CHAPTER 3: REACTOR REGULATING SYSTEM

MODULE A: MEASURING INSTRUMENTS AND TECHNIQUES

MODULE OBJECTIVES:

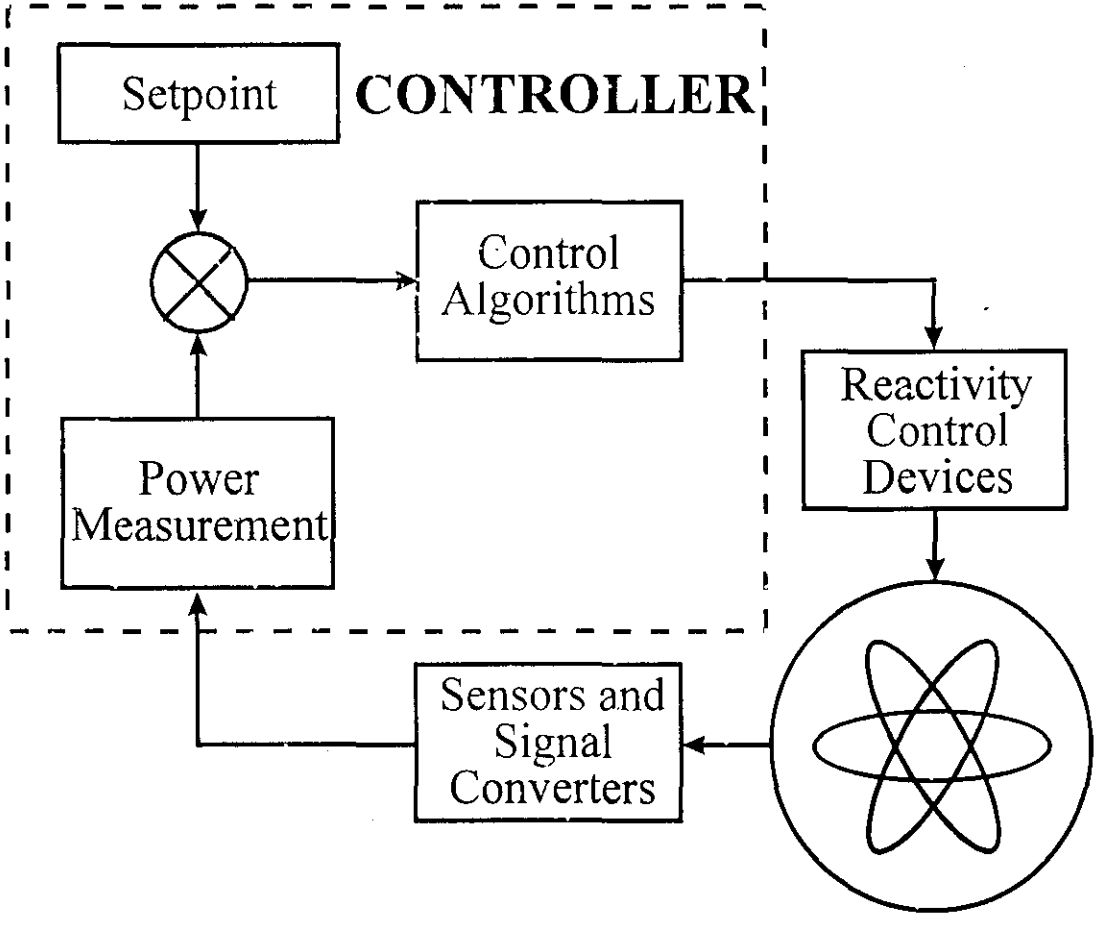
At the end of this module, you will be able to describe the following features of a CANDU reactor:

1. **The instruments used to measure neutron flux;**
2. **The measurement techniques used to monitor bulk reactor power;**
3. **The measurement techniques used to monitor zonal reactor power;**
4. **The use of thermal power measurement to calibrate the neutron flux signals.**

1. INTRODUCTION

Controlling a nuclear reactor poses the following main problems:

- how to measure neutron flux over the complete range of reactor operations
  - initial start-up
  - low power operation
  - at-power operation
  - preventing fuel damage
  - spatial distribution of flux
- how to measure the thermal power produced by the reactor
- how to ensure that reactor is at the required level of criticality
  - guaranteed shutdown case
  - approach to critical
  - maintaining criticality
  - small degrees of sub- or super-criticality
  - must avoid going prompt-critical



- reactor control is by altering the number of neutrons available for fission from one generation to the next
  - principal means is by changing the amount of neutron absorbers in the core
  - also possible to add neutron source, more fissile material, change leakage rate, resonance capture
- controller design must ensure safe, reliable & economic reactor operation within the above constraints

2. REACTOR CONTROL: LICENSE REQUIREMENTS

Legal obligations of the license are as follows:

- must be able to regulate bulk power at all power levels, otherwise must place the reactor into the Guaranteed Shutdown State (GSS)
- must be able to regulate the spatial distribution of power in the reactor when at high power (above 20%FP)
- there must be reactor shutdown systems that are independent of the reactor control systems, and the shutdown systems must be fully available, (i.e. "poised"), otherwise must go to the GSS
- must be able to monitor the neutron flux whenever there is fuel in the reactor

2.1 REACTOR POWER - TERMINOLOGY

- Neutron Power is proportional to fission rate, it excludes decay heat (& conventional heating)
- Reactor Thermal Power is the useful heat, i.e. the heat transferred from the reactor to the boilers to generate steam and via the turbine-generator produce electricity; it includes pump (friction) heat
- Fission Power is the total heat from all nuclear processes in the fuel, including waste heat; it excludes pump heat, or other conventional heat

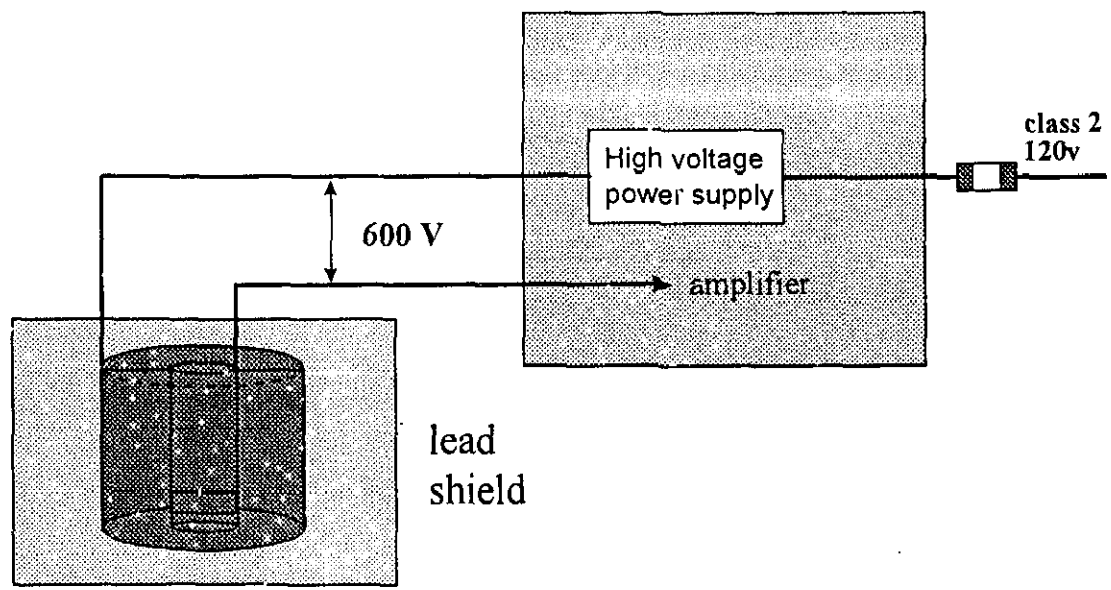
3. PRINCIPLES OF ION CHAMBER (IC) OPERATION

- Ion chambers used to measure the neutron flux in a reactor work on the principle that a thermal neutron reacting with Boron-10 results in the emission of an alpha particle:

  $_5B^{10} + {}_0n^1 \rightarrow {}_3Li^7 + {}_2He^4(\alpha)$

  - the emitted α particle ionizes the gas inside the ion chamber
  - applying a polarizing voltage between the anode and cathode will result in a current flow
  - the curent flow is directly proportional to the neutron flux reaching the ion chamber
  - note that because the ion chambers are mounted outside the reactor they measure the leakage flux
  - lead housing around the ion chamber shields it from γ radiation
  - failure of the power supply will cause an alarm in the control room

- There are typically three ion chambers for measuring the neutron flux for the purpose of reactor control.
- Additional ion chambers are used for reactor protection.

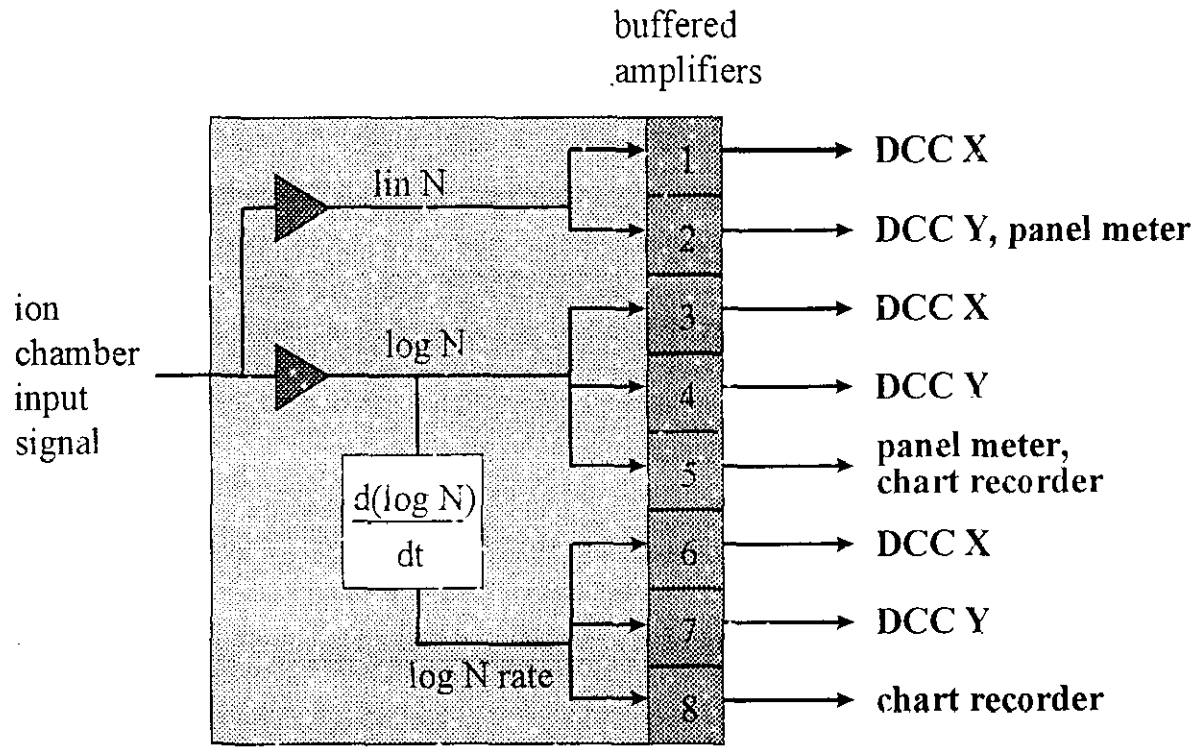


4. ION CHAMBER AMPLIFIER

- Three types of measurements are derived from the ion chamber signal:

  Lin N 0 to 150 %FP
  Log N -7 to 0 decades
  Log N rate -15 to +15 %/sec

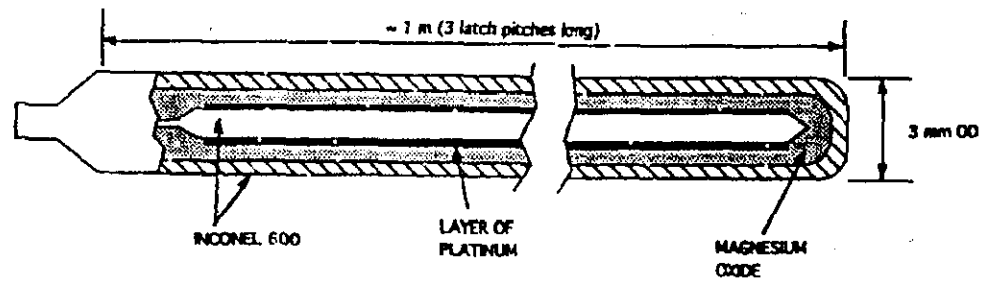
- the signals go to the control computers and to the control room panels
- because the ion chamber signal is not an accurate measure of the absolute value of the flux inside the reactor, the Lin N signal cannot be used for the direct control of reactor power
- at low power levels the inaccuracy is relatively smaller and less significant, hence Log N can be used directly for control of reactor power



- the Log N signal is not affected by the inaccuracies in the absolute value of the ion chanber signal, since it is only concerend with the rate of change of the signal
- there are typically three such amplifiers, one for processing each of the three ion chamber output signals.

5. IN-CORE (SELF-POWERED) DETECTORS (ICDs)

- An emitter electrode is surrounded by insulating material that separates it from a grounded conducting sheath (the collector).
- Radiation (neutrons & γ) interact with the emitter and eject electrons that travel across the insulator to the collector, creating a voltage difference
- Electrons "leak" from the ground back to the emitter via connecting wires and amplifier; amplified signal is proportional to radiation
- The Inconel type in-core detectors respond to:
  - neutrons from fission (prompt)
  - γ rays from fission (prompt)
  - γ rays from fission product decay (delayed)



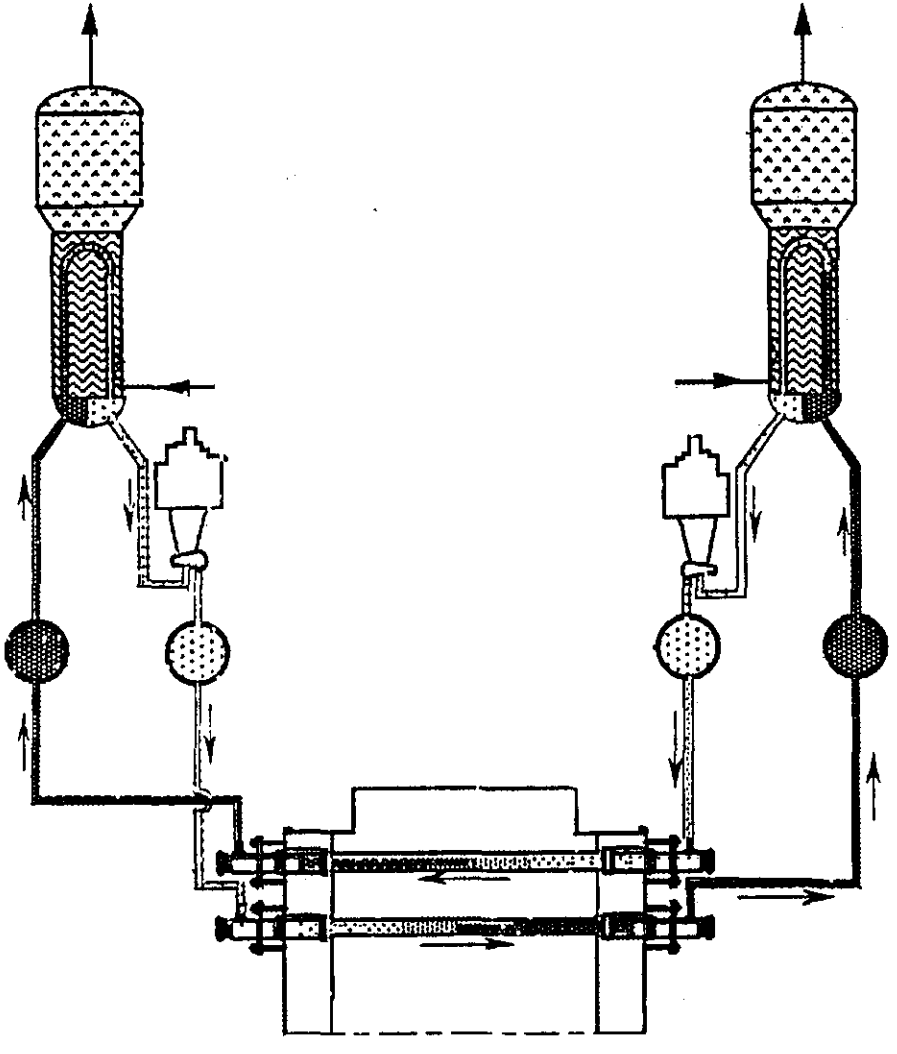
- prompt radiation is $\propto$ to neutron power; delayed radiation is $\propto$ to decay heat; but:
- the instruments do not have a balanced response to n and γ
- typical instruments under-respond to n and over-respond to γ: not enough prompt response, too much delayed response, but they do give an immediate response, and are used from 5%FP to 120%FP
- they don't directly measure neutron power or thermal power, but give readings somewhere in between
- another type of in-core self-power detector uses Vanadium emitter that captures neutrons by

  V-51(n, γ)V-52 reaction, and the V-52 decays by (β^-, γ) with half-life of 3.76 minutes, with the energetic β^- (electrons) crossing to the collector
- these detectors are physically quite small and hence give very localized reading
- they are almost 100% neutron sensitive, but are too slow for direct control.

6. THERMAL POWER MEASUREMENT

6.1 Heat Output from the Reactor

- measure the coolant flow through the reactor and the temperature increase
- for CANDU, it is possible to measure individual reactor fuel channel powers by measuring Reactor Inlet Header Temperature and Fuel Channel Outlet Temperatures, and assume that Channel Flows are as per design; this technique is good if there is no boiling (P < 80% or so)
- many CANDUs also have Fully Instrumented Channels (FINCH) to assist in calibrating the regulating system detectors.
- FINCHes measure channel inlet flow, outlet flow, and temperature increase from inlet to outlet; flow differences between inlet and outlet of a given channel give an indication of the degree of saturation
- Typically 22 such channels provide a distributed "sample" of the up to 480 fuel channels



6.2 Heat Input to the Boilers

- Measure steam flow & saturation pressure (\temperature), as well as feedwater flow and temperature
- This gives an accurate measure of heat transferred to the boilers at power levels > 50 %FP

CHAPTER 3: REACTOR REGULATING SYSTEM

MODULE B: CONTROL ALGORITHMS

MODULE OBJECTIVES:

At the end of this module, you will be able to describe the following features of a CANDU reactor:

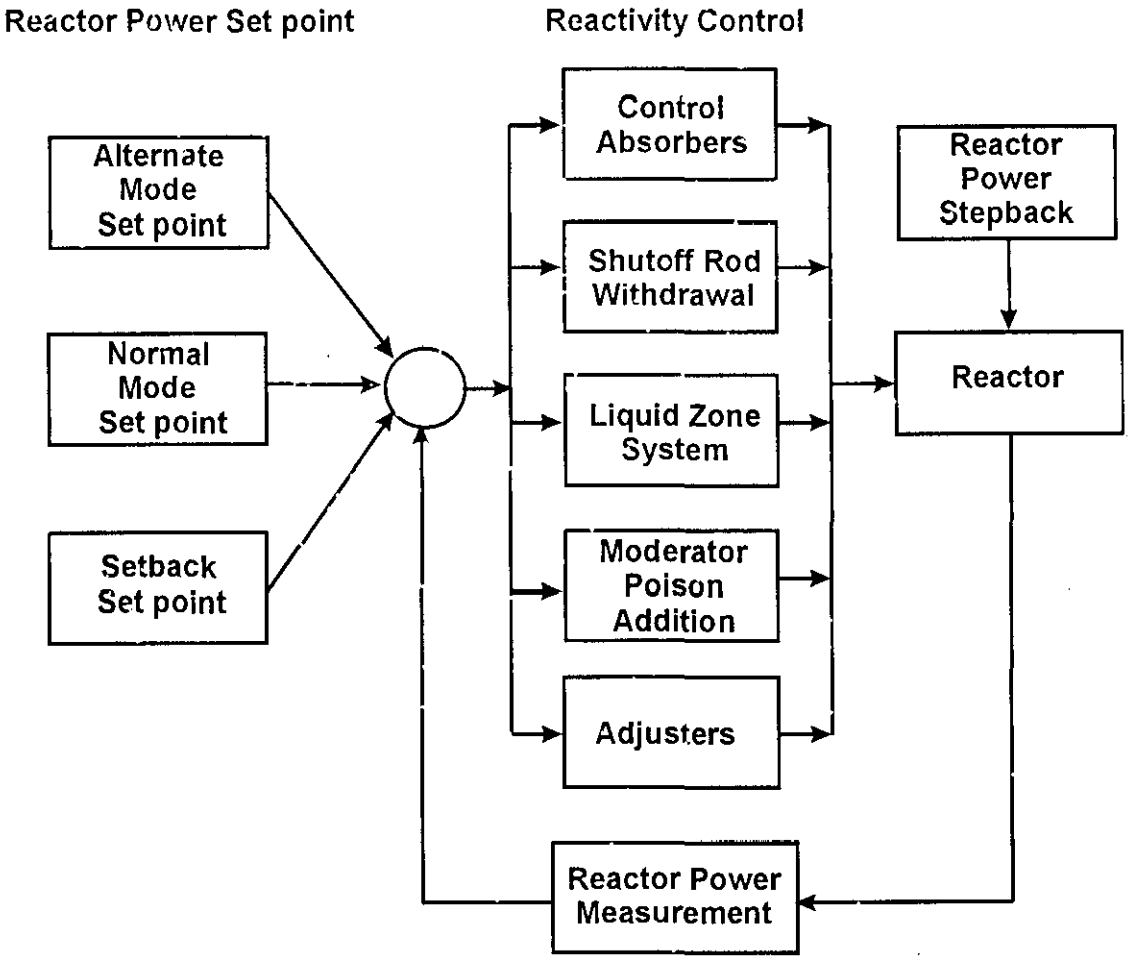
1. **The functional requirements to control reactor power;**
2. **The manner in which reactor power changes are performed;**
3. **How the various reactivity control devices are controlled to eliminate power error;**
4. **Under what conditions are Reactor Setback and Stepback initiated and their consequences;**
5. **The role of RRS in shutdown rod withdrawal.**

1. FUNCTIONAL REQUIREMENTS

- Automatic control of reactor power to a given setpoint at any power level between 10^{-7} full power and 100% full power. The setpoint and its rate of change may be specified by the operator (alternate mode) or by the steam generator pressure control program (normal mode).
- Maneuvering of reactor power at controlled rates between any two power levels in the automatic control range (above 10^{-7} full power).
- Insertion or removal of reactivity devices at controlled rates to maintain a reactivity balance in the core. These devices compensate for variations in reactivity arising from changes in xenon concentration, fuel burnup, moderator poison concentration or reactor power.
- Maintaining the neutron flux distribution close to its nominal design shape so that the reactor can operate at full power without violating bundle or channel power limits. This requirement, along with the natural spatial instability of the core, dictates the need for spatial control.
- Monitoring of a number of important plant parameters and reduction of reactor power when any of these parameters is out of limits.
- Withdrawal of shutdown rods from the reactor automatically when the trip channels have been reset following reactor trip on shutdown system number 1.

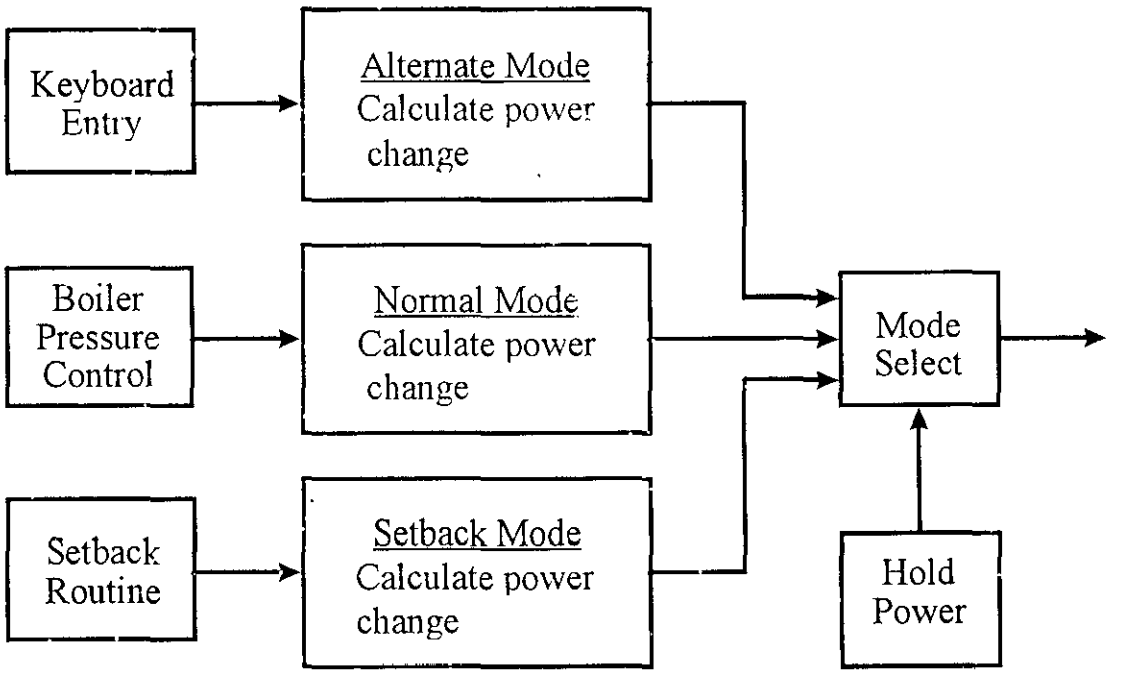
2. OVERVIEW OF THE CONTROL ALGORITHM

- For CANDUs the Control Algorithm has the following main components:
- reactor setpoint calculations
  - ⇒ mode selection
  - ⇒ demanded power calculation
- power error calculation
- control of reactivity devices
  - ⇒ adjuster rods
  - ⇒ control absorber rods
  - ⇒ liquid zone level control
  - ⇒ adjuster and absorber speed control
  - ⇒ poison addition
  - ⇒ shutdown rods withdrawal
- reactor setback
- reactor stepback



3. REACTOR POWER SETPOINT CALCULATION

- The reactor power setpoint is determined by one of the following four sources, and the reactor control program is said to be in the corresponding "modes":
  - ⇒ operator keyboard entry ("alternate" mode)
  - ⇒ boiler pressure control program ("normal" mode)
  - ⇒ setback program ("setback" mode, which terminates in "alternate" mode)
  - ⇒ hold power program ("hold power" mode which places reactor control into "alternate" mode)



- The two basic modes of reactor control are "normal" and "alternate", since both of the other modes results in reactor control being placed into "alternate" mode. Specific operator action is required to take the reactor control from "alternate" to "normal".
- The main functions of the setpoint calculation program are the calculation of demanded power and demanded power rate.

4. DEMANDED POWER ROUTINE

- All power level changes are achieved by ramping the setpoint up or down at a specified rate, towards the specified target endpoint.
- On each iteration the amount of change in demanded power is computed and added to the value of demanded power from the previous iteration
- During large difference between Target Setpoint and Demanded Power, the rate limit will keep the step increases between successive iterations small.
- As the Target Setpoint is approached, the error becomes progressively smaller, and the size of demanded power change on each iteration will decrease, resulting in a smooth approach to the Target Setpoint, minimizing the tendency for actual reactor power to overshoot the target value.
- On a "HOLD POWER" operation the change in demanded power is set equal to zero
- All reactor power setpoint changes are limited by the control program to safe rates and upper limits.
- A deviation limiter prevents the power setpoint from being more than 5% above the actual power to preclude the possibility of a large power increase at excessive rates.

5. POWER ERROR CALCULATION

- The power error is a measure of the difference between the measured power and the demanded power of the reactor, plus a rate of change of power error term.

POWER ERROR = K1(ACTUAL POWER - DEMANDED POWER) + K2(ACTUAL RATE - DEMANDED RATE)

This relationship has a fundamental role in RRS determining the movements of reactivity devices:

- the sign of the power error determines whether to
  - ⇒ increase or decrease the levels of the zones
  - ⇒ remove or insert adjuster rods
  - ⇒ remove or insert the mechanical control absorbers.
- When the power error is zero, no movement of devices will be ordered, although device movements ordered before will be completed.
- A zero power error during a given time interval implies that the reactor is critical.
- Note that a reactivity balance is not computed for reactor control.
- The design of the devices and how they are controlled (i.e. individually or in a group) is based on the reactivity worth and design purpose of each device.

6. SETBACK ROUTINE

- The setback routine reduces reactor power promptly in a RAMP fashion if any parameter exceeds specified operating limits - designed to protect fuel from overheating, reactor structures, turbine and against loss of heat sink.
- The rate at which reactor power is reduced and the power level at which the setback ends will be appropriate for each parameter.
- The setback overrides other reactor power demands and is accompanied by alarm window annunciation.
- Unit control mode will be placed in ALTERNATE mode whenever SETBACK is activated.

Conditions	Setback Rate (percent per second)	End Point (percent of Full Power)
Zone Control System Failure	0.2	60
Spatial Control Off Normal	0.1	-
Zone power > 110 % at full power	-	60
Flux tilt >20 % above 60 % full power	-	20
Flux tilt >40 % between 20 & 40 %FP	-	20
High Local Neutron Flux	0.1	60
High Steam Generator Pressure	0.5	10
Low Deaerator Level	0.8	2
High Moderator Level	0.8	2
Turbine Trip or Loss of Line	0.8	60
Endshield Flow	0.8	2
Endshield Temperature	0.8	2
Sustained Low Condenser Hot Well Level	0.8	2
Manual	0.5	2

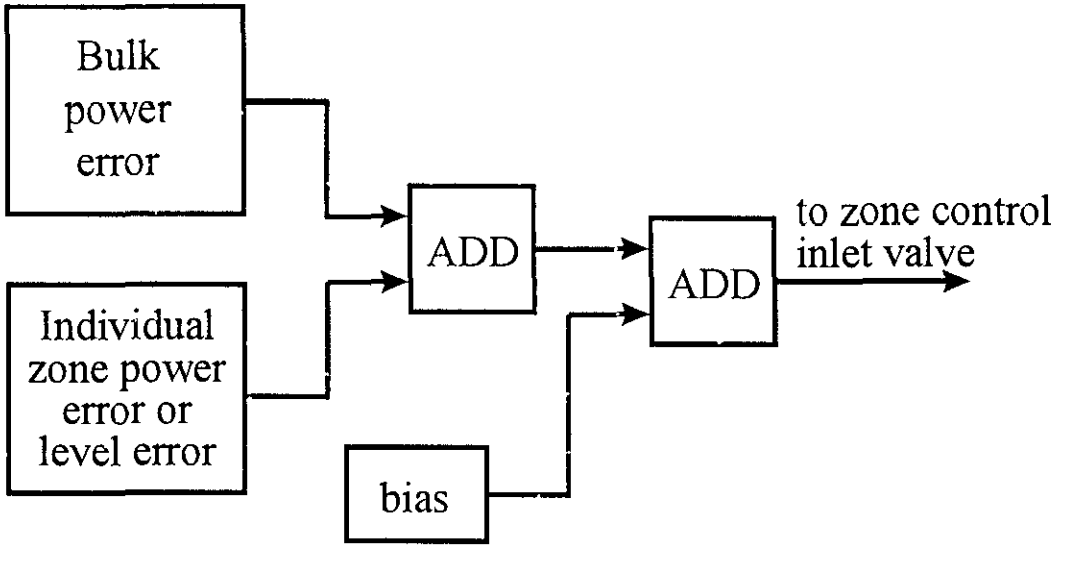
7. STEPBACK ROUTINE

- The stepback routine monitors a number of plant parameters and reduces reactor power in a STEP fashion by dropping the mechanical control absorbers either fully or partly into the reactor - the action is designed to avoid reactor trip.
- Unit control mode will be placed in ALTERNATE mode whenever SETBACK is activated.

Conditions	Control Absorber Response
Reactor Trip 2/3 contacts on SDS1 or SDS2	Full rod drop
All Heat Transport Pumps Trip	Full rod drop
Single pump trip	Full rod drop
Trip of two pumps at same end of reactor	Full rod drop
Heat Transport High Reactor Outlet Header Pressure & Reactor Power > 1 %FP	Full rod drop
High Zone Power	Full rod drop
High Rate of Log Neutron Power	Full rod drop
Low Moderator Level	Full rod drop
Low Steam Generator Level	Full rod drop

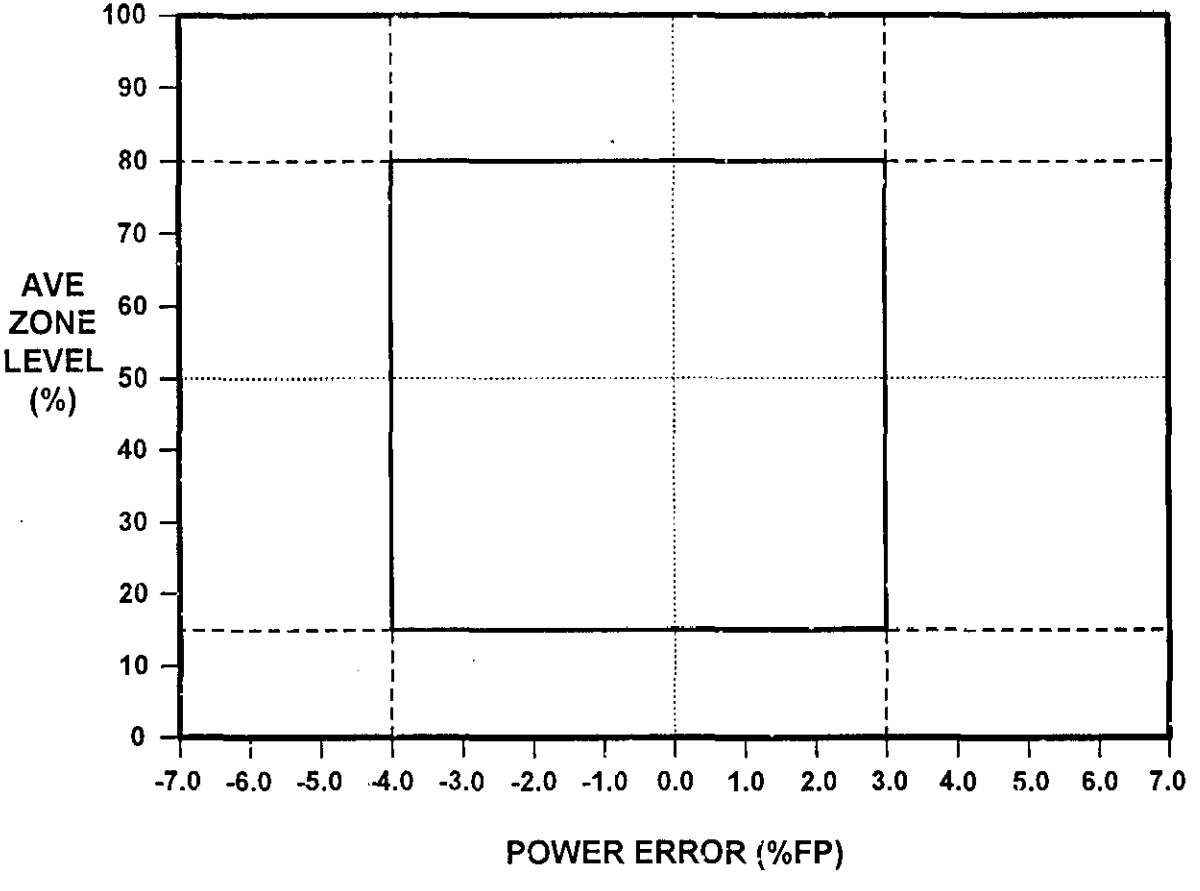
8. LIQUID ZONE LEVEL CONTROL

- the zones are the primary means of reactivity control in CANDU
- they are continuously adjusted to ensure bulk and spatial reactor power control, in response to setpoint changes as well as other reactivity variations
- the bulk power control signal is applied equally to each of the 14 zones
- in addition, each zone level control valve receives a specific control signal for spatial power distribution
- at low power control of the zones is based on liquid level, and is the same for every zone
- since the inlet valve must be open at steady state (zero error) to compensate for the constant outflow, a bias signal is applied to each valve
- a positive error will add to the bias, increasing the opening of the vaive, hence the inflow, hence the level, producing more negative reactivity, and therefor reducing power and power error
- a negative error will have the opposite effect
- logic in the control program overrides the signal before it reaches valve if the level in a given zone falls below 5% or rises above 95%



9. REACTIVITY DEVICE CONTROL

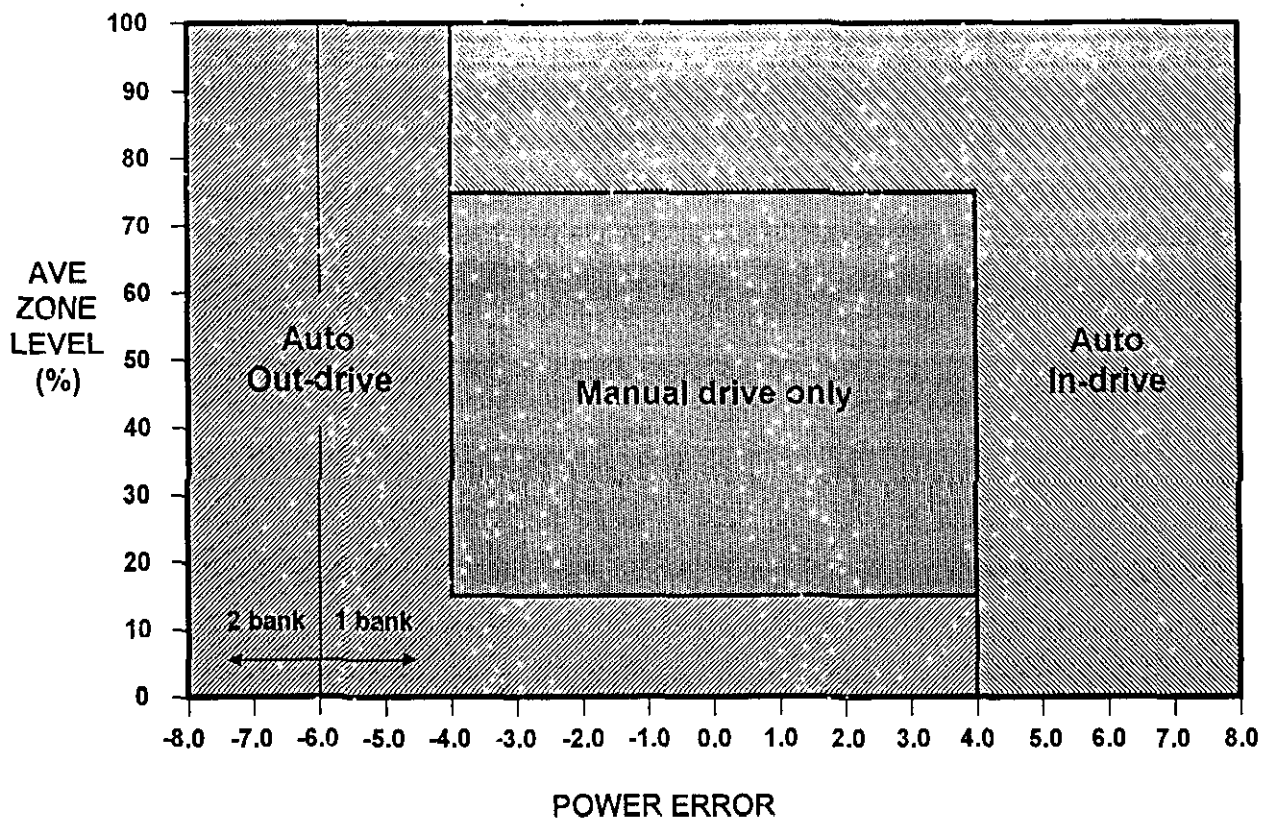
- The primary method of short-term reactivity control is by varying the liquid level in the zone controllers.
- Normally, the adjusters are fully inserted, the control absorbers are fully withdrawn and the average liquid zone control compartment level is between 30% & 50%.
- If the zones are unable to provide the required reactivity effect, other devices are operated by the reactor regulating system.
- A shortage of negative reactivity will be indicated by either a high zone controller level or a positive power error, and will cause the mechanical control absorbers to be driven in, one bank at a time (if any adjusters are not fully in the core, they too will be inserted).



- A shortage of positive reactivity will be indicated by either a low zone controller level or a negative power error, and will result in the adjusters driven out in a specific sequence (if any absorbers are not fully out of the core, they too will be driven out).

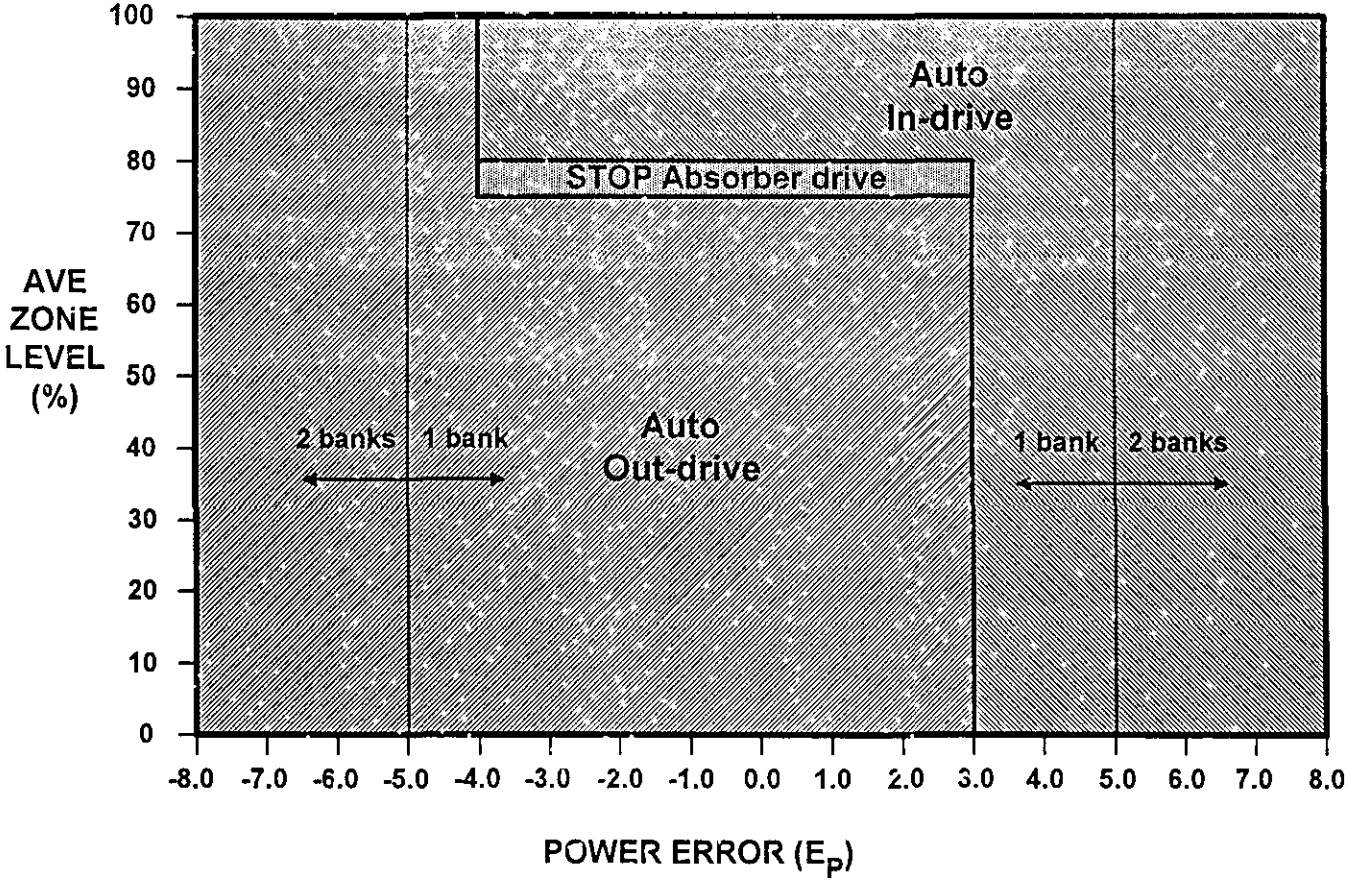
10. ADJUSTER RODS

- the Adjuster rods are normally fully inserted into the core, resulting in a flattening of the flux and providing a reserve of positive reactivity when the liquid zones have used up their range of control (reached the low level limit), and in particular as a reserve of positive reactivity (approximately 17 mk) to override xenon transients following certain power level reductions;
- CANDU-9 reactors are designed to have 24 adjusters, CANDU-6 units have 21 adjusters;
- the adjuster rods are normally on AUTO and controlled by RRS, they are moved in "banks", i.e. in groups of 2, 3 or 4 rods, in a predetermined sequence arranged in such a way as to have approximately the same reactivity worth, and to minimize the spatial flux distortion when a given bank is moved;
- can be controlled manually, either in "banks" or as individual rods.



11. CONTROL ABSORBER RODS

- the usual position of the Control Absorber rods is completely outside the core; they can be driven into the core to provide negative reactivity when the liquid zones have used up their range of control (reached the high level limit);
- there are four control absorber rods, in two banks of two rods each, normally on AUTO and controlled by RRS, but can also be controlled manually, either in "banks" or as individual rods;
- the control absorbers can be dropped into the core fully or part way by the Stepback program;
- total reactivity worth of the four control absorbers is 9 mk.



12. SPEED CONTROL SYSTEM FOR THE REACTIVITY MECHANISMS

- Variable speed control is provided to drive the adjuster and mechanical control absorber elements into or out of the core.
- Dedicated reversing motor starters control the elements individually. Speed, normally on automatic control, can be manually set from the main control room. A manual speed setting will also apply to the automatic control of adjusters and mechanical control absorbers.

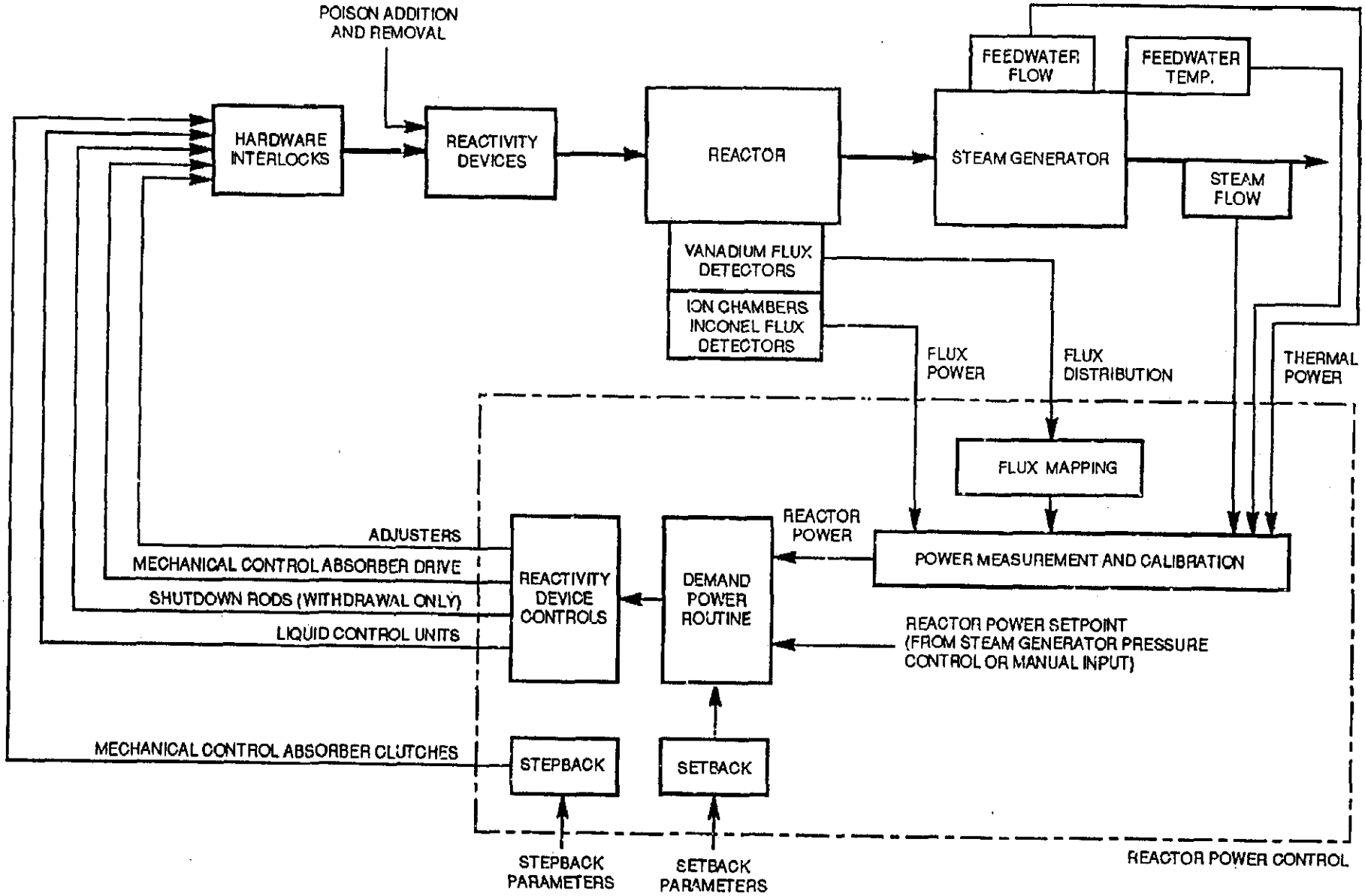
12.1 HARDWARE INTERLOCKS

- The automatic control of the reactivity mechanisms are subject to a number of interlocks to limit the consequences of a gross loss of regulation.
- To prevent the reactor from being started up with the safety systems unavailable, the adjusters and mechanical control absorbers are inhibited from being withdrawn unless both shutdown systems are poised.
- The adjusters are further interlocked to prevent more than a certain number of rods from being withdrawn at the same time. This limits the maximum rate of addition of positive reactivity. Another interlock is provided which prevents the reactor from coming critical on shutdown rod withdrawal. It prevents the shutdown rods from being withdrawn unless the mechanical control absorbers are in the core.

13. SHUTDOWN ROD WITHDRAWAL LOGIC

- Dropping of the shutdown rods is controlled by Shutdown System #1.
- Withdrawal of the rods is controlled by the Reactor Regulating system.
- Withdrawal is inhibited until the reactor trip signal is cleared and SDS#1 is 'RESET'.
- For withdrawal, the shutdown rods are arranged in two banks.
- For normal withdrawal, controlled by the reactor regulating system, both banks are withdrawn simultaneously, with withdrawal being stopped if the power error or the rate log power change exceeds a specified limit.
- Manual withdrawal is by separate banks and is allowed only if computer control is unavailable. The operator may also select individual rods to be driven in or out under manual control.

14. REGULATING SYSTEM BLOCK DIAGRAM



CHAPTER 3: REACTOR REGULATING SYSTEM

MODULE C: SIMULATOR EXERCISES

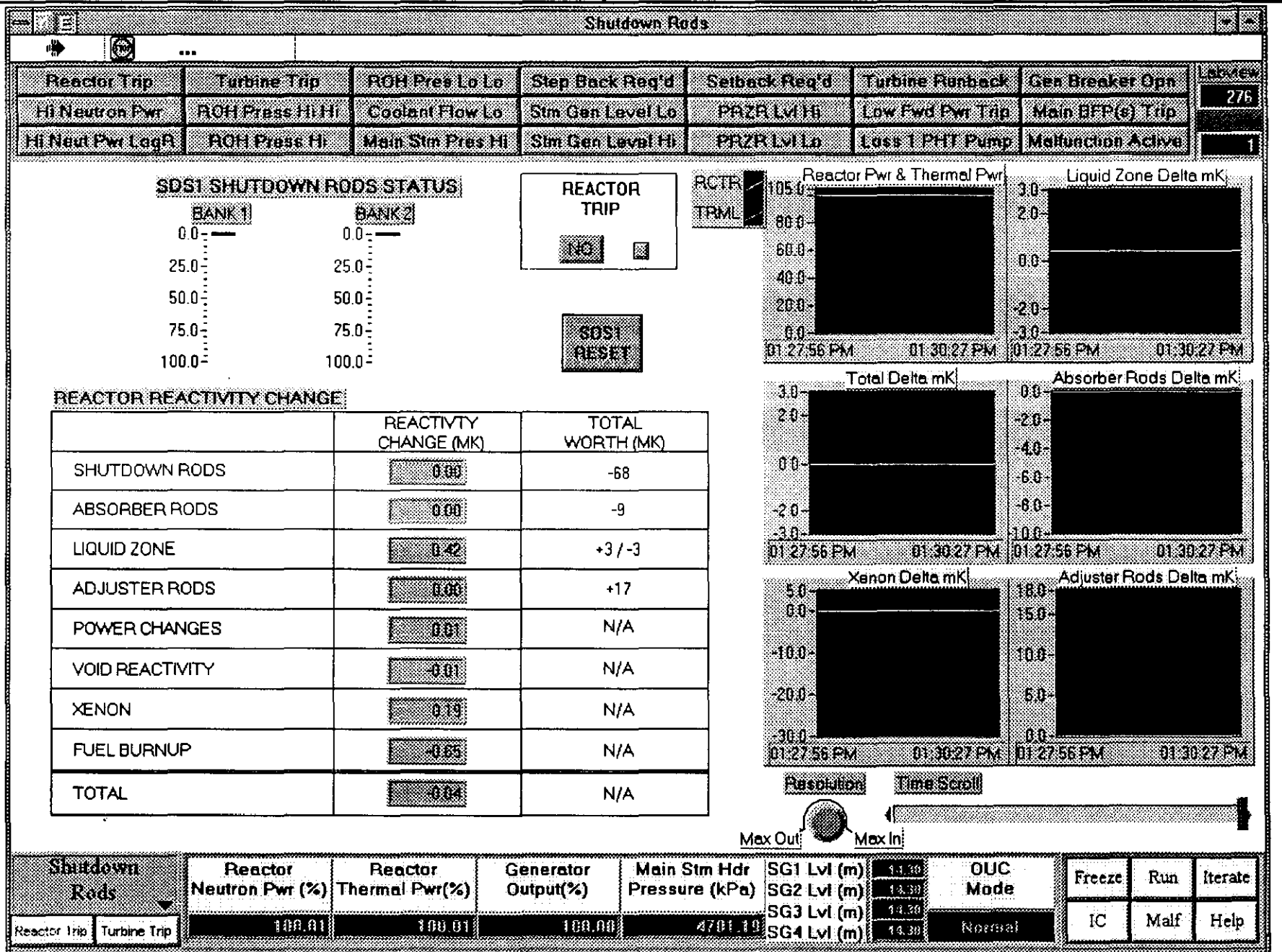
MODULE OBJECTIVES:

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

1. **Identify the parameters associated with reactivity and reactor control;**
2. **Respond correctly to the following events:**
   - **Reactor Stepback and Recovery**
   - **One Bank of Absorber Rods Drop**
   - **All Liquid Zone Pumps Trip**
   - **Fail Open Liquid Zone 1 & 2 Inlet Valves**

1. SHUTDOWN RODS PAGE

- The screen shows the status of SDS#1, as well as the reactivity contributions of each device and physical phenomenon that is relevant to reactor operations.
- The positions of each of the two SDS1 SHUTDOWN ROD banks are shown relative to their normal (fully withdrawn) position.
- REACTOR TRIP status is shown as NO (green) or YES (yellow), the trip can be reset here (as well as on the RRS / DPR page); note that SDS1 RESET must also be activated before RRS will begin withdrawing the Shutdown Rods.
- The REACTIVITY CHANGE of each device and parameter from the initial 100% full power steady state is shown, as well as the range of its potential value.
  - ⇒ Note that reactivity is a computed not a measured parameter, it can be displayed on a simulator but is not directly available at an actual plant.
  - ⇒ Note also that when the reactor is critical the Total reactivity must be zero.


Shutdown Rods
Reactor Trip
Turbine Trip
ROH Pres Lo Lo
Step Back Req'd
Setback Req'd
Turbine Runback
Gen Breaker Opn
Hi Neutron Pwr
ROH Press Hi Hi
Coolant Flow Lo
Stm Gen Level Lo
PRZR Lvl Hi
Low Fwd Pwr Trip
Main BFP(s) Trip
Hi Neut Pwr LogR
ROH Press Hi
Main Stm Pres Hi
Stm Gen Level Hi
PRZR Lvl Lo
Loss 1 PHT Pump
Malfunction Active
Labview
276
1
SDS1 SHUTDOWN RODS STATUS
BANK 1
BANK 2
0.0
25.0
50.0
75.0
100.0
REACTOR TRIP
NO
SDS1 RESET
RCTR
TRML
Reactor Pwr & Thermal Pwr
105.0
80.0
60.0
40.0
20.0
0.0
01:27:56 PM
01:30:27 PM
Liquid Zone Delta mK
3.0
2.0
0.0
-2.0
-3.0
Total Delta mK
Absorber Rods Delta mK
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
Xenon Delta mK
5.0
-10.0
-20.0
-30.0
Adjuster Rods Delta mK
18.0
15.0
10.0
5.0
Resolution
Time Scroll
Max Out
Max In
REACTOR REACTIVITY CHANGE
REACTIVTY CHANGE (MK)
TOTAL WORTH (MK)
SHUTDOWN RODS 0.00 -68
ABSORBER RODS 0.00 -9
LIQUID ZONE 0.42 +3 / -3
ADJUSTER RODS 0.00 +17
POWER CHANGES 0.01 N/A
VOID REACTIVITY -0.01 N/A
XENON 0.19 N/A
FUEL BURNUP -0.65 N/A
TOTAL -0.04 N/A
Shutdown Rods
Reactor Trip
Turbine Trip
Reactor Neutron Pwr (%)
Reactor Thermal Pwr(%)
Generator Output(%)
Main Stm Hdr Pressure (kPa)
100.01
100.01
100.00
4701.19
SG1 Lvl (m)
SG2 Lvl (m)
SG3 Lvl (m)
SG4 Lvl (m)
14.30
OUC Mode
Normal
Freeze
Run
Iterate
IC
Malf
Help

2. REACTIVITY CONTROL PAGE

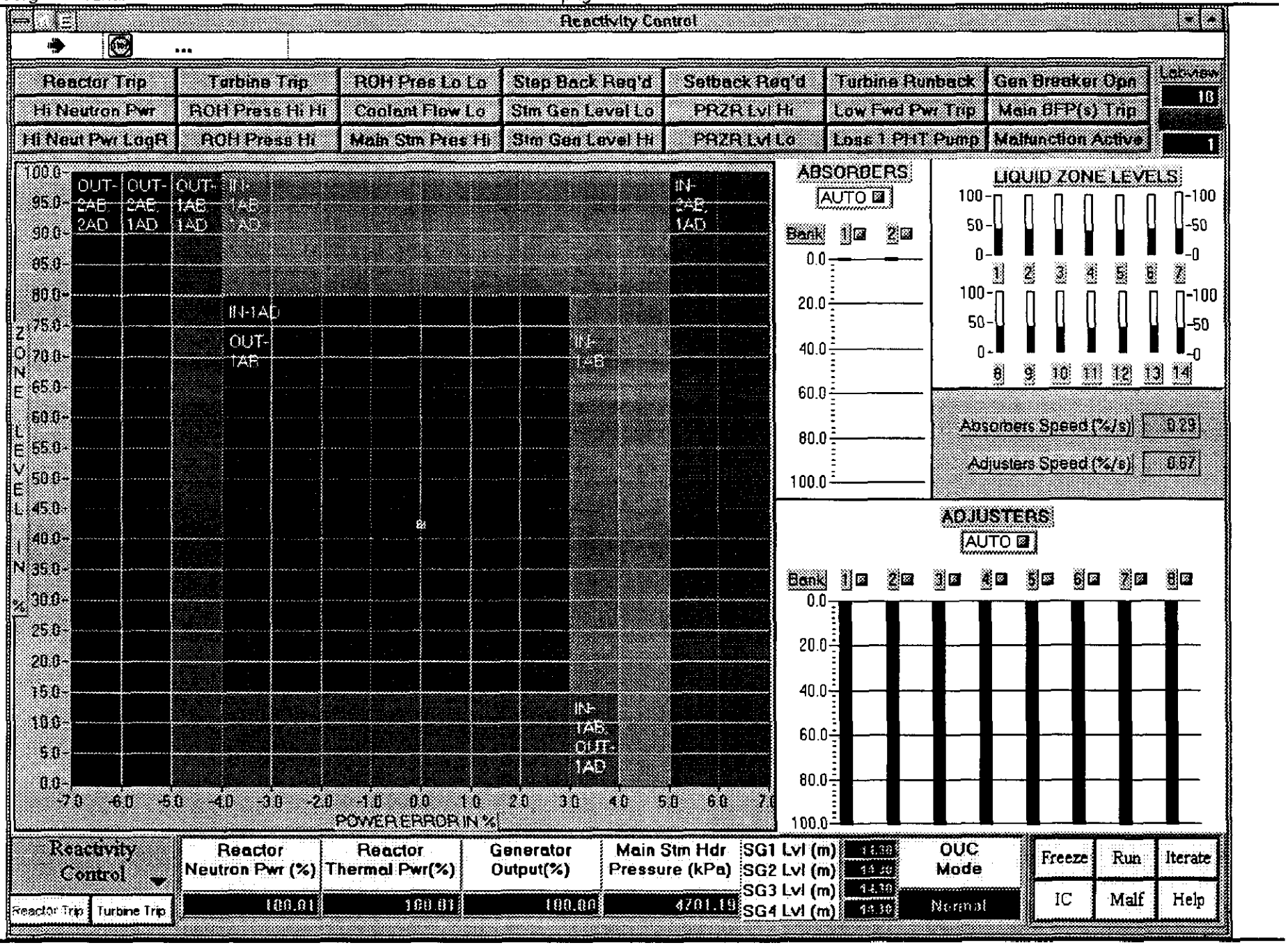
- This screen shows the Limit Control Diagram, and the status of the three reactivity control devices that are under the control of RRS.
- The Limit Control Diagram displays the Operating Point in terms of Power Error and Average Liquid Zone level.

POWER ERROR = ACTUAL POWER - DEMANDED POWER

⇒ If power error is negative, more (positive) reactivity is needed, hence liquid zone level will decrease and if this is insufficient, absorber rods and adjuster rods will be withdrawn from the reactor.

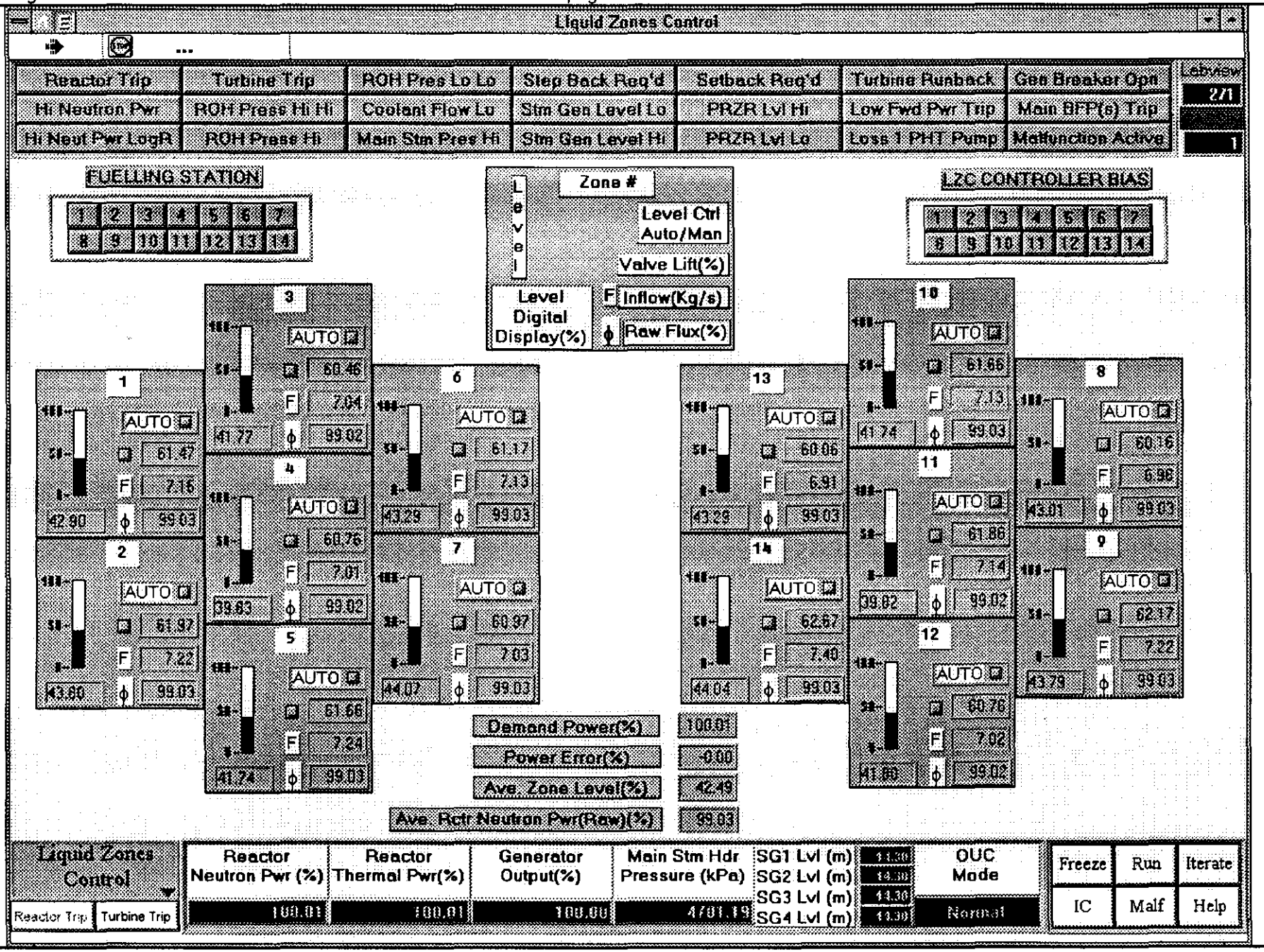
⇒ If power error is positive, negative reactivity is needed, hence liquid zone level will increase and if this is insufficient, absorber rods and adjuster rods will be driven into the reactor.

- The ABSORBERS are moved in two banks, and are normally outside the core. They can be moved by RRS if AUTO is selected, or manually if they are placed in MANUAL mode.
- The ADJUSTERS are moved in eight banks, and are normally fully inserted into the core. They can be moved by RRS if AUTO is selected, or manually if they are placed in MANUAL mode.
- The level in each of the 14 liquid zones is displayed but cannot be controlled from this page.
- The speed of the Absorbers and Adjusters is displayed but cannot be controlled from this page.


Reactivity Control
Reactor Trip
Turbine Trip
ROH Pres Lo Lo
Step Back Req'd
Setback Req'd
Turbine Runback
Gen Breaker Opn
Hi Neutron Pwr
ROH Press Hi Hi
Coolant Flow Lo
Stm Gen Level Lo
PRZR Lvl Hi
Low Fwd Pwr Trip
Main BFP(s) Trip
Hi Neut Pwr LogR
ROH Press Hi
Main Stm Pres Hi
Stm Gen Level Hi
PRZR Lvl Lo
Loss 1 PHT Pump
Malfunction Active
Labview
16
1
ZONE LEVEL IN %
POWER ERROR IN %
OUT-2AB 2AD
OUT-2AB 1AD
OUT-1AB 1AD
IN-1AB 1AD
IN-2AB 1AD
IN-1AD
OUT-1AB
IN-1AB
OUT-1AD
ABSORBERS
AUTO
Bank 1 2
LIQUID ZONE LEVELS
Absorbers Speed (%/s) 0.29
Adjusters Speed (%/s) 0.67
ADJUSTERS
AUTO
Bank 1 2 3 4 5 6 7 8
Reactivity Control
Reactor Trip
Turbine Trip
Reactor Neutron Pwr (%) 100.01
Reactor Thermal Pwr(%) 100.01
Generator Output(%) 100.00
Main Stm Hdr Pressure (kPa) 4701.19
SG1 Lvl (m)
SG2 Lvl (m)
SG3 Lvl (m)
SG4 Lvl (m)
OUC Mode
Normal
Freeze
Run
Iterate
IC
Malf
Help

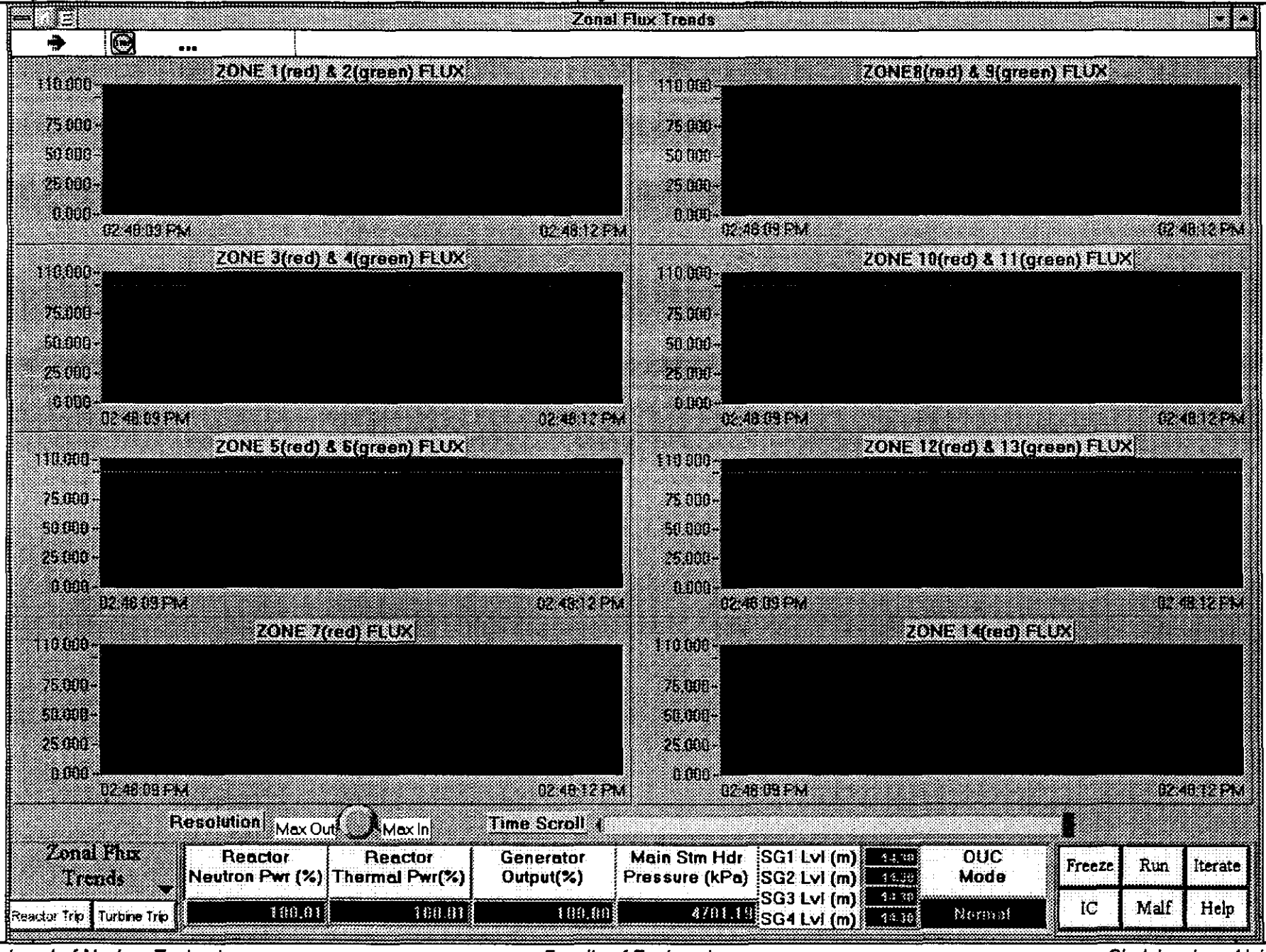
3. LIQUID ZONES CONTROL

- This screen shows the status of each of the 14 Liquid Zones Controllers. The block near the top middle part of the page gives the key to the various parameters displayed on this page.
- Each of the 14 Liquid Zone Controllers shows:
  - ⇒ the zone's number
  - ⇒ zone level (% full)
  - ⇒ zone level numerical display (% full)
  - ⇒ level controller status (AUTO or MANUAL), which can be selected here
  - ⇒ valve lift, i.e. % open of the inlet valve to the zone
  - ⇒ inflow of water to the zone compartment (kg/sec)
  - ⇒ raw (uncorrected) flux measurement for the zone
- LZC CONTROLLER BIAS allows the setting of the control point which gives the inlet valve opening that corresponds to the steady state position .
- FUELLING STATION allows the introduction of a predetermined amount of positive reactivity into the particular zone, to simulate refuelling operations.
- Parameters critical to reactor regulation are shown on a global basis:
  - ⇒ Demand Power (%)
  - ⇒ Power Error (%)
  - ⇒ Average Zone Level (%)
  - ⇒ Average Reactor Neutron Power (Raw) (%)


Liquid Zones Control
Reactor Trip
Turbine Trip
ROH Pres Lo Lo
Step Back Req'd
Setback Req'd
Turbine Runback
Gen Breaker Opn
Hi Neutron Pwr
ROH Press Hi Hi
Coolant Flow Lo
Stm Gen Level Lo
PRZR Lvl Hi
Low Fwd Pwr Trip
Main BFP(s) Trip
Hi Neut Pwr LogR
ROH Press Hi
Main Stm Pres Hi
Stm Gen Level Hi
PRZR Lvl Lo
Loss 1 PHT Pump
Malfunction Active
FUELLING STATION
LZC CONTROLLER BIAS
Zone #
Level Ctrl Auto/Man
Valve Lift(%)
Level Digital Display(%)
Inflow(Kg/s)
Raw Flux(%)
Demand Power(%)
Power Error(%)
Ave. Zone Level(%)
Ave. Rctr Neutron Pwr(Raw)(%)
Reactor Neutron Pwr (%)
Reactor Thermal Pwr(%)
Generator Output(%)
Main Stm Hdr Pressure (kPa)
SG1 Lvl (m)
SG2 Lvl (m)
SG3 Lvl (m)
SG4 Lvl (m)
OUC Mode
Normal
Freeze
Run
Iterate
IC
Malf
Help

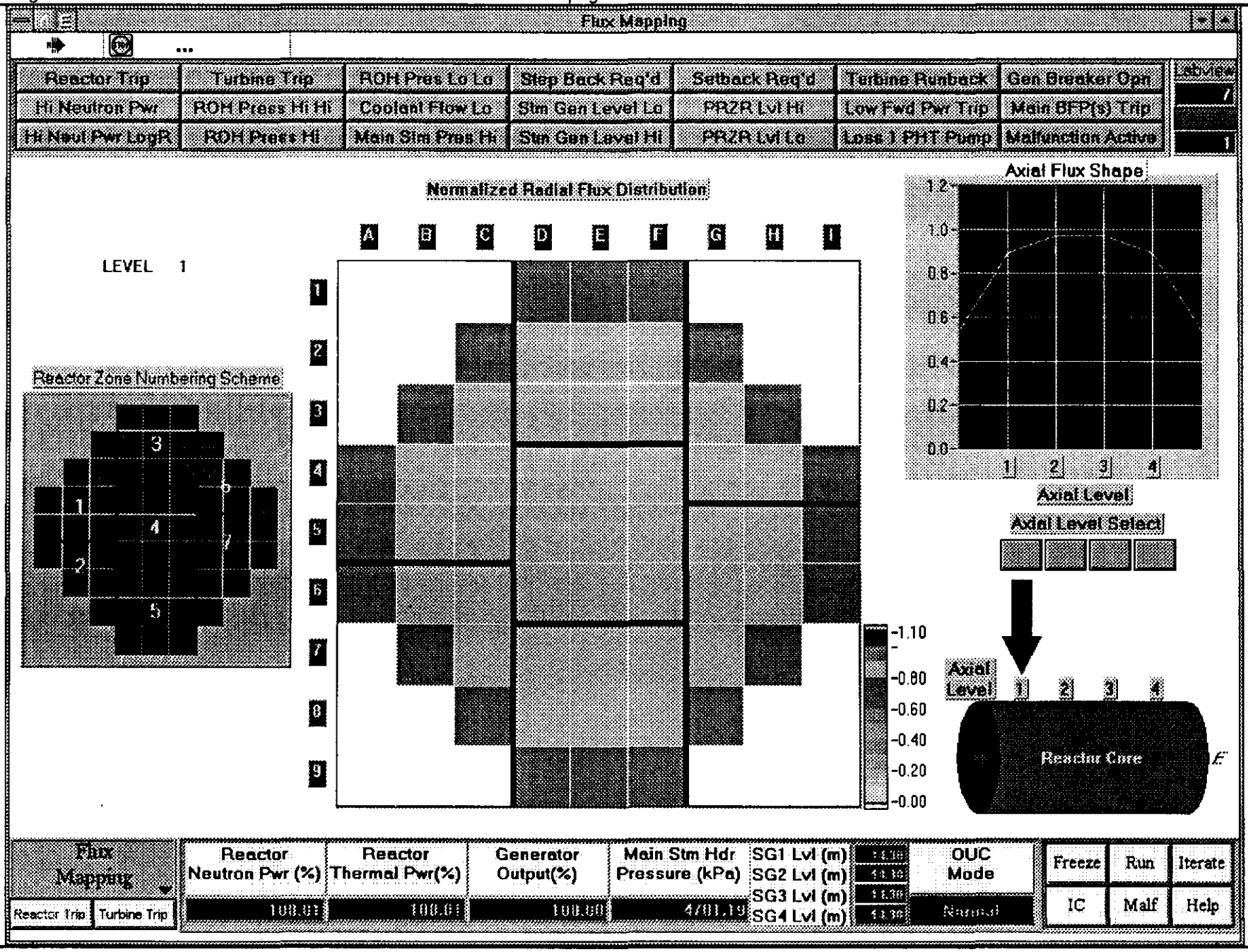
4. ZONAL FLUX TRENDS PAGE

- Each of the fourteen zonal fluxes are displayed as % Full Power.
- Note that zone fluxes 1-6 and 8-13 are displayed in pairs while each of the fluxes in zone 7 and in zone 14 is shown as a single plot.
- Whenever there are disturbances in the spatial flux distribution this page will show the extent of the differences between the fluxes in the various zones. Note that, as with all other such time plots on the Simulator, only the values computed when this page is displayed will be shown.


Zonal Flux Trends
ZONE 1(red) & 2(green) FLUX
ZONE8(red) & 9(green) FLUX
ZONE 3(red) & 4(green) FLUX
ZONE 10(red) & 11(green) FLUX
ZONE 5(red) & 6(green) FLUX
ZONE 12(red) & 13(green) FLUX
ZONE 7(red) FLUX
ZONE 14(red) FLUX
110.000
75.000
50.000
25.000
0.000
02:48:09 PM
02:48:12 PM
Resolution
Max Out
Max In
Time Scroll
Zonal Flux Trends
Reactor Trip
Turbine Trip
Reactor Neutron Pwr (%)
Reactor Thermal Pwr(%)
Generator Output(%)
Main Stm Hdr Pressure (kPa)
100.01
100.01
100.00
4701.19
SG1 Lvl (m)
SG2 Lvl (m)
SG3 Lvl (m)
SG4 Lvl (m)
OUC Mode
Normal
Freeze
Run
Iterate
IC
Malf
Help

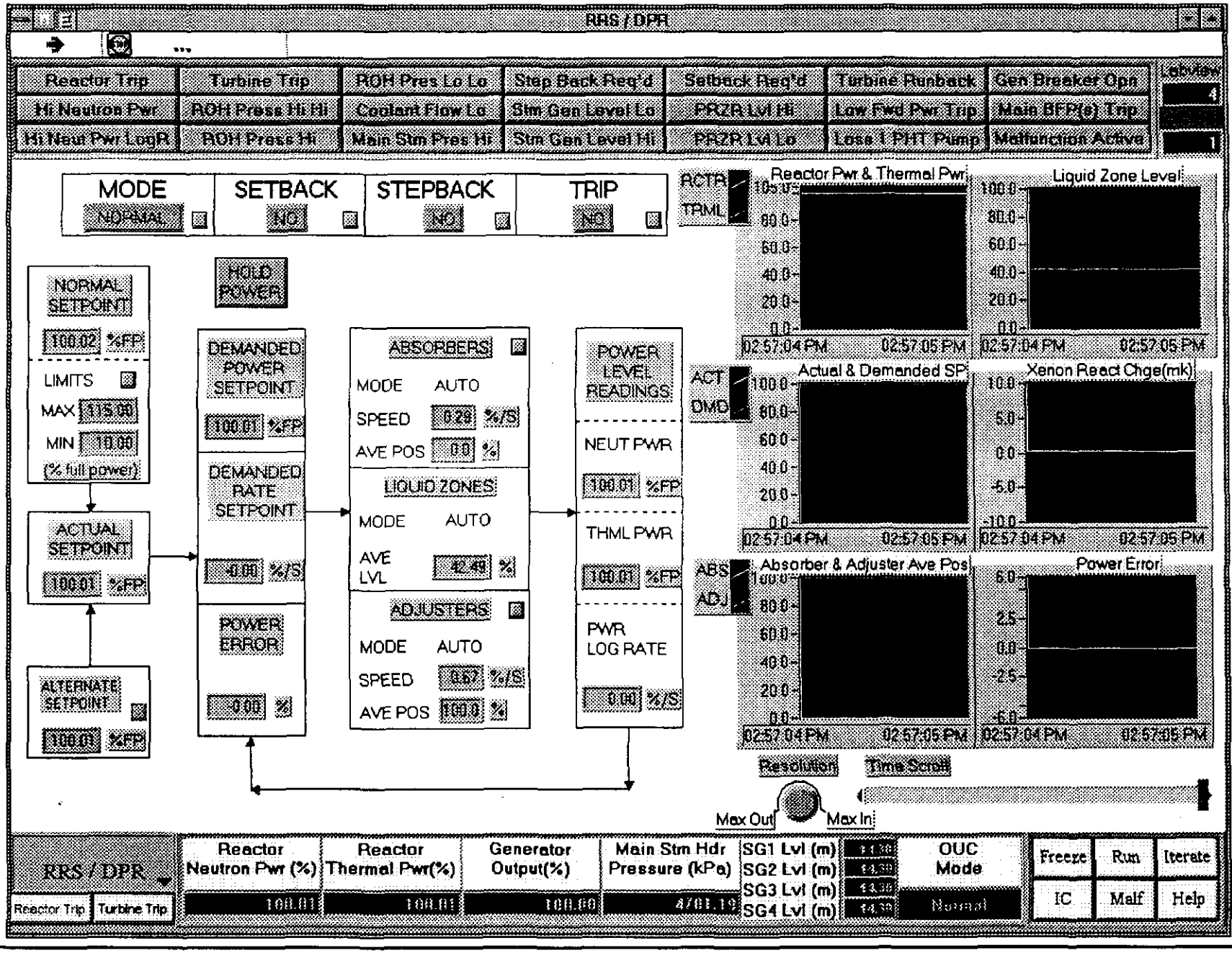
5. FLUX MAPPING PAGE

- This screen shows the spatial distribution of reactor flux along the reactor's axis parallel to the pressure tubes, as well as the radial flux distribution perpendicular to the pressure tubes. Because of the simplified models used, the flux is displayed only at four axial planes, and each radial plane shows only 57 flux regions.
- The Axial Flux Shape is shown on the diagram at the upper right hand side of the screen. The flux is normalized and corresponds to computations made at four "Axial Levels". The cross section along the axis where the flux is to be displayed is chosen via the "Axial Level Select" buttons.
- The center of the screen shows the "Normalized Flux Radial Distribution" corresponding to the axial level that was selected.
- The left hand side of the screen shows the number of the Axial Level currently selected as well as the zone numbering (East or West) that corresponds to the Axial Level selection.


Flux Mapping
Reactor Trip
Turbine Trip
ROH Pres Lo Lo
Step Back Req'd
Setback Req'd
Turbine Runback
Gen Breaker Opn
Hi Neutron Pwr
ROH Press Hi Hi
Coolant Flow Lo
Stm Gen Level Lo
PRZR Lvl Hi
Low Fwd Pwr Trip
Main BFP(s) Trip
Hi Neut Pwr LogR
ROH Press Hi
Main Stm Pres Hi
Stm Gen Level Hi
PRZR Lvl Lo
Loss 1 PHT Pump
Malfunction Active
Normalized Radial Flux Distribution
LEVEL 1
A B C D E F G H I
1 2 3 4 5 6 7 8 9
1.10
0.80
0.60
0.40
0.20
0.00
Reactor Zone Numbering Scheme
Axial Flux Shape
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1 2 3 4
Axial Level
Axial Level Select
Axial Level 1 2 3 4
Reactor Core
F
Flux Mapping
Reactor Trip
Turbine Trip
Reactor Neutron Pwr (%)
Reactor Thermal Pwr(%)
Generator Output(%)
Main Stm Hdr Pressure (kPa)
SG1 Lvl (m)
SG2 Lvl (m)
SG3 Lvl (m)
SG4 Lvl (m)
OUC Mode
Normal
Freeze
Run
Iterate
IC
Malf
Help

6. RRS / DPR PAGE

- This screen permits control of reactor power setpoint and its rate of change while under Reactor Regulating System (RRS) control, i.e. in 'alternate' mode. Several of the parameters key to RRS operation are displayed on this page.
- The status of reactor control is indicated by the four blocks marked MODE, SETBACK, STEPBACK AND TRIP. They are normally green but will turn yellow when in the abnormal state.
  - ⇒ MODE will indicate whether the reactor is under NORMAL to ALTERNATE control, this status can also be changed here.
  - ⇒ SETBACK status is indicated by YES or NO; Setback is initiated automatically under the prescribed conditions by RRS, but at times the operator needs to initiate a manual Setback, which is done from this page on the Simulator: the Target value (%) and Rate (%/sec) need to be input.
  - ⇒ STEPBACK status is indicated by YES or NO; Stepback is initiated automatically under the prescribed conditions by RRS, but at times the operator needs to initiate a manual Stepback, which is done from this page on the Simulator: the Target value (%) need to be input.
  - ⇒ TRIP status is indicated by YES or NO; trip is initiated by the Shutdown Systems, if the condition clears, it can be reset from here. Note however, that the tripped SDS#1 must also be reset before RRS will pull out the shutdown rods, this must be done on the Shutdown Rods Page
- Key components of RRS and DPR control algorithm are also shown on this screen.
  - ⇒ The ACTUAL SETPOINT is set equal to the NORMAL SETPOINT under UPR control ('normal mode'), the upper and lower limits on this setpoint can be specified here.
  - ⇒ The ACTUAL SETPOINT is set equal to the ALTERNATE SETPOINT under RRS control ('alternate mode'); the value of ALTERNATE SETPOINT is input on this page.
  - ⇒ HOLD POWER will select 'alternate mode' and sets DEMANDED POWER SETPOINT equal to the measured Neutron Power.


RRS / DPR
Reactor Trip
Turbine Trip
ROH Pres Lo Lo
Stop Back Req'd
Setback Req'd
Turbine Runback
Gen Breaker Opn
Hi Neutron Pwr
ROH Press Hi Hi
Coolant Flow Lo
Stm Gen Level Lo
PRZR Lvl Hi
Low Fwd Pwr Trip
Main BFP(s) Trip
Hi Neut Pwr LogR
ROH Press Hi
Main Stm Pres Hi
Stm Gen Level Hi
PRZR Lvl Lo
Loss 1 PHT Pump
Malfunction Active
Labview
MODE
NORMAL
SETBACK
NO
STEPBACK
NO
TRIP
NO
NORMAL SETPOINT
100.02 %FP
LIMITS
MAX 115.00
MIN 10.00
(% full power)
HOLD POWER
ACTUAL SETPOINT
100.01 %FP
ALTERNATE SETPOINT
100.01 %FP
DEMANDED POWER SETPOINT
100.01 %FP
DEMANDED RATE SETPOINT
0.00 %/S
POWER ERROR
0.00 %
ABSORBERS
MODE AUTO
SPEED 0.29 %/S
AVE POS 0.0 %
LIQUID ZONES
MODE AUTO
AVE LVL 42.49 %
ADJUSTERS
MODE AUTO
SPEED 0.67 %/S
AVE POS 100.0 %
POWER LEVEL READINGS
NEUT PWR
100.01 %FP
THML PWR
100.01 %FP
PWR LOG RATE
0.00 %/S
ACTR
TRML
Reactor Pwr & Thermal Pwr
Liquid Zone Level
ACT
DMD
Actual & Demanded SP
Xenon React Chge(mk)
ABS
ADJ
Absorber & Adjuster Ave Pos
Power Error
02:57:04 PM
02:57:05 PM
Resolution
Time Scroll
Max Out
Max In
RRS / DPR
Reactor Trip
Turbine Trip
Reactor Neutron Pwr (%)
Reactor Thermal Pwr(%)
Generator Output(%)
Main Stm Hdr Pressure (kPa)
SG1 Lvl (m)
SG2 Lvl (m)
SG3 Lvl (m)
SG4 Lvl (m)
OUC Mode
Normal
Freeze
Run
Iterate
IC
Malf
Help

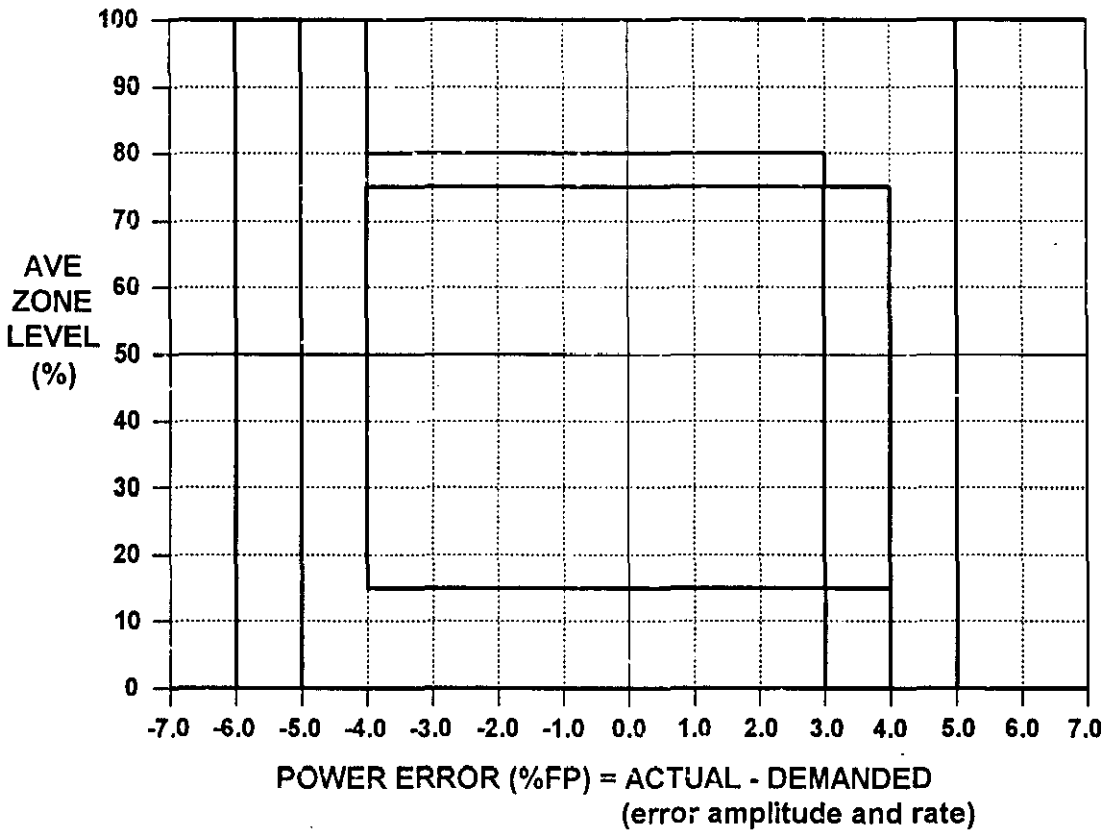
7.1 SIMULATOR EXERCISE: Unit Response to Power Maneuver in 'Alternate' mode

(1) initialize the Simulator to 100%FP, record parameters
(2) reduce power using RRS to 50% at 0.5%/sec, observe parameter changes during transient, and freeze as soon as Reactor Neutron Power reaches 50% and record parameter values
(3) unfreeze and let parameters stabilize, record parameter values
(4) return reactor power to 100%FP at 0.5%/sec, freeze as soon as Reactor Neutron Power reaches 100% and record parameter values
(5) unfreeze and let parameters stabilize, record parameter values

Parameter	Unit	(1)100%	(2) 50%	(3) 50%	(4)100%	(5)100%	Comments
Reactor Neutron Power	%						
Reactor Thermal Power	%						
Average Zone Level	%						
Actual Setpoint	%						
Demanded Power Setpoint	%						
Demanded Rate Setpoint	%/sec						
Power Error	%						
Boiler Pressure	MPa						
Boiler Temperature	°C						
Boiler Level	m						
Steam Flow	kg/s						
Feedwater Flow	kg/s						
Governor valve opening	%						
Turbine-Generator Power	%						

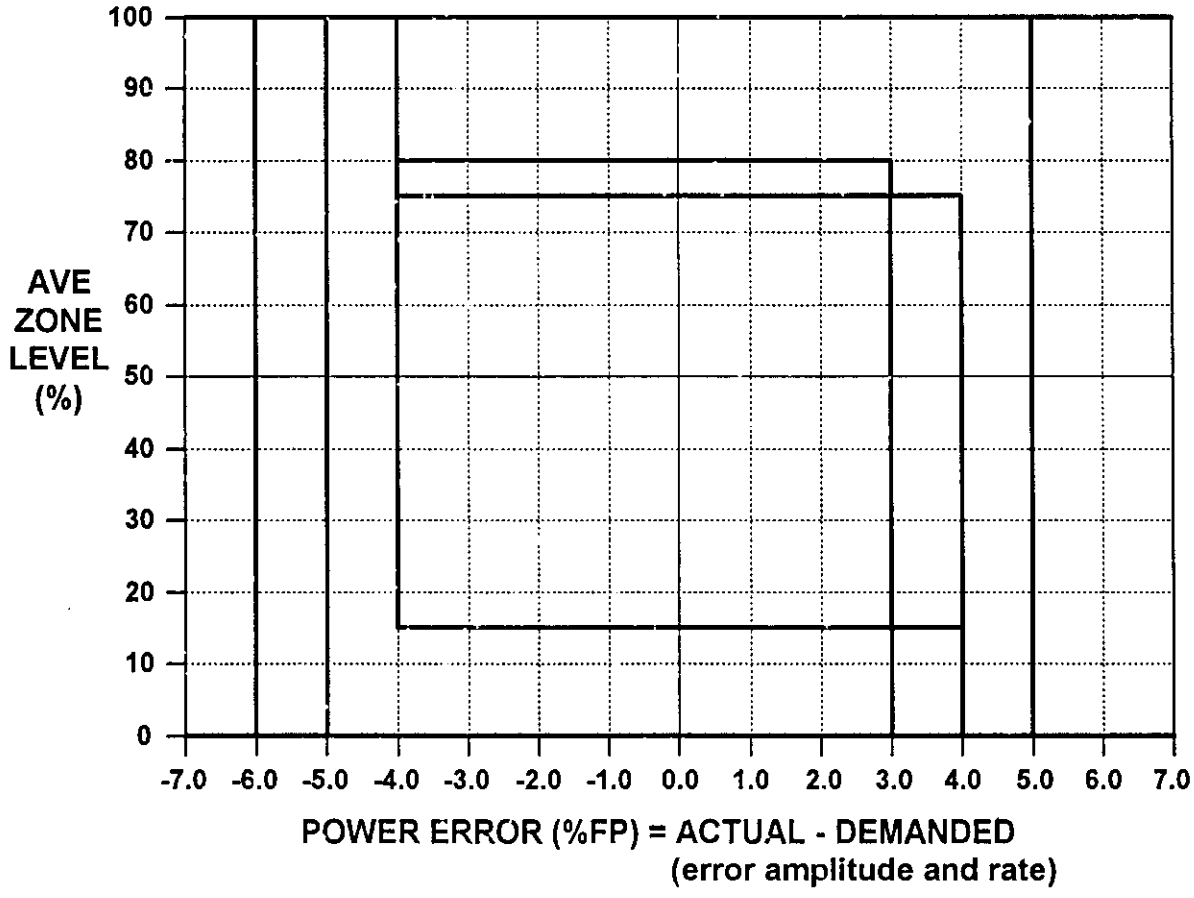
7.2 SIMULATOR EXERCISE: Response of RRS Control Algorithm to Power Maneuver

- initialize the Simulator to 100%FP and from the Reactivity Control page note the position of the operating point on the attached diagram (confirm the value of Average Zone Level on the Plant Overview page):
- insert a power reduction request using RRS to 70%FP at 0.8%/sec and freeze the simulator
- go to the Reactivity Control page, unfreeze, and note the path of the operating point on the attached diagram, until power error has stabilized at or near zero (about 3 - 4 minutes)
- confirm the value of average zone level on the Plant Overview page:
- why is the final zone level higher than the original zone level?



7.3 SIMULATOR EXERCISE: Reactor and RRS Response to Power Maneuver

- initialize the Simulator to 100%FP and from the Reactivity Control page note the position of the operating point on the attached diagram
- insert a power reduction request using RRS to 10%FP at 0.8%/sec and freeze the simulator
- go to the Reactivity Control page, unfreeze, and note the path of the operating point on the attached diagram, until at least one Adjuster Rod bank is out of the reactor (about 20 minutes) - once the first Adjuster Bank is more than 50% withdrawn, place Absorbers on Manual and drive them fully OUT.
- compare the response to case 7.2 and explain the main differences, particularly the 'end' state



7.4 SIMULATOR EXERCISE: Response to Power Maneuver under Manual Control

- initialize the Simulator to the ZONESMAN initialization point (note that all liquid zone controllers are on Manual - they are not to be used during this exercise)
- on the Reactivity Control page place the Absorbers and Adjusters to Manual
- using Absorber and Adjuster drives on Manual, maneuver reactor power to keep generator power between 80$\pm$1%FP
- note the time taken from the start of lowering reactor power until steady operation within the specified error limits is achieved

7.5 SIMULATOR EXERCISE: Response to Manual withdrawal of Adjuster rods

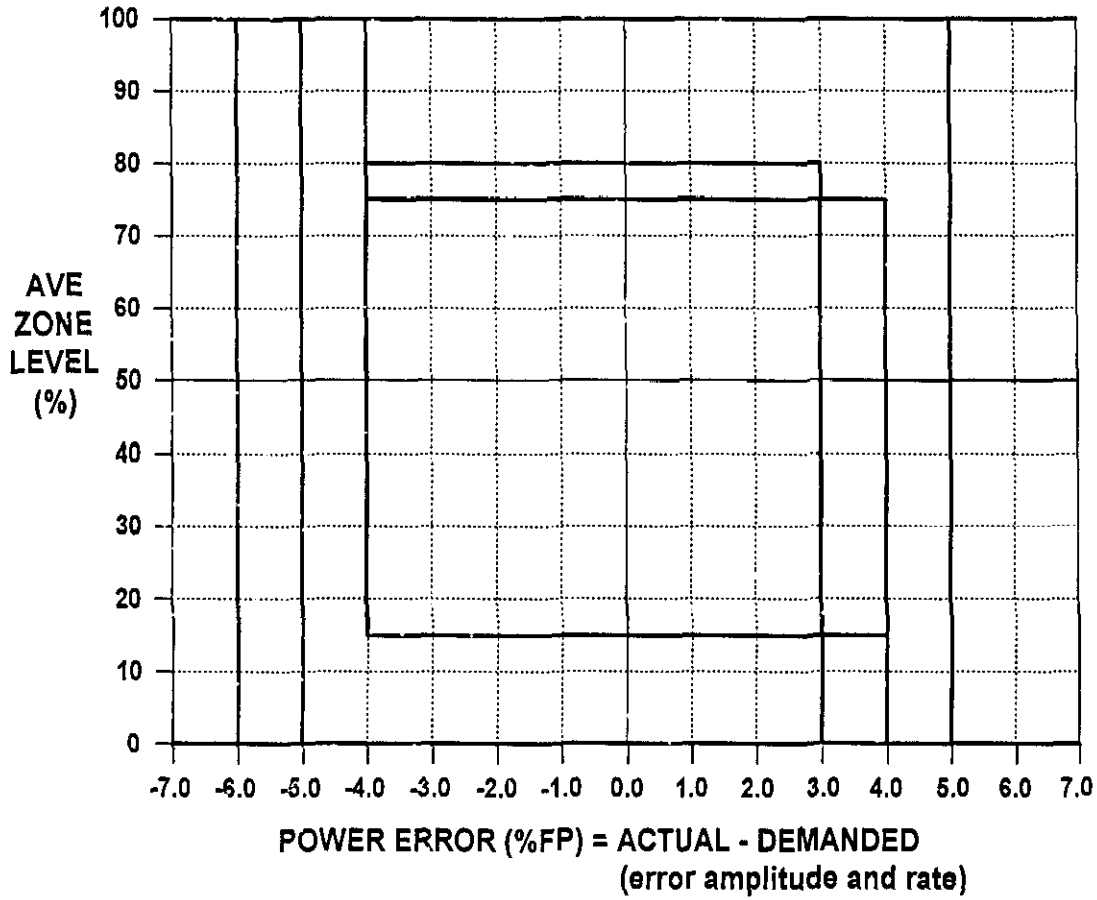
- initialize the Simulator to the ZONESMAN initialization point (note that all liquid zone controllers are on Manual - they are not to be used during this exercise)
- on the Reactivity Control page place the Absorbers and Adjusters onto Manual
- manually withdraw the Adjuster rods
- describe and explain the response of the system

7.6 SIMULATOR EXERCISE: Response to Manual withdrawal of Adjuster rods

- initialize the Simulator to the ZONESMAN initialization point (note that all liquid zone controllers are on Manual - they are not to be used during this exercise)
- on the Reactivity Control page place the Absorbers and Adjusters onto Manual
- manually drive both banks of Absorbers into the core, and by the simultaneous withdraw of one or more the Adjuster banks keep reactor neutron power within 2% of 100%FP
- once all the Absorbers are fully in the core, attempt to drive all remaining Adjusters simultaneously out of the core
- describe and explain the response of the system

7.7 SIMULATOR EXERCISE: Response to Malfunction "One Bank of Absorber Rods Drop"

- initialize the Simulator to 100%FP and from the Reactivity Control page note the position of the operating point on the attached diagram
- insert the Malfunction "One Bank of Absorber Rods Drop" (use a five second time delay)
- observe system response on the Reactivity Control page and note the path of the operating point on the attached diagram
- note OUC mode and reactor power
- clear the malfunction
- once the Absorbers have fully withdrawn from the reactor, raise reactor power to a level dependent on the number of Absorber banks out of the reactor:
- for each bank partially or fully out, reactor power is limited by 5% (i.e. one bank - 95%FP, two banks - 90%FP, etc)
- what is the maximum power level that can be achieved?



7.8 SIMULATOR EXERCISE: Response to Failing Open Liquid Zone 1 Inlet Valve

- initialize the Simulator to 100%FP and select the Liquid Zones Control page
- place Liquid Zone 1 controller on MANUAL and select Inlet Valve opening to 100%
- observe the response of the Reactor Regulating System, compensating for the flux tilt while keeping total reactor power at the setpoint

7.9 SIMULATOR EXERCISE: Response to Malfunction "Fail Open Liquid Zone 1 & 2 Inlet Valves"

- initialize the Simulator to 100%FP and select the Liquid Zones Control page
- insert the Malfunction "Fail Open Liquid Zone 1 & 2 Inlet Valves" (use a five second time delay)
- observe the response of the reactor regulating system
- how and why is the response different from the previous exercise?

7.10 SIMULATOR EXERCISE: Response to SDS#1 REACTOR TRIP AND RECOVERY

- initialize the Simulator to 100%FP
- manually trip the reactor
- observe the response of the overall unit
- wait until Generator power is zero and reactor neuron power less than 0.1%
- reset Reactor Trip and SDS#1
- record the time (using the display under the chart recorders) needed to withdraw all shutdown rods
- raise reactor power to 60%FP
- observe the response of the reactor regulating system and the reactivity changes that take place

7.11 SIMULATOR EXERCISE: Response to SDS#1 REACTOR TRIP AND POISON-OUT

- initialize the Simulator to 100%FP
- manually trip the reactor
- observe the response of the overall unit
- wait one hour before resetting Reactor Trip and SDS#1
- after the shutdown rods have been withdrawn observe the status of the reactivity control devices
- attempt to raise reactor power - why is it not possible?
- note the reactivity changes that have taken place, in particular note the magnitude and estimate the rate of change of Xenon reactivity build-up

7.12 SIMULATOR EXERCISE: Response to SDS#1 REACTOR TRIP AND POISON OVERRIDE

- using the data from the previous two exercises, estimate the time available to the operator from the initiation of the reactor trip until the trip must be reset to avoid a poison outage: the desired end state of this exercise is reactor power at 60%FP and less than one bank of adjuster rods left in the core (i.e. the last bank is partially withdrawn)
- initialize the Simulator to 100%FP
- manually trip the reactor
- wait until the above calculated time has expired
- reset Reactor Trip and SDS#1
- raise reactor power to 60%FP
- note the final state of the adjuster rods and Average Liquid Zone level

CHAPTER 3: REACTOR REGULATING SYSTEM

MODULE C: SIMULATOR EXERCISES

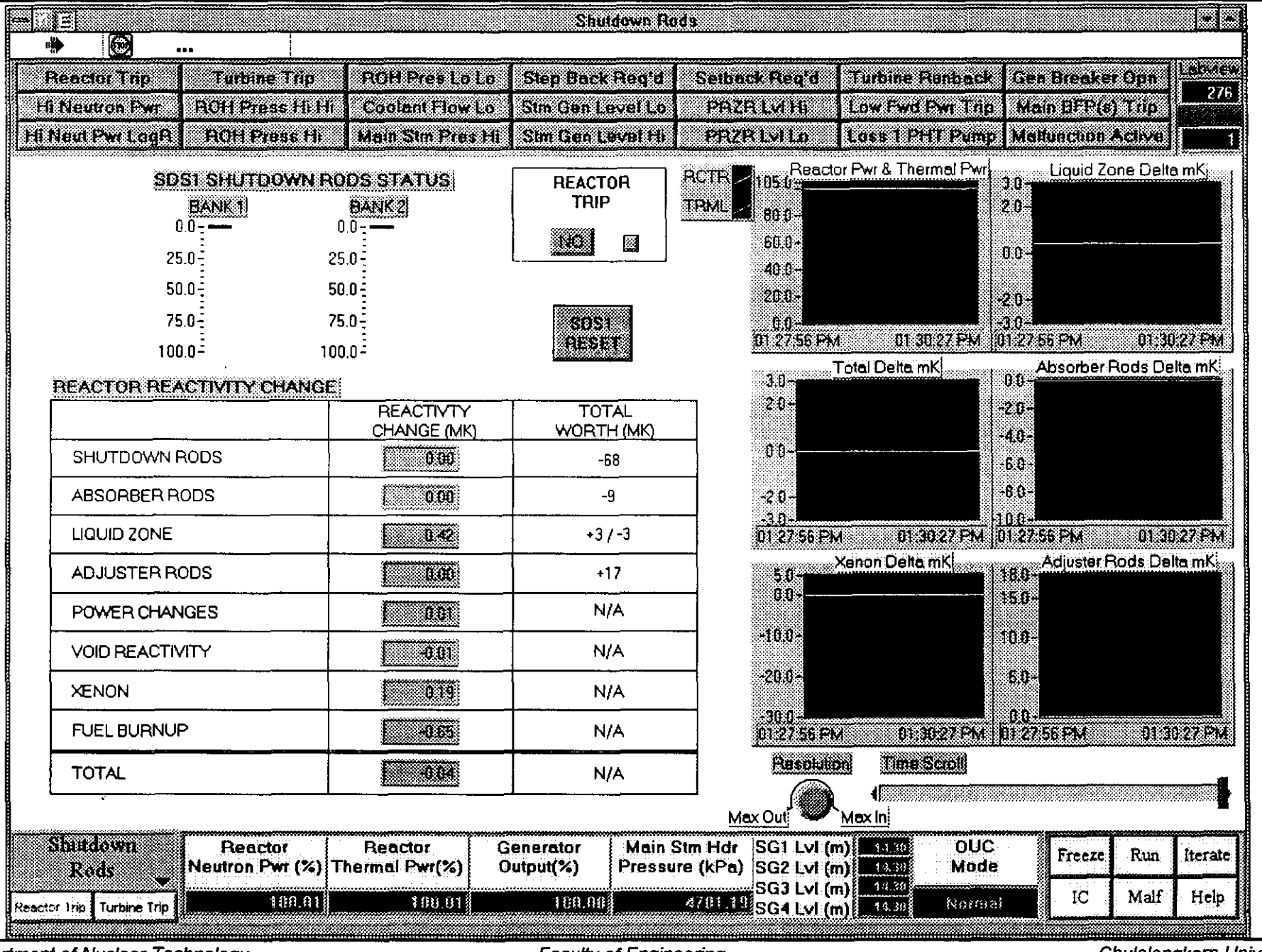
MODULE OBJECTIVES:

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

1. **Identify the parameters associated with reactivity and reactor control;**
2. **Respond correctly to the following events:**
   - **Reactor Stepback and Recovery**
   - **One Bank of Absorber Rods Drop**
   - **All Liquid Zone Pumps Trip**
   - **Fail Open Liquid Zone 1 & 2 Inlet Valves**

1. SHUTDOWN RODS PAGE

- The screen shows the status of SDS#1, as well as the reactivity contributions of each device and physical phenomenon that is relevant to reactor operations.
- The positions of each of the two SDS1 SHUTDOWN ROD banks are shown relative to their normal (fully withdrawn) position.
- REACTOR TRIP status is shown as NO (green) or YES (yellow), the trip can be reset here (as well as on the RRS / DPR page); note that SDS1 RESET must also be activated before RRS will begin withdrawing the Shutdown Rods.
- The REACTIVITY CHANGE of each device and parameter from the initial 100% full power steady state is shown, as well as the range of its potential value.
  - ⇒ Note that reactivity is a computed not a measured parameter, it can be displayed on a simulator but is not directly available at an actual plant.
  - ⇒ Note also that when the reactor is critical the Total reactivity must be zero.


Shutdown Rods
Reactor Trip
Turbine Trip
ROH Pres Lo Lo
Step Back Req'd
Setback Req'd
Turbine Runback
Gen Breaker Opn
Hi Neutron Pwr
ROH Press Hi Hi
Coolant Flow Lo
Stm Gen Level Lo
PRZR Lvl Hi
Low Fwd Pwr Trip
Main BFP(s) Trip
Hi Neut Pwr LogR
ROH Press Hi
Main Stm Pres Hi
Stm Gen Level Hi
PRZR Lvl Lo
Loss 1 PHT Pump
Malfunction Active
LabView
276
1
SDS1 SHUTDOWN RODS STATUS
BANK 1
BANK 2
0.0
25.0
50.0
75.0
100.0
REACTOR TRIP
NO
SDS1 RESET
RCTR
TRML
Reactor Pwr & Thermal Pwr
105.0
80.0
60.0
40.0
20.0
0.0
01:27:56 PM
01:30:27 PM
Liquid Zone Delta mK
3.0
2.0
0.0
-2.0
-3.0
Total Delta mK
Absorber Rods Delta mK
-4.0
-6.0
-8.0
-10.0
Xenon Delta mK
5.0
-20.0
-30.0
Adjuster Rods Delta mK
18.0
15.0
10.0
Resolution
Time Scroll
Max Out
Max In
REACTOR REACTIVITY CHANGE
REACTIVTY CHANGE (MK)
TOTAL WORTH (MK)
SHUTDOWN RODS
0.00
-68
ABSORBER RODS
0.00
-9
LIQUID ZONE
0.42
+3 / -3
ADJUSTER RODS
0.00
+17
POWER CHANGES
0.01
N/A
VOID REACTIVITY
-0.01
N/A
XENON
0.19
N/A
FUEL BURNUP
-0.65
N/A
TOTAL
-0.04
N/A
Shutdown Rods
Reactor Trip
Turbine Trip
Reactor Neutron Pwr (%)
100.01
Reactor Thermal Pwr(%)
100.01
Generator Output(%)
100.00
Main Stm Hdr Pressure (kPa)
4701.19
SG1 Lvl (m)
SG2 Lvl (m)
SG3 Lvl (m)
SG4 Lvl (m)
14.30
OUC Mode
Normal
Freeze
Run
Iterate
IC
Malf
Help

2. REACTIVITY CONTROL PAGE

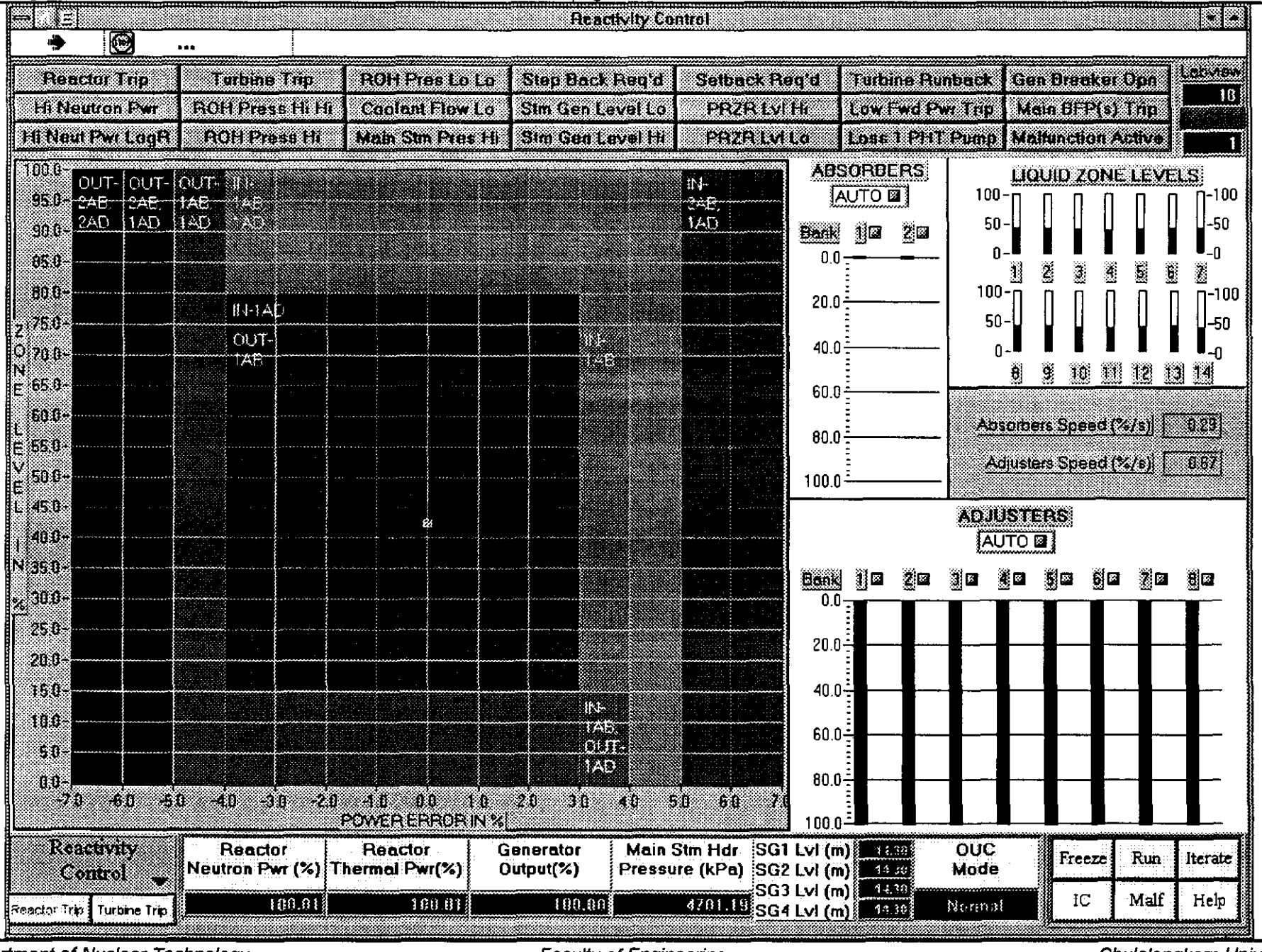
- This screen shows the Limit Control Diagram, and the status of the three reactivity control devices that are under the control of RRS.
- The Limit Control Diagram displays the Operating Point in terms of Power Error and Average Liquid Zone level.

POWER ERROR = ACTUAL POWER - DEMANDED POWER

⇒ If power error is negative, more (positive) reactivity is needed, hence liquid zone level will decrease and if this is insufficient, absorber rods and adjuster rods will be withdrawn from the reactor.

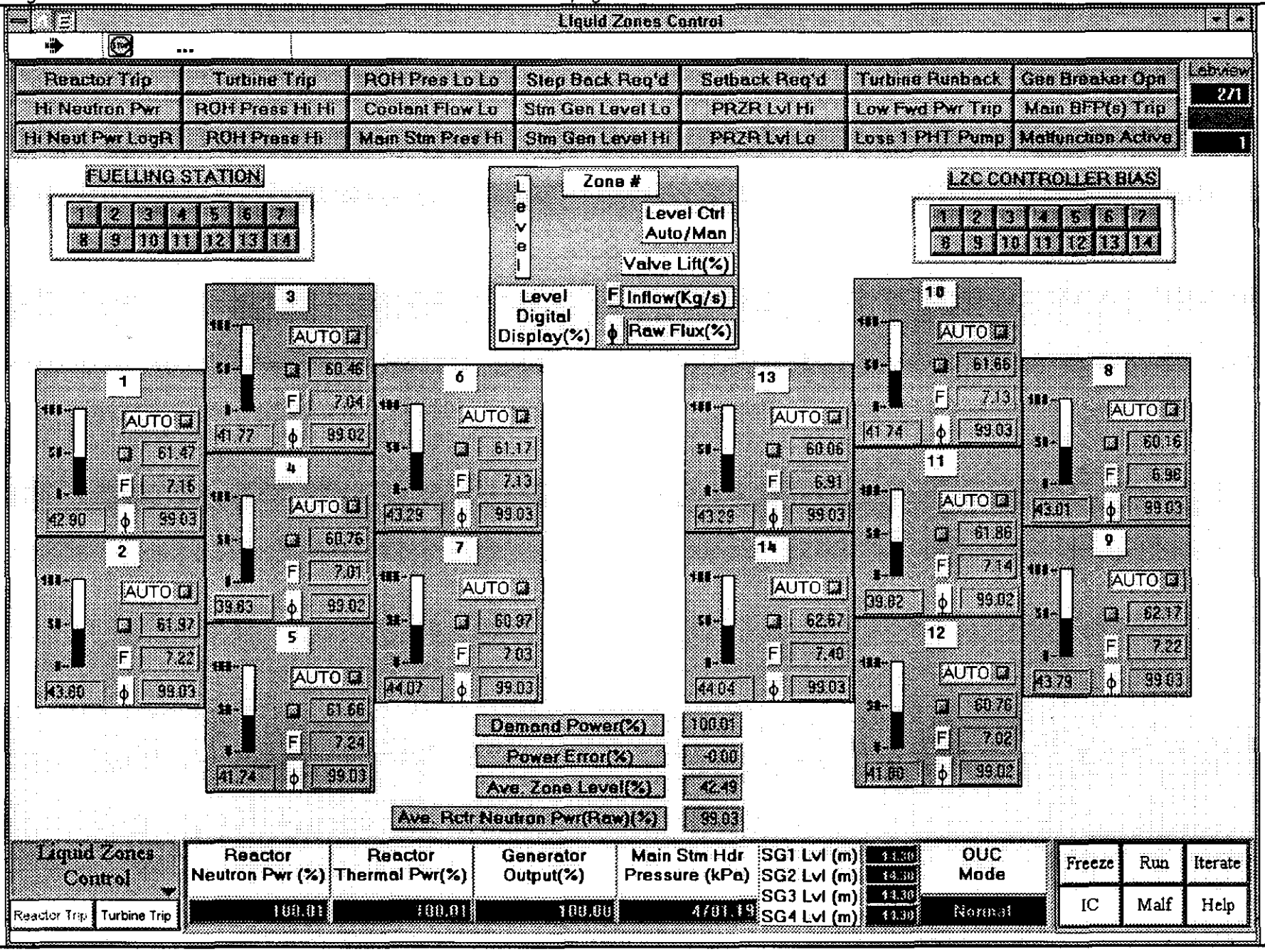
⇒ If power error is positive, negative reactivity is needed, hence liquid zone level will increase and if this is insufficient, absorber rods and adjuster rods will be driven into the reactor.

- The ABSORBERS are moved in two banks, and are normally outside the core. They can be moved by RRS if AUTO is selected, or manually if they are placed in MANUAL mode.
- The ADJUSTERS are moved in eight banks, and are normally fully inserted into the core. They can be moved by RRS if AUTO is selected, or manually if they are placed in MANUAL mode.
- The level in each of the 14 liquid zones is displayed but cannot be controlled from this page.
- The speed of the Absorbers and Adjusters is displayed but cannot be controlled from this page.


Reactivity Control
Reactor Trip
Turbine Trip
ROH Pres Lo Lo
Step Back Req'd
Setback Req'd
Turbine Runback
Gen Breaker Opn
Hi Neutron Pwr
ROH Press Hi Hi
Coolant Flow Lo
Stm Gen Level Lo
PRZR Lvl Hi
Low Fwd Pwr Trip
Main BFP(s) Trip
Hi Neut Pwr LogR
ROH Press Hi
Main Stm Pres Hi
Stm Gen Level Hi
PRZR Lvl Lo
Loss 1 PHT Pump
Malfunction Active
Lo View
16
1
ZONE LEVEL IN %
POWER ERROR IN %
OUT-2AB 2AD
OUT-2AB 1AD
OUT-1AB 1AD
IN-1AB 1AD
IN-1AD
OUT-1AB
IN-1AB
IN-2AB 1AD
IN-1AB OUT-1AD
ABSORBERS
AUTO
Bank 1 2
LIQUID ZONE LEVELS
Absorbers Speed (%/s) 0.23
Adjusters Speed (%/s) 0.67
ADJUSTERS
AUTO
Bank 1 2 3 4 5 6 7 8
Reactivity Control
Reactor Trip
Turbine Trip
Reactor Neutron Pwr (%)
100.01
Reactor Thermal Pwr(%)
100.01
Generator Output(%)
100.00
Main Stm Hdr Pressure (kPa)
4701.19
SG1 Lvl (m)
SG2 Lvl (m)
SG3 Lvl (m)
SG4 Lvl (m)
OUC Mode
Normal
Freeze
Run
Iterate
IC
Malf
Help

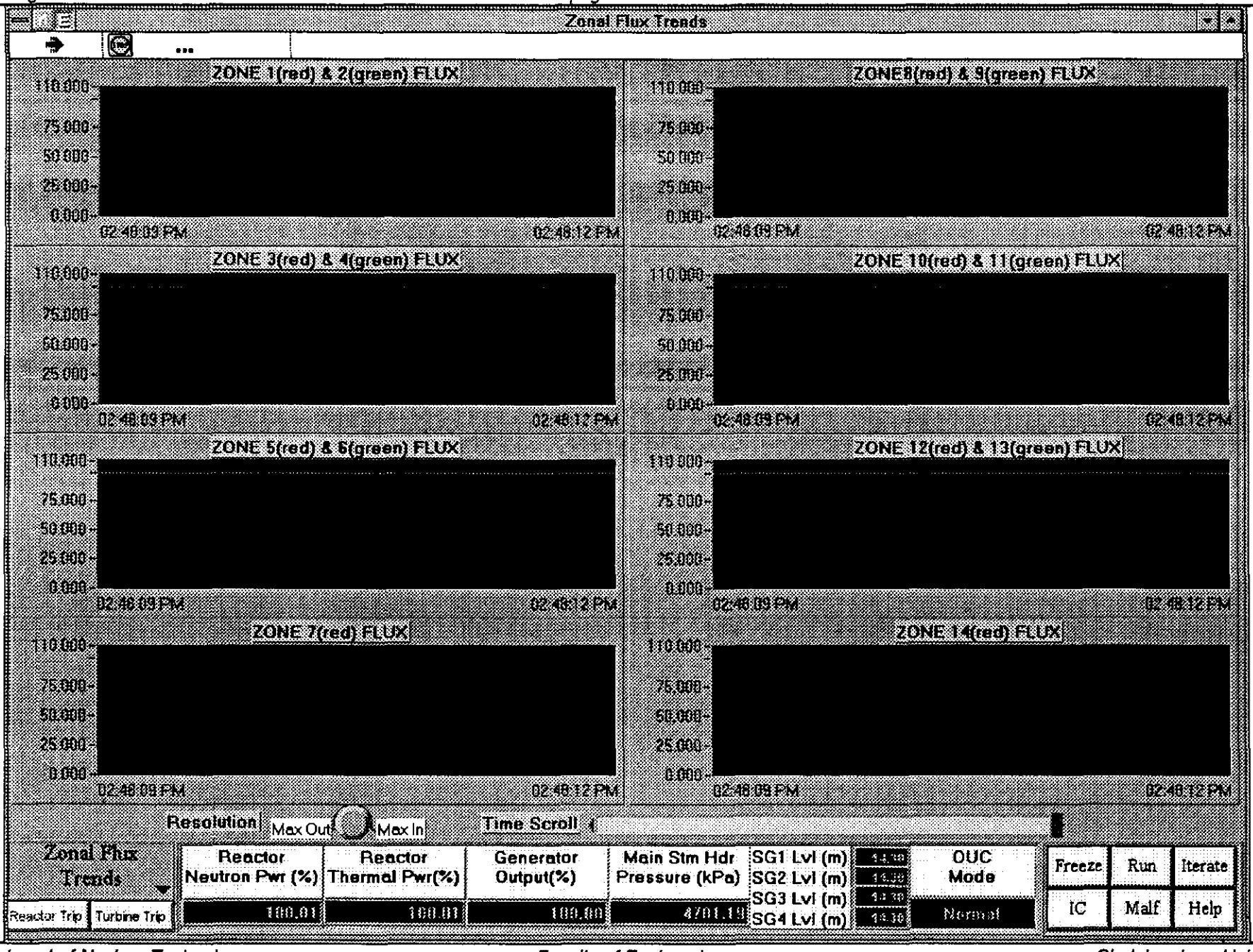
3. LIQUID ZONES CONTROL

- This screen shows the status of each of the 14 Liquid Zones Controllers. The block near the top middle part of the page gives the key to the various parameters displayed on this page.
- Each of the 14 Liquid Zone Controllers shows:
  - ⇒ the zone's number
  - ⇒ zone level (% full)
  - ⇒ zone level numerical display (% full)
  - ⇒ level controller status (AUTO or MANUAL), which can be selected here
  - ⇒ valve lift, i.e. % open of the inlet valve to the zone
  - ⇒ inflow of water to the zone compartment (kg/sec)
  - ⇒ raw (uncorrected) flux measurement for the zone
- LZC CONTROLLER BIAS allows the setting of the control point which gives the inlet valve opening that corresponds to the steady state position .
- FUELLING STATION allows the introduction of a predetermined amount of positive reactivity into the particular zone, to simulate refuelling operations.
- Parameters critical to reactor regulation are shown on a global basis:
  - ⇒ Demand Power (%)
  - ⇒ Power Error (%)
  - ⇒ Average Zone Level (%)
  - ⇒ Average Reactor Neutron Power (Raw) (%)


Liquid Zones Control
Reactor Trip
Turbine Trip
ROH Pres Lo Lo
Stop Back Req'd
Setback Req'd
Turbine Runback
Gen Breaker Opn
Hi Neutron Pwr
ROH Press Hi Hi
Coolant Flow Lo
Stm Gen Level Lo
PRZR Lvl Hi
Low Fwd Pwr Trip
Main BFP(s) Trip
Hi Neut Pwr LogR
ROH Press Hi
Main Stm Pres Hi
Stm Gen Level Hi
PRZR Lvl Lo
Loss 1 PHT Pump
Malfunction Active
Labview
271
1
FUELLING STATION
1 2 3 4 5 6 7
8 9 10 11 12 13 14
Level
Zone #
Level Ctrl Auto/Man
Valve Lift(%)
Level Digital Display(%)
F Inflow(Kg/s)
Raw Flux(%)
LZC CONTROLLER BIAS
1 2 3 4 5 6 7
8 9 10 11 12 13 14
1 AUTO 61.47 F 7.16 42.90 99.03
2 AUTO 61.97 F 7.22 43.60 99.03
3 AUTO 60.46 F 7.04 41.77 99.02
4 AUTO 60.76 F 7.01 39.83 99.02
5 AUTO 61.66 F 7.24 41.74 99.03
6 AUTO 61.17 F 7.13 43.29 99.03
7 AUTO 60.97 F 7.03 44.07 99.03
8 AUTO 60.16 F 6.96 43.01 99.03
9 AUTO 62.17 F 7.22 43.79 99.03
10 AUTO 61.66 F 7.13 41.74 99.03
11 AUTO 61.86 F 7.14 39.82 99.02
12 AUTO 60.76 F 7.02 41.60 99.02
13 AUTO 60.06 F 6.91 43.29 99.03
14 AUTO 62.67 F 7.40 44.04 99.03
Demand Power(%) 100.01
Power Error(%) -0.00
Ave. Zone Level(%) 42.49
Ave. Rctr Neutron Pwr(Raw)(%) 99.03
Liquid Zones Control
Reactor Trip
Turbine Trip
Reactor Neutron Pwr (%) 100.01
Reactor Thermal Pwr(%) 100.01
Generator Output(%) 100.00
Main Stm Hdr Pressure (kPa) 4701.19
SG1 Lvl (m) 11.30
SG2 Lvl (m) 11.30
SG3 Lvl (m) 11.30
SG4 Lvl (m) 11.30
OUC Mode
Normal
Freeze
Run
Iterate
IC
Malf
Help

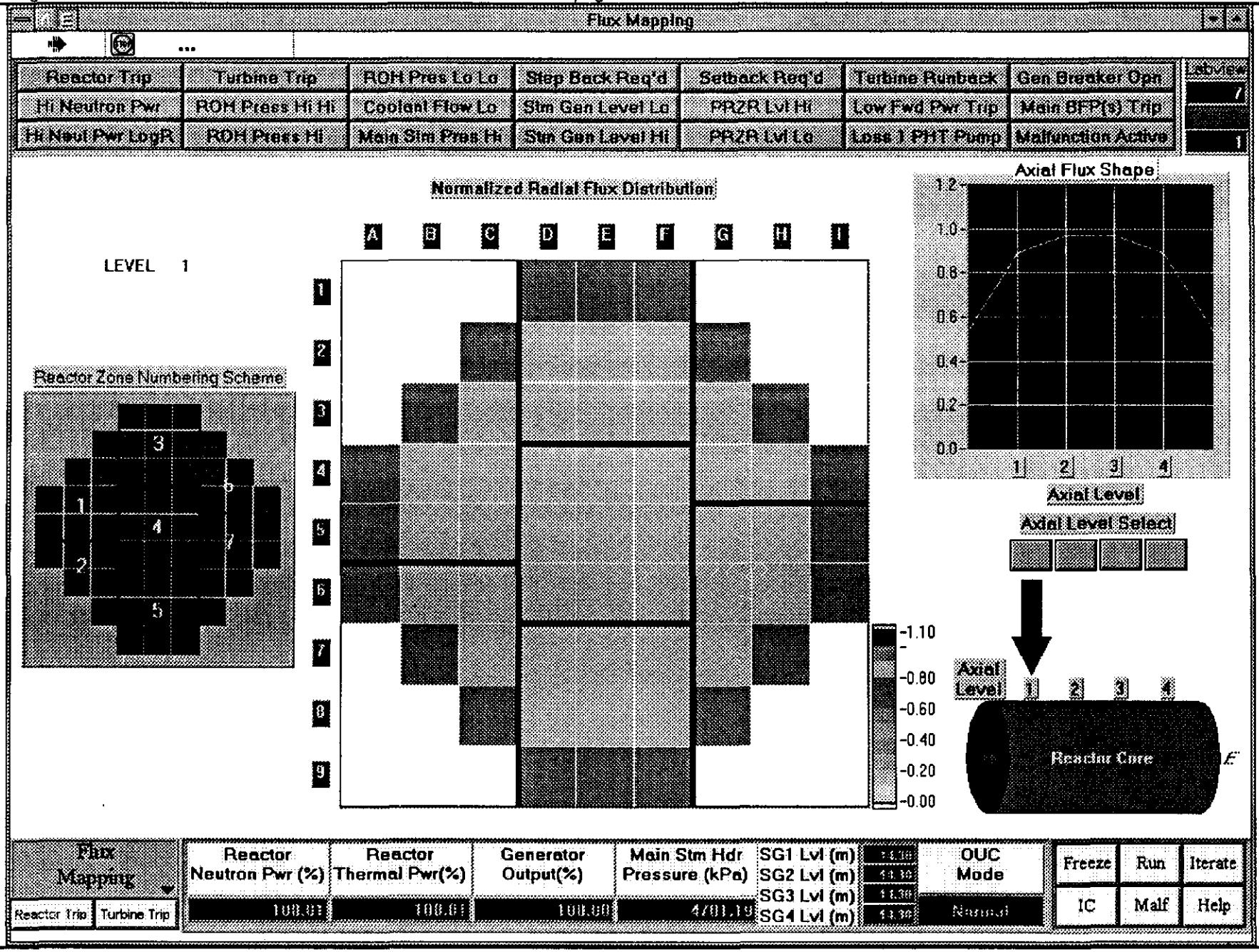
4. ZONAL FLUX TRENDS PAGE

- Each of the fourteen zonal fluxes are displayed as % Full Power.
- Note that zone fluxes 1-6 and 8-13 are displayed in pairs while each of the fluxes in zone 7 and in zone 14 is shown as a single plot.
- Whenever there are disturbances in the spatial flux distribution this page will show the extent of the differences between the fluxes in the various zones. Note that, as with all other such time plots on the Simulator, only the values computed when this page is displayed will be shown.


Zonal Flux Trends
ZONE 1(red) & 2(green) FLUX
ZONE8(red) & 9(green) FLUX
ZONE 3(red) & 4(green) FLUX
ZONE 10(red) & 11(green) FLUX
ZONE 5(red) & 6(green) FLUX
ZONE 12(red) & 13(green) FLUX
ZONE 7(red) FLUX
ZONE 14(red) FLUX
110.000
75.000
50.000
25.000
0.000
02:46:09 PM
02:46:12 PM
Resolution
Max Out
Max In
Time Scroll
Zonal Flux Trends
Reactor Trip
Turbine Trip
Reactor Neutron Pwr (%)
Reactor Thermal Pwr(%)
Generator Output(%)
Main Stm Hdr Pressure (kPa)
100.01
100.01
100.00
4701.19
SG1 Lvl (m)
SG2 Lvl (m)
SG3 Lvl (m)
SG4 Lvl (m)
OUC Mode
Normal
Freeze
Run
Iterate
IC
Malf
Help

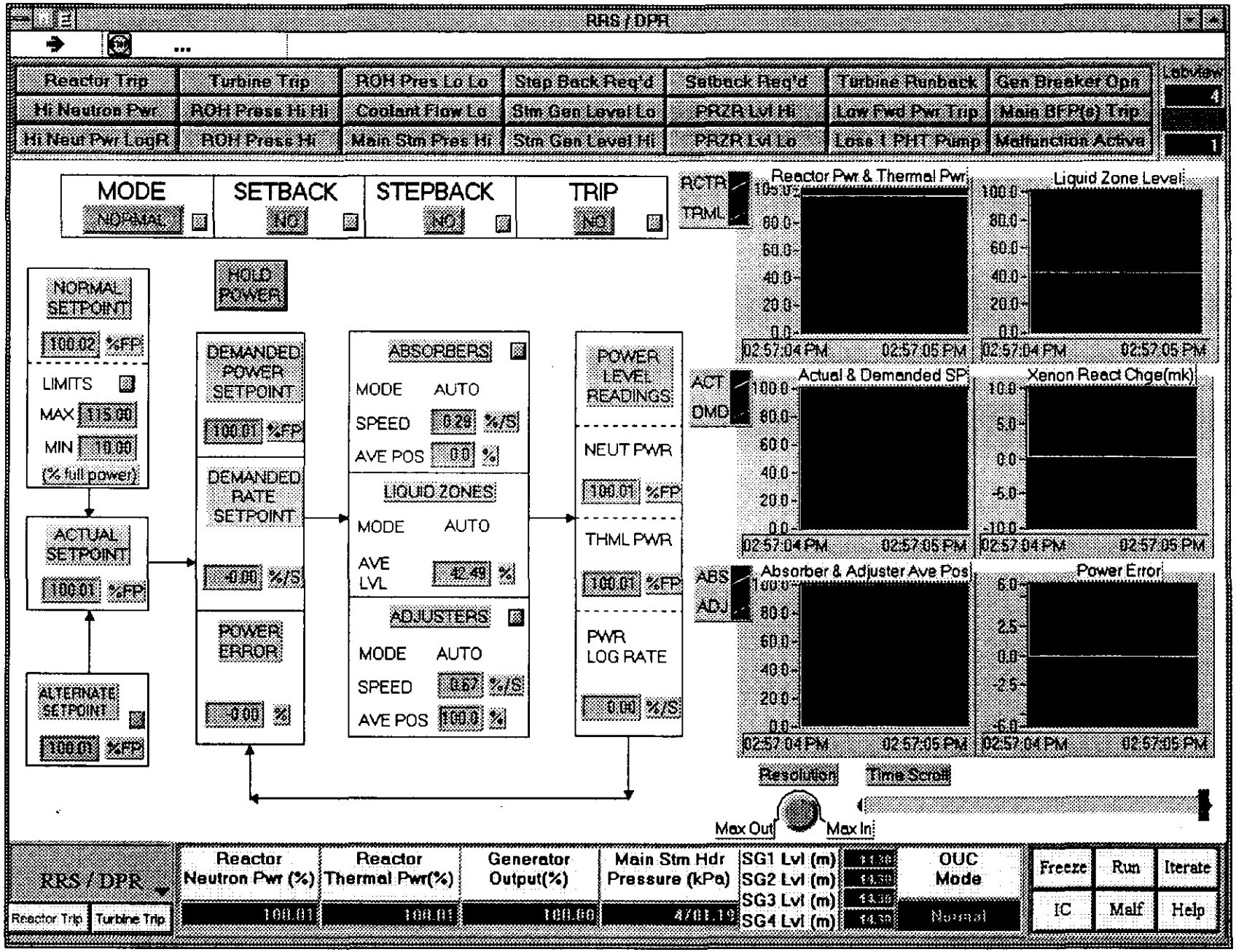
5. FLUX MAPPING PAGE

- This screen shows the spatial distribution of reactor flux along the reactor's axis parallel to the pressure tubes, as well as the radial flux distribution perpendicular to the pressure tubes. Because of the simplified models used, the flux is displayed only at four axial planes, and each radial plane shows only 57 flux regions.
- The Axial Flux Shape is shown on the diagram at the upper right hand side of the screen. The flux is normalized and corresponds to computations made at four "Axial Levels". The cross section along the axis where the flux is to be displayed is chosen via the "Axial Level Select" buttons.
- The center of the screen shows the "Normalized Flux Radial Distribution" corresponding to the axial level that was selected.
- The left hand side of the screen shows the number of the Axial Level currently selected as well as the zone numbering (East or West) that corresponds to the Axial Level selection.


Flux Mapping
Reactor Trip
Turbine Trip
ROH Pres Lo Lo
Step Back Req'd
Setback Req'd
Turbine Runback
Gen Breaker Opn
Hi Neutron Pwr
ROH Press Hi Hi
Coolant Flow Lo
Stm Gen Level Lo
PRZR Lvl Hi
Low Fwd Pwr Trip
Main BFP(s) Trip
Hi Neut Pwr LogR
ROH Press Hi
Main Stm Pres Hi
Stm Gen Level Hi
PRZR Lvl Lo
Loss 1 PHT Pump
Malfunction Active
Normalized Radial Flux Distribution
LEVEL 1
A B C D E F G H I
1 2 3 4 5 6 7 8 9
1.10
0.80
0.60
0.40
0.20
0.00
Reactor Zone Numbering Scheme
Axial Flux Shape
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1 2 3 4
Axial Level
Axial Level Select
Axial Level 1 2 3 4
Reactor Core
F
Flux Mapping
Reactor Trip
Turbine Trip
Reactor Neutron Pwr (%)
Reactor Thermal Pwr(%)
Generator Output(%)
Main Stm Hdr Pressure (kPa)
SG1 Lvl (m)
SG2 Lvl (m)
SG3 Lvl (m)
SG4 Lvl (m)
OUC Mode
Normal
Freeze
Run
Iterate
IC
Malf
Help

6. RRS / DPR PAGE

- This screen permits control of reactor power setpoint and its rate of change while under Reactor Regulating System (RRS) control, i.e. in 'alternate' mode. Several of the parameters key to RRS operation are displayed on this page.
- The status of reactor control is indicated by the four blocks marked MODE, SETBACK, STEPBACK AND TRIP. They are normally green but will turn yellow when in the abnormal state.
  - ⇒ MODE will indicate whether the reactor is under NORMAL to ALTERNATE control, this status can also be changed here.
  - ⇒ SETBACK status is indicated by YES or NO; Setback is initiated automatically under the prescribed conditions by RRS, but at times the operator needs to initiate a manual Setback, which is done from this page on the Simulator: the Target value (%) and Rate (%/sec) need to be input.
  - ⇒ STEPBACK status is indicated by YES or NO; Stepback is initiated automatically under the prescribed conditions by RRS, but at times the operator needs to initiate a manual Stepback, which is done from this page on the Simulator: the Target value (%) need to be input.
  - ⇒ TRIP status is indicated by YES or NO; trip is initiated by the Shutdown Systems, if the condition clears, it can be reset from here. Note however, that the tripped SDS#1 must also be reset before RRS will pull out the shutdown rods, this must be done on the Shutdown Rods Page
- Key components of RRS and DPR control algorithm are also shown on this screen.
  - ⇒ The ACTUAL SETPOINT is set equal to the NORMAL SETPOINT under UPR control ('normal mode'), the upper and lower limits on this setpoint can be specified here.
  - ⇒ The ACTUAL SETPOINT is set equal to the ALTERNATE SETPOINT under RRS control ('alternate mode'); the value of ALTERNATE SETPOINT is input on this page.
  - ⇒ HOLD POWER will select 'alternate mode' and sets DEMANDED POWER SETPOINT equal to the measured Neutron Power.


RRS / DPR
Reactor Trip
Turbine Trip
ROH Pres Lo Lo
Step Back Req'd
Setback Req'd
Turbine Runback
Gen Breaker Opn
Hi Neutron Pwr
ROH Press Hi Hi
Coolant Flow Lo
Stm Gen Level Lo
PRZR Lvl Hi
Low Fwd Pwr Trip
Main BFP(s) Trip
Hi Neut Pwr LogR
ROH Press Hi
Main Stm Pres Hi
Stm Gen Level Hi
PRZR Lvl Lo
Loss 1 PHT Pump
Malfunction Activa
MODE
NORMAL
SETBACK
NO
STEPBACK
NO
TRIP
NO
NORMAL SETPOINT
100.02 %FP
LIMITS
MAX 115.00
MIN 10.00
(% full power)
HOLD POWER
DEMANDED POWER SETPOINT
100.01 %FP
DEMANDED RATE SETPOINT
0.00 %/S
POWER ERROR
0.00 %
ABSORBERS
MODE AUTO
SPEED 0.29 %/S
AVE POS 0.0 %
LIQUID ZONES
MODE AUTO
AVE LVL 42.49 %
ADJUSTERS
MODE AUTO
SPEED 0.67 %/S
AVE POS 100.0 %
POWER LEVEL READINGS
NEUT PWR
100.01 %FP
THML PWR
100.01 %FP
PWR LOG RATE
0.00 %/S
ACTUAL SETPOINT
100.01 %FP
ALTERNATE SETPOINT
100.01 %FP
RCTR
TRML
Reactor Pwr & Thermal Pwr
Liquid Zone Level
ACT
DMD
Actual & Demanded SP
Xenon React Chge(mk)
ABS
ADJ
Absorber & Adjuster Ave Pos
Power Error
Resolution
Time Scroll
Max Out
Max In
RRS / DPR
Reactor Trip
Turbine Trip
Reactor Neutron Pwr (%)
100.01
Reactor Thermal Pwr(%)
100.01
Generator Output(%)
100.00
Main Stm Hdr Pressure (kPa)
4701.19
SG1 Lvl (m)
SG2 Lvl (m)
SG3 Lvl (m)
SG4 Lvl (m)
OUC Mode
Normal
Freeze
Run
Iterate
IC
Malf
Help

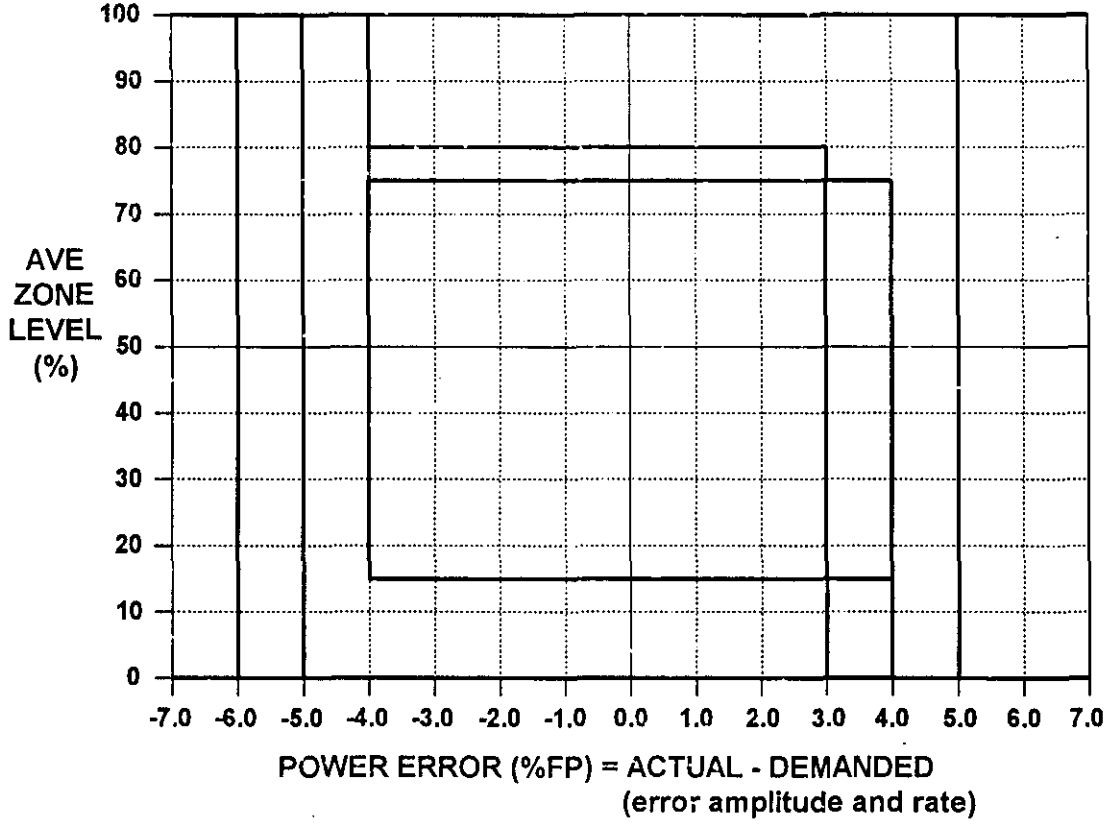
7.1 SIMULATOR EXERCISE: Unit Response to Power Maneuver in 'Alternate' mode

(1) initialize the Simulator to 100%FP, record parameters
(2) reduce power using RRS to 50% at 0.5%/sec, observe parameter changes during transient, and freeze as soon as Reactor Neutron Power reaches 50% and record parameter values
(3) unfreeze and let parameters stabilize, record parameter values
(4) return reactor power to 100%FP at 0.5%/sec, freeze as soon as Reactor Neutron Power reaches 100% and record parameter values
(5) unfreeze and let parameters stabilize, record parameter values

Parameter	Unit	(1)100%	(2) 50%	(3) 50%	(4)100%	(5)100%	Comments
Reactor Neutron Power	%						
Reactor Thermal Power	%						
Average Zone Level	%						
Actual Setpoint	%						
Demanded Power Setpoint	%						
Demanded Rate Setpoint	%/sec						
Power Error	%						
Boiler Pressure	MPa						
Boiler Temperature	°C						
Boiler Level	m						
Steam Flow	kg/s						
Feedwater Flow	kg/s						
Governor valve opening	%						
Turbine-Generator Power	%						

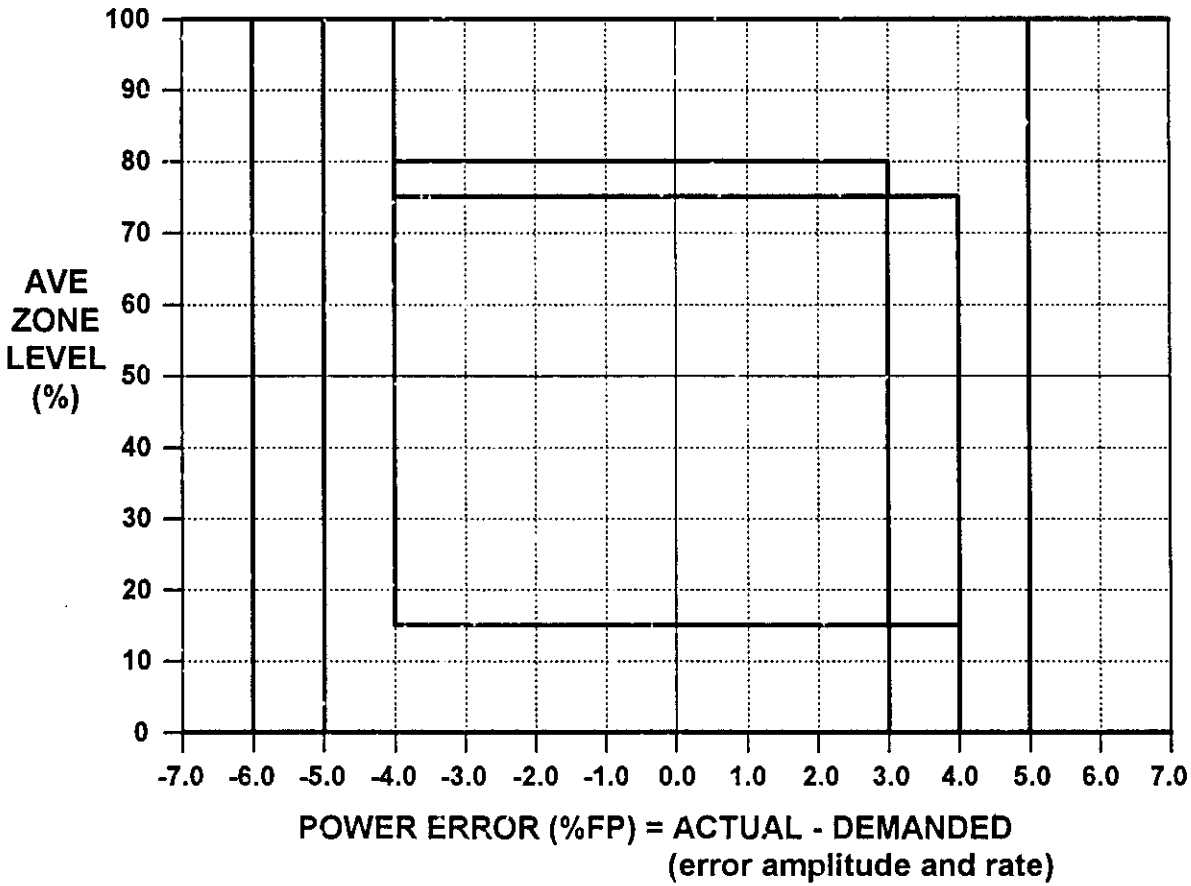
7.2 SIMULATOR EXERCISE: Response of RRS Control Algorithm to Power Maneuver

- initialize the Simulator to 100%FP and from the Reactivity Control page note the position of the operating point on the attached diagram (confirm the value of Average Zone Level on the Plant Overview page):
- insert a power reduction request using RRS to 70%FP at 0.8%/sec and freeze the simulator
- go to the Reactivity Control page, unfreeze, and note the path of the operating point on the attached diagram, until power error has stabilized at or near zero (about 3 - 4 minutes)
- confirm the value of average zone level on the Plant Overview page:
- why is the final zone level higher than the original zone level?



7.3 SIMULATOR EXERCISE: Reactor and RRS Response to Power Maneuver

- initialize the Simulator to 100%FP and from the Reactivity Control page note the position of the operating point on the attached diagram
- insert a power reduction request using RRS to 10%FP at 0.8%/sec and freeze the simulator
- go to the Reactivity Control page, unfreeze, and note the path of the operating point on the attached diagram, until at least one Adjuster Rod bank is out of the reactor (about 20 minutes) - once the first Adjuster Bank is more than 50% withdrawn, place Absorbers on Manual and drive them fully OUT.
- compare the response to case 7.2 and explain the main differences, particularly the 'end' state



7.4 SIMULATOR EXERCISE: Response to Power Maneuver under Manual Control

- initialize the Simulator to the ZONESMAN initialization point (note that all liquid zone controllers are on Manual - they are not to be used during this exercise)
- on the Reactivity Control page place the Absorbers and Adjusters to Manual
- using Absorber and Adjuster drives on Manual, maneuver reactor power to keep generator power between 80±1%FP
- note the time taken from the start of lowering reactor power until steady operation within the specified error limits is achieved

7.5 SIMULATOR EXERCISE: Response to Manual withdrawal of Adjuster rods

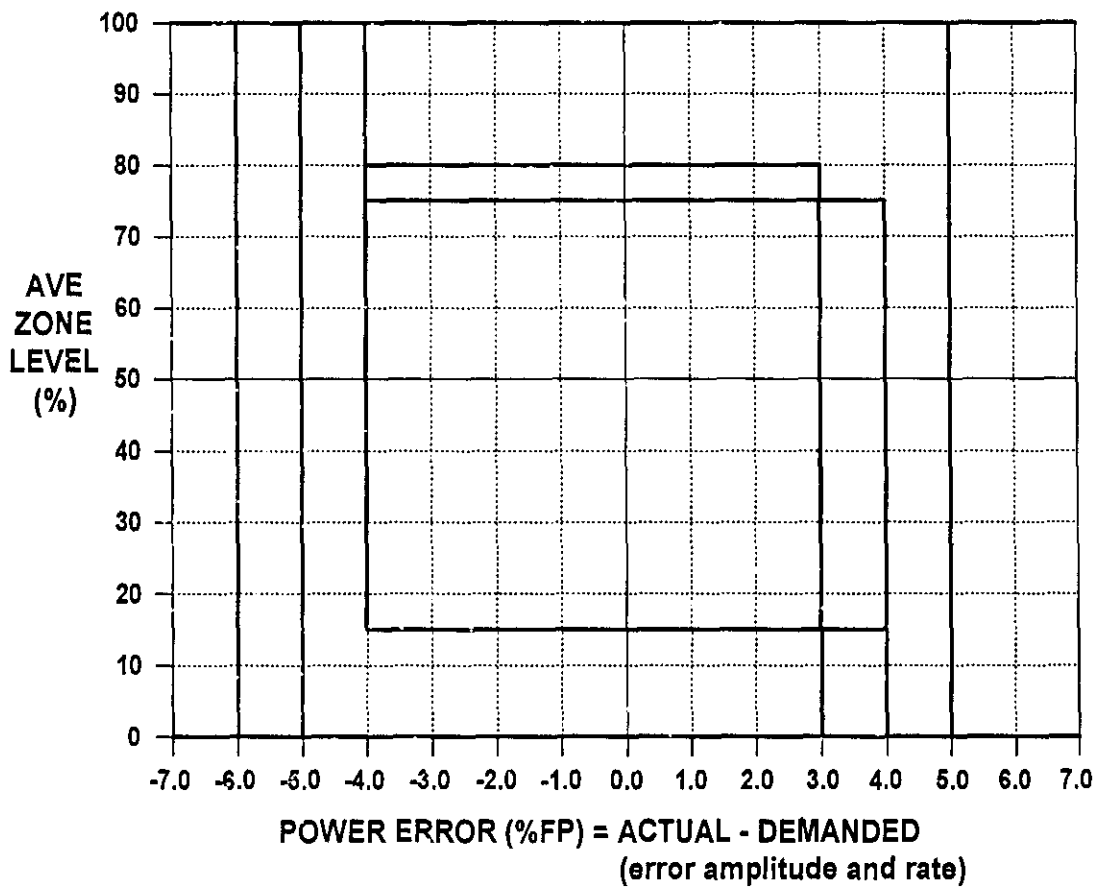
- initialize the Simulator to the ZONESMAN initialization point (note that all liquid zone controllers are on Manual - they are not to be used during this exercise)
- on the Reactivity Control page place the Absorbers and Adjusters onto Manual
- manually withdraw the Adjuster rods
- describe and explain the response of the system

7.6 SIMULATOR EXERCISE: Response to Manual withdrawal of Adjuster rods

- initialize the Simulator to the ZONESMAN initialization point (note that all liquid zone controllers are on Manual - they are not to be used during this exercise)
- on the Reactivity Control page place the Absorbers and Adjusters onto Manual
- manually drive both banks of Absorbers into the core, and by the simultaneous withdraw of one or more the Adjuster banks keep reactor neutron power within 2% of 100%FP
- once all the Absorbers are fully in the core, attempt to drive all remaining Adjusters simultaneously out of the core
- describe and explain the response of the system

7.7 SIMULATOR EXERCISE: Response to Malfunction "One Bank of Absorber Rods Drop"

- initialize the Simulator to 100%FP and from the Reactivity Control page note the position of the operating point on the attached diagram
- insert the Malfunction "One Bank of Absorber Rods Drop" (use a five second time delay)
- observe system response on the Reactivity Control page and note the path of the operating point on the attached diagram
- note OUC mode and reactor power
- clear the malfunction
- once the Absorbers have fully withdrawn from the reactor, raise reactor power to a level dependent on the number of Absorber banks out of the reactor:
- for each bank partially or fully out, reactor power is limited by 5% (i.e. one bank - 95%FP, two banks - 90%FP, etc)
- what is the maximum power level that can be achieved?



7.8 SIMULATOR EXERCISE: Response to Failing Open Liquid Zone 1 Inlet Valve

- initialize the Simulator to 100%FP and select the Liquid Zones Control page
- place Liquid Zone 1 controller on MANUAL and select Inlet Valve opening to 100%
- observe the response of the Reactor Regulating System, compensating for the flux tilt while keeping total reactor power at the setpoint

7.9 SIMULATOR EXERCISE: Response to Malfunction "Fail Open Liquid Zone 1 & 2 Inlet Valves"

- initialize the Simulator to 100%FP and select the Liquid Zones Control page
- insert the Malfunction "Fail Open Liquid Zone 1 & 2 Inlet Valves" (use a five second time delay)
- observe the response of the reactor regulating system
- how and why is the response different from the previous exercise?

7.10 SIMULATOR EXERCISE: Response to SDS#1 REACTOR TRIP AND RECOVERY

- initialize the Simulator to 100%FP
- manually trip the reactor
- observe the response of the overall unit
- wait until Generator power is zero and reactor neuron power less than 0.1%
- reset Reactor Trip and SDS#1
- record the time (using the display under the chart recorders) needed to withdraw all shutdown rods
- raise reactor power to 60%FP
- observe the response of the reactor regulating system and the reactivity changes that take place

7.11 SIMULATOR EXERCISE: Response to SDS#1 REACTOR TRIP AND POISON-OUT

- initialize the Simulator to 100%FP
- manually trip the reactor
- observe the response of the overall unit
- wait one hour before resetting Reactor Trip and SDS#1
- after the shutdown rods have been withdrawn observe the status of the reactivity control devices
- attempt to raise reactor power - why is it not possible?
- note the reactivity changes that have taken place, in particular note the magnitude and estimate the rate of change of Xenon reactivity build-up

7.12 SIMULATOR EXERCISE: Response to SDS#1 REACTOR TRIP AND POISON OVERRIDE

- using the data from the previous two exercises, estimate the time available to the operator from the initiation of the reactor trip until the trip must be reset to avoid a poison outage: the desired end state of this exercise is reactor power at 60%FP and less than one bank of adjuster rods left in the core (i.e. the last bank is partially withdrawn)
- initialize the Simulator to 100%FP
- manually trip the reactor
- wait until the above calculated time has expired
- reset Reactor Trip and SDS#1
- raise reactor power to 60%FP
- note the final state of the adjuster rods and Average Liquid Zone level