CANDU Safety
#11 - Reactivity Control

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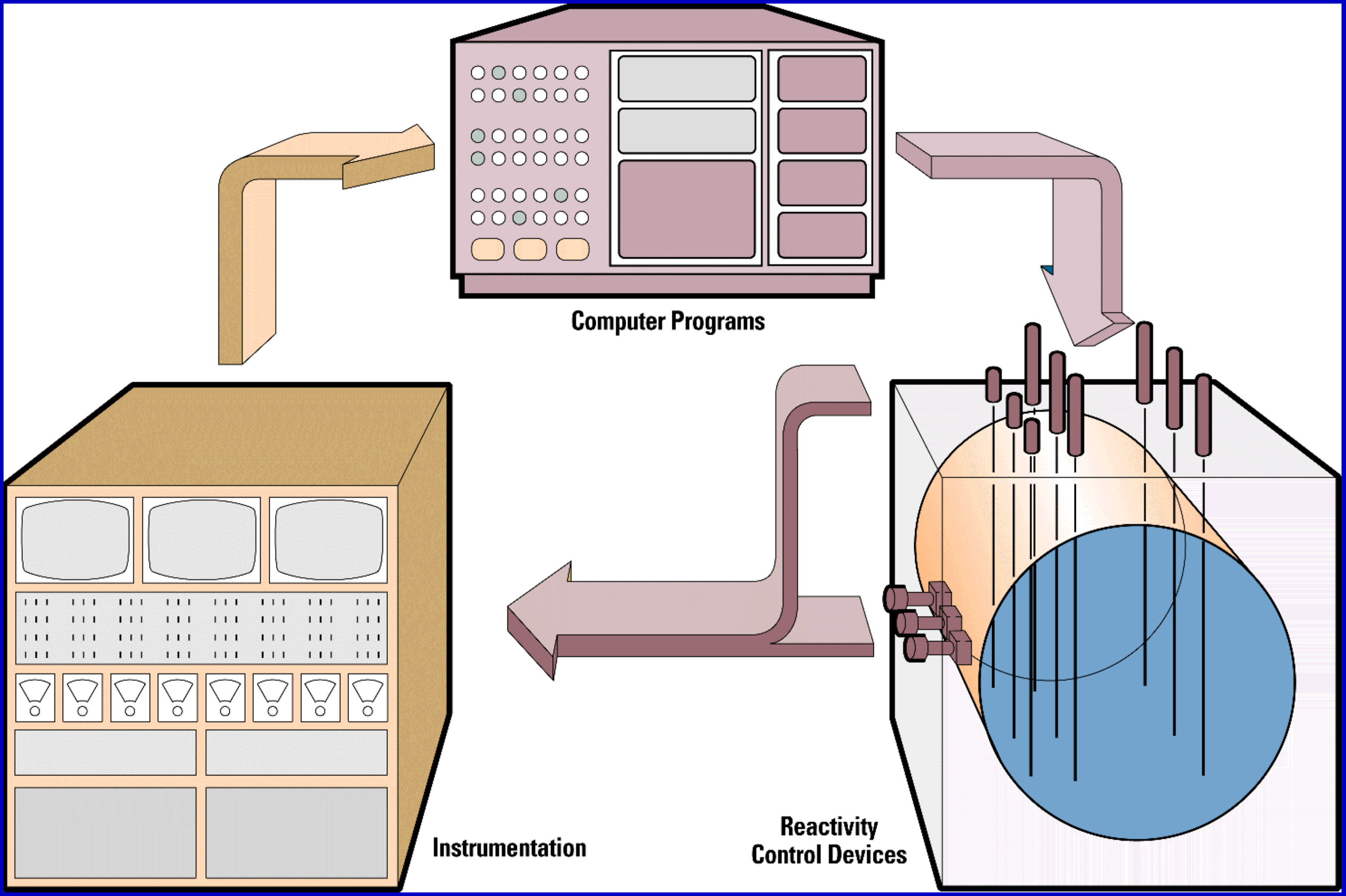
Basis for Reactivity Control

- CANDU
  - small reactivity feedback: continuous automatic control
  - dual redundant digital computers
  - small rates of reactivity increase
  - just enough reactivity range for short term control
  - refuelling is the long-term control
- LWRs
  - large negative feedback: “set and forget”
  - manual or semi-automatic control
  - large reactivity depth to compensate for fuel burnup

Basic Reactivity Control Logic - Short Term



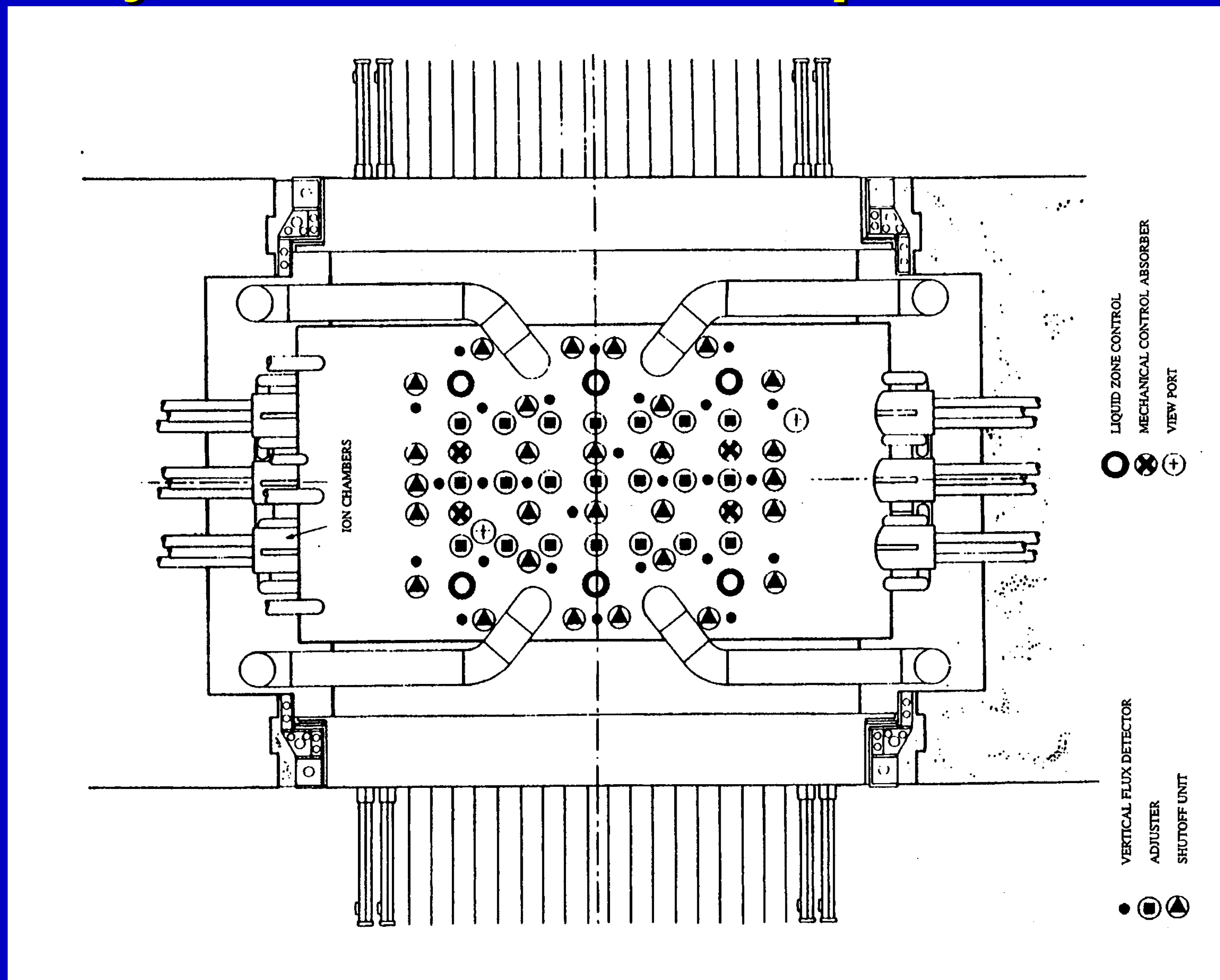
Digital Computer Control

- 2 identical computers
  - "master" (controlling), "slave" (active standby)
  - control, alarms and display
  - all major functions duplicated (except for fuelling)
- hardware and software self-checking, external timer
- input / output rationality checking
- fault in one computer transfers control to the other
- fault in both computers causes station shutdown
- experience: availability of >99% for each computer

Reactivity Devices

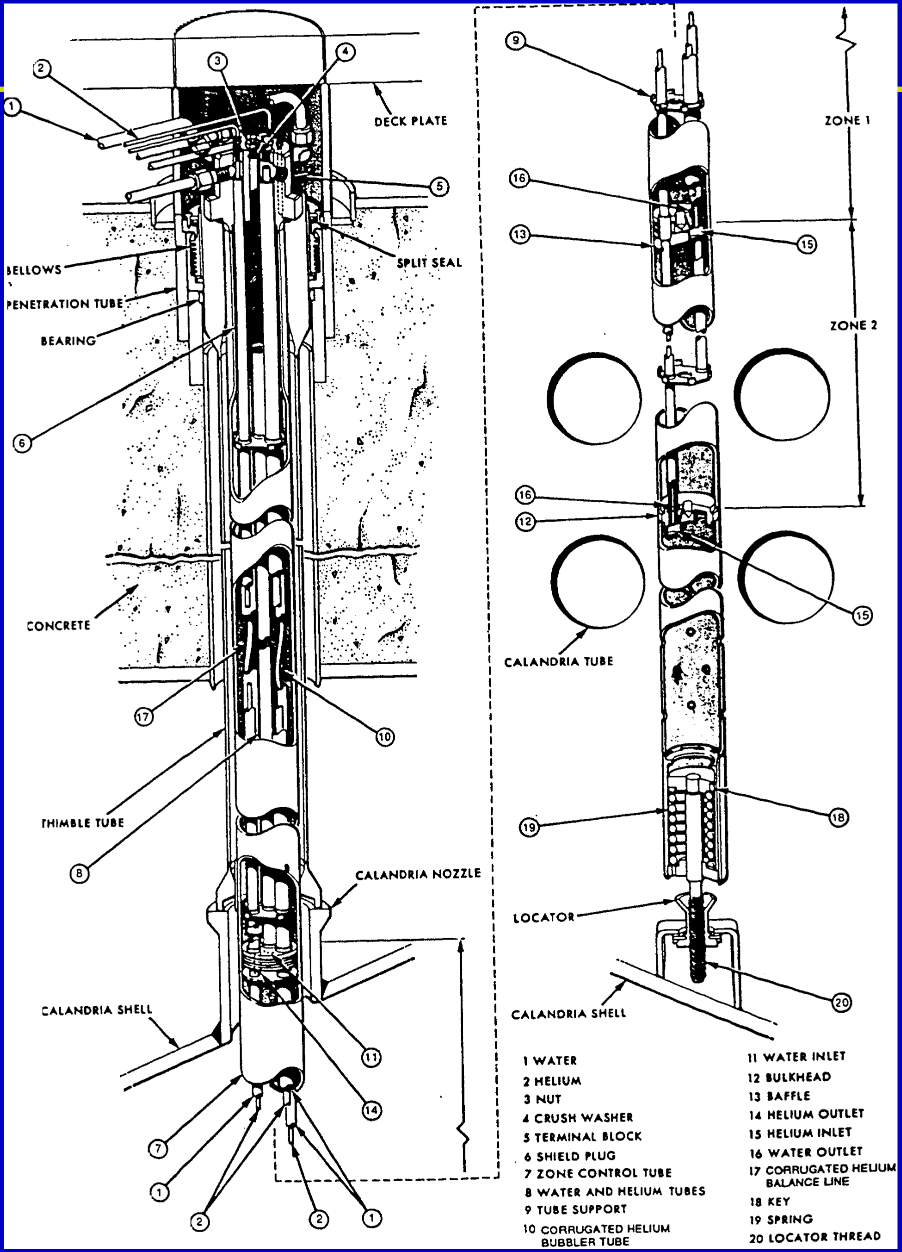
Reactivity Control Device (number)	*Typical Reactivity Rate (mk/sec)*	*Typical Reactivity Range (mk)*
Light-water zone controllers (14)	±0.14	7
Adjuster Rods (21)	±0.1 per bank (7 banks)	15
Mechanical Control Absorbers (4)	±0.1 - driving -3.5 - dropping	10
Moderator poison	-0.0125 +0.0008	40+
Refuelling		0.4 per channel
Shutoff Rods (SDS1)	+0.6 - withdrawal -40 - trip	-80
Liquid Injection (SDS2)	-35 - trip	-400

Reactivity Control Devices - Top of Reactor View



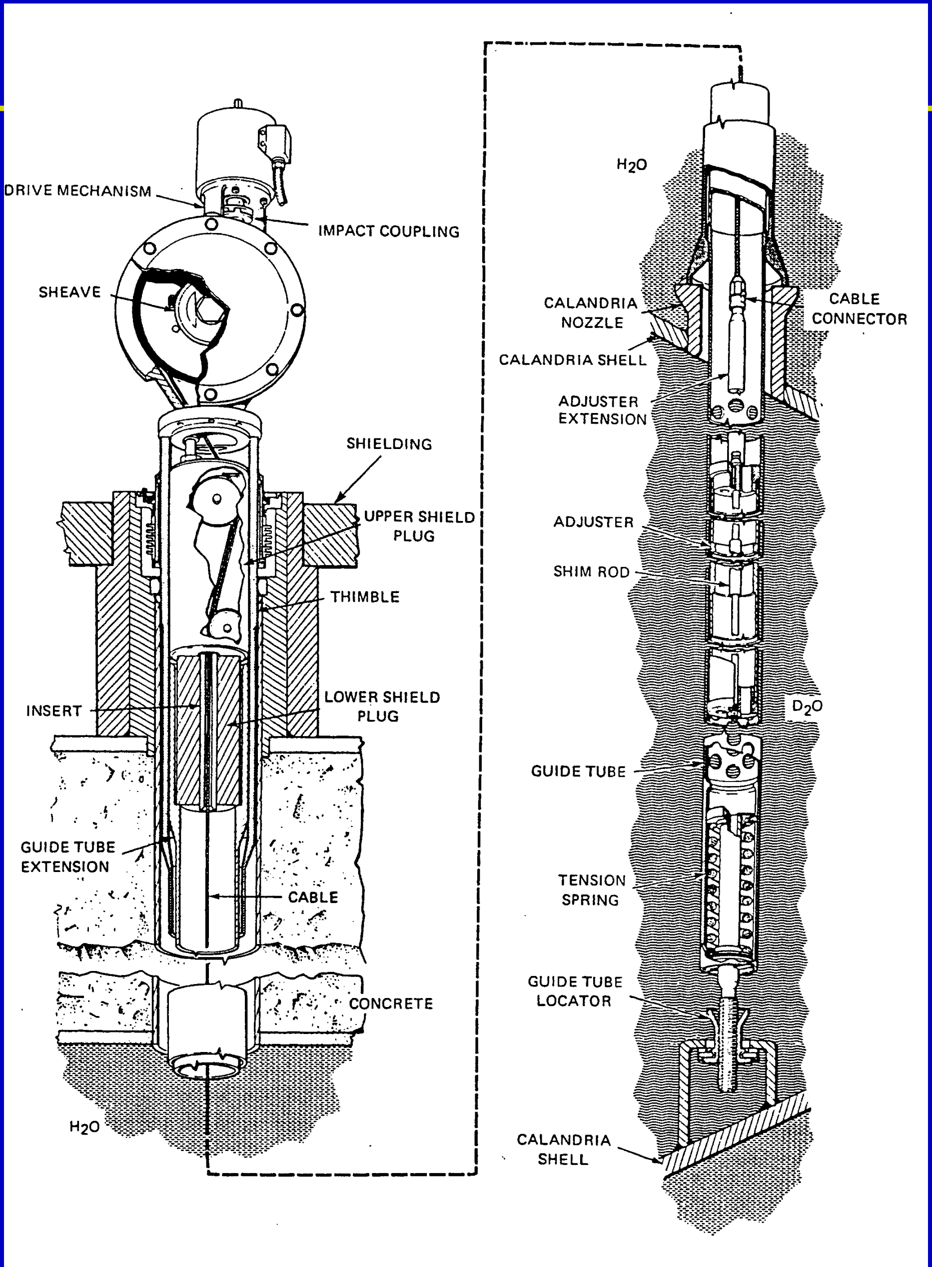
Zone Controllers

- primary means of normal control
- bulk power control and spatial flux control
- they work by varying level in H_2O filled compartments
- 14 controllers in 6 vertical tubes
- fill on reactor trip



Adjuster Rods

- 21 rods, in 7 banks
- normally fully inserted for flux shaping
- used for partial xenon override to recover from trip
- used in case of unavailability of fuelling machine
- freeze on reactor trip



Absorber Rods

- 4 rods, normally out of core
- like shutoff rods but no spring
- drive in / out or drop by releasing clutch
- used to supplement zone controllers
- fast power reduction for abnormal events (3 seconds) - stepback
- prevent reactor from going critical on shutoff rod withdrawal
- dropped on reactor trip

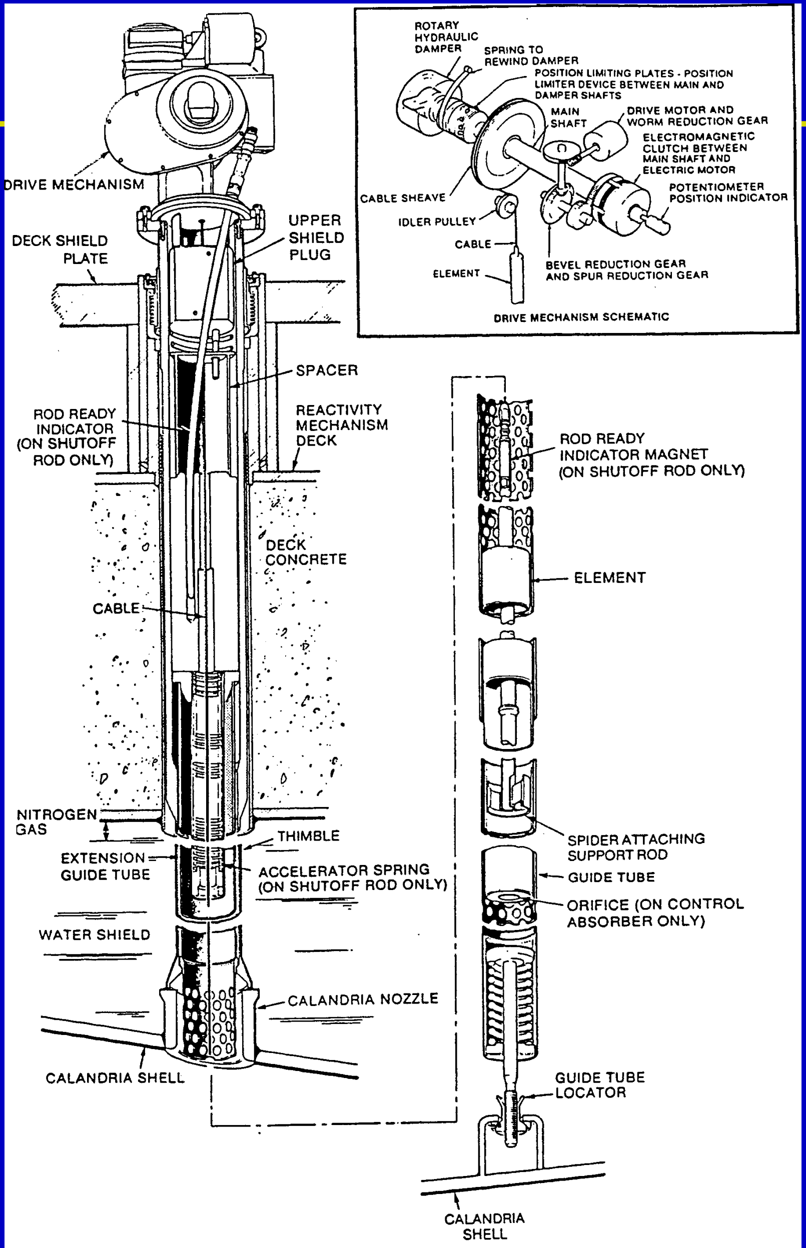
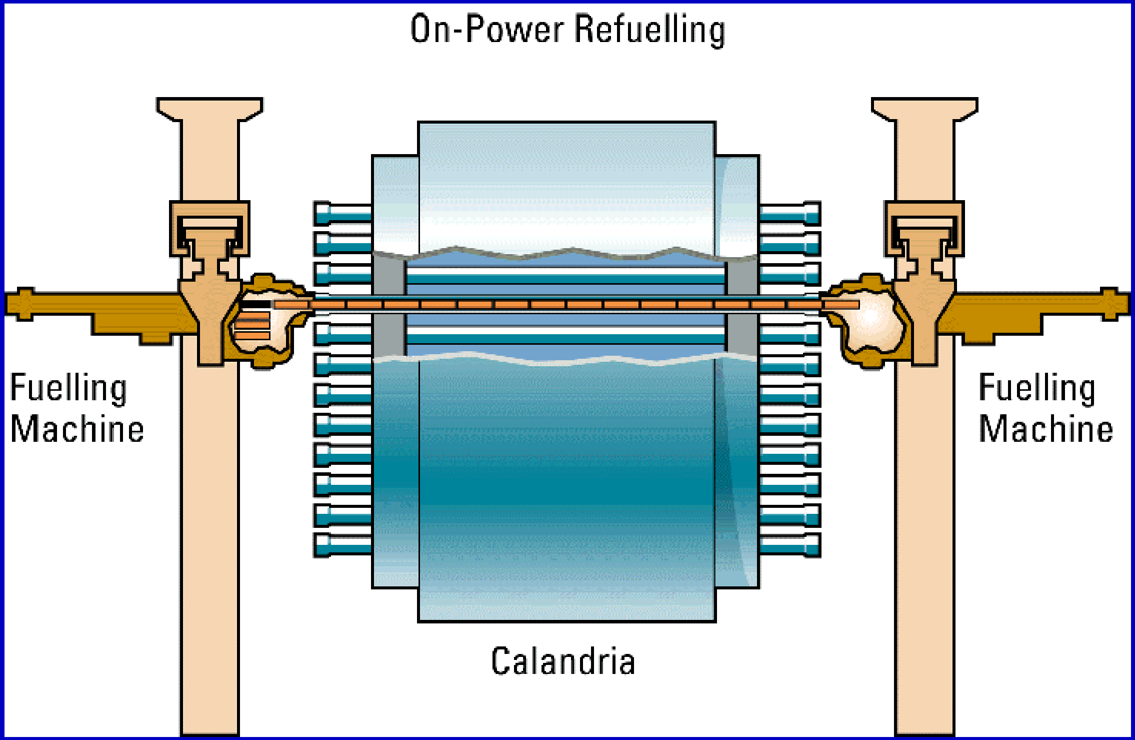


FIGURE 2.3.1-26 SHUTOFF AND MECHANICAL CONTROL ABSORBER UNITS

On-Power Fuelling

- long term reactivity control
- long term power shape control
- typically 2 channels / day
- fuel management code advises on channels to be refuelled
- refuelling operation mostly automatic & completely remote



Hardware Safety Interlocks

- **if reactor is tripped:**
  - **prevent adjuster / absorber removal**
  - **prevent moderator poison removal**
- **cannot withdraw shutoff rods if shutdown system 2 is unavailable (not re-poised)**
- **cannot withdraw excess number of adjusters simultaneously**

Setback

- reduces power at controlled rate if normal limits exceeded
- initiated by control computers
- end points vary from 60% to 0.02% full power
- examples:

Variable	*Initiating Setpoint*	*Power change (%FP/sec)*	*Endpoint (% Full Power)*
High local flux	110%	0.1	60
High moderator temperature	79 C	1	2
High boiler pressure	4.83 MPa	0.5	8
Turbine trip	2/3 contacts	1	60

Stepback

- fast reduction of power, may avoid reactor trip
- initiated by control computers
- releases clutches on control absorbers, full or partial drop
- examples:

Condition	*Initiating Setpoint*	*End-point (%FP)*
Heat transport pump failure	1 pump trip	1
High heat transport pressure	10.24 MPa	0.5
High log rate rise in power	3.3% / sec	0
Low moderator level	75.5 cm	0.5

Accident Analysis - Loss of Reactivity Control

- definition: reactor regulating system malfunctions so as to cause increase in local or bulk power
- defences:
  - setback (not credited)
  - stepback (not credited)
  - Shutdown System 1 - independent of control computers
  - Shutdown System 2 - independent of control computers
- early experience: > 1 loss of reactivity control per year on average; all stopped by shutdown system
  - improved with addition of setback / stepback
  - current design target: 1 per 100 years

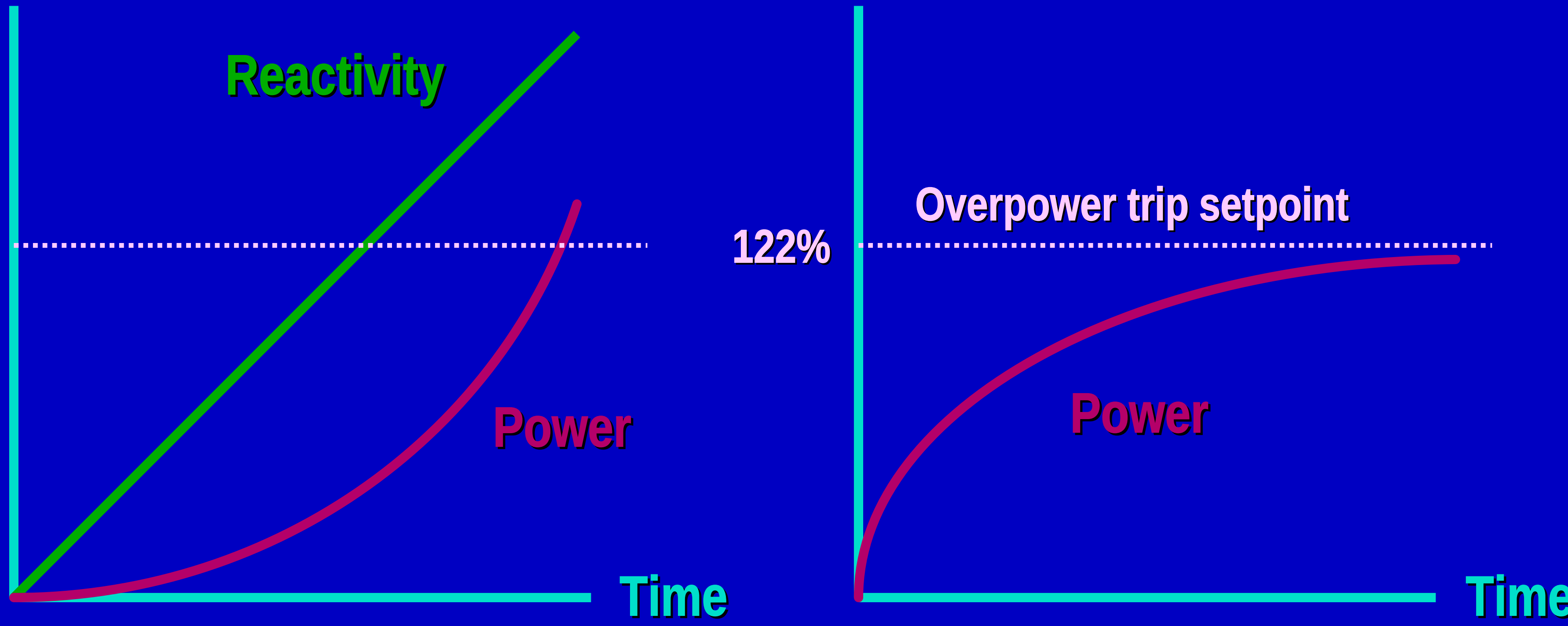
Acceptance Criteria

- Class 1 dose limits set by AECB
- two effective trips on each shutdown system where practical
  - prevent fuel sheath failures
    - no dryout or limited time in dryout
    - *not* the same as burnout in a LWR
  - prevent heat transport system boundary failure
    - pressure <110% design for SDS1, <120% for SDS2
    - no pressure tube failure due to overheating

Cases Analyzed

- **increase in bulk power**
  - **power continues to rise, or**
  - **power stops rising just below neutron trip setpoint**
- **increase in local power**
  - **slow increases from distorted flux shapes**
  - **hundreds of cases**
  - **basis of Regional Overpower Protection System design**
- **various initial power levels from full power to shutdown**
  - **primary circuit pressurized or depressurized at zero power**

Typical Cases Analyzed



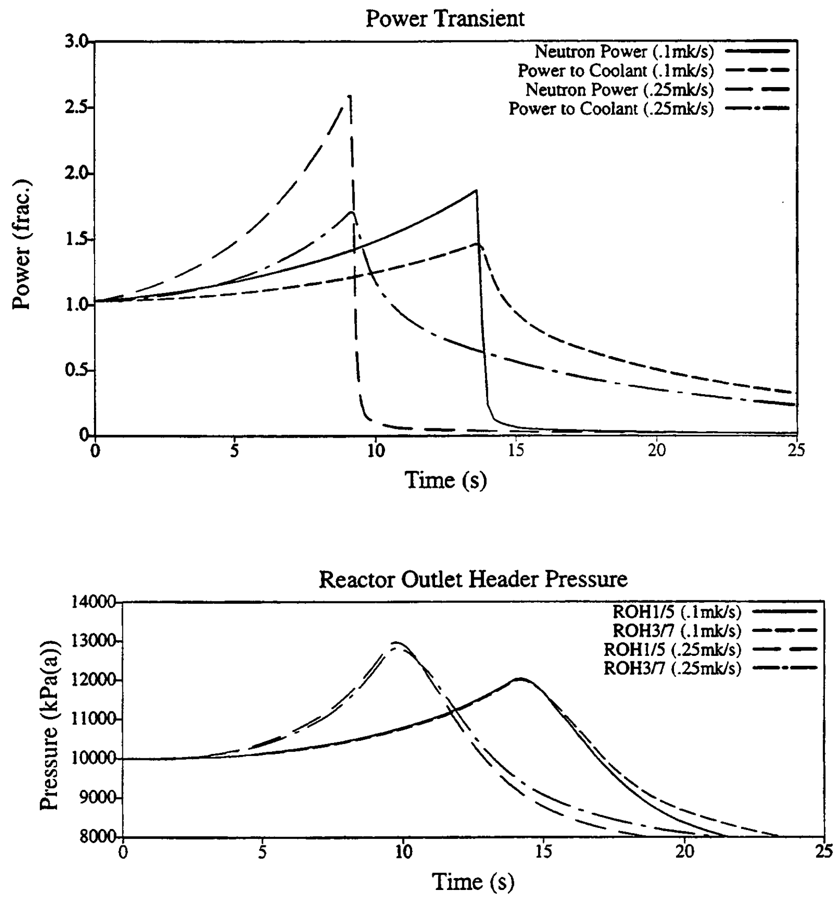
Reactivity Ramp | **Bounded Power Rise**

Relevant Trips

- high neutron power trip (122%)
- high rate log neutron power trip
  - 10% / sec for SDS1, 15% / sec for SDS2
- high heat transport system pressure trip
  - 10.34 MPa, if power >70%, 3-5 second delay
  - 10.55 MPa on SDS1, 11.72 MPa on SDS2, immediate
- low coolant flow if power >0.1% (SDS1)
- low core differential pressure if power >0.3 - 5% (SDS2)

Reactivity Ramp

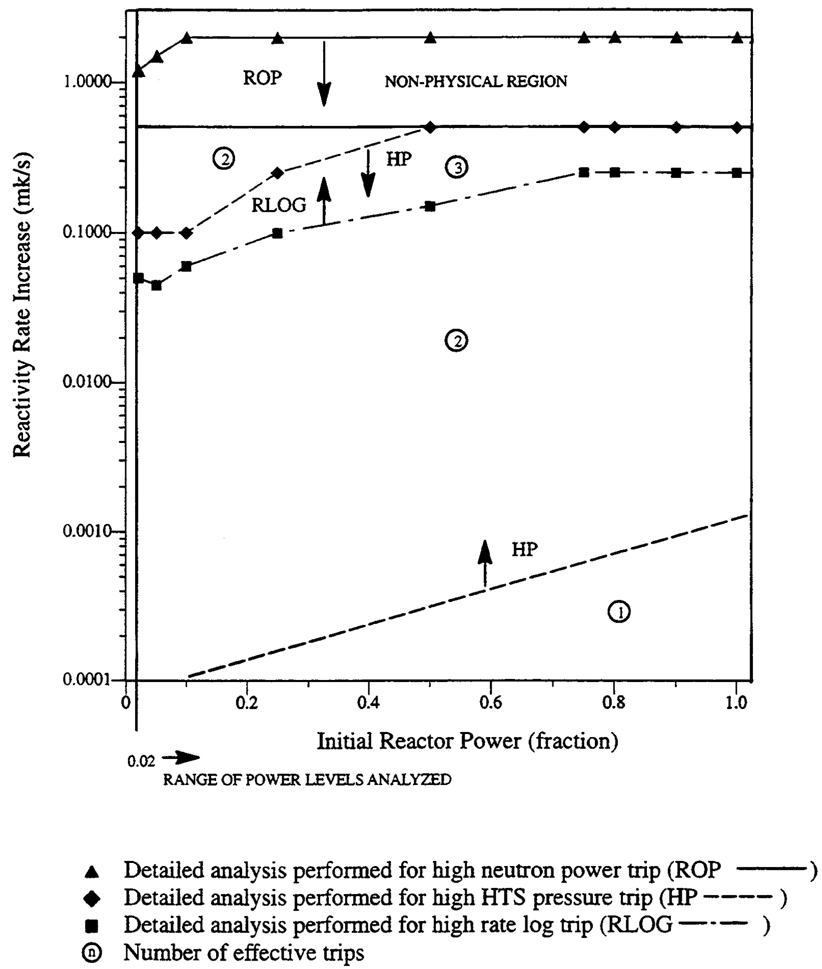
- linear reactivity ramps
- varied from very slow to the fastest the control devices can achieve
- system simulations to predict
  - reactor physics
  - fuel temperature
  - heat transport system thermohydraulics
  - pressure tube temperature
- key calculation: critical versus actual heat flux for hottest fuel element



Relative Power and ROH Pressure for LORC at 0.1 and 0.25 mk/s from 103% FP, SDS2 High Pressure Trip (without LRVs)

Trip Coverage Map

- purpose: to show for *each* shutdown system there are at least 2 trips for an accident starting from various operating states
- whole power range
- various initial conditions
- in some cases only one trip is practical: e.g., fast reactivity ramps from very low power



SDS2 Trip Coverage Map for Loss of Reactivity Control – Fuel and Fuel Channel Criterion
(Fouled and Clean Steam Generators, Equilibrium Fuel)

Summary

- low reactivity rates and small ranges because of on-power refuelling
- reliable redundant digital computer control
- large core means that spatial overpower protection is required for control & safety
- setback, stepback and two shutdown systems provide defences against loss of reactivity control