VALIDATION OF FORTRAN EMULATORS FOR THE G2 VARIAN CONTROL PROGRAMS

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ABSTRACT

The extensive use of the Gentilly full scope simulator for training and verification of plant procedures, forced the development of a reliable desktop simulator for software maintenance purposes. For that we needed emulators for the control programs which run on the DCC Varian computers in the full scope simulator. This paper presents the validation results for the Reactor Regulating System (RRS) program. This emulator was programmed in a modular fashion providing ease of maintenance and of transportation to another environment. The results obtained with specific tests or with integrated testing involving complex control rule interactions, compared favorably with the ones obtained using the actual plant control programs running on the full scope simulator, which constitutes an irrefutable validation procedure. This RRS package along with the other emulators being validated in this manner could be used in safety codes with confidence.

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1.0 INTRODUCTION

The G2 simulator was designed by CAE Electronics, and put into service in 1988. The full scope simulator is used extensively for the training of our operation staff consisting of first operators and shift supervisors, together with trainees coming first from Argentina and then Korea. Added to this, the simulator is also used more and more by the technical system engineers to validate changes or test procedures before executing them in the plant; the simulator proved to be an indispensable tool for validating abnormal incident procedures. Other programs came into effect like the yearly recycling of accredited shift personnel.

The simulator time thus became an increasingly precious commodity; the decision was taken to produce a reliable desktop version of the simulator, that could be run on a VAX workstation by each analyst; it had to give the same numerical results as the full scope simulator. For that, we needed reliable emulators of the DCC control programs that ran on the DCC computers used with the full scope simulator. A nucleus of emulators for the control programs, was originally developed at CAE during the design phase of the simulator; these programs contained only the basic functions of control and could not be trusted to reproduce exact results in all incidents; this was specially true for the Reactor Control Program. A major effort was thus made to upgrade these programs. For the Reactor Control Program which is the main topic of this paper, we discarded the original module of the design phase, and imported the control program used in the SMOKING2 safety code. After an effort to adapt this program to our simulator environment, it was found more advantageous in the long run to almost rewrite the entire program based on the G2 flow sheets and program specifications.

The programming of RRS is completed and this paper present the ongoing extensive validation process undertaken. The main advantage in the simulation environment as compared the to validation undertaken with the original SMOKING2 package coupled with the RFSP code [1], is that we can rerun the same transient on the simulator with the original control programs of the DCC, thus validating the control algorithms against real plant control. A logger was also implemented to output the different alarms generated by the control programs, and also to check for Contact Input messages and alarm windows coming from the field. A new more versatile version of this logger is currently being developed [2], in which we will be able to modify the variables monitored during a test run, using an up-to-date interface built with a graphic protocol based on X-Window Motif.

2.0 PROGRAM STRUCTURE

We do not want to elaborate on the programs themselves, but for the sake of completeness, figure 2.1 (1) gives an overview of program interactions; let us just add that the Reactor Power Measurement and Calibration routine (MCP), is the measuring routine feeding power measurements to Demand Power Routine (CEP), which calculates a power error based on power setpoint fixed by manual keyboard input or by the Setback routine. Note also that in the MCP routine, the neutronic power is constantly calibrated by thermal parameters and that zonal calibration of the 28 platinum detectors is done via the 102 vanadium detectors using the flux mapping routine FLU.

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(1) Courtesy of Bernard Leblanc, Control Process Section, Gentilly-2.

This power error is in turn fed into the Liquid Water Zone Control Absorbers routine (CBL), which is the reactivity fine tuning mechanism; this routine also uses zonal power measurements calculated in the MCP routine to affect differential zonal power control. The Adjusters Control and Monitoring routine (CBC), affects Adjuster Rods withdrawal upon low average liquid zone level (NMBL), or excessive negative power error, and their reinsertion on high NMBL or excessive positive power error. The Mechanical Control Absorbers routine (CBS), plays a analogous role for the Mechanical Control Absorbers (MCA), in response to the power error. The Shut Off Rod routine affects the withdrawal of the Shut Off Rods upon rearmement of the Shut Down Systems (SDS), with a subsequent negative power error.

Finally there is the Stepback Routine (RRP); it monitors nine possible Stepback conditions for which the MCA clutches are released thereby resulting in a sharp power reduction to a specific power endpoint. The Setback routine (BCP), also checks ten possible conditions for which a more controlled power reduction is obtained at a specific rate by varying the power setpoint to the CEP routine.

With this simplified vue of the rudiments of RRS programs, we can focus on the program structure which is as simple as following the different flow sheets for the RRS programs. A main program (G2TSJRR), plays the role of the driver in the DCC computers, and calls the different routines according to their scheduled timing sequence computed in the main program; the following routines are called in sequence: RRP, FLU, MCP, BCP, CEP, RBA, CBC, CBL, CBS (correspondence to the English version of these routines is given in table 2.1). Fast program segments are called every 0.5 second: RRP (0.25 second when Stepback is in progress), the power measurement segment of MCP, the bulk power control segment of CBL, CEP, BCP and CBS routine. Every 2.0 seconds the spatial control segment of CBL is called along with the thermal calibration segment of MCP, together with the CBC and RBA routines. The FLU mapping routine is executed in one call every 120 seconds. Control program messages are outputted by a call to MESEC routine. Time filtering of variables is done by a call to SRFILT routine which was downgraded to the simplified first order filter found in the assembler code.

Provision is also made for program failures; the driver or main program opens the D/O for the Adjuster Rods and Mechanical Absorbers upon RRS failure. Stepback status is also determined in the driver with the D/I fed by the simulation modules for the clutch status which in turn is dependent on the D/O from the RRP routine. All inputs through the keyboard are also processed in the main program. The keyboard themselves will soon be simulated with the new interface we are developing at Hydro-Québec [3], to represent and operate the panels.

The programming was done in a modular fashion, strictly following the different logical blocks that can be found on the flow sheets, with internal comments and mnemonic names for the FORTRAN variables that reflect the parameter names used on these sheets. All inputs and outputs to the different programs, are referred to in the program by the number of the specific Analog or Digital Input/Output. These internal variables are connected to the simulator variables by blocks of equivalence, that can be readily interchange, thus rendering the transportation of the emulator to another environment a relatively easy task; the emulator is therefore a black box that can literally be plugged into any environment via these equivalence blocks for the Analog and Digital Input/Output. Another advantage of the programming modeled so closely to the flow sheets, is the ease of maintenance when reflecting changes in the plant control programs.

3.0 VALIDATION RESULTS

In the validation process there are two kinds of testing available: there is block by block testing in which various inputs are changed to obtain specific response of an output variable in a control program; there is also what can be called integral test case where a perturbation is made in the field. For example a Shut Off Rod drops into the core and the overall response of the control programs is evaluated. In the latter testing, because we can reproduce the same transient using the same modules for the plant simulation, with the FORTRAN emulators on the desktop simulator and with the control programs of the DCC Varian computers on the full scope simulator, we can be sure of our reference point for the verification of our emulator response.

We expect to get very close agreement although slight differences do exist due to transmission delays in the real time environment, round off errors which are smaller on the desktop simulator, and small differences in internally calculated values like filtered or integral terms, between the simulation store point of the simulator and the one on our desktop computer. Note also that validation of the RRS programs at this date, is done with the original emulator of the design phase for the BPC control program; HTC and MTC control programs were reprogrammed and partially validated, and BLC was reprogrammed and the validation is ongoing. The status of each emulator is summarized in table 3.1.

Block by block testing is however still required, because integrated testing cannot go through every path of logic within the control program. The two modes of testing were used extensively.

For the choice of the integrated tests we used reference [1] as a guideline, extending the tests when judged useful.

3.1 Validation of the Stepback Routine

In this simple test we manually initiate Stepback action on SDS trip, by overriding the Digital Input for SDS trip to the Stepback routine, (D/I 64B6 and D/I 52B7 for channels D and E of SDS#1). Actual SDS action is however inhibited in order to test the Stepback routine.

In figure 3.1-1 we can see the rapid insertion of the MCA devices, 0 to 100% in just under 3 seconds, and in figure 3.1-2 the gradual increase in average liquid zone level at around 0.84% per second (this rate corresponds to the measured filling rate for the SDS1 trip event which occurred on the 29th of August 1988 at the Gentilly II power plant). The MCA insertion time is a little slow as compared to the annual test data, which clocks the insertion of the MCA at an average of 2.65 seconds; this will be revised in our model. The linear calibrated power drops off rapidly to around 10% FP. MCA response and average zone level response are confirmed in figures 3.1-3, using the actual plant control programs on the full scope simulator.

Note that extensive testing for each of the nine possible Stepback conditions was made using the block by block testing method where each input for the particular Stepback considered, was overridden using our DCC overriding utility. The Stepback condition and the power endpoint were checked; for the non-zero power endpoint a fix was necessitated in the emulator to match the full scope transient response. As an example the turbine trip generates a Stepback to 60% FP, but in the full scope simulator as in the real plant, the final power is always below that mark averaging around 45%. To obtain the same power endpoint, the Stepback is delayed for one iteration, thereby matching closely the one obtained on the full scope simulator with the real plant control program. The difference between the full scope simulator results with the ones obtained on our desktop simulator using the emulator, can be explained by the fact that there is no transmission delays on the desktop simulator. The lower power endpoint in the real plant is harder to explain; this undershoot is currently attributed to clutch slipping upon catching the MCA rods, a phenomenon not included in our model. This could be accounted for by the transmission delays on the full scope simulator.

Another patch was necessitated in the Stepback routine; as the analog inputs are updated by the models every 200 ms and the Stepback routine executes at every 250 ms during a Stepback, a change in input power is skipped every 4 executions of the Stepback routine. This in turn causes the power extrapolation algorithm in the Stepback routine to underpredict the extrapolated power at the subsequent execution, thereby ending the Stepback prematurely. This was fixed by executing the routine every 200 ms during a Stepback. This should also happen in the full scope simulator but it does not; why, we still don't know ?

Clearing of the particular Stepback was also validated for each parameter. Integrated tests for turbine trip, PHT pump trip, islanding on loss of power grid, moderator low level Stepback were also performed; all these test performed up to expectation and the emulator gave similar results to the ones obtained with the full scope simulator using the real plant control programs.

3.2 Validation of the Setback Routine.

In this test a manual Setback is initiated by overriding the Digital Input 63B13. In figure 3.2-1, power ramps down at 0.5%/sec corresponding to the Setback index rate for a manual Setback and the average liquid zone level increases slowly to affect the power reduction; this slow increase compensates for the increasing precursor source, thermal reactivity effects having been canceled by freezing the heat transport module and the reactivity module for thermal effects. The transient is confirmed by the one ran on the full scope simulator shown in figure 3.2-2.

This routine was also validated using the block by block validating process where each Setback condition was tested by varying the corresponding input parameter. Setback power rate and power endpoint for the 10 Setback conditions where validated also in this manner along with end of Setback condition.

3.3 Power Reduction from 100 to 95% and then to 80%

This test verifies zone response and Demand Power Routine (CEP), for power maneuvers; this test also corresponds to station maneuvers for which data is available. From a 100% FPSS, we proceed to reduce the power at .1% per second to 95% power and hold steady for up to 486 seconds. The power is then further reduced at the same rate to 80% power, followed by some 800 seconds of steady state run.

During each ramp-down, the average zone level initially increases and maintains itself slightly above the expected slope for the xenon transient, figure 3.3-1. Depending on the amount of void initially present, we get a differing initial response of the average zone level, the latter being also dependent on the power coefficients used [4],[5]. We now know for a fact [6], that a substantial amount of subcooled void is present in the core, starting much earlier in the channels that was previously though of, and that there exist uncertainties in the power coefficients themselves. Subcooled void correlations will be incorporated into our simulation model in the near future and power coefficients will be revised in light of the results of the ongoing research into the problem.

Notwithstanding our emulator results when compared to the ones obtained with the real plant control program on the full scope simulator, are in excellent agreement (figure 3.3-2).

3.4 Power Ramp-down from 100% to 44% at .5%/sec

This test verifies liquid zone response to the xenon transient and more importantly the adjuster bank control. The power is ramped-down at .5% per second from 100% FPSS to 44% starting from an average liquid zone level of 50%, and letting the buildup of xenon extract successive banks of adjusters when the average liquid zone level falls below 20%.

Depending on the power coefficients in use, we get a somewhat differing initial average liquid zone level response. In figure 3.4-2, where we zeroed the power coefficients for reactivity due to fuel temperature, coolant temperature, void and finally moderator temperature (all the reactivity input attributable to thermal effects), we obtained a similar response to that of reference [1], with the characteristic initial shark fin upon an abrupt power reduction due to the precursor source term. As the power ramp terminates, the liquid average zone level turns around and progressively as the initial source term disappears, returns lower than the initial starting level to compensate the increasing reactivity load of the xenon buildup. Figure 3.4-3 confirms the functionality of the emulator, where we see a excellent comparison for the average liquid zone level response and extraction time for the first two banks of adjusters.

The complete set of rules governing the extraction of adjuster banks as a function of power error and average liquid zone level illustrated in figure 3.4-1, was verified using block by block validation, varying the input power error and the average liquid zone level to the CBC program. The rules governing rod movement, sequencing, selection and inhibition of rod movement where also tested in that manner. Irrational position and end of travel fault were also validated; for rules for which ambiguities from the flow sheets were apparent, tests were made on the full scope simulator with the plant control and verifications within the assembler code itself were also made with the help of the system engineers.

The results for these specific validations are difficult to present in graphical form but an integrated test for validating the rules on power error boundaries can however be performed by extending the above transient up to the cycling of bank # 7.

In the continuation of the transient in a subsequent 1000 seconds run (figure 3.4-4), we accelerate the xenon buildup in order to create a negative error greater than 4%, thus resulting in the simultaneous extraction of two adjuster banks. The figure shows the simultaneous extraction of two sequential adjuster banks every time the power error reaches - 4% as shown in figure 3.4-5, the greatest overlap being on the extraction of bank # 5 when the power error stayed the longest under -4%. Note also that during the simultaneous extraction of banks # 4 and 5, the extraction of the latter is interrupted when the power error goes above - 4%.

The acceleration on the xenon transient is terminated with the extraction of the seventh bank in order to observe the cycling of the latter; power is also raised to the maximum permissible level of 53% with 7 banks of adjusters out of core, this in order to accelerate the reinsertion of bank #7 upon average liquid zone level reaching 70%. Alternating extractions and insertions can then be seen when the power error reaches -3% and +3% respectively. This conforms to the algorithm for the adjuster rods.

Note that this alternating sequence of insertions and extractions on Power Error, should be termed oscillation of the bank, cycling denoting slower in and out actions of the bank on high and low average liquid zone level.

3.5 Power Maneuver 100% Ramp-down to 60%, Steadied & Ramped-backup to 100%

In this simple test power maneuvering is tested using liquid zone action in response to the Demand Power Routine algorithm. This test is better suited though to validate secondary side control (BPC and BLC), which is heavily taxed during this transient.

The test starts from a 100% steady state run for at least 4000 seconds on our desktop simulator in order to achieve steady state conditions on the secondary side. A 60% power setpoint is then requested at a normal rate of 0.25%/sec for a run of 170 seconds by which time the target power is reached (Figure 3.5-3).

A feature of the simulator reactor model which was added at G2, allowing reinitialisation of Xenon concentration and/or precursor concentrations at any given power, is then activated by means of a malfunction, thus simulating as far as neutronics is concerned, a long term steady state equilibrium. The run is extended by an additional 100 seconds, at which time we can rearm the low pressure reheaters which were tripped during the power ramp-down (a longer run without rearming the reheaters would result in a Setback on low level of dearator storage tank). A power maintain request is logged in by a keyboard equivalent deposit on emulator variables and followed by a 2000 seconds run in order to achieve a secondary side steady state equilibrium. Even then, the average liquid zone level is still slightly increasing due to thermal effect on the primary side (mainly moderator temperature), and also secondary side transient like boiler pressure and thermal calibration factors.

The variations are sufficiently small though to postulate steady state and carry on with the sharp power ramp-up at 1%/sec and examine the resulting zone level response and power ramp. In figure 3.5-1 a), we can see the power ramp at the specified rate, followed by at steady state transient and in figure 3.5-2 a), the average liquid zone level response which starts by decreasing in response to the requested power increase and then start to sharply increase to compensate the burn off of the xenon at the higher power.

The fundamental flux amplitude of figure 3.5-1 a) and the average liquid zone level in figure 3.5-2 a), can be used to compare the transient obtained using the actual control program on the full scope simulator, the results of which are shown in figures 3.5-1 b) and 3.5-2 b). The latters are in complete agreement with the ones obtained on the desktop computer using the RRS emulator. Note that the run on the full scope simulator, necessitated an inhibition of the SDS and Setback in order to complete the transient; a Setback on low boiler level or a SDS on high PHT pressure are marginal on both runs, on the desktop simulator and with the full scope simulator. Depending on the degree of stabilization on the secondary side, either one can come in. Even though it is not shown here, we did have significant difference in secondary side boiler pressure and level response between the two simulations; this does not however prevent us from validating the RRS emulator.

3.6 SOR Drop Test to 50% Insertion.

This test verifies the Setback logic on spatial control, together with the zone level control for spatial flux tilts.

In this test we drop SOR rod #19 into the core to the 50% position starting from steady state at 100% power. This test differs from the one in reference [1], because having no steady state iteration algorithm, we cannot start the test with a distorted flux. The asymmetry is created dynamically with the drop test, with the control reacting to correct the flux tilt and maintain the criticality of the reactor.

On the onset we observe a Setback on flux tilt (more than 20%) caused by the shut off rod, which is cleared by the liquid zone response in roughly 24 seconds.

The transient was extended up to 700 seconds. The initial power drop to 75% due to the SOR insertion, tripped the low pressure reheaters on the secondary side, eventually producing a Setback on low level of the dearator storage tank at about the 300 second mark to be cleared at around 530 seconds into the transient (figure 3.6-1). This transient produces large variations in the different liquid zone levels; these levels obtained using our desktop simulator with the RRS emulator, can be compared in figures 3.6.-2 with the ones obtained with the simulator using the actual Varian control programs on the DCC computers (only one zone is shown in order to keep the number of plots within a reasonable number, but it is typical of the agreement between the two runs). With the two Setbacks we have a check of the Setback algorithm and also of the Demand Power Routine (CEP program), where the power setpoint is ramped down according to the rate set by the Setback routine (BCP program). The Light Water Zone Control Routine (CBL program), is also tested for overall reactivity control and spatial flux control; in turn the Power Measurement and Calibration Program (MCP program), must provide accurate power measurements to the other control programs (CBL,CEP,BCP and RRP the Reactor Power Stepback routine).

The initial drop in power with the emulator is slightly smaller than the one obtained with the DCCs (around 1 % higher); this is well within expected deviations attributable to intrinsic differences between the two simulations as mentioned previously. Apart from that, there is complete agreement between the two simulations which constitute a good example of an integrated test where there is multiple control actions; without the comparison between the desktop simulation and the simulator, it would be difficult to judge the degree of validity of the emulator.

Another tool is the logger with which we can compare the message output using the emulators and the one using the simulator with the actual plant control programs. The sequence and timing of the different messages are comparable in so far as the RRS emulator is concerned.

3.7 Moderator Poison Dilution

In this test we verify the functionality of the zone controller model together with the MCA rod movement logic.

The test matches closely the one in reference [1], titled IN-CORE LOCA TEST, in which a fuel channel ruptures discharging coolant into the moderator and disabling MCA Rod #1 and 2. Our test only simulates the poison dilution. We found that it was not necessary to simulate the change in moderator density or the downgrading of the moderator purity or the reactivity excursion due to coolant density change to validate the control process. We did have to increase the reactivity ramp due to the poison dilution though to try to match as closely as possible the transient in reference [1].

The initial conditions were the same as in reference [1], with initial power at 75% in steady state condition and initial zone levels at 70%. The extraction process of the Boron poison was speeded up from 0.02 mk/sec to 0.028 mk/sec in order to match as closely as possible the overall reactivity insertion in reference [1]; the extraction rate was found by tuning for the average zone fill response and the power excursion. SDS action was inhibited, along with Setback and Stepback action. Gadolinium injection by the Demand Power Routine upon log rate or power error greater than 10%, was also inhibited by jamming closed PV16 by means of a malfunction.

With these safety functions inhibited, it was found that a reactivity insertion greater than the above rate with liquid zones being practically full, resulted in an uncontrolled power excursion and produced failure of the RRS control program on six or more zonal powers being irrational.

Comparing the power error in figure 3.7-1, with the average liquid zone level movement and MCA Rod #3 and 4 movement in figures 3.7-2, it can be seen than the control rules for these reactivity devices are functioning as designed.

Average liquid zone level begins to rise on the onset by increasing valve lift, stabilizing the reactor power for the first 55 or so seconds, until approaching the 95% mark, when limiting values for individual zone lift take effect, along with the spatial control factor being ramped to zero for a zone level between the 80 and 90% value.

When the average zone level reaches 80%, MCA bank#1 is inserted according to the rules in shown in figure 3.4-1; the change in slope at about 58 seconds into the transient, reflects the increasing velocity with increasing power error above 2%. At about the 61 second mark, the second bank of MCA Rods is activated for a power error greater than 4% (this is a relative error which corresponds a calibrated linear power of 78% on figure 3.7-3). The first 10 or 15% of MCA insertion cannot compensate for the combined rate of 0.0279 mk/sec of positive reactivity by the poison dilution and the positive thermal reactivity feedback. The power turns around at about the 120 second mark, and we observe a decrease in the average zone level upon an negative power error around 168 seconds into the transient; we also note the slowing down of MCA Rod #4, the power error lowering below 2%, and the stoppage of MCA Rod #3 of bank #2, with the power error being less than 4%. Rod # 4 of bank #1 keeps inserting itself in spite of the fact that the power error is less than 1.5%, because the average zone level is still above the 80% value.

MCA Rod #4 will be completely inserted just after 205 seconds while Rod #3 will restart its insertion when the increasing power error reaches 4%. It's rate of insertion will be controlled by the oscillation of the power error around the 4% mark; this corresponds to the logic governing MCA insertion: bank #1 is first activated if there is at least one rod available (that is: not irrational and not fully inserted). Our disabling of rod #1 of bank #1, did not produce an irrational reading for the position of that rod, or activate its end of travel switch; thus bank #2 , (Rod # 3), would be requested upon only if the error was greater than 4% on the logic of simultaneous insertion of two banks. Our results differ from that of reference [1], but agree with the revised test published in reference [7].

The test was confirmed by running the same transient in foreground, using the actual DCC programs. Figures 3.7-4 agree with the results obtained using the emulators. Some small discrepancies are however present like the peak power obtained for the modal fundamental amplitude and the minimum reached for the average zonal level when the power error becomes negative; an in depth study did not revealed any discrepancies in the RRS module itself although we did correct the driving speed of the MCA rod to respect the lack of precision in the assembler code, that is the minimum speed is not 50% but rather 49.6%. That did not change the results significantly. We suspected that the discrepancies were attributable to secondary side control, which was not yet validated at that moment, and could change the overall reactivity due to thermal effects. This was confirmed by freezing the thermal reactivity feedback routine, and we did produce the same results in the foreground and background simulations.

Note that a detailed validation of the rules illustrated in figures 3.4-1, was also done block by block of the flow sheet, by varying the corresponding inputs and observing the response; thus each region and boundary of figure 3.4-1, was individually tested. These results are difficult to present in graphical form however. The same testing was done for the Shut Off Rod program (RBA), and the Adjuster Rod program (CBC). Corrections to the SOR flow sheet were even implemented after discussions with the system analyst and verification in the assembler code. Clarifications to the Adjuster flow sheet were also suggested.

4.0 CONCLUSIONS

Although the validation process is an ongoing task, we can already conclude from the results obtained so far, that the RRS emulator package is functional for our background software maintenance program on our desktop computer; block by block verification was performed on the following routines: CBC,CBS,RBA,RRP,BCP; partial block testing of MCP, CBL and CEP was also done. The Flux Mapping program is considered valid if a sustained steady state can be maintained; experience with the simulator demonstrate that a faulty FLU program results in a Setback on flux tilt within 20 minutes of steady state running time; this is not however an absolute validation criteria and further testing of the FLU program is planned.

Our integrated testing where a number of control rules come into play throughout the transient and the possibility of rerunning the same transient with the actual plant control programs on the DCC Varian computers using the full scope simulator, gives us confidence in our validation process. We are aware that some logical paths in the emulator code may not be executed for the transients experimented, and only a combined extensive integrated and block by block validation can provide us with one hundred percent confidence. This extensive integrated testing will be performed through our software maintenance program, where daily use of the emulators in solving deficiencies for the full scope simulator will provide further testing of the package.

This package can also be integrated easily and with confidence in safety code necessitating control program actions. The modular programming where all inputs/outputs from and to the field are grouped into blocks of equivalence with the internal variables of the emulator, facilitates the integration of the package into another environment; only the Analog and Digital Inputs/Outputs need to be identified in the recipient code and replaced in the equivalence blocks of the package, the latter can be considered as a self-standing black box. The emulator in which the programming strictly conforms itself with the logic on the flow sheets, can however be easily modified; that feature will be used on a regular base in our software maintenance program to update the emulators with latest modifications in the plant control programs.

Detailed review of the programming of irrationalities and validation has yet to be performed; these irrationalities may have adverse effects, like the failure of the control program and have to be considered specially with the use of safety codes. Although limit check for irrationalities are performed in each routine, a new self-standing routine will be programmed (the equivalent of AAS), to check all the Analog inputs using the latest irrationality table from the plant control; only then will a detailed validation of the irrationalities be undertaken.

The package provides complete alarm output, which is very useful for following what is going on in the transient, and can also be used to validate the package.

What is new in this validation is that we have a unique tool by which we can test directly our emulators with the real plant programs; it goes even further, insofar as we are also validating the documentation, the program flow sheets, against the actual assembler programming. The Shutoff Rod withdrawal program flow sheet was specially unclear; errors where also found in other flow sheets like Moderator Temperature Control [8], and the PHT control program.

5.0 RECOMMENDATIONS

It is hard to decipher the assembler code even for an experienced assembler programmer; efforts should be made to further develop control programs in higher programming language so that in the near future we could contemplate replacing the DCC Varian with machines having unlimited capacity as far as program control improvements, and compatibility with higher level programming language, thus providing ease of maintenance and modification.

The RRS package along with the other emulators developed in the framework of our software maintenance program could serve as a basis for this update; the present work demonstrates that the simulator can serve as a tool for the validation of these control programs in high level programming language, thereby providing a high level of confidence in the package. The latter should also be used in safety codes whenever control actions are needed ; our continuous update of the emulators to conform to the latest change in the plant control programs would assure an up-to-date control package for the safety codes, together with the follow-up validation. The extended use of the package would contribute the validation of the latter. Generalizing the use of the package to other simulators of CANDU 600, would also serve that purpose.

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TABLE 2.1
Relation between the Different Nomenclatures Used

French Acronym	French Program name	English Program name
SRR	Système de Régulation du Réacteur	Reactor Regulating System (RRS)
RRR	Régulation Rapide du Réacteur	Reactor Regulating Fast (RRF)
RLR	Régulation Lente du Réacteur	Reactor Regulating Slow (RRS)
CBC	Contrôle des Barres de Compensation	Adjusters Control and Monitoring Logic
CBL	Contrôle des Barres Liquides	Light Water Zone Control Absorber
CBS	Contrôle des Barres Solides	Mechanical Control Absorbers
RBA	Retrait des Barres d'Arrêt	Shutoff Rod Withdrawal
RRP	Recul Rapide de Puissance	Reactor Power Stepback
BCP	Baisse Contrôlée de Puissance	Reactor Power Setback
MCP	Mesure et Calibration de la Puissance	Reactor Power Measurement and Calibration
CEP	calcul de la Consigne et de l'Erreur de Puissance	Demand Power Routine (DPR)
FLU	cartographie du FLUx	Reactor FLuX mapping (FLX)
RPC	programme de Régulation de la Puissance de la Centrale	Unit Power Regulation (UPR)
RNG	programme de Régulation des Niveaux G.v.	Boiler Level Control (BLC)
RPG	programme de Régulation de la Puissance des G.v.	Boiler Pressure Control (BPC)
RTM	Régulation de la Température du Modérateur	Moderator Temperature Control (MTC)
CCA	Contrôle du CAloporteur	Heat Transport Control (HTC)
SAD	Surveillance d'Alarmes Diverses	Miscellaneaous Alarm Scan (MAS)
SAA	Surveillance d'Alarmes Analogiques	Analog Alarm Scan (AAS)
SAC	Surveillance d'Alarmes par Contact	Contact Alarm Scanner (CAS)

TABLE 3.1
Validation Status for each Emulator

Program	Program Revision Flowsheet	Validation status (May 96)
SRR	66551SFI-01 rev.F	(extensive but not 100% for irrationals)
RRR		
RLR		
CBC	66551SFI-07 rev.F	block by block logic: 100%
CBL	66551SFI-06 rev.E	integrated test 100% match to plant control + some block by block testing
CBS	66551SFI-08 rev.F	block by block logic 100%
RBA	66551SFI-09 rev.D	block by block logic 100%
RRP	66551SFI-05 rev.J	block by block logic 100%
BCP	66551SFI-03 rev.G	block by block logic 100%
MCP	66551SFI-02 rev.K	Integrated test 100% match to plant control + some block by block testing
CEP	66551SFI-04 rev.J	Integrated test 100% match to plant control + some block by block testing
FLU	66552SFI-01 rev. 95-08-22	indirect integrated testing (to be further valited)
RPC	66558SFI-01 rev.K	only partially programmed for turbine rpm ramp-down upon islanding
RNG	66556SFI-01 rev.K	ongoing validation
	66556SFI-01 rev.J	
RPG	66553SFI-01 rev.K	ongoing reprogramming
	66553SFI-02 rev.H	
RTM	66554SFI-01 rev.D	sheet 1 validated by integrated testing
	66554SFI-02 rev.C	sheet 2 not validated
CCA	66555SFI-01 rev.D	integrated test 100% match to plant control + 100% block by block testing
SAD		not yet programmed
SAA		not yet programmed (will use XDO utility)
SAC		done by the logger 100% functionnal

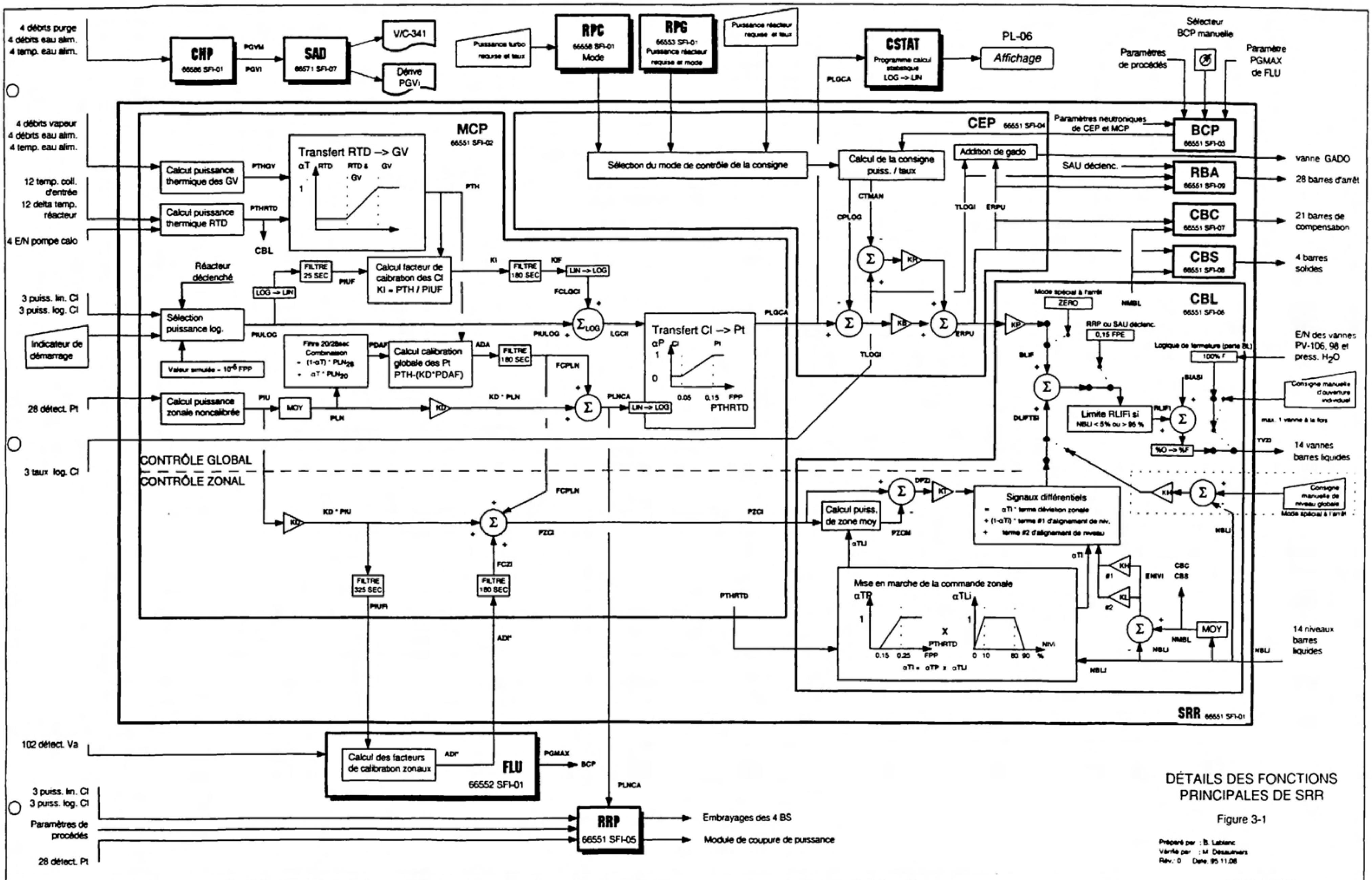


Figure 2.1 *OVERVIEW OF THE CONTROL PROGRAM RRS (COURTESY OF BERNARD LEBLANC)*

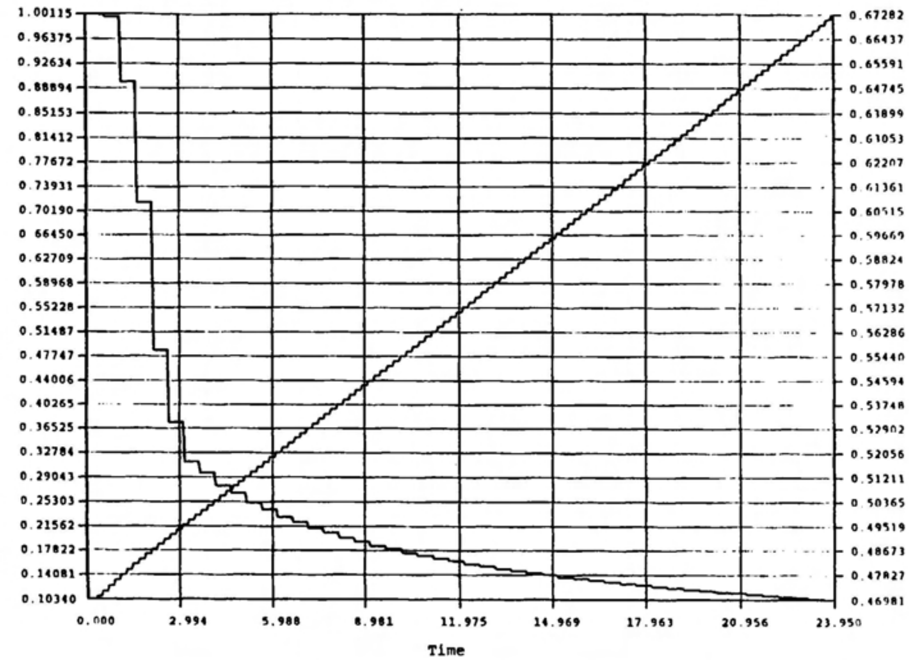


Figure 3.1-2 POWER AND AVERAGE LIQUID ZONE RESPONSE TO A STEPBACK (EMULATOR CONTROL)

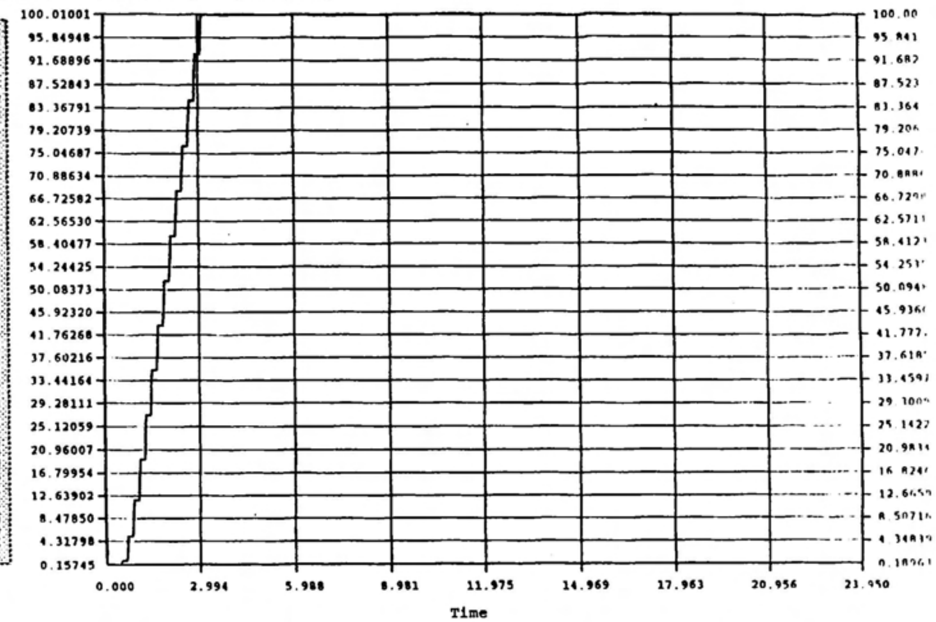


Figure 3.1-1 MECHANICAL ROD ABSORBERS INSERTION, UPON A STEPBACK (EMULATOR CONTROL)

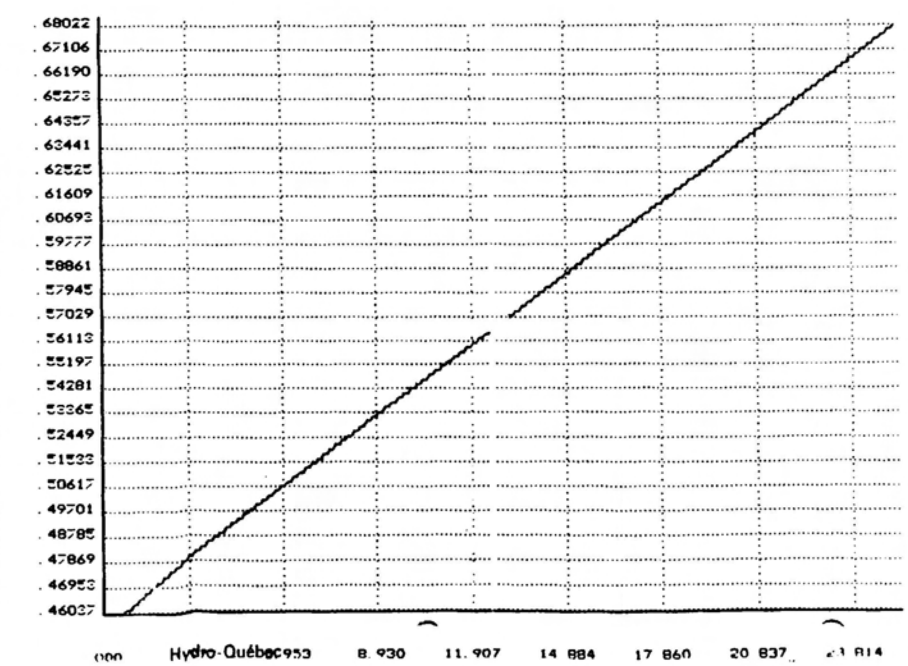


Figure 3.1-3b) AVERAGE LIQUID ZONE RESPONSE UPON STEPBACK (ACTUAL PLANT CONTROL PROGRAMS)

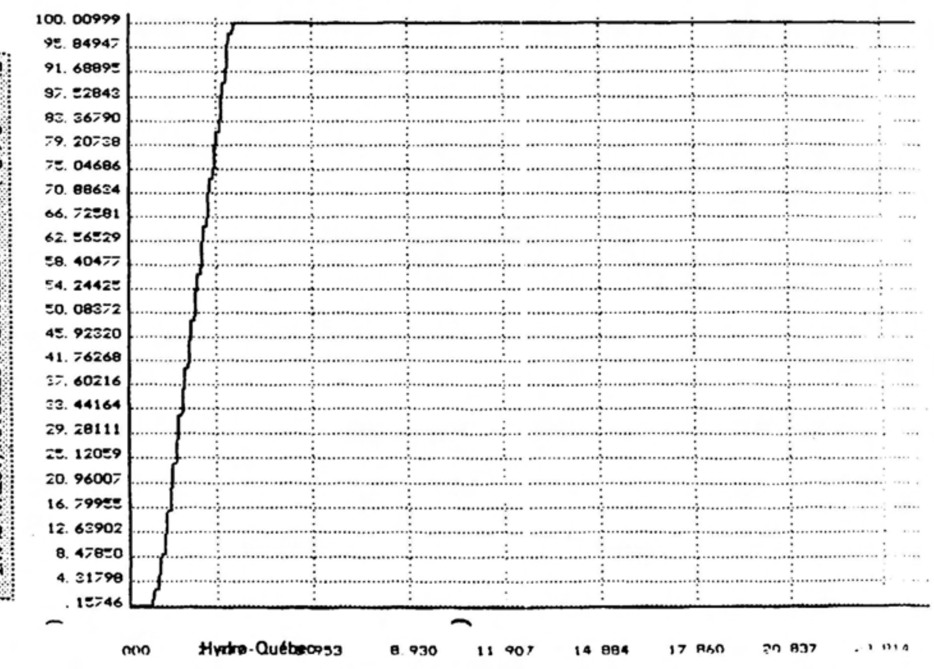


Figure 3.1-3a) MCA INSERTION TO A STEPBACK (ACTUAL PLANT CONTROL PROGRAMS)

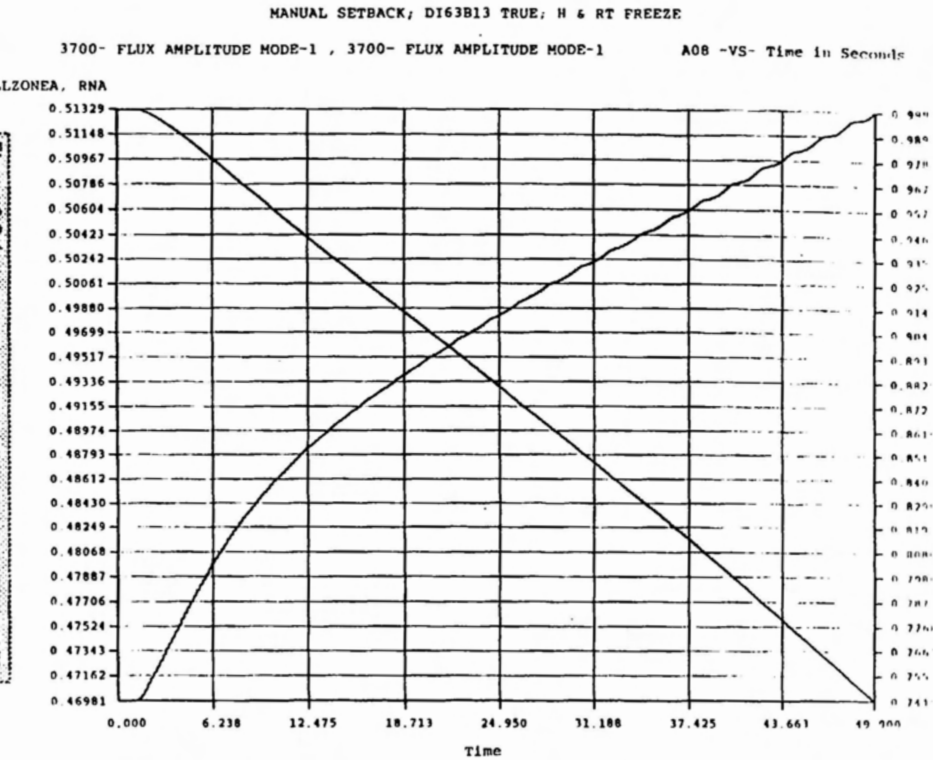


Figure 3.2-1 POWER AND AVERAGE LIQUID ZONE RESPONSE TO A SETBACK (EMULATOR CONTROL)

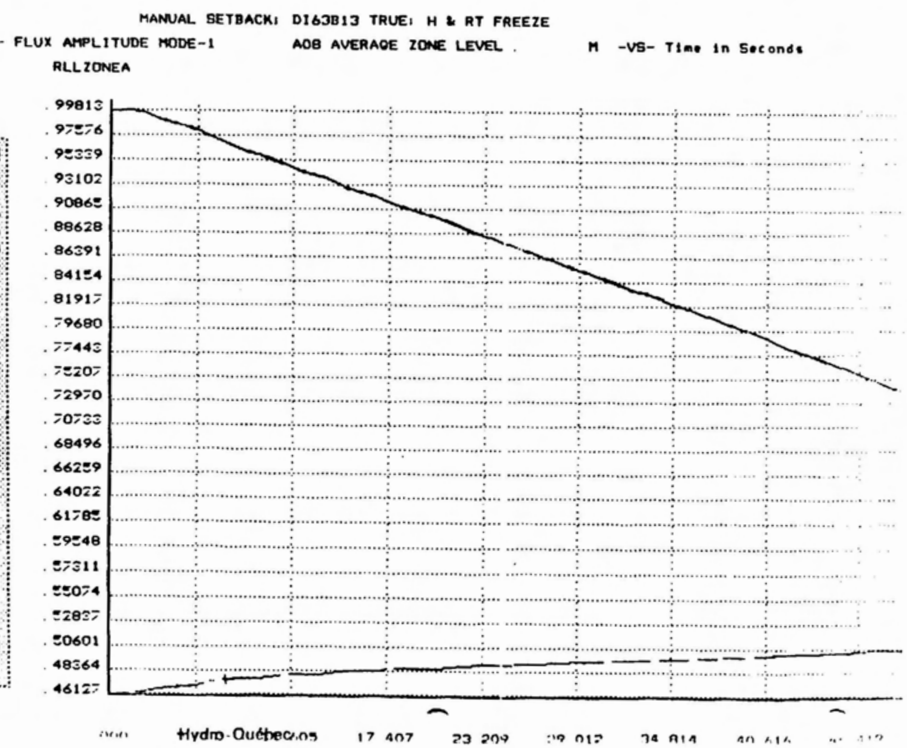


Figure 3.2-2 POWER AND AVERAGE LIQUID ZONE RESPONSE TO A SETBACK (ACTUAL PLANT CONTROL PROGRAMS)

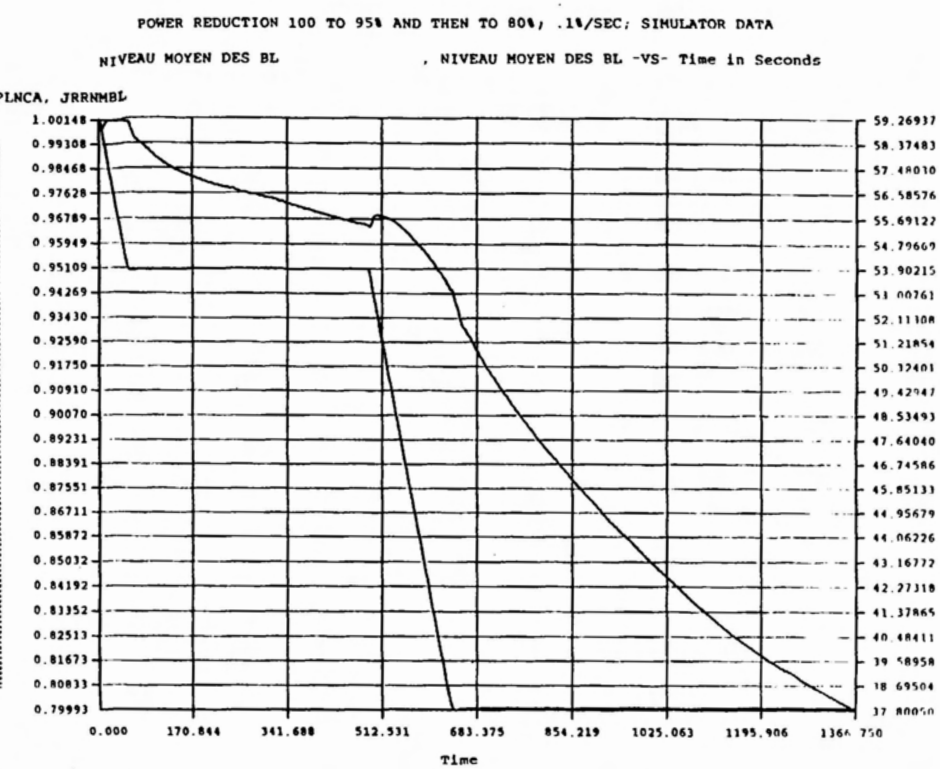


Figure 3.3-1 POWER REDUCTION AND CORRESPONDING LIQUID ZONE RESPONSE (EMULATOR CONTROL)

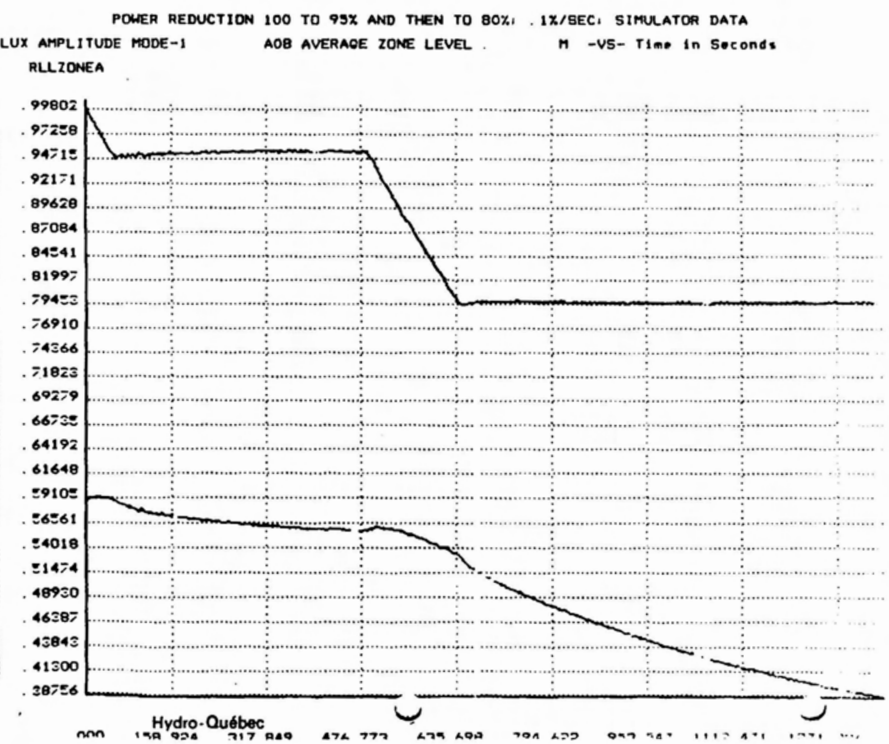
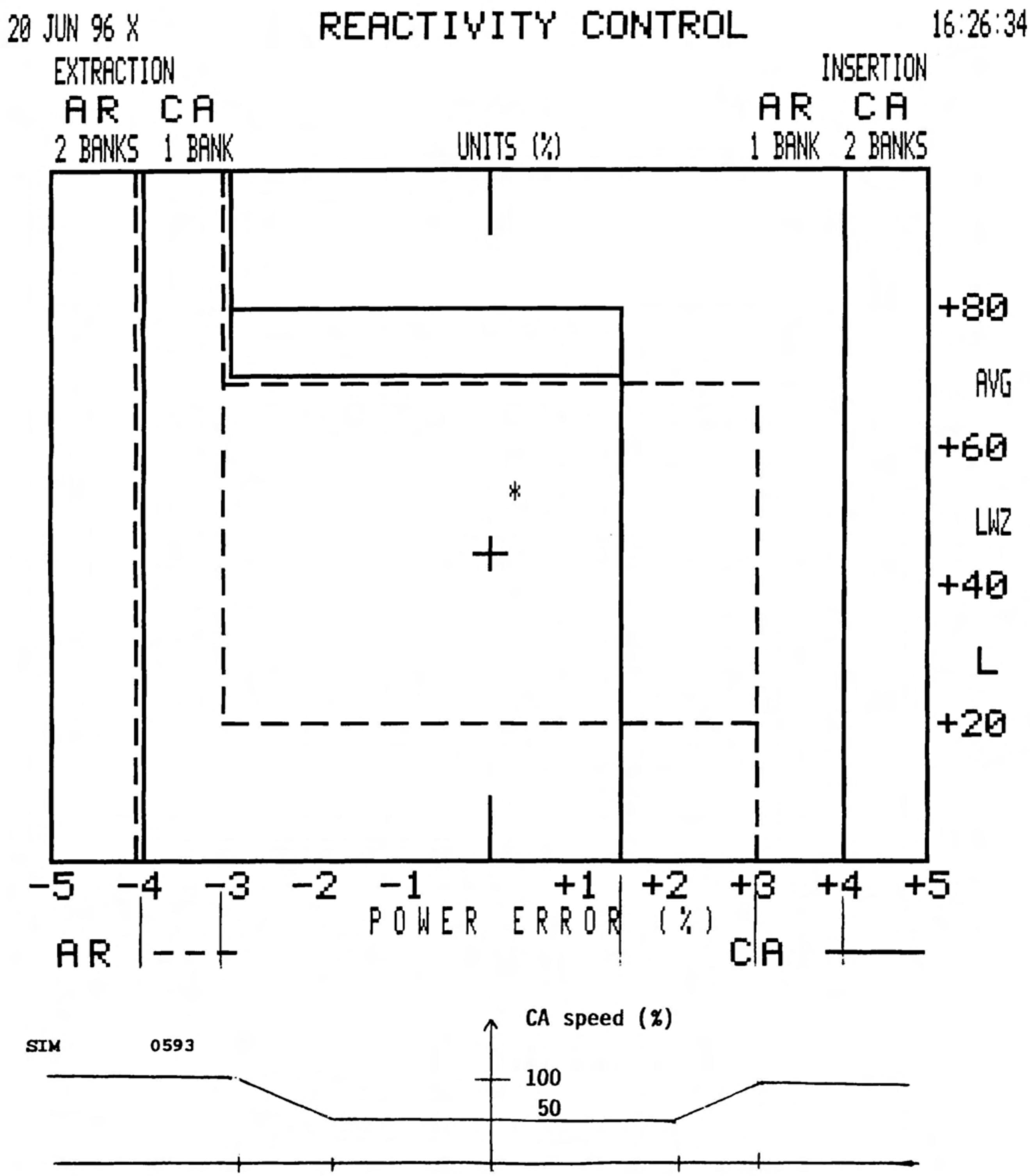


Figure 3.3-2 POWER REDUCTION AND CORRRESPONDING LIQUID ZONE RESPONSE (ACTUAL PLANT CONTROL PROGRAMS)



NOTE: CA = Mechanical Control Absorbers
AR = Adjuster Rods

Figure 3.4-1 CONTROL RULES FOR MCA AND ADJUSTER ROD EXTRACTION AND INSERTION

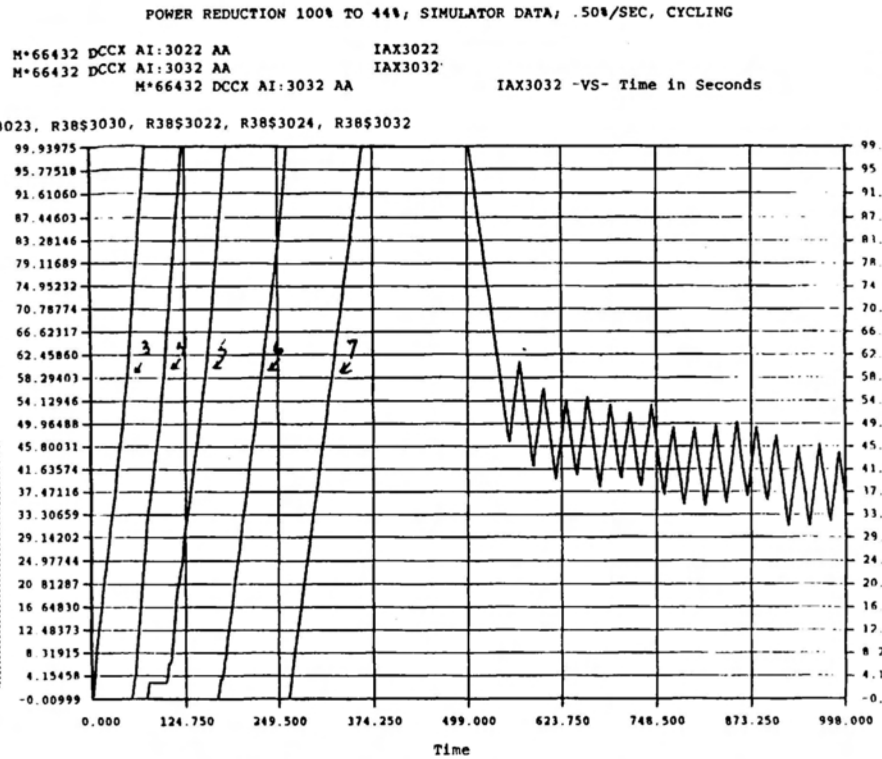


Figure 3.4-4 EXTRACTION OF BANKS #3 TO 7 AND CYCLING OF BANK #7, SUBSEQUENT 1000 SECONDS (EMULATOR CONTROL)

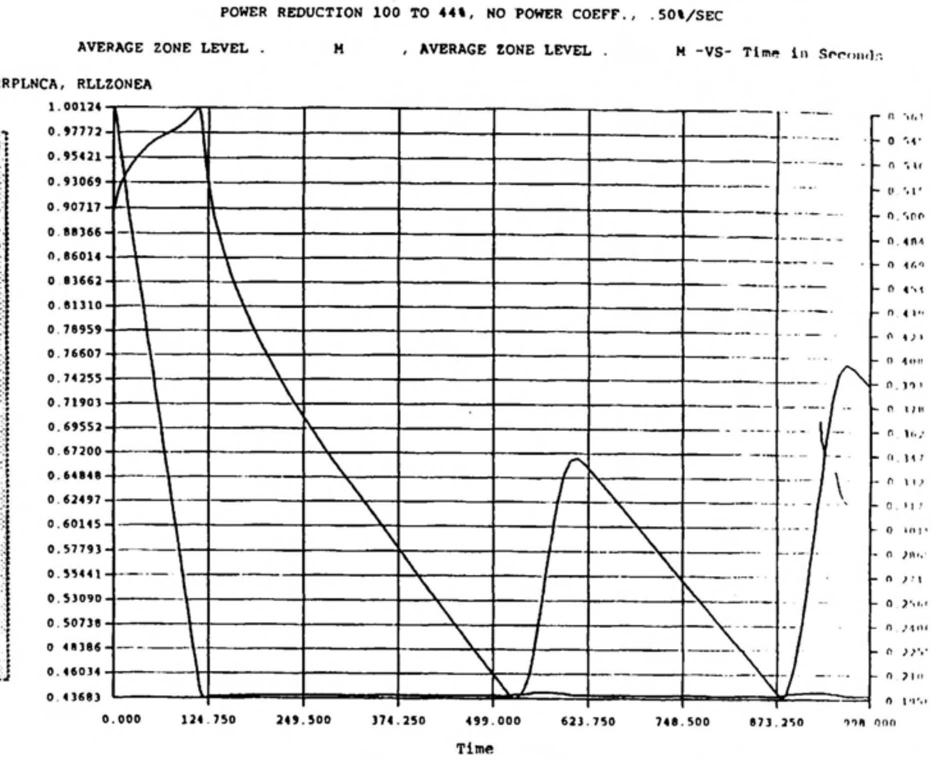


Figure 3.4-2 AVERAGE LIQUID ZONE RESPONSE AND POWER RAMP (EMULATOR CONTROL)

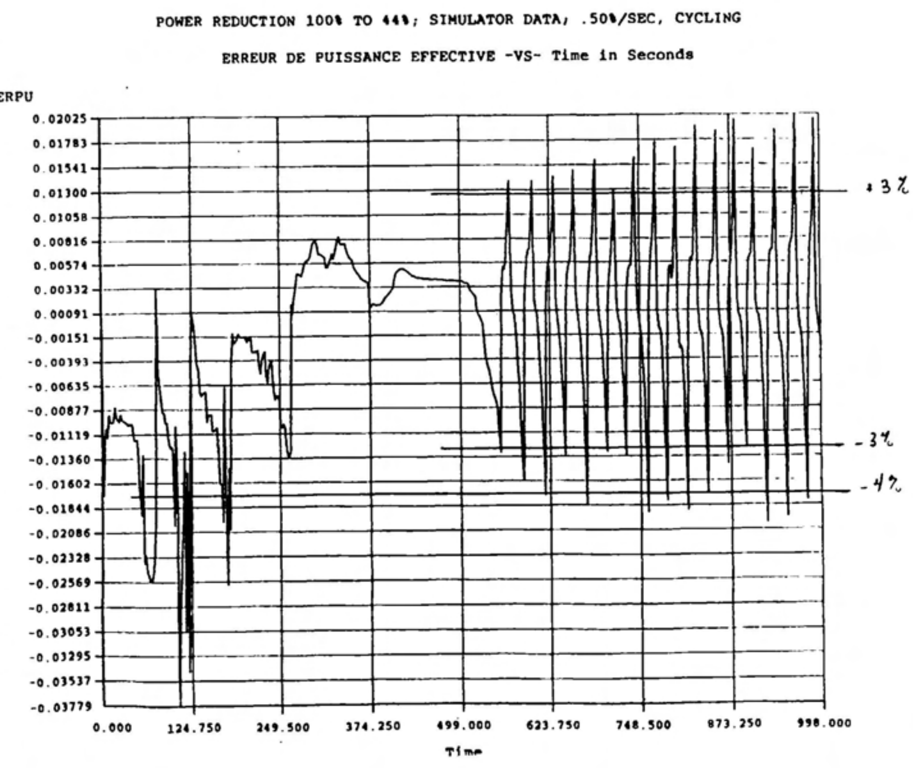


Figure 3.4-5 POWER ERROR DURING EXTRACTION OF ADJUSTER BANKS #3 THROUGH 7 (EMULATOR CONTROL)

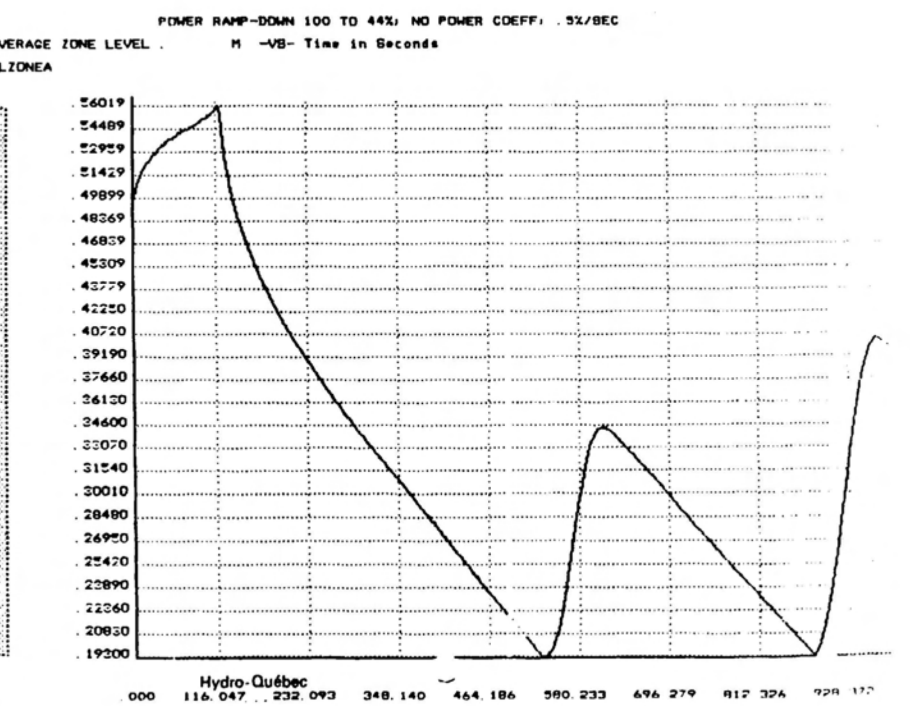


Figure 3.4-3 AVERAGE LIQUID ZONE RESPONSE TO THE POWER RAMP (ACTUAL PLANT CONTROL PROGRAMS)

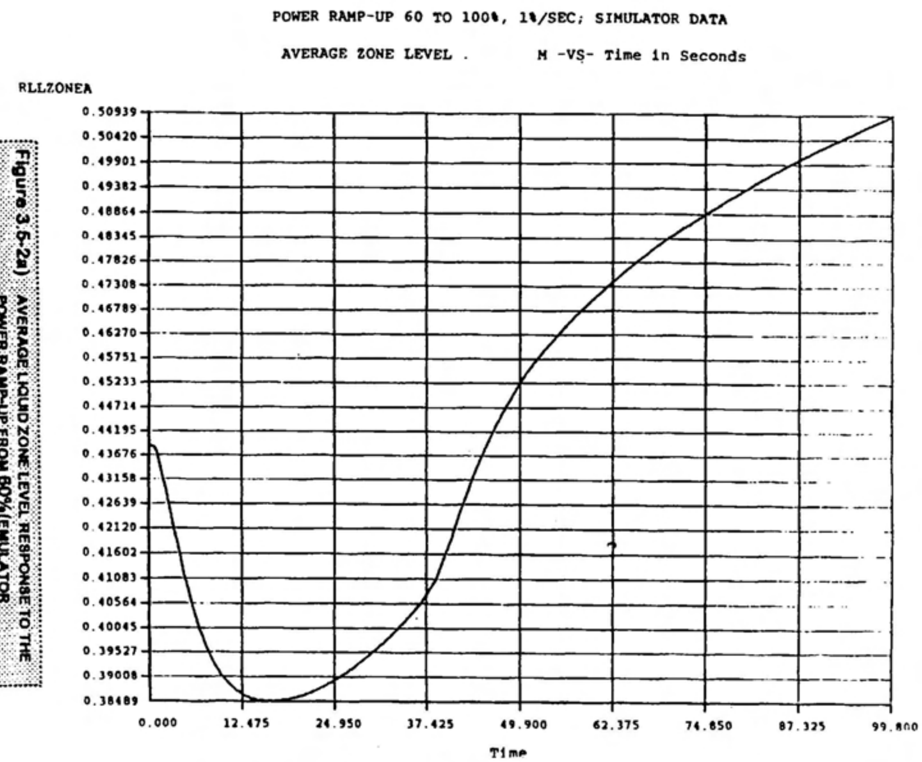


Figure 3.5-2a) AVERAGE LIQUID ZONE LEVEL RESPONSE TO THE POWER RAMP-UP FROM 60%(EMULATOR CONTROL)

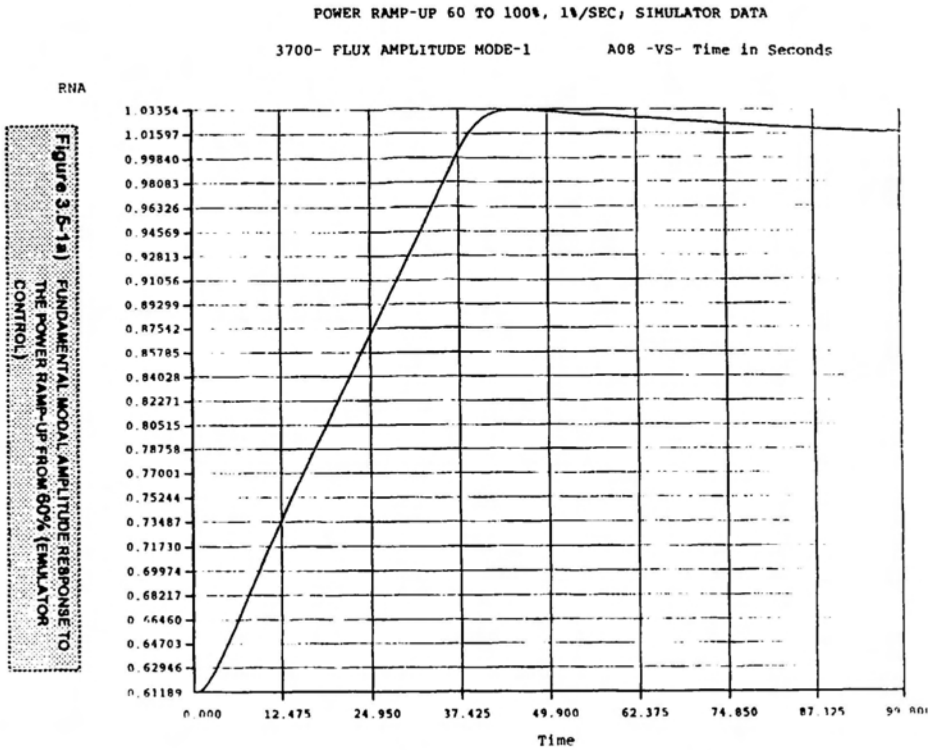


Figure 3.5-1a) FUNDAMENTAL MODAL AMPLITUDE RESPONSE TO THE POWER RAMP-UP FROM 60% (EMULATOR CONTROL)

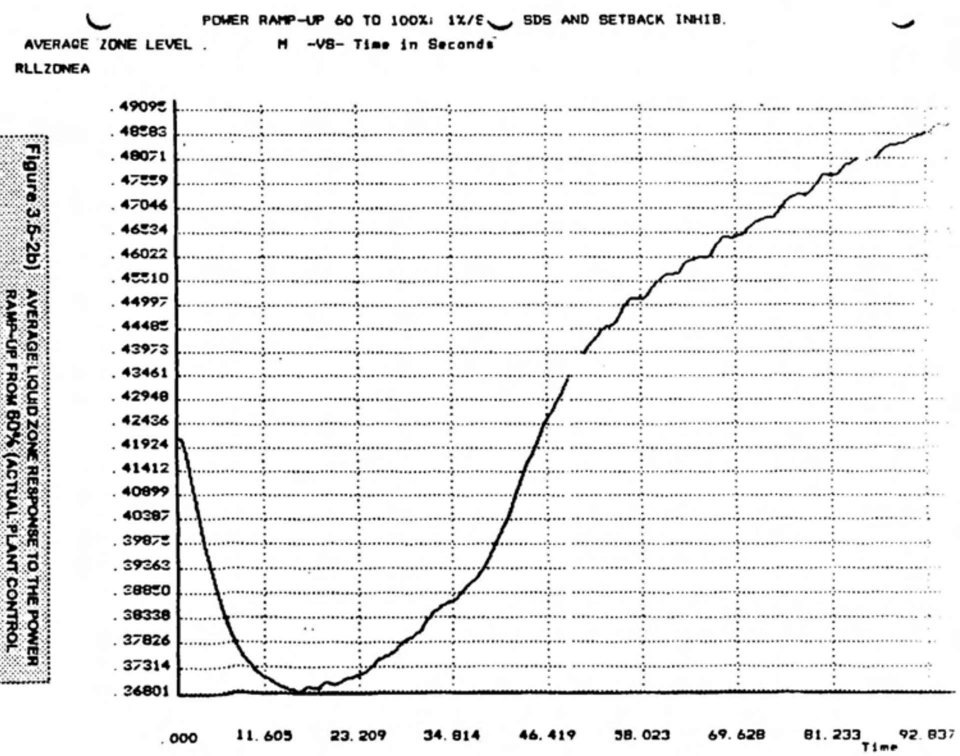


Figure 3.5-2b) AVERAGE LIQUID ZONE RESPONSE TO THE POWER RAMP-UP FROM 60% (ACTUAL PLANT CONTROL PROGRAMS

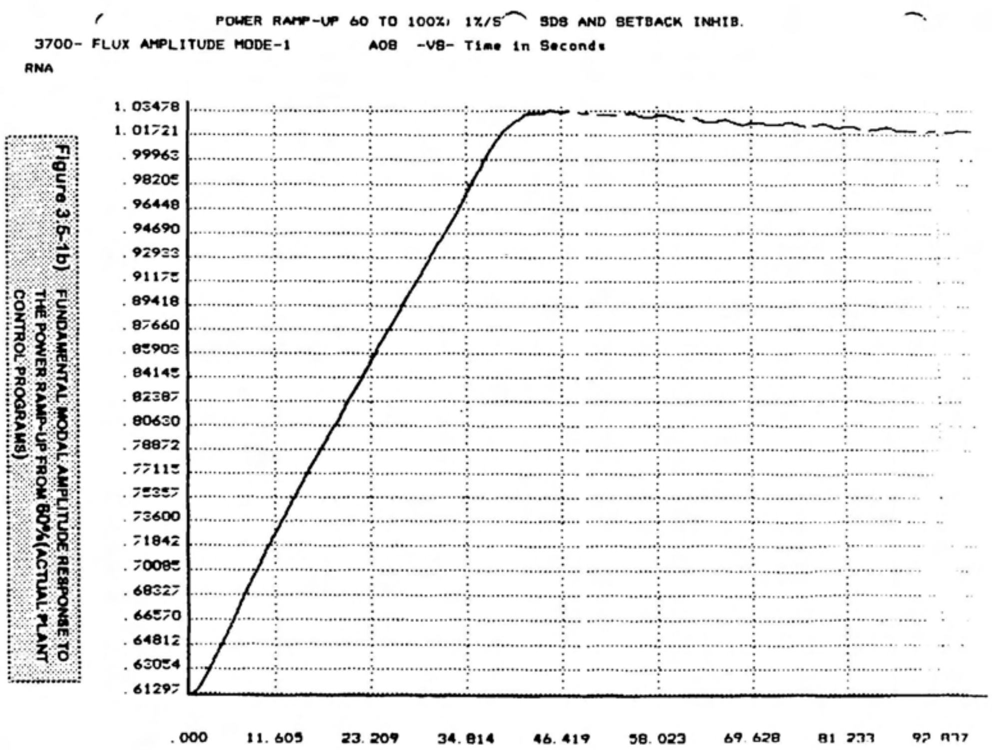


Figure 3.5-1b) FUNDAMENTAL MODAL AMPLITUDE RESPONSE TO THE POWER RAMP-UP FROM 60%(ACTUAL PLANT CONTROL PROGRAMS)

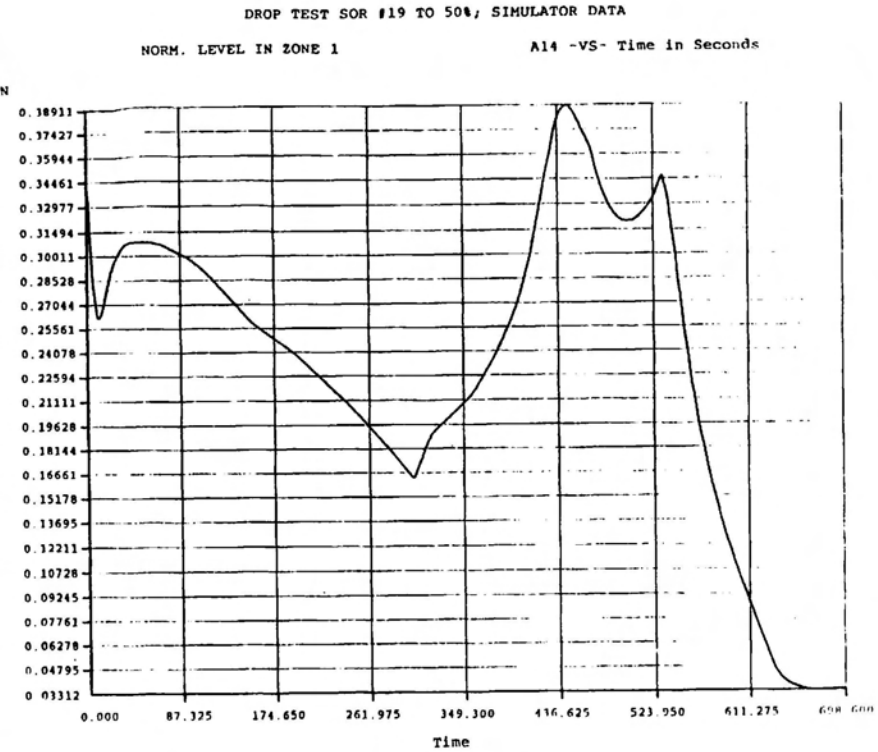


Figure 3.6-2a) LEVEL RESPONSE IN LIQUID ZONE #1 TO THE SOR DROP (EMULATOR CONTROL)

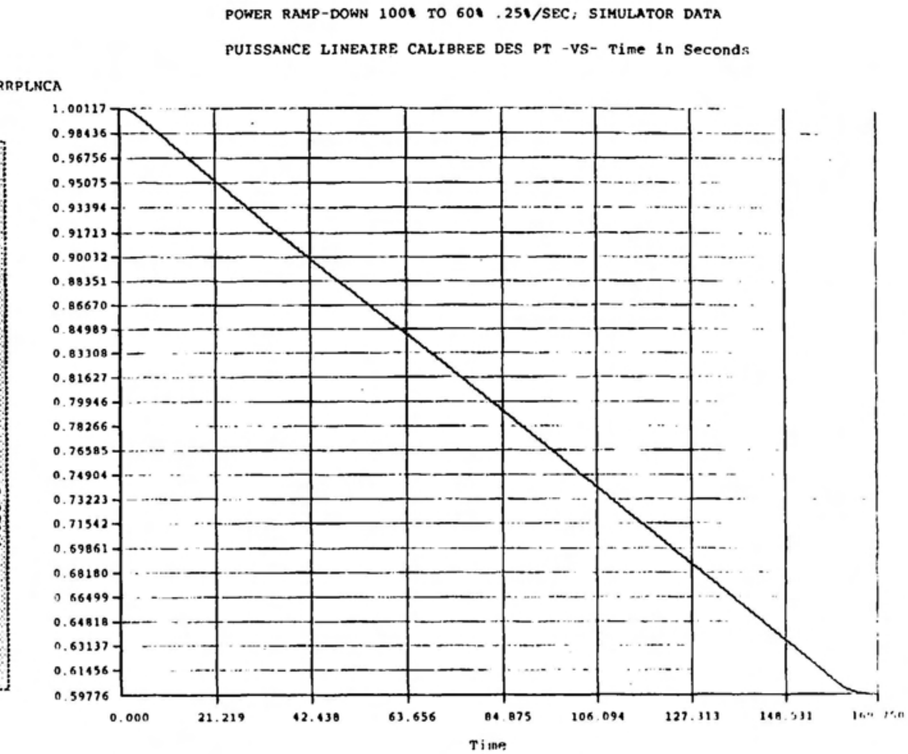


Figure 3.5-3 POWER RAMP-DOWN AT 0.25%/SECOND (EMULATOR CONTROL)

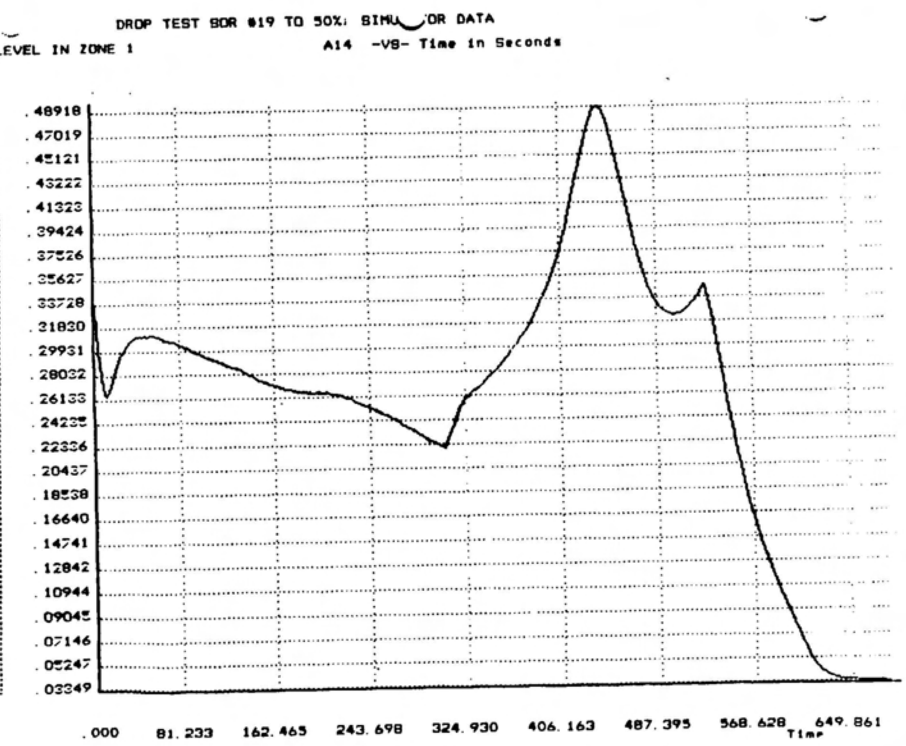


Figure 3.6-2b) LEVEL RESPONSE IN LIQUID ZONE #1 TO THE SOR DROP ON THE FULL SCOPE SIMULATOR (ACTUAL PLANT CONTROL PROGRAMS)

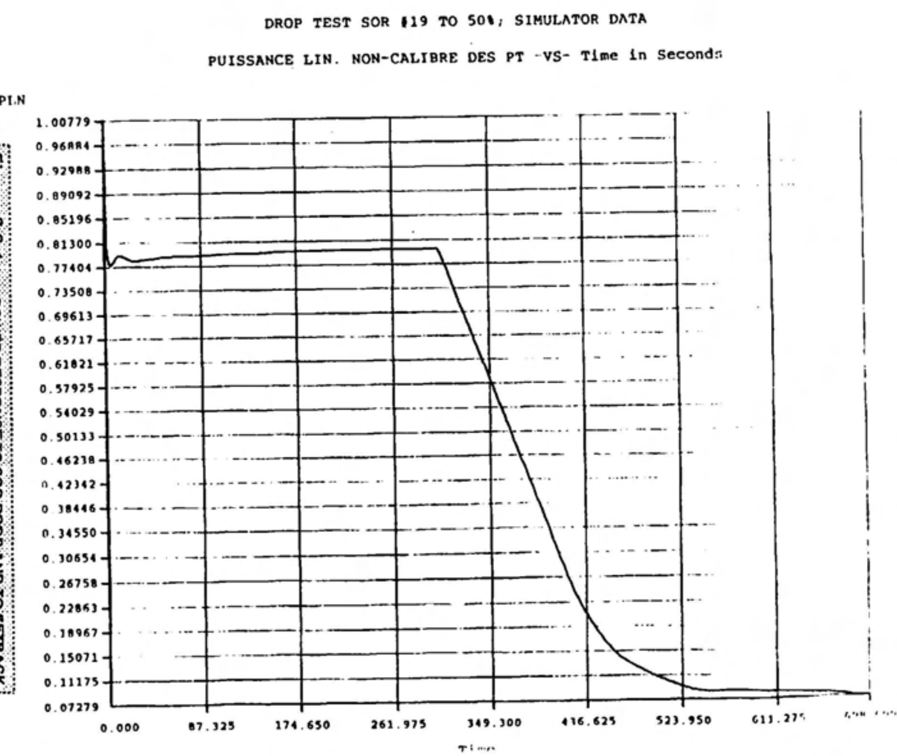


Figure 3.6-1 POWER RESPONSE TO SOR DROP AND TO SETBACK ON LOW DEARATOR STORAGE TANK LEVEL (EMULATOR CONTROL)

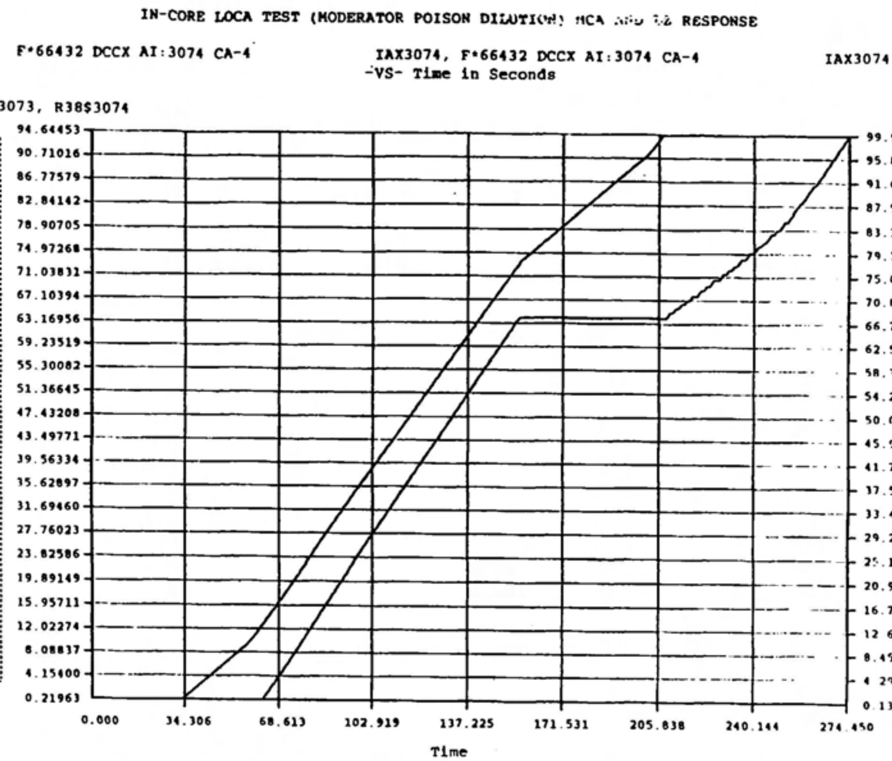


Figure 3.7-2b) EXTRACTION OF MCA #3 OF BANK 2 AND MCA #4 OF BANK 1 DURING THE BORON REACTIVITY RAMP (EMULATOR CONTROL)

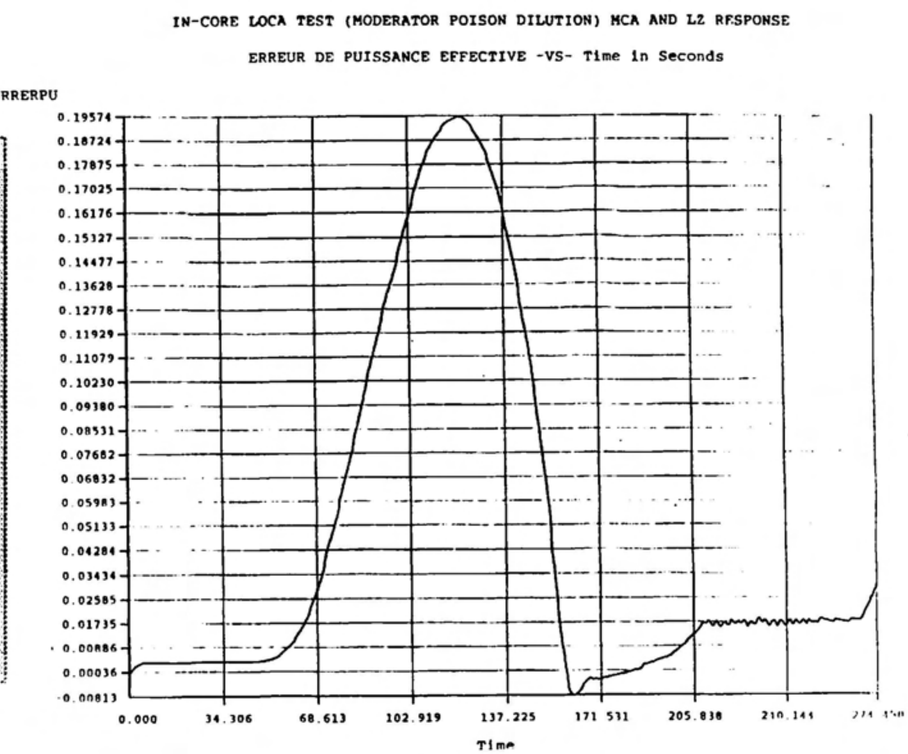


Figure 3.7-1 POWER ERROR DURING THE BORON REACTIVITY RAMP IN DECADES (EMULATOR CONTROL)

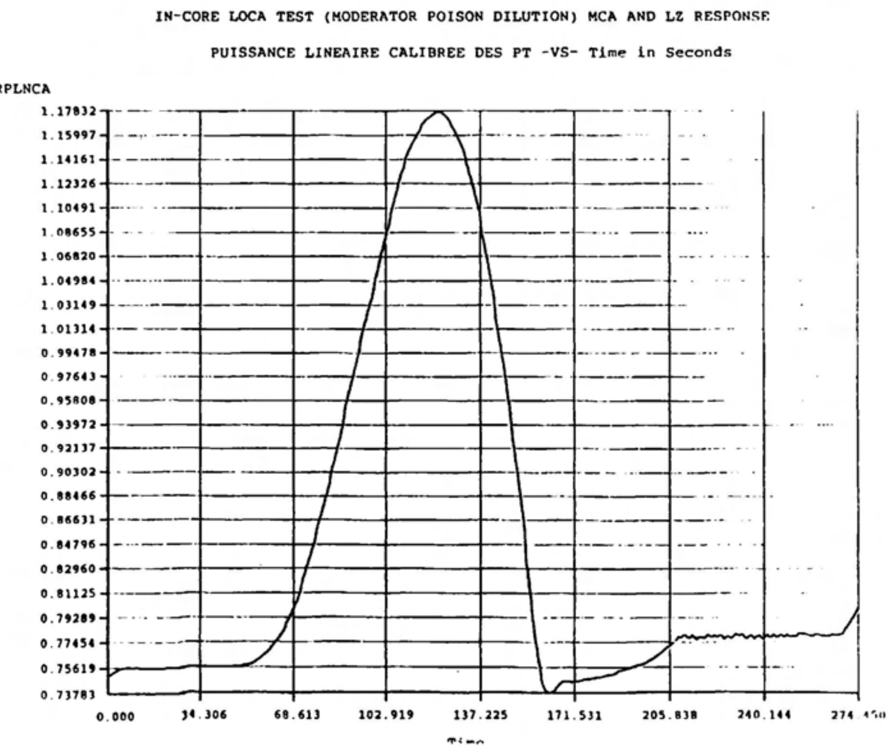


Figure 3.7-3 LINEAR CALIBRATED POWER DURING THE BORON REACTIVITY RAMP (EMULATOR CONTROL)

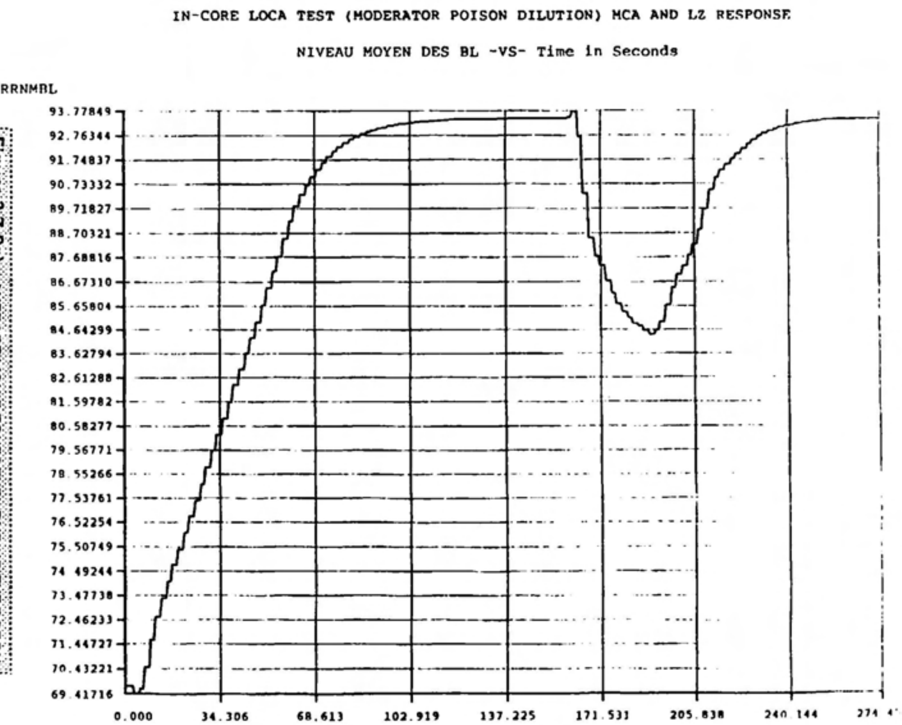


Figure 3.7-2a) AVERAGE LIQUID ZONE LEVEL DURING THE BORON REACTIVITY RAMP (EMULATOR CONTROL)

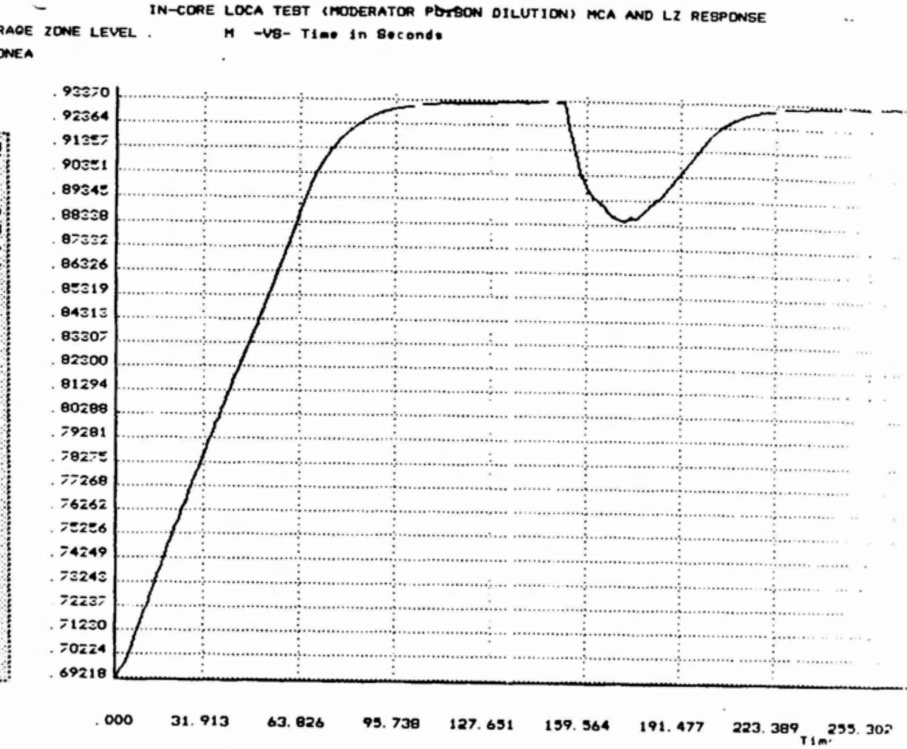


Figure 3.7-4a) AVERAGE LIQUID ZONE LEVEL DURING THE BORON REACTIVITY RAMP (ACTUAL PLANT CONTROL PROGRAMS)

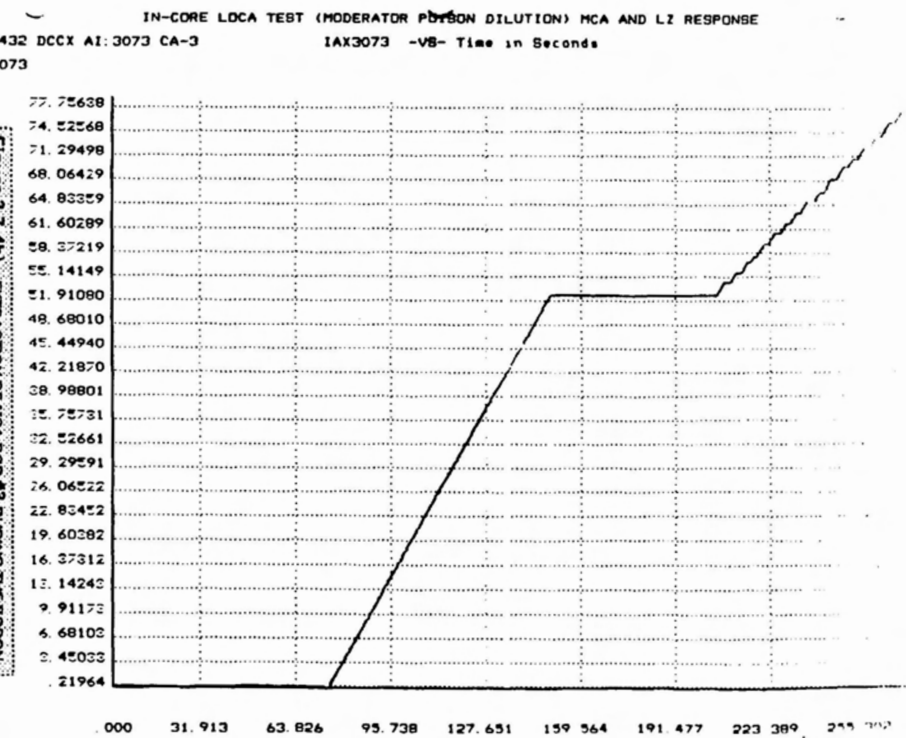


Figure 3.7-4b) EXTRACTION OF MCA ROD #3 DURING THE BORON REACTIVITY RAMP (ACTUAL PLANT CONTROL PROGRAMS)

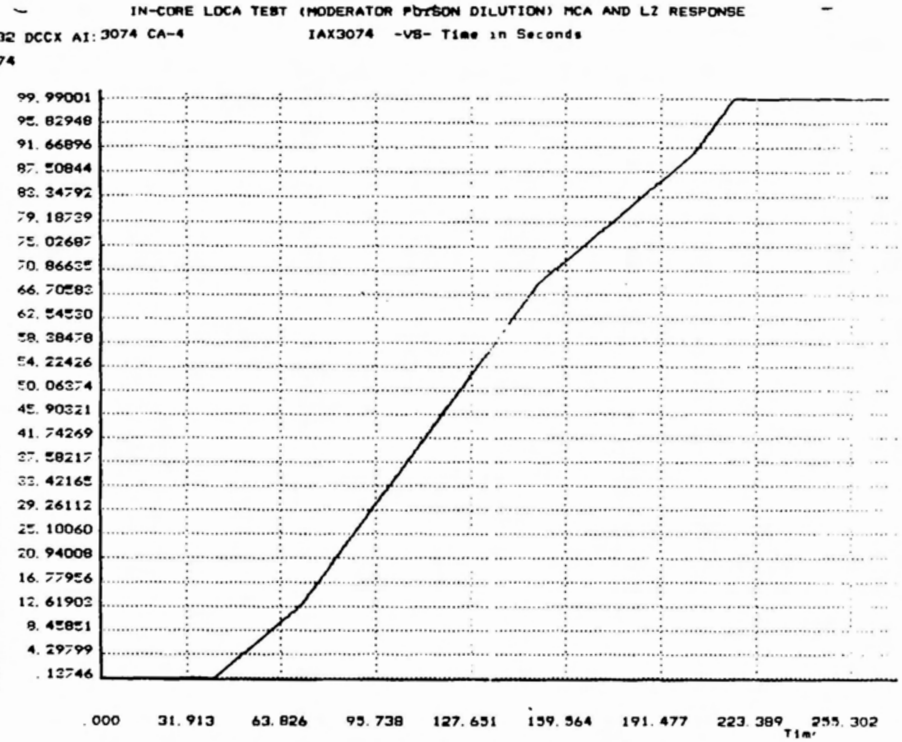


Figure 3.7-4c) EXTRACTION OF MCA ROD #4 DURING THE BORON REACTIVITY RAMP (ACTUAL PLANT CONTROL PROGRAMS))