ZONE CONTROL UNITS EFFICIENCY

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ABSTRACT

The simulations and tests usually are done for the entire Light Water Zone Control System and not for their components. This paper presents the simulations results for the Zone Control Units behavior. They were obtained using *TIME-AVER module of RFSP code.

Also, attached to those simulations are presented the results of the test for the Zone Control Units behavior. Of interest is to study how these results fit the Light Water Zone Control Program.

1. INTRODUCTION

The Light Water Zone Control System is one of the several reactivity control systems. It consists of fourteen Liquid Zone Controllers, a Helium Control System and a Water Control System.

This presentation will be focused only on the physical effects of the water level onto the associated reactivity of the liquid zone control units. The present material is structured in four important steps:

- The first step for this presentation was provided by simulations with the RFSP code using *TIME-AVER, Reference /1/ and Reference /2/. The results have been presented in Reference /3/ and they are condensed in Appendix A.

- A second step was done by the verification test of the Zone Control Units behavior following 0.3 mk Gd $(NO_3)_3 \cdot 6H_2O$ insertion into the reactor core as manual poison addition from 3271-TK3. These evolutions especially for zone power and zone water level are presented as graphics in the Appendix B of this presentation.

The purpose of this test was to identify if the Zone Control Unit #3 and #10 have indeed a different behavior from the remaining Liquid Zone Control Units, as the simulations suggest.

- Between all these test and simulation results and the Zone Control Units Control Program, Reference /6/, a comparison has been done.

- Finally, the COG Station Performance Newsletters for Liquid Zone System Events since April 1992 up to date have been consulted and related to the simulation results, Reference /7/ to /16/.

2. LIQUID ZONE CONTROL SYSTEM

In this chapter it will be only pointed out the system function, the function of the related system and the level control.

2.1 System Function

The system may control the zonal reactivity and short term bulk reactivity by varying the light water content of the fourteen cylindrical compartments within the calandria.

The level excursion from full to empty at unison provides reactivity of 6.51 mk as the Cernavodã Unit #1 commissioning phase B test demonstrated.

2.2 Function of Related System

The water level is controlled using differential pressure between Bubbler Header and Balance Header. The Bubbler Header controls the pressure into the Storage Tank and provides an equal amount of He for each Liquid Zone. The Balance Header keeps uniform differential pressure against delay tank pressure and a constant light water overflow from each compartment to the delay tank. The recombination unit provides the oxygen and hydrogen recombination for the atoms radiolitically decomposed into the Liquid Zone Control Units. In addition, the He compressor, the Light Water Supply Pump, the Delay Tank and the He Storage Tank may be mentioned as related systems.

2.3 Level Control

Controlling the valve lift for any zone either simultaneously or independently performs the level control. The light water is a good absorber of neutrons. The light water level maneuvering involves the variation of neutron absorption. This effect of the absorption for each zone control unit is treated in a balance terms like a zone control water reactivity.

According to the Flowsheet for the Liquid Zone Control System, the system is able to
control the water level between 20% and 80% in normal operation. The simulation results indicate an area of normal operation for the level values of 20% to 70%. In addition, this range is similar to that from Reference /5/, Chapter 3.1.4.

3. SIMULATION

3.1 Simulation Program

The *TIME-AVER module of RFSP code, Reference/1/ and /2/, was used as software platform for this type of evaluations. This module provides the value for the reactor effective multiplication constant k_{eff} by solving the diffusion equation. Using a guess flux distribution, the program can determine the k_{eff} values for each light water level inserted manually into the input block data, based on the determined time-average cross-sections and the solved neutron diffusion equation.
A new water level is considered as a perturbation and a new flux distribution is obtained. So, based on the values for k_{eff} and flux, the reactivity and power are calculated.

The time-average option was chosen due to the fact that time-average model gives a realistic image of the core flux distribution. In addition, it provides the lattice properties, especially the time-average cross sections at the position of interest.

3.2 Data Library

For the present study, the flux distribution provided by Reference /4/ was used as a guess flux. The input data block used in simulation have been completed with data provided by the Reactor Physics and Fuel Performance Group Library.

3.3Hardware and Software

The simulations were done on a Hewlett-Packard Apollo Workstation Platform using UNIX operating system. Then the results of interest have been transferred on PC using the File Transfer Protocol Program (FTP). Here, the data have been processed with Microsoft Excel 97 and the text was issued with Microsoft Word 97.

4. METHODOLOGY OF CALCULATION

The simulations were done considering two cases of interest: an equilibrium reactor core state and a perturbed reactor core state. For the equilibrium reactor core a single simulation has been done. For the perturbed case 21 simulations were done for each light water zone control unit starting from 0% to 100% water level. The level step was of 5%. The water level for each zone control unit was changed while the remaining levels of the zone control units were kept unchanged. In addition, to estimate the net contribution to the reactivity of the level modification, the remaining reactivity devices were kept in the same state as for the equilibrium simulation.

The simulations were done considering the following initial core conditions: Romanian fuel ROFUO2-NAT, coolant temperature of 288 ºC, coolant purity of 98.7a/%D_2O, moderator purity of 99.87a/%D_2O, thermal power of 2061.4 MW.
The main results are presented as graphics at the end of this paper in Appendix A. For the majority of the Zone Control Units the reactivity dependence of water level may be represented as a linear function (function of first degree) with two exceptions: the Zone Control Unit#3 and #10.
The reactivity for the majority of the zones can be written as:

$$\rho(l) = \alpha l \qquad (1)$$

where $0.005 \leq \alpha \leq 0.0087$ and l represents the level in (%)

In the zone#3 and #10 the reactivity evolution may be represented as a second degree function in water level variable (l) as:

$$\rho(l) = \beta\, l + \gamma\, l^2 \qquad (2)$$

where $\beta = 0.0062$ and $\gamma = 4 \cdot 10^{-5}$

Also, the graphs of power evolution according to the water level change are presented in the same Appendix.

Analyzing the behavior of the zone compartments for various water levels, it is of interest to underline that for the zone units #3 and #10, starting from around 65% the reactivity is very strong flattened. It seems to be a physical behavior for the reactivity like the saturation phenomena into a chemical solution: it is not important how much substance is added to the solution starting from a certain concentration of the solution because the effect is the same. A similar behavior is seen for reactivity: increasing the water level over around 70% the reactivity value does not change.

Evaluating the data presented in the Figures 17 and 24 it can bee seen that starting with ~70% zone water level, the power remains approximately the same even the water level rises while we would expect to have a power diminution with the water level rising.

A physical explanation may be advanced considering the behavior of the reactivity as function of the flux, position or time:

$$\rho \quad = \rho\,(F , \overset{?}{r}, t) \qquad (3)$$

The time dependence, $\rho = \rho\ (t)$, can not be taken into account because it is of interest to evaluate the reactivity net effect of the zone control units, not the reactivity modification due to a transient. Neither the position, $\rho = \rho\ (r)$ can be considered as an influence factor of the reactivity. It remains only to explain this flattening by a different reactivity behavior due to the neutronic flux.

The zone control units #3 and #10 are located in the upper zone of the reactor core. During the water level increase the upper limit of the water comes near to the reflector. So, the flattening of the reactivity may be well explained by the reflected neutrons existence. More the water level is rising more the water column surface into the ZCU brings near the reflector and the flattening is stronger.

5. DATA TEST

The test was done on 10 June 1998 at 12:54:30. This represents the moment of initiation poison injection. The data recording started at 12:52:20 and stopped at 12:58:20.

At the initiation moment of poison injection the average power for the Zone Control Units System was 95.35%FP and the average zone water level was 62.46%. After 30 seconds from the injection the average power level was 94.76%FP and the average water level are 54.32%. As it can be seen in Appendix B, for the zone control unit #3 and #10 the power evolution may be approximated with a second degree function of time as:

$$P(t) = P_0 - 0.3?t + 10^{-2}\ ?t^2$$

while for the remaining zones this power dependence can be approximated with a first degree function of time as:

$$P\ (t) = P_0 - a\ ?t$$

P represents the initial power level for zone # i, a is a coefficient which has the value between $-4\ ?10^{-2}$ and $11?\,10^{-2}$, t represents the time.

A similar reactivity behavior for the zone #3 and #10 can be observed in simulation and test results.

6. ZONE CONTROL UNITS CONTROL PROGRAM

According to the previous results a change into the water zone control units flowsheet was suggested. Normally the system shall be capable of controlling compartment water levels between 20% and 70% in normal operation. This conclusion resulted from the good agreement between the simulation results and data from Reference /5/.

The phasing out factor (a) was proposed to be changed according to the previous observation.

7. LIQUID ZONE CONTROL SYSTEM EVENTS REPORTED IN COG REVIEWS

All the events reported in COG Reviews related to LZCU events are referenced from /7/ to /16/ in Chapter 8. These reviews have been consulted before starting this evaluation. The events related to Liquid Zone Control System behaviour and presented in COG reviews had some common points:

- they started with a tilt flux,
- the zone compartments are filling and then the Helium header is flooded
- the instability of the water level control appears
- the units were stopped for few days.

8. REFERENCES

/1/ B Rouben “Reactor Fuelling Simulation Program – RFSP Program Description” TTR-370, Rev 1, COG-94-580, 1995, April

/2/ D.A. Jenkins “Reactor Fuelling Simulation Program-RFSP: User’s Manual for Microcomputer Version”, TTR-321, Rev 1, COG-93-104, July 1993

/3/ G. -M. Toma “Eficienta Zonelor de Reglare “, Notã Internã, 79-63710-STASL/ANL-180, 10 Aprilie 1998, Cernavodã Unitatea 1

/4/ V. Toma “ Time-Average Calculation with Local Parameter Option”, Internal Memo, 79-03310-STASC/RPCP-346, 14 July 1997, Cernavodã Unitatea 1

/5/ Shin Sung-Ky “ Liquid Zone System Events at Wolsung Unit 2”, 5th TCM Information, Sept. 7-11 1998, COG Conference, Mangalia – România

/6/ D. Popa-Nemoiu “ RRS-Liquid Zone Control Operational Flowsheet” 1-FS-66551-P50, 95/04/11, Centrala Nuclearoelectricã Cernavodã

/7/ CANDU – Station Performance Newsletter, April 1992, page1, Gentilly-2 Liquid Zone System Event dated 22/04/1992

/8/ CANDU – Station Performance Newsletter, Sept. 1993, page 2, Pickering NGS A Unit 3, 12/09/1993

/9/ CANDU – Station Performance Newsletter, Nov. 1993, Pickering B Unit 5, Liquid Zone System Event dated 27/09/1993

/10/ CANDU – Station Performance Newsletter, March 1995, Bruce B, Unit 7, Liquid Zone System Event dated 21/03/1995

/11/ CANDU – Station Performance Newsletter, January’95, Bruce A, Unit 2, Liquid Zone Event dated 01/01/’95

/12/ CANDU – Station Performance Newsletter, Feb/March 1996, Bruce A Unit 1, Liquid Zone Event dated 13/03/’96

/13/ CANDU – Station Performance Newsletter, Feb/March 1996, Bruce B Unit 5, Liquid Zone Event dated 12/02/’96

/14/ CANDU – Station Performance Newsletter, Nov/Dec ’96, Bruce A, Unit 1, Liquid Zone Event dated 10/11/’96

/15/ CANDU – Station Performance Newsletter, October 1997, Darlington A, Liquid Zone Event dated 24/10/’97

/16/ CANDU – Station Performance Newsletter, July ’97, Bruce A, Unit 3, Liquid Zone Event dated 16/07/’97

APPENDIX A – SIMULATION RESULTS

A.I REACTIVITY BEHAVIOUR

Figure 1- Zone Control Unit#1 Reactivity Variation versus Zone Water Level

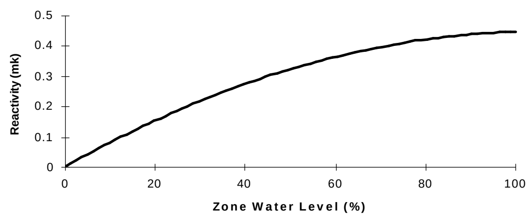


Figure 2 Zone Control Unit #2 Reactivity Variation versus Zone Water Level

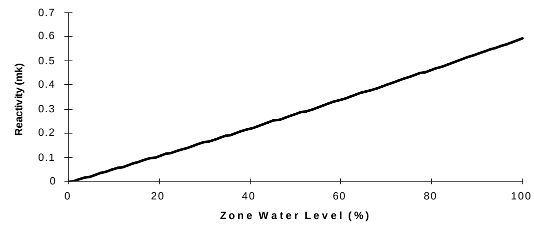


Figure 3 Zone Control Unit #3 Reactivity Variation versus Zone Water Level

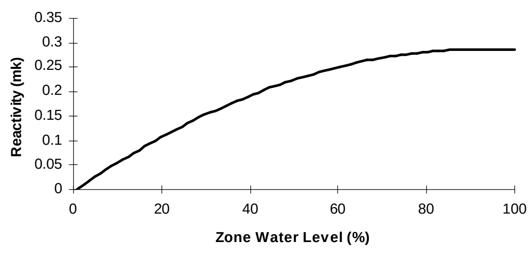


Figure 4 Zone Control Unit #4 Reactivity Variation versus Zone Water Level

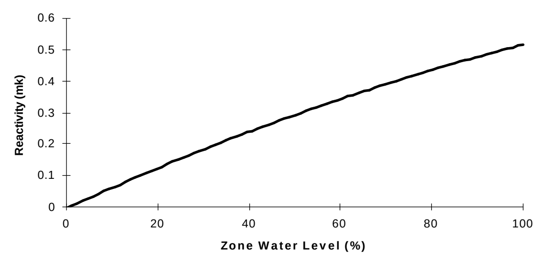


Figure 5 Zone Control Unit #5 Reactivity Variation versus Zone Water Level

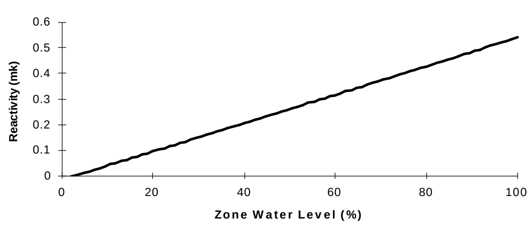


Figure 6 Zone Control Unit #6 Reactivity Variation versus Zone Water Level

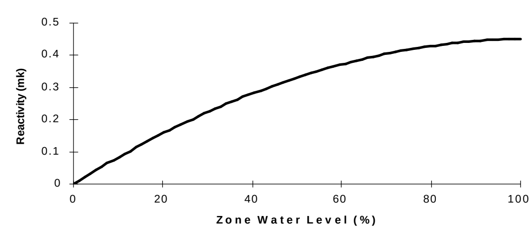


Figure 7 Zone Control Unit#7 Reactivity Variation versus Zone Water Level

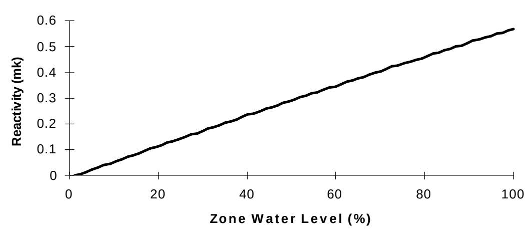


Figure 8 Zone Control Unit#8 Reactivity Variation versus Zone Water Level

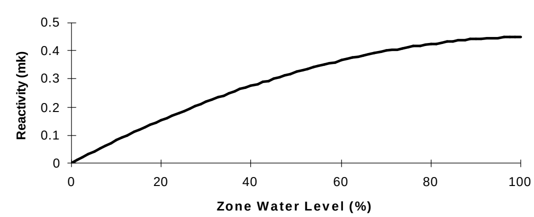


Figure 9 Zone Control Unit#9 Reactivity Variation versus Zone Water Level

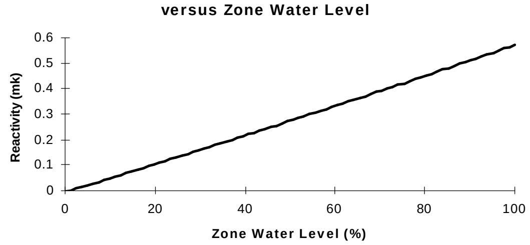
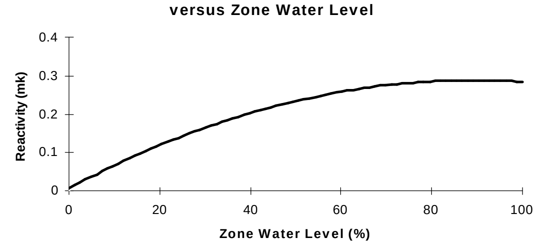


Figure 10 Zone Control Unit #10 Reactivity Variation versus Zone Water Level



APPENDIX A – SIMULATION RESULTS

Figure 11 Zone Control Unit#11 Reactivity Variation versus Zone Water Level

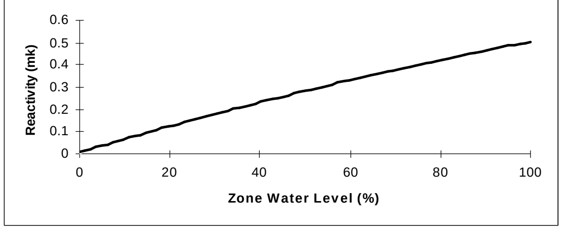


Figure 12 Zone Control Unit #12 Reactivity Variation versus Zone Water Level

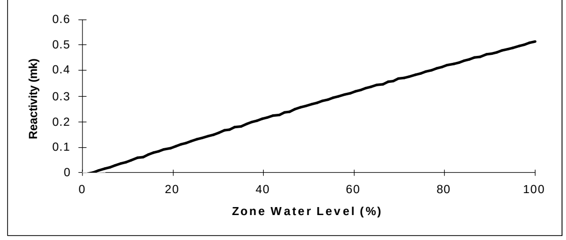


Figure 13 Zone Control Unit #13 Reactivity Variation versus Zone Water Level

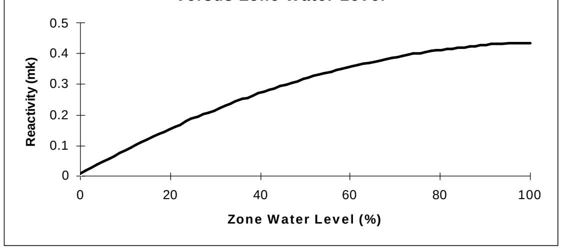
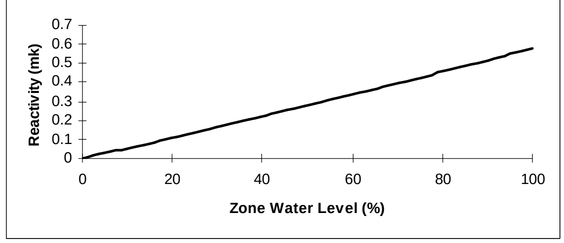


Figure 14 Zone Control Unit #14 Reactivity Variation versus Zone Water Level



A.II POWER BEHAVIOUR

Figure 15 Zone Control Unit#1 Power Variation versus Zone Water Level

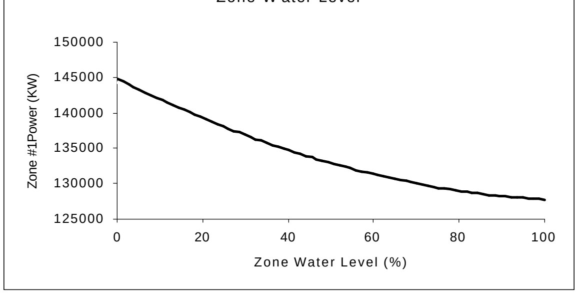


Figure 16 Zone Control Unit #2 Power Variation versus Zone Water Level

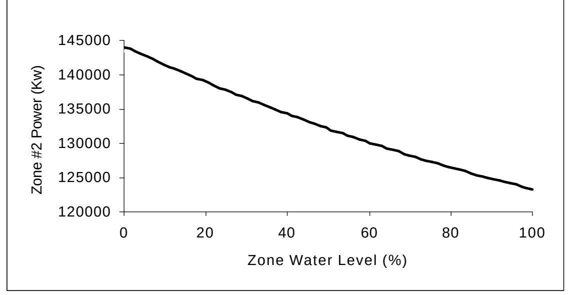


Figure 17 Zone Control Unit#3 Power Variation versus Zone Water Level

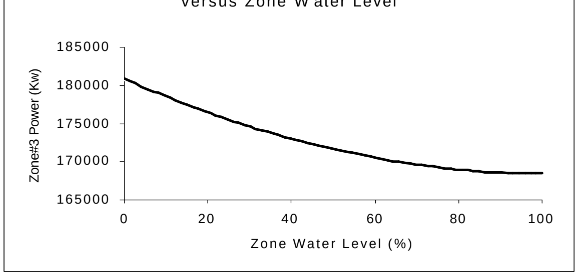
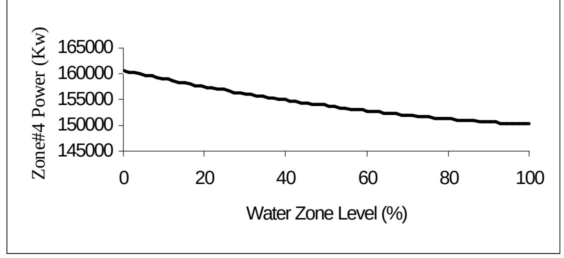


Figure 18 Zone Control Unit #4 Power Variation versus Zone Water Level



APPENDIX A – SIMULATION RESULTS

Figure 19 Zone Control Unit#5 Power variation versus Zone Water Level

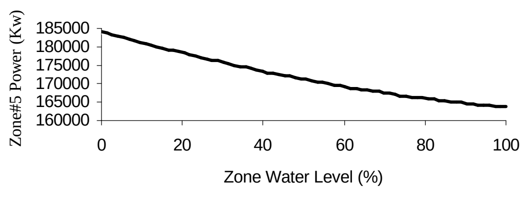


Figure 20 Zone Control Unit#6 Power Variation versus Zone Water Level

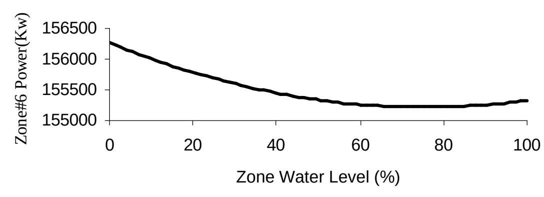


Figure 21 Zone Control Unit#7 Power Variation versus Zone Water Level

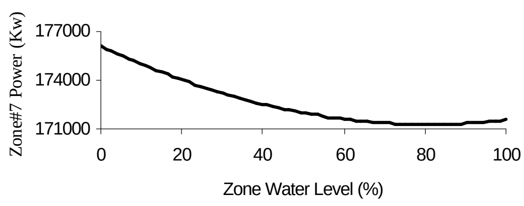


Figure 22 Zone Control Unit#8 Power Variation versus Zone Water Level

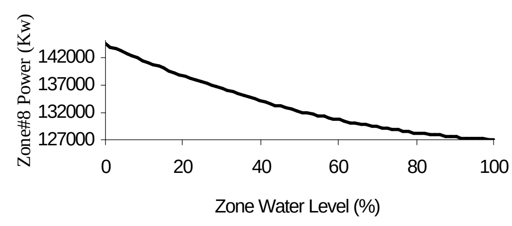


Figure 23 Zone Control Unit#9 Power Variation versus Zone Water Level

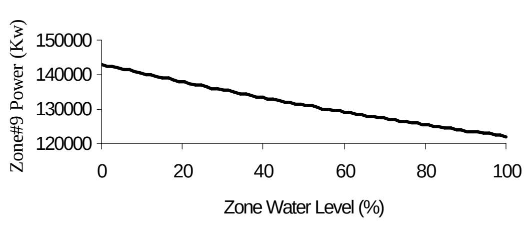


Figure 24 Zone Control Unit#10 Power Variation versus Zone Water Level

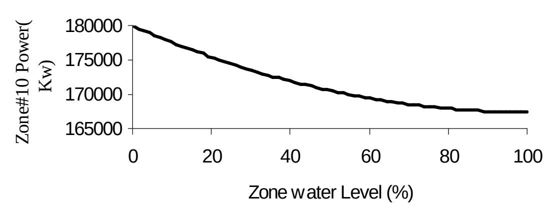


Figure 25 Zone Control Unit#11 Power Variation versus Zone Water Level

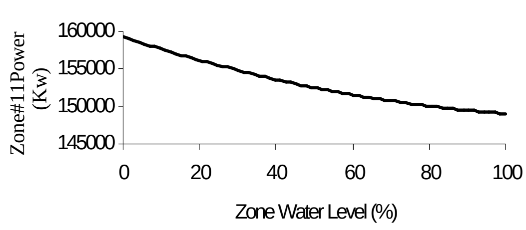


Figure 26 Zone Control Unit#12 Power Variation versus Zone Water Level

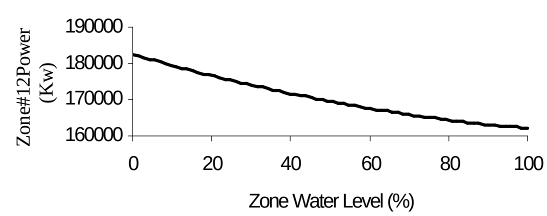


Figure 27 Zone Control unit#13 Power Variation versus Zone Water Level

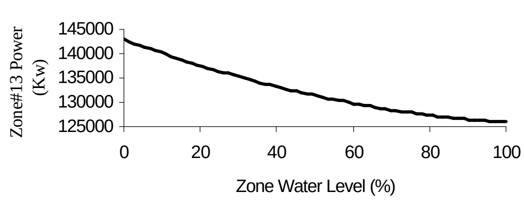
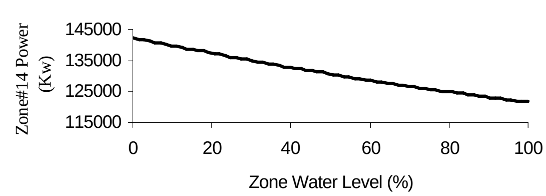
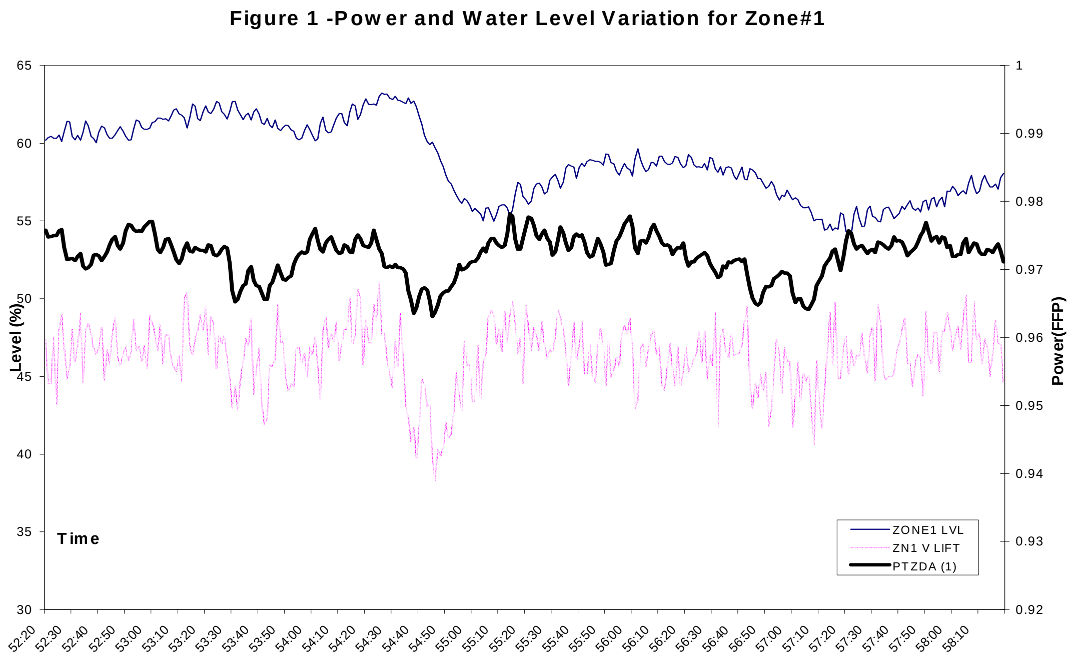
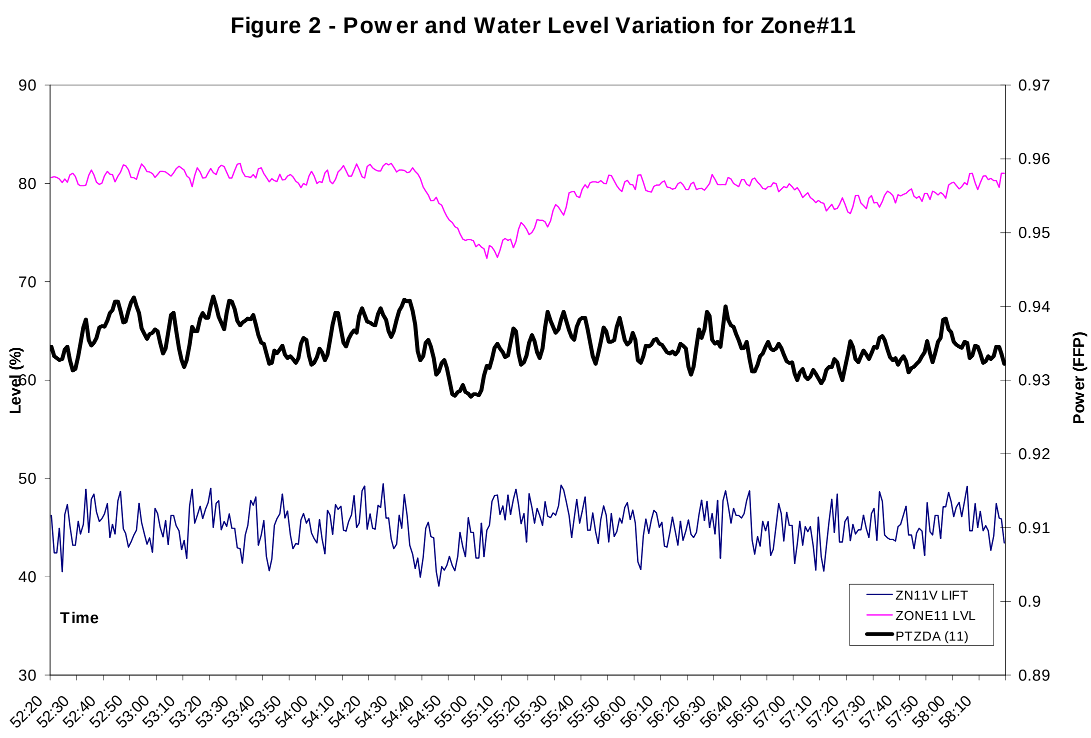


Figure 28 Zone Control Unit#14 Power Variation versus Zone Water Level



APPENDIX B – TEST RESULTS





APPENDIX B – TEST RESULTS

Figure 3 - Power and Water Level Variation for Zone #3

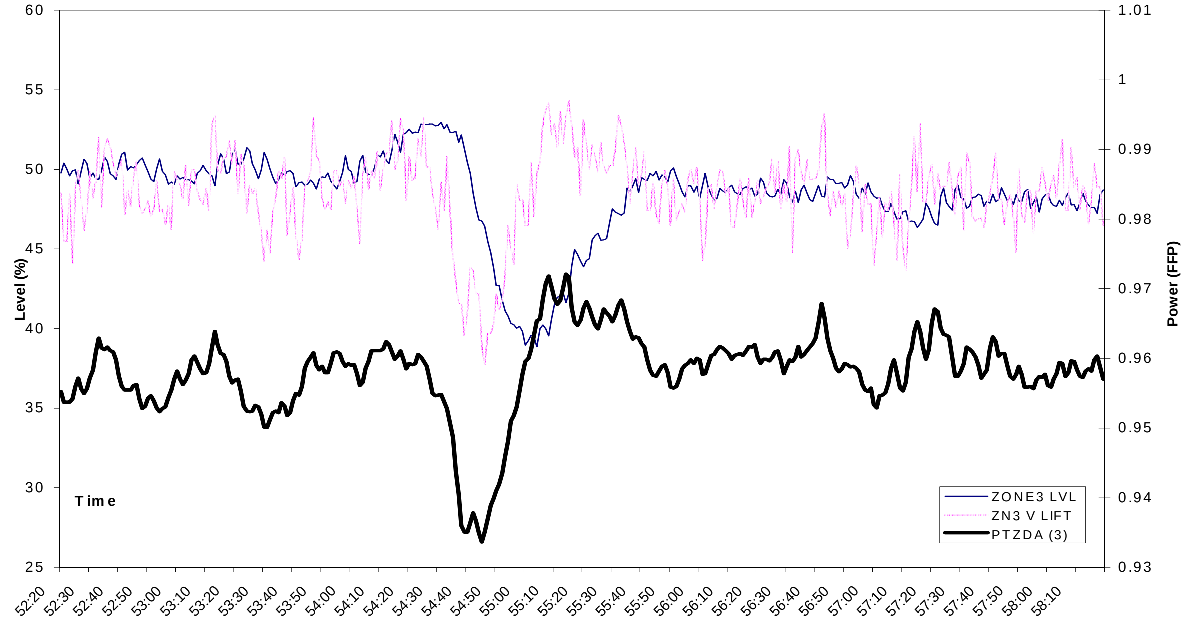


Figure 4 - Power and Water Level Variation for Zone#10