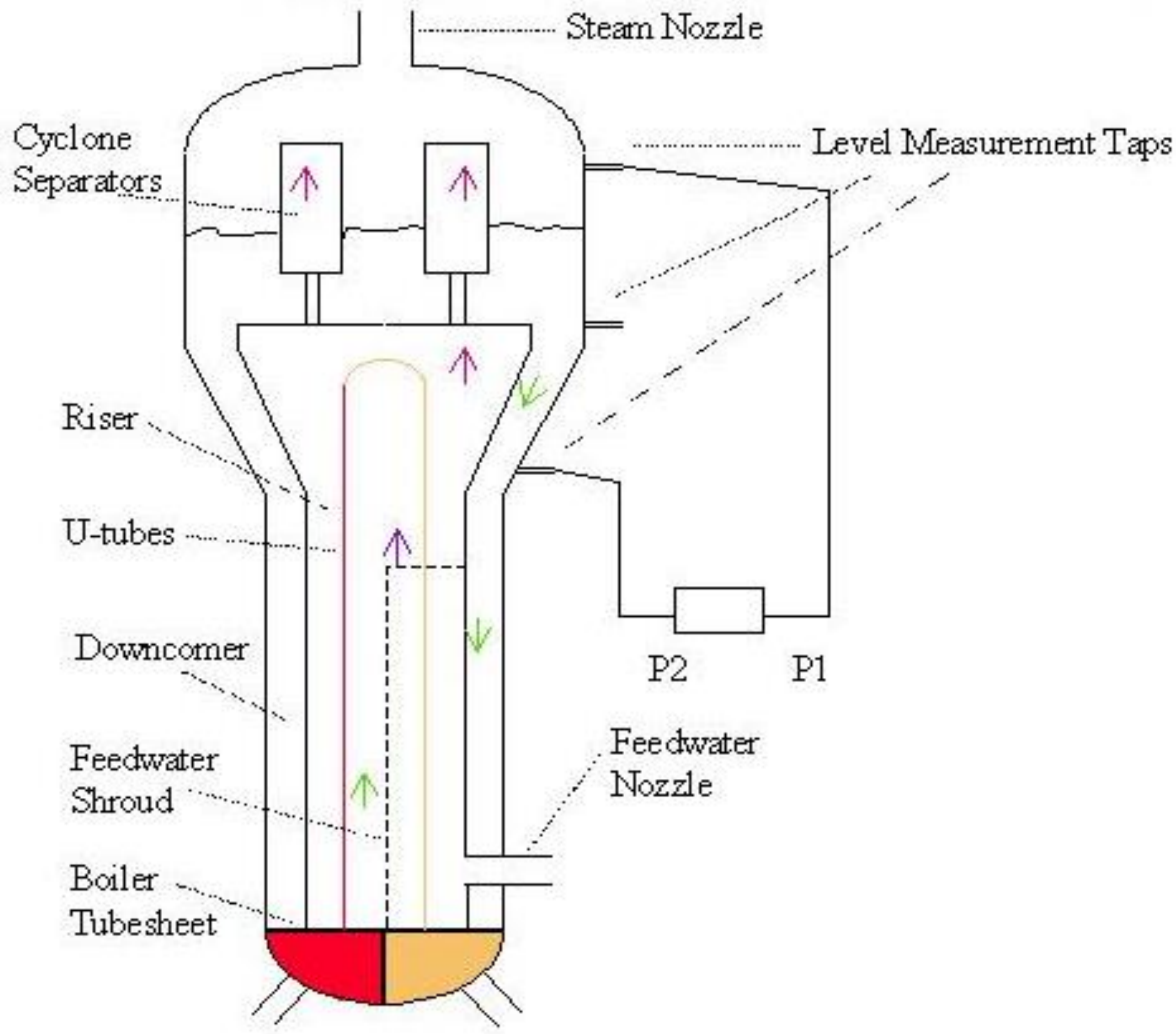
HTS Inventory Control



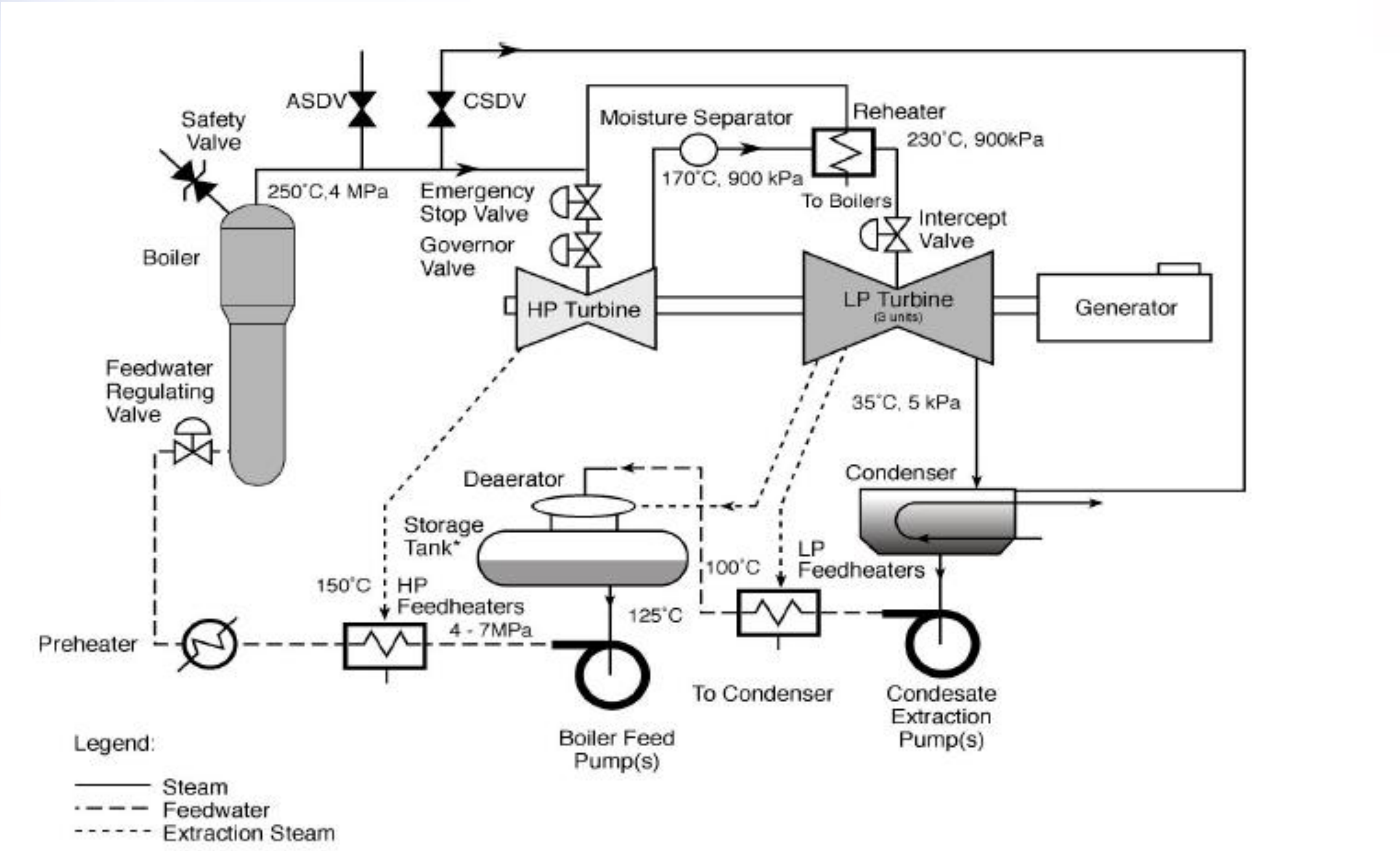
HT Purification

- **HT Purification in CANDU 6 is done at high pressure and bleed flow is taken from after the ion exchange columns in the HT purification system**
- **HT Purification in Bruce/Darlington is done at low pressure and bleed flow is into the bleed condenser**
  - **Purification bias is added to bleed valve opening control and control system compensates using the feed valve**

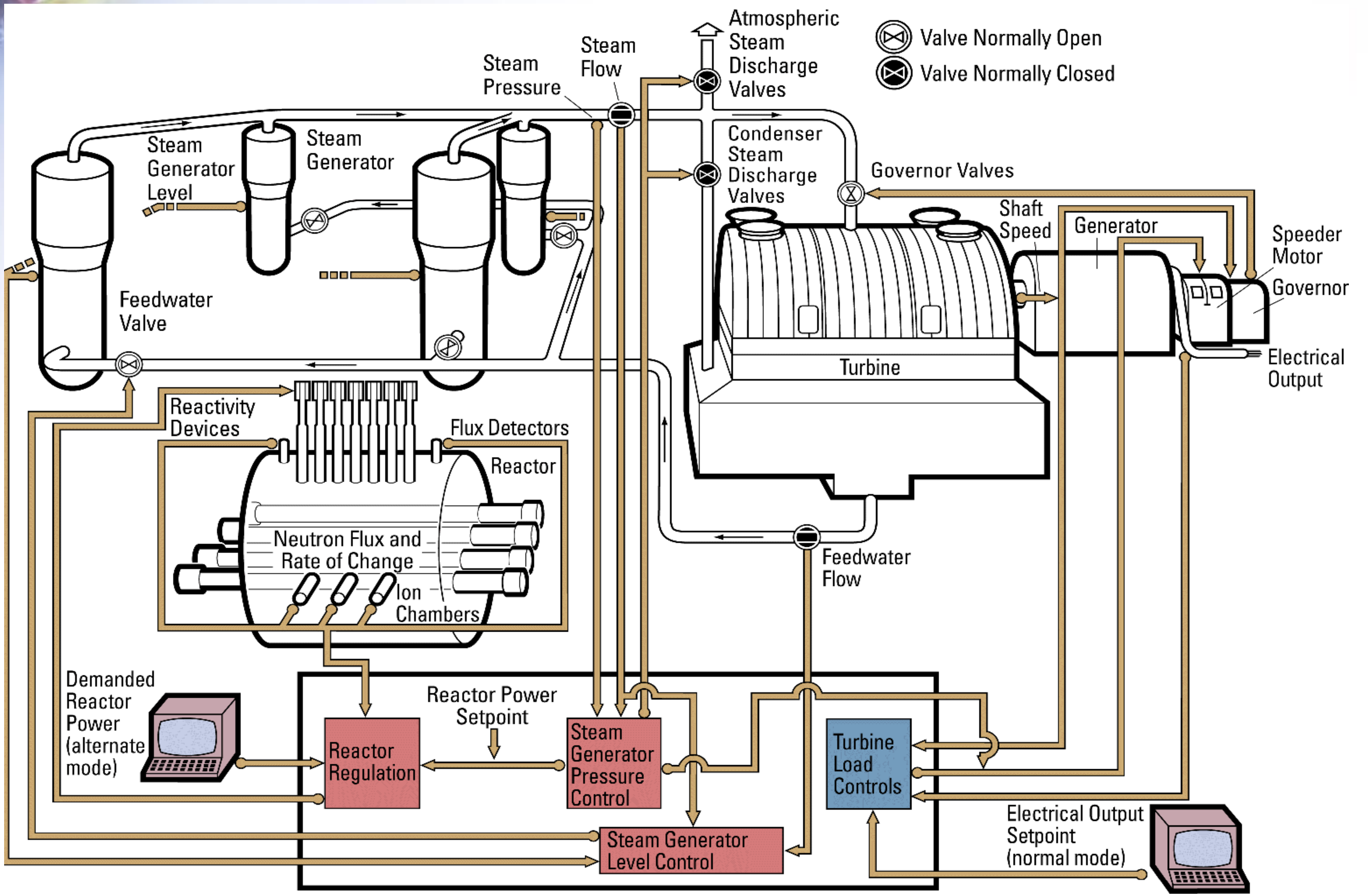
CANDU Steam Generator Components



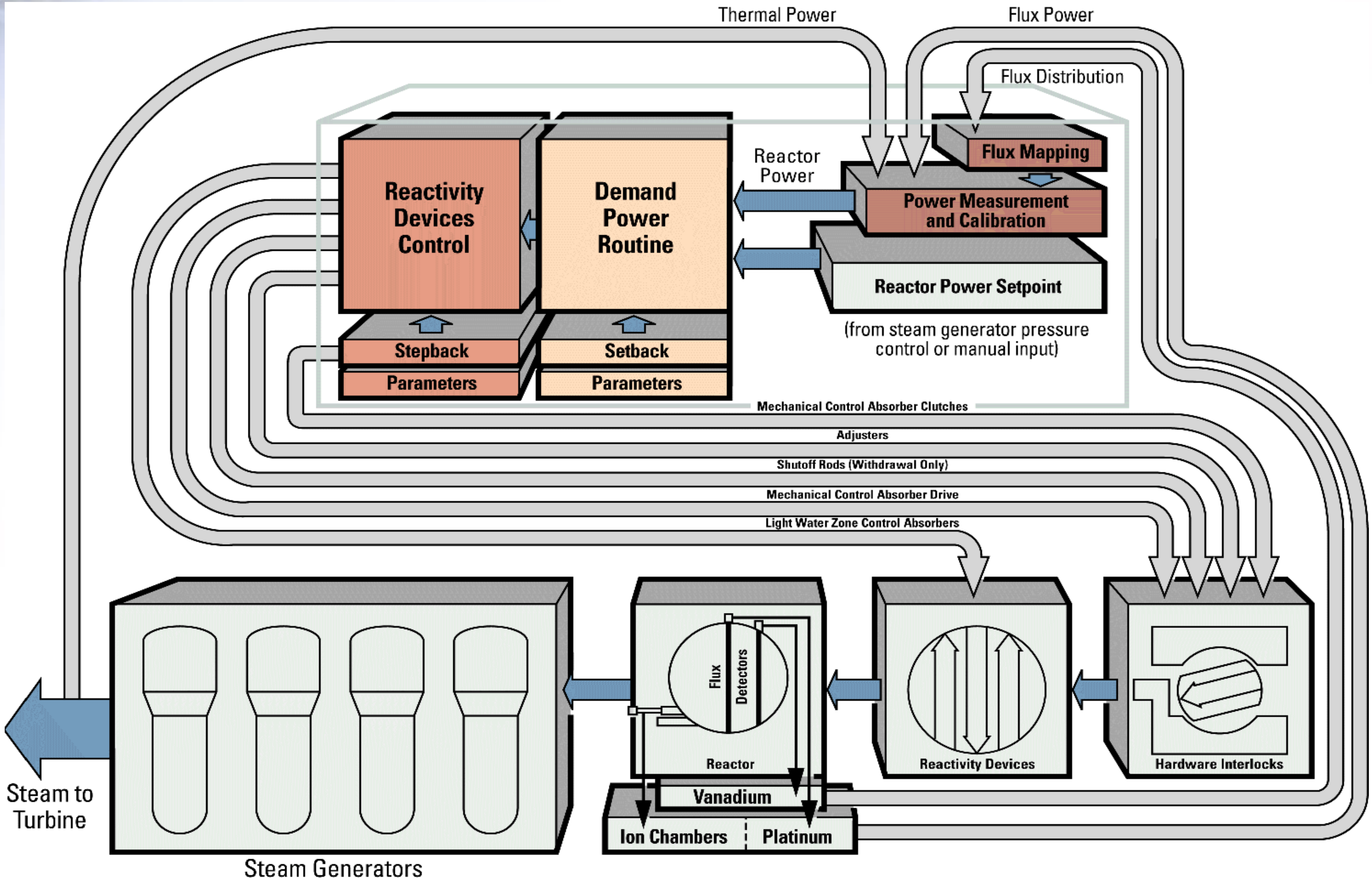
Simplified Steam & Feedwater Cycle



Overall Plant Control



Reactor Regulating System (RRS)



Control of Flux Shape

- **The physical dimension of CANDU reactor is large in relation to average distance travelled by neutron, hence local neutron flux disturbances could develop while bulk power is constant.**
- **An even flux distribution is necessary to achieve maximum extraction of energy (burn-up) from each fuel bundle.**
- **Preventing local flux peaks is essential to minimize damage to fuel.**

Flux Mapping Routine

- Reads 102 in-core vanadium detectors
- Calculates mode amplitudes (least squares fit to pre-calculated mode shapes, via matrix-vector multiplication)
- Uses different sets of matrices (and modes) for different operating conditions (e.g. shim)
- Calculates flux at any point or area (e.g. zone average “powers”, channel “powers”, total reactor “power”, selected bundle “powers”, flux mapping detector sites)
- Zone averages are used for zonal calibration of zone control flux detectors
- A peaking factor is used (in conjunction with zone flux detectors) to initiate a setback on high local flux

Thermal Power Calculation

- **Fully instrumented channel powers based on coolant channel inlet/outlet flow, inlet temperature & temperature rise across the fuel channel (used in OPG Reactors for all power levels)**

- **Reactor thermal Power based on RIH temperature and temperature rise across the core**
  (used in CANDU 6 below 50% power)

- **Boiler Power based on boiler feedwater flow and feedwater temperature and steam flow**
  (used in CANDU 6 above 70% power)

Defense in Depth

- Levels of action
  - Reactor Regulating System (RRS) - normal reactor control
  - Setback – reduction of reactor power setpoint
  - Stepback – dropping of Mechanical Control Absorbers (MCAs)
  - SDS1 trip – dropping of Shutoff Rods (SORs)
  - SDS2 trip – injection of gadolinium into moderator
- Setbacks and stepbacks reduce the need for SDS action during process upsets
- Reactor Control
  - Liquid Zone Controls – normal control
  - Adjusters – provide positive reactivity when needed
  - MCAs – stepback on process upsets and loss of regulation(LOR)
  - SDS action

Setback Routine

- Monitors a number of plant conditions which may require power reduction
- If any setpoint is exceeded, initiate controlled downward power manoeuvre
- Continue until condition clears or a pre-defined power endpoint is reached
- If more than one condition calls for a setback, the one with the greater setback rate governs
- A fast downward power manoeuvre takes precedence over a slow setback
- Typical setback rates vary from 0.1 to 1.0 % FP per second
- Typical end points vary from 60 to 2 % FP

Typical Setback Conditions

- High Local Neutron Flux
- High Flux Tilt
- High Steam Generator Pressure
- Low Deaerator Level
- High Moderator Temperature
- Low Moderator Pump Differential Pressure
- High Pressurizer Level
- Low End Shield Flow
- High End Shield Inlet Temperature
- High Bleed Condenser Pressure
- Turbine Trip or Loss of Line
- Manual

Stepback Routine

- Monitors a number of plant conditions which may require fast power reduction
- If any setpoint is exceeded, drop MCA rods by opening clutches
- Catch rods (re-energize clutches) when the condition clears, or the lower power endpoint is reached
- Comparison with endpoint is based on <u>projected</u> flux value (to compensate for rod momentum)
- <u>Both</u> computers must call for stepback (for plant availability)

Typical Stepback Conditions

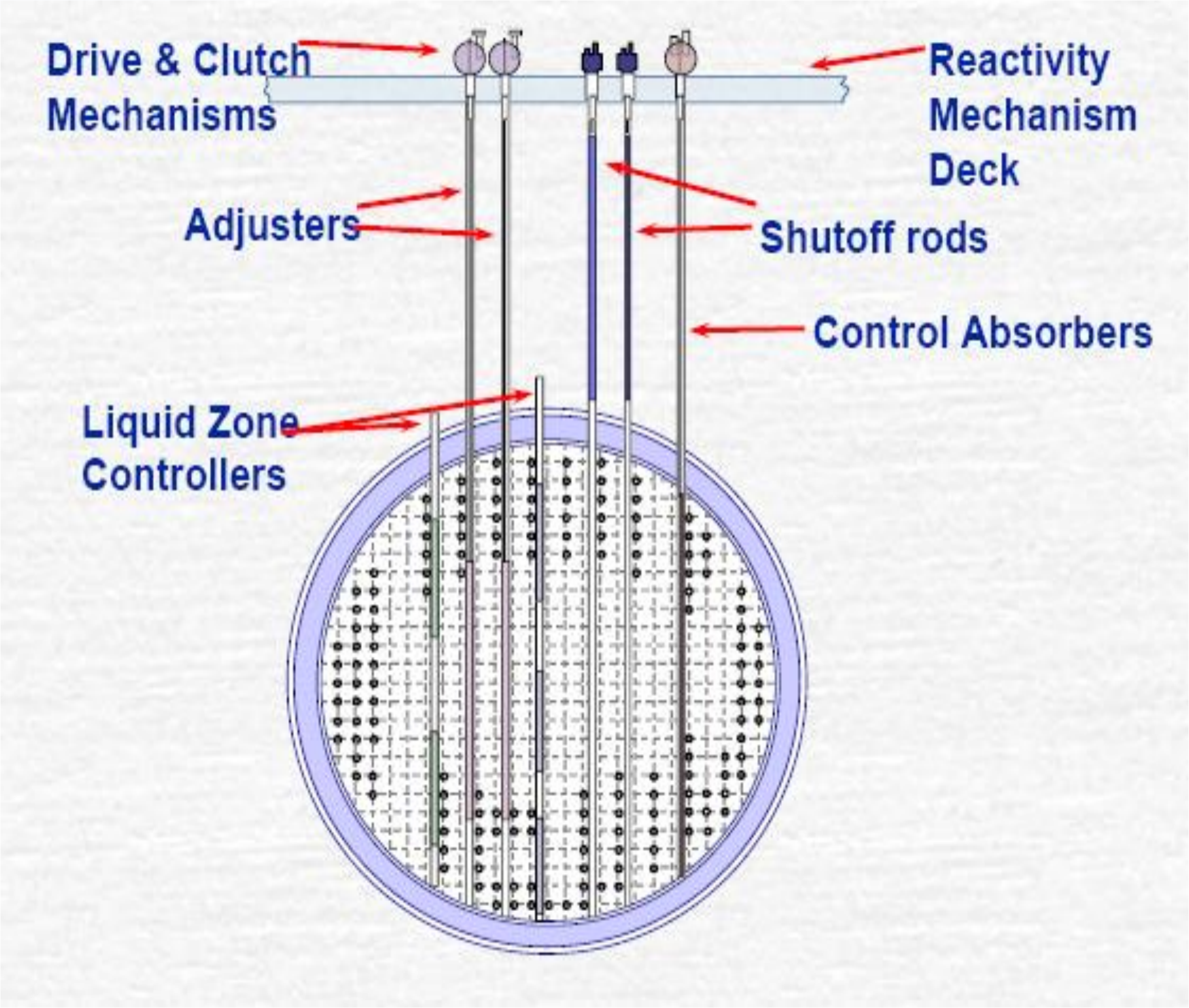
- Reactor Trip
- Heat Transport Pump Trip
- Heat Transport High Pressure
- High Zone Powers
- High Log Rate
- Low Steam Generator Level

Mechanisms

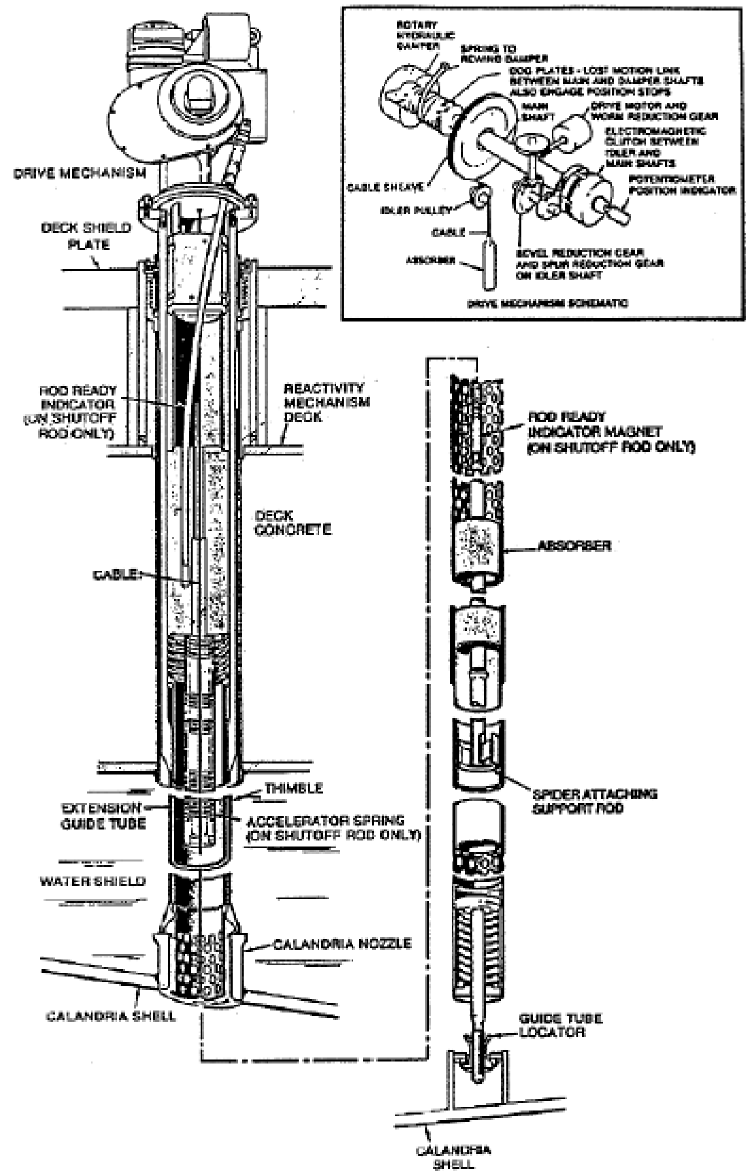
- Liquid Zone Controllers
  - fill of drain for bulk and spatial reactivity control
- Control Adjusters
  - insert and remove for control & flux shaping
  - remove for positive reactivity
- Mechanical Control Absorbers
  - drop into of core on Stepback
- SDS1 Shutoff Rods
  - drop into of core on SDS1 trip
- SDS2 Gadolinium Injection
  - inject into moderator on SDS2 trip

- All contain neutron absorbing materials which effect the rate of change of neutron population

Reactivity Mechanisms



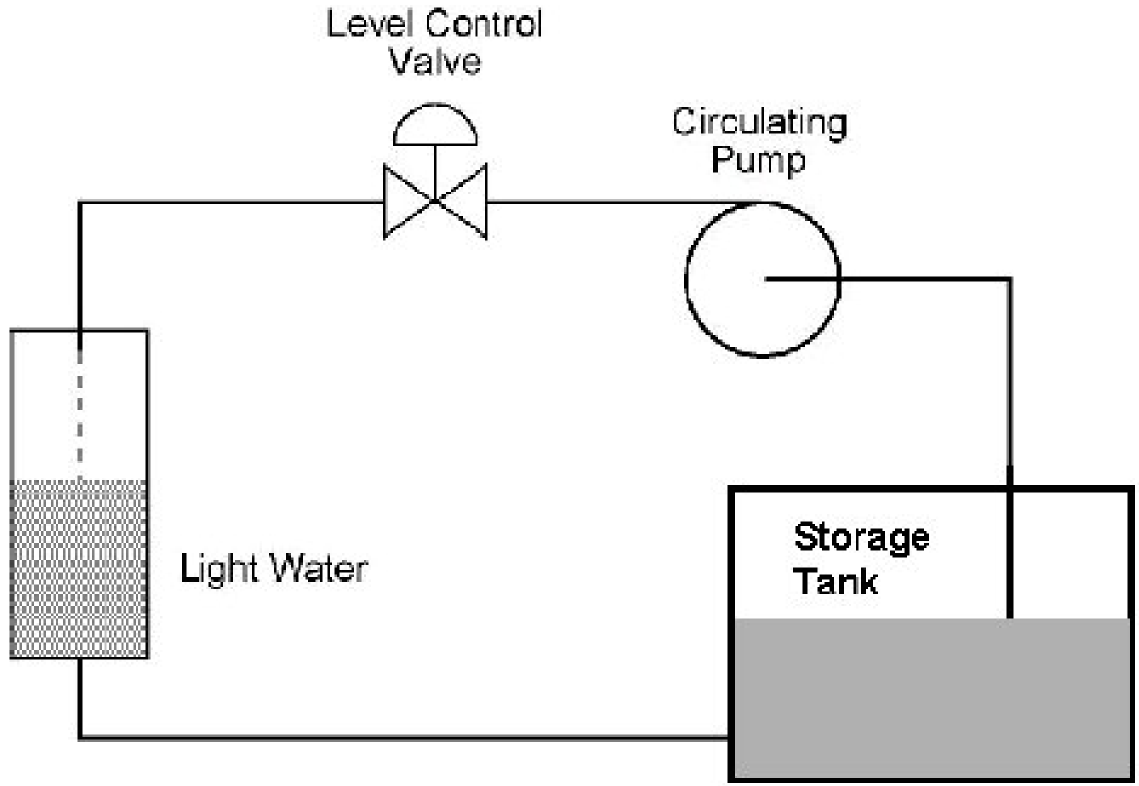
Typical Adjuster, Control Absorber and Shutoff Rod Details



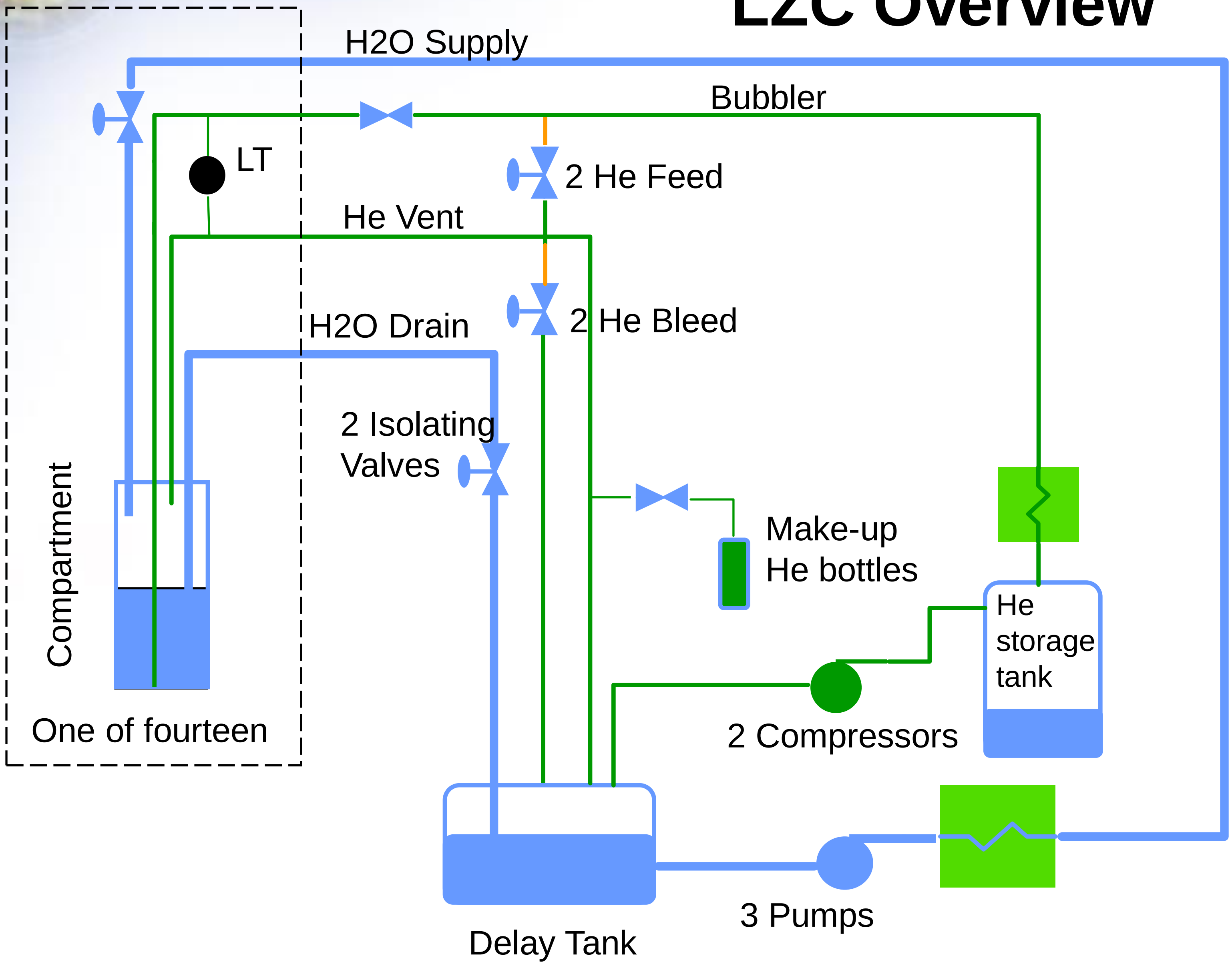
Liquid Zone Controllers (LZC)

- 14 LZC's are the primary reactivity control devices made up of tubes filled with "light water" as the neutron absorber
- Light water is forced into the 14 LZC compartments by pumps through "individual valves" at "variable rate" and drained from the compartments at a "constant rate" to control power on a continuous basis.
- Normally are partly filled
- Fill/drain in unison for bulk reactor power control
- Fill/drain differentially for spatial flux control
- Reactivity worth ~7 mk
- Max. reactivity rate ~0.14 mk/s
- Fill/drain rate is ~ 60 second

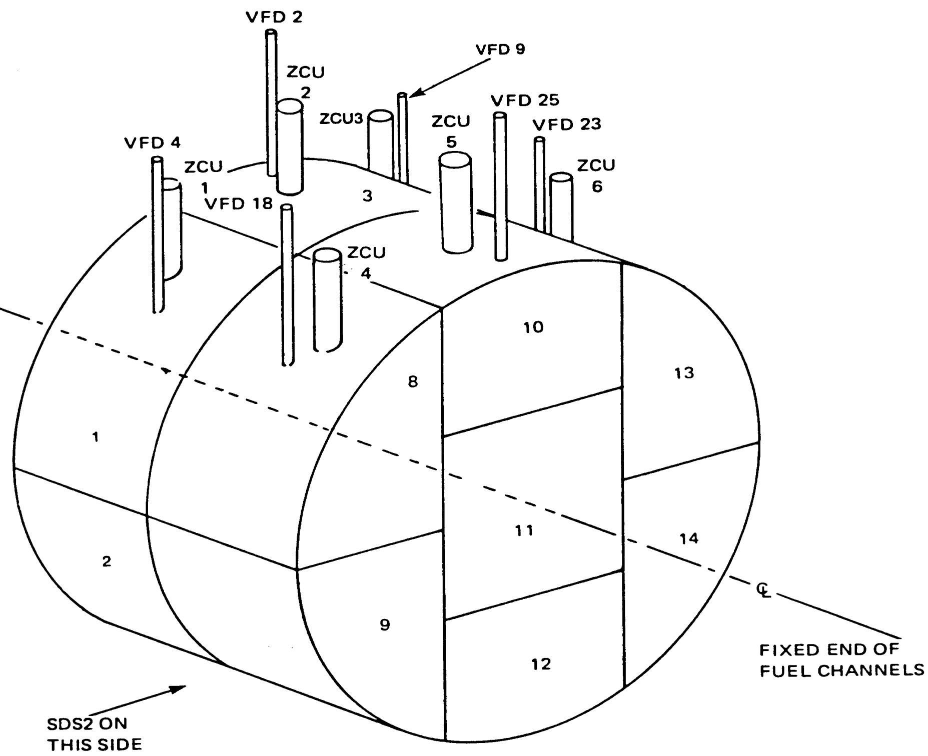
LZC Simplified



LZC Overview



Liquid Zone Controller Arrangement



Adjusters

- 21 Adjuster rods normally fully inserted ~ 17 mk worth when withdrawn:
  - to compensate for the xenon transient in a power reduction
  - to allow the reactor can be re-started after shutdown from full power (up to ~ 20 minutes)
  - to compensate for fuelling machine unavailability
  - can be used for flux flattening
- Adjusters are made of either cobalt or stainless steel.
- RRS/Manual Drive requests generate commands to the electric motor starters to Stop/Drive-In/Drive-out the rods at variable speed
- During operation limited number of Adjuster can be withdrawn at a time.
- The maximum total reactivity which may gained on withdrawal of adjuster rods is $\approx$17 mk
- The maximum reactivity change rate of any bank of adjuster is $\pm$0.07 mk/s

Mechanical Control Absorbers (MCA)

- 4 units, driven in/out in banks (or singly manually)
- Cadmium is the neutron absorber
- MCAs are identical to shut-off rods, except for a flow restricting orifice at the bottom to slow their fall, allowing them to be caught during a stepback
- The rods are long, for maximum reactivity worth
- Normally all fully withdrawn - they are inserted to help the zones add negative reactivity
- Reactivity worth ~11 mk
- Average reactivity rate ~0.09 mk/s
- Drive time at full speed 140s
- Drop time 3s
- Rods can be caught while dropping

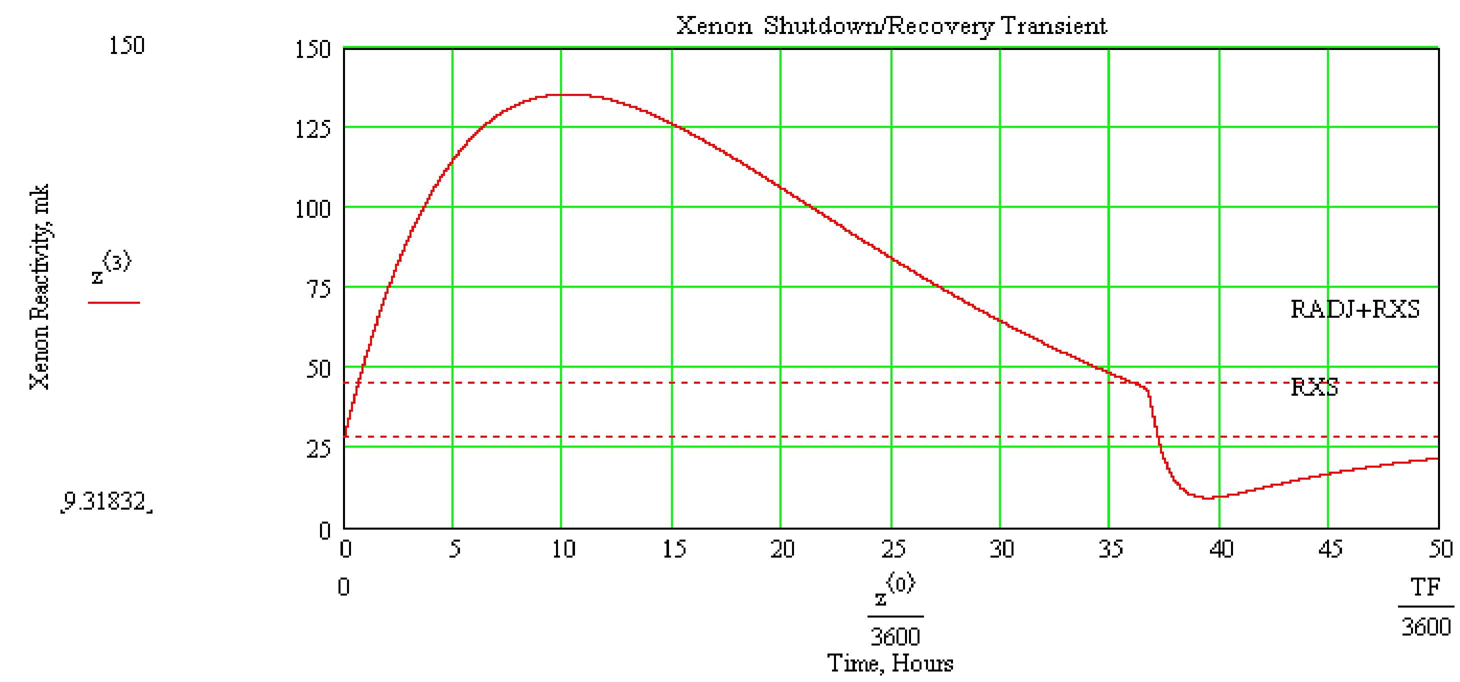
Shut-Off Rods

- 28 devices, arranged in 2 banks
- RRS controls shut-off rod out-drive only (1 bank at a time), withdrawal is interrupted if:
  - Control is switched to manual
  - The flux power error is excessive
  - The reactor is tripped
  - The log rate exceeds 7%/s
- Reactivity worth ~80 mk
- Avg reactivity rate on withdrawal ~0.6 mk/s
- Spring assisted gravity drop, fully inserted in 1 second

Moderator Liquid Poison System

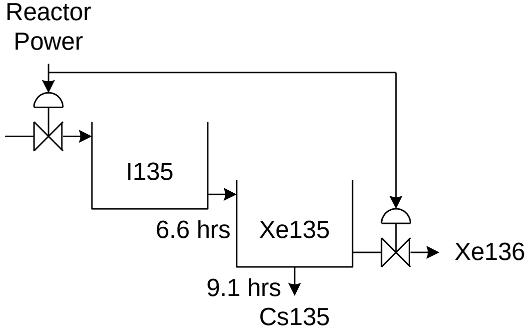
- Boron or gadolinium poison are strong neutron absorbing solutions added to the moderator to suppress excess reactivity under unusual conditions
- Both are normally added (and removed) manually
- Only gadolinium can be added by RRS, via simple valve opening
- Poison addition is a "last resort", when other devices are exhausted
- Gadolinium addition rate is 0.75 mk/minute, adequate for worst case (Xe burn-out)
- This system is separate from,but is often confused with, the Liquid Injection System (LISS) which is activated by SDS2 to injection gadolinium into the moderator

The Consequence for Not Overriding Xenon for a Recoverable Trip



Xenon Poison-out

- **During normal reactor operation, a balance of Xenon 135 production (a neutron absorber), Xe135 production and decay exists**
- **When reactor power falls rapidly, decay products continue to produce Xe135 but neutron flux is not high enough burn-off Xe135. On a rapid power reduction, maintaining reactor power > 60%FP maintains neutron flux high enough to prevent the reactor from poisoning out.**
- **In “poison prevent” mode, the turbine is bypassed by opening the CSDVs and reactor power is maintained above 60% FP**



Summary of The Reactivity Control Devices

Reactivity control devices are provided to alter the rate of neutron multiplication (either as control or shutdown devices).

Control is provided for the following effects:

a) Long-term bulk reactivity is mainly controlled by on-line refuelling.

b) Small, frequent reactivity changes for both global and spatial control by the LZC system

c) Additional positive reactivity for Xenon override and fuelling machine unavailability, compensated by withdrawal of adjuster rods

d) Additional negative reactivity for fast power reduction and to override negative fuel temperature effect, is provided by insertion of MCAs

e) The excess reactivity due to fresh fuel and decay of Xenon following a long shutdown, are compensated by adding poison to moderator

f) Rapid reactor shutdown by dropping MCAs/SORs into the core and/or by fast injection of large amount of liquid poison into the moderator.

Reactivity Controls and Disturbances

Reactivity Controls

	Refuelling
	Poison Removal (manual)
+ve Help	Adjusters
Normal	Zone Controllers
-ve Help	Mechanical Control Absorbers
	Poison Addition (auto + manual)

Reactivity Disturbances

Fuel Burn-up	Refuelling
Xenon	Feedback Effects (Temp., Density)
Poison Addition/Removal	Motion of any Reactivity Device

CANDU Safety Systems

Requirement	Special Safety System(s)
Cool the fuel	ECC
Control (limit the fuel power)	SDS1, SDS2
Contain any releases	Containment

Design Basis Accidents

- Loss of coolant (LOCA)
  (heat transport system pipe break)
- Loss of regulation (LOR)
  (uncontrolled power increase)
- Loss of heat sink
  (loss of boiler feedwater supply)
- Loss of primary coolant flow
  (loss of electrical power, pump failure, channel blockage)

- For each design basis accident, and its many variations, we must meet the safety requirements. In addition to specific safety system <u>actions</u>, there is a requirement for reliable post-accident <u>monitoring</u> (PAM).

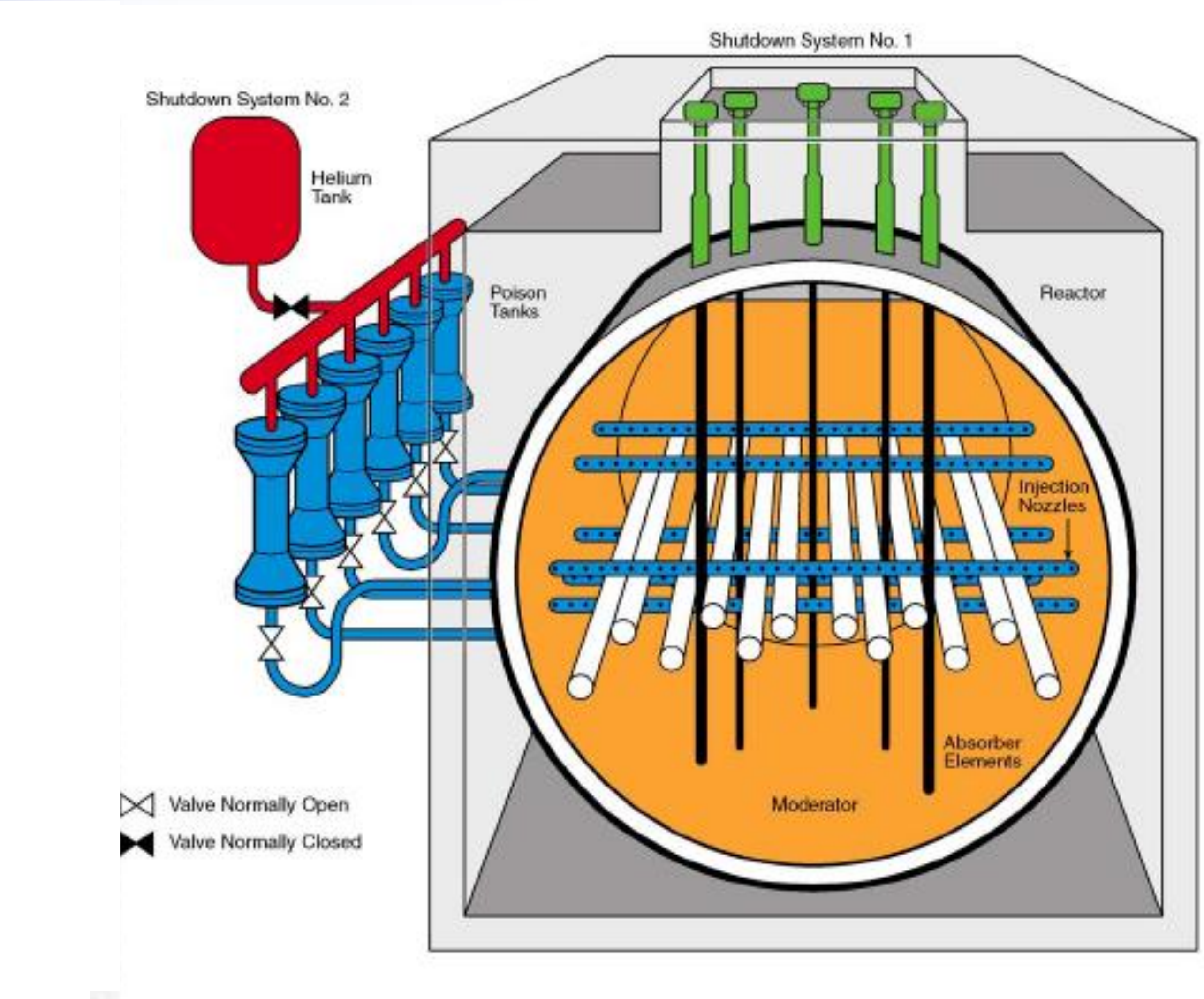
Safety System Requirements/Characteristics

- Reliability
- Testability
- Independence/Separation from Process Systems
- Qualification
- Redundancy
- Robustness
- Simplicity

Grouping and Separation

- Systems are divided into two groups, which must be maximally separated to prevent simultaneous failure for any common cause, including large fires.
- All important safety functions (reactor shutdown, fuel cooling, release barriers, status monitoring/control by operator) must be represented in each group.
- Group 1 contains all process systems and some of the safety systems, Group 2 contains most of the safety systems.

Shutdown Systems 1 and 2



Shutdown System 1 (SDS1)

- **Based on mechanical shutoff rods (SOR), 28 in C-6, dropped under gravity. The system components are oriented vertically in the reactor, accessed from the reactivity mechanism deck on top of the reactor.**
- **SDS1 can be re-poised fairly quickly. A trip does not necessarily result in a reactor poison-out.**

Typical SDS1 Trip Parameters

- Neutronic Trips
  - High Neutron Power
  - High Rate Log Neutron Power
- Process Trips
  - Heat Transport High Pressure
  - Heat Transport Low Flow
  - Reactor Building High Pressure
  - Pressurizer Low Level
  - Steam Generator Low Level
  - Moderator High Temperature
  - Heat Transport Low Pressure
  - Steam Generator Feedline Low Pressure
- Manual / PDC Watchdog
- Start-up Count Rate

SDS Considerations

- Trip Conditioning
  - Automatic conditioning on power for startup, shutdown and maintenance
    - Heat Transport low flow
    - Heat Transport low pressure
    - Pressurizer low level
    - Steam Generator feedline low pressure
    - Steam Generator low level
- Trip Setpoints as a function of reactor power
  - Heat Transport low pressure
  - Pressurizer low level
  - Steam Generator low level

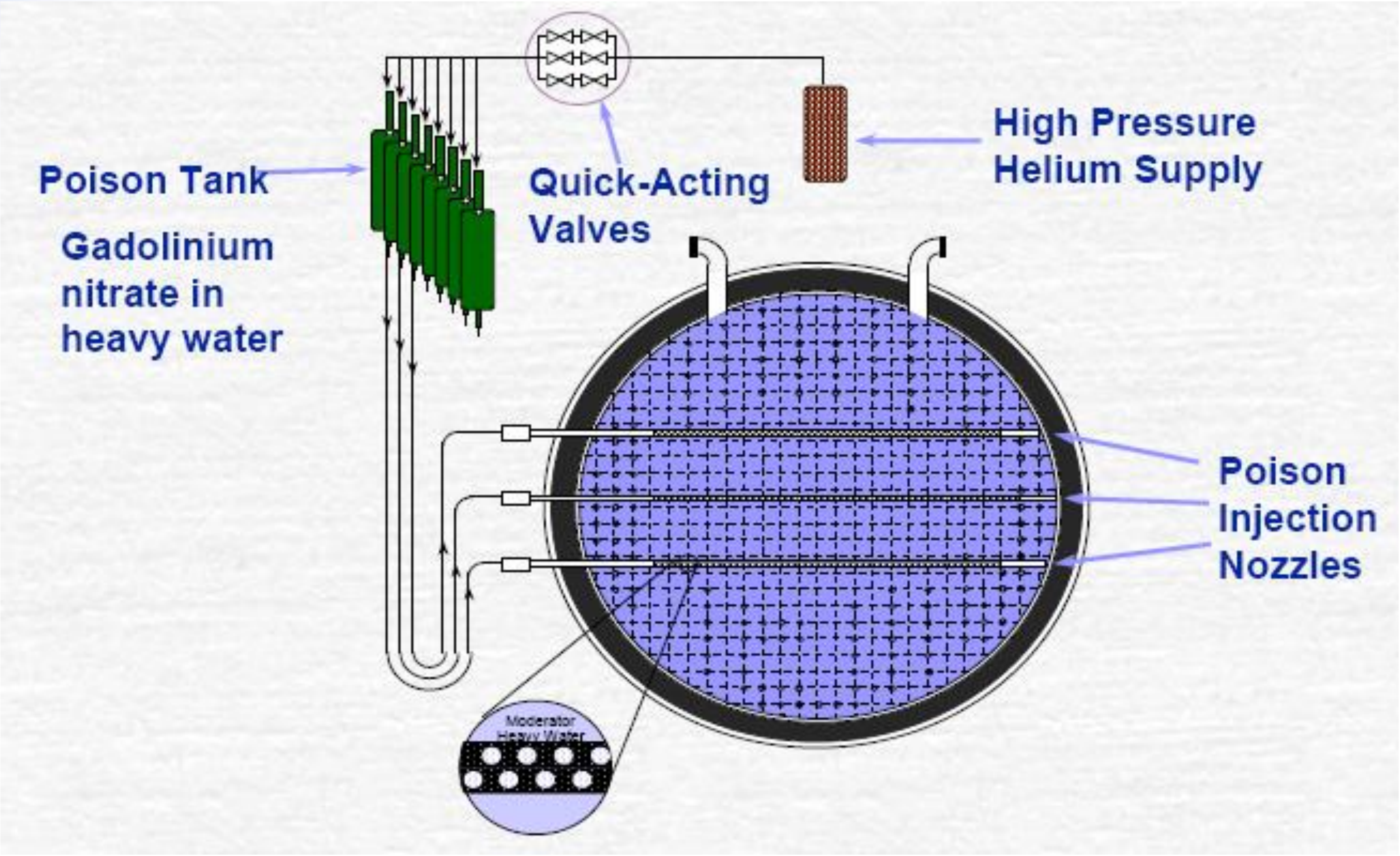
Shutdown System 2 (SDS2)

- Based on injection of a liquid poison solution into the moderator. The system components are oriented horizontally in the reactor, accessed from the side of the reactor.
- SDS2 takes a long time to re-poise. A trip will always result in a reactor poison-out. It is therefore particularly important to avoid spurious initiation of SDS2. The systems should be designed so that SDS1 acts before SDS2.

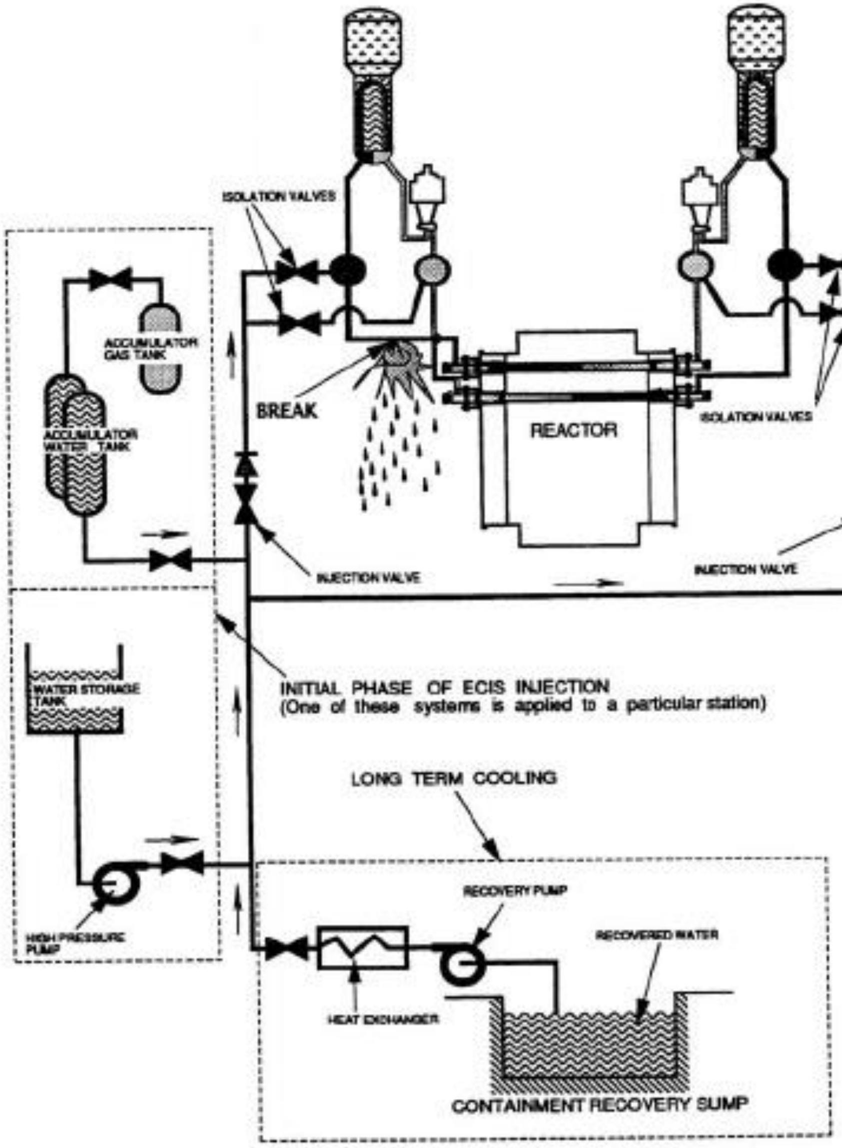
Typical SDS2 Trip Parameters

- Neutronic Trips
  - High Neutron Power
  - High Rate Log Neutron Power
- Process Trips
  - Heat Transport High Pressure
  - Heat Transport Low Pressure
  - Low Core Differential Pressure
  - Pressurizer Low Level
  - Steam Generator Low Level
  - Steam Generator Feedline Low Pressure
  - Reactor Building High Pressure
  - Moderator High Temperature
- Manual / PDC Watchdog

SDS2 & LISS Components



Emergency Core Cooling Overview



Emergency Core Cooling (ECC) and Containment

- The ECC and containment systems are physically complex, but have relatively simple instrumentation and actuation requirements. Because of the economic penalty of downgrading the heavy water coolant, ECC injection is subject to a number of conditions to avoid accidental actuation.
- Like the shutdown systems, these systems use triplicated measurements, voting, on-line testing, etc. A separate panel in the control room is dedicated to each of these systems.

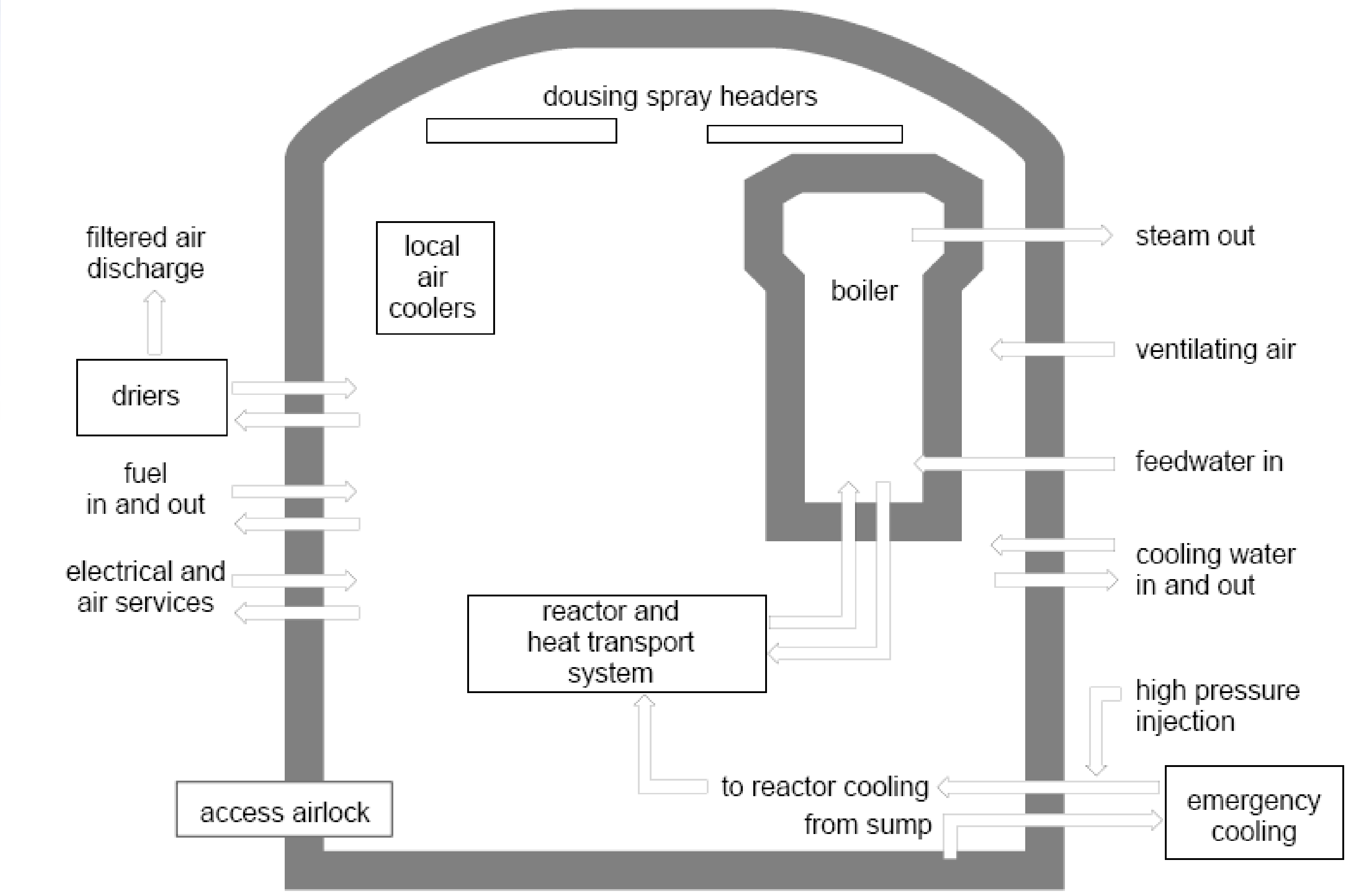
ECC and Containment (cont'd)

- The major challenge in these systems, which rely much more on operator action than do the shutdown systems, is to present the necessary information to the operator in a clear and unambiguous fashion. On the ECC system, the testing provisions are also very complex.
- So far, these systems have not been computerized to any extent, but in future, it is planned to computerize the display and testing provisions, greatly simplifying the task of the operators.

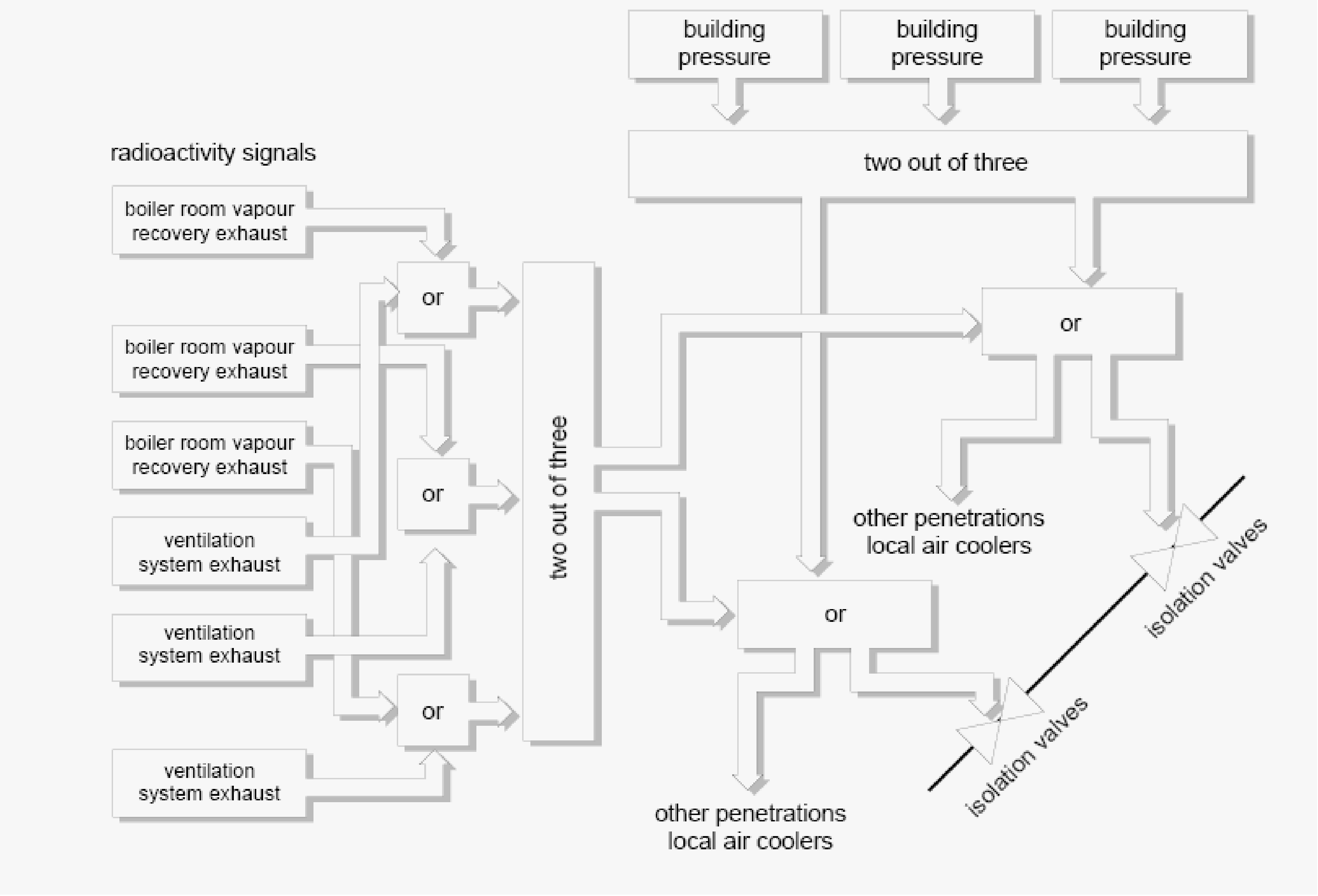
HTS Depressurization by ECC

- MSSVs normally provide overpressure protection for the steam generators
  - Spring operated relief valves
  - 4 on each SG opening on staggered setpoints
- Pneumatic lifters on MSSVs allow them to opened by ECC to depressurize and cooldown the primary side of the SG (HTS coolant)

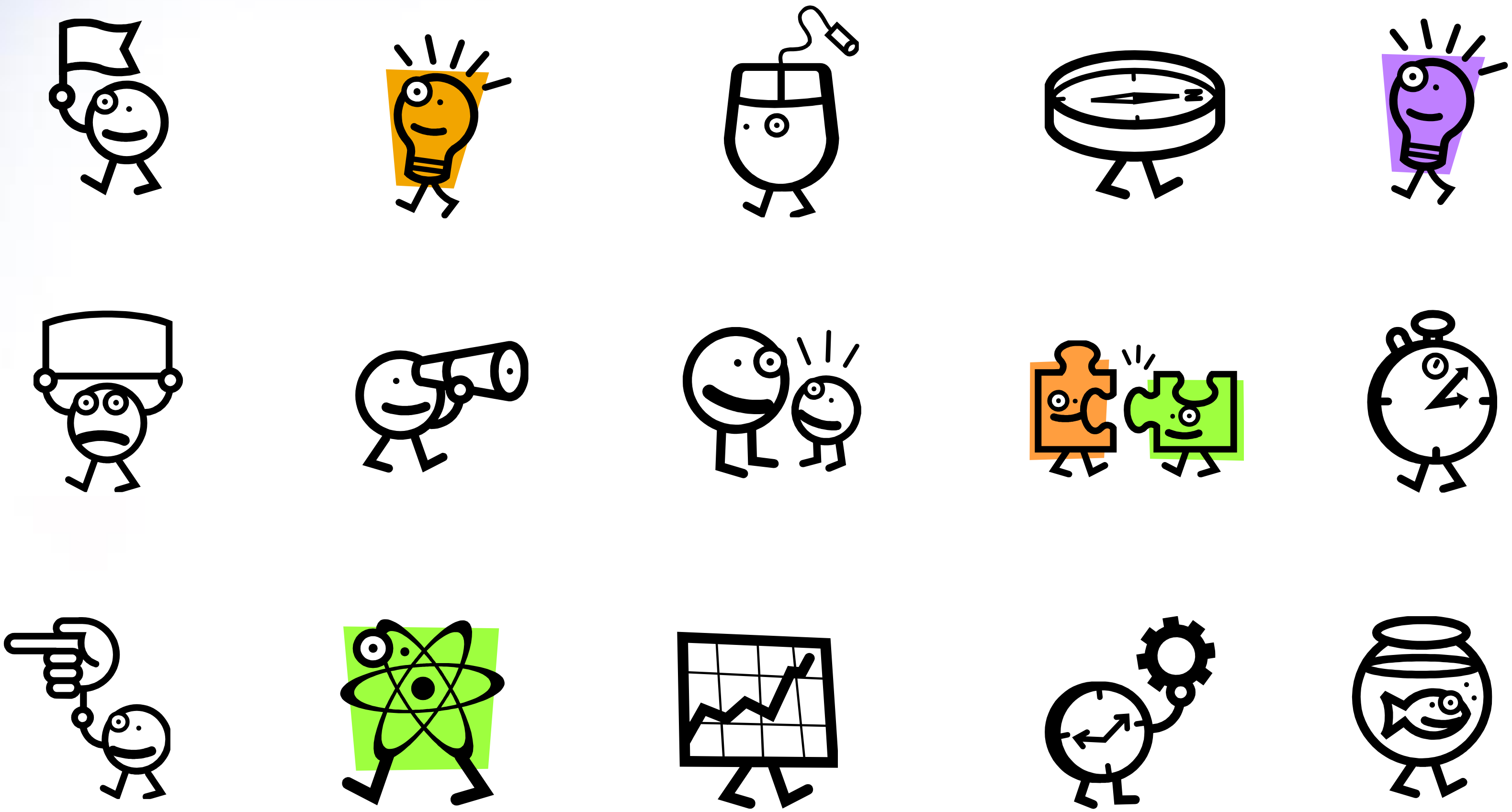
Containment Overview



Containment Isolation Initiation



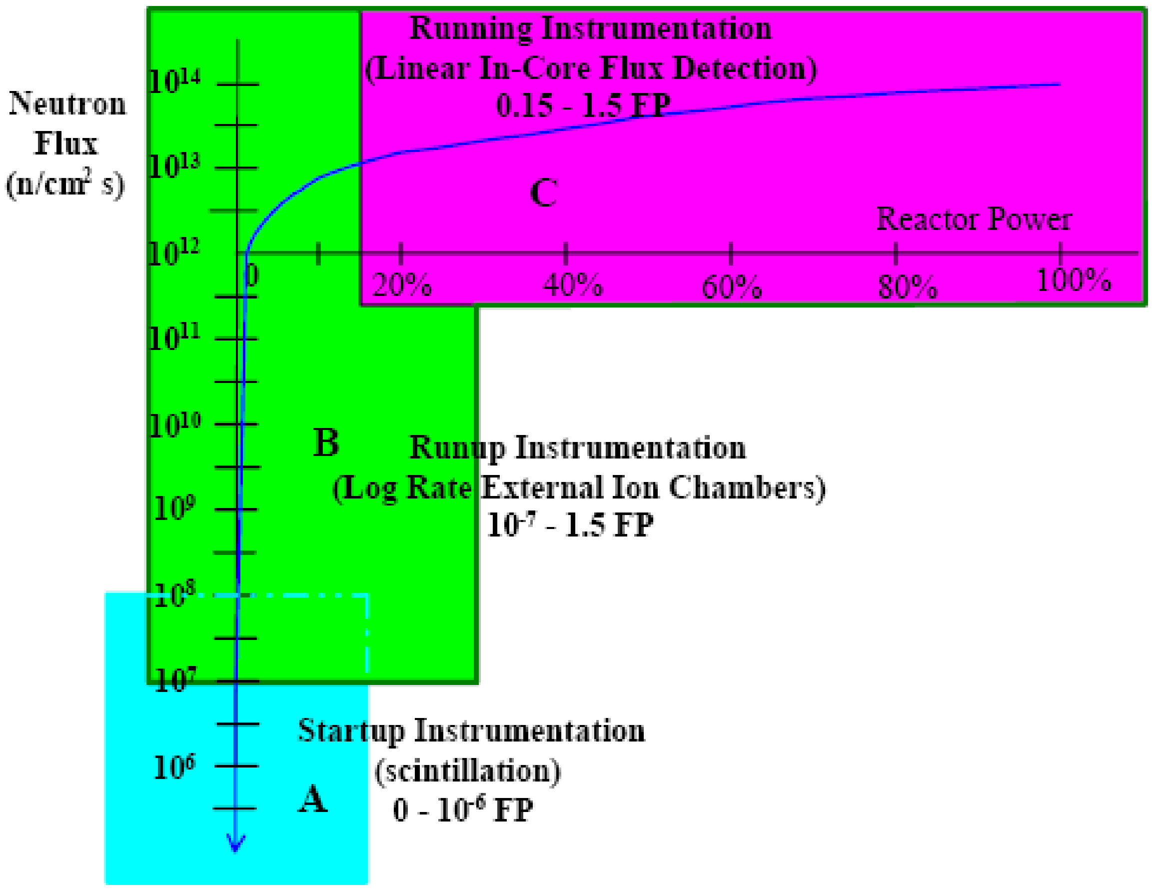
Short Break



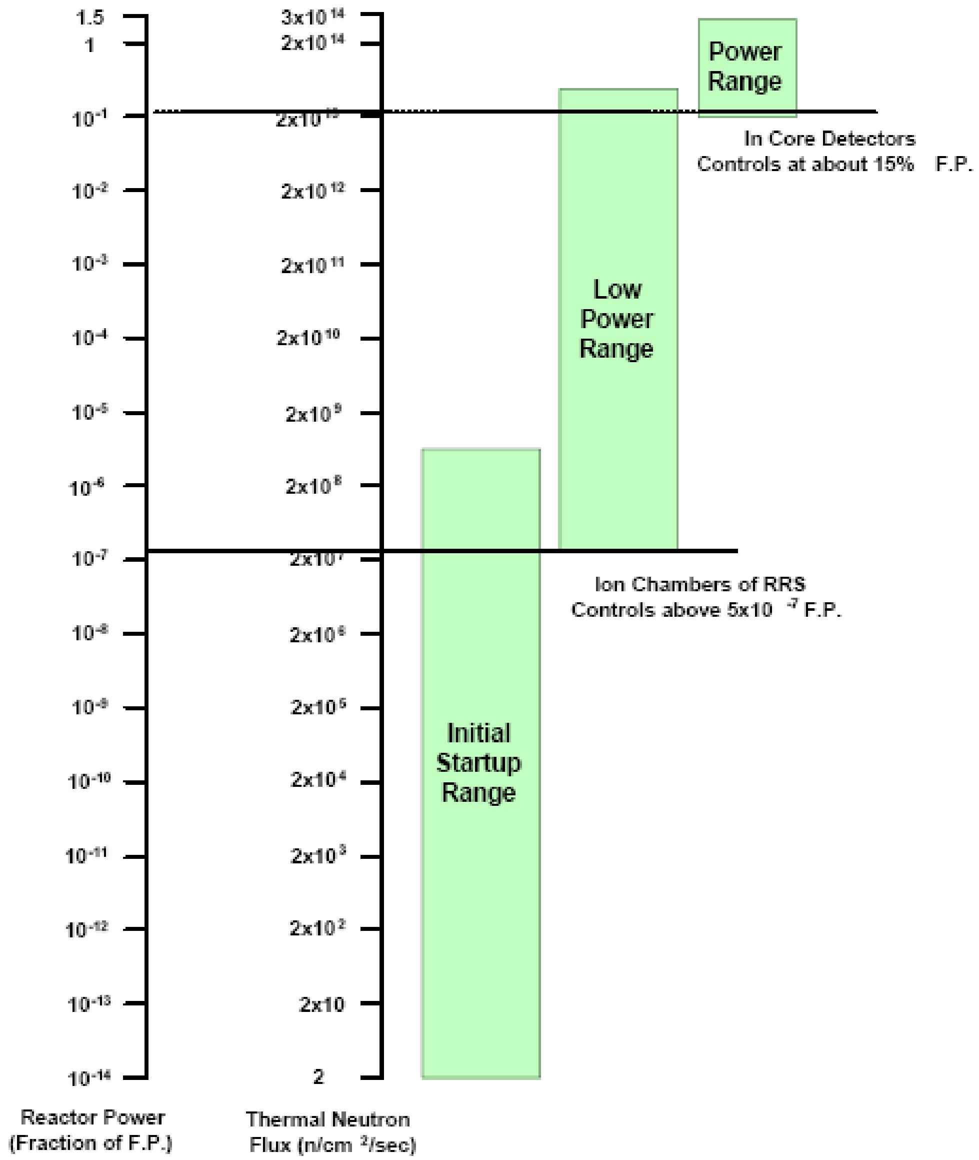
Nuclear Instrumentation

- Startup Instrumentation
- Ion Chambers
- Fission Chambers
- In-Core Flux Detectors
  - Inconel
  - Pt Clad Inconel
  - Vanadium

Overlapping Ranges of Flux Measurement



Neutron Detector Overlap



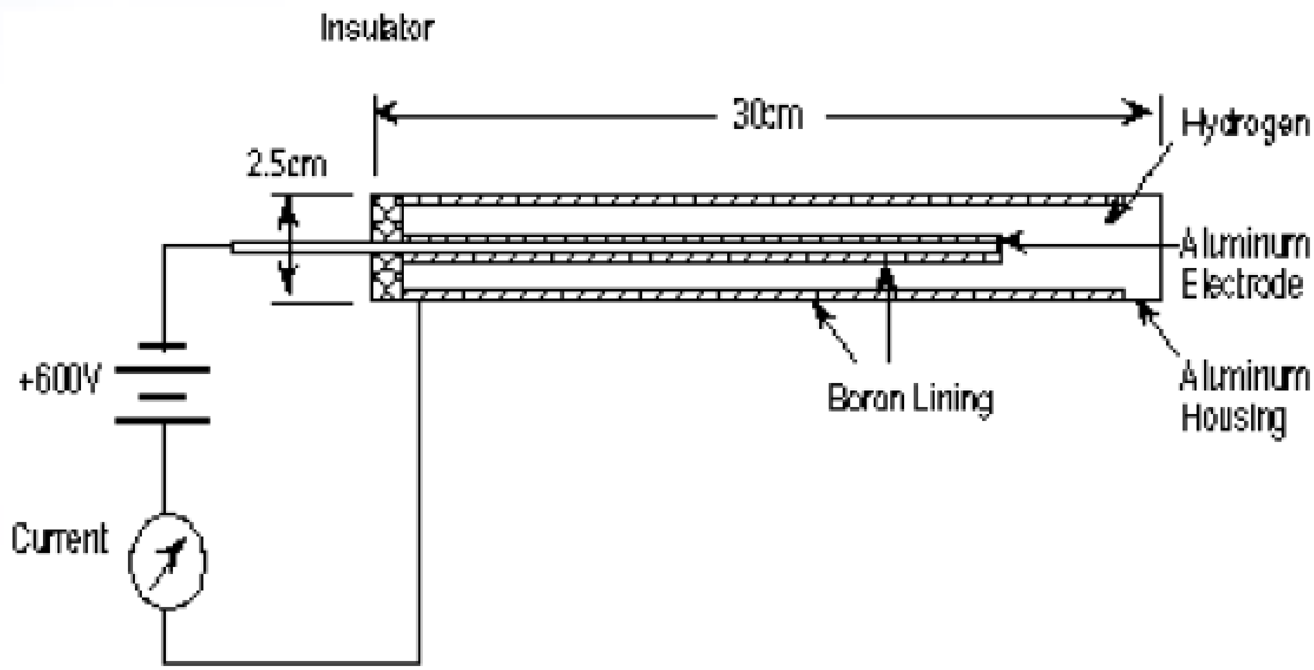
Startup Instrumentation

- Installed only temporarily for initial criticality and startups after long shutdowns, when ion chambers are off scale
- Thermal neutron detector, tube filled with boron fluoride enriched in boron-10
- Neutron capture releases alpha particle and lithium ion, causing ionization of gas
- A high applied voltage (~1800 VDC) multiplies the ionization
- Amplifiers detect individual neutrons, each resulting in a counted event
- Pulse height discriminator filters out smaller gamma induced pulses
- Can be located out-of-core or inside-of-core

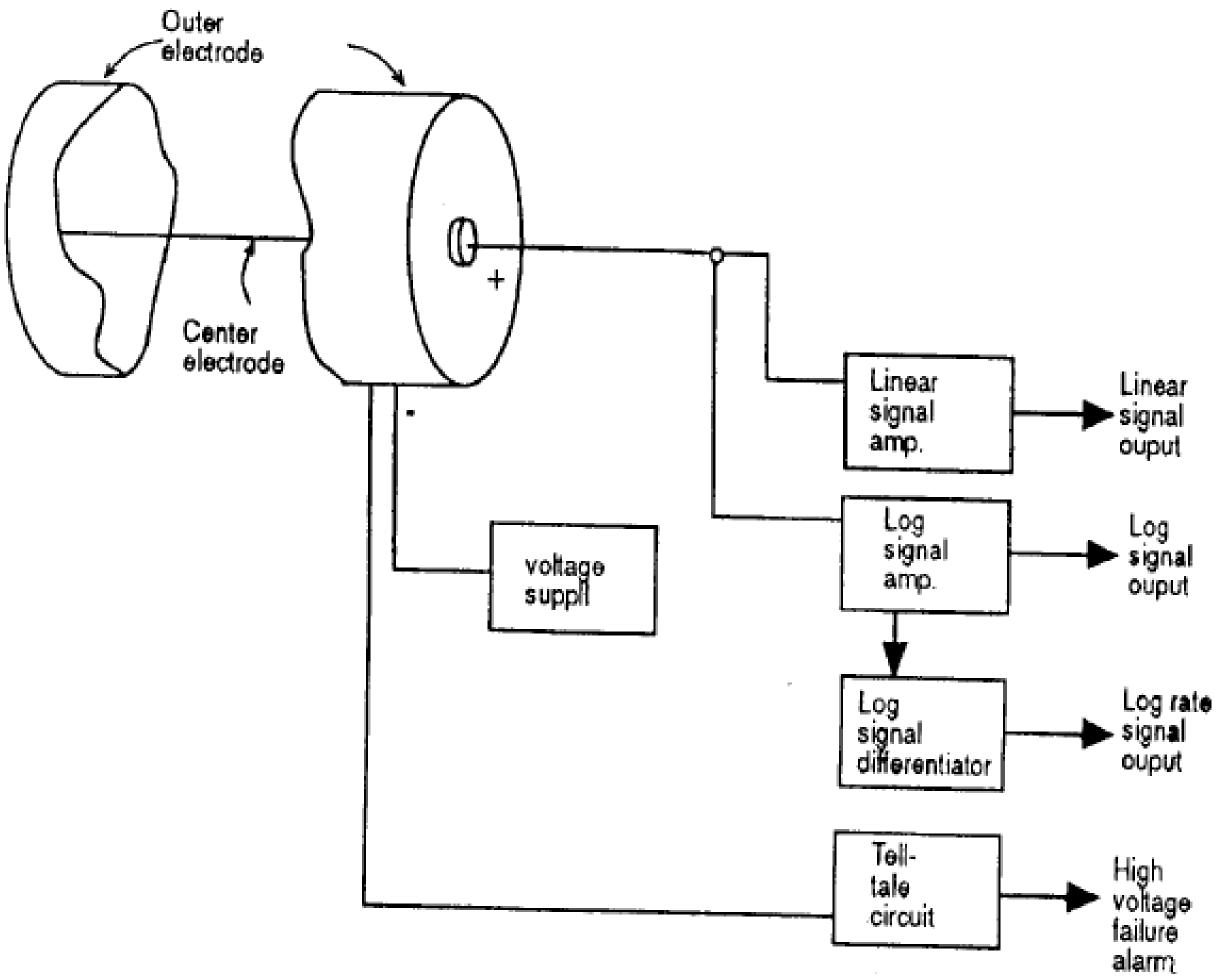
Ion Chambers

- Wide range monitoring of neutron flux
- Located outside of the core
- n, alpha reaction to thermal neutron capture by boron
- Alpha (and lithium ion) ionize hydrogen gas
- The applied DC high voltage collects electrons
- Resulting signal current is linearly proportional to thermal neutron flux and fully prompt
- Full power current signal ~100 micro-amps
- Ion chamber log N is the primary control signal below 5% FP (between 5 and 15 %, a proportional mix of ion chamber and flux detector signals is used, e.g. 50-50 at 10% FP)
- Wide signal range, 10E-7 to 1.5 times full power (very low residual effects)
- Air operated shutter mechanism for testing neutron log rate trip

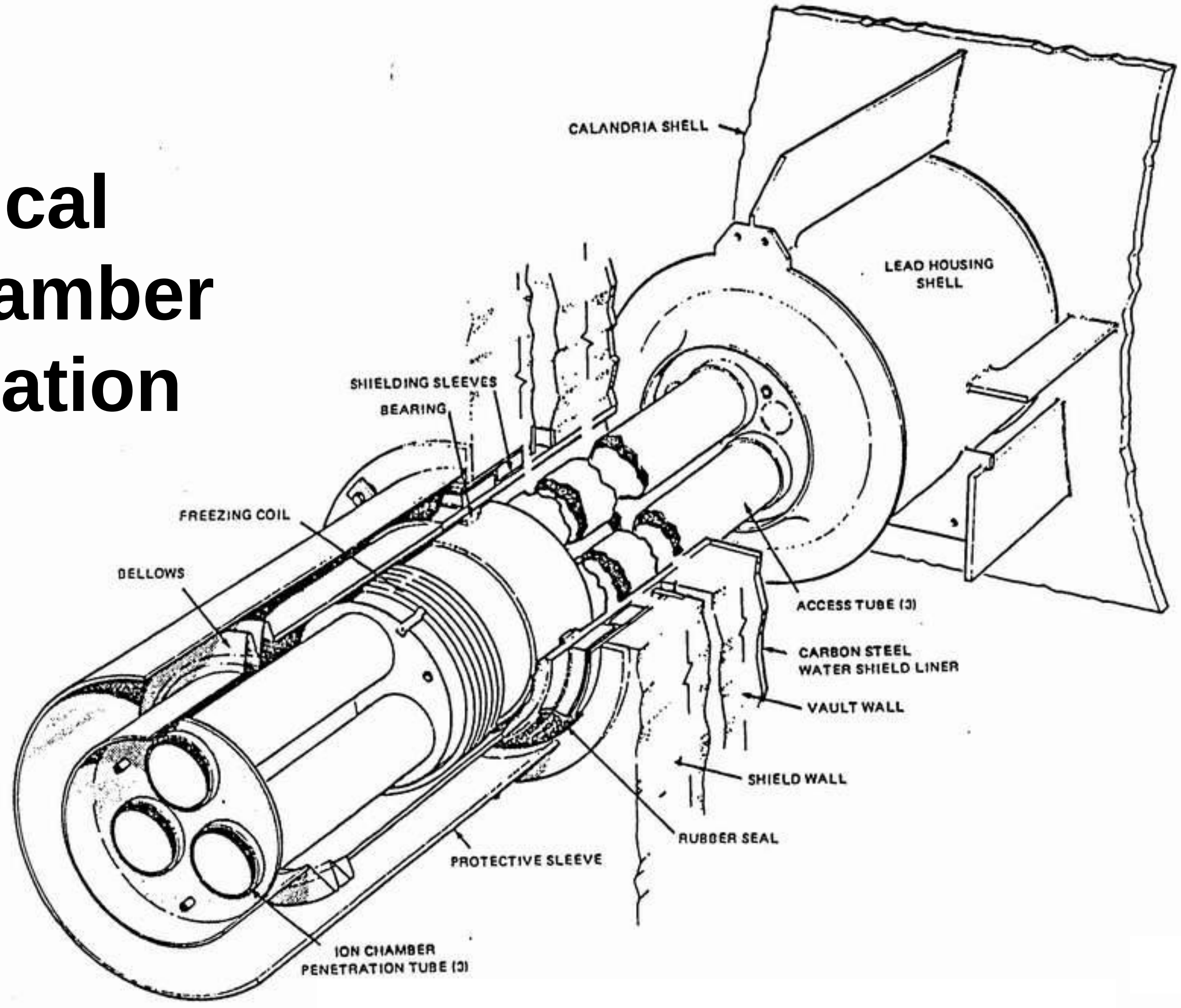
Ion Chamber Circuit



Ion Chamber Neutron Detector System



Typical Ion Chamber Installation



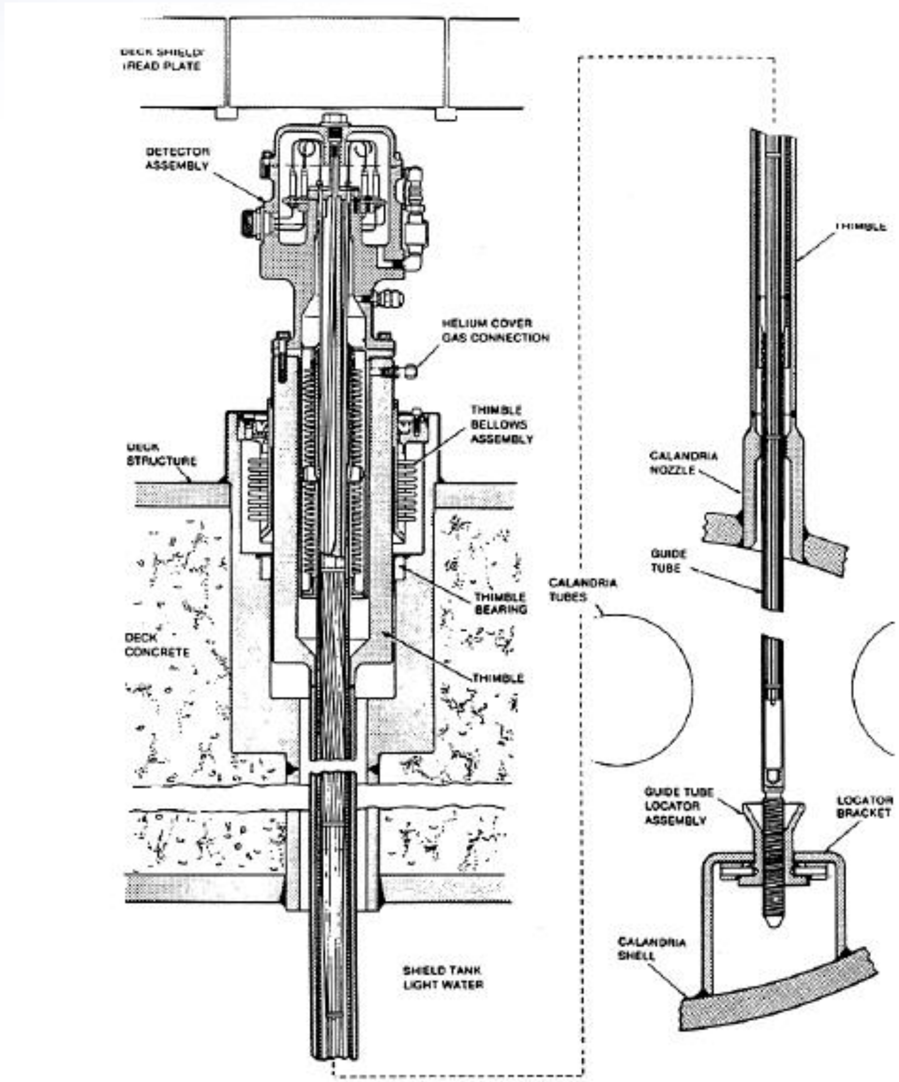
Fission Chambers

- Wider (lower) range of flux monitoring than Ion Chambers
- Eliminates the need for startup instrumentation in most cases
  - Startup instrumentation still req'd for long outages
- Used in Pickering A SDSE, MMIR and ACR
- Located out-of-core
- Subject to shading and tilts

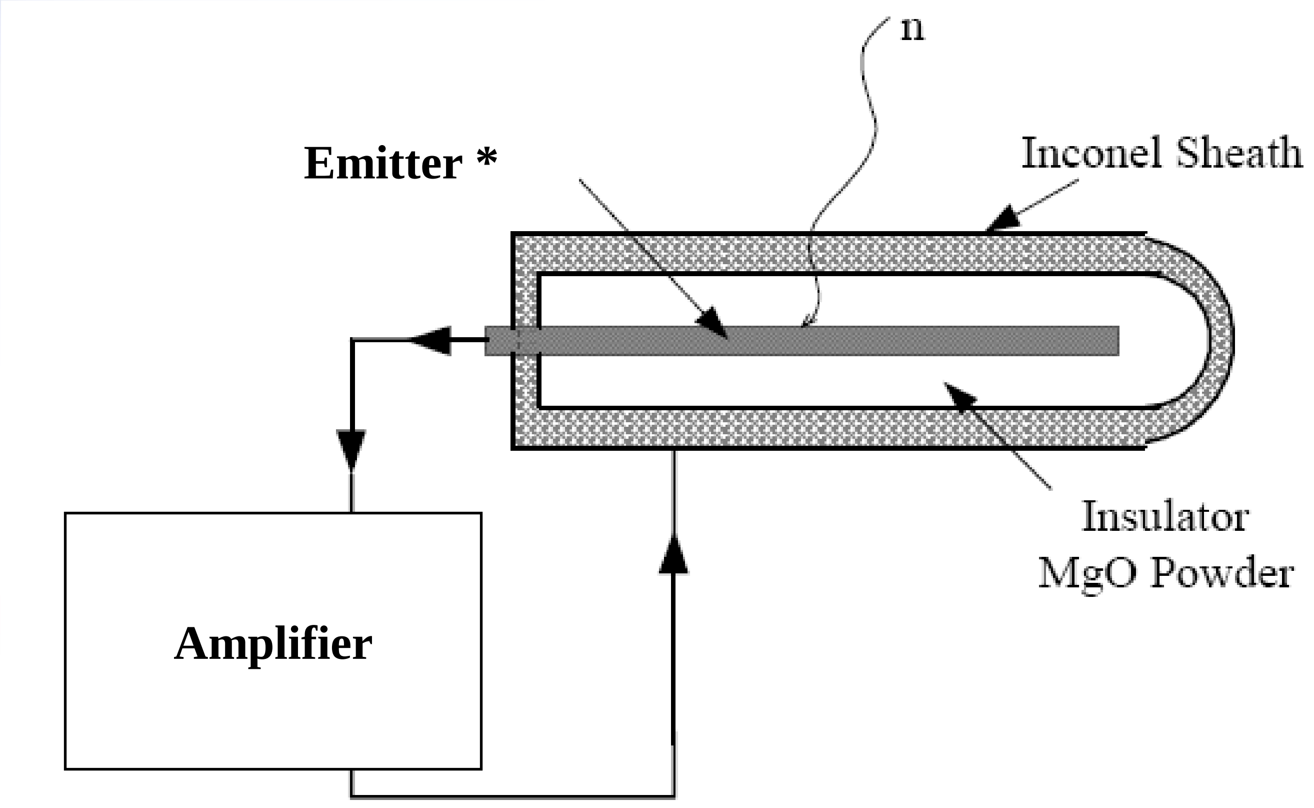
Self-powered In-Core Flux Detectors

- Very local measurement, subject to local distortions (e.g. zone controller level changes, refuelling)
- Self powered, no power supply needed
- Limited range ~5 to 150%FP (sundry side effects - not a “clean” signal)
- Distributed in various locations inside the core

Typical Flux Detector Details

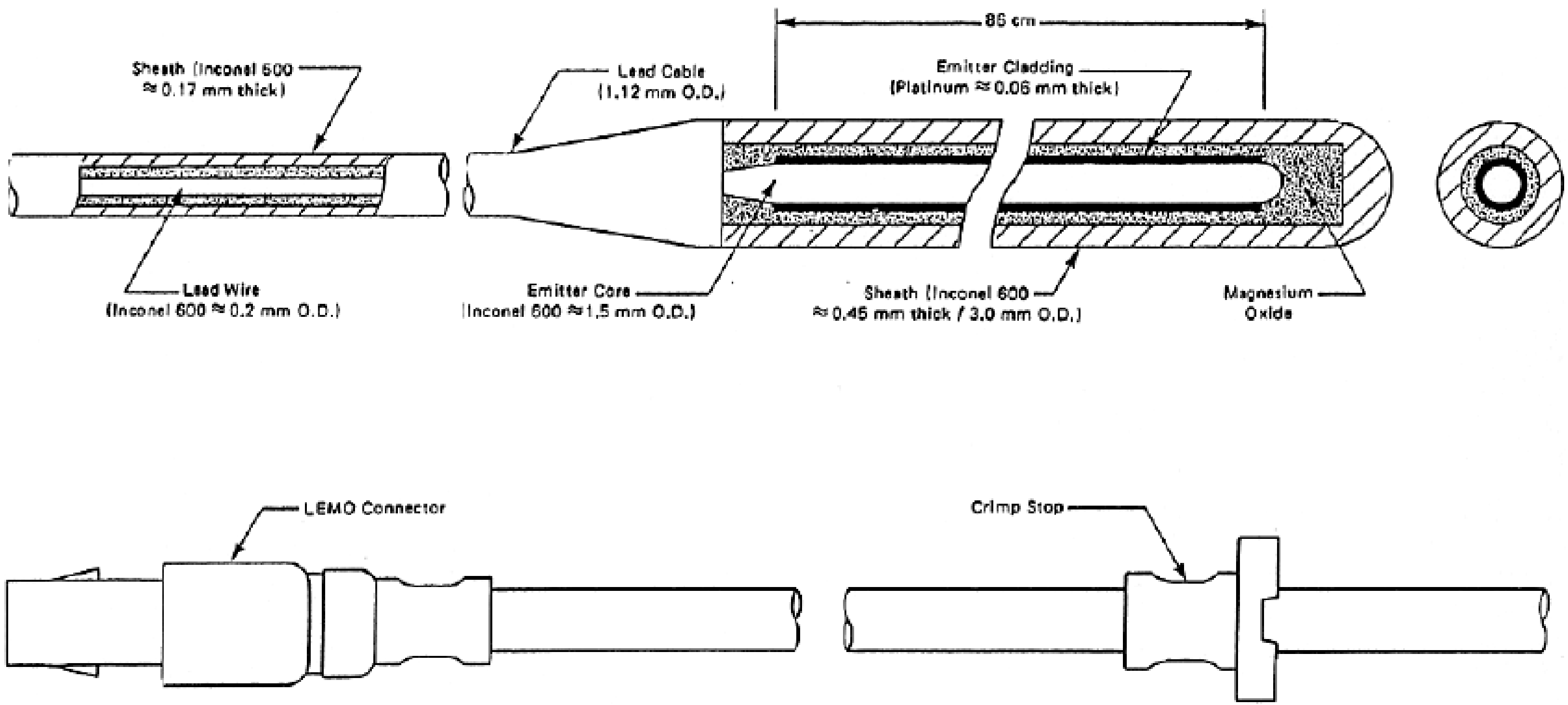


Self-powered In-Core Flux Detectors

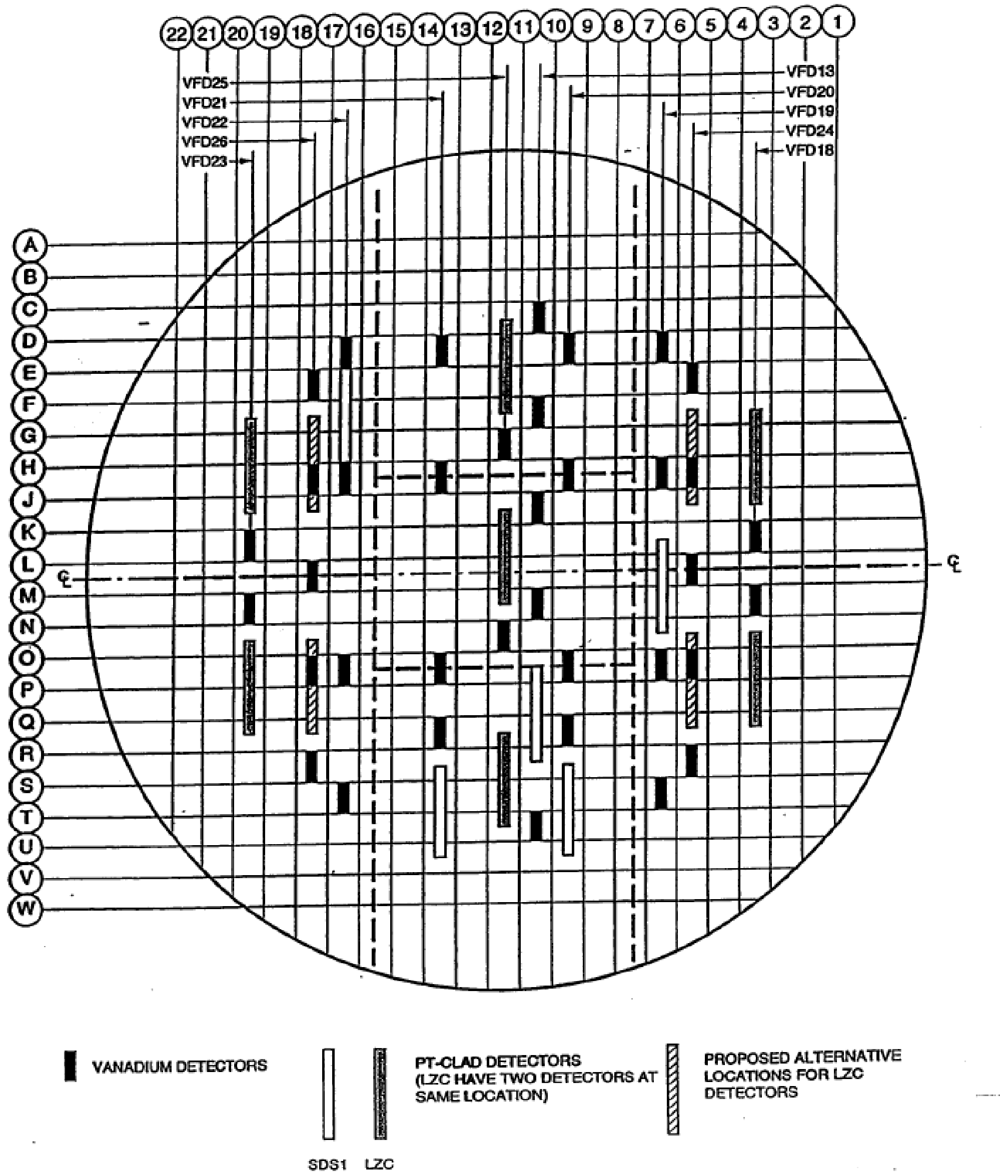


*** Emitter may be made from inconel, platinum clad inconel or vanadium**

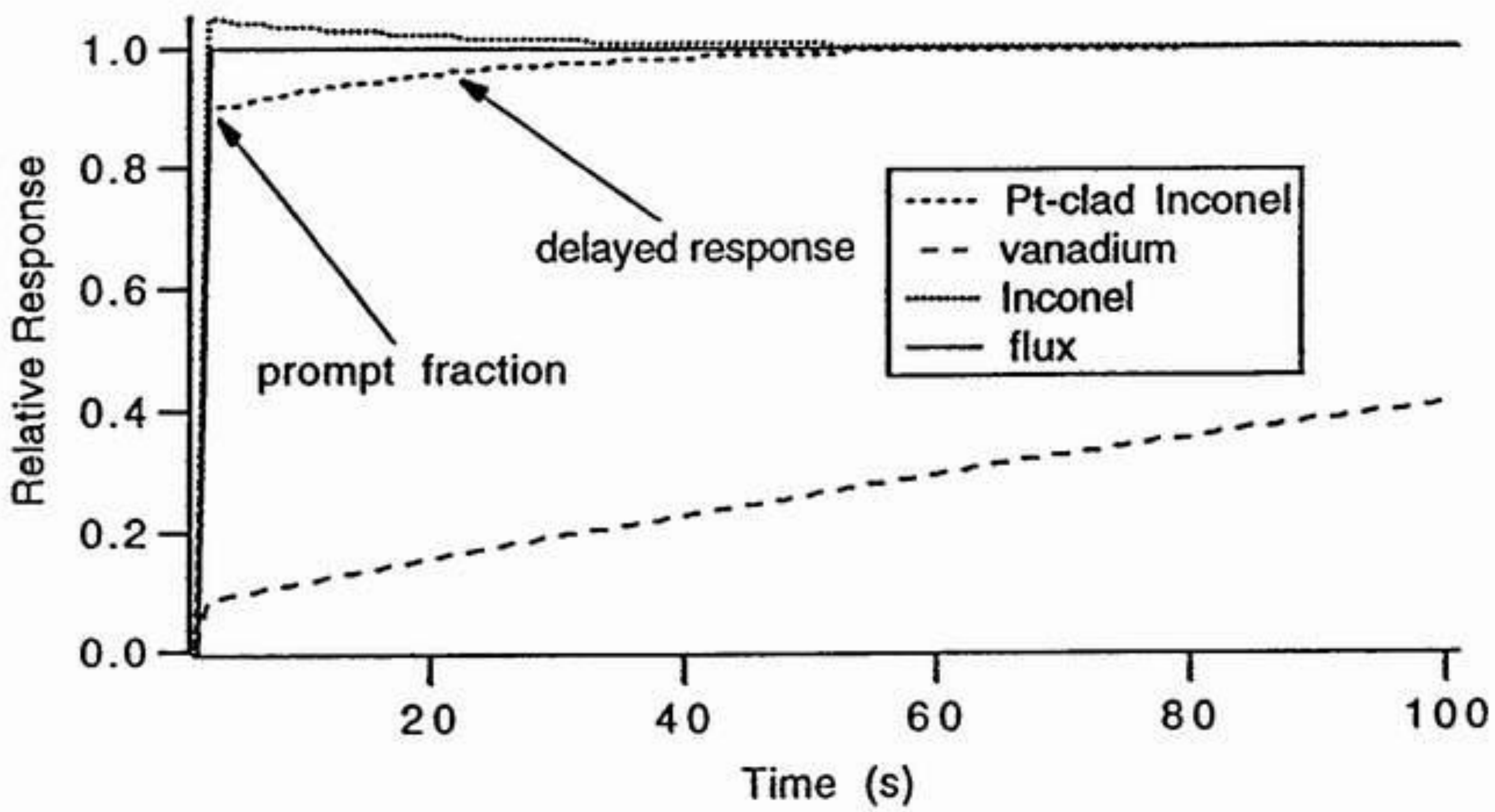
In-Core Flux Detector Details



In-Core Flux Detector Locations



Typical Dynamic Response of Various Types of In-Core Flux Detectors to a Step Change in Flux



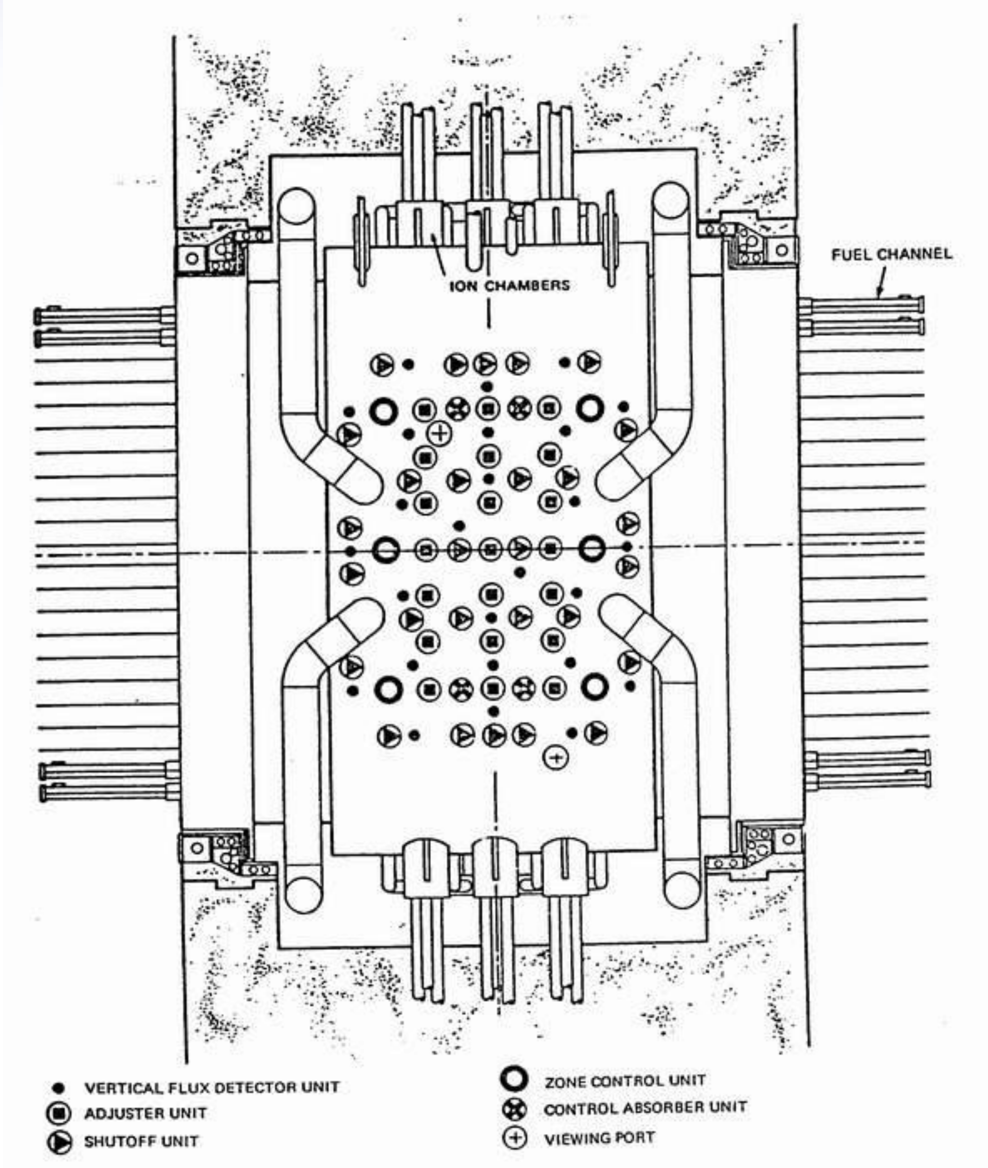
Reason for Using Log Scale for Flux and Rate:

- **The reactor is intrinsically logarithmic (exponential), because the fission process is a multiplying effect**
- **Log measurement is equally sensitive at all power levels, in terms of fraction of current power level**
- **Log rate (measured in % of present power per second) is equally applicable at all power levels**

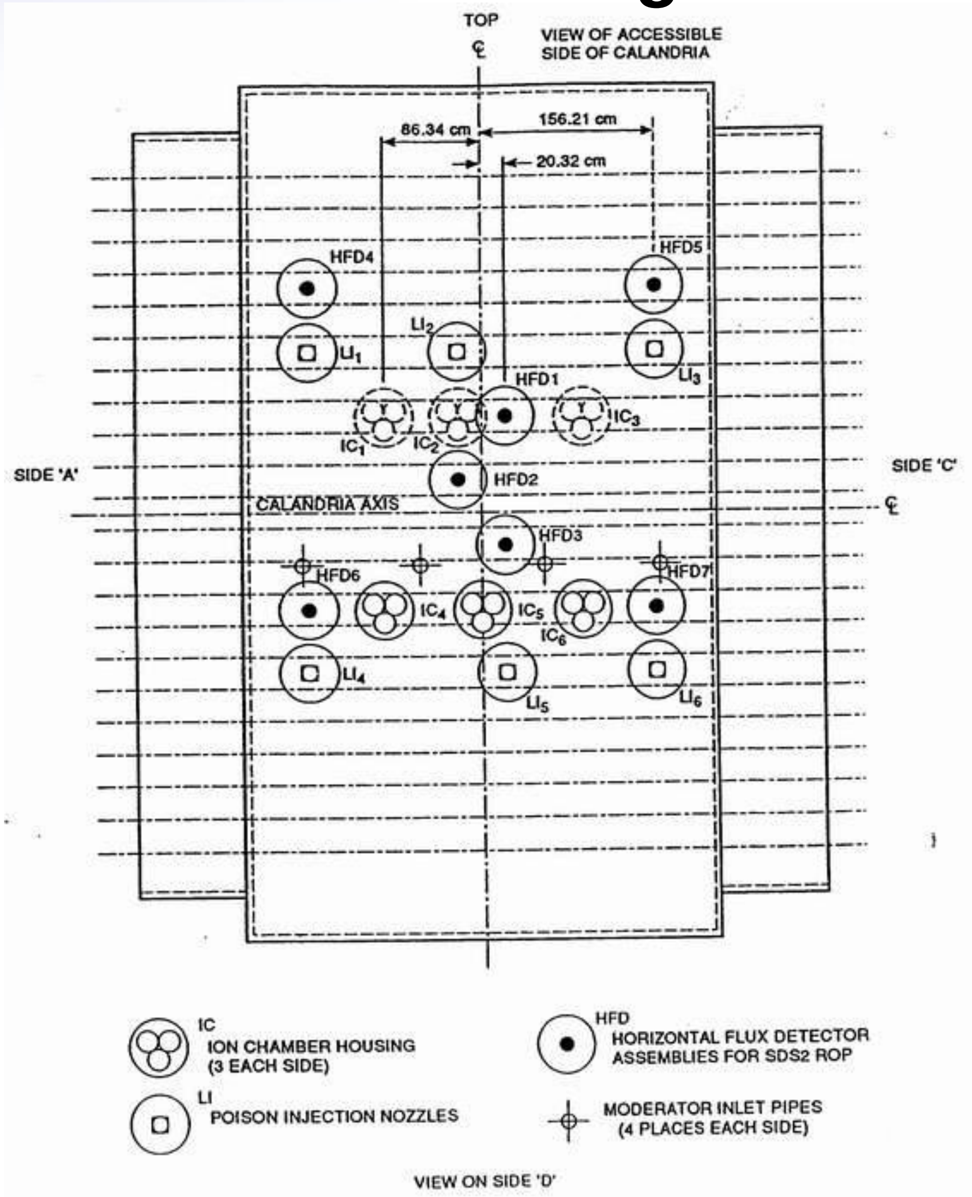
How the Reactor Power Is Calculated?

- The <u>median</u> of "3 ion chamber signals" is a measure of reactor power when below 5%.
- The <u>average</u> of "28 incore flux detectors" is a measure of reactor power above 15% power level.
- The <u>averages of zone pairs</u> of "28 incore flux detectors" are a measure of regional power above 15% power level.
- The <u>median</u> of "3 ion chamber rate signal" is a measure of the rate of change of reactor power.
- Calibrate the "flux measurements" against "Thermal Power" derived from accurate "Thermal Power Measurements"

Reactor General Arrangement – Plan View



Reactor General Arrangement – Side View



Sources of Measurement Errors

- Sensor variation (e.g. flow element erosion)
- Transmitter calibration
- Transmitter stability/drift
- Transmitter temperature
- Supply voltage variation
- Electromagnetic interference
- Impulse line density (gas or temperature)
- Computer AI accuracy
- Computer sampling time interval
- Computer signal quantization

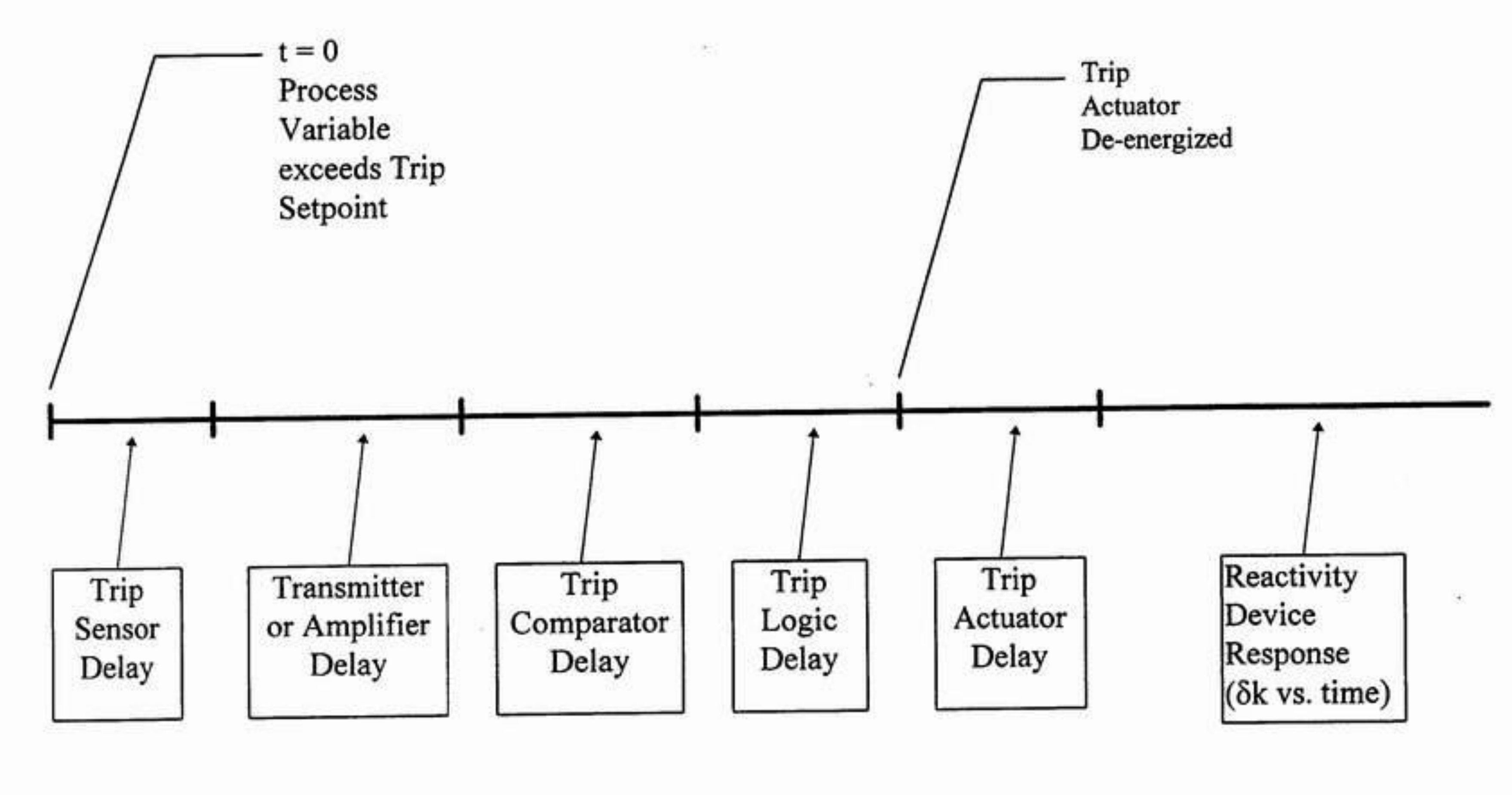
Trip Chain & Trip Setpoints

A typical trip chain consists of the following components:

- Sensor, amplifier
- Trip units/comparator (the trip setpoint may be fixed or variable)
- Trip (voting) logic
- Shutdown mechanism
- Panel displays/alarms
- Test provisions

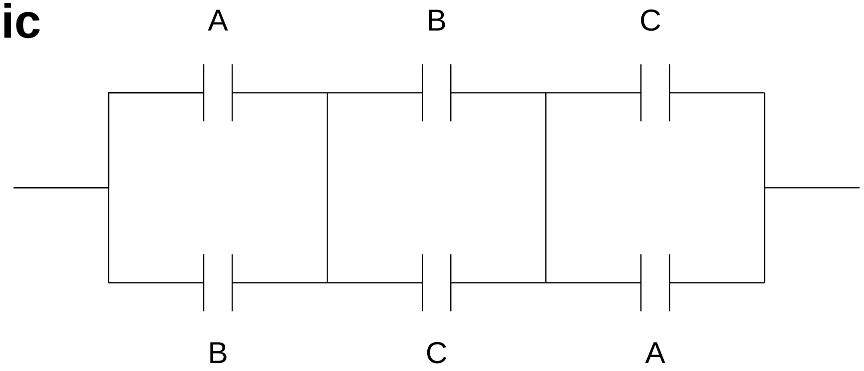
- The trip setpoints used in the comparators may be fixed or variable, e.g. a function of reactor power. A given trip may be unconditional, or may be inhibited under certain conditions, e.g. HT low pressure or low flow trips, inhibited at very low reactor power, to permit maintenance.

Trip Time Delays



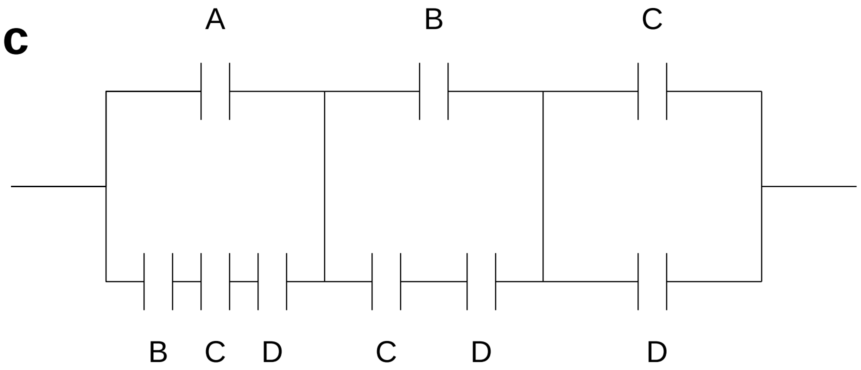
Trip Logic Configurations

2 of 3 logic



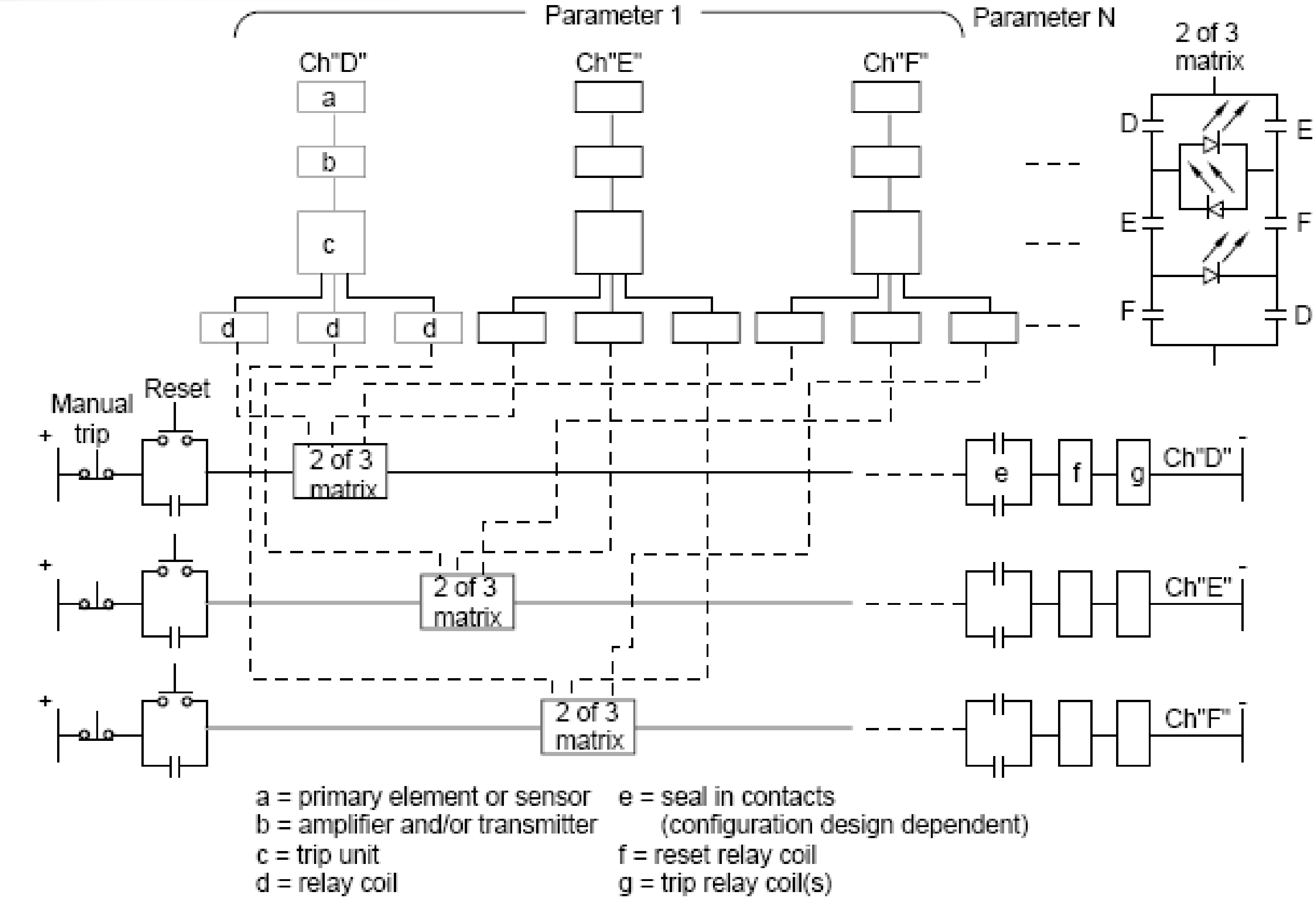
- **Channel under test is tripped, logic is 1 of 2 during test & mtce.**
- **CANDUs typically use 2 of 3 logic**

2 of 4 logic

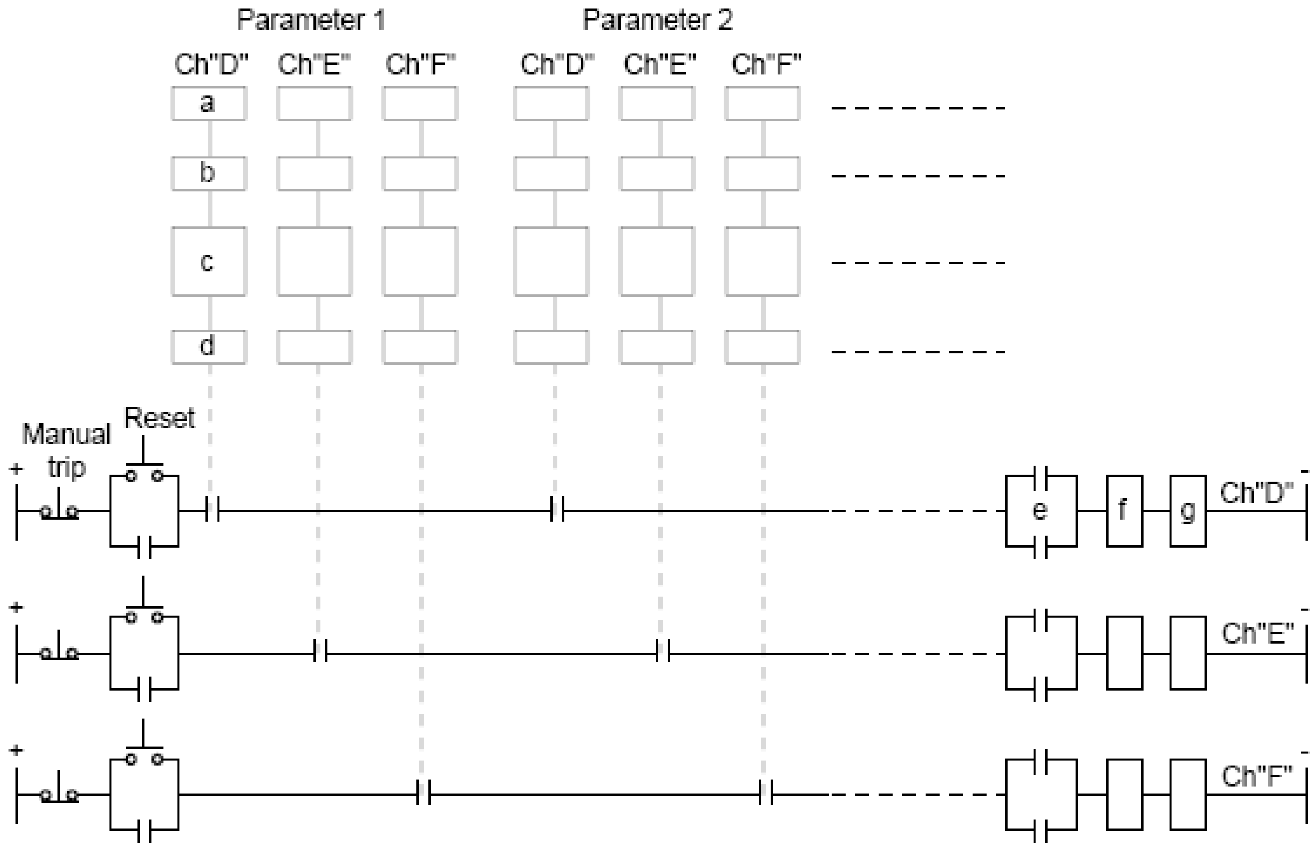


- **Channel under test is “vetoed”, logic is 2 of 3 during testing & mtce.**

Local Coincidence Logic



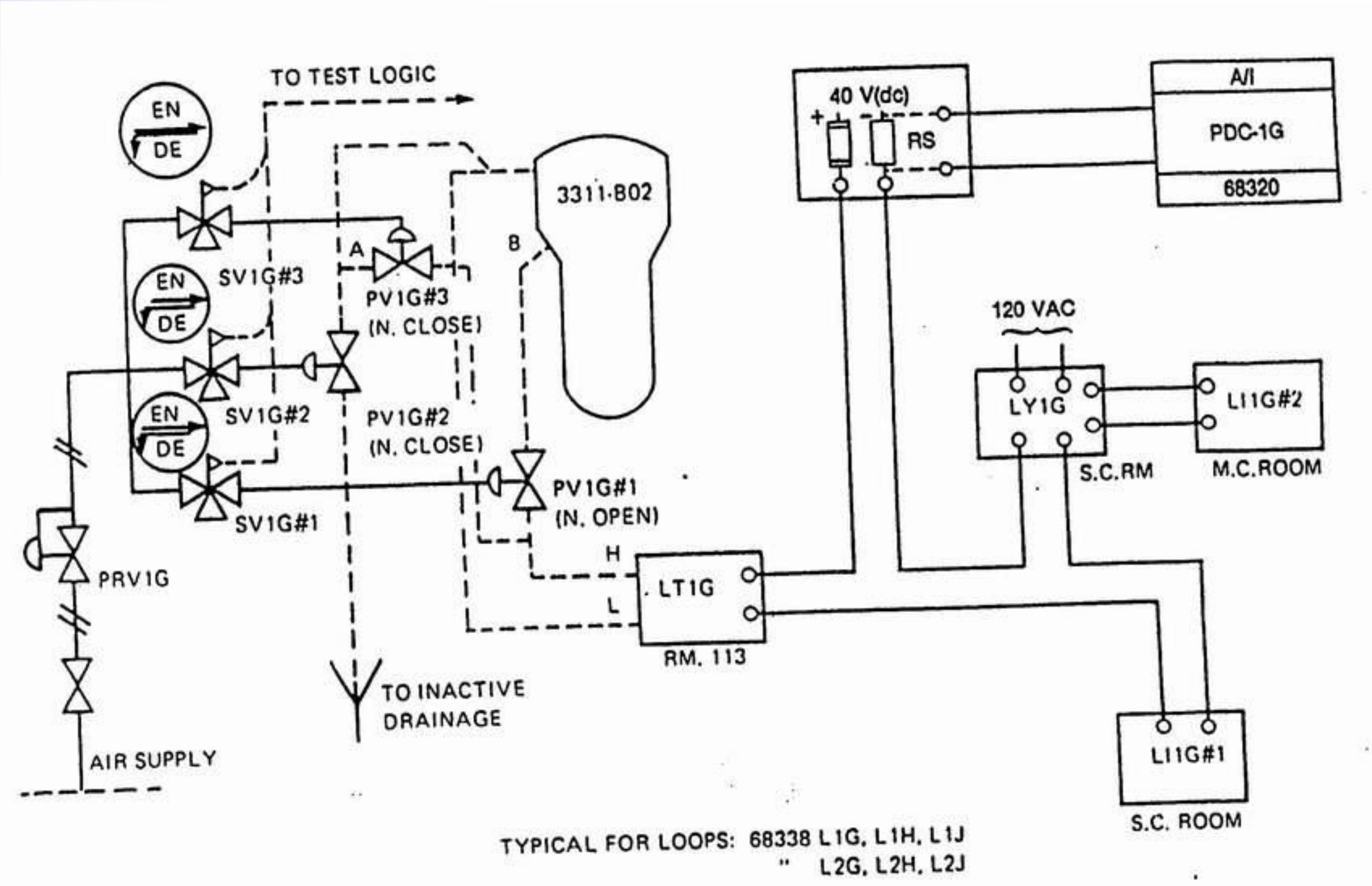
General Coincidence Logic



a = primary element or sensor
b = amplifier and/or transmitter
c = trip unit
d = relay coil

e = seal in contacts (configuration design dependent)
f = reset relay coil
g = trip relay coil(s)

SG Low Level Trip Components



Regional Over Power (ROP) System

- The ROP system is relatively simple, although it involves a large number of measurements. Each SDS channel has 10-20 in-core detectors with associated amplifier, dynamic compensator, and trip unit. When any detector exceeds its trip setpoint, the channel is tripped.
- The trip setpoints are fixed, but may be lowered by a set of hand switches when the reactor operates in a mode that was not analyzed.
- Sometimes referred to as Neutron Overpower (NOP) system

ROP Design Process

The ROP design process is very complicated, involving iteration and trial and error.

Requirements:

- Trip before dry-out in any fuel channel for any initial flux shape
- Provide adequate operating margin to trip.

Design steps

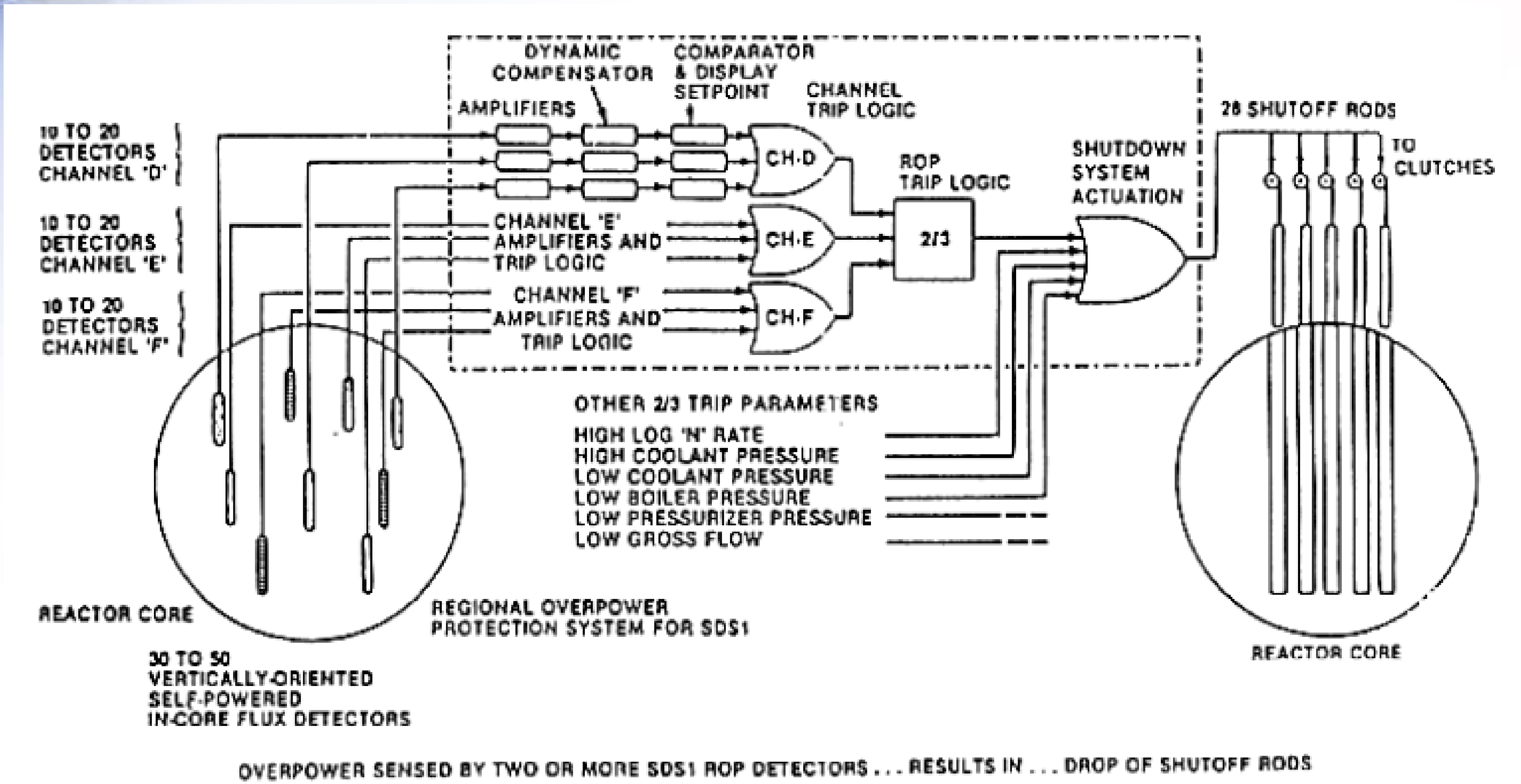
- simulate hundreds of reactor flux shapes, both normal and abnormal
- predict detector readings at potential detector locations, including lead cable effects
- perform comprehensive error analysis
- ensure each flux shape will lead to trip before dryout in all three channels >98% of the time, including realistic refuelling “ripple” effects
- ensure adequate is protected maximizing the operating margin during all expected operating modes

ROP Operation

Operation of the ROP system is also quite complicated and laborious. Aside from regular testing, the following is required:

- Monitor the operating state of the reactor for conditions that were not included in the analysis (e.g. reactivity devices stuck part-way in core, not all HT pumps running) and set the setpoint reduction hand switches as required.
- Monitor the detector readings relative to actual reactor power, and re-calibrate any that lie outside a defined band (much easier with trip computers).
- Determine the current reactor refuelling “ripple” for use in the detector recalibration.
- Over the longer term, monitor aging related variables to ensure that the trip setpoints adequately protect against dry-out (creep/flow, coolant inlet temperature) and that detectors response remains as expected.

ROP Overview



AECL
EACL

Knowledge Resources

- **COG Canteach Website**
  - Suggested documents are in the CNSC document area at http://canteach.candu.org/cnsc.html
    - Fundamentals of Power Reactors Training Course (3 modules) CANDU Fundamentals Training Course (2003) (6.2 Mb, 314 pages)
    - Intermediate Reactors, Boilers and Auxiliaries - Training Course and Presentations (5.3 Mb, 413 pages)
    - Basic Instrumentation and Control - part of Science & Reactor Fundamentals Training Course (851 kb, 125 pages)
- **IAEA Website**
  - IAEA Nuclear Safety Standards Series at http://www-pub.iaea.org/MTCD/publications/ResultsNS.asp
  - Technical Documents at http://www-pub.iaea.org/MTCD/publications/tecdocs.asp
- **US Department of Energy Website**
  - http://hss.energy.gov/NuclearSafety/techstds/standard/standard.html

CSA Standards

- CSA N290.1 - Requirements for the Shutdown Systems of CANDU Nuclear Power Plants-General Instruction No 1
- CSA N290.4 - Requirements for the Reactor Regulating Systems of CANDU Nuclear Power Plants-General Instruction No 1
- CSA N290.5 - Requirements for the Support Power Systems of CANDU Nuclear Power Plants-General Instruction No 1
- CSA N290.6 - Requirements for Monitoring and Display of CANDU Nuclear Power Plant Status in the Event of an Accident-General Instruction No 1-2
- CSA N286.2 - Design Quality Assurance for Nuclear Power Plants-Second Edition; General Instruction No 1
- CSA N293 - Fire Protection for CANDU Nuclear Power Plants-Second Edition; General Instruction No 1-2

CNSC Regulations

- R7 Requirements for Containment Systems for CANDU Nuclear Power Plants
- R8 Requirements for Shutdown Systems for CANDU Nuclear Power Plants
- R9 Requirements for Emergency Core Cooling Systems for CANDU Nuclear Power Plants
- R10 The Use of Two Shutdown Systems in Reactors
- R77 Overpressure Protection Requirements for Primary Heat Transport Systems in CANDU Power Reactors Fitted with Two Shutdown Systems

International Publications

- **IEC 61508 - Functional safety of electrical/electronic/programmable electronic safety-related systems**
- **IEC 61513 - Nuclear power plants - Instrumentation and control for systems important to safety –
General requirements for systems**
- **IEC 61226 - Nuclear power plants – Instrumentation and control systems important to safety – Classification of instrumentation and control functions**
- **IEC 61131-3 - Programmable controllers – Part 3: Programming languages**
- **IAEA NS-R-1 - Safety of Nuclear Power Plants: Design**
- **IAEA NS-G-1.3 - Instrumentation and Control Systems Important to Safety in Nuclear Power Plants**