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RETRAN SIMULATION OF A BWR/6

LOAD REJECTION TRANSIENT

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ABSTRACT

Gulf States Utilities (GSU) has a single unit BWR6 that began commercial operation in 1986. As part of continuously improving engineering support for River Bend Station (RBS), reactor transient simulation methods are being benchmarked for a Topical Report on GSU methods. This paper presents the results of a loss of electrical load event which occurred at the RBS plant on August 25, 1988 (Scram 88-04).

The RETRAN-02[1] computer code along with other support computer programs were used to simulate this event. Results show that the water level dropped significantly soon after initiation of the transient, but the drop was short of the level required to initiate HPCS and RCIC. The evaluations provided in this paper confirmed the judgement that both narrow and wide range level signals provided lower than expected readings during the transient, due to the presence of high frequency hydraulic oscillations in the water level process piping. Instrument damping constants for the wide range sensors, which initiate HPCS and RCIC, have been increased to reduce the amplitude of high frequency level fluctuations.

Since the load rejection transient is a significant pressurization event, it is important that calculated peak pressure matches measured peak pressure. This comparison was made and the match was excellent. Reasonable comparisons of RETRAN water level predictions were obtained, but it is clear that further improvements are needed in this area.

RETRAN results showed very good agreements with core power, system pressure and core flow data. Recirculation flow also agreed well with plant data. Simulation of plant data for this pressurization transient provides evidence that the model is suitable for operational transient performance predictions of the River Bend Station.

INTRODUCTION

River Bend Station (RBS) is a 2894 MW(t) Boiling Water Reactor (BWR/6) with a Mark III containment[2]. The reactor core contains 624 8x8 fuel assemblies. The BWR/6 has a high power density core with fast scram capabilities. The high pressure core spray (HPCS) is an emergency core cooling system (ECCS) that can provide a large quantity of water into the upper plenum at rated power, and the reactor core isolation cooling (RCIC) system can provide make-up water at rated pressure through a nozzle at the top of the steam dome. Both of these systems are automatically actuated on a Level 2 low water level indication in the reactor vessel and are of importance for the transient results provided in this paper.

DESCRIPTION OF THE EVENT

At 1232 on 8/25/88 with the reactor at 100 percent power, the main turbine automatically tripped due to a generator trip on loss of field excitation, resulting in an automatic reactor scram due to the turbine control valve (TCV) fast closure. Concurrent with the generator/turbine trip, the reactor recirculation pumps automatically transferred to the low frequency motor generator (LFMG) sets (slow speed) upon receiving an end-of-cycle reactor recirculation pump trip (EOC RPT) signal. Immediately following the scram, reactor pressure spiked to a peak between 1100 and 1117 psig causing the five low-low set safety relief valves (SRVs) to cycle open. The turbine bypass valves also opened.

Reactor water level initially decreased due to the collapse of steam voids as a result of the reactor pressure spike and scram. The lowest actual water level reached was +11 inches, +10 inches and +6 inches as indicated by the "A", "B", and "C" channel narrow range instruments, respectively. The lowest wide range water level indication was +4 inches. However, the plant computer showed evidence of a hydraulic perturbation on the wide range level instrumentation resulting in a low level spike in excess of -29 inches. The actual lowest reading must have been less than -43 inches since this is the low water level-2 setting. However, the ERIS data acquisition system sampling rate of 0.1 seconds is relatively slow compared to the high frequency signal. The lowest level sampled by ERIS was -29 inches.

The HPCS and RCIC systems received an automatic initiation signal and injected. These initiation signals resulted from the spurious reactor water level 2 signal caused by the hydraulic perturbation on the wide range reactor water level instrumentation. The controller for the "A" feedwater control valve was in the manual mode at 50 percent position. As a result of feedwater flow continuing and the HPCS injection, reactor water level rapidly increased to level 8 causing the HPCS injection valve and the RCIC steam supply valve to automatically close and the three reactor feedwater pumps to trip per design. The HPCS and RCIC systems responded as designed and injected to the reactor vessel for approximately 30 and 31 seconds, respectively.

PHYSICS AND THERMAL HYDRAULIC MODELS

Models developed for RBS are based on as-built information which represent the nuclear reactor and associated systems in detail. Design specific documents and other relevant studies(2-5) are integrated into the models.

Core Analysis Program Description

The core analysis programs used at GSU consist of two parts, i.e., core physics and lattice physics.

1. At GSU, four codes are used to perform the lattice physics calculations. These four codes are the CASPRP code, the MICBURN code, the CASMO code and the AMANDA code.

   The CASPRP code is used to provide input data for a number of other codes including the MICBURN, CASMO, SIMULATE-E and FIBWR codes.

   Detailed multi-group lattice physics calculations are performed using the MICBURN code and the CASMO code. The MICBURN code uses multi-group neutron transport theory to calculate the detailed multi-group neutronic properties of the burnable absorber, Gadolinium, for a single fuel pin containing Gadolinium. The CASMO code uses the results of the calculations performed using the MICBURN code as input data. The CASMO code calculates the two-group neutronic properties of the entire lattice using multi-group neutron transport theory.

2. The AMANDA code converts the results of the calculations performed using the CASMO code into a form that is easily utilized by the coarse-mesh three-dimensional nodal code. The AMANDA code is a very substantially improved version of the NORGE-B code. The coarse-mesh three-dimensional nodal code used for the core physics calculations at Gulf States Utilities is the SIMULATE-E code.

The FIBWR code is used to provide thermal hydraulic input data to the SIMULATE-E code. The ABLEDA code provides important Albedo boundary condition data to both the SIMULATE-E code and to the SIMTRAN code. Output from SIMULATE-E and ABLEDA, in addition to reflector cross sections, are provided to SIMTRAN so 1-D reactor kinetics input can be prepared for use in RETRAN.

River Bend RETRAN Model Used For Transient Simulation

Figure 1 shows a nodalization diagram of the River Bend RETRAN model. Both recirculation loops are modeled as a single combined loop and jet pump. The vessel region at the separator elevation is modeled with three nodes, one inside the separators, one between the dryer skirt and the separators and one between the dryer skirt and vessel. A total of twelve axial nodes are used to model the active core region. The unheated region immediately below the core and above the core plate is represented as a separate node to allow the bypass leakage to be accurately modeled.

The steam line is represented by eight nodes with an additional two nodes in the bypass header and bypass line to the condenser. Eight banks of SRV's are modeled with discharge to a containment volume. Control system models are included for the pressure, recirculation flow and reactor water level control systems. The pressure regulator controls the turbine control valve and bypass valve positions, while the recirculation flow controller modulates the flow control valve position. HPCS is modeled as a fill flow into the upper plenum (node 210). A total of 46 nodes and 65 junctions are used to represent the River Bend plant.

Prior to simulating the subject load rejection transient, the RETRAN model was updated based upon startup test and other measured plant performance data. This effort included updating the control system settings to reflect the optimization and tuneup of control systems during startup testing. The model was also updated to reflect actual jet pump, recirculation flow control valve and main turbine control valve performance.

The three element vessel water level control model tuned to startup test data was not appropriate for use in this transient analysis. Due to a misoperating control valve in one feedwater train, only two of the three trains were in auto control mode at the time the event occurred. The third valve was in manual mode, which fixed the valve position at 50% open. While some success was achieved in modeling this off normal control mode, the limited usefulness of such a model precluded extensive efforts to refine the model. All simulations reported here have the feedwater flow input to match plant data. That is, a RETRAN function table was used to specify feedwater flow as a function of time.

Since the HPCS and RCIC systems were not a part of the base model, it was necessary to add models for these systems[2]. These systems are not normally activated during operational transients such as the load rejection, so they are normally not included in base models. Since both systems were activated by spurious oscillations attributed to hydraulic phenomenon in the wide range level instrument lines, it was necessary to initiate these systems at the appropriate time in the RETRAN model. Since the instrument lines are not explicitly modeled, RETRAN does not predict the high frequency oscillations which generated the low level signal. Subsequent plant modifications have resulted in filtering of the wide range level signal to eliminate the high frequency component. The narrow range signal has a filter with a 1.0 second time constant. As shown later, RETRAN results for wide range level are in good agreement with the filtered wide range level signal, obtained by passing the plant data through a numerical filter.

It is noted that the subcooled HPCS flow was injected directly into the two-phase upper plenum in the RETRAN model, while the RCIC flow was injected into the downcomer. In the plant,RCIC injection is into the steam dome. Direction of HPCS flow to the two-phase upper plenum resulted in a tendency to calculate water packing in the core bypass. Water packing is an artificial pressure spike which is calculated when a node fills with liquid. One RETRAN model modification which can decrease the tendency to calculate water packing is to decrease the number of nodes in the core bypass from four to two. Decreasing the maximum allowable time step size also reduced water packing,

SR/V opening and closing pressures were adjusted based on data from the actual transient. Measured vessel pressures varied among themselves by about 17 psi. Since the actual pressure is not known precisely, the opening and closing setpoints in the RETRAN model were adjusted so that they opened on the same pressure increase indicated by the data. Other best estimate features used for these simulations included actual measured data for steam line pressure drop and scram speed as opposed to design data and/or technical specification input.

ANALYSIS AND RESULTS OF THE TRANSIENT

The load rejection transient was simulated for a period of 45 seconds. This period includes the SRV cycling, pressure peak, HPCS initiation and termination, RCIC initiation, and feedwater flow termination. The minimum critical power ratio (MCPR) will occur very early in the transient. The purpose of these calculations was to benchmark RETRAN system response predictions to plant data, so no thermal limits calculations, i.e., critical power ratio (CPR), were performed.

The plant data was obtained by the ERIS monitoring and data collection system which operates continuously at the River Bend plant. Data was obtained at a 0.1 second sampling rate for a period of about 30 seconds prior to the scram and extending for several minutes after the scram. Table 1 provides the sequence of events for the generator load rejection event as measured during Scram 88-04. Some information on the accuracy of measured data can be obtained by comparing alternative measurements of the same quantity. For example, six measurements of dome pressure differ by up to 17 psia (1.7 percent). Core flow is measured in three different ways from core plate differential pressure and jet pump differential pressure measurements. At rated flow the measurements differ by a maximum of 2.4 percent. Level measurements appear to be the least accurate especially in transient situations. This is due to the instrument line dynamic effects and possibly also to the presence of non-condensible gases in the lines and condensing pots. Some measure of the accuracy can be obtained by comparing wide range and narrow range levels, although the instruments are affected differently by changes in downcomer velocity, i.e., dynamic head effects at the lower tap.

Figure 2 shows a comparison of core flow versus time. During the first two seconds of the event, the water level, as measured in the downcomer, drops off as a result of the void collapse caused by the pressurization. Simultaneously, the core flow increases as a result of the decrease in the two-phase flow resistance. After the first half second, the core flow begins to decrease, since the recirculation pumps have been tripped. Excellent agreement between RETRAN and the ERIS data is evident. RETRAN results drop below the ERIS data late in the transient when RETRAN predicts a temporary backflow of water from the separators to the upper plenum and core. This prediction appears to result from a calculated flooding of the separators and a buildup of water in the separator/dryer region.

Figure 3 shows dome pressure response. Since the six ERIS channels, all measuring vessel pressure, differed by about 17 psia prior to scram, the smallest and largest of these pressure measurements are plotted. The RETRAN predicted peak pressure falls between the peaks of the measured pressure. Predicted pressure falls faster than measured pressure following the pressure peaks. However, the RETRAN predicted pressure recovers to match the data following SR/V closure at around 11 seconds. This indicates that the predicted SR/V flow is slightly higher than the actual flow. It is noted that the 10% conservatism required by the ASME code is not used in this best estimate SR/V model. Predicted pressure also decreases for a longer period of time following SR/V closure. This is due to a longer delay in bypass valve modulation predicted by RETRAN. As shown, however, the RETRAN pressure begins to recover as the bypass valves begin to close toward the end of the transient. Operator action may explain the early closing of bypass valves.

HPCS flow is shown in Figure 4. Agreement between data and predictions is good, including the RETRAN prediction of the HPCS isolation.

As shown in Figure 5, the narrow range level reaches the L-8 high level trip setpoint of 51 inches just prior to 45 seconds. The minimum water level predicted by RETRAN is in reasonable agreement with the data. However, in general, the RETRAN values lie below the data. This is believed to be due to the calculation of a significant increase in separator liquid mass by RETRAN to the point of filling the separators with liquid. If this liquid mass were not predicted to accumulate in the separators, it would be available to increase the level outside of the separators. While some liquid inventory increase is expected, complete flooding is unlikely. The need for further improvements in separator modeling is indicated, although the overall response is predicted well; especially the rate of level recovery. The slowdown in predicted level increase late in the transient is due to a predicted fallback of water from the separator to the upper plenum. This appears to be a consequence of the predicted separator flooding.

Figure 6 shows predicted and measured wide range level response. Note the significant amount of high frequency oscillations in the data. As previously discussed, these oscillations are attributed to hydraulic surge phenomenon in the water level instrument lines. The narrow range response has a 1.0 second filter, while the wide range instrument had essentially no filter. The wide range lower instrument tap is located in a more confined region of the downcomer where the fluid velocity past the tap is larger. Therefore, a dynamic head effect reduces the pressure at this location. There is much less of a pressure reduction at the narrow range lower tap which is located higher up in the downcomer where the flow velocity is significantly lower.

Figure 7 shows filtered wide range level response. The measured wide range level data shown in Figure 6 were numerically filtered using a first order lag of 0.8 seconds, the time constant for the filter which has subsequently been installed in the plant. The measured data is much smoother and does not reach the low level L-2 value of -43 inches. This shows that the new filter is adequate to prevent a spurious L-2 trip should a similar transient occur in the future. Note that the RETRAN prediction and the data reach the 60 inches top of level span at approximately the same time.

Figure 8 shows feedwater flow versus time. In this case, the flow was input to the RETRAN model from test data. Steam flow test data was not shown since the data taken was not considered valid.

CONCLUSIONS

The results of this simulation provided the following information.

1. The RETRAN model provides a good simulation of the steam dome pressure in a pressurization event (i.e., turbine control valve fast closure). The calculated steam dome pressure peak is between the highest measured steam dome peak pressure and the lowest steam dome peak pressure. This provides excellent agreement with a very important aspect of the load reject/turbine transient, i.e., peak steam dome pressure.

2. The RETRAN model provides a confirmation that the filter provided in the water level sensing instrumentation will resolve the problem of inadvertent actuation of the emergency core cooling system (ECCS). During Scram 88-04, high frequency hydraulic ringing due to the pressurization transient caused the high pressure core spray (HPCS) system to actuate without a true low water at level 2.

3. The RETRAN model provided an excellent simulation of the core inlet flow. The comparisons between measured data and the calculated parameters show that system pressure and core flow simulations were in excellent agreement with test data. Although water level agreement was reasonable, more work on the water level model is needed.

The results of these comparisons show that GSU methods and computer programs accurately model RBS reactor system response. Further work is required to fully qualify GSU methods, but the ultimate goal is to provide GSU engineers with tools to improve RBS plant performance. It is expected that validated methods will save GSU significant sums of money with benefits coming in Technical Specification Changes, Fuel Management Support, Reload Analyses, Plant Operation Support, Nuclear Licensing Support, Training Support and Engineering Support.

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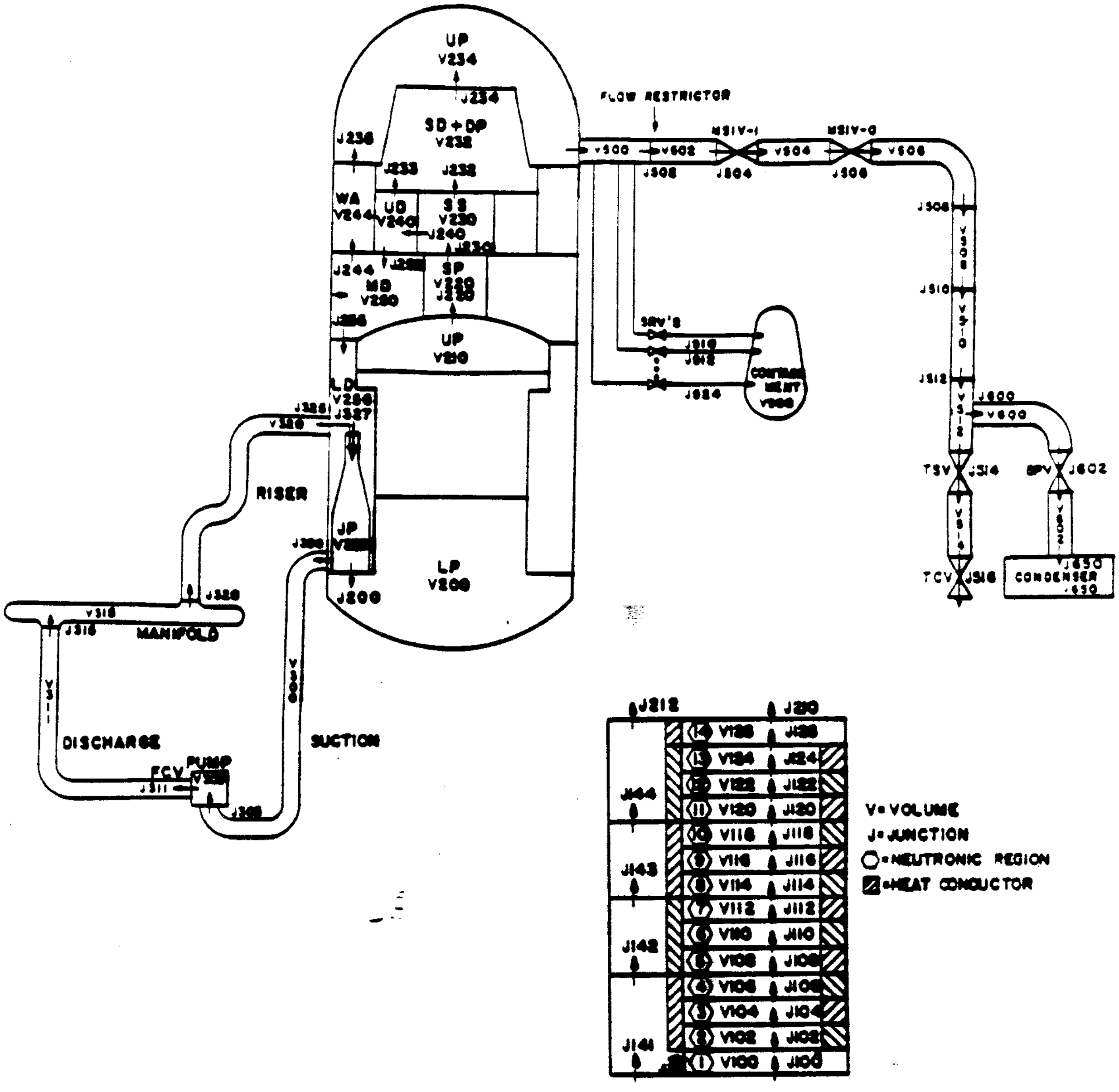

Figure 1. RETRAN Nodalization

Table 1

SEQUENCE OF EVENTS FOR LOAD REJECTION
SCRAM 88-04

Time (sec	Event
-0.015 (est)	Turbine-generator detection of loss of electrical load.
0	Turbine-generator power load unbalance (PLU) devices trip to initiate turbine control valve fast closure.
0	Turbine-generator PLU initiates rapid turbine bypass opening.
0	Relief valves begin to close.
0	Turbine bypass valves start to open.
0.10	Fast control valve closure initiates scram and recirculation pumps transfer to the low frequency M/G sets.
0.10 (est)	Turbine control valve closed.
0.20	Water Level 2 reached, RCIC and HPCS initiated. Low frequency M/G sets are tripped off.
0.5	Control Rods Fully Effective
1.7	Peak Pressure occurs
2.2	Relief valves begin to open.
3.2	RPV Level (NR) indicates low point at 10-11 inches
13.2	HPCS injection valve opens - flow increase to 3230 gpm
13.4	Relief valves begin to close.
31.2	High Level 8 stops HPCS injection.

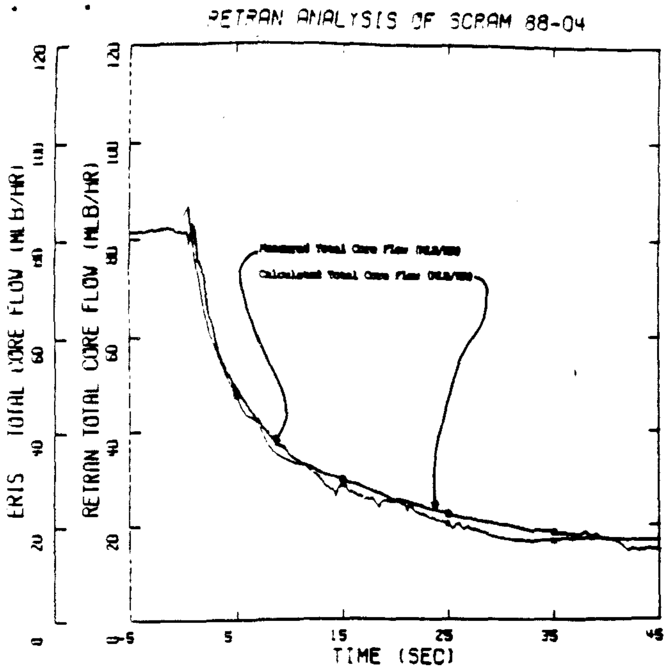

Figure 2. Calculated Total Core Flow Versus Measured Total Core Flow

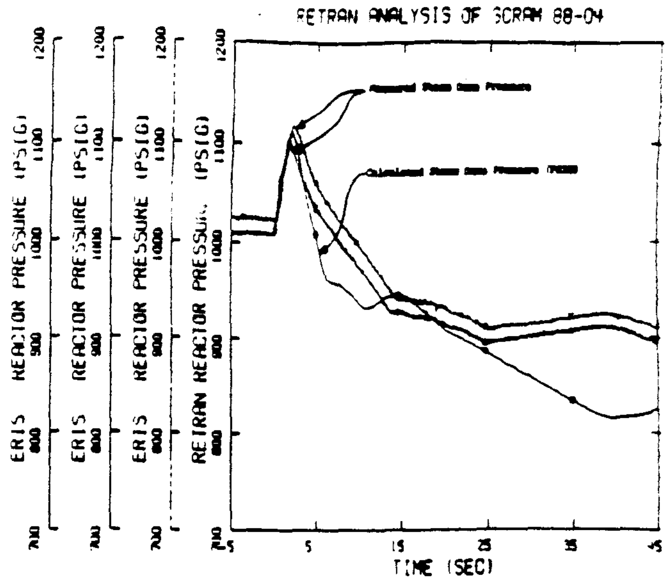

Figure 3. Measured Dome Pressures Versus Calculated Steam Dome Pressures

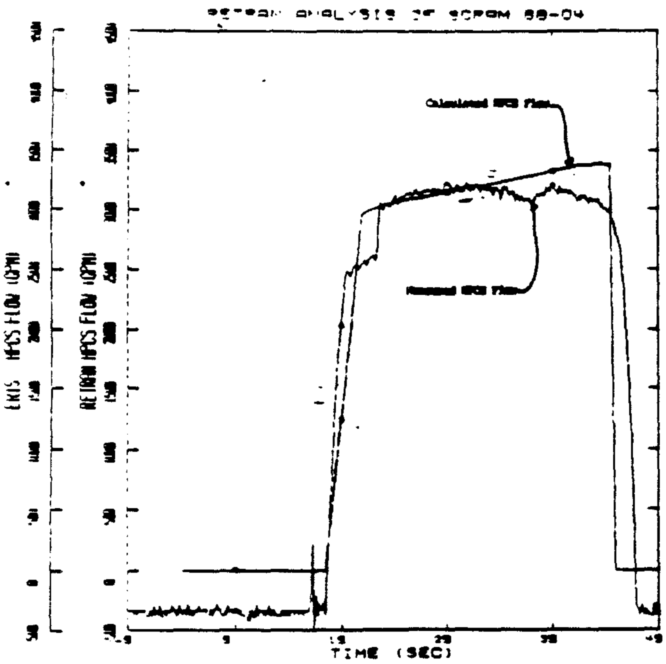

Figure 4. Measured HPCS Flow Versus Calculated HPCS Flow

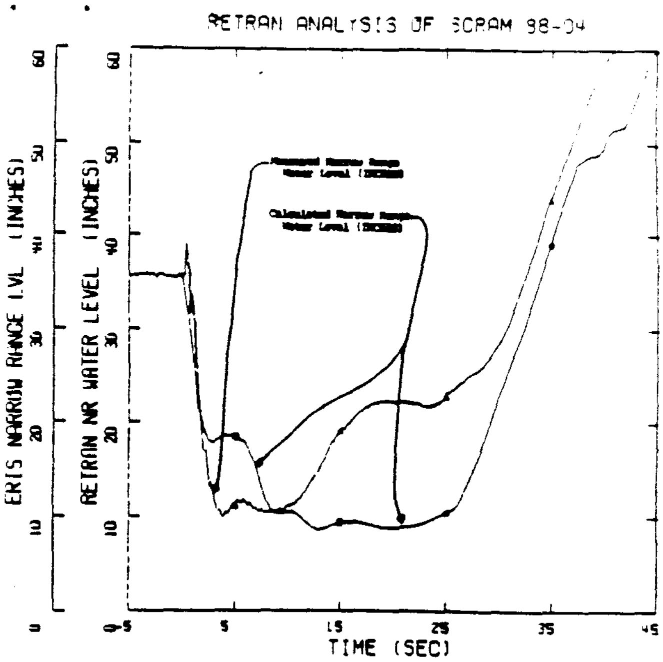

Figure 5. Measured Narrow Range Water Level Versus Calculated Narrow Range Water Level

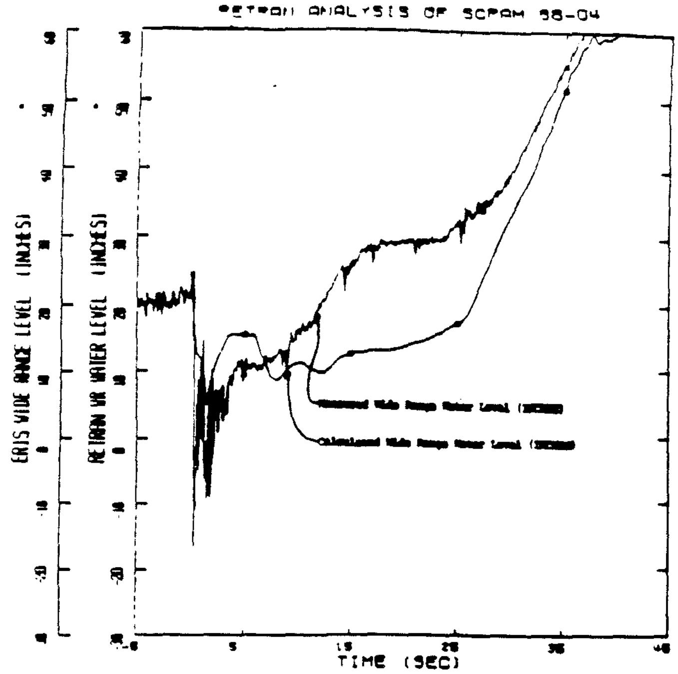

Figure 6. Measured Wide Range Water Level (without filter) Versus Calculated Wide Range Water Level

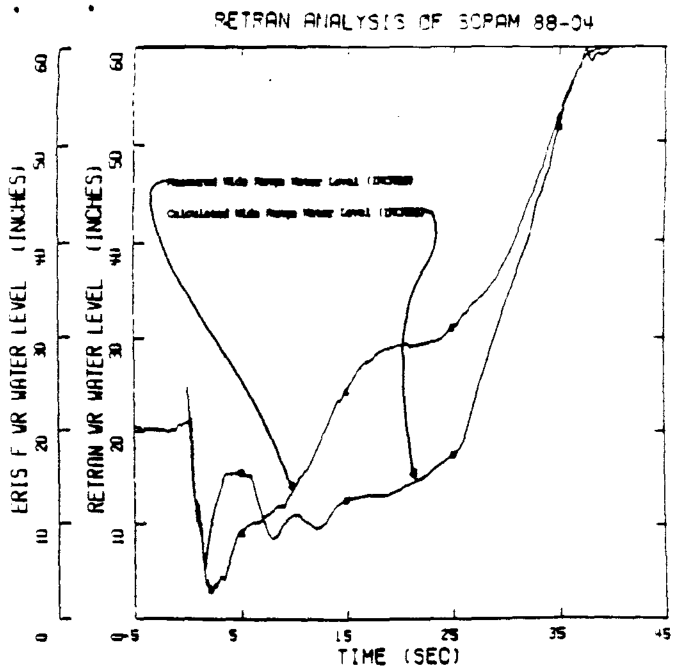

Figure 7. Measured Wide Range Water Level (with filter) Versus Calculated Wide Range Water Level

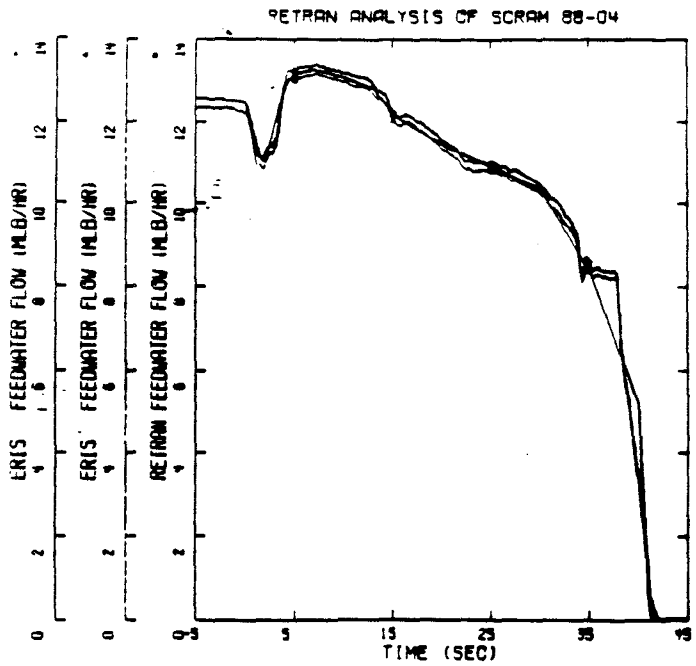

Figure 8. Measured Feedwater Flow Versus Calculated Feedwater Flow