VERIFICATION OF THE POINT LEPREAU SMOKIN CODE WITH PLANT TRANSIENT DATA

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ABSTRACT

Recently a simulation model of the Point Lepreau reactor has been developed using the modal kinetic solutions incorporated in the SMOKIN computer code. This model utilizes 15 harmonic flux modes calculated from eigenvalue solutions of the two group diffusion equation. This model includes the capability to model most reactor physics and reactor control aspects of the plant. In order to verify the correct functioning of the model, simulations of past Point Lepreau plant transients were performed with the SMOKIN computer code. Comparisons were made with plant transient data taken from the Point Lepreau PAW data base. This verification process will ensure that future transient and impairment analysis can be performed reliably, and with confidence, within the verified bounds of the models fidelity. This paper describes these comparisons, the methodology of the verification, and the results.

1.0 INTRODUCTION

The SMOKIN computer code simulates the space-time kinetics behavior of CANDU-PHW reactors (Reference 1). Reactivity device movement, xenon effects, delayed neutron effects, feedback effects, in-core and out-of-core detector response, trip instrumentation, and bulk and spatial control can be modeled. The computer code utilizes harmonic flux modes pre-calculated from eigenvalue solutions of the two group diffusion equation. The neutronic power distribution is calculated by application of modal kinetic theory to solve the space-time kinetics equations governing core behavior. This theory is based on the assumption that the distribution of neutron flux, delayed neutron pre-cursors, xenon, iodine and feedback effects, can be synthesized from the weighted sum of pre-calculated harmonic modes each modified by a time dependent weighted amplitude.

Recently a SMOKIN model for the Point Lepreau reactor has been developed using 15 harmonic flux modes. In order to verify this model, simulation of actual plant transients that have occurred in the past were performed, and the simulation results compared with the actual plant data. A set of 14 test cases have been proposed for verifying the SMOKIN code. These cases contain upset transients that have occurred at the Point Lepreau and the GII plant. A list of these cases is shown in Table 1.

This paper will present the comparisons and verification with test cases 3, 4 , 13 and 14. It should be noted that this type of verification has only become possible due to the recent development in accessing and storing plant transient data. The plant data presented here was obtained from the Point Lepreau PAW data base. In the past comparisons with plant data required a specific test with pre-arranged data retrieval. Thus only limited data was available for unplanned transients. With the PAW data base, there is always available a complete set of on-line plant data, collected at regular time periods, for use in analyzing these unplanned transients.

2.0 TEST CASE 3 - POWER REDUCTION TO 60 %FP

2.1 Description of the Transient

On May 29 of 1992, a power reduction occurred at Point Lepreau plant. Power was reduced from 96%FP to 60%FP. Following this power reduction, the Xenon buildup and subsequent decay caused the first five adjuster rod banks to be removed and then re-insert. Figure 1 shows measured data from the transient, as extracted from the PAW data base. In Figure 1 the variation of PLIN (linear reactor power) and the AVZL (average liquid zone controller level) is shown for the first 5.5 hours (20000 seconds) of the transient. Also shown as vertical lines, is the position indicator for each of the adjuster rod banks as they move. An adjuster bank position of 1 is fully in, and zero is fully out.

As can be seen, the AVZL decreased as power was reduced, but increased as the first bank of adjusters were removed when 20% AVZL was reached, as required by RRS logic. The AVZL continued to decrease in between adjuster removal as a result of the build in of Xenon negative reactivity, but increased as each of the five banks of adjuster rods were pulled. After the removal of the fifth bank of adjusters, the AVZL started to increase instead of decreasing, indicating that the Xenon build in had stopped and that Xenon was now starting to burn out (Xenon negative reactivity peaked). The AVZL continued to increase until 70% was reached where the fifth bank re-inserted. Figure 2 shows PLIN, for the same time period taken from the plant data base (PAW). As seen it remains more or less constant at 60%FP. However, DTAB 333 (steam power) appears to deviate by up to 3 %FP from the PLIN signal as adjuster rods are removed. Similar deviations in plant reactor power measurements have also been reported at the GII plant in these situations.

2.2 Simulation With SMOKIN-PLP Version 4.0

The Point Lepreau SMOKIN code (Version 4.0) was used to simulate the first 20000 seconds of the Test 3 transient. From the power data (Figure 2) the actual bulk power at the lower level was 58.5%FP as taken from DTAB 333. This was used as the simulated power reduction level. All other RRS control in SMOKIN was left on automatic as per the nominal input control data.

Preliminary simulations indicated that in order to obtain the best agreement it was necessary to follow in the simulation the DTAB 333 (steam power) measured power level as shown in Figure 2. This actual reactor power differs from PLIN (RRS control point) because of inaccuracies in PLIN caused by changes in inlet header temperature when adjusters are moved. This results in small changes in actual reactor power even though RRS is controlling to a constant PLIN.

The results of this simulation are shown in Figure 3 Five adjuster rod banks are predicted to be removed in the simulation, the same number of banks as were removed in the test. Figure 4 compares the measured AVZL trend with the simulated average zone level trend. As can be seen, the measured trend appears to be well predicted.

To examine the variation in Xenon reactivity during the test, measured Xenon reactivity was constructed by converting the change in zone level measured in the test to reactivity using the conversion factor of 0.0782 mk/%AVZL. Also the change in Xenon reactivity during the adjuster pull was added by extrapolating the zone trend just before the movement. Figure 5 shows the calculated measured Xenon reactivity. Also shown in Figure 5 is the simulated Xenon reactivity. As can be seen good agreement is obtained.

2.3 Conclusions From Test 3 Comparisons

The adjuster bank worths in the simulation agrees well with the measurements during the out drive portion of Test 3, as shown in Table 2. The agreement is within a one standard deviation of 3.3 percent. The Bank 5 In drive worth was measured to be 18.4 % greater then the simulated worth. This discrepancy appears to be related to a secondary Xenon transient apparent during the test which seems to be triggered by the power reduction just before or during the in-drive. The predicted response of the adjuster rods and liquid zone controllers agrees well with the test measurements and expected RRS response. As shown in Figure 5 the rate and magnitude of the in-growth of Xenon negative reactivity is well predicted..

3.0 TEST CASE 4 - ADJUSTER BANK 7 OSCILLATION

3.1 Description of Test Case 4

In this event, one oscillation of Adjuster Bank 7 was observed during a restart transient following a long maintenance outage. The reactor was operating at low power (0.012% FP) after just becoming critical following a long shutdown. All adjusters were out of core with poison added to the moderator to compensate for the positive Xenon decay reactivity as a result of the shutdown (i.e. the core was Xenon free). Adjuster in-drive was initiated by removing moderator poison. Figure 6 shows Adjuster bank 7 position and AVZL change measured following poison removal. As the AVZL reached the upper control limit of 70% adjuster in-drive began. Adjuster in-drive continued until the AVZL reached the lower control limit of 20%. At this point, the adjuster was not fully in, and reversed direction since the lower control limit had been reached. The adjuster bank then drove out until 70% AVZL was reached again where it then reversed direction and drove in again. Adjuster rod control was then placed on manual to terminate this transient oscillation. The reason for this oscillation appears to be due to the fact that in this particular state, low power after a long outage, the worth of the adjuster Bank 7 exceeds the full scale worth of the AVZL (70 - 20 = 50%).

3.2 Simulation of Test Case 4

SMOKIN Version 4.0 was used starting from the nominal input data set. Steady state power was initialised at .00001 FP (Xenon Free). The long lived neutron precursor fractions were increased to emulate conditions at long shutdown. The decay fractions for the delayed neutrons were adjusted to account for the additional long lived photo neutron source flux of about 1.0 x 10-7 (15 group model) arising from the 120 day shutdown from an 100% FP state. Spatial control was turned off.

It should be noted that low power initialisation option in SMOKIN was used to produce a xenon free state rather then simulating the long shutdown transient directly since this would have been too time consuming. Both techniques would result in the same core state except initialising at low power results in no net xenon reactivity gain. Therefore to start the simulation, poison addition was simulated to drive all 7 banks of adjusters out prior to the event. Then a restart file was created as a starting point of the test case scenario.

Adjuster bank 7 was driven back in core. by removing the simulated poison at a rate calculated to match the AVZL drop measured just prior to adjuster insertion in the Test Case 4 event. See Figure 6.

3.3 Comparison of Simulations With Test

Figure 7 shows the variation of adjuster position and AVZL taken from the simulation results. As shown a complete cycle of adjuster bank oscillation was predicted. This oscillation was almost identical to the oscillation observed in the test. The only difference is the period of oscillation in the simulation is slightly longer. From the test measurements the 1/2 period of oscillation was measured to be 200 seconds whereas in the simulation this time was calculated as 300 seconds. This discrepancy could be due to modelling in-accuracy of the inverted logic and adjuster speed control. This discrepancy will be further investigated.

3.4 Conclusions from Test Case 3 Simulation.

The phenomena of adjuster cycling is well captured in the SMOKIN simulation. The observed reactivity change in adjuster is well predicted as is the response of the liquid zone controllers. A discrepancy between modeled adjuster speed of drive and the speed measured has been noted. This effect should be further investigated.

4.0 TEST CASE 13 - 1-4 ADJUSTER BANKS DRIVEN OUT BY POISON ADDITION

4.1 Description of Test Case 13 Transient

As part of the '92 Restart Tests at Point Lepreau, at 50 %FP, 4 Banks of adjusters were driven out in sequence on automatic control by liquid poison addition. The banks were then driven back in by removal of the liquid poison.

4.2 Test Case 13 - Simulation With SMOKIN-PL Version 4.0

This test case was simulated with SMOKIN-PL Version 4.0. An initial steady state condition at 50%FP was assumed. Removal of the 4 Banks was accomplished in the simulation by emulating poison as a general change in the fundamental reactivity with general reactivity addition option in SMOKIN. In order to drive all adjusters out poison addition of -9.6 mk was required over a 5.9 hr period. This reactivity was then removed to re-insert all adjusters by 11.9 hrs following initiation of the test. Figure 8 shows the variation in AVZL and Adjuster Bank Position taken from the simulation.

A comparison of the measured change in AVZL with each adjuster bank movement is shown in Table 3 in comparison to the simulation results. It should be noted that the measurements for the in-drive results are estimates because of uncertainties and overshoot in Gd liquid poison addition indicated during the test.

5.0 TEST CASE 14 - SIMULATION OF POINT LEPREAU SDS1 1992 TRIP TEST

On March '92 a SDS1 trip test was done as part of the commissioning test of the new in-core ROP detector system . This trip test was simulated with the SMOKIN-PL computer code. The results of this simulation are compared to the results of the test.

5.1 Simulation Methodology

The simulation was performed with the SOR insertion characteristics shown in Figure 9. A Steady State Xenon distribution was assumed at 60%FP prior to the test. The origin of the measured characteristics were taken as the clutch de-energization signal. To account for the delay between the manual push trip button used in the test and the clutch de-energization signal a pure delay of 20 msec was assumed in this simulation.

5.2 Simulation and Test Results Comparisons

During the trip test, the ROP detector outputs on SDS1 and SDS2 were recorded along with two traveling fission chamber detectors. The ROP and fission chamber detector outputs from these core locations will be used to compare to the simulated values at these points. It should be noted that in some of the measured detector data there were time periods where data were lost. These data discontinuities show up as a straight line on the plots.

Figures 10 to 12 show comparisons between a selection of measured ROP detector output on SDS1 and the vertical fission chamber (VFTD), with that calculated in the simulation. The predicted ROP detector output includes modeling of the detector dynamics and the electronic compensation circuit. The fission chamber predicted response was taken as the neutron flux predicted at the detector site (ie. prompt response is assumed).

5.3 Discussion of Results

The two main sources of measurement uncertainty is the timing of the SOR drop characteristics and the uncertainty in the time base of the detector measurements. The uncertainty in SOR times has been calculated to be +/- 42.0 msec and ROP detectors to be +/- 32.5 msec. The predicted response of detectors relative to the measured response is affected by both these uncertainty components. Thus in comparing predictions to measurements the RMS combined error of +/- 53.1 msec should be a used to estimate the maximum expected accuracy.

As can be seen from the comparisons in Figures 10 to 12, the predicted and measured responses are close to the measurement uncertainty of +/- 53.1 msec. The differences between measured and simulated detector readings for other detectors not shown here are also within this uncertainty. Thus the prediction is in good agreement with the measurements.

In general the dynamic spatial responses of the detectors to the inserting SORs are well predicted. The results for two detectors (5D and 6F), one near the top of the core and one near the bottom, showed the offset in time of the curves to be approximately 200 msec which corresponds to the travel time of the SOR between these points in the core. This top to bottom delay in flux response due to the travel of the rods from top to bottom is seen in all the measurements and is also reflected well in the simulation. Thus the main spatial flux perturbation transient due to the inserting rods, is well predicted by SMOKIN.

5.4 Discrepancies

The general agreement between measured and predicted response is good, and is close to the expected accuracy. However, there are some small systematic effects which can be seen. These discrepancies are due to the small flux mapping errors in the modal kinetic approximation. For example of the 60 monitored in-core flux detector sites, 6 sites show a small over-response of 1 to 3 % to the inserting SORs around .4 to .6 sec from trip. The SORs at this early time in the transient are all still in the reflector region and have not entered the core. For times greater then .6 sec the shutoff rods are in core and the over response disappears rapidly and much better agreement is obtained. The predicted over responding detectors are generally near the bottom of the core directly opposite the SORs and is probably caused by a slight momentary over-coupling of the rod absorption in the reflector with the top to bottom flux mode in SMOKIN (azimuthal mode). This suggests that the modal reactivity coupling coefficients for strong absorbers in a predominately scattering media without fuel (the reflector), are not as well predicted by SMOKIN as when the absorber is in the fuel region. It should be noted that since the effect on in core flux when the rods are in the reflector is very small, this small loss of accuracy is not important to safety analysis type transients and the prediction of fuel power.

Also it is noted, that some detector responses nearer the side of the core in the low power area, are not as well predicted then most detectors which are the high powered area of the core. Better agreement would be obtained in the core periphery if the local condition correction factor was used directly in SMOKIN to predict detector response. In important safety analysis the local condition correction factor can be used in post processing SMOKIN simulation data to obtain more accurate flux and fuel power estimates during shutdown transients following overpower accidents.

The fission chamber response has been assumed to be prompt, the simulated signal was taken to be the response of the calculated flux at that site which differs from the NOP detector response since the expected dynamic delays in the NOP detectors are also modeled. However, in the measured response curves, the fission chamber and ROP detector response are almost the same in the first second (ie. the expected delay in the ROP detector is not seen). This tends to suggest the response of the fission chambers, as measured in the test, is not prompt and is delayed due to possible electronic monitoring circuit effects in the test. This may also explain why the predicted Vertical TFD response leads the measured response during most of the first 1.2 seconds.

5.5 Simulation with 33 Delayed Neutron Group Option

The number of delayed neutron groups in the model was increased from 15 groups to 33 groups in SMOKIN and the Test Case 14 was re-simulated. In general there is no apparent difference between the 15 group simulation and the 33 group simulation. Over a 30 second time period following trip there was no apparent difference in the flux rundown response.

This indicates that the 33 delayed group model was implemented properly, since in short term simulations it is not expected that the larger groups with longer time constants will affect short term results. Longer term transients should be performed to determine the improvement of more groups on long term neutron flux during shutdown.

5.6 Conclusions and Recommendations- Test Case 14

In general the simulated response of in-core detectors agree well with the measured response during the trip test and deviations are close to the measurement uncertainty of +/- 53.1 msec. In particular the flux rundown at detector sites in the central high powered area of the core are well modeled in the test.

Small discrepancies in the peripheral area of the core, which are attributed to small flux mapping errors associated with the modal kinetics approximation, have been noted but do not significantly affect the overall spatial fidelity of the simulation and the agreement of the predicted detector response with measured response.

Thus, the comparison with the SMOKIN simulation indicates that the ROP detectors installed in spring 1992 outage responds to a SDS1 trip as expected by design, and also as modeled in the SMOKIN computer code.

It is recommended that the calculation of modal reactivity coupling terms in SMOKIN when strong absorbers are in the reflector be reviewed in an effort eliminate the small over response errors noted in the prediction of some of the detectors.

6.0 REFERENCES

1 M. Gold, "Power Feedback Effects in the SMOKIN Code", 16 th Annual CNS Simulation Symposium, 1991.

7.0 ACKNOWLEDGMENTS

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TABLE 1
SMOKIN TEST CASES

Case	Site	DESCRIPTION	Date
1	G2	Power reduced from 100%FP to 44%FP and held while all 7 AA banks withdraw and re-insert.	n/a
2	G2	Power reduced from 100%FP to 50%FP to pull all 7 AA banks by Xenon buildup.	83-01-26
3	PL	Power reduced from 96%FP to 60%FP. Five AA banks with drew and reinserted.	92-05-29
4	PL	Cycling of AA Bank 7 at low power without spatial control.	93-04-24
5	PL	Cycling of AA Bank 7 at 48%fp, With AA Rod 13 stuck-in.	92-10-15
6	G2	Criticality check at 0.08%FP several days after a shutdown.	93-11-22
7	PL	Setback/setback/SDS-1 trip and recovery followed by cycling of AA Bank 7 at 56%FP.	93-11-02
		PLGS 1992 Perturbation & Trip Cases at 50%FP	
8	PL	MCA Bank 1 in 50% and AA Bank 1 out.	92-05-24
9	PL	SOR 19 in 50%.	92-05-24
10	PL	LZC 2 drained	92-05-24
11	PL	AA rod 18 out.	92-05-24
12	PL	AA Bank 1 out.	92-05-24
13	PL	AA Banks 1-4 out	92-05-25
14	PL	SDS-1 Trip Test from 50%FP.	92-05-25

TABLE 2

Comparison of Adjuster Bank Worth in Test Case 3

	Simulated AVZL	Measured AVZL	Difference
Bank 1 Out	18.1	16.6	1.5
Bank 2 Out	25.7	22.6	3.1
Bank 3 Out	27.6	23.9	3.7
Bank 4 Out	27.5	27.9	-0.4
Bank 5 Out	31.5	35.9	-4.4
Bank 5 In	26.3	44.7	-18.4
		1 sigma *	3.2642

* excludes Bank 5 In case.

TABLE 3

Comparison of Adjuster Bank Worth in Test Case 13

Adjuster Bank	Simulated AVZL Change	Measured AVZL Change	Difference (% (M-S)/M)
1 Out	22.9	17	-34.7
2 Out	30.6	29.5	-3.7
3 Out	31.4	28.7	-9.4
4 Out	36.3	33.46	-8.5
4 In	38.8	37	-4.9
3 In	32	31	-3.2
2 In	32.8	31	-5.8
1 In	18.9	23	17.8
		1 Sigma	14.2

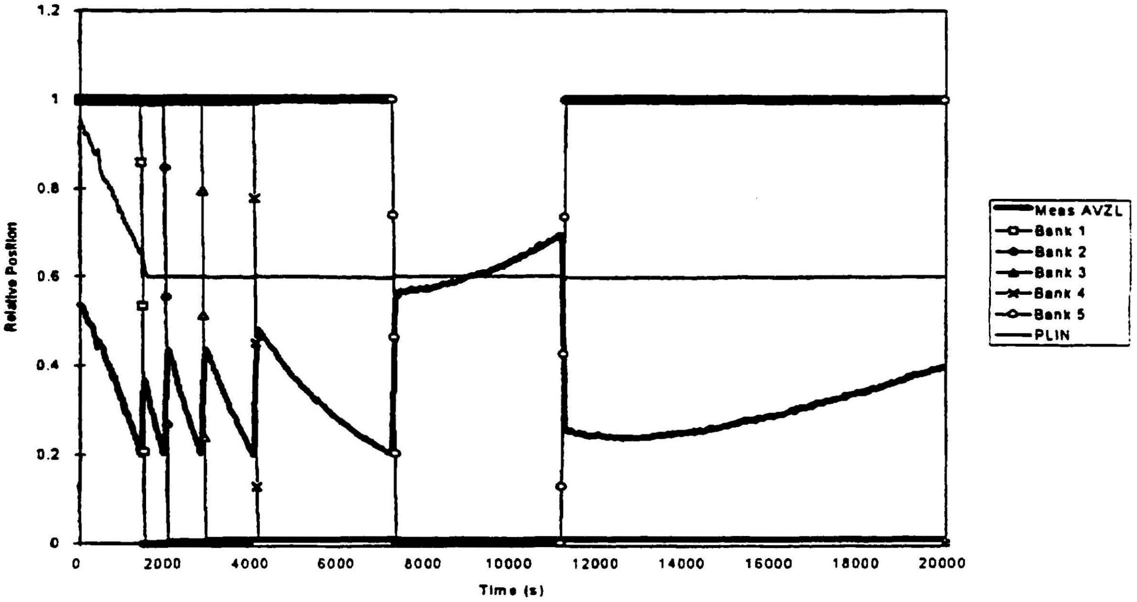


FIGURE 1

Test Case 3 Measured Data Taken From PAW Data Base

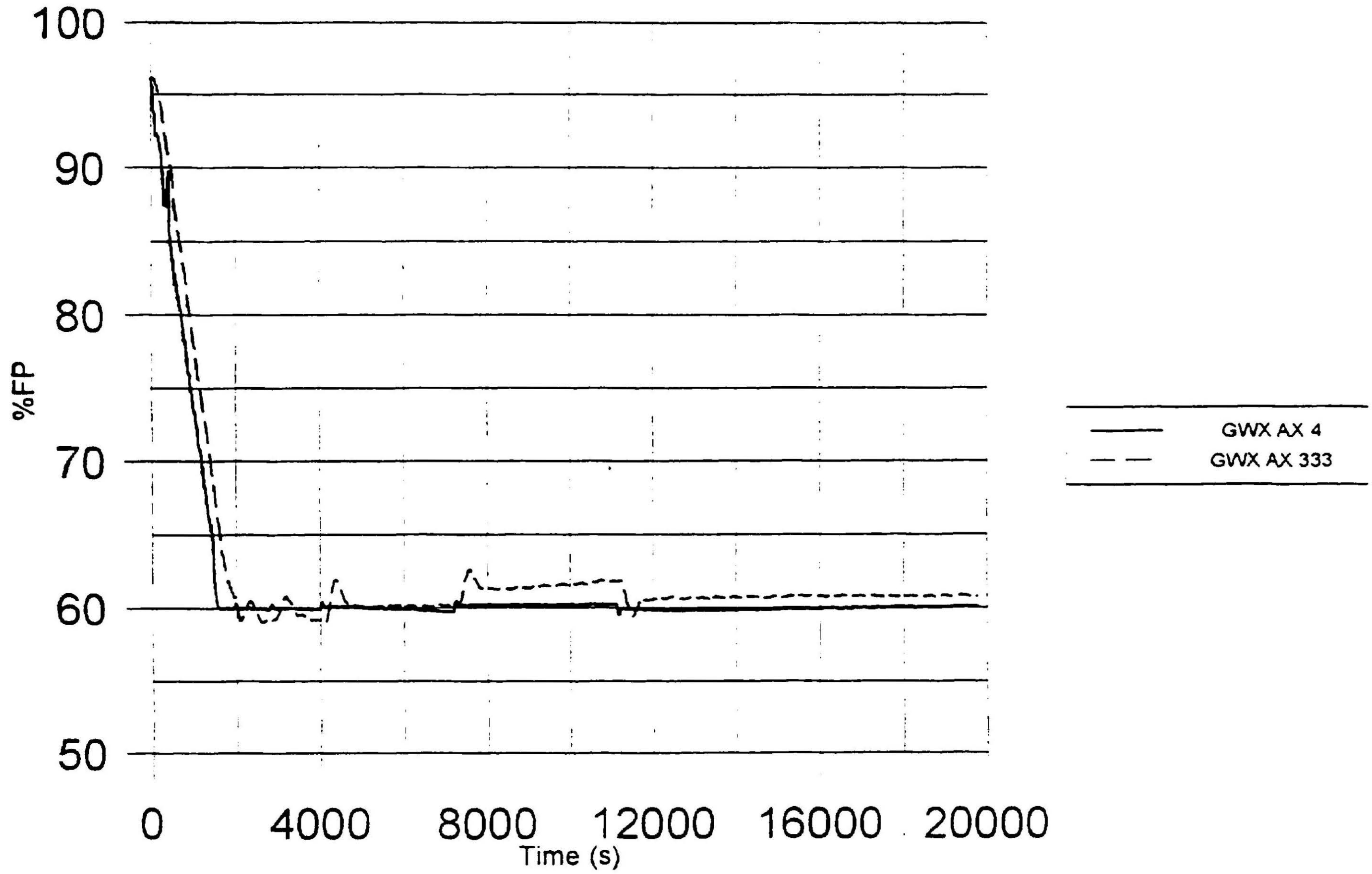


FIGURE 2

PLIN and DTAB333 Variaiton During Test Case 3

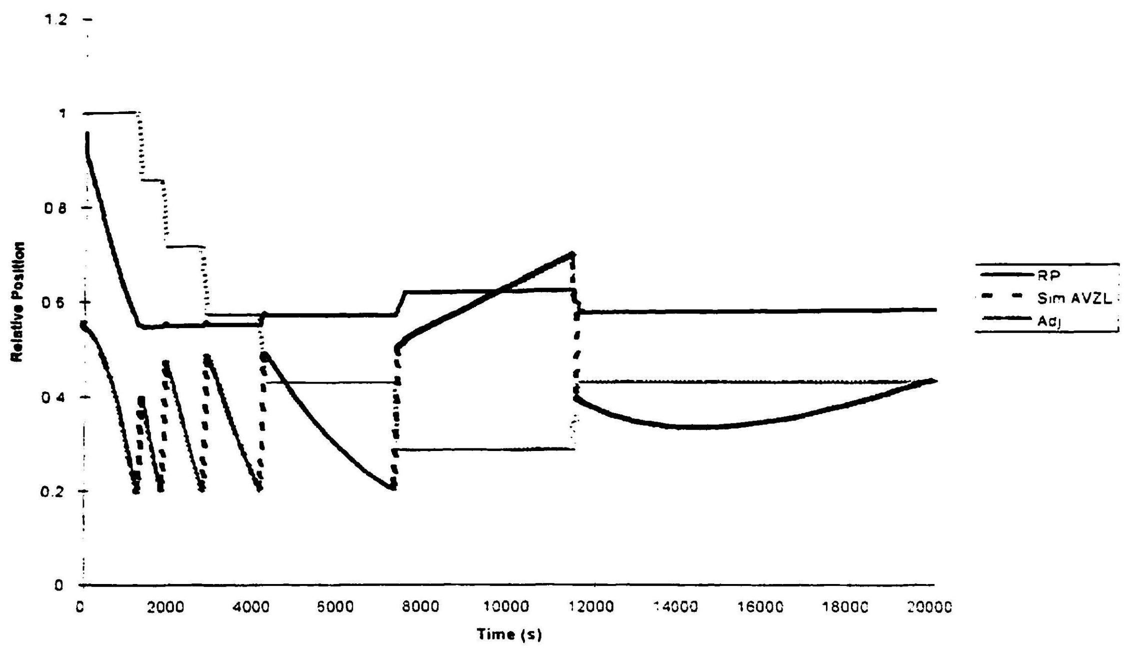


FIGURE 3

TEST CASE 3 SIMULATED DATA

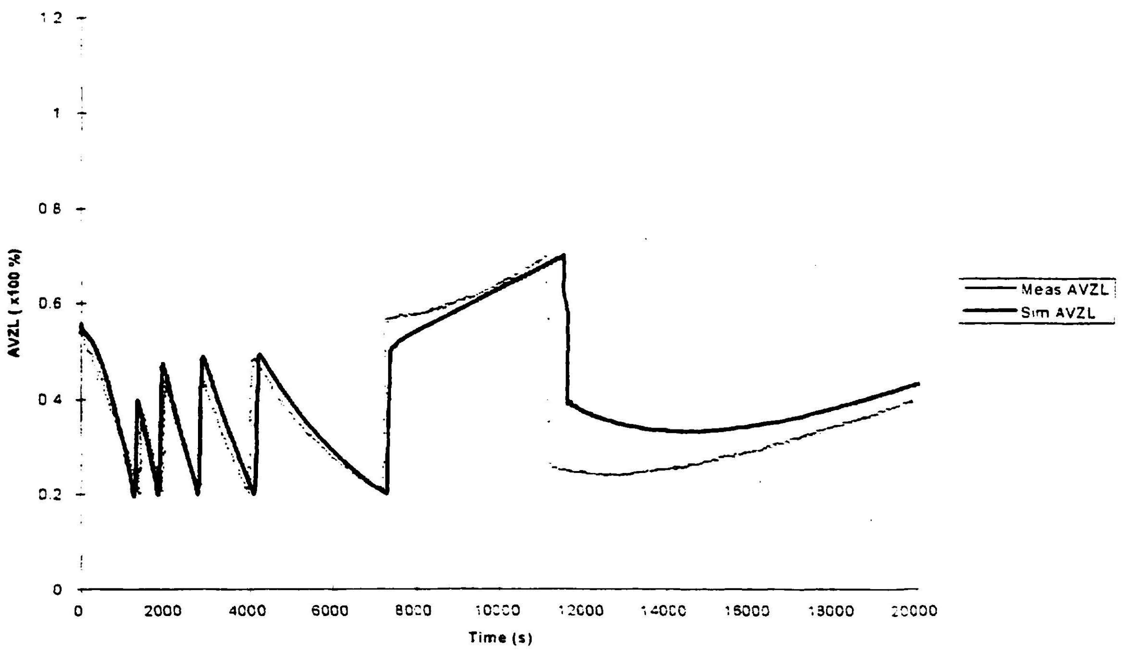


FIGURE 4

COMPARISON OF MEASURED AND SIMULATED AVZL CHANGE-TEST CASE 3

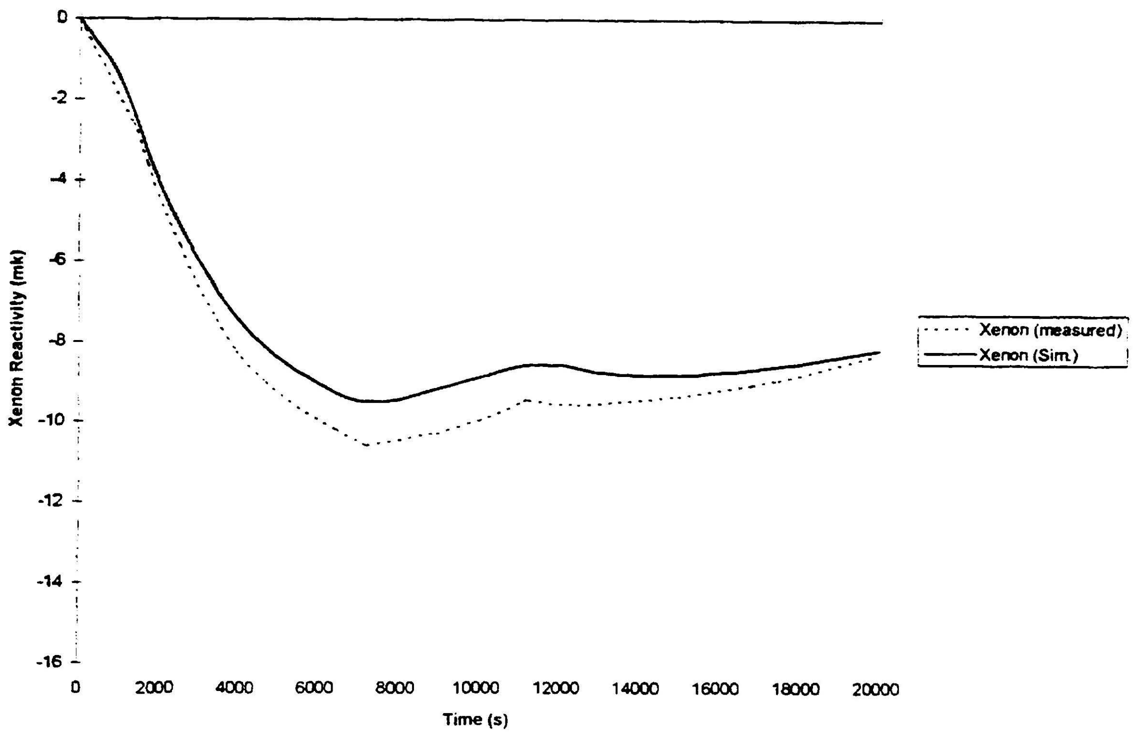


FIGURE 5

COMPARISON OF MEASURED AND SIMULATED XENON REACTIVITY- TEST CASE 3

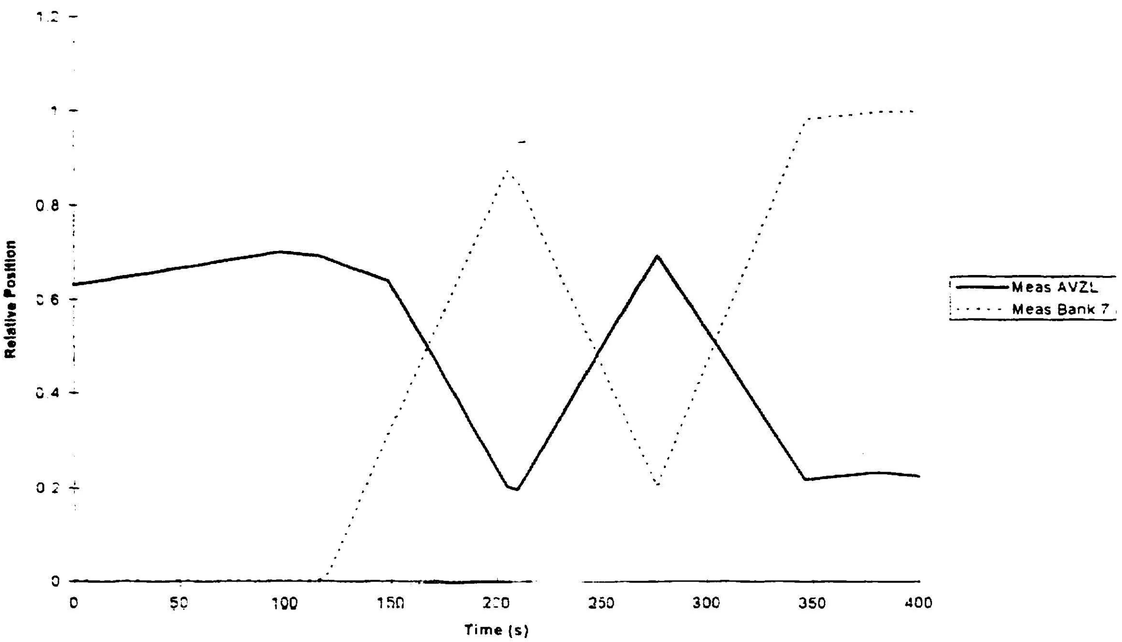


Figure 6

TEST CASE 4 - MEASURED RESULTS (PAW DATA)

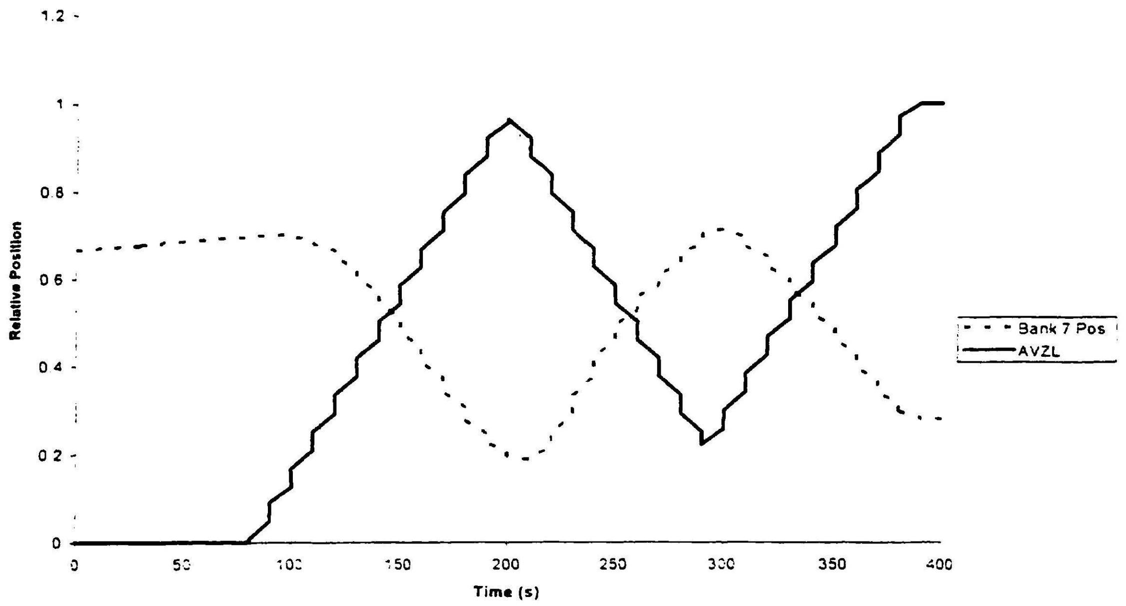


FIGURE 7

TEST CASE 4 - SIMULATED DATA

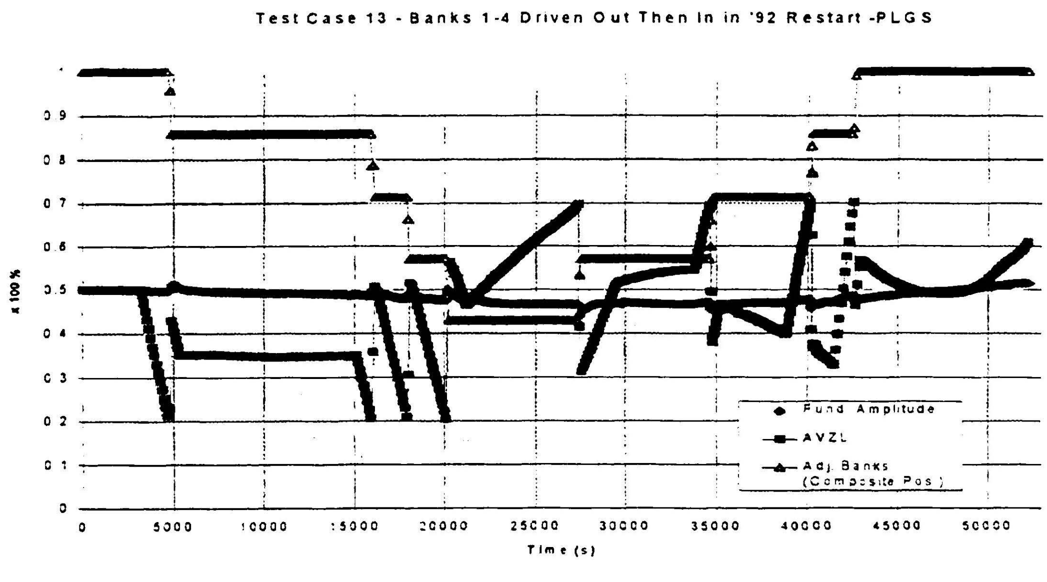
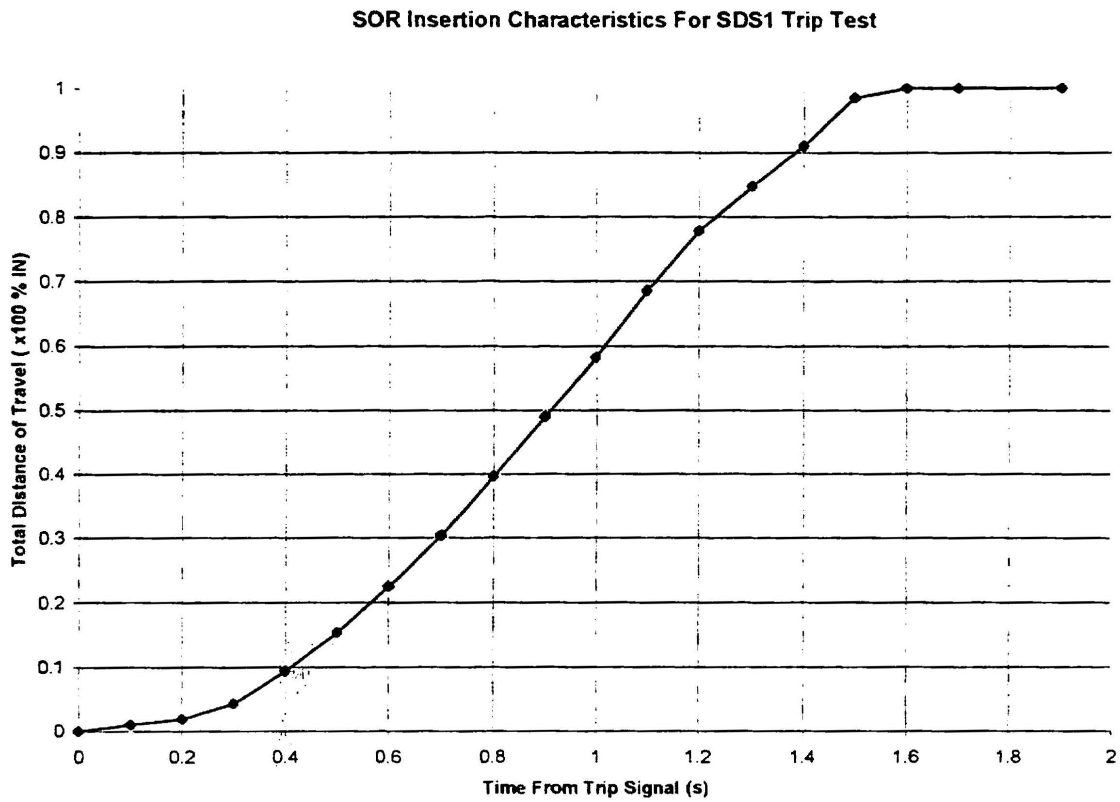


FIGURE 8



SOR Insertion Characteristics For SDS1 Trip Test
Total Distance of Travel (x100 % IN)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Time From Trip Signal (s)

FIGURE 9

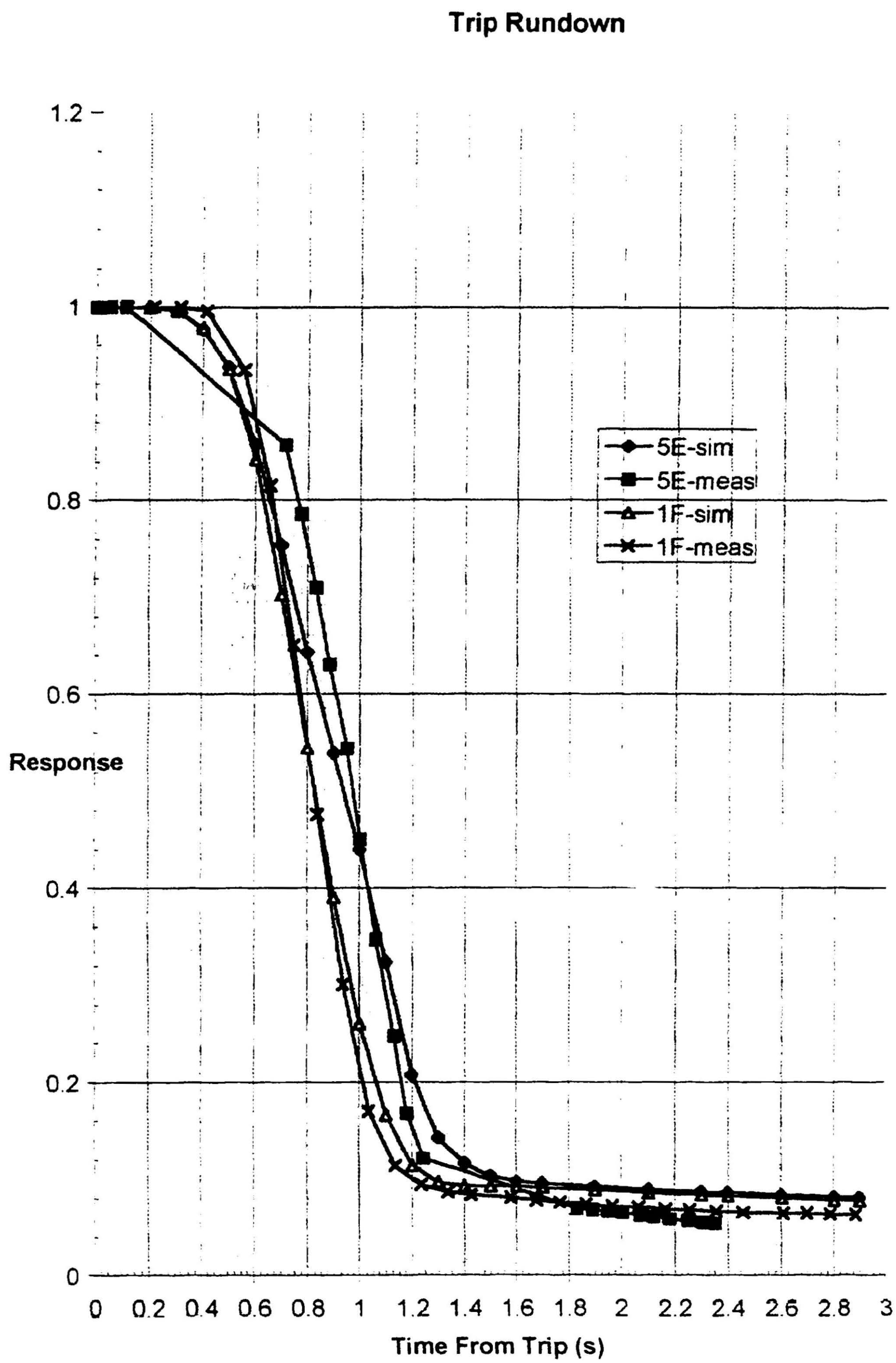

Trip Rundown
1.2
1
0.8
0.6
0.4
0.2
0
Response
5E-sim
5E-meas
1F-sim
1F-meas
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2 2.2 2.4 2.6 2.8 3
Time From Trip (s)

FIGURE 10

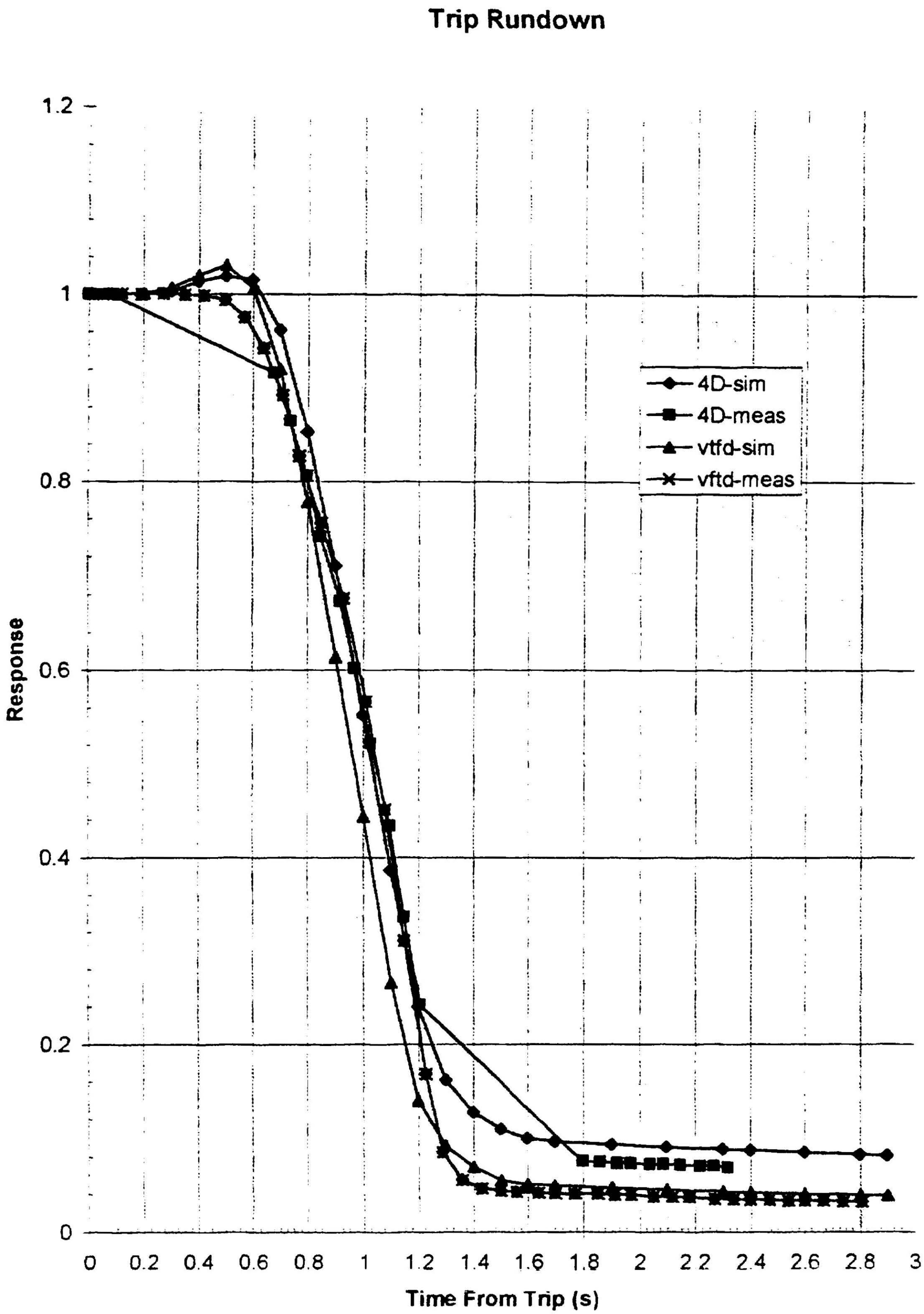
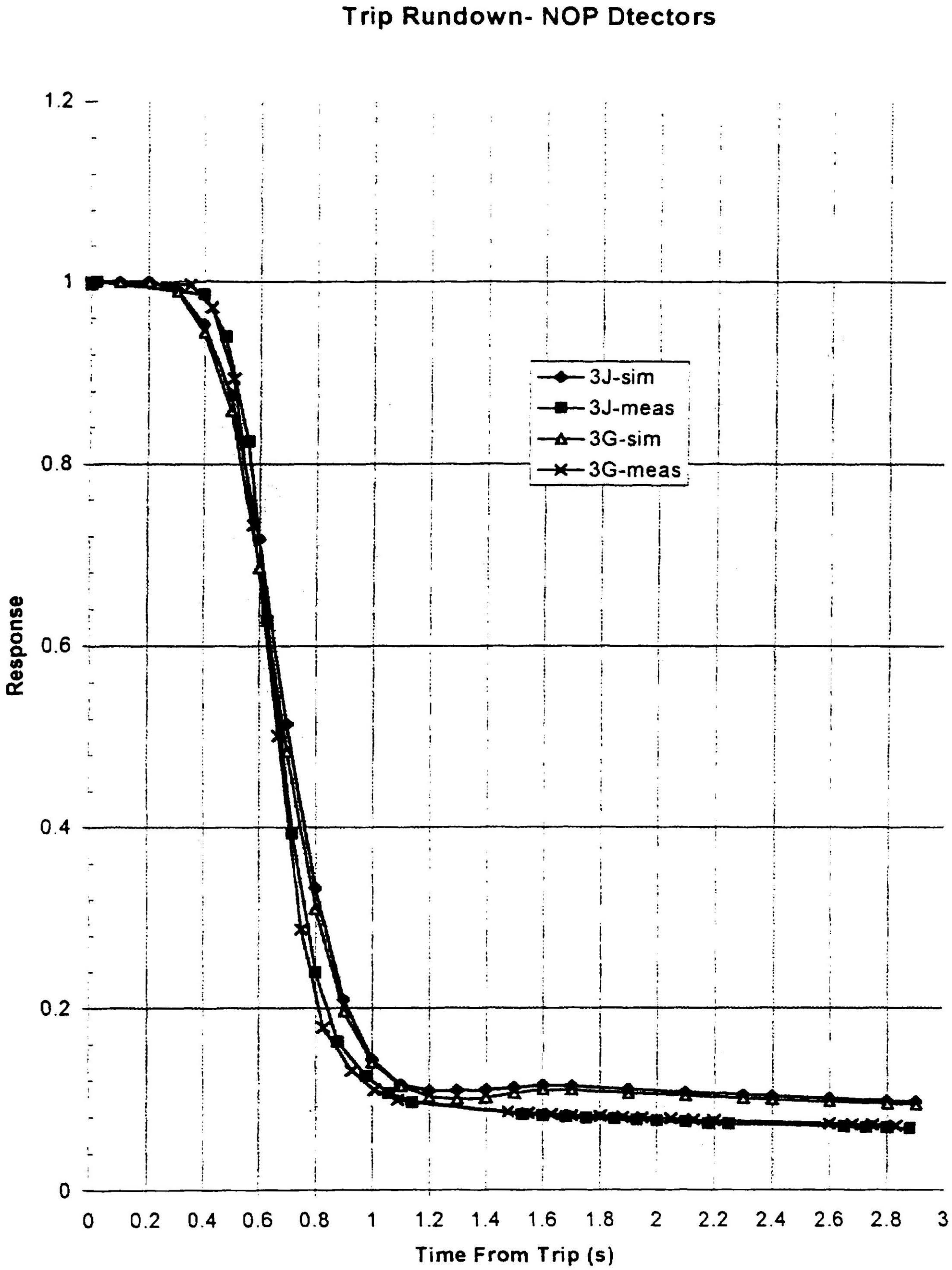

Trip Rundown
1.2
1
0.8
0.6
0.4
0.2
0
Response
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
Time From Trip (s)
4D-sim
4D-meas
vtfd-sim
vftd-meas

FIGURE 11



Trip Rundown- NOP Dtectors
Response
Time From Trip (s)
3J-sim
3J-meas
3G-sim
3G-meas
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3

FIGURE 12