Lesson 7: REACTOR CONTROL AND PROTECTION

MODULE 1: RECOVERY FROM A POISON OUTAGE

RECOVERY FROM A POISON OUTAGE OBJECTIVES:

At the end of this module, you will be able to:

1. **Describe the basic production of Xenon-135 to show why there is a peak produced following a reactor trip.**
2. **Define the term '*override time*' and explain its reactor control significance.**
3. **State four key time phases of an override time and briefly describe each.**
4. **Sketch and describe the Xenon-135 *transient curve* following a reactor trip.**
5. **Prepare a logic flowchart to describe an accelerated approach to criticality at the end of a poison outage to minimize the operation time needed.**
6. **Describe one cycle of the coordination of average zone level, power error, xenon level and adjuster rod position to show how the operator could approach criticality by the sequence flowcharted.**

MODULE 1: RECOVERY FROM A POISON OUTAGE

Override Time

- **If the reactor is tripped after establishing the equilibrium xenon level (say -28 mk), there will no longer be any excess of neutrons available to "burn off" the Xe-135.**
- **Xe-135 production (5%) as a fission product has stopped but the decay of I-135 continues to produce Xe-135 (95%).**
- **The xenon level rises rapidly following a trip until the transient peaks due to I-135 depletion, and then the xenon starts to decay.**
- **Unless sufficient extra reactivity is available to overcome the negative reactivity of this poison, the reactor cannot be restarted until the xenon level decreases sufficiently.**
- **The reactor is said to be *poisoned out* in such a condition.**

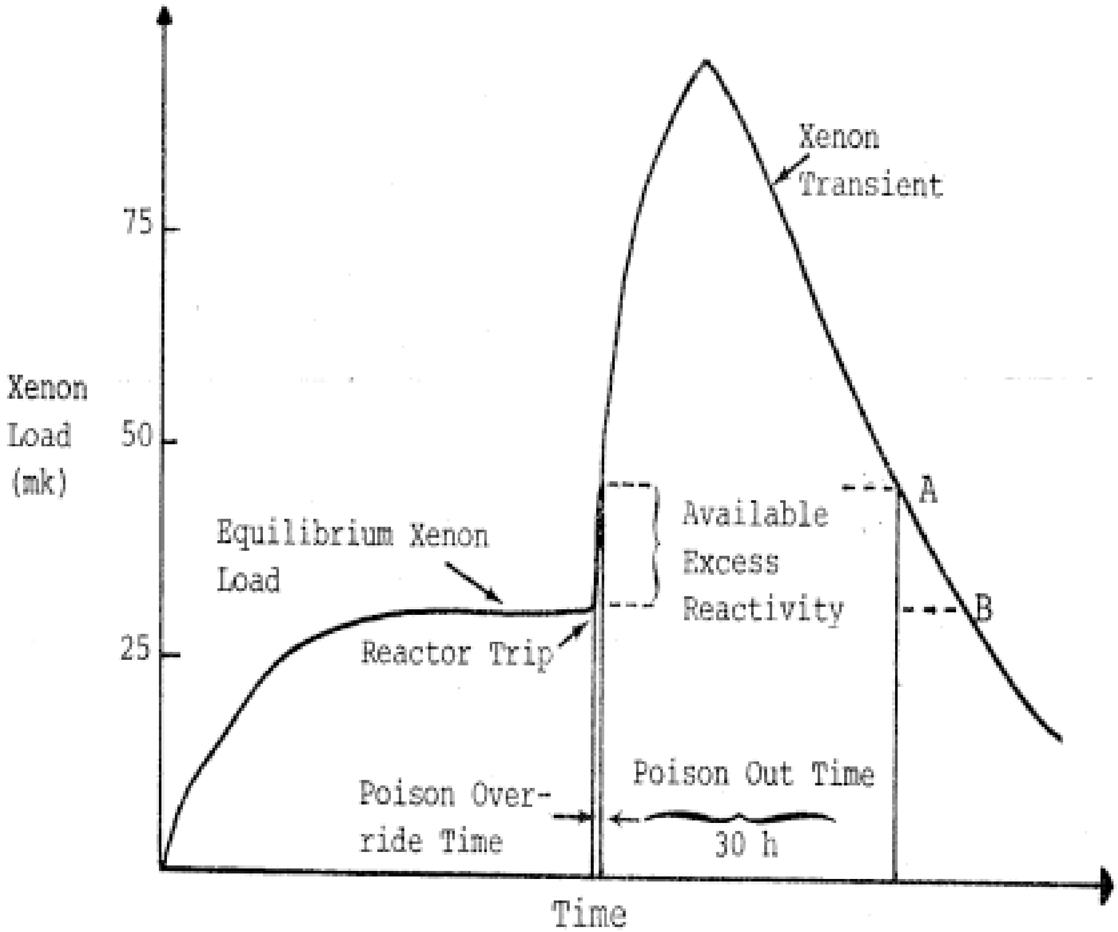
Override Time

- **The interval from reactor shutdown until the xenon level rises to match the extra control reactivity available is called the override time.**
- **If the override time elapses before the system can be returned to normal, then the reactor will be *poisoned out*.**
- **A typical override time of 40 minutes would consist of:**

2 minutes	**- confirm SDS actions and reactor shutdown**
23 minutes	**- diagnose & verify cause and clear trip**
11 minutes	**- regain criticality**
4 minutes	**- raise power level to 60 - 70% FP**
40 minutes	**- override time**

Xenon Transient

- **If the reactor was tripped, the Xe-135 level will peak in approximately ten hours and then gradually reduce.**
- **Beyond point A, it is only the override reactivity of inserted *<u>adjuster rods</u>* that prevents the reactor from becoming critical.**
- **If it is desired to delay the return to criticality beyond point B, it will be necessary to poison the moderator with boron and achieve criticality, when desired, by boron removal.**



<u>Figure 1: Xenon Load Following a Reactor Trip.</u>

Approach to Critical Following a Poison Outage

- **Assume that the reactor operation is near the end of a poison outage (approaching Point "A" in Figure 1).**

- **The reactor conditions at this time would have the adjuster rods fully inserted.**
- **The natural approach to criticality can be expedited by manually withdrawing the adjuster rods and allowing automatic control to adjust the zone levels.**

- **The *power error* and the *average zone level* should be selected for display.**

- **A "*Hold Power*" command would be entered by the operator before the first bank of adjusters is manually driven out of core (following the prescribed rod sequence) to define the starting point.**

Approach to Critical Following a Poison Outage

- **As the Xenon continues to decrease and the adjuster rods drive out of core, the RRS will respond by *increasing zone levels* in an attempt to satisfy the "Hold Power" request.**
- **It should be noted that the Xe-135 load is decreasing at a rate of approximately 2.5 mk/hour.**
- **When the liquid zone average level approaches 70%, the adjusters out drive will be stopped by the operator, allowing the zone levels to stabilize.**
- **The reactor power should be noted at this time (expected to be say 2.6×10^{-6} FP).**

Approach to Critical Following a Poison Outage…continued

- The entry of a raise power command will now cause the zone levels to drop.
- The power increase with average zone level decrease (and adjuster rods unchanged) can be terminated by the operator around 25% average zone level by entering another "Hold Power" command.
- The new power level should be noted (say 2.9×10^{-6}FP) and compared to the last power reading.
- The operator would be looking for an approximate doubling of power for a given change in zone level.
- Once the power has doubled for a given change in zone level, the reactor will go critical for a subsequent, similar change in level (***power doubling rule***).

Approach to Critical Following a Poison Outage…continued

- **In this fashion, the adjuster rods are pulled to allow the zone levels to respond and rise to 70% level while a "*Hold Power*" is in effect.**

- **The adjuster rod drive is then stopped and the zone levels are decreased to 25% level with a "*Raise Power*" command.**

- **A "Hold Power" command will be initiated once the power doubles for the first time.**

- **The operator can now approach criticality in half steps of the previous zone level changes to confidently approach and detect the criticality state.**

- **The reactor would now be critical and power could be increased on the log range once the *post-criticality check list* requirements are satisfied.**

RECOVERY FROM A POISON OUTAGE ASSIGNMENT

1. **Describe the basic production of Xenon-135 to show why there is a xenon peak produced following a reactor trip.**
2. **Define the term '*override time*' and explain its reactor control significance.**
3. **State four key time phases of an override time and briefly describe each.**
4. **Sketch and describe the Xenon-135 *transient curve* following a reactor trip.**
5. **Prepare a logic flowchart to describe an accelerated operations approach to criticality at the end of a poison outage.**
6. **Describe one cycle of the operation coordination of average zone level, power error, xenon level and adjuster rod position to show how the operator could approach criticality in the method flowcharted.**

Lesson 7: REACTOR CONTROL

MODULE 2: ZONE LEVEL CONTROL

ZONE LEVEL CONTROL OBJECTIVES:

At the end of this module, you will be able to:

1. **Sketch & label a reactor core layout to show the approximate location of the** *14 liquid zones*.
2. **Sketch & label the *reactivity platform* view of the zone level guide tubes and show which zones would reside in each guide tube.**
3. **Sketch a simplified zone control scheme to define the controlled and manipulated variables.**
4. **State the difference in zone level control response when control sensing is by (a) ion chambers (b) in-core flux detectors?**
5. **Sketch an overall *zone control system* showing key components**
6. **Briefly describe zone level behavior following a successful power increase request.**
7. **State the reactivity worth of the 14 zones and approximate complete filling time.**
8. **State an overriding *fail-safe* requirement to be specified for a liquid zone system?**
9. **State how the zone outflow is maintained relatively constant?**

LWZC Principle of operation

The light water in each of the 14 individual zones is a *neutron absorber* and can be considered as a liquid absorber rod.

- **The *higher the light water level* in any particular zone, the more neutrons will be absorbed and so the *reactivity will be decreased* in the area surrounding that zone.**

- **The *lower the light water level* in any particular zone, the fewer neutrons will be absorbed and so the *reactivity will be increased* in the area surrounding that zone.**

- **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.**

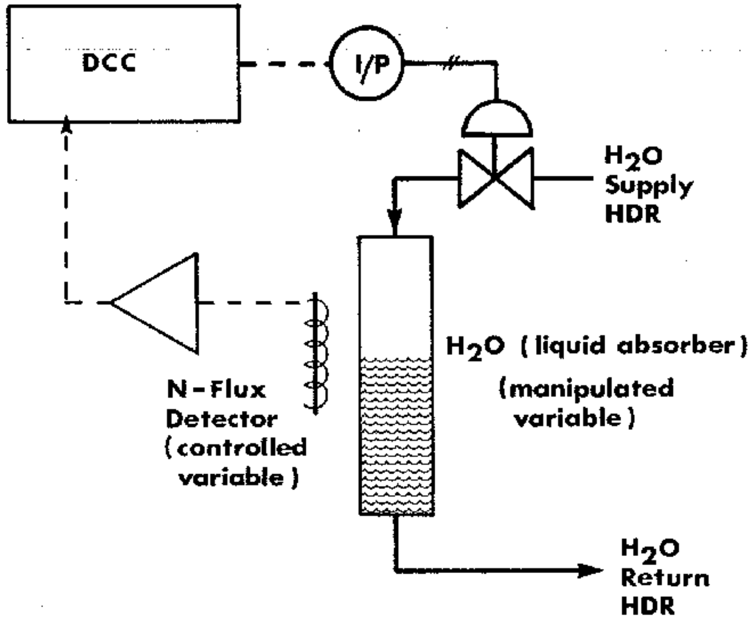


Figure 1: Simplified Zone Control Circuit.

Control Loop Performance

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

Bulk versus Differential Zone Control

- **Ion chamber sensing: all zones are *controlled together* to the same level to provide *bulk power* control.**
- **In-core flux sensing: each zone can be *individually controlled* to allow *differential* zone control**

Location of Zones

The fourteen zones are located as shown in Figures 2 and 3, seven zones per axial core half.

Figure 2 - Guide Tubes & Zone Locations

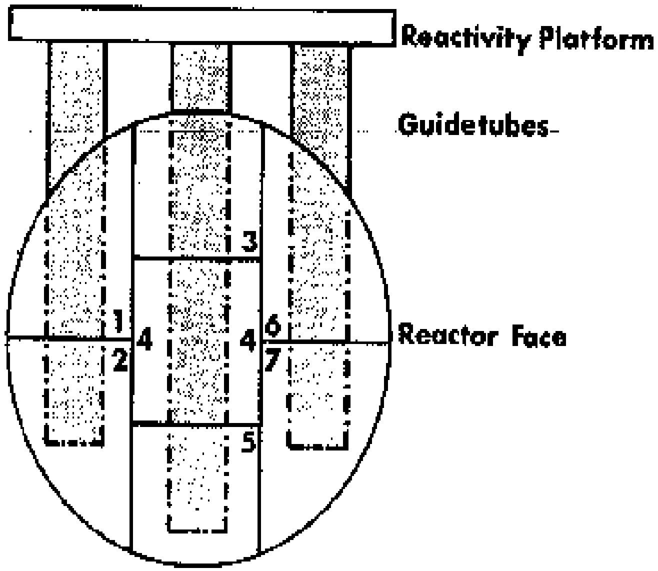
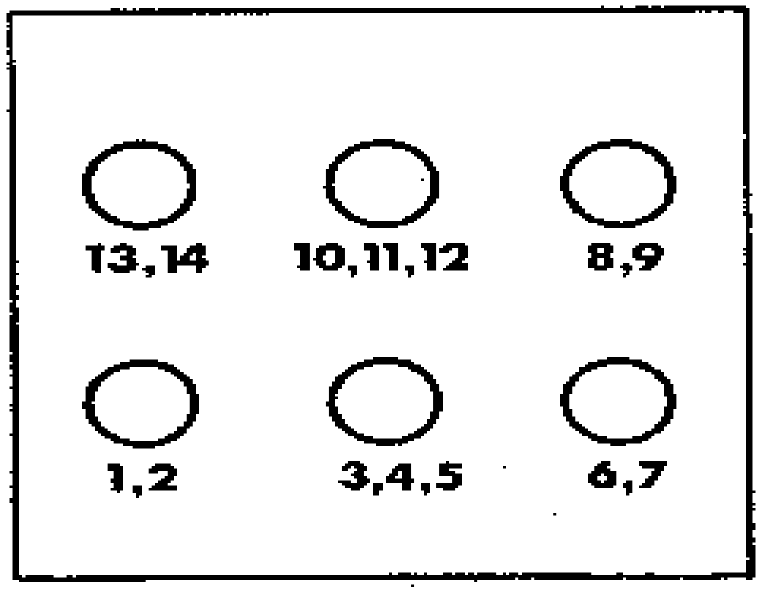


Figure 3 - Guide Tubes on Reactivity Platform



- **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).**

Zone Level Sensing by Bubbler Level Measurement System

- **Recall that the bubbler detection method measures the *back pressure* of an injected gas**

- **The bubbler gas is fed to the *base level* of the process liquid, and is 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* of the process liquid 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 height of the process liquid column (h) such that:**

$$P = S*h$$

- **With constant density, the *base pressure is measured* (back pressure) and the *level* can be determined (h=P/S)**

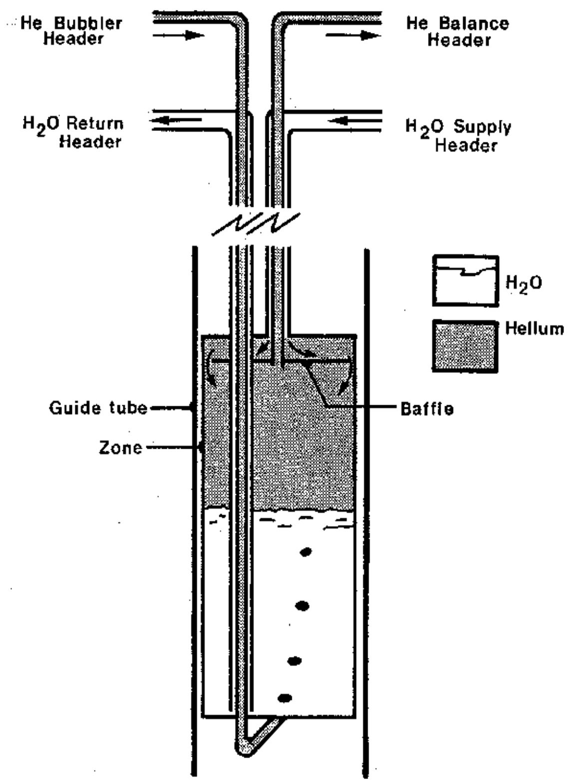
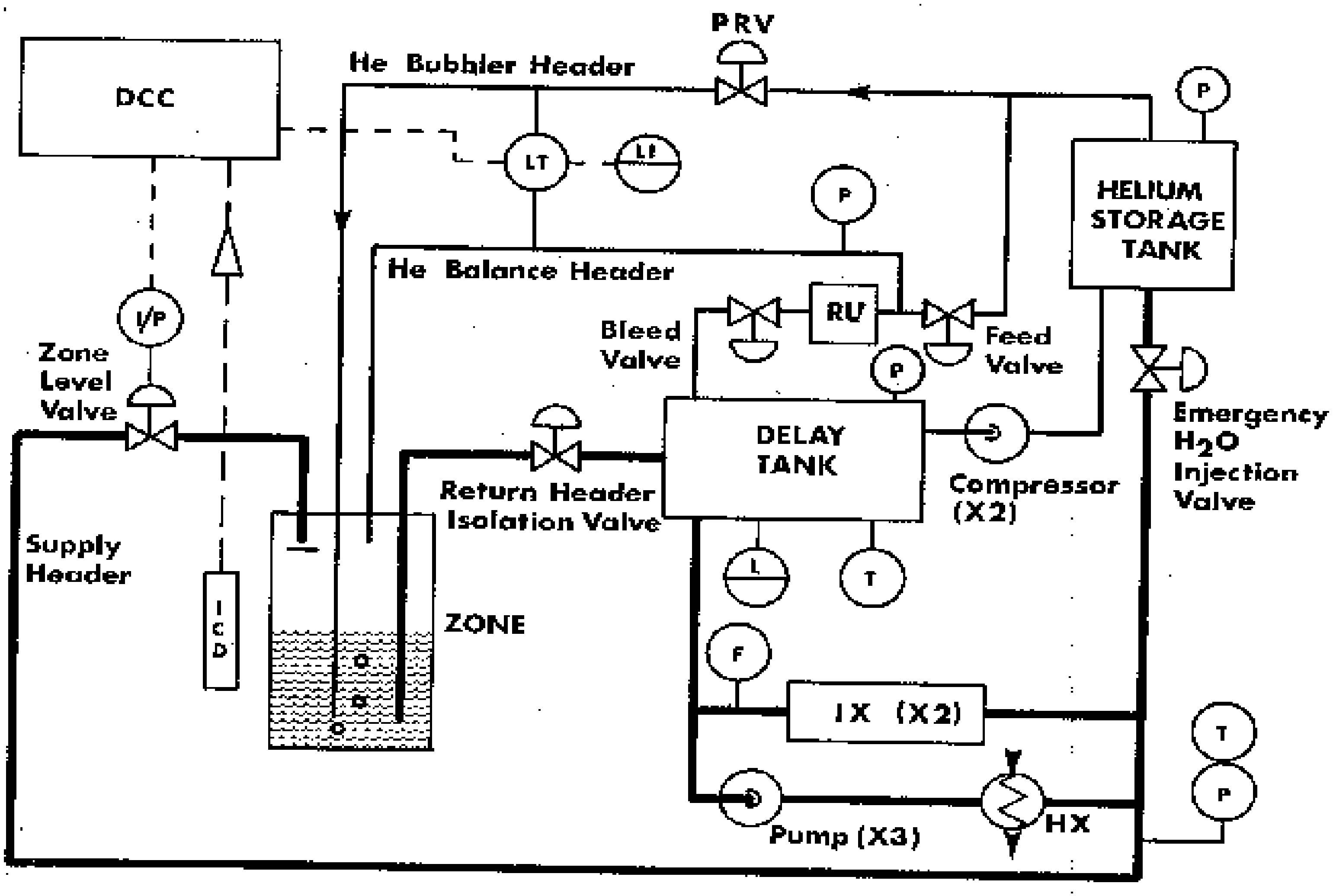


Fig 4: Typical Zone Feed Tube Connections.

- **The *back pressure* developed from the helium bubbler header supply will be applied to the *high pressure port* of an electronic differential pressure transmitter which will provide a signal proportional to the level in that zone.**

Bubbler Principle (continued)

- **Since the zone compartment is essentially a closed tank, the low pressure port of the DP cell must be connected to the gas space above the liquid (which is the Helium Balance Header connection).**
- **This applies the gas (helium) pressure to *both sides* of the transmitter, canceling out the cover gas pressure effect.**
- **There must also be provision for *regulating the helium pressure* supplied to the bubbler to prevent the bubbler supply from pressurizing the cover gas and stopping the bubbler action.**
- **The bubbler system is used to *prevent the process from entering the DP cell* impulse lines, and hence contaminating the pressure transmitter.**
- **The level transmitters can be *mounted some distance from the reactor*, and relative elevation changes will not introduce any significant level measurement errors.**
- **The chosen *inert bubbler/cover gas*, helium, ensures that there will be no neutron activation products.**



The Light Water Liquid Zone Control System - Water and Helium Circuits

Basic LZC System Operation

- The light water is routed from the H_2O supply header via *fourteen control valves* (fail open type) to the individual zones.
- The *inflow rate is variable*, by control valve opening, typically between 0.2 and 0.9 L/secs, at a temperature of approximately 55° C.
- The *outflow rate is constant*, typically 0.45 L/sec
- The outflow temperature will be approximately 90° C.
- Zones can fill from 50% to 100% in 30 seconds

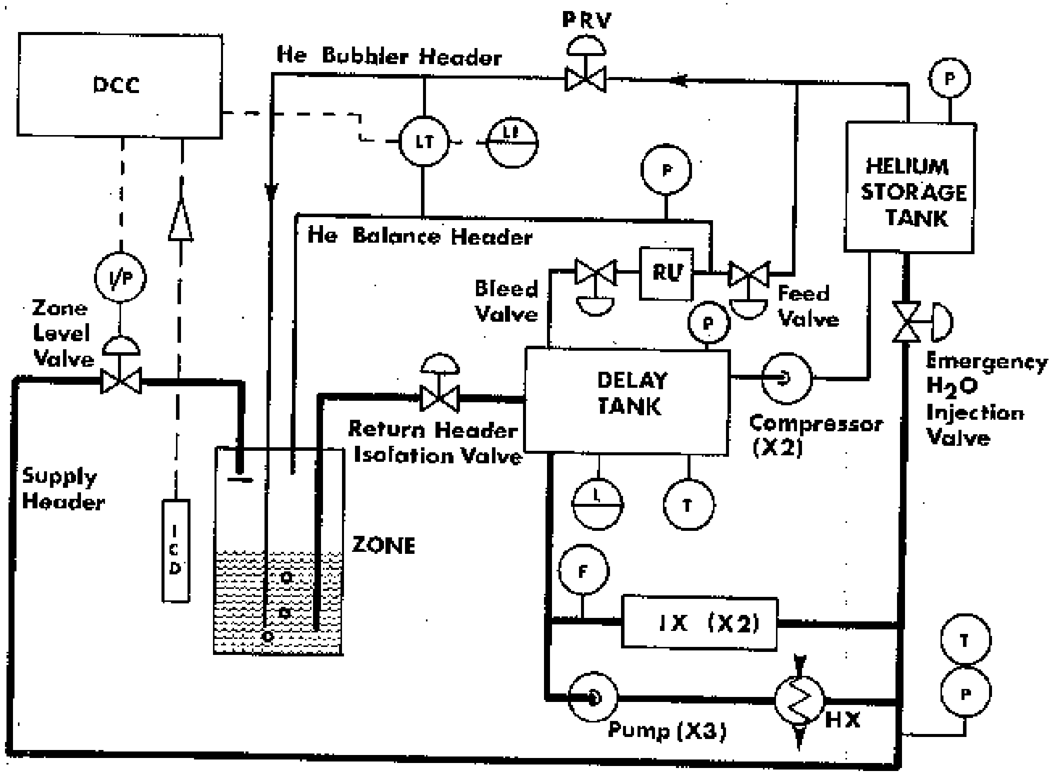


Figure 5: Zone Level Control Water and Helium Circuits.

Pressure Dependent Constant Outflow

- A constant pressure differential of 0.45 MPa maintained from the helium balance header to the delay tank cover gas (i.e., across the zone), ensures that the outflow from the zones is relatively constant.

Pressure Dependent Constant Outflow (continued)

- **This constant differential pressure is maintained by either admitting helium (i.e. feed) from the helium storage system through a *<u>Helium feed valve</u>* to the helium balance header**

- **or, this constant differential pressure is maintained by *<u>bleeding helium</u>* from the balance header to the delay tank via a helium bleed valve**

- **This is an example of *<u>split range control</u>* where two control valves (the helium *feed* and the helium *bleed* valves) accept one common control signal to act in a coordinated manner to manipulate the system inflow and outflow at the same time.**

- **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 *<u>fail closed</u>* type, which prevents draining of the zones on loss of instrument air and hence *prevents an uncontrolled increase in reactivity*.**

- **The water circuit is completed by the *<u>delay tank</u>*, 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 stable power level when an increase in power is requested to a new power level (PDEM).**
- **The power (PACT) will be *ramped up* at a controlled rate (PREQ) until the new setpoint is reached, a negative power error (PERR) will exist between the actual power and the ramped requested power.**
- **The zone *levels must decrease* in order 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 go to zero when the Actual Power equals the Requested Power (i.e., when the power reaches the acting Setpoint).**
- **As the liquid zone control is *straight proportional*, the control function can be described by the standard proportional control equation:**

  $m = k_c . e + b$,where:
  m = control signal used to drive the manipulated variable,
  k_c = controller gain,
  e = error between the actual power and the requested set point,
  b = bias which sets the valve lift so inflow equals outflow when power error is zero

- **When the control error equals zero, the control signal equals the bias.**
- **Thus when the power is at the set point, the control signal is defined as LBIAS so that valve position matches zone inflow to outflow.**
- **If the power had reached the acting setpoint, the acting power setpoint could now be increased again (continue to be ramped up) if the acting setpoint is not equal to the demanded power.**

Control of Reactor Power (continued)

- **If the power rises above the setpoint, the power error will go positive and zone levels would start to rise in proportional response decreasing the reactivity and forcing the power back down toward the setpoint.**

- **If at the conclusion of the power increase, the multiplication factor k was still greater than 1, then the power will continue to increase raising the actual power above the demanded power.**

- **PERR is now positive. Zone levels will begin to rise to reduce power and k will be reduced towards one.**

- **Equilibrium will only be achieved when PERR = 0 and k = 1. The *zone level* provides the *integrating effect* of zone inflow change which holds the power at the requested value.**

- **At completion of the power increase, the *zone level will return to essentially at the same level* as before the power change took place.**

- **In fact, there will be a small initial deviation from the original zone level due to the effects of fuel temperature coefficient, followed by in the case of a power increase, a rise in zone level due to Xe-135 burn-off, peaking 5 or 6 hours later as Xe-135 reaches the new equilibrium condition.**

- **This zone level response compensates for the decrease in Xenon level due to the increased burn up at the higher flux levels.**

- **As the Xenon builds to the new equilibrium level, the zones will once again approach the original level (assuming negligible fuel burn up).**

Zone Control Panel Manual Loading Station

The operator indications provided are:

- ***zone level*** **in meters (H_2O Level)**
- ***valve signal*** **in %**
- ***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 *fail-safe 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 downgrade 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 zone inventory (i.e. low He storage tank level) will indicate the existence of this fault.**
- **An abnormally high average zone level indicates a high level of zone reactivity. Further control by the liquid zone system in these conditions is not likely to be achieved and supplementary reactivity control means must be initiated (e.g., by inserting adjuster rods or 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 between 25% to 75%.***

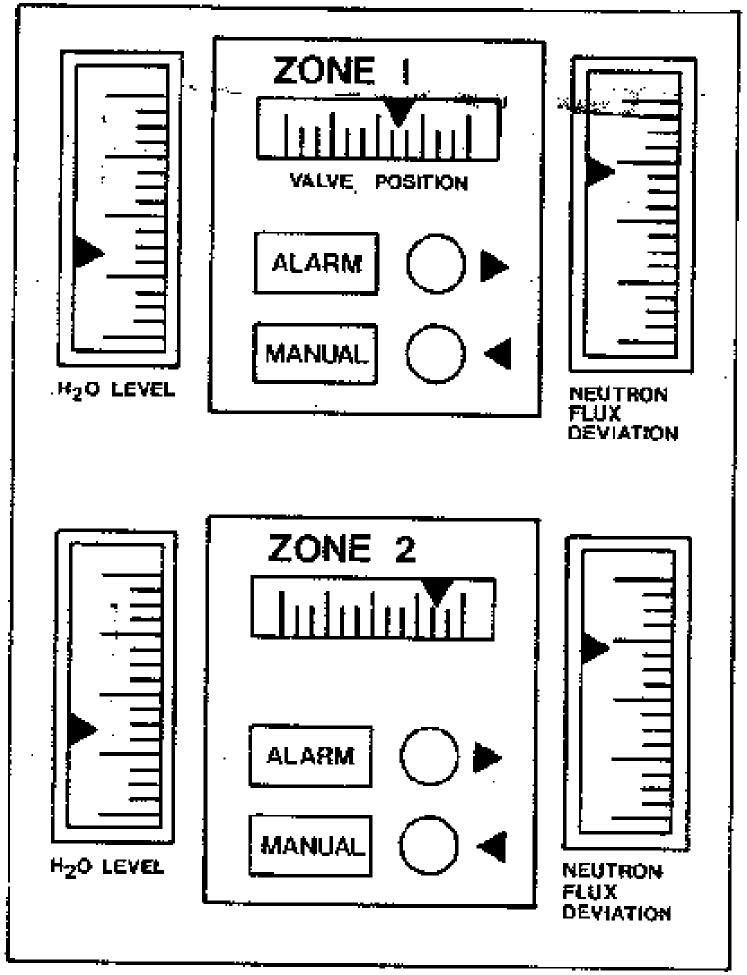


Figure 6: Zone Control Panel Manual Loading Station.

LZCS Summary

1. **The zone level control system is the first choice method (*preferred mechanism*) for reactor control.**

2. **The zone system is designed to *fail-safe*.**

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

4. **Zone level control is a *relatively fast acting*, low volume system (zones can completely fill from mid-level position within 30 seconds)**

5. **The 14 zones are worth approximately 6 mK**

6. **The 14 zone compartments are *distributed in 6 guide tube assemblies* accessible from the reactivity platform deck.**

7. **The availability of the *zone level control system is necessary* for reactor operation or the reactor should be in the Guaranteed Shutdown State (GSS).**

8. **The zone *levels are measured via a helium bubbler* system.**

9. **The helium differential pressure from the liquid zones to the delay tank is controlled relatively constant to provide a *constant zone outflow rate*.**

10. **The zone control system is *straight proportional* which is able to maintain the power at the setpoint only when the power error is zero and the multiplication factor k=1. Zone level provides the integral effect for the zone inflow control action.**

ZONE LEVEL CONTROL ASSIGNMENT

1. Sketch & label a reactor core layout to show the approximate location of the 14 liquid zones.

2. Sketch & label the reactivity platform view of the zone level guide tubes - show which zones would reside in each guide tube.

3. Sketch a simplified zone control scheme to define the *controlled* and *manipulated* variables.

4. What is the difference in zone level control response when control is by (a) ion chambers (b) hilborn (incore) detectors?

5. Sketch an overall zone control system showing:

   1. zone
   2. incore detector
   3. zone level control valve
   4. return header isolation valve
   5. He compressor
   6. H_2O pumps
   7. ion exchange columns
   8. recombination unit RU)
   9. He feed and bleed valve
   10. control computer
   11. H_2O circuit heat exchanger
   12. helium storage tank
   13. delay tank
   14. Helium bubbler header
   15. Helium balance header

6. Briefly describe zone level behavior following a successful power increase request.

7. State the reactivity worth of the 14 zones and approximate complete filling time.

8. What overriding fail-safe requirement would you specify for a liquid zone system?

9. How is the zone liquid outflow maintained relatively constant?

Lesson 7: REACTOR CONTROL

MODULE 3: REACTOR REGULATING SYSTEM

Reactor Regulating System (RRS) OBJECTIVES:

At the end of this module, you will be able to:

1. **State the general purpose for the RRS.**
2. **State the necessary reactor condition if the RRS is not operational.**
3. **Describe the reactor automatic and manual operational intent strategy.**
4. **List five CANDU reactivity mechanisms and state the prime intent for each mechanism**
5. **State three general requirements for the principle reactivity mechanism**
6. **Sketch and describe a reactivity mechanism coordinating strategy as provided by the LIMCR.**
7. **Describe the operational intent and means for reactor setback routines and give three examples.**
8. **Describe the operational intent and means for reactor stepback routines and give three examples.**
9. **Describe the purpose and general means (including type of detectors) for Flux Mapping.**

MODULE 3: REACTOR REGULATING SYSTEM

Introduction

- **The general objective for the reactor regulating system is to provide *smooth, steady and safe operation* of the reactor within the design parameters of the reactor system.**
- **The reactor regulating system (RRS) must be available or else the reactor must be placed in the *guaranteed shutdown state* (GSS).**
- **Manual control of the reactor regulating system is not allowed (or feasible although up to two zones can be controlled manually).**

- **The set power and the rate at which the power is changed are limited to ensure a safe power change with no danger of fuel damage. A reactor power request greater than 102% F.P. (site dependent) will be clipped and higher values will not be recognized by the regulating system - this is an absolute control limit.**
- **Operator entries can be made to raise or lower the reactor power.**

- **All entries are in the form of a requested *setpoint* (i.e. 90.0%) with a predefined, particular *rate of change* (i.e. 0.1%FP/sec).**

- **Comprehensive reactor control is carried out by the digital control computers (DCCs) under the direction of the reactor regulating system (RRS) programs.**
- **Should the controlling computer stall, the *back-up computer will assume control* in a relatively bumpless fashion.**
- **If both computers stall, the reactor control system will *fail-safe* with the zones filling.**

Reactivity Balance

- **During steady state reactor operation, the neutron multiplication factor (k) must be held equal to 1.**
- **To raise power (reactor supercritical) k must be increased (k>l) and vice versa to lower power (k<1).**
- **This variation from k being equal to 1 (Δk = k-1) will be *very small* and hence changes in reactivity are usually measured in milli-k (k/1000).**
- **The source of positive reactivity within the reactor is the *fuel*. A control balance (k = 1) can be achieved by *manipulating the negative reactivity devices* (liquid zone, adjusters, poison, etc).**
- **The reactor operation will produce quantities of Xe-135, a neutron absorber, which will tend to complicate the reactivity balance. After prolonged operation, in the steady state, Xe-135 will present an *equilibrium poison burden* to the reactor (in the order of -28 mk) which can easily be accommodated by the reactivity device design and fueling.**
- **However, during reactor maneuvering *Xe-135 transients* can occur following power changes. These short term (12 hours) excursion must be *compensated* for by the Reactor Regulating System.**
- **Following a prolonged outage, the Xenon load will be very small. A *moderator poison* load (a few ppm of boron or gadolinium) is used to *replace the negative reactivity worth of the Xenon* until the Xe value returns to normal.**
- **There is a practical limit to the ppm poison level in the moderator (*reactivity banking*) that is allowed (it is only a temporary negative shim and could be lost if an in-core LOCA occurred).**

Reactivity Mechanisms

In order to control the flux of a large CANDU reactor, the following *reactivity mechanisms* can be manipulated:

1. **zone levels (preferred - principle reactivity mechanism)**
2. **adjuster rods (withdraw to provide positive reactivity supplement)**
3. **mechanical control absorbers (insert to provide negative reactivity supplement)**
4. **poison addition (add to moderator to provide negative reactivity shim)**
5. **shut down rods (withdrawal *only*)**
6. **moderator level (not on newer designs)**

From these available methods, it is important to choose one method of "first line" or preferred control for normal day to day operation. This preferred method must be capable of fulfilling the following three requirements:

- ***That reactor power is fully controllable as selected by the operator.***
- ***That rate of change of reactor power is fully controllable as selected by the operator.***
- ***That the control system must be able to prevent large flux tilts within the reactor core.***

- **The method chosen to satisfy the above requirements is the *zone level control* system.**
- **It must be capable of providing a *fine* and *relatively fast acting* control response. The system must also possess *sufficient reactivity capacity* to compensate for normal reactivity changes due to temperature fluctuations, slight xenon transients and refueling.**

Spatial Flux Control

- **To provide control of the spatial flux distribution in the reactor, the core is divided into 14 separate zones.**
- **The control system must be capable of controlling the flux in each zone individually, as well as for the complete reactor (i.e. bulk power).**
- **This spatial distribution will satisfy the demands of *flux tilt control*. At low power levels, flux tilts are not important, the reactor can then be controlled in a bulk manner with all zone levels changed in unison.**
- **The liquid zone control system must be available at all times or the reactor must be shut down and placed in the *guaranteed shutdown state (GSS)*.**

Control Sequencing (Limit Control Routine (LIMCR))

- **Recall that the preferred method of reactor control is by the manipulation of zone level and that the total reactivity worth of the zones is effectively 6 mk (± 3 mk if the zone level starts from 50%).**
- **Power error (PERR) corrections may require a larger change of reactivity than the zones are capable of providing. For example, a freshly fueled reactor would probably have a *high average zone level* and any resultant positive power error (power greater than setpoint) would require an increase in zone level to reduce power to the setpoint. If the required increase is not possible to achieve without zone level exceeding say 75%, then some other reactivity adjustment (e.g., adjuster rod or moderator poison) should be used to keep zone levels in the most responsive level range (say 15 to 85 % level).**
- **LIMCR is the coordinating control program which ensures that zone level control remains the first line method of reactor control within the defined 'control box' of *average zone level* and *power error*.**

Limit Control Routine (LIMCR)

- **The methods used to achieve this coordinating control strategy will differ according to the actual reactivity mechanisms available at a particular reactor site.**

Using the 500MWe CANDU as an example.

Figure 1 shows *__Power Error__* displayed on the horizontal axis *__and Average Zone Level__* on the vertical axis for an LIMCR. The ideal operating state would be with a *__zone level of 50%__* and *__zero power error__*.

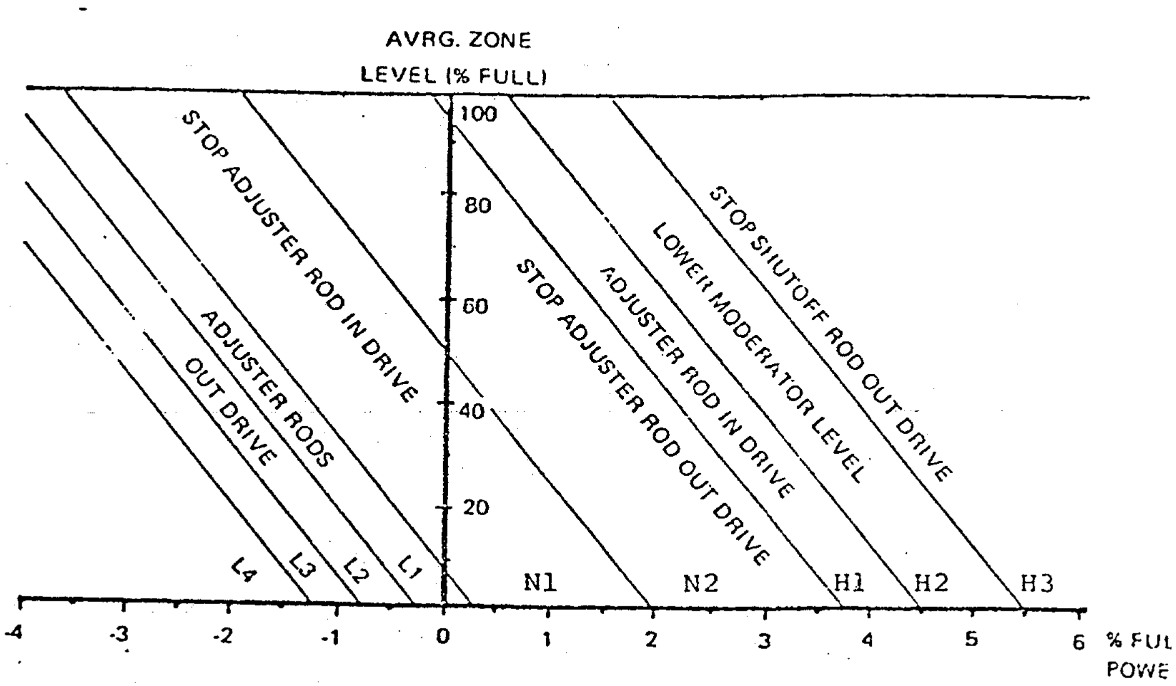


Figure 1: Power Error = P_{ACT} - P_{DEM}.

- **As an example consider the reactor operating state to be in the region H1 (ZL= 80% & PE>1.5%). Zone level adjustment alone does not seem to be capable of reducing the power error to zero. An adjuster rod(s) will be driven into the reactor core. When the reactor operating state has been shifted to region N1 (say LZ= 43% & PE > 0%) the adjuster in-drive will cease.**
- **Now consider reactor operation in regions L1, L2, L3 and L4. In these cases, at least one adjuster rod will be selected to be withdrawn since PERR is negative and zone level is low. When the reactor state has been shifted to region N2 (with a higher zone level and less negative PERR), adjuster rod withdrawal is stopped.**

- **Note that the two regions N1 and N2 provide a deadband to *__prevent adjuster rod drive cycling__*.**

Setbacks and Stepbacks

- **Setbacks and stepbacks are *control methods* used to *quickly reduce reactor power* in the event that certain reactor power, pressure or level parameters exceed predetermined limits.**

- **These systems are entirely separate from the shutdown systems and are present to reduce the frequency of operation of the safety systems (i.e. to prevent an unnecessary reactor trip).**

- **A *stepback* is effected by opening the clutches on the four control absorbers thus allowing them to *drop into the reactor*, making the core subcritical.**
- **It is possible to *limit the fall* of these absorbers by re-energizing the clutches after a very short, predetermined, period. The reactor will now be operating at a lower power state than previously, say 60%FP. If the clutch re-energizing is not performed soon enough the reactor will remain subcritical and power will drop towards the zero power hot condition.**
- **If the need for a power reduction is not so urgent a *setback* will be initiated rather than a stepback. For a setback, the reactor power is lowered at a *controlled rate*, by filling the liquid zone compartments.**
- **The setback will terminate either when the variable causing it has returned to within its limits or when a predetermined end power level is reached.**
- **The rate at which power is reduced and the power level at which the setback ends may be different for each variable.**

Stepbacks and Setbacks Continued

Typical Setback Conditions

Condition	Terminal Reactor Power
Low D/A Level	2%FP
Hi Mod Temp	2%FP
High Pressurizer Level	2%FP

Typical Stepback Conditions

Condition	Endpoint
High Zone Flux	5%FP
High ROH Press	1%FP
Turbine Trip	60%FP

Flux Mapping

- **Flux mapping is a method of *monitoring the reactor three dimensional power* distribution within the core so that individual fuel bundles and fuel channels *are operated within their design and licensing power extraction limits*.**

- **Flux mapping uses a large number of *in-core detectors located spatially throughout the reactor*.**

- **These detectors have *vanadium emitters* and their response, unlike those with platinum emitters, is *entirely due to neutrons*. The speed of response is, however, *slower than the platinum* emitter in-core detectors.**

- **This flux mapping technique is a monitoring system that will provide information to other control routines within the RRS as *required for reactor power and flux distribution calculations* as well as for off-line analysis purposes.**

MODULE 3: REACTOR REGULATING SYSTEM ASSIGNMENT

1. **State the general purpose of the *Reactor Regulating System*.**

2 . **State the necessary reactor condition if the RRS is not operational.**

3 . **Describe the reactor automatic and manual operational intent strategy for RRS. Would it be practical to operate the reactor in manual for a prolonged time? Can it partially be operated in manual mode?.**

4. **List five CANDU reactivity mechanisms and state the prime operational intent for each mechanism.**

5. **State three (desirable) general requirements for the principle reactivity mechanism.**

6. **Sketch and describe a simplified reactivity mechanism coordinating strategy as provided by the LIMCR.**

7. **Describe the operational intent and means for reactor setback routines and give three examples.**

8. **Describe the operational intent and means for reactor stepback routines and give three examples.**

9. **Briefly describe the method of producing a three dimensional neutron flux profile for the reactor.**