T.T.0-5.637.1

NUCLEAR ELECTRIC G.S. - TECHNICAL TRAINING COURSE

5 - NPD Systems

637 - Reactor Boiler Control

.1 - Reactor Boiler Regulating System

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0. GENERAL

0.1 Functions of Reactor Boiler Regulating System

The primary function of the Reactor-Boiler Regulating System is the control of the reactor to supply the thermal demands of the station, within safe operating limits.

A secondary function is to control the reactor in selected shutdown states when the station thermal demands are zero and to safely and efficiently control the reactor during changes between the shutdown states and the operating state.

0.2 Power Control of Reactors

We know from Nuclear Physics that for a controlled chain reaction

$$P = Poe^{\frac{\delta k \; t}{\ell}} \qquad 1)$$

where Po = Power at time zero

P = Power at time t

δk = k-1, the "reactivity" of the reactor

ℓ = the neutron lifetime

Thus, if we can control δk to both positive and negative values, we can control P. Some further terms require review:

The Reactor Period is a convenient measure of the way in which reactor power is changing and is defined as

$$T = t \text{ for } \frac{P}{Po} = e$$

$$\text{i.e. } \frac{\delta k}{\ell} T = 1 \quad \text{or} \quad T = \frac{\ell}{\delta k} \qquad 2)$$

A more readily measured value related to reactivity is the rate of change of the logarithm of power, as this may be measured instantaneously using a logarithmic amplifier and a differentiating circuit.

$$\text{From 1) and 2)} \quad \frac{P}{Po} = e^{\frac{t}{T}}$$

$$\ln \frac{P}{Po} = \frac{t}{T}$$

$$\frac{d}{dt} (\ln P - \ln Po) = \frac{d}{dt} \left(\frac{t}{T} \right)$$

$$\frac{d}{dt} \ln P = \frac{1}{T} \qquad 3)$$

$$\text{or} \quad \frac{d}{dt} \ln P = \frac{\delta k}{\ell} \qquad 4)$$

Thus we see that the rate of change of the logarithm of power (often abbreviated to Rate Log Power) is equal to $\frac{1}{T}$ and is directly proportional to δk.

Examples

$\frac{d}{dt}\ell nP \left(\% \text{ sec}^{-1}\right)$	T (sec)
1	100
2	50
4	25
10	10

0.3 Reactivity Control

Recall from Reactor Physics that

$$k_{eff} = k_{\infty} - \text{leakage}$$

$$= \eta \epsilon p f - M^2 B^2 \quad \text{for large reactors} \qquad 5)$$

where: η = the number of fast neutrons produced from fission per thermal neutron absorbed in the fuel

ϵ = the total number of fast neutrons produced from fission divided by the fast neutrons produced from thermal fission.

p = the fraction of fast neutrons which reach thermal energies.

f = the fraction of the neutrons reaching thermal energies which are absorbed in the fuel.

M = the average distance travelled by a neutron before capture.

B^2 = Buckling - a factor which is inversely related to the square of the linear dimension describing the reactor size. (e.g. radius, for a sphere).

Thus anything which changes any of the above factors changes keff and will result in a change in the reactor power.

Without going into the details of various methods of control and how they affect the above factors, we should note that in NPD the primary control is by changing the size of the reactor - i.e., by varying B^2 we change the leakage term in equation 5). The relationship between reactivity and moderator level in NPD is shown in Figure 1 (Critical at full tank).

0.4 Moderator Level Control - NPD (Figure 2)

The heavy water moderator is pumped at a constant rate from the dump tank to the calandria and flows back through the dump port to the dump tank. The amount of heavy water which is retained in the calandria is determined by the pressure difference between the surface of the moderator and the dump tank. This pressure differential is established by helium pumps and is controlled by the regulating system control valves. Note that the maximum rate of increase of moderator level is determined by the capacity of the helium pumps while the maximum controlled rate of decrease is determined by the capacity of the control valves in excess of that of the helium pumps. The capacity of the moderator pumps has no effect providing it is enough to supply at least the volume required for increasing level. The helium pumps are sized to limit the maximum rate of reactivity increase to $\angle$ 0.29 mk/sec. With only one helium pump operating the level may still be raised but control is very sluggish.

Six control valves are arranged in an array as shown in Figure 3. This results in three virtually independent channels of control, the failure of any one of which will not result in loss of control. The valves are sized so that each branch of two valves has a capacity twice that of the helium blowers; thus, with two branches failed closed, the maximum controlled down-rate is at least equal to the maximum controlled up-rate. (Although this criterion was used in design, its significance seems to have been lost in history).

If we assume a constant helium pump capacity and reference gas conditions there will be a unique relationship between average control valve position and steady state moderator level. This relationship is quite sensitive to changes in cover gas density and is noticeably affected by increased water vapour at high moderator temperatures or by increased nitrogen concentration due to air in-leakage to the helium system. The relationship between average valve position (equilibrium valve position) and moderator level is shown on Figure 4.

0.5 Power Measurement

If reactor power is to be controlled and if it is to enter into the regulating system in any significant way, then it must be measured with reasonable accuracy and with short time constant instrumentation.

One of the most obvious methods of measuring thermal power is to calculate it from mass flow and temperature rise measurements. If the flow and specific heat of the heat transport fluid are constant, then ΔT may be used directly as a measure of thermal power. However, time constants of several seconds are involved and this is not a satisfactory response for reactivity control.

Steam flow from the boiler is also an indication of the thermal power delivered to the boiler but is only applicable to steady state conditions.

Reactor power is determined by the neutron flux in the reactor. Neutron flux at a detector may be measured accurately and with suitable instrument response times; however, it is important that the flux at the detector be representative of the flux over the whole reactor. In NPD we define the <u>sensitivity</u> of the measuring devices (ion chambers) as:

$$S = \frac{\text{Output/unit power}}{\text{Output/unit power at reference conditions}}$$

S, of course, varies with the distribution of neutrons in the reactor. Since the ion chambers measure the flux at three similar positions near the bottom of the reactor (Figure 5) the major influence on sensitivity is variation in moderator level. Other factors which change S are the fuel loading and the position of the booster. The reference condition for any fuel loading is with moderator level at full tank (175").
Thus

$$S = \frac{\text{ion chamber current/unit power}}{\text{ion chamber current/unit power with moderator at 175"}}$$

The theoretical relationship between S and moderator level is shown in Figure 6 together with a measurement taken with a recent fuel loading situation.

The method used at NPD to obtain a useful measurement of reactor power involves measuring neutron flux as the primary variable and then calibrating it (or compensating it) to be equal to the thermal power as determined from steam flow and/or ΔT. For the relatively small variations in moderator level that are required for power control, the response and accuracy of the neutron detection system are adequate and the relatively slow changes which require re-calibration of this system may be effected using long time constant instruments or by manual adjustment. The implications of improper manual compensation of the neutron power instruments will be discussed later.

The automatic compensators installed in NPD have been unsatisfactory due to the varying transient response of their temperature sensing devices and mechanical components. Manual adjustment of these compensators has been used since startup. A more satisfactory method of manual compensation has been studied and will be installed, with individual channel controls on the control console.

0.6 Thermal Demand Assessment

The reactor-boiler must be controlled to supply the thermal demands of the turbine-generator - i.e., to supply sufficient steam to carry the load and to do so at proper steam conditions. (At NPD the primary control of station output is the positioning of the turbine governor speed changer).

Thus the power demanded of the reactor boiler is:

Demand Power = Steam Flow + Steam Pressure Error.

0.7 Limitations on Reactor Boiler Performance

1) Fuel

The primary limitation on reactor power is the limit of ability to remove the heat from the fuel. This results in two practical limits.

1. The fuel must not be over-rated, therefore a maximum power per fuel channel has been set.
2. In the present design of NPD the heat transport fluid must not be allowed to boil, therefore a maximum fuel channel outlet temperature has been set.

Note that the above limits are limits on fuel channels and not on reactor power itself. It is clear that the permissible reactor power will vary with moderator level, for two reasons:

a) At low levels the centre of the core and hence the peak heat output is lowered so that lower channels may be producing a greater proportion of the power than they were designed for. (They may have either 7-element fuel or lower coolant flow or both).

b) At very low moderator levels the power is being produced by fewer channels, the upper channels being out of the moderator.

Figure 7 shows the Permissible Reactor Power v.s. Moderator Level for an equilibrium fuel loading.

2) Rate of Power Increase

To prevent overshoot when starting up from low power, it is important to limit the rate at which reactor power increases.

In fact the rate of rise of the logarithm of power is limited, which is effectively a limit on the reactor period or reactivity. (See section 0.2). Rate Log Power is readily measured, even at extremely low powers (several decades below rated power).

3) Warming Rate

Thermal stresses set up in the heavy components of the heat transport system dictate that limits be placed on the rate of change of temperature of the heat transport fluid. The permissible rate is higher at operating temperatures and is not a major limitation except during startup.

4) Miscellaneous Limits

In addition to the fundamental limits described above, the nature of the regulating system will impose certain other restrictions on the system operation. These will be noted in discussion of the regulating system proper.

1. REACTOR-BOILER REGULATING SYSTEM

1.0 General

a) The reactor boiler regulating system is a "high gain proportional control" system. Thus there is one set of reference conditions at which the system controls all variables to their set points; at all other conditions there will be an "off-set" in the controlled variable. The high gain implies that a minimum off-set is required to restore equilibrium. The most significant of the reference conditions for power operation are:

Moderator level - 165 inches
Moderator temperature - 100°F
Cover gas - helium

Under these conditions the average control valve position is 35% open and the steam pressure will be at its demanded valve (i.e. steam pressure error = 0). Under all other conditions a steam pressure error will exist.

b) The regulating system is triplicated, consisting of three virtually independent regulating channels each controlling a non-series pair of control valves. In the event of failure of any one channel satisfactory regulation is maintained by the other two. Output signals from the three channels are compared by Interchannel Comparators which act to reject any channel which disagrees significantly from the other two.

1.1 Functional Description by States

1.1.1 Manual Operating State

In this state instrument air is supplied directly to the control valve loading stations which are on "Manual" so that the valves may be positioned manually without interference from the regulating system. The conditions for which manual control is permitted are restricted by administrative policies.

1.1.2 Shutdown State

In the shutdown state all signals from the regulating system are disconnected from the control valves and their power air is vented so that they are open.

1.1.3 Low Moderator Level State

As a preliminary stage in starting up a reactor, it is desirable to check the operation of the control ion chambers - as a minimum to see that they are "on scale". Thus in the low moderator level state the moderator is controlled at a level above the ion chambers, but well below the minimum critical height. This control is effected by the circuit shown in block form in Figure 8. The discriminator compares a moderator level signal with a level set point (demand) and produces an output proportional to the excess of level over set point. In the absence of any such signal ($H \leq H$ set), demands from the remainder of the regulating system will cause the valves to be closed. Thus the moderator level control signal is an over-ride causing the valves to open until an equilibrium is set up between the moderator level, the valve position and the moderator level set point. Note that this moderator level will always be above the set point, the amount of this error is determined by the gain of the system. (i.e. the demand change in valve position per inch of moderator level over set point).

Rather than disconnect any of the above signals when it is desired to raise moderator level beyond the low moderator level control point, a high set point is connected to eliminate the output from the discriminator (Output zero for $H \leq H$ set).

1.1.4 Low Log Power State

In transferring from the low moderator level state to power control, it is desirable to pass through an intermediate state in which the reactor is controlled at a negligible thermal power but at a power sufficiently high that the reactor is normally critical and therefore poised to raise power with a minimum delay. Radiation levels at this power are low enough to permit access to the boiler room.

In the low log power state the reactor is controlled by the circuit shown in block form in Figure 9. The operation of this circuit is identical to the low moderator level control circuit except that two over-ride circuits are active. Valves are opened by either Log Power exceeding the Log Power set point or Rate Log Power exceeding the Rate Log Power set point. The former determines the power at which the reactor is controlled in this state, while the latter limits the rate at which the transition is made from the moderator level state. (As shown in section 0.2, limiting the Rate Log Power limits the reactivity and hence the reactor period).

Note that there is no rate log high set point - this over-ride remains active in all modes of control but is normal effective only in the low log power and high power modes. (In the original design, it was made inactive in the low moderator level control mode to avoid instability as the ion chambers were covered. In practise no such instability exists and so the high set point feature has been removed although it still appears in some drawings and manuals.).

1.1.5 High Power Control State

The control system used for high power control is made up of two control loops.

In the first loop steam pressure is compared with the steam pressure set point and the error is added to a steam flow signal. The resulting output is the "thermal power set point" and represents the thermal demands of the turbine generator.

In the second loop the thermal power set point is compared with a measure of the reactor thermal power and the error is used to position the control valves. It should be noted again that there is only one control valve position corresponding to zero error in this loop; all deviations from this position are proportional to the error existing.

Safety limits are obtained by various over-rides and limits and these will be discussed as part of the section in which they act. The computer control system will now be described in general terms, section by section, with reference to Figure 10.

SECTION I

Section I is the steam pressure error computer and its output is proportional to the difference between the steam pressure set point (manually set from the control console) and the steam pressure. This output acts through the rest of the control system to tend to eliminate this error. This output is added to steam flow to produce the thermal power set point, thus it is the thermal power demanded for the warming and loading of the station. During plant warming with constant steam flow, the fuel, heat transport fluid, piping, boiler and feedwater are all heated at the same rate. To limit thermal stresses the rate of warming is limited to 200°F/hr. The reactor power calculated to achieve this warming rate is 6% of rated power. The output of Section I is therefore limited to an error which will produce a change in the thermal power demand of ±6% during warming of the station.

During station loading, essentially only the fuel and heat transport system are being heated, the feedwater and the boiler holding a relatively constant temperature. The reactor power calculated to heat the fuel and coolant at a rate corresponding to loading the plant at the maximum allowable rate of 20% of rated power per minute is 12% of rated reactor power. The output of Section I is therefore limited to ±12% during plant loading.

The transition from warming to loading limits is carried out automatically when the reactor outlet temperature exceeds 430°F.

SECTION II

Section II sums the output of Section I and measurements of steam flow to compute the thermal power set point. Also included in its inputs is a "warming trim" which permits the operator to manually trim the thermal power set point by ±4% to correct for inaccuracies in the automatic control circuits.

The output of Section II is limited to thermal power demands between 5% and the "Permissible Power". The 5% lower limit is required for stability of the system. The Permissible Power upper limit is computed as a function of moderator level as described in section 0.7 and is shown on Figure 7. The Permissible Power is reduced or cut back by approximately 10% of permissible power if the outlet temperature of any fuel channel exceeds a preset limit.

SECTION III

In Section III the actual reactor power is compared with the thermal power set point computed in Section II. This error, expressed as a demanded change in valve position is added to a 35% open bias to give a demanded valve position or "% valve stroke demand". It is this 35% open bias which results in a moderator level of 165 inches for zero difference between reactor power and thermal power set point. This section also has an input from a coolant temperature override circuit which acts to demand "valves open" if the reactor outlet temperature exceeds a "Hot Leg Temperature Set Point".

The output of Section III is not limited in the sense that valve stroke demands are restricted to less than is available physically, but it is effectively prevented by the output circuitry from demanding over-closure of valves. This is done so that over-rides operating in Section V are not swamped by over-close signals from Section III.

SECTION IV

Section IV produces an output which tends to open the control valves when the rate of increase of log power exceeds a set point. The output is proportional to the excess of log power over its setpoint and operates as an over-ride on Section V. It is effective in all control states and was previously described in Section 1.1.4, Low Log Power Control.

SECTION V

Section V mixes the output from Section III (Valve Stroke Demand) with over-ride signals from the rate log, log N and moderator level circuits. The output of section V goes to two parallel control channels - sections VII and VIII which each control one of the pair of control valves associated with the regulating channel.

SECTION VI

Section VI compares the Section V output from the three channels to detect, by coincident disagreement, the failure of one channel. Three comparators are used to compare pairs of channels. When two comparators operate a failed channel is indicated by its disagreement with the other two channels and after a 10 second time delay a relay is de-energized to open the valves on the "faulty" channel. If the third comparator operates indicating complete disagreement of the three channels, the reactor is tripped. This tripping feature is currently being reviewed and will probably be removed as it has caused a number of unnecessary trips and is of doubtful value from a safety point of view.

SECTIONS VII and VIII

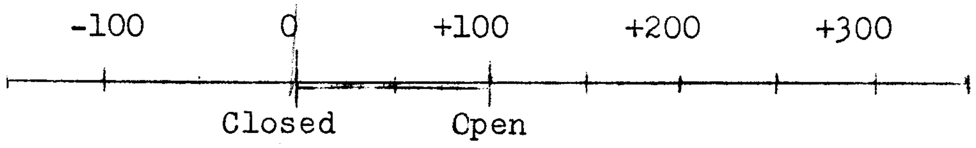
Sections VII and VIII generate a demanded valve position from the output of Section V such that over the range of 8% to 92% valve opening there is a linear response. Beyond this range the gain is reduced by a factor of 20 such that for any normal channel disagreement the valves will remain at least 4% from their closed or open limits. This keeps the valves "live" to permit monitoring for valve failures.

SECTION IX

Section IX compares the valve stem position for the two valves of the channel. If the disagreement is excessive an alarm sounds and if disagreement occurs on all three channels the reactor is tripped.

1.2 Valve Stroke Demand Convention

It is important that a consistent terminology be applied to describe the valve stroke demand by various sections of the regulating system, as over-closed and over-open demands are possible. The line diagram below defines this terminology:



1.3 The Regulating System - Block by Block Description

1.3.0 Operational Amplifiers

The operational amplifiers used in the NPD regulating system may be treated as "black boxes" whose gain is a function of the ratio of feedback to input impedances only and is independent of the gain of the amplifier proper. Various types of limiting circuits are used to effect the limits on output. Details of the amplifiers and their gain and limit circuits are described in Design Manual 637.1 section 2.4-7. It is sufficient for this lesson to understand that the amplifier is a simple computer with input output relationships which may be expressed either as voltages or in terms of the physical parameters represented; for example, the output of the steam pressure error computer may be expressed in terms of

a) volts

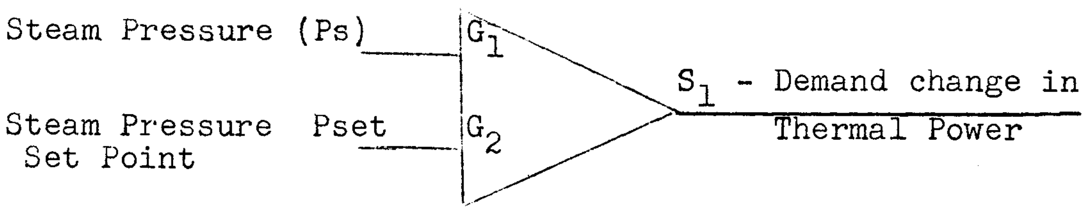
or b) steam pressure error

or c) demand change in thermal power

or d) demand change in valve position

The relationship between a particular input and the output of the amplifier is referred to as GAIN and the complete equation describing the relationship of all inputs and outputs is called the TRANSFER FUNCTION.

For example consider the steam pressure error computer.



$$S_1 = G_2 \text{Pset} - G_1 P_s$$

For $G_1 = G_2 = G$

$$S_1 = G(\text{Pset} - \text{Ps})$$

Now $G = \frac{1\%}{\text{psi}}$ for $N > 20\%$

$\frac{0.5\%}{\text{psi}}$ for $N < 20\%$

Thus we say that the <u>gain</u> of this computer is <u>one</u> for reactor powers $>20\%$ and <u>0.5</u> for powers $< 20\%$ and <u>the Transfer Functions</u> for this computer are:

$S_1 = \text{Pset} - \text{Ps}$ for $N_c > 20\%$

$S_1 = 0.5(\text{Pset} - \text{Ps})$ for $N_c < 20\%$

1.3.1 Steam Pressure Error Computer (Block 1)

As noted in the examples above, the steam pressure error computer subtracts steam pressure from the steam pressure demanded by the setpoint; the output is the steam pressure error which is used as an input to the thermal power setpoint computer and may therefore be expressed as a demanded change in thermal power.

Transfer Function: $S_1 = \text{Pset} - \text{Ps}$ $(N > 20\%)$
$S_1 = 0.5(\text{Pset} - \text{Ps})$ $(N < 20\%)$

Limits on S_1: $\pm 6\%$ $T_H < 430^\circ F$
$\pm 12\%$ $T_H > 430^\circ F$

Ranges: Ps 100 to 500 psig
Pset 50 to 450 psig

Inputs: The steam pressure input is derived from a slide wire on the steam pressure recorder while the set point is picked off a manually positioned potentiometer. One potentiometer is provided for each channel but the three are mounted on a single shaft and are located on the control console.

1.3.2 Thermal Power Set Point Computer (Block 2)

This computer sums the steam pressure error (S_1) and steam flow (F_s) demands together with a warming trim (T_R) to give a demanded thermal power or Thermal Power Set Point. All inputs and the output are normally expressed in terms of % of rated power.

Transfer Function: $S_2 = F_s + S_1 + T_R$

Limits on S_2 : $5\% < S_2 <$ Permissible Power (Np)

Permissible power is reduced 10% by high channel outlet temperature.

The permissible power limit is computed from moderator level in accordance with the relationship shown on Figure 7. This relationship is cut into a cam on a moderator level recorder. The difficulty in co-ordinating this function with the Linear Power Trip (also a function of moderator level) is discussed in Section 2.

Ranges:

F_s 3% to 117%

T_R ± 4%

Inputs: To obtain suitable accuracy over the range, two measurements of steam flow are made, the first covering the range 3% to 25% rated power and the second covering the range from 25% to 117%. The input signals are generated by retransmitting slide wires on steam flow recorders.

The warming trim input is via a potentiometer which, like that of the steam pressure set point, is mounted on the common shaft with those for the other two channels. The trim is manually positioned at the control console.

1.3.3 Thermal Power Error Computer (Block 3)

In Block 3 the demanded thermal power is compared with the actual thermal power and the difference is used to position the control valves. A 35% bias is added so that in the absence of a thermal power error (Nset = Nc) the valves will be 35% open, the estimated position for 165" moderator level. An over-ride also operates in this computer to effectively reduce the thermal power set point if the reactor outlet temperature (T_H) exceeds a set point (T_{Hset}). Although it is not immediately apparent from the transfer function of this computer, it is possible to express the output in terms of the eventual affect on valve position - the % valve stroke demand (% VSD). When so expressed, it is apparent that a change in the difference between Nc and N_{set} of 1% results in a change of 10% in VSD for $N > 20\%$. A similar thermal power error results in 20% VSD for $N < 20\%$. Each degree of $T_H - T_{set}$ results in 20% VSD regardless of power level (however, it is extremely unlikely that the T_H over-ride would operate except near rated power).

It was noted in the general discussion (section 1.1.5) that the output of Block 3 must be effectively limited to positive valve position demands so that it does not swamp the over-ride signals of Block 5 with over-closed demands. At the same time it is desirable to monitor the complete regulating system with the Interchannel Comparators and this would not be meaningful if one or more of the channels were "saturated" at valves closed demand. The method employed to resolve this problem relies on the fact that the operational amplifiers act as signal inverters. Therefore, as long as the Block 5 amplifier is in its linear range, any signal from Block 3 calling for over-closure of the valves will be transferred to Block 5 output, but with opposite voltage polarity. Now by summing the over-closure demand of Block 3 with its inverted equivalent of Block 5 at the input to Blocks 7 and 8, complete cancellation results. Thus the output stages of the computer are still unable to demand over-closure of the valves even though such a restriction is not placed on Blocks 3 and 5. The only reason why limits are actually provided is to guarantee operation as described by ensuring that Block 3 saturates before Block 5.

Transfer Function:

$$S_3 = 2(N_c - N_{set}) + 4(T_H - T_{Hset})_{+only} + 7 \quad (N > 20\%)$$

$$S_3 = 4(N_c - N_{set}) + 4(T_H - T_{Hset})_{+only} + 7 \quad (N < 20\%)$$

Taking into account further gain of 5 in Block 7 and 8

$$VSD_3 = 10(N_c - N_{set}) + 20(T_H - T_{Hset})_{+only} + 35 \quad (N > 20\%)$$

$$VSD_3 = 20(N_c - N_{set}) + 20(T_H - T_{Hset})_{+only} + 35 \quad (N < 20\%)$$

Limits on S_3: -150 to +250 %VSD.

Ranges:	T_{Hset}	530°F	to	535°F
	T_H	400°F	to	500°F
	Nc	0	to	150%

Inputs: The actual reactor power is derived as described in section 0.5, Power Measurement and is referred to as "Compensated Neutron Power (Nc)". This power signal is also used as an input to a relay which switches the gains of Block 1 and Block 3 and changes the sensitivity of the inter channel comparators.

The thermal power set point (N_{set}) is of course the output of Block 2 (S_2).

The reactor outlet temperature signal (T_H) is picked off a retransmitting slidewire on the temperature recorder while the set point (T_{Hset}) is adjusted by adjusting an internal potentiometer. The outlet temperature signal is also used as an input to a differential relay which changes the limits on Block 1.

1.3.4 Rate Log Power Over-ride Computer (Block 4)

Block 4 computes an over-ride signal whenever the rate of change of log power exceeds the set point. This signal acts at the input of Block 5 to open the control valves. The gain of this amplifier is such that 1%/sec. excess of rate over setpoint results in 20% VSD. This over-ride has been made active for all modes of control - a change from the original design.

Transfer Function:

$$S_4 = 4(\text{Rate Log N} - \text{Rate Log N}_{set})$$

Taking into account a further gain of 5 in Blocks 7 and 8:

$$VSD_4 = 20(\text{Rate Log N} - \text{Rate Log N}_{set})$$

Limits: 0 to +300% VSD.

Ranges: Rate Log N -10%/sec to +10%/sec.

Rate Log N_{set} +1%/sec to + 5%/sec.

Inputs: The Rate Log N input comes directly from the rate amplifier in the neutron power instruments. The set point is a screwdriver adjustment within the computer.

1.3.5 Over-ride Computer and Mixer (Block 5)

Block 5 computes the over-ride signals for moderator level and low log power control and mixes these with the outputs from Blocks 3 and 4. The output is the total valve stroke demand from the regulating system and is monitored by the comparators for interchannel disagreement.

The moderator level over-ride computer has a gain such that for a moderator level one foot above the set point a final VSD of 100% results.

The low log power over-ride has a gain such that 200% VSD results from 1 decade excess log power over the setpoint.

The gains of the mixer amplifier are all unity so that all inputs and outputs may be expressed as valve stroke demands.

Transfer Function:

$$S_5 = S_3 + S_4 + \frac{4}{12}(H-H_{set})_{+only} + 8(\text{Log N}-\text{Log N}_{set})_{+only}$$

Taking into account gain of 5 in Blocks 7 and 8.

$$VSD_5 = VSD_3 + VSD_4 + \frac{20}{12}(H-H_{set})_{+only} + 40(\text{Log N}-\text{Log N}_{set})_{+only}$$

Limits: -150 to +350 % VSD.

Ranges:	Moderator Level (H)	21 to 175 inches
	Mod. Level Set Point (H_{set})	63 to 83 inches
	Log N	10^{-6} to 1 x Rated Power
	Log N_{set}	10^{-4} to 10^{-2} x Rated Power

Inputs: The Moderator level signals are produced by retransmitting slidewires on moderator level recorders. The log N signals are produced by the neutron power logarithmic amplifiers. The setpoints are both screwdriver adjustments in the computer module.

1.3.6 The Interchannel Comparator (Block 6)

It is desirable to monitor the regulating channels for failure so that complete loss of regulation does not result. A few possibilities were considered:

a) Simple comparison of each input and each minor circuit in the computers. A multitude of interconnections between channels and a great many comparators would be required.

b) Interchannel comparison at various points, with or without averaging of signals. As for a) reliability would be sacrificed.

c) Interchannel comparison at a minimum of points with no averaging. Reliability and simplicity suffer only slightly but effectiveness of failure detection is reduced.

d) No comparators but equipment for routine testing of computers. This minimizes the sacrifices in reliability and simplicity but increases the probability of undetected failures existing coincidentally on two or more channels.

A combination of c) and d) has been chosen. Interchannel comparison, without averaging, is made just before the high gain output stages of the computer, and comparison within each channel is made of the positions of the two control valves. Equipment for routine testing of the circuits not monitored by the comparators is provided.

As discussed in section 1.1.5, three comparators are arranged to compare each combination of pairs of channels. When one comparator operates an alarm is sounded; when two comparators operate the channel common to both is rejected; when all three operate the reactor trips. (The tripping feature is being studied and may be eliminated).

The interchannel comparators consist primarily of magnetic amplifiers to detect interchannel disagreement and time delay relays which operate to reject channels. The sensitivity of the detection circuit is switched depending upon the control state and/or power level so that limits appropriate to the normal range of tolerances are selected. Figure 12 is a simplified schematic of the interchannel comparators.

Sensitivity Settings:

Control Mode	VSD disagreement to actuate comparator
Shutdown	40%
Low Moderator Level	40%
Low Log Power	40%
High Power, $Nc < 20\%$	120%
High Power, $Nc > 20\%$	90%

Ranges of Sensitivity Settings available:

a) Shutdown, Mod. Level or Log Power 0-100% VSD

b) High Power, $Nc < 20\%$ (1.25 to 1.75) x c) % VSD

c) High Power, $N > 20\%$ 0-150% VSD

Inputs: Other than the Block 5 output signals to be compared, the only inputs are from the reactor power differential relay (mentioned in Block 3), which switches the sensitivity for reactor powers above or below 20%, and from the routine startup circuits which switch the sensitivity as the reactor is switched between High Power Control and lower states.

1.3.7 Valve Position Function Generators (Blocks 7 and 8)

Blocks 7 and 8 provide the output signals from the control computers to drive the electro-pneumatic transducers. Dual output stages - one for each valve - are provided primarily to permit monitoring of all equipment following the interchannel comparator point.

In Blocks 7 and 8 a functional gain of 5 is applied to the Block 5 output and any negative (valves over-closed) signal from Block 3 is subtracted (also with a gain of 5). The resulting signal positions the valves.

Transfer Function:

$$S_7 = S_8 = 5(S_5 - S_{3_{-ve\ only}}) \quad \text{for } 8\% < S_{7/8} < 92\%$$

$$S_7 = S_8 = 0.25(S_5 - S_{3_{-ve\ only}}) \quad S_{7/8} < 8\%$$

$$\text{or } S_{7/8} > 92\%$$

The reason for the gain changes at 8% and 92% VSD is given in discussion of Block 9 below.

Limits:	0 to 100% VSD
Ranges:	See limits for Block 3 and 5
Inputs:	The only functional inputs are the output signals from Block 5 and Block 3(-ve only).

1.3.8 Valve Comparators (Block 9)

The dual output blocks (Blocks 7 and 8) are driven by the same input signals, S_5 and $S_{3_{-ve}}$ only. Thus the random tolerance in valve position is quite small. Disagreements beyond ±4 % are considered outside normal scatter and so the operation level is set at this value.

A non-linear gain in Blocks 7 and 8 is used to improve the effectiveness of the valve stem position comparators. It is quite possible, as a result of normal channel disagreement during power control, that one pair of valves will tend to be fully closed or fully open for prolonged periods. If the valves are allowed to stroke fully and remain on their stops, the valve comparator for that channel is quite useless. The use of a gain reduction by a factor of 20 effectively limits the valve position demand between 8% and 92% and allows for monitoring of failures which would cause the valves to go fully open or fully closed.

To lose control of moderator level, and therefore reactor power, it is necessary for three control valves, each in a different helium line, to fail unsafely. Improbable as this may be, the operation of all three valve comparators must be considered to indicate such an unsafe condition and therefore this action causes a reactor trip. Operation of less than three valve comparators is annunciated but causes no automatic action. To prevent comparative action on spurious disagreements a time delay (set for 10 secs) is provided between the detection of disagreement and any further action (either annunciation or trip).

1.3.9 Valve Control

With reference to Figure 13, the signals from Blocks 7 and 8 are fed through channel rejection and shutdown contacts to electro pneumatic transducers. These transducers provide a pneumatic output which is fed via "Bailey Selector Stations" to the valve positioners. At the positioners the pneumatic signal is amplified to drive the control valve to the required position. A three-way solenoid intercepts the e/p transducer output and vents the positioner if the reactor is tripped. Manual control is also available through the Bailey Selector Stations providing the "Manual Air Key Switch" is opened to supply air to the manual loader.

The valve position is detected by a movable core transformer and is fed to the valve comparators. This signal is also fed, via an e/p transducer to the valve position indicator on the Bailey Selector Station.

There are four scales on the Bailey Selector Station; from left to right they are:

TRANSDUCER:	The output of the main electro pneumatic transducer.
VALVE:	Actual valve position, derived through mechanical linkage, movable core transformer and e/p transducer.
TRANSFER:	Output of the mode of control (AUTO or MANUAL) not being used.
CONTROL:	Signal to the valve.

S. G. Horton

Example Problems on Regulating System - NPD

1. The reactor is critical at Low Log Power. Moderator level is 150".

   a) What is the average control valve position?

   b) What excess of log power over set point is required to produce this valve position?

   c) If the Xenon decays and moderator level drops to 125", what is the effect on the controlled power level? (direction and magnitude).

2. It has been suggested that the moderator level setpoint be raised so that automatic startup is possible after prolonged shutdowns. The desired controlled moderator level is 90 inches.

   What is the set point required?

3. The reactor is critical at 75% rated power with a moderator level of 140 inches. The compensators are either on auto or are kept at their correct setting manually.

   a) What is the average valve position?

   b) What thermal power error is required to produce this valve position?

   c) If the Xenon builds up so that the reactor is now critical at 165 inches, what is the power error required?

   d) What parameter changes to produce the change in error between b) and c)? By how much does the parameter change.

4. The reactor is at its maximum power for the existing moderator level of 140 inches. The compensators are correctly set.

   a) What are the values of Nc, Nset.

   b) If a similar situation existed at 165 inches moderator level, would the margin between the reactor Δ T and the Δ T trip setting be more than, less than, or the same as in a).

5. The reactor is in the high power state and the following conditions exist:

H = 130 inches

Pset = 400 psig

Trim = Zero

Power ≐ 75% R.P. controlled constant by the Base Load Controller.

Compensators are set correctly manually.

Xenon is building toward equilibrium and moderator level is rising.

If the system is left, without further adjustment, to control the reactor boiler, what will ultimately occur? Your answer should demonstrate an understanding of the problem.

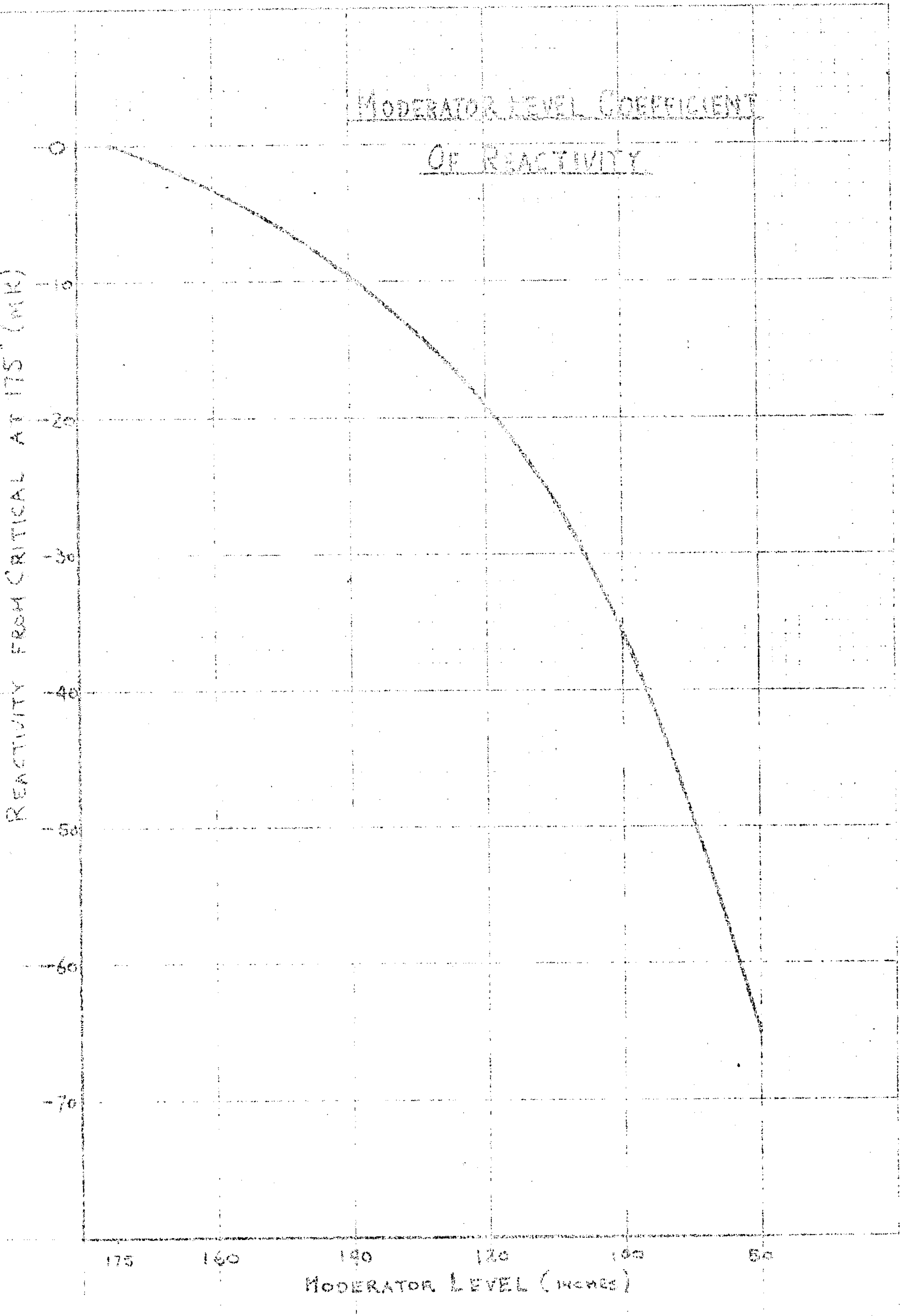

MODERATOR LEVEL COEFFICIENT
OF REACTIVITY
REACTIVITY FROM CRITICAL AT 175" (mK)
0
-10
-20
-30
-40
-50
-60
-70
175
160
140
120
100
80
MODERATOR LEVEL (INCHES)

FIGURE 1.

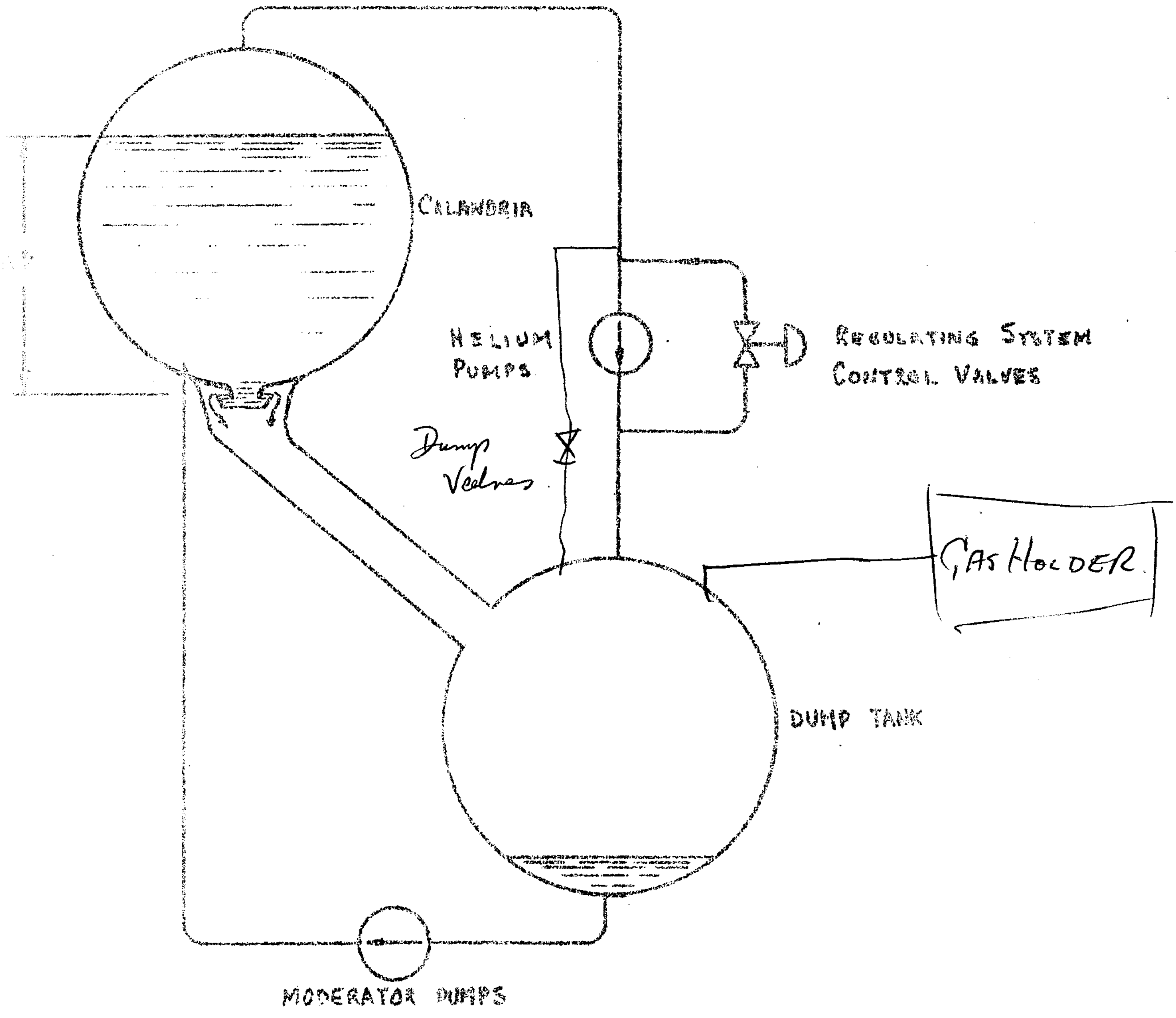
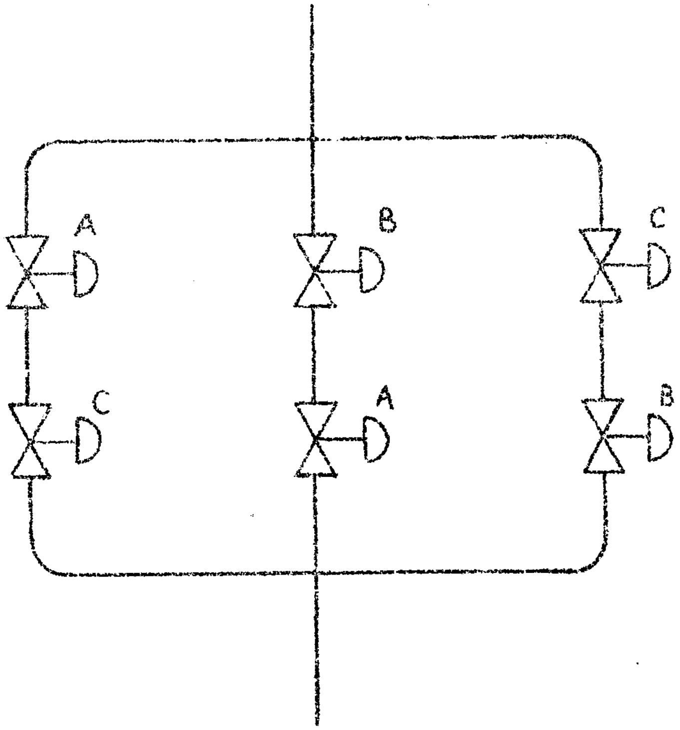


FIGURE 2 - NPD MODERATOR LEVEL CONTROL



with one path serviceable.
the He flow capacity is twice the cap. of the He pump combination

FIGURE 3 · ARRANGEMENT OF CONTROL VALVES

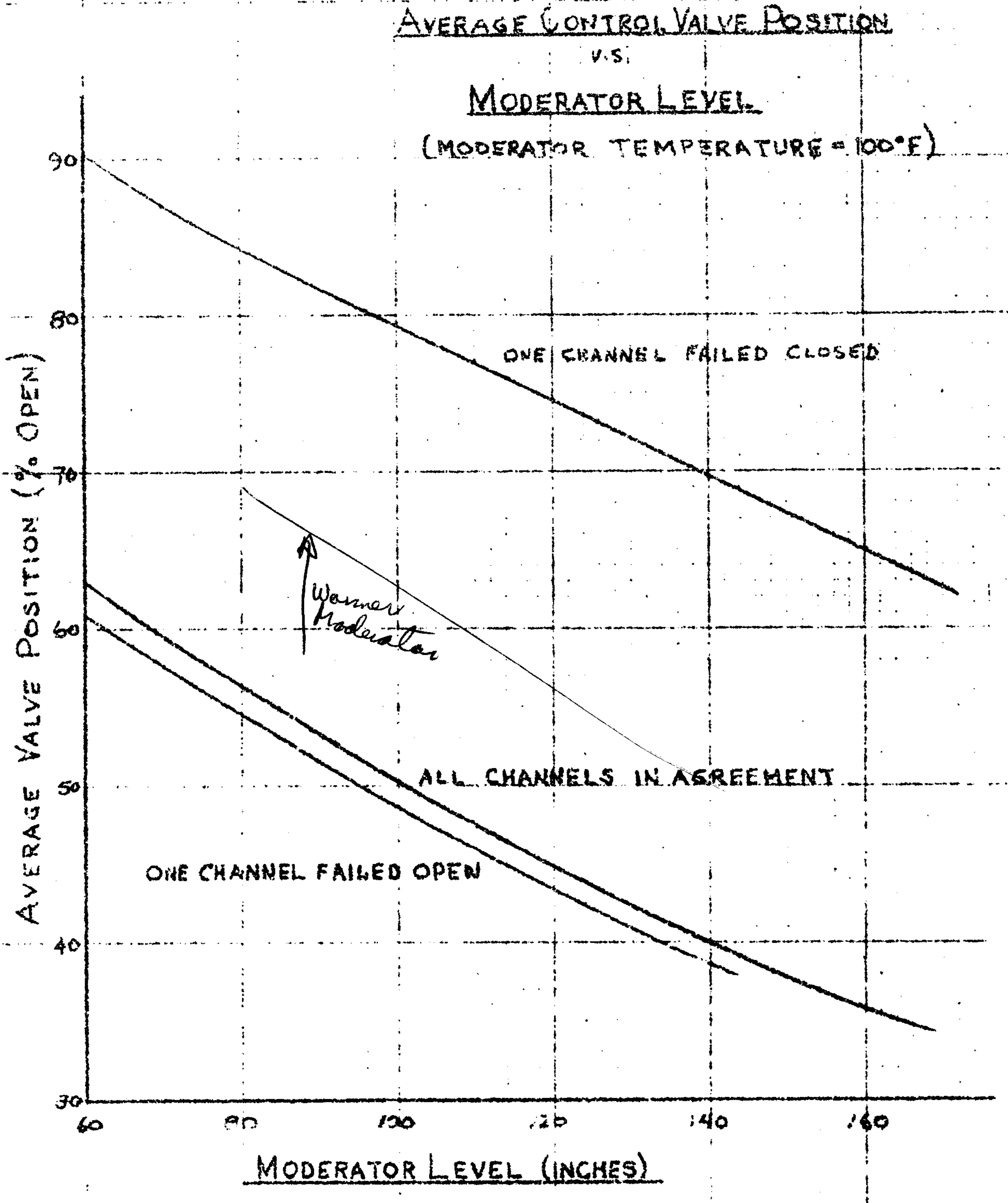
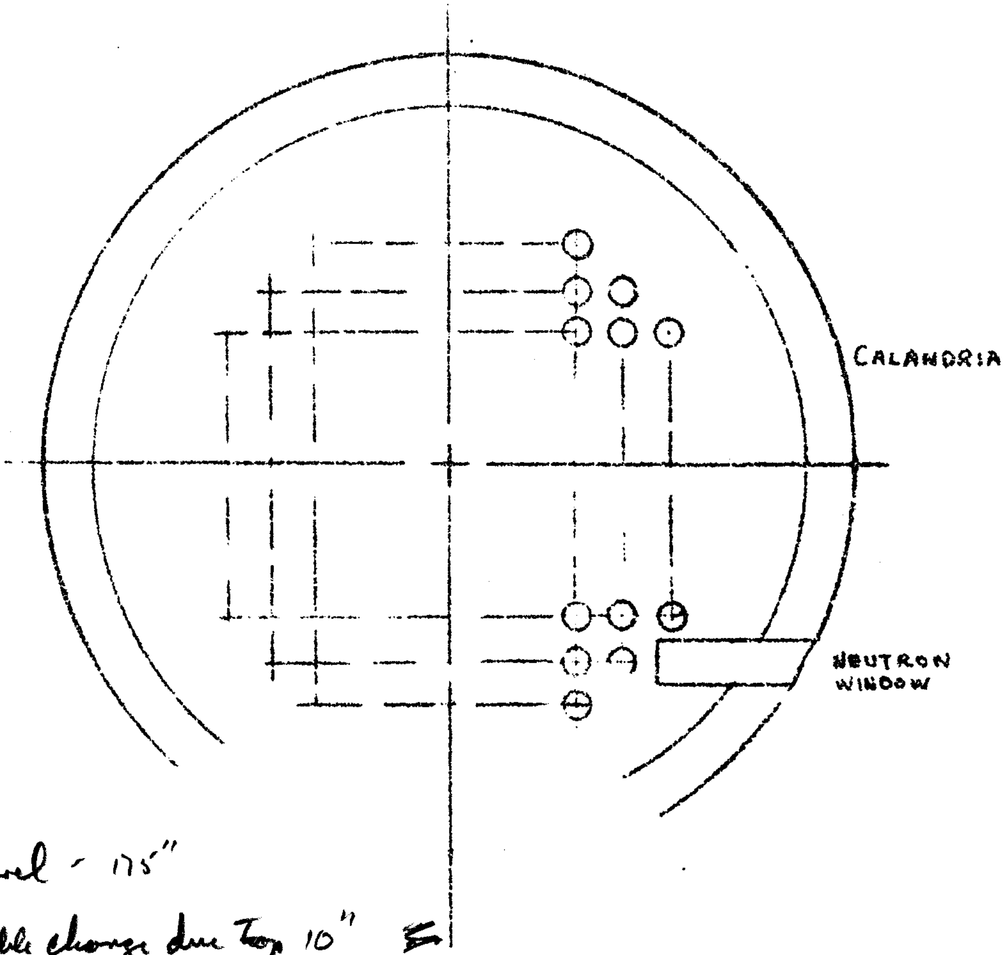
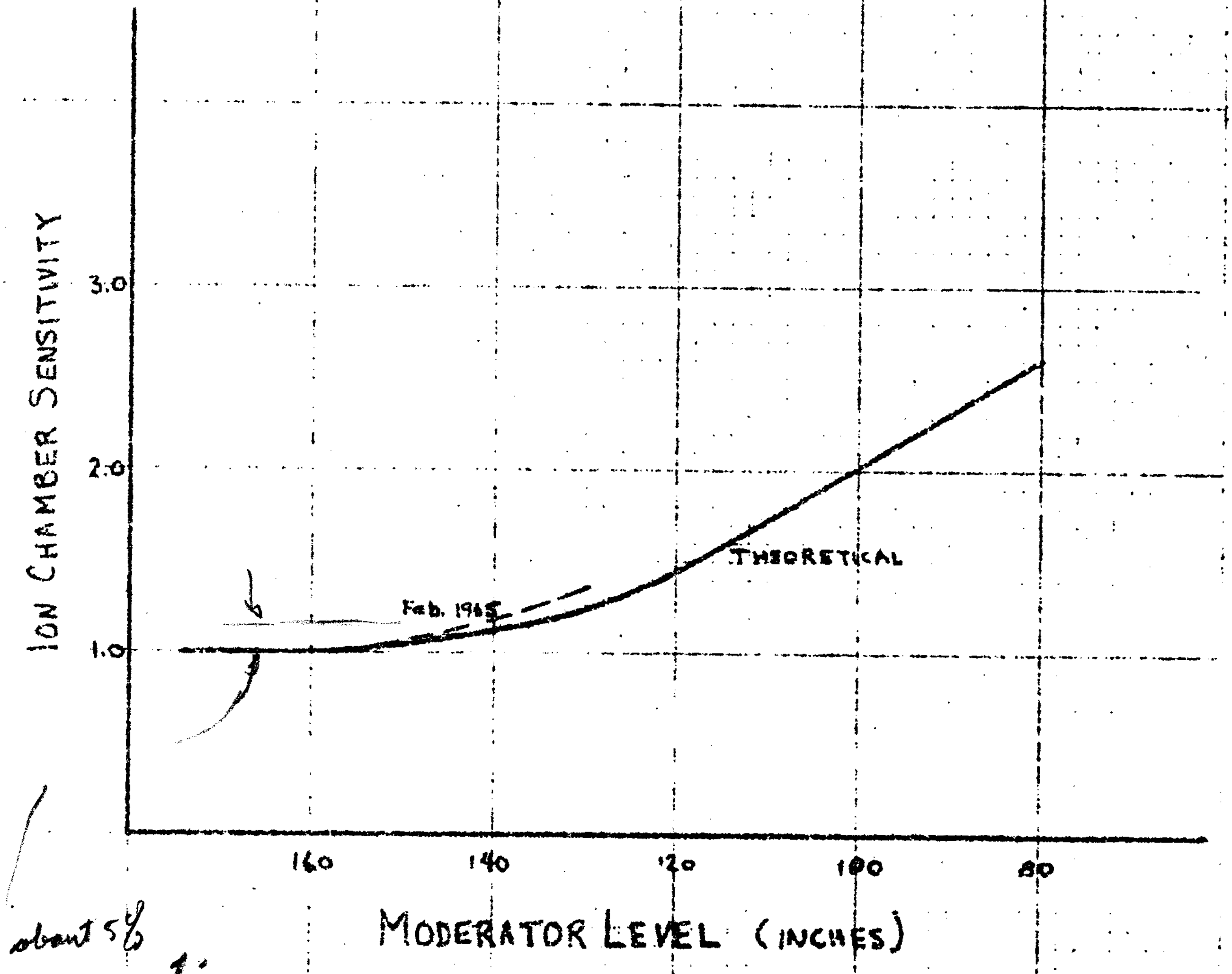

AVERAGE CONTROL VALVE POSITION
V.S.
MODERATOR LEVEL
(MODERATOR TEMPERATURE = 100°F)
ONE CHANNEL FAILED CLOSED
Warmer Moderator
ALL CHANNELS IN AGREEMENT
ONE CHANNEL FAILED OPEN
AVERAGE VALVE POSITION (% OPEN)
90
80
70
60
50
40
30
60
80
100
120
140
160
MODERATOR LEVEL (INCHES)

FIGURE 4



Ref level - 175"
Negligible change due Top 10" ⇒
∴ 165" response very similar

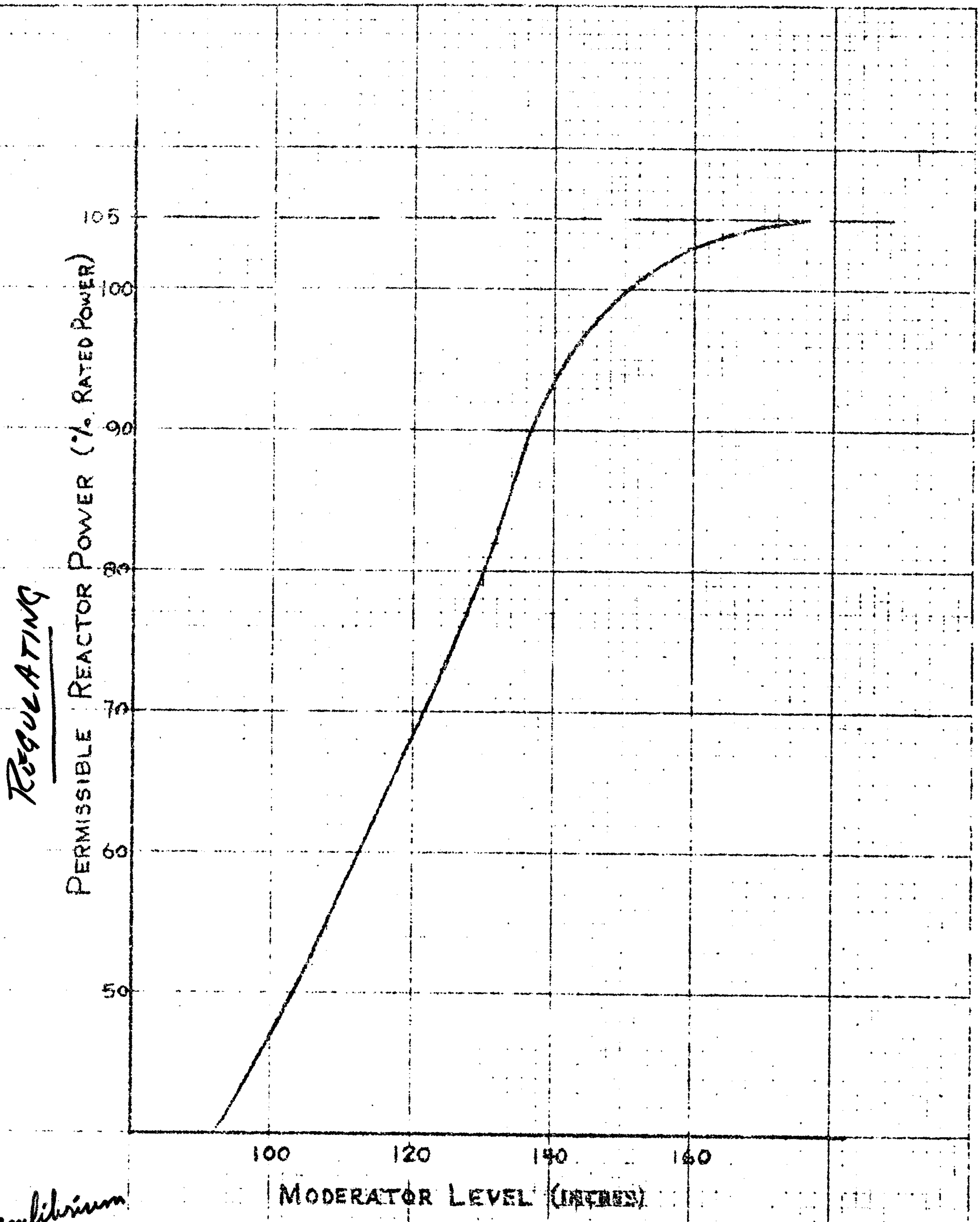
FIGURE 5 - LOCATION OF NEUTRON WINDOWS



Note about 5% change in operating range.

FIGURE 6. - ION CHAMBER SENSITIVITY

K6 to have 3 Cobalt bundles.
this is expected to yield 3% change.



REGULATING

Equilibrium Core.

FIGURE 7 - PERMISSIBLE POWER V.S. MODERATOR LEVEL

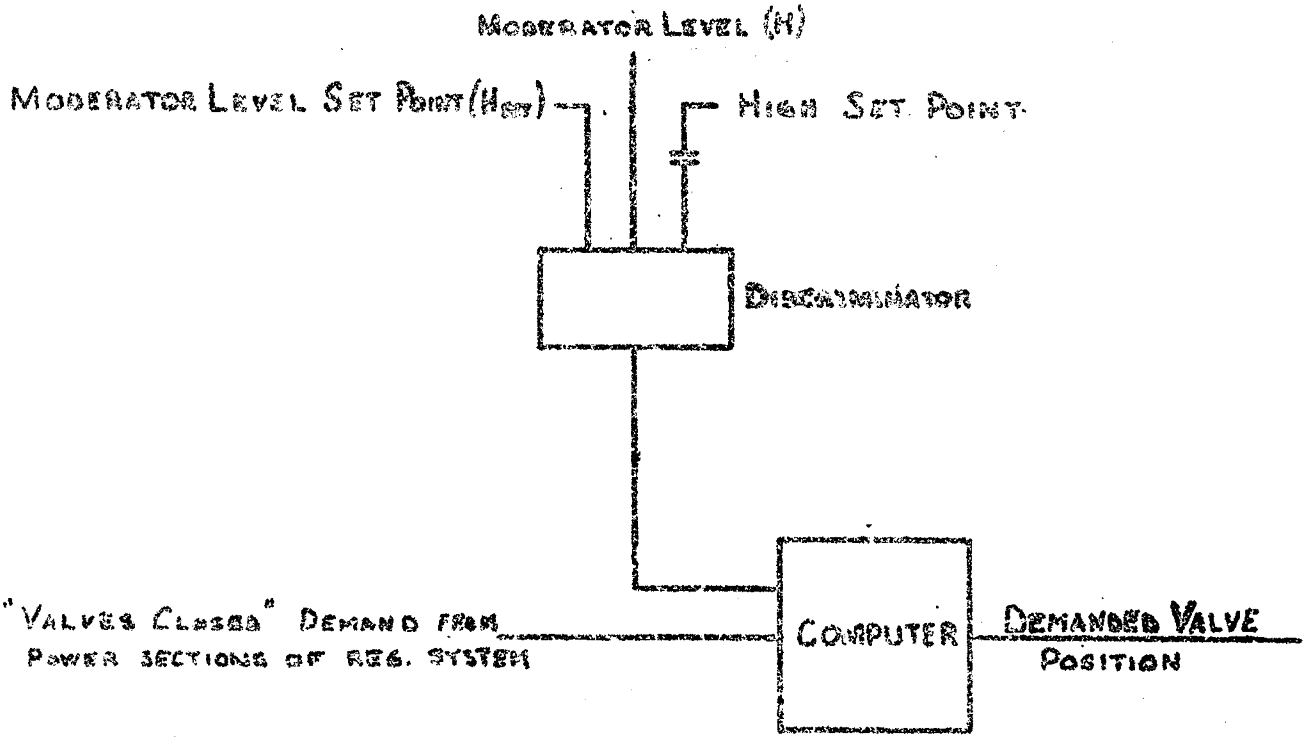


Figure 8.
Low Moderator Level Control
Block Diagram

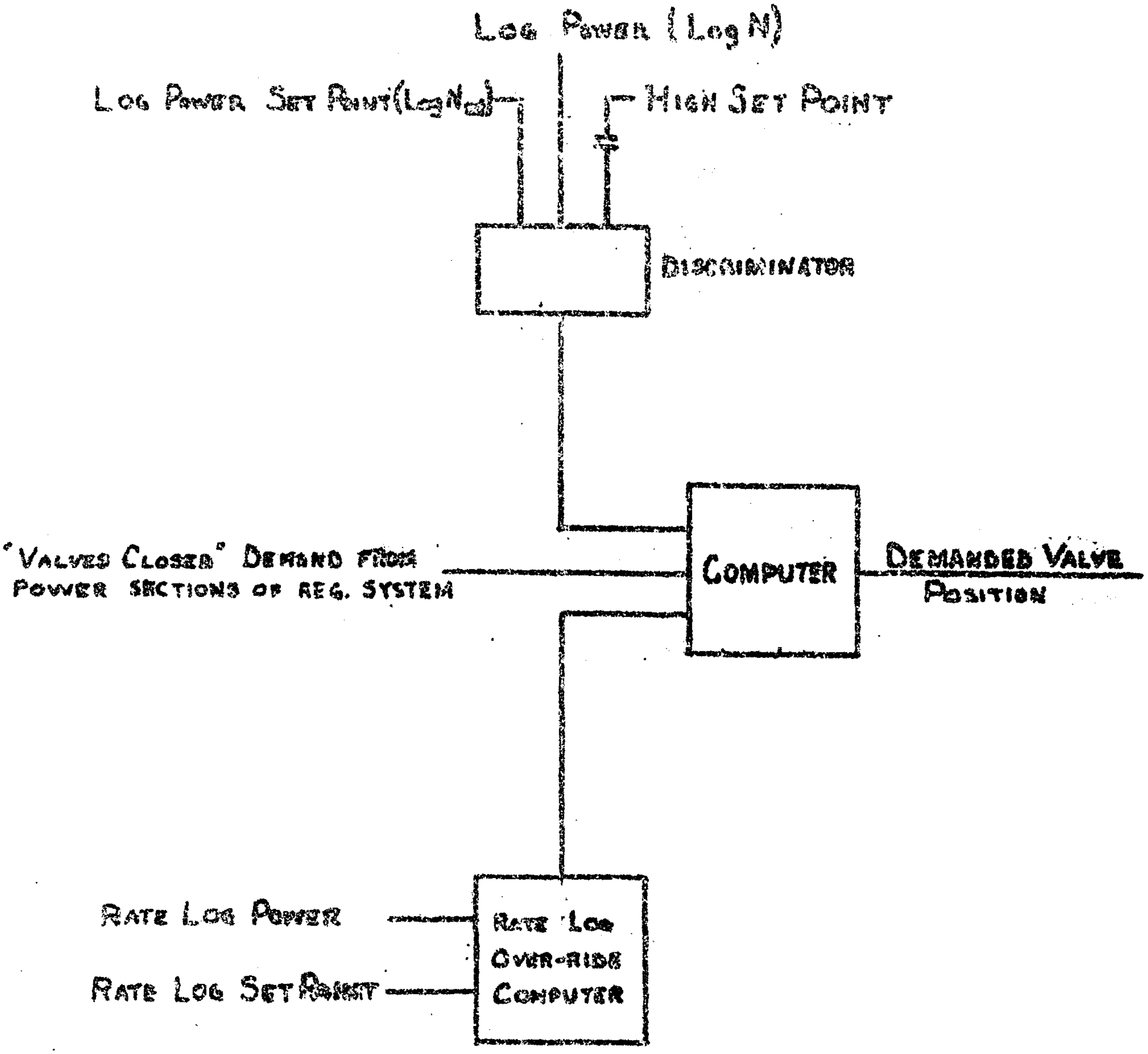


Figure 9.

Low Log Power Control Circuit

Block Diagram

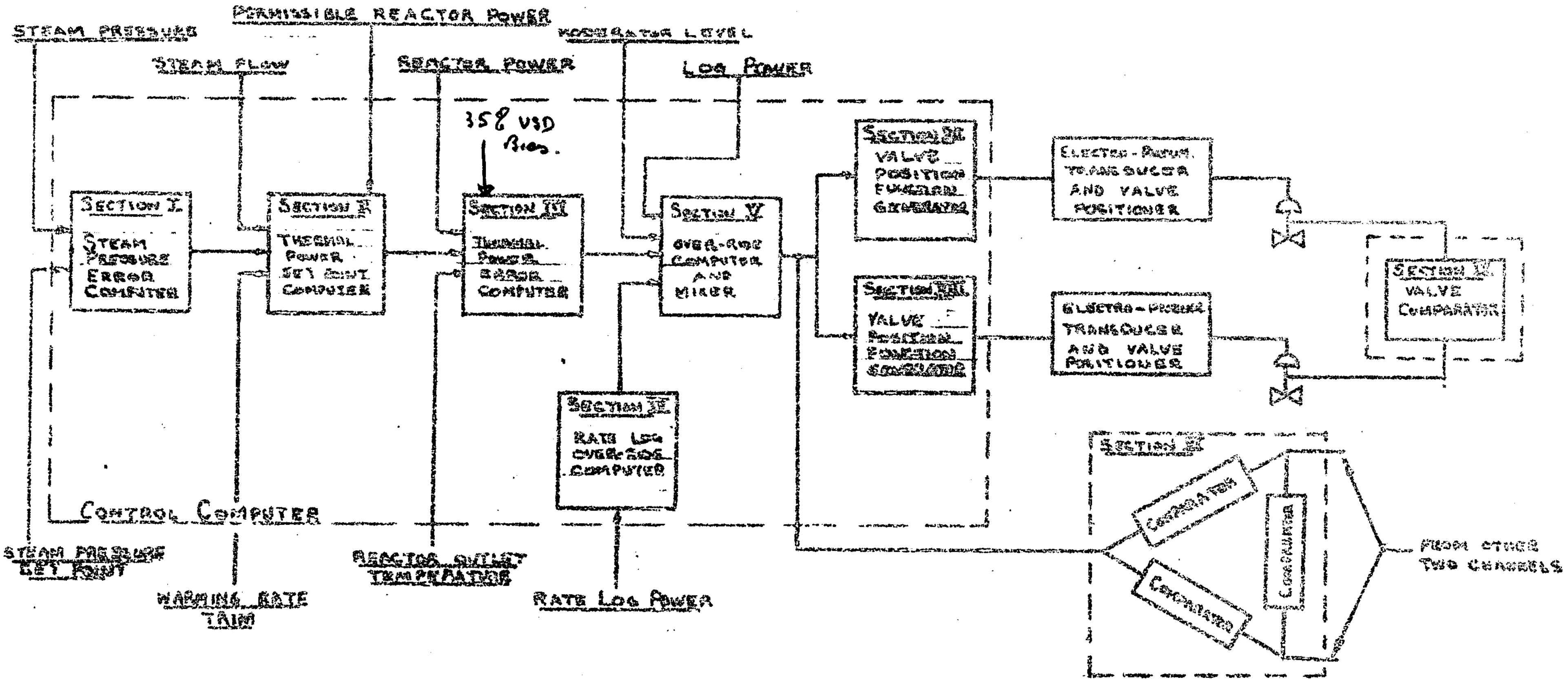


Figure 10 · High Power Control Circuit - Block Diagram

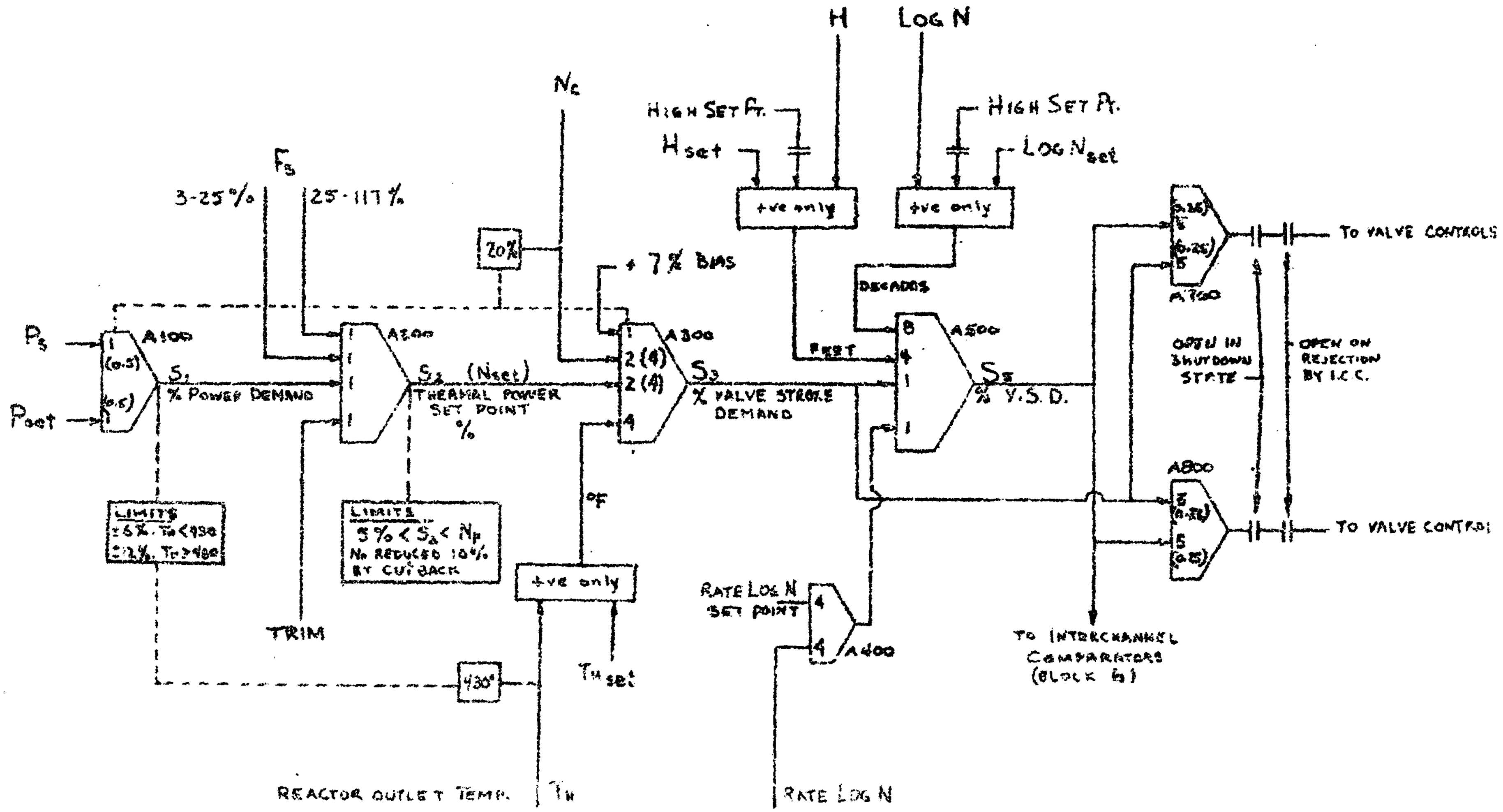


FIGURE 11 - SIMPLIFIED SCHEMATIC - REGULATING SYSTEM CHANNEL

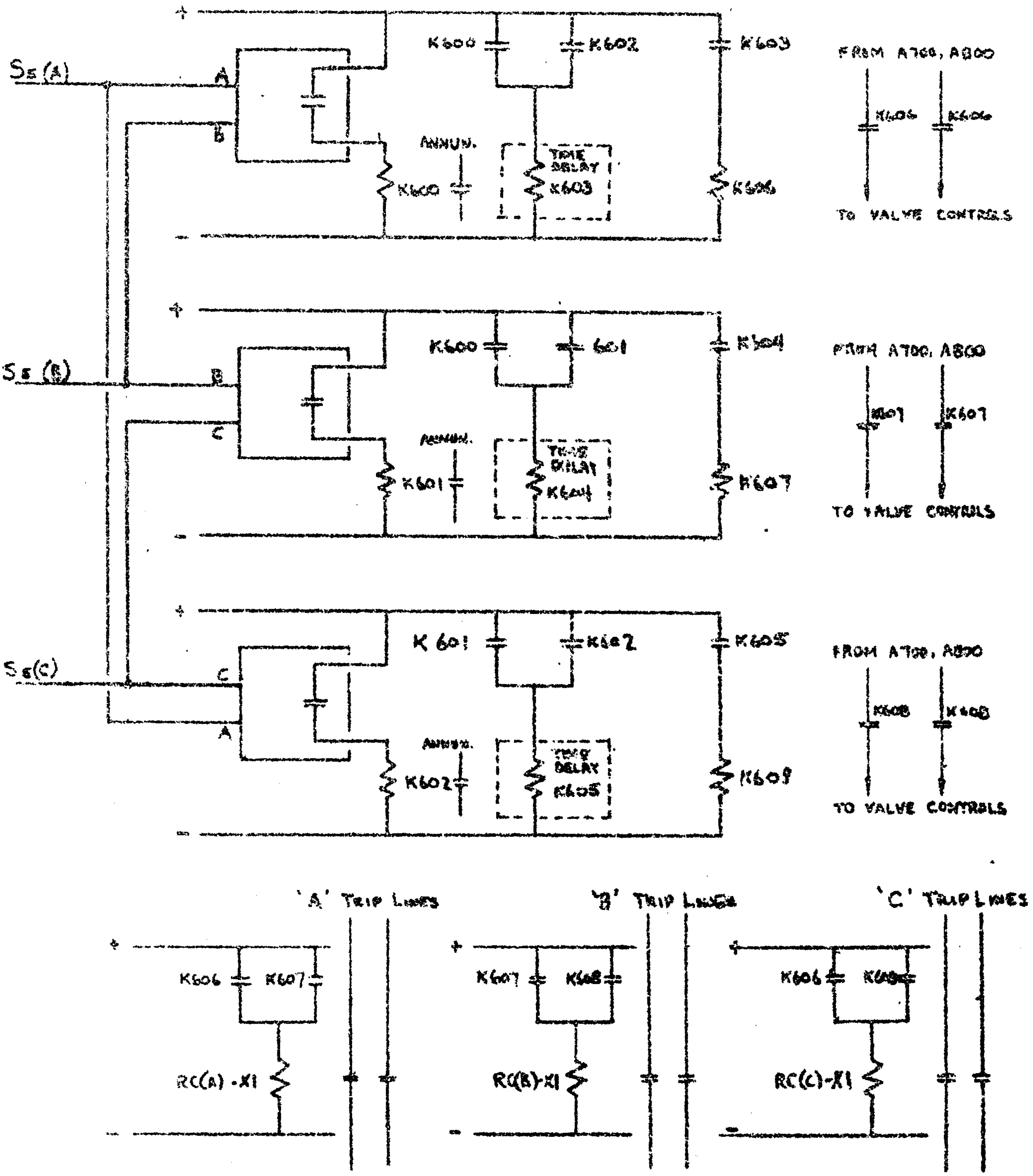


FIGURE 12 - SIMPLIFIED SCHEMATIC - INTER CHANNEL COMPARATOR