CANDU Reactor Control

- General overview only
  - taken from Technical Summary document
- Power and power shape control
  - zone control system
  - fourteen light water compartments
- Flux flattening and Xenon override
  - adjuster rods normally in the core
- Rapid power reduction
  - mechanical control absorbers, out of core
- Gadolinium nitrate addition
  - only used under extreme conditions

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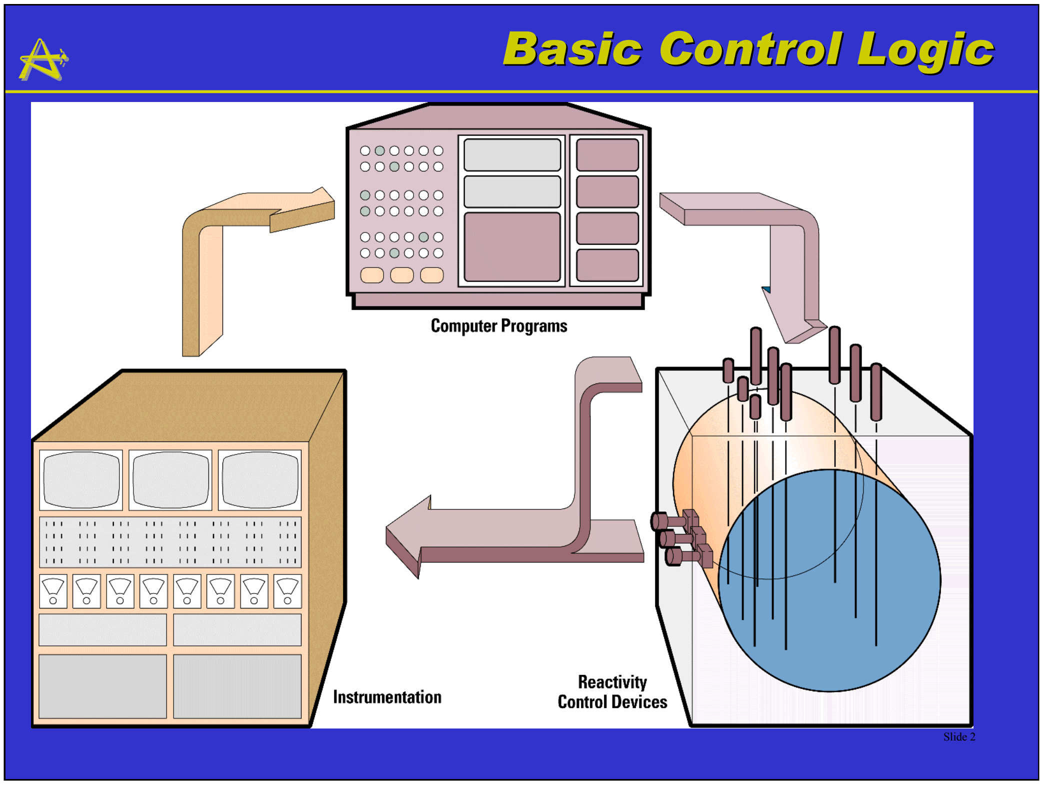
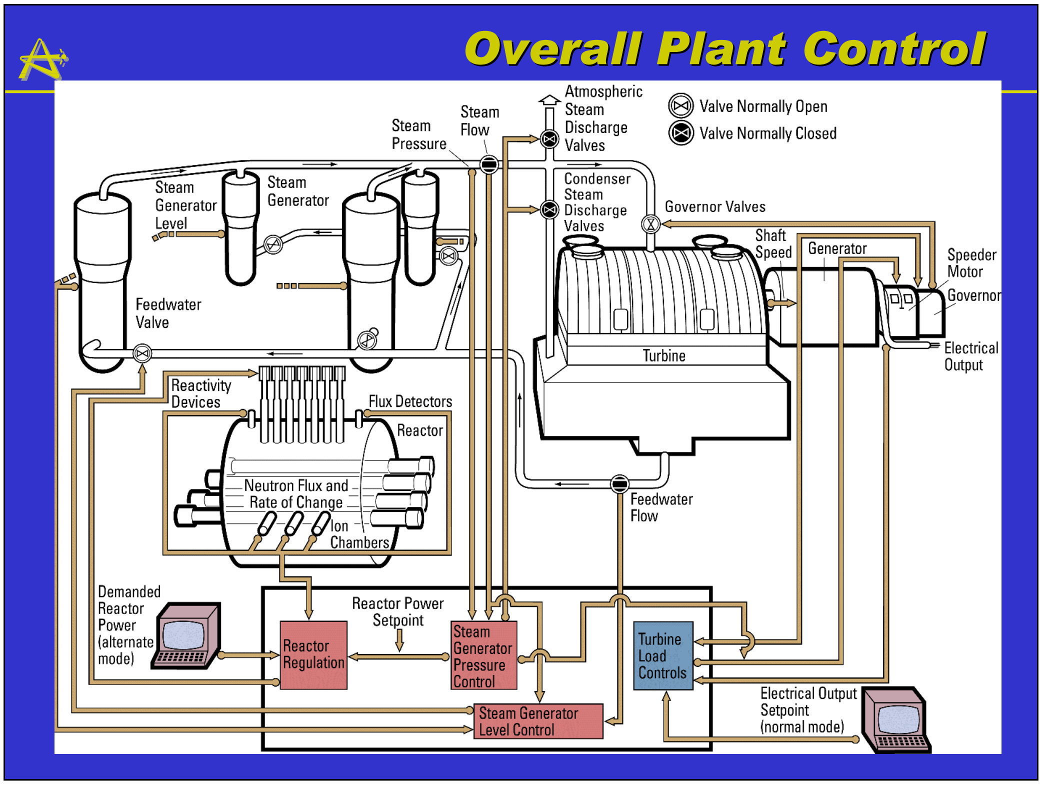
- In the long term, the reactivity of the core and the power shape are controlled by changing fuel. The procedure is to first calculate the effect of proposed fuel changes using a fuel management code located at the station. Flux shapes calculated by this code are verified by comparison with a flux shape measured by the vanadium flux detectors.
- This fuel management code includes an expert system which selects channels with high burnup that are located in regions of the core with lower power level. The fuelling engineer may add criteria based on his knowledge of the reactor state.
- The first operator and shift supervisor make the final selection of each channel to be fuelled. The F/M operator then initiates the semi-automatic fuelling sequence.
- The first level of short-term control elements consists of 14 simple cylindrical tanks which can be filled and emptied with ordinary water. These are assisted by adjuster rods, mechanical control absorbers, and (in rare cases) the addition of gadolinium nitrate solution to the moderator water.
- All control instruments and reactivity control mechanisms are located in the low-pressure, low-temperature moderator.

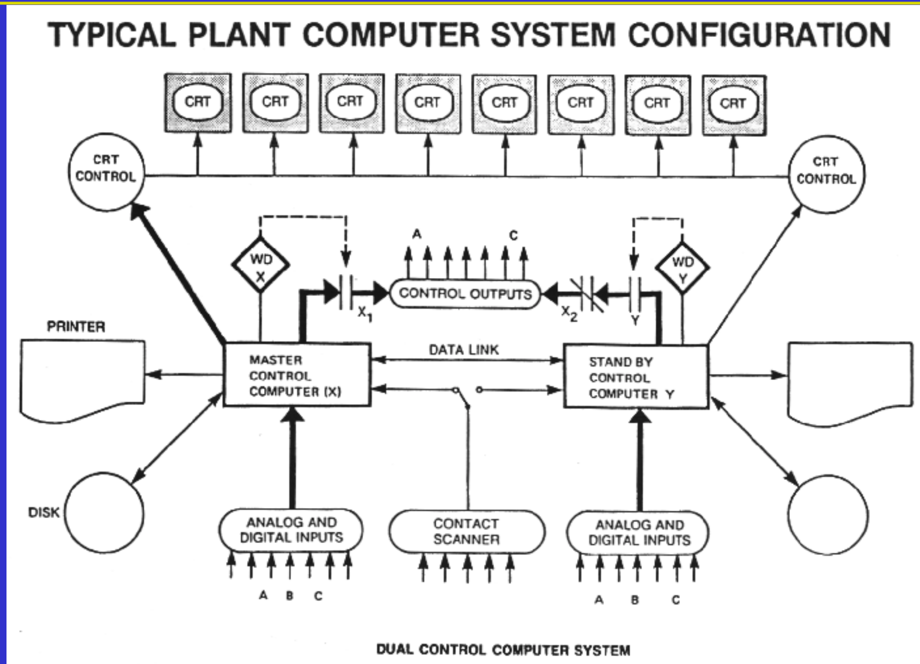


- The first computer-controlled CANDU reactor was Pickering A, put into service in 1971. Since that time there have been many improvements, so that today's CANDU control systems are both very reliable and very capable.
- The reactor is controlled by a small digital computer. This machine has modest speed and storage requirements but must be of very high reliability. The control programs must meet very high quality assurance standards because of the fairly complicated control logic, with the result that there are many conditional control actions which depend on the exact state of the reactor and the control system at the specific moment of time.
- Instrumentation is quite conventional, except that redundancy of instruments is greater than in most industrial applications.

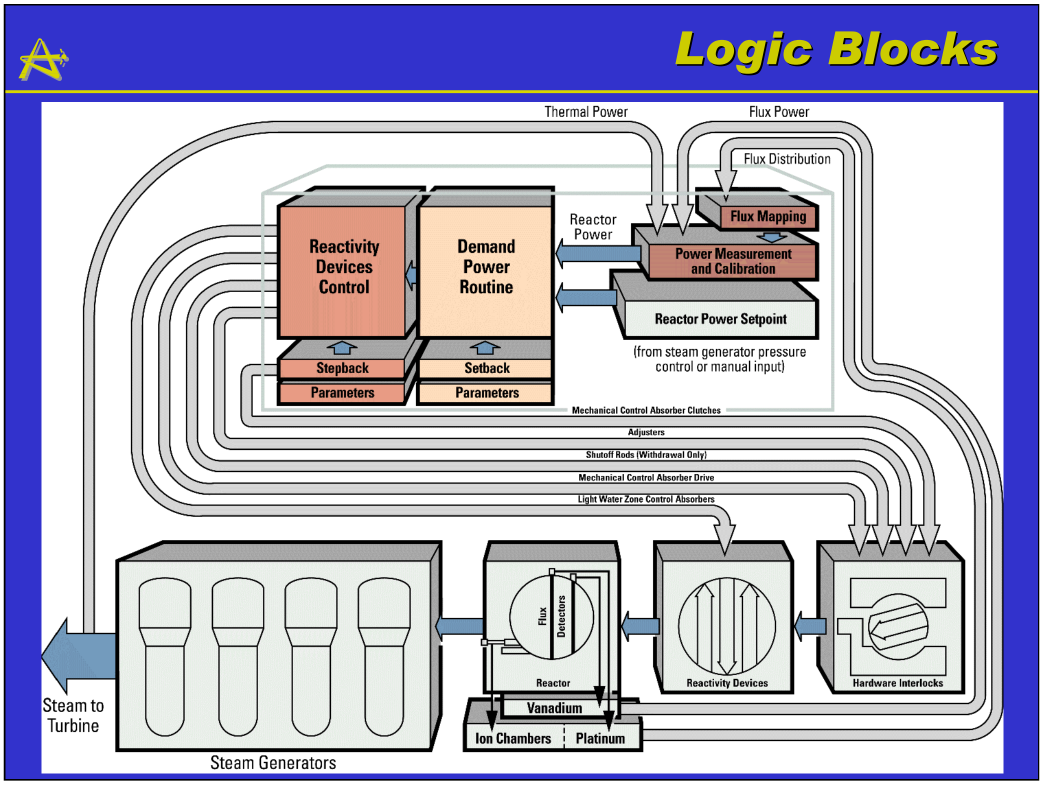


- The small black-line box indicates the control functions located in the station control computer. In addition to the reactor control functions, the computer also controls the steam generator pressure and water level and the turbine load.
- Either the demand reactor power is specified (alternate operation mode) or the electrical output is specified (normal mode).
- The system includes detection of abnormal conditions (such as HT pump shutdown or steam generator high level) and specified control actions which are taken by the control system. One of these actions may be complete shutdown of the reactor (to zero power hot conditions) using the mechanical control absorbers.

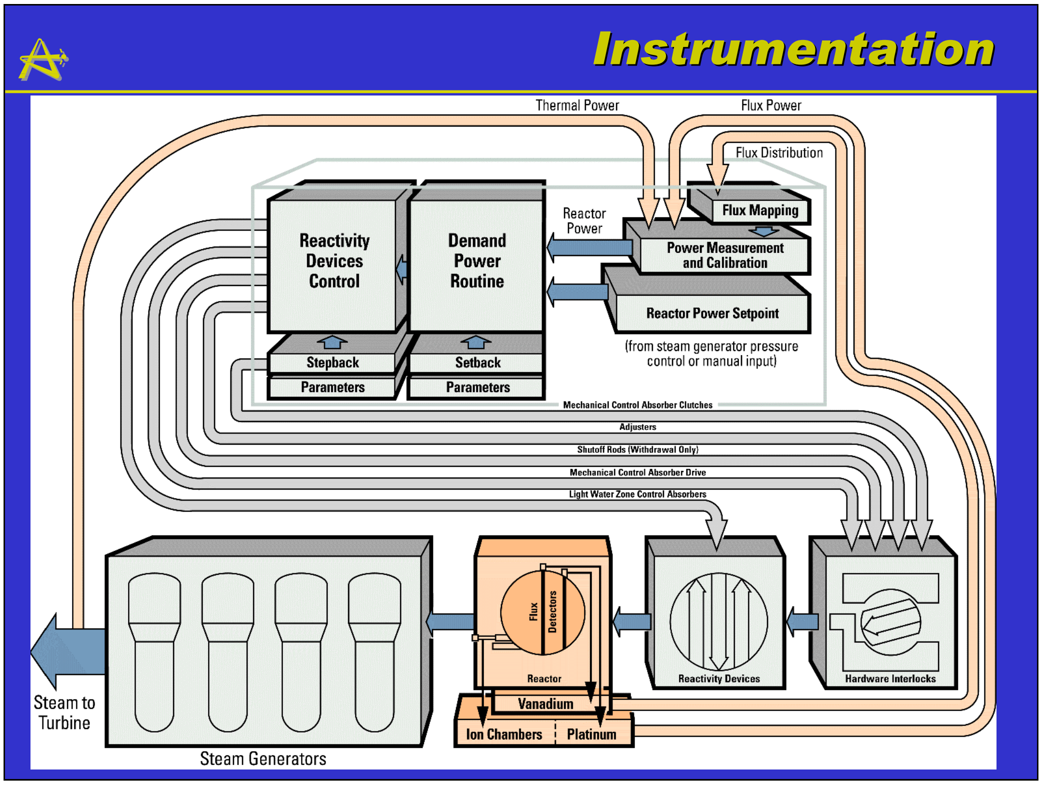
Control Computer Schematic



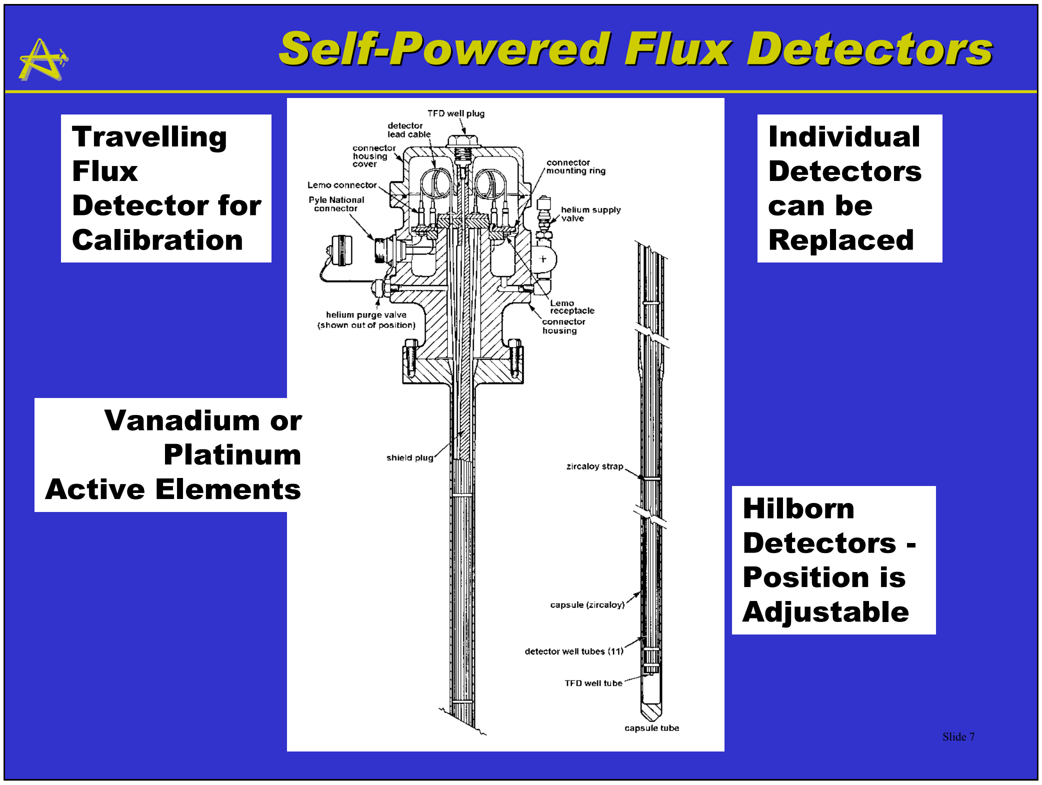
- This simple diagram shows the logical layout of the control computer system and its connections to external systems.
- Though both machines accept input information at all times, only one machine takes control action at any time.



- The logical structure of the reactor control system is shown here.
- Reactor power measurement, calibration, and setpoint are input to the demand power routine, a block or programs which calculate the difference between actual and demanded power and power shape.
- The reactivity devices control block calculates the control actions required to maintain the reactor in the desired state.
- The setback (slow linear decrease) and stepback (fast decrease) routines respond to abnormal condition signals and take action to restore the station to the normal operating domain.



- Instrumentation systems in the reactor and the main steam lines are first used to find the actual power level for comparison with demanded power.



- In-core flux detectors of the self-powered type are distributed in several sets through the core:

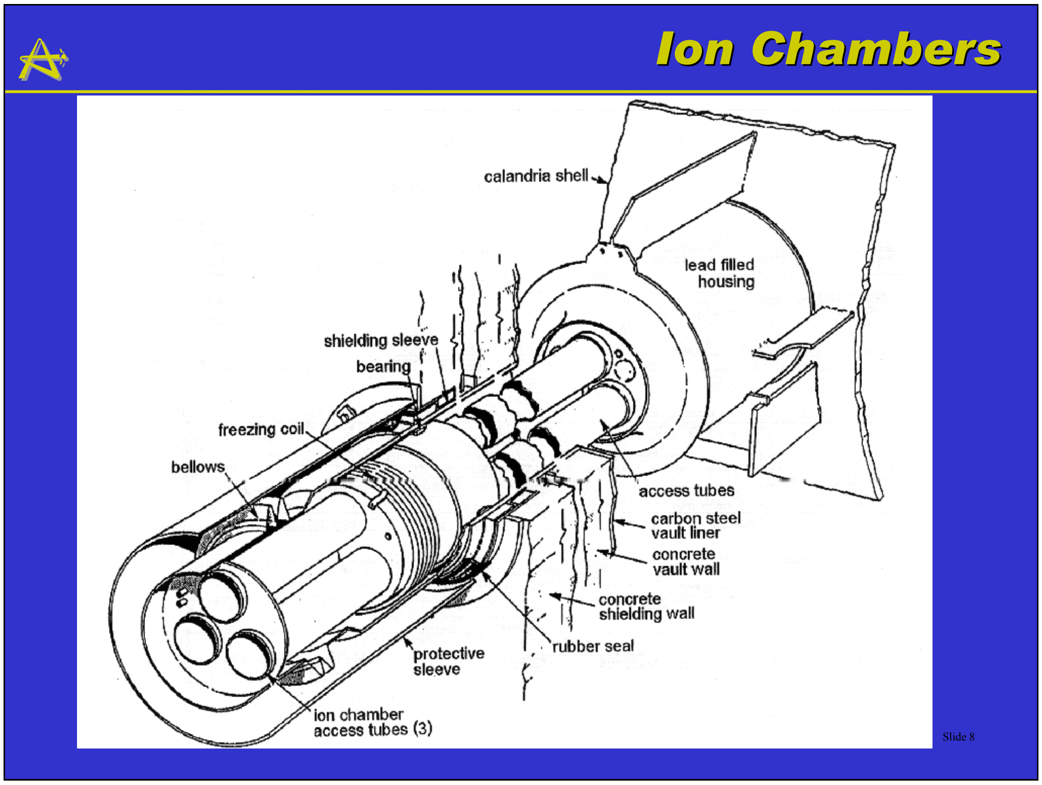
  slow-response Vanadium detectors for flux mapping

  fast-response platinum detectors for zone power, needed by the zone control system

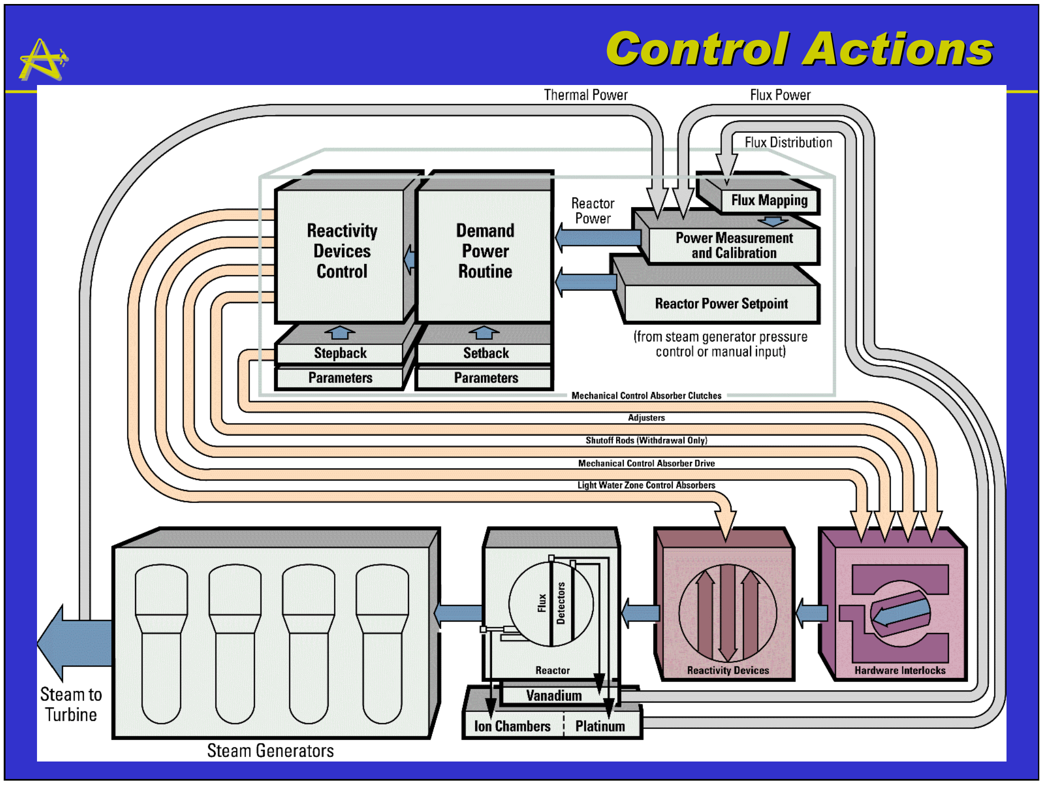
  fast-response platinum detectors needed for local overpower protection on SDS1

  fast-response platinum detectors needed for local overpower protection on SDS2

- These detectors can be calibrated by a movable fission chamber which travels in the detector assembly central hole
- Detectors are replaceable with the reactor at full power

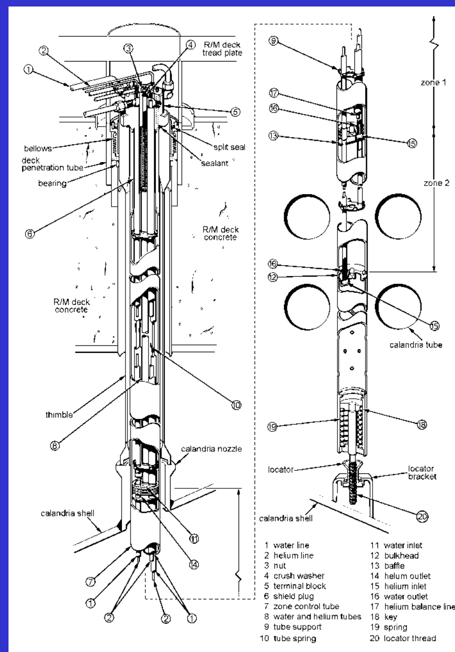


- At each side of the reactor, three ion chamber assemblies are located. In one tube of each assembly is placed an ion chamber connected to either SDS1 or SDS2. The detectors assigned to SDS1 are located on one side of the reactor and those for SDS2 are on the opposite side, to achieve systems separation.
- On one side of the reactor, a second tube of each assembly contains an ion chamber which provides data for the reactor power measurement system.
- The third tube contains either a boral shutter (used for ion chamber testing) or startup instrumentation (necessary under very low signal conditions).
- The assemblies are surrounded by lead shielding to discriminate against gamma rays coming from the reactor.



- Several kinds of control action may be taken. Aside from zone controllers, the rest of these devices are interlocked using hardware interlocks, so that more than one kind of device are <u>never</u> driven in the direction of positive reactivity at the same time.
- Adjuster rods can only be driven slowly, not dropped.
- Mechanical control absorbers either can be driven slowly or they can be dropped.
- Shutoff rods can only be driven out.
- Liquid poison (not shown) can be removed at a limited rate by ion exchange systems. This action cannot be started until the SDS1 rods are out of the reactor and available for use. (It should be noted that it is a requirement in Canada to have at least one fast shutdown system available for use at all times.

Zone Control Unit



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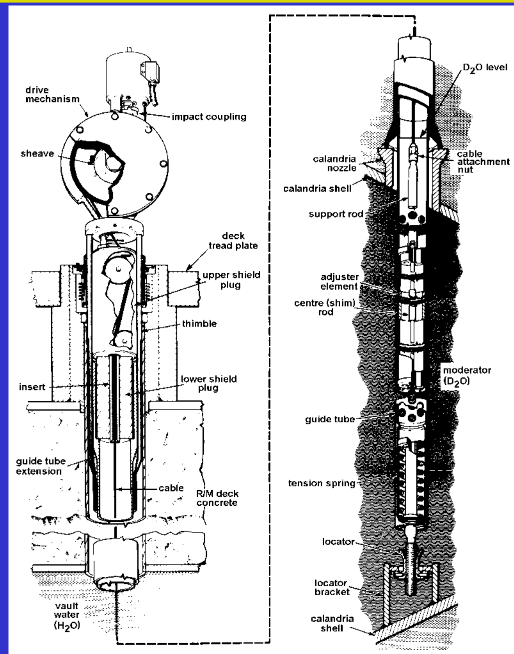
- This shows the detail of a zone control tube. Either two (in the outer core regions) or three (in the central core regions) zone control tanks are located in each tube.
- Water is drained from the bottom of each tank at a constant rate (governed by an external control valve). The filling rate is varied according to the needs of the control system.
- The water level in each tank is measured by a helium gas bubbling system.
- Helium is circulated to a recombiner system to reduce gaseous hydrogen concentrations. Helium pressure is regulated to provide a driving force for the water circulation; external water pumps set this pressure.

Adjuster Rod Unit



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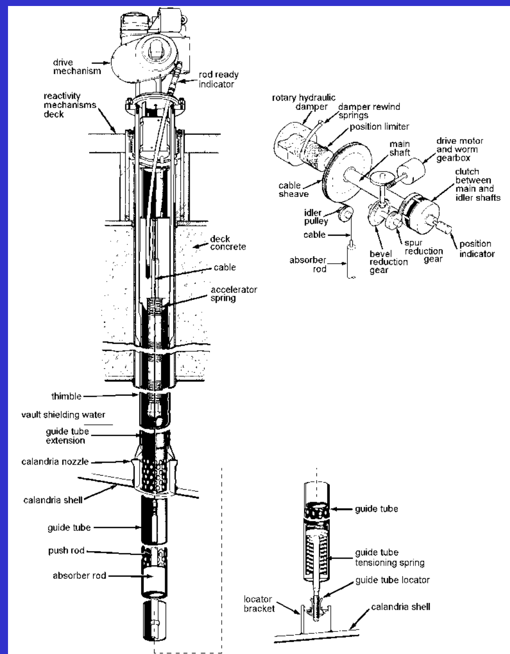
- The absorber material used in adjuster rods is normal stainless steel. Thickness is varied along the length to get the correct flux flattening. Rod length is varied according to the rod's radial position in the core to achieve an approximately flat cylindrical core region. (Flattening is refined by using appropriate fuel management patterns).
- The rods are suspended on a simple cable and are positioned by winding on a sheave. Shock absorbers are located at the bottom of each guide tube in case the cable breaks.
- Adjuster rods can be driven either out of or into the reactor by the reactor regulating system. They are driven in groups of two or four so that the neutron flux shape is maintained as well as possible.

Mechanical Control Absorber



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- The mechanical control absorber (MCA) is the same as an SDS1 shutoff rod, except that it has no spring for fast acceleration.
- Rod drop can be stopped part way to reach whatever final power level specified by the control system.
- The four rods can be driven either in pairs or as a single bank. They all drop simultaneously.
- The four MCA's have a reactivity worth of about -1%, which is sufficient to decrease the CANDU reactor power to hot standby conditions from full power.