

Chapter 6 Control

6.1 Introduction

Although the bulk of the process design of the Heat Transport System is done prior to the control design, it is helpful to have the key features of the control systems in mind while carrying out the process design. In this way, the total design is enhanced.

HTS control is, in principle, quite simple. The system requires control of its pressure, D₂O inventory and temperature. No flow control is required since the HT pumps seek a flow at which the circuit hydraulic losses balances the pump head (as discussed in Chapter 3). Figure 6.1 shows the simplified HT circuit with its main control elements. Figure 6.2 shows in block diagram form, the main control elements.

Pressure is controlled by control of the surge tank (or pressurizer). Pressure is measured at all reactor outlet headers (ROH's). Depending on the details of the control program, the pressure signals define the control input signal. Usually, the maximum pressure signal is chosen since over-pressure protection is an over-riding consideration. If the pressure signal is lower than the setpoint (approximately 10 MPa for the present generation of CANDU's, then the pressurizer heaters turn on. This causes the pressurizer pressure to rise and D₂O liquid is forced out to the HTS, thereby raising the pressure in the HTS. All other things remaining equal, the flow out of the pressurizer causes the level in the pressurizer to drop below the level setpoint. This causes the feed valves to open and D₂O liquid is injected in the HTS. The pressure in the PHTS will rise and D₂O will flow back into the pressurizer.

If the pressure in the ROH should be too high, steam is bled from the pressurizer via the steam bleed valves. The level in the pressurizer will rise and the liquid bleed valves will open to bring the level back to its setpoint. Thus the pressure and inventory control programs are tightly linked. The control designer ensures a proper control system that is stable and minimizes "hunting" or excessive valve movement.

In all CANDU's, the ROH pressure setpoint is held constant. For stations with boiling HTS, swell and shrink of the HTS D₂O is taken care of by the pressurizer (from 0% F.P. hot to 100% F.P. - see figure 6.3) while the D₂O storage tank accommodates swell and shrink from 0% F.P. cold to 0% F.P. hot. This is not the only means, however. Pickering, for example, has no pressurizer. Feed and bleed are used to control the pressure at the ROH. The steam drum pressure setpoint goes down as power goes up. The resulting drop in secondary side temperature causes the primary side RIH temperature to go down so that the average HT temperature remains constant as the ROH temperature rises with power.

So far, pressure and inventory control and flow self-control has been discussed. The one remaining major item is temperature control.

HT temperature control is achieved indirectly via the boiler pressure control. As discussed in Chapter 3, the RIH temperature (or boiler outlet temperature) is closely linked to the secondary side temperature. For a given power, the average HT temperature rides above the average secondary side temperature so that the power (heat) is transferred. The design of the HT requires that the secondary side pressure (and hence its saturation temperature) be chosen such that acceptable HT temperature and quality, if any, result.

While operating at some steady power level, the steam flow from the boilers (steam generators) to the turbine is such that this power is removed from the boilers. The boiler pressure will be constant. If the electrical grid should demand more power, the governor valve will open further to permit more steam to flow to the turbine. The boiler pressure will start to drop. The boiler pressure control will increase the reactor power via a signal to the Demand Power Routine (described in Section 6.5). The increased reactor power increases the temperature differential between the primary and secondary side and increases the boiler heat transfer. This causes the steaming rate to go up and the boiler pressure to rise back to the setpoint. There are many second order effects, not the least of which is the water level in the steam drum. Changes in power and boiler pressure alter the quality distribution in the boiler and the swell or shrink of the boiler. A boiler level controller is thus required. This control is achieved by throttling the feedwater control valves to maintain a level dictated by the level setpoint. The setpoint is a function of power and is usually designed to maintain constant inventory in the steam generator.

This, then, is a quick overview of the main control features for the primary heat transport system.

System dynamics depends on both the system design details and on the controller details. Thus, at least a rough estimate of controller behaviour, especially the boiler pressure control and the boiler level control, is required before system transient performance can be fully checked. More on this in Chapter 9.

Suggested readings are given as references [CHA76, MOR74 and TDSI-105]. The following sections are based on these references.

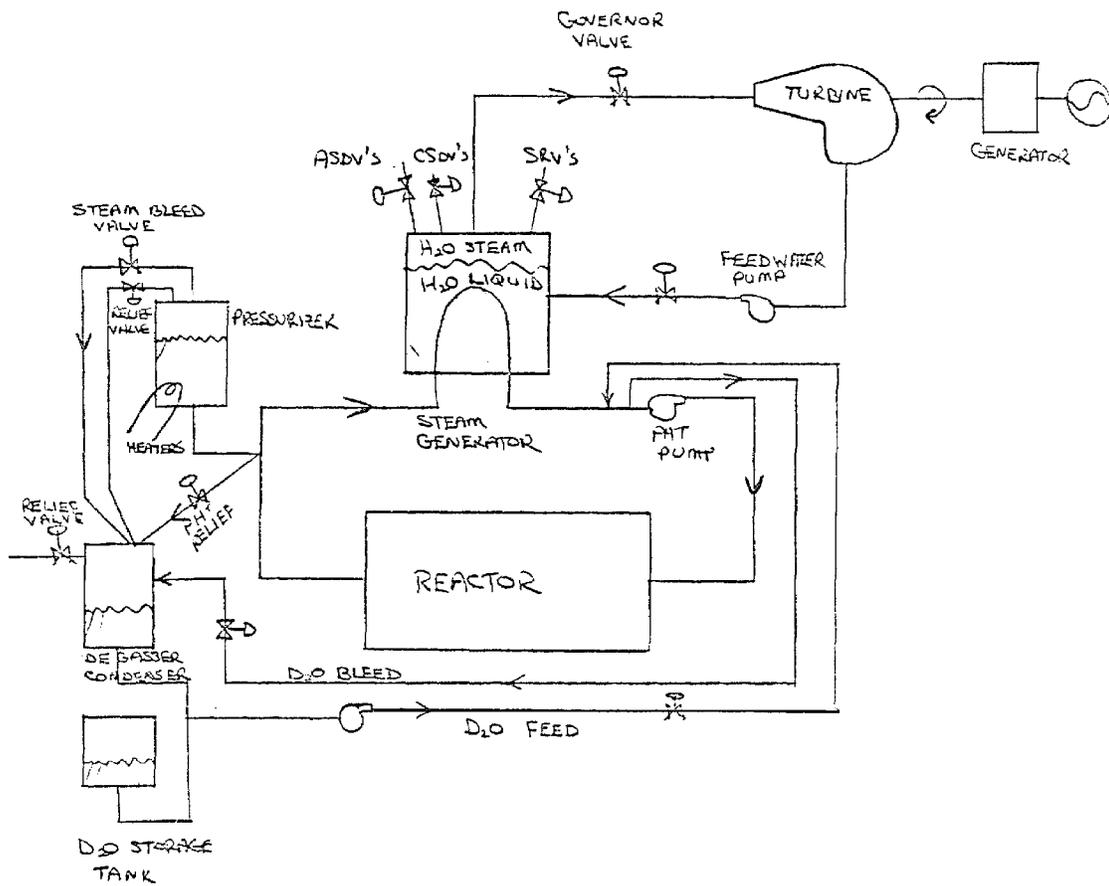


Figure 6.1 Simplified schematic with the main control elements

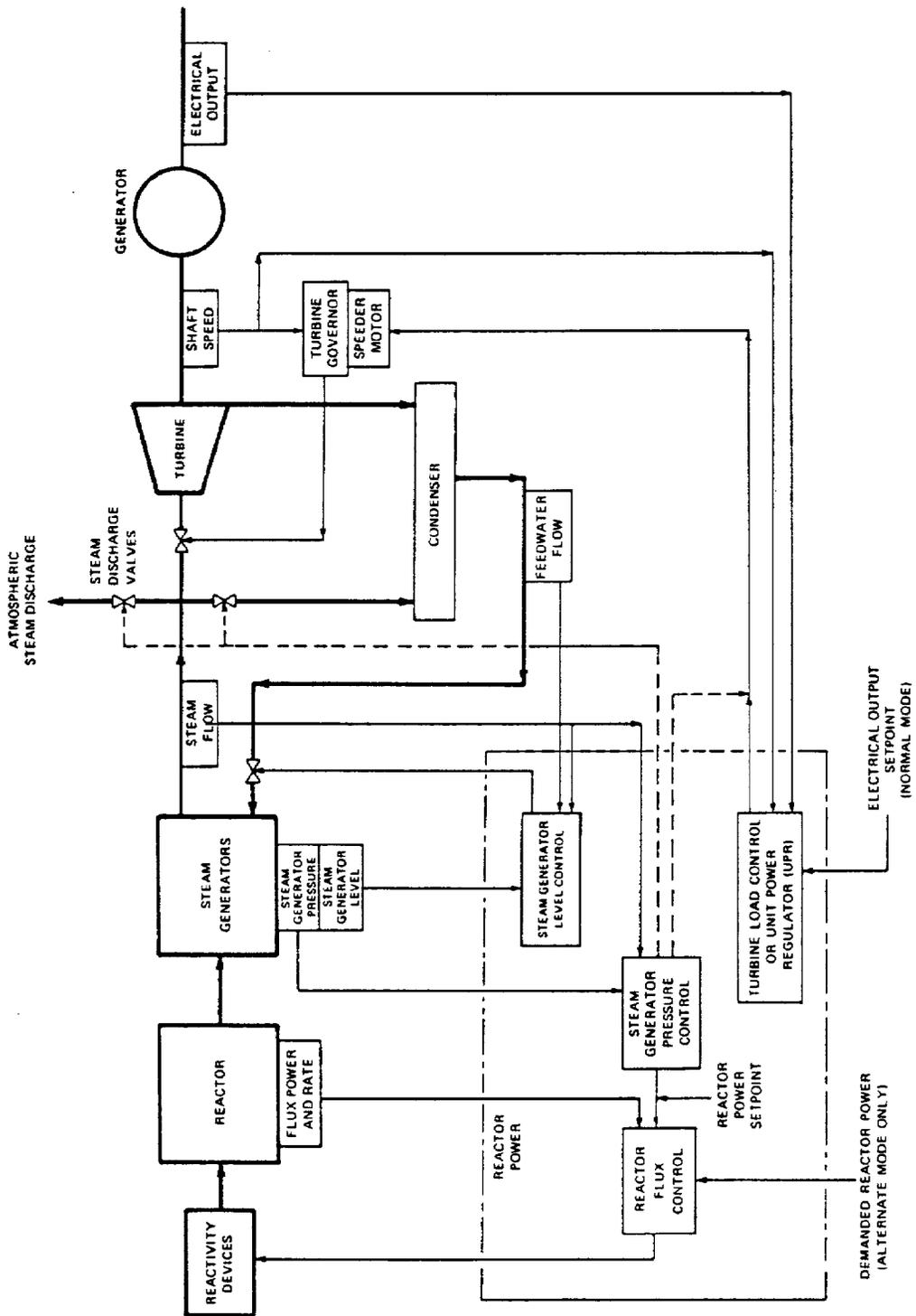


Figure 6.2 Overall plant control - block diagram for a CANDU 600 [Source: unknown]

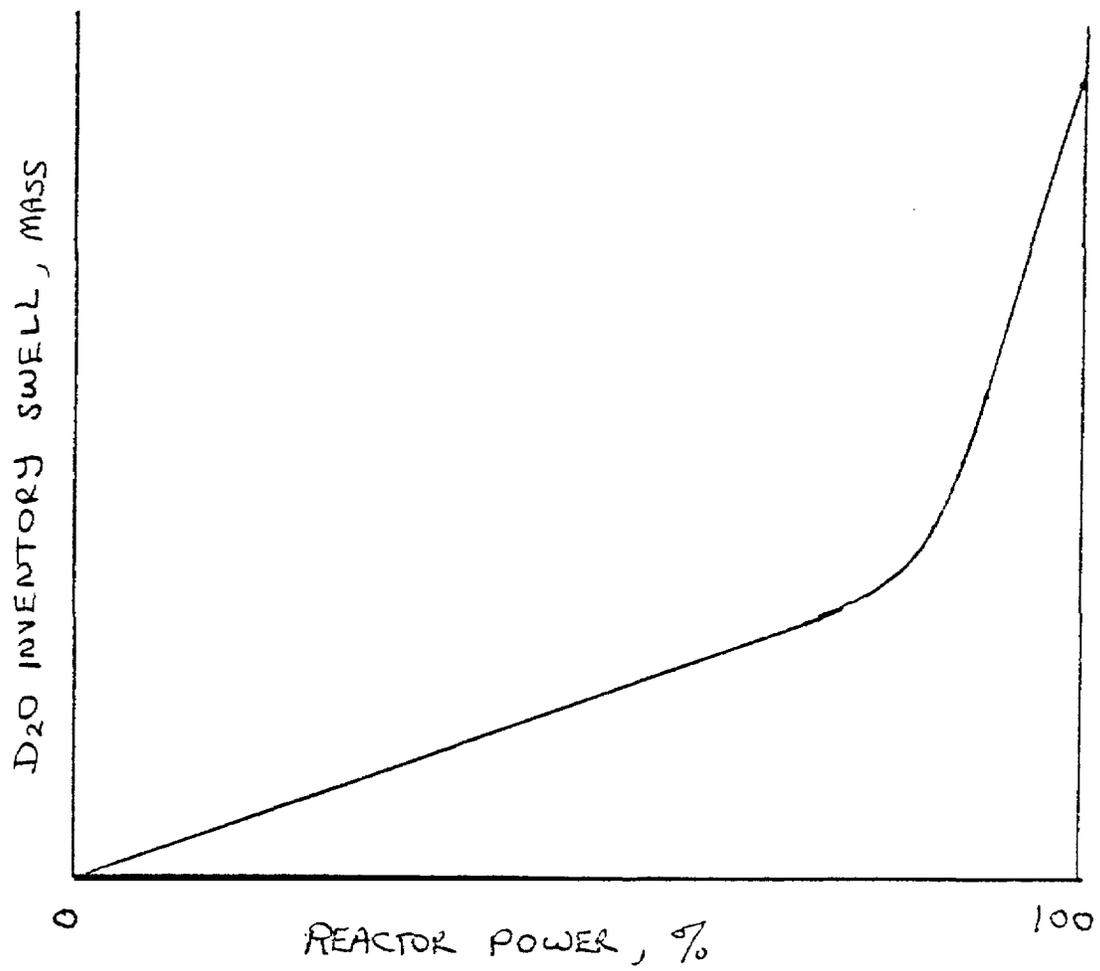


Figure 6.3 Heat transport system swell accommodated by the pressurizer for a typical CANDU 600

6.2 Boiler Pressure Controller

The Boiler Pressure Control (BPC) is part of the overall plant control program, using boiler steam pressure as the main independent control variable. It controls the boiler pressure in the heat transport system warmup and cooldown modes, the hold mode, the turbine after synchronizing mode, the turbine trip and runback modes by manipulating one or more of the following:

- 1) reactor power setpoint,
- 2) atmospheric and condenser steam discharge valves, (ASDV and CSDV), and
- 3) turbine speeder setpoint.

When the reactor Demand Power Routine (DPR) is in the 'normal' modes, BPC raises or lowers the reactor power setpoint to compensate for any boiler pressure error. CSDV or ASDV are only used to trim pressure transients. When DPR is in the 'Alternate' mode, the reactor setpoint is not responsive to BPC, and pressure control is then via plant loads - which are controlled through the turbine speeder, and CSDV, and the ASDV.

The program normally runs at sampling period of two seconds, except during a turbine trip when interrupt occurs immediately.

6.3 Boiler Level Controller

For the CANDU stations there are four boilers in each unit. Each boiler has its own program rules, with its own steam flow, feedwater flow and boiler level control.

To compensate for the swell effect during power manoeuvring, the boiler level setpoint is programmed as a function of boiler power.

At constant reactor power, the steam flow should be the same as feedwater flow plus reheater drains flow to maintain a steady boiler level. The steam flow changes due to either change of turbine power or reactor power. The change of turbine power has immediate effect on steam flow. The error signal between these two flows is sent to the control valve. Any unbalanced mass due to inaccuracy measurement of the flow transmitters and mass loss due to blowdown flow is compensated for by the level feedback control loop.

6.4 Unit Power Regulator

Under normal conditions the Unit Power Regulator (UPR) changes the turbine load by varying the governor valve position. The demand of changes is set by the operator or by the electrical grid. The Boiler Pressure controller then responds to the change in power demand, as discussed in Section 6.1 and 6.2.

6.5 Demand Power Routine

The DPR monitors the power demands by the operator or by the BPC and determines the reactor power setpoint (Demand Power) for the Reactor Regulating System. RRS adjusts the reactivity control mechanisms (liquid zone, absorbers and adjusters) and changes the reactor power.

6.6 Reactor Regulating System

The reactivity control mechanisms used in a 600 MW GS include, (1) refuelling, (2) moderator poison and (3) reactivity control devices.

The reactivity control devices are controlled by the reactor regulating system (RRS) (figure 6.4) which compares the actual (measured) reactor power and power rates with their setpoints and computes the power error. This power error is used to control the following reactivity devices:

- 1) LIGHT WATER ZONE CONTROL ABSORBERS
- 2) ADJUSTERS
- 3) MECHANICAL CONTROL ABSORBER RODS
- 4) SHUTOFF RODS (The shutoff rods are a part of the reactor shutdown system No. 1. Only their withdrawal is controlled by RRS.)

Upon failure of RRS, the following action occurs:

- ADJUSTER drive stops;
- ABSORBER drive stops;
- ZONE VALVE open fully to fill the zone at the maximum rate.

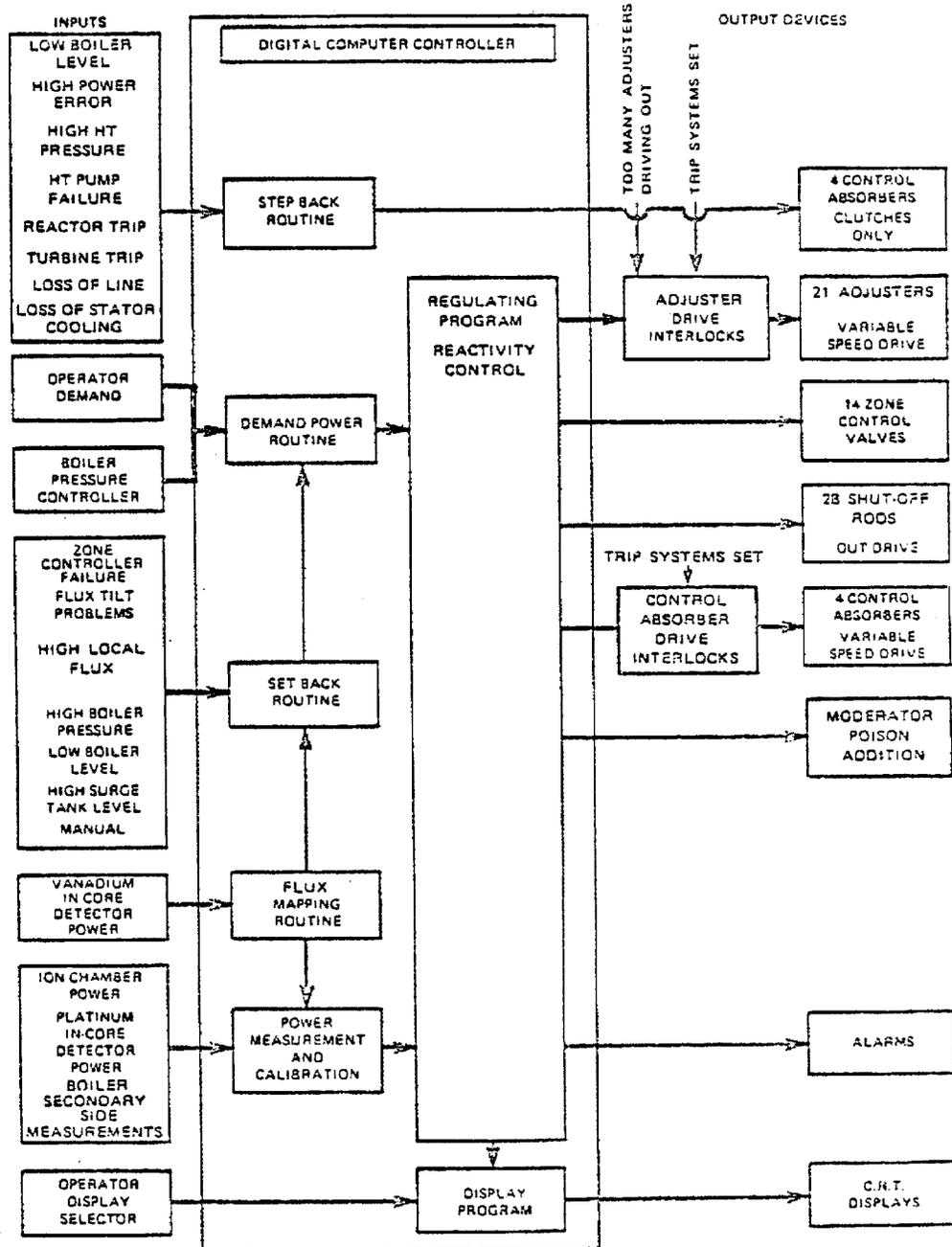


Figure 6.4 Typical CANDU 600 Reactor Regulating System Block Diagram [Source: unknown]

6.7 Pressure and Inventory Control

The 600 MW heat transport system pressure at the reactor outlet header is normally controlled by modulating the pressurizer steam bleed valves and the pressurizer heaters. In case of 'solid' mode operation at low power, the pressurizer may be isolated from the heat transport system. The heat transport system pressure is then controlled by the feed and bleed valves. Four liquid relief valves are provided to protect the heat transport system from over-pressurization.

The D₂O swell from zero power hot to 100% power in the heat transport system is accommodated in the pressurizer, so that if a reactor trip occurs the D₂O is available for immediate return to the heat transport system, thus avoiding main heat transport pump cavitation. The pressurizer level setpoint for controlling the feed and bleed is generated

by the computer program using neutron power, heat transport system outlet header pressure and reactor inlet header temperature. From these variables a heat transport system mass balance is made and a pressurizer level setpoint is derived.

The computer sampling period for heat transport system inventory control is 2 seconds.

6.8 Safety System Control

The shutdown system #1 is the primary method of rapidly terminating any reactor power increase or reducing reactor power when certain parameters exceed preset values. This is accomplished by the release of 28 cadmium rods which fall under gravity from the top of the reactor. This gravity drop is accomplished by de-energizing direct current clutches which normally hold the shutoff rods out of the core. The shutoff rod units are divided into two banks of fourteen. Each bank is supplied with dual 90 volt DC power supply for the clutches. Each clutch coil is held energized by the contact of the separate relay.

The design philosophy is based on triplicating the measurement of each of the variables that can initiate reactor shutdown. Protective action is initiated when any two of the three measurements exceed their present values. The selection of variables is such that where practicable, there are at least two different sensing parameters for the specific process failure being protected against. Examples of trip parameters on shutdown system #1 are high neutron power, high rate log neutron power, high heat transport pressure, high reactor building pressure, low steam generator level, low pressurizer level.

A partial drop test facility is provided to allow the operation of each shutoff unit to be checked during reactor operation. The shutoff unit housings are located on the reactivity mechanism deck which permits regulated, one unit at a time, access to the clutches, motors, potentiometers, gear boxes, and winches for removal or for maintenance on power.

Separately channelled Class I and Class II power supplies are provided for each channel of shutdown system #1. The logic is arranged so that any loss of power to a channel results in a channel trip. The direct current clutches energized by rectified Class II power will release if power is disrupted. This will shut down the reactor.

The static negative reactivity worth of the 28 shutoff rods is about 80 mk.

The second method, shutdown system #2, of quickly terminating any reactor power increase or rapidly reducing reactor power is by the injection of concentrated gadolinium nitrate poison solution into the moderator through six horizontal nozzles. A vessel containing high pressure helium supplies the source of energy for this rapid injection. This vessel is connected through six quick opening valves to a helium header which supplies the poison tanks. The quick opening valves are "air-to-close, spring-to-open" design so that loss of instrument air initiates automatic poison injection. Each of the poison tanks contains gadolinium nitrate solution at a concentration of above 8,000 parts per million. The six zircaloy injection nozzles penetrate the calandria horizontally and at right angles to the fuel channels. Holes are drilled into the nozzle along its length to form four rows of jets which facilitate complete dispersion of the poison into the moderator.

Each poison tank contains a floating polyethylene ball. When an injection is initiated the helium driving gas transfers the poison to the calandria and the ball is driven to the tank bottom. In the bottom position, the ball seats at the poison tank outlet and prevents the release of a large volume of helium into the calandria.

As with shutdown system #1 all initiating variables are triplicated and protective action is initiated by any two of these measurements exceeding preset values.

The eventual negative reactivity from the poison injection system is in excess of 300 mk.