



CANDU Safety

#11 - Reactivity Control

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Basis for Reactivity Control

λ CANDU

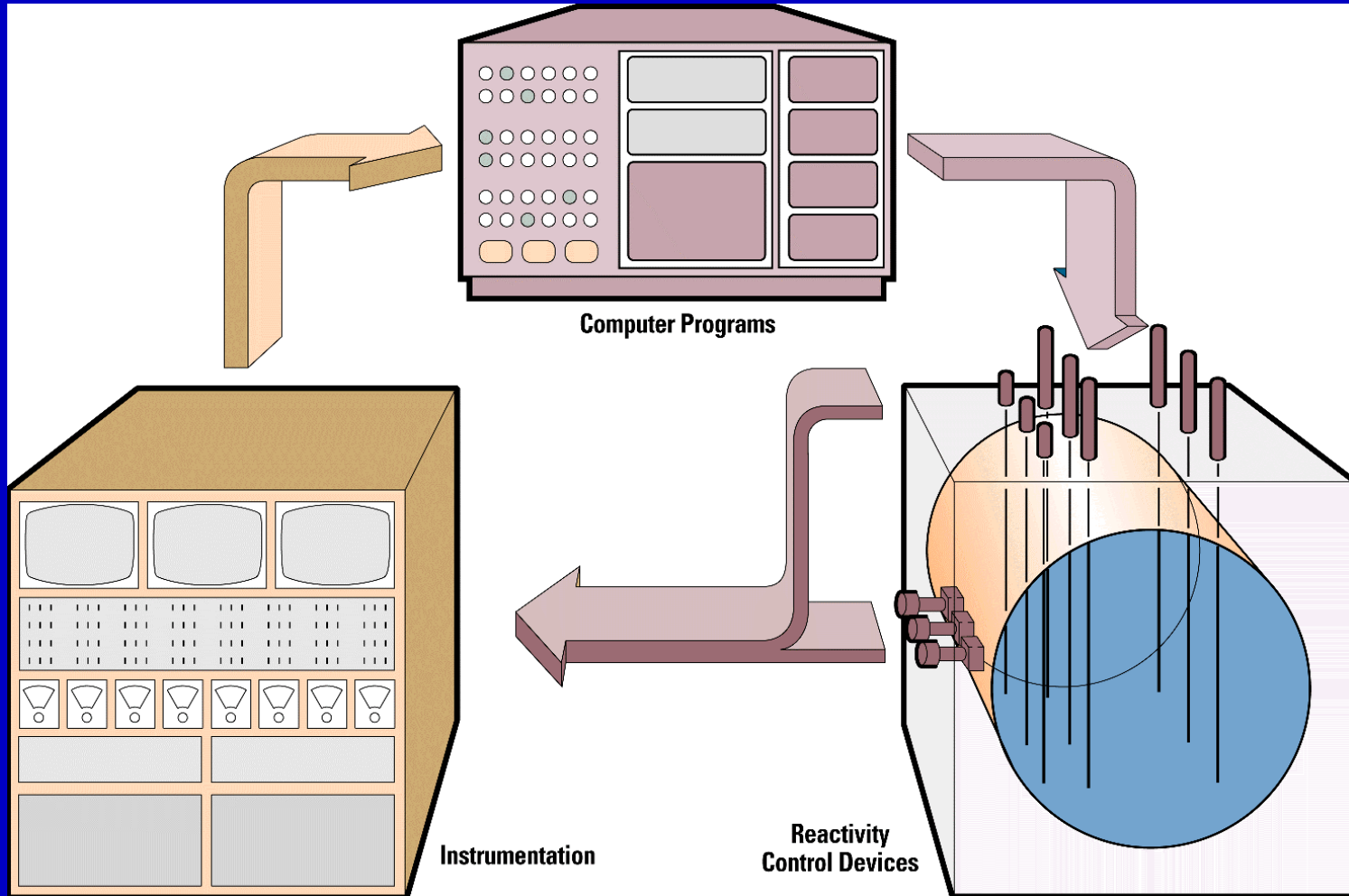
- small reactivity feedback: continuous automatic control
- dual redundant digital computers
- small rates of reactivity increase
- just enough reactivity range for short term control
- refuelling is the long-term control

λ 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

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

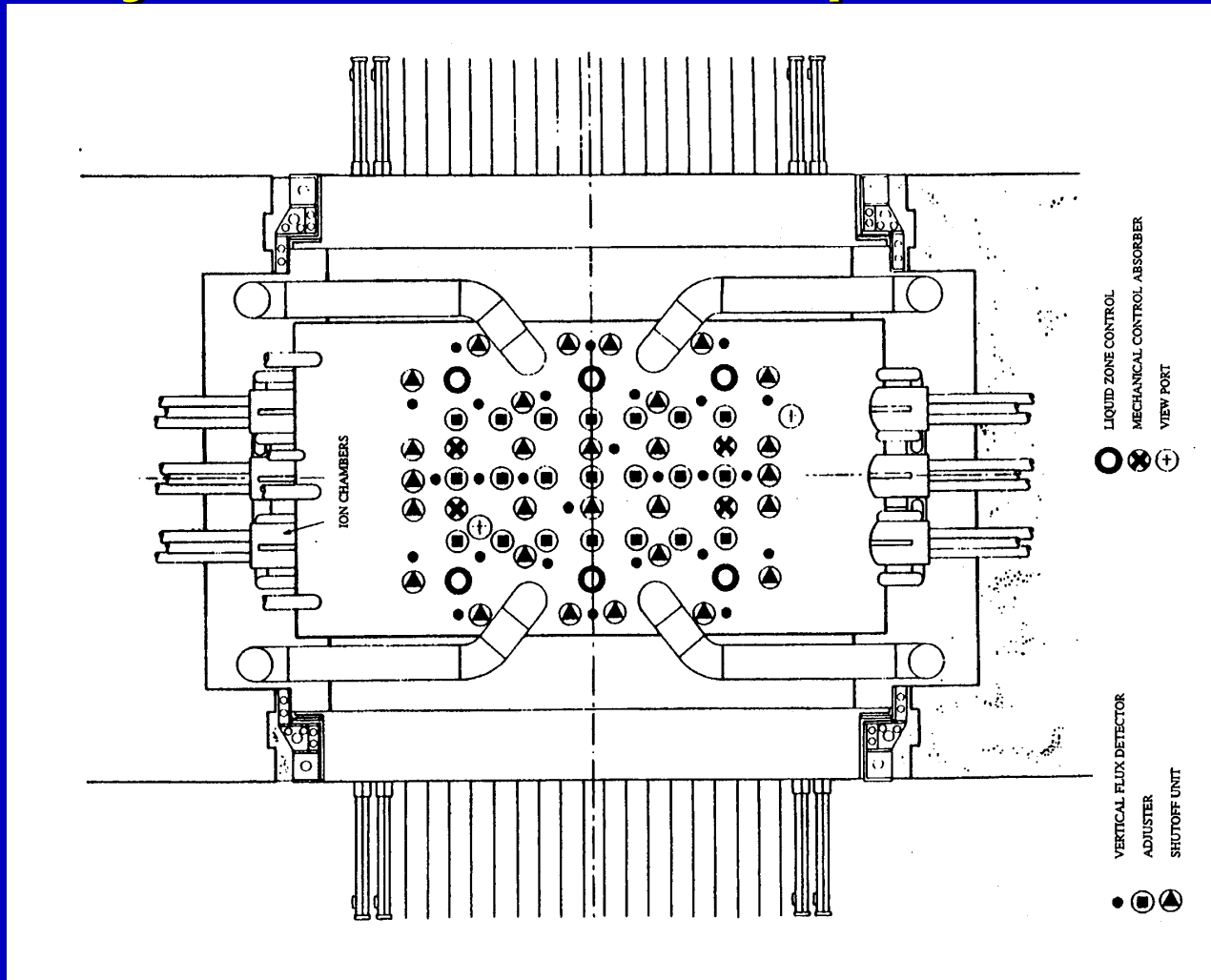


Reactivity Devices

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



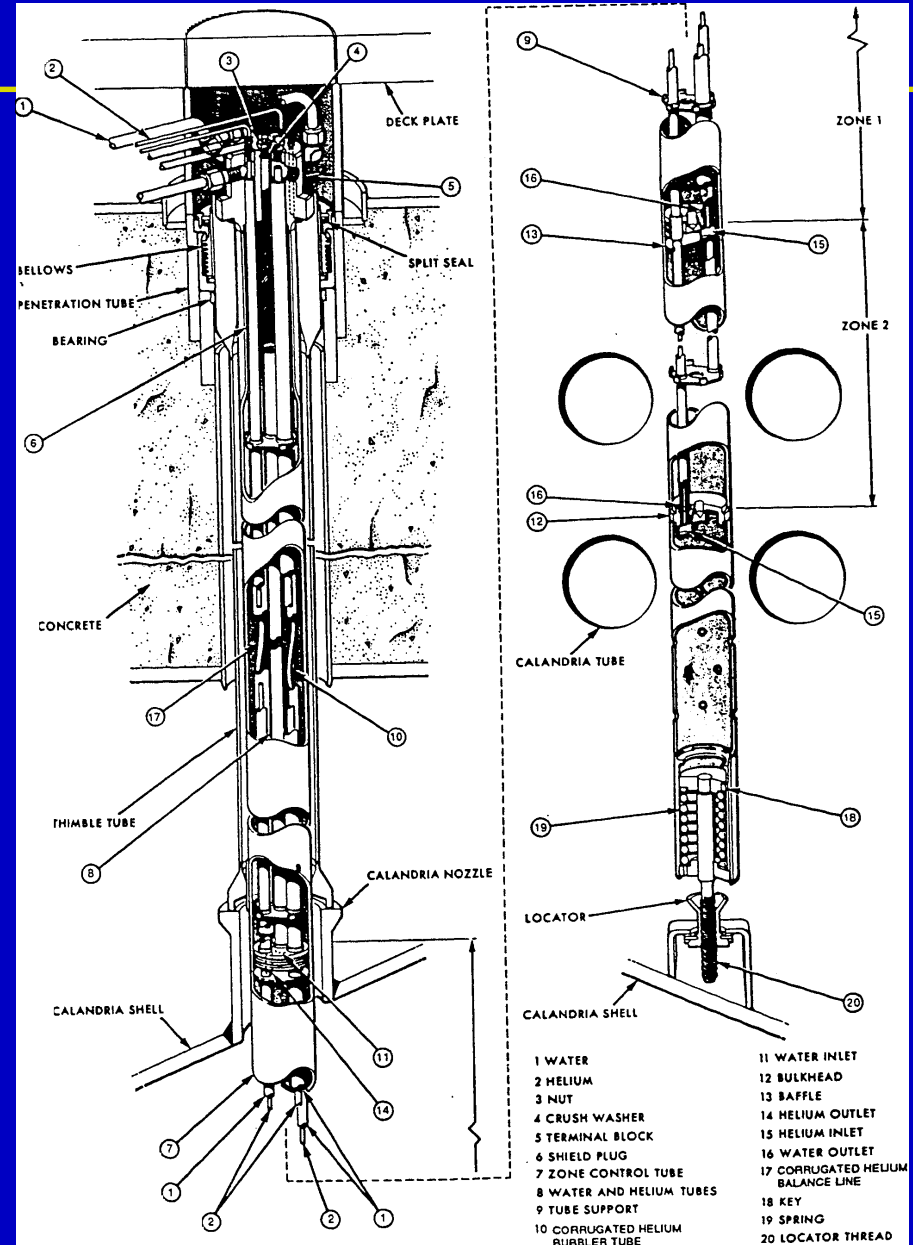
Reactivity Control Devices - Top of Reactor View





Zone Controllers

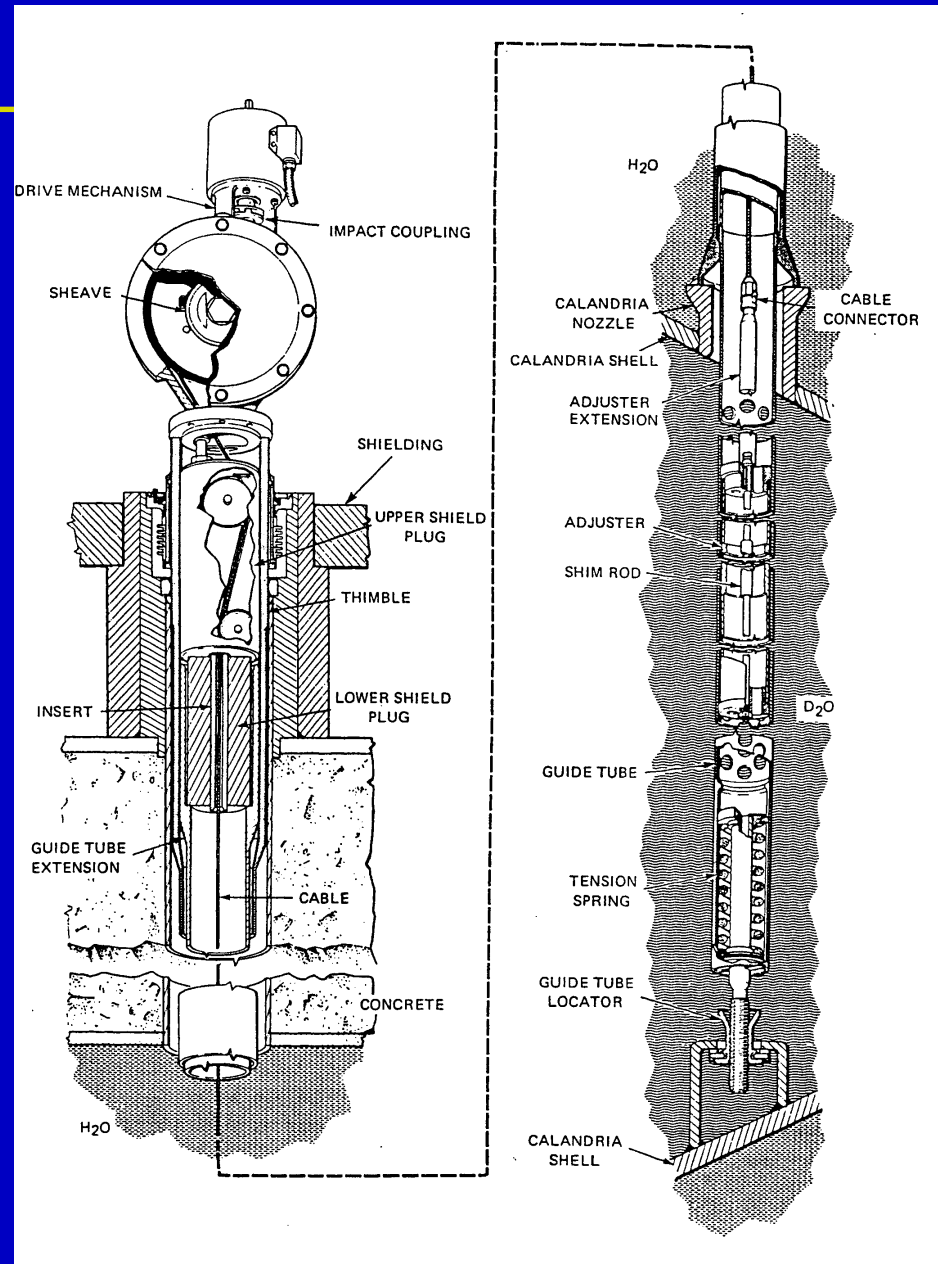
- λ primary means of normal control
- λ bulk power control and spatial flux control
- λ they work by varying level in H₂O filled compartments
- λ 14 controllers in 6 vertical tubes
- λ fill on reactor trip





Adjuster Rods

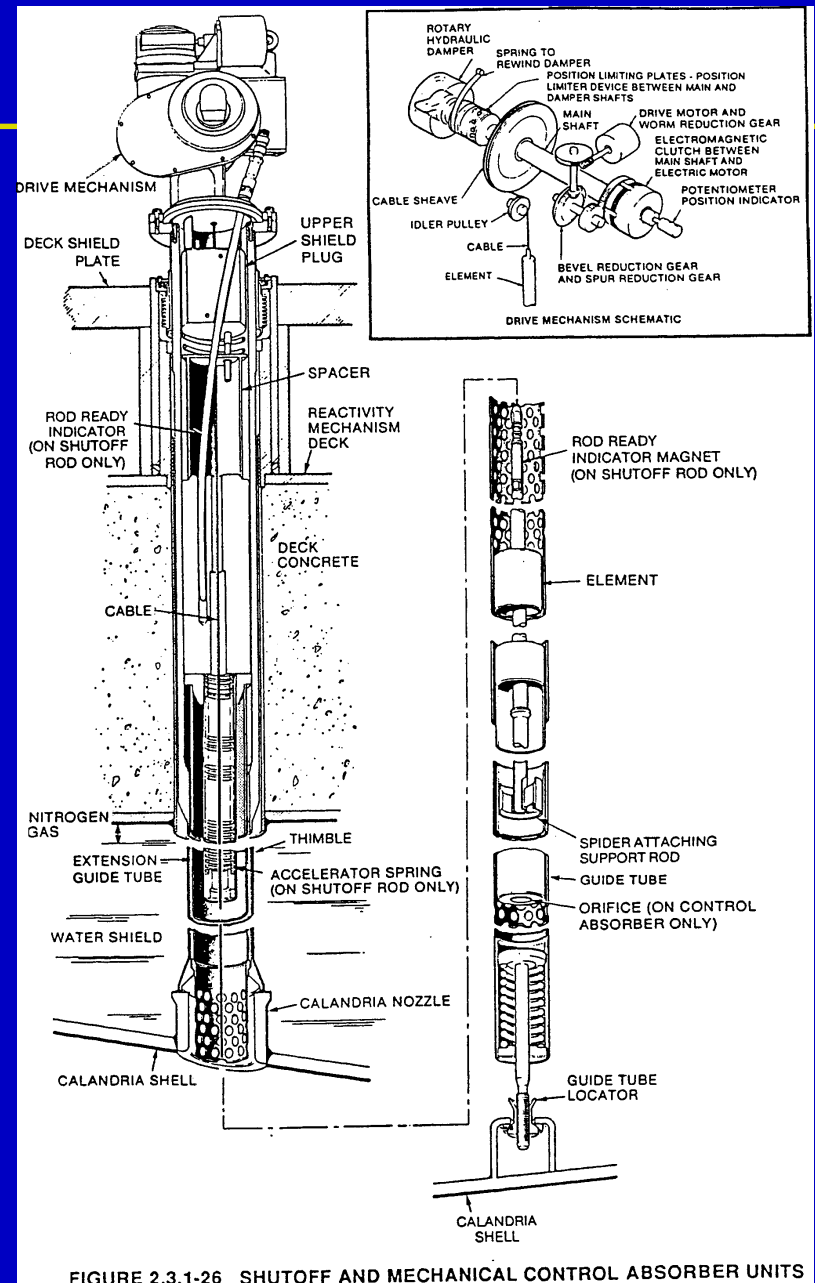
- λ 21 rods, in 7 banks
- λ normally fully inserted for flux shaping
- λ used for partial xenon override to recover from trip
- λ used in case of unavailability of fuelling machine
- λ freeze on reactor trip





Absorber Rods

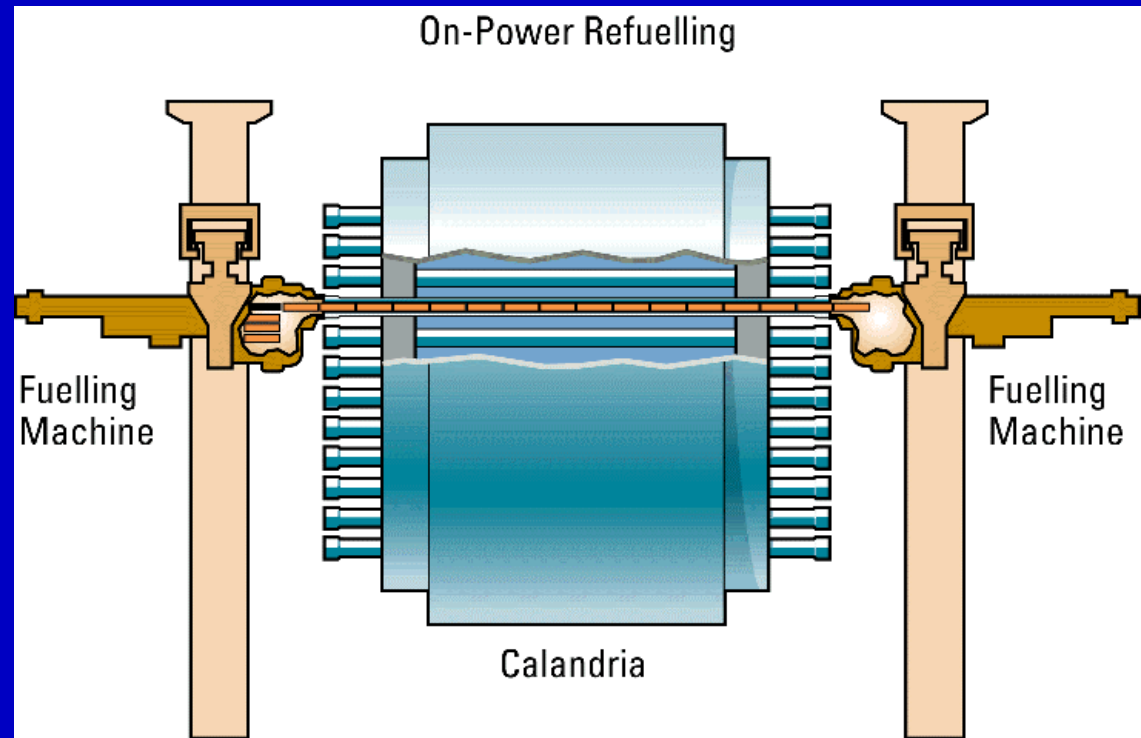
- λ 4 rods, normally out of core
- λ like shutoff rods but no spring
- λ drive in / out or drop by releasing clutch
- λ used to supplement zone controllers
- λ fast power reduction for abnormal events (3 seconds) - stepback
- λ prevent reactor from going critical on shutoff rod withdrawal
- λ dropped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





On-Power Fuelling

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





Hardware Safety Interlocks

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



Setback

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

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



Stepback

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

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



Accident Analysis - Loss of Reactivity Control

- λ definition: reactor regulating system malfunctions so as to cause increase in local or bulk power
- λ defences:
 - setback (not credited)
 - stepback (not credited)
 - Shutdown System 1 - independent of control computers
 - Shutdown System 2 - independent of control computers
- λ 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

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

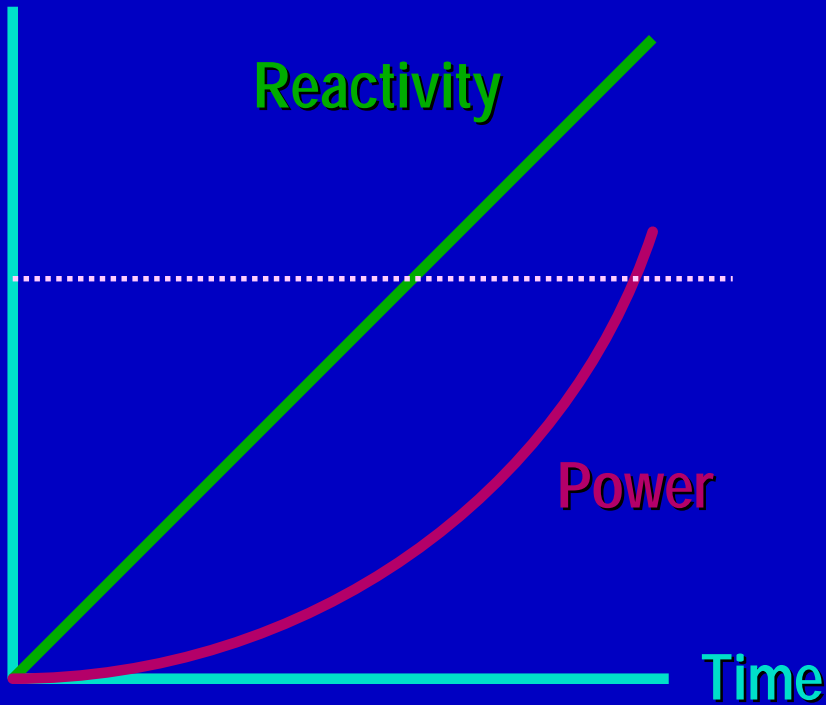


Cases Analyzed

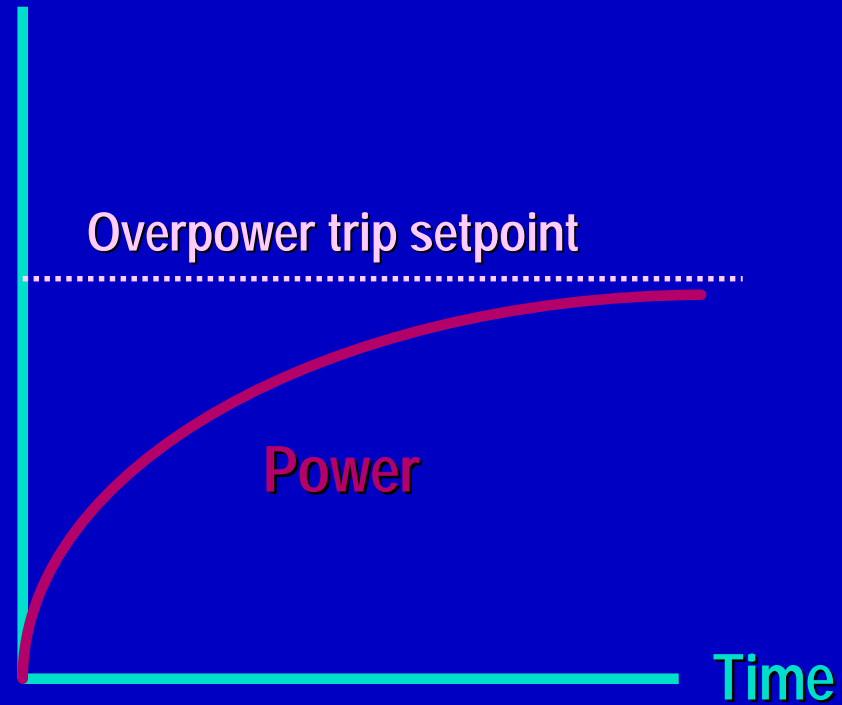
- λ increase in bulk power
 - power continues to rise, or
 - power stops rising just below neutron trip setpoint
- λ increase in local power
 - slow increases from distorted flux shapes
 - hundreds of cases
 - basis of Regional Overpower Protection System design
- λ various initial power levels from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



Typical Cases Analyzed



Reactivity Ramp



Bounded Power Rise



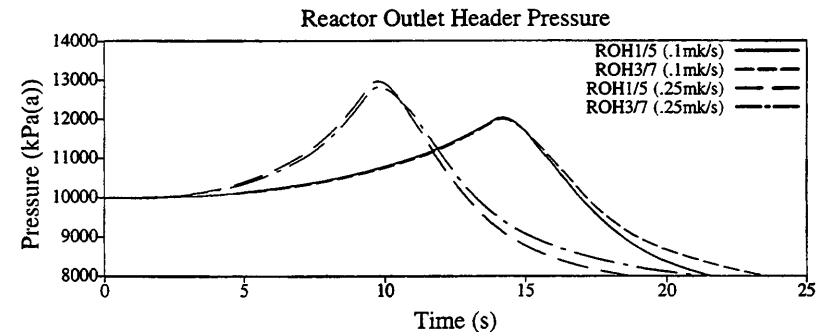
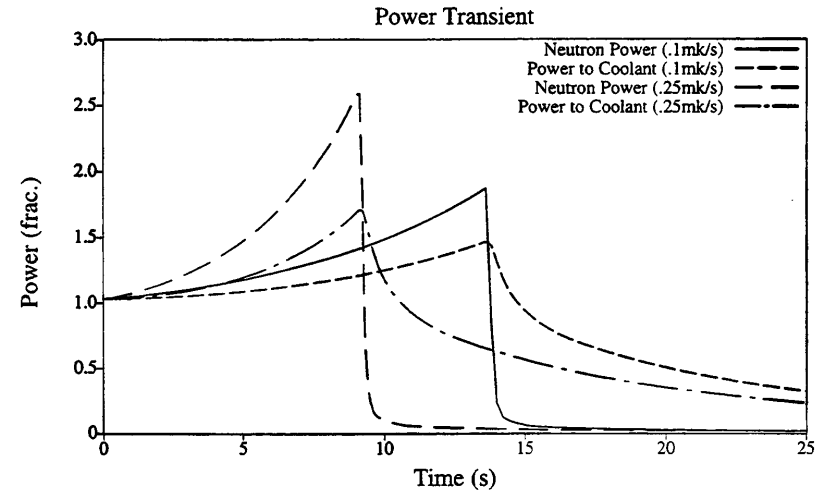
Relevant Trips

- λ high neutron power trip (122%)
- λ high rate log neutron power trip
 - 10% / sec for SDS1, 15% / sec for SDS2
- λ 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
- λ low coolant flow if power >0.1% (SDS1)
- λ low core differential pressure if power >0.3 - 5% (SDS2)



Reactivity Ramp

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

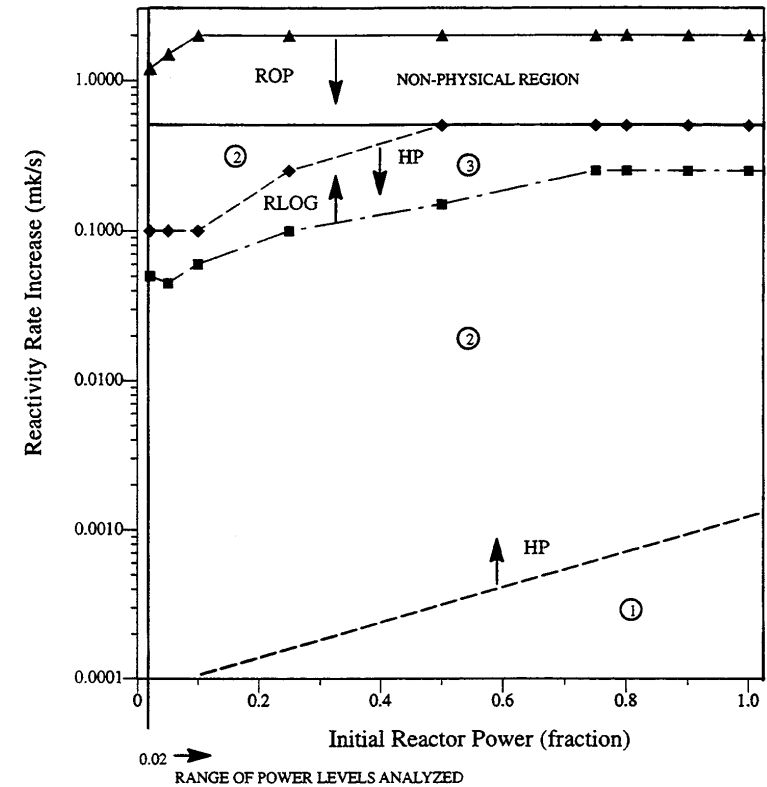


Relative Power and ROH Pressure for LORC at 0.1 and 0.25 mk/s from 103% FP, SDS2 High Pressure Trip (without LRVs)



Trip Coverage Map

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



- ▲ Detailed analysis performed for high neutron power trip (ROP ———)
- ◆ Detailed analysis performed for high HTS pressure trip (HP - - - -)
- Detailed analysis performed for high rate log trip (RLOG - · - ·)
- ⊙ Number of effective trips

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



Summary

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