CHAPTER 5: REACTOR CONTROL AND PROTECTION

MODULE 1: ZONE LEVEL CONTROL

Principle of operation

Each of the 14 individual zones can be considered as a liquid absorber rod.

- The higher the light water level in any particular zone, the more reactivity will be decreased in the area surrounding that zone and vice versa.
- The problem of reactivity control is therefore one of multiple tank level control with reactor flux the controlled variable and water level in the zone, the manipulated variable.

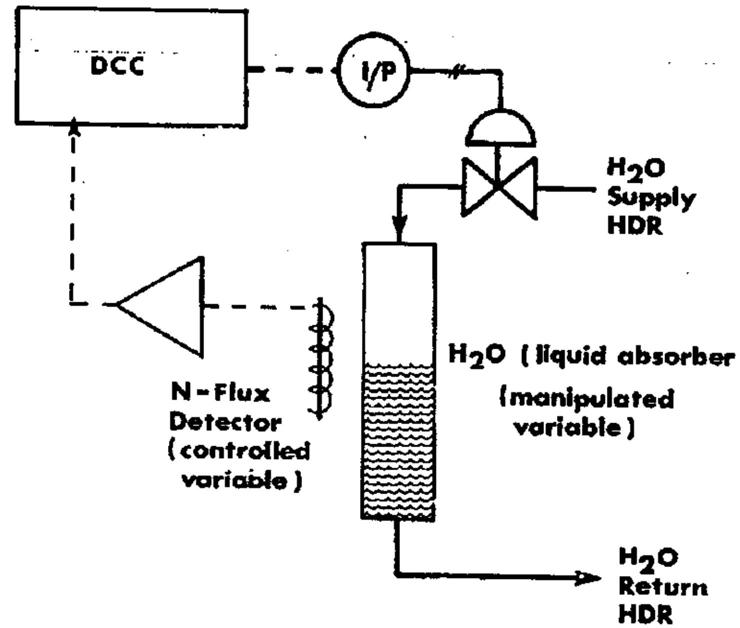

Figure 1: Simplified Zone Control Circuit.

Control Action

- An electronic signal, proportional to the neutron flux, will be fed to the control computer which will make the necessary adjustment to the control valve in the light water supply line to the zone.
- Changing the level in the zone will change the reactivity in the area surrounding that zone.
- It is also necessary to continuously monitor the level of water in the zones in order to establish whether or not the zone has the capacity to provide the change in reactivity requested.
- The water level is measured by a bubbler system using helium gas.

Location of Zones

The fourteen zones are located as shown in Figures 2 and 3, seven zones per axial half. The reactor face (Figure 2) is marked to show the approximate location of the zones. Each zone is accessible through guide tubes from the reactivity platform. It should be noted that the guide tubes can contain either two zones, (e.g., zones 1 and 2), or three zones, (e.g., zones 3, 4 and 5).

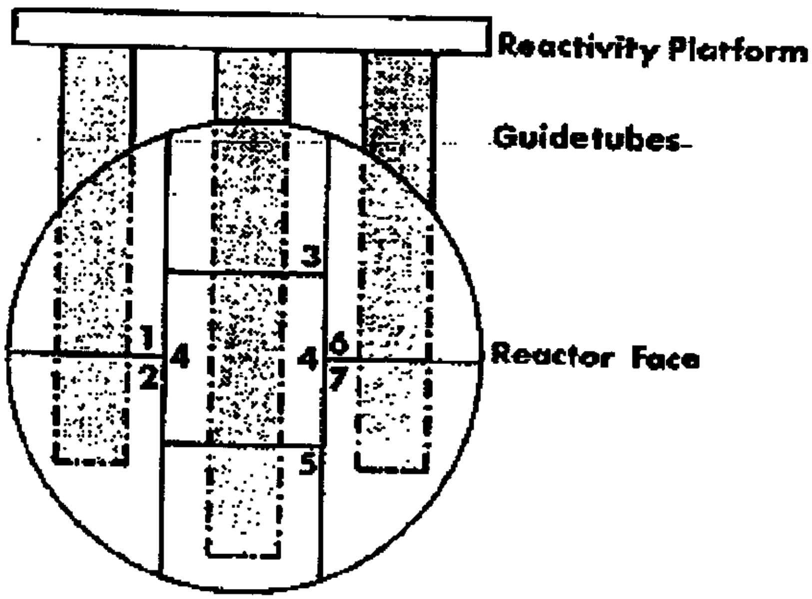

Figure 2: Relative Guide Tube Location WRT Zones.

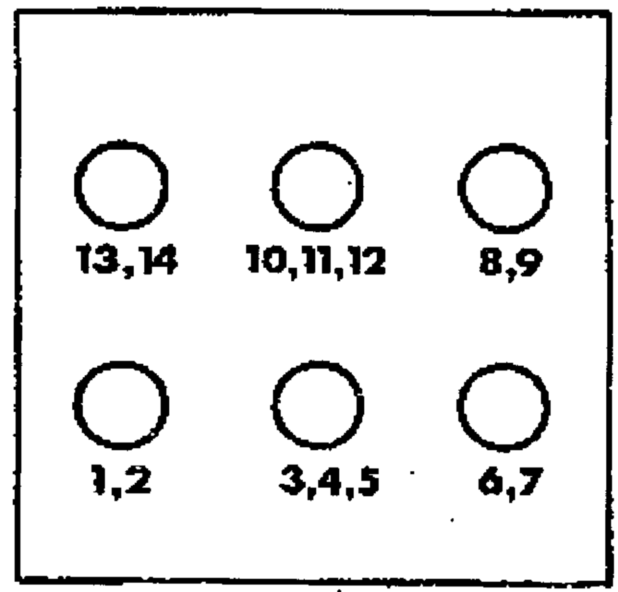

Figure 3: Relative Guide Tube Location on the Reactivity Platform.

Bubbler Level Measurement System

Recall that the bubbler detection method measures the back pressure of a gas which is fed to the base level of the process and allowed to bubble up through the process. This bubbling is assured by maintaining the gas at a pressure slightly greater than the maximum expected hydrostatic head plus any gas pressure which may exist above the liquid. The pressure at the base of a column of liquid is dependent upon the specific density(s) and the depth of the column(h) such that:

$$P = sh$$

Thus, if the density is constant and base pressure is measured (back pressure), the level can be determined.

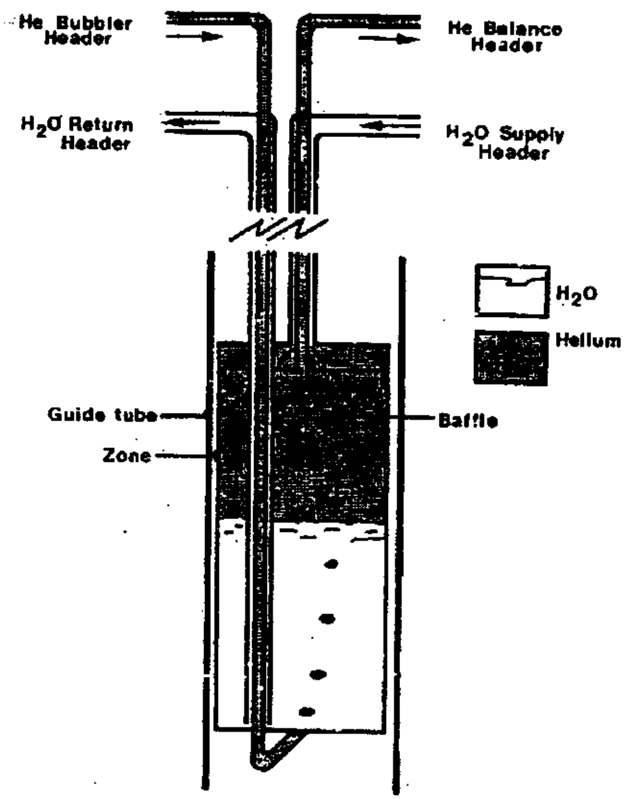

Figure 4: Typical Zone Feed Tube Connections.

The back pressure developed will be applied to the high pressure port of an electronic differential pressure transmitter which will provide a signal proportional to the level in the zone. Since the zone is essentially a closed tank, the low pressure port of the DP cell must be connected to the gas space above the liquid. This applies the gas (helium) pressure to both sides of the transmitter, canceling out its effect.

There must also be provision for regulating the helium pressure to prevent the bubbler supply from pressurizing the gas space and stopping bubbler action. The bubbler system is used to prevent the process from entering, and hence contaminating, the pressure transmitter. It also allows the level transmitters to be mounted at a distance from the reactor. The chosen gas, helium, ensures that there will be no neutron activation products.

Basic System Operation

The water leaves the supply header via fourteen control valves (fail open type) to the individual zones. The input flow rate is variable, by control valve opening, typically between 0.2 and 0.9 L/secs, . at a temperature of approximately 55°C.

A constant pressure differential of 0.45 MPa maintained between the delay tank and the helium balance header (i.e., across the zone), ensures that the outflow from the zones is at a constant rate. The outflow temperature will be approximately 90°C. This constant differential pressure is maintained by either admitting helium from the helium storage system through a feed valve to the helium balance header, or by bleeding helium from the balance header to the delay tank via a bleed valve. This is an example of split range control where two control valves accept one common control signal.

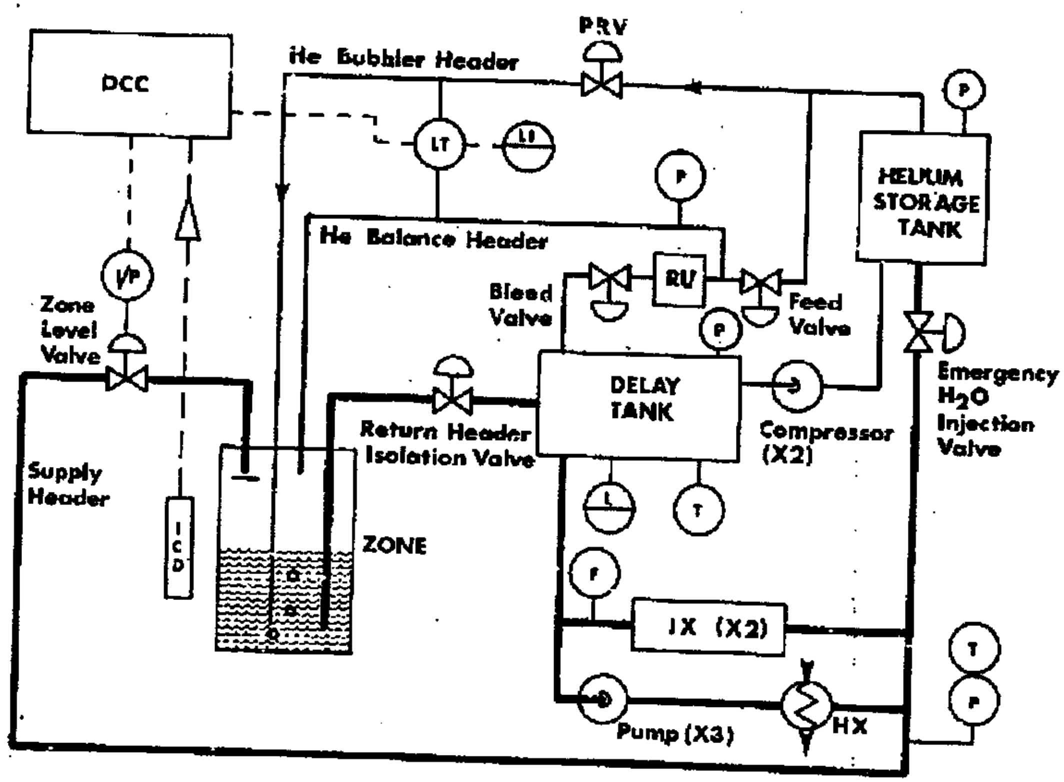

Figure 5: Zone Level Control Water and Helium Circiuts.

The H_2O return header carries water from all fourteen zones to the delay tank through the output header isolation valve. This valve is a 'fail closed' type, which ensures closure to prevent draining of the zones and hence an uncontrolled increase in reactivity. The water circuit is completed by the delay tank, the circulating pumps, heat exchanger and ion exchange columns. The delay tank provides a time delay for the decay of short lived isotopes (e.g., O^{19}, N^{16}).

Control of Reactor Power

Consider the situation with the reactor at some power level when there is a request an increase in power. The power will be raised at a controlled rate (i.e., ramped) and until the new setpoint is reached, a negative power error (PERR) will exist between the Actual Power and the demanded power. The zone level must drop to increase the neutron multiplication factor k to a level greater than 1 (reactor must go slightly supercritical). Power output will rise and power error will eventually be zero when the Actual Power equals the Demanded Power (i.e., at Setpoint). As the control is straight proportional, the action can be described by the standard proportional control equation.

$$m = k_c . e + b$$

where m = control signal, k_c = controller gain, e = error, b = bias -

Therefore, when error equals zero, the measurement equals the bias. Thus when at the set point, the control signal is defined as LBIAS so that valve position matches inflow to outflow.

However, it should be noted that at this stage, k is still greater than 1. (Zone level has gone down) therefore power will continue to increase raising the actual power above the demanded power. PERR is now positive. Zone level will begin to rise to reduce power and k will be reduced towards zero. Equilibrium will only be achieved when PERR = 0 and k = 1.

The zone level will be essentially at the same level as before the power change took place. In fact, there will be a small initial deviation from the original level due to the effects of temperature coefficient, followed by in the case of a power increase, a rise in zone level peaking 5 or 6 hours later. The zone response compensates for the decrease in Xenon level due to the increased burn up. As the Xenon builds to the new equilibrium level, the zones will once again approach the original level (assuming negligible fuel burn up).

Zone Controller Unit

The indicators are:

- zone level in meters
- valve signal in % (note valve is air to close)
- zone neutron flux deviation from the average of all fourteen zone flux levels

The overall design concept of the liquid zone system generally results in a failsafe condition in the event of any upset or abnormality.

- Should any zone compartment leak, light water may find its way into the moderator system. This will down grade the isotopic quality of the moderator D_2O resulting in lower fuel burnup and higher operating costs. The subsequent need to replenish the light water inventory will indicate the existence of this fault.
- An abnormally high average zone level indicates a high level of reactivity. Control by the liquid zone system in these conditions is likely to be lost and consideration must be given to controlling reactivity by other means (e.g., by adding boron to the moderator D_2O) in order to lower general zone level and regain a normal control situation, i.e., with zone level at approximately 50%.

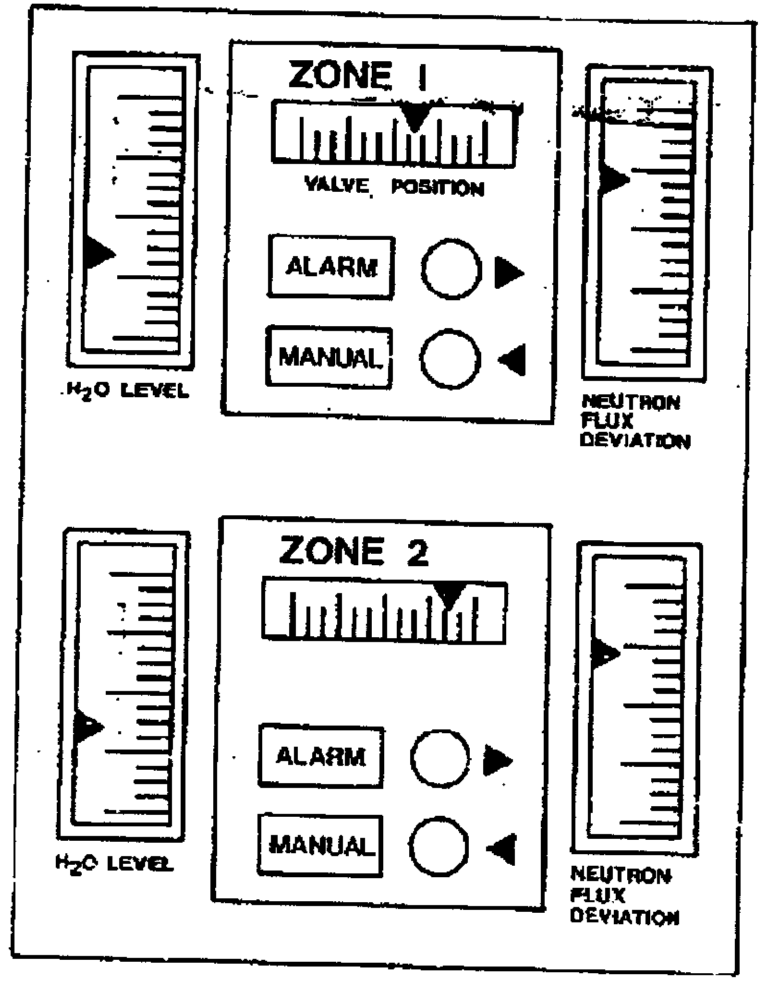

Figure 6: Zone Control Unit.

Summary

1. The zone level control system is the first choice method for reactor control.

2. The zone level system is a closed system. Normally no additional light water or helium to the system should be required.

3. Zone level control is a fast acting, low volume system (the total light water inventory is hundreds of litres only).

4. The availability of the zone level control system is necessary for reactor operation-.

5. The system is designed to fail safe.

ASSIGNMENT

1. State the two principle control requirements that should be met by the zone level system.
2. Sketch a simplified zone control scheme to define the controlled and manipulated variables.
3. What is the difference in zone level control response when control is by (a) ion chambers (b) hilborn (incore) detectors?
4. Sketch an overall zone control system showing:
    1. zone
    2. incore detector
    3. zone level control valve
    4. return header isolation valve
    5. compressor
    6. pumps
    7. ion exchange columns
    8. recombination unit
    9. feed and bleed valve
    10. control computer
    11. plant exchanger
    12. helium storage tank
    13. delay tank
5. Briefly describe zone level behaviour following request for a power increase.
6. What is the system control response following a loss of all three pumps due to electrical failure?
7. What will be the control response following a loss of the helium bubbler supply?
8. What effect will air ingress to the zone cover gas system have and how is it detected?
9. State the interaction between ion exchange columns, recombination units, and conductivity measurements in the zone systems.