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POSITION PAPER ON

SCRAM DISCHARGE VOLUME (SDV) INDEPENDENCE FROM VENTING

FOR SAFETY FUNCTION

BACKGROUND

The most significant feature that contributed to the Browns Ferry Unit 3 (BF3) partial scram failure which is common to most BWRs, is the inadequate hydraulic coupling between the SDV headers and the instrumented volume (IV). This finding is shared by the NSSS supplier (GE), the BWR owners and NRR, IE and AEOD staff.

To improve the overall design of the SDV system and particularly the hydraulic coupling of the SDV headers and the IV, an NRR task force with IE participation has been working with a subgroup of the BWR owners to develop revised SDV system design and safety criteria. This effort has identified two major differences in opinion between the task force and owners subgroup. This paper is to document our position and reasoning for one of these differences.

POSITION

Our position on the design criteria for SDV to IV hydraulic coupling is that the SDV system design shall function independent of its vent system given up to a maximum possible inleakage into the SDV headers. (System function is defined as: The SDV shall have sufficient capacity to receive and contain water exhausted by a full reactor scram without adversely affecting scram performance.) Our position varies from the owners subgroup by the phrase that requires independence from vents. The owners subgroup, while not ruling out systems independent of SDV vent, would prefer to permit as an option, a design which precludes loss of system function due to a single active failure

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in the SDV vent. AEOD has recommended independence from vents.

JUSTIFICATION

Our position is based on several points:

1. GE has analyzed the system extensively and has recommended a system configuration which incorporates an improved hydraulic coupling between the IV and SDV. In our opinion this improvement would permit operation of the SDV without reliance on its vent and is due to system difficulties from vent interfaces. The proposed GE design is to attach directly to the SDV header a large diameter instrument volume. This assures immediate hydraulic communication between the SDV headers and the IV.
2. Further, the GE recommendation does not use a previously untried system configuration and thus decreases the probability of unobserved adverse effects, e.g., water hammer. This design is currently in place at 5 operating reactors. It has been subject to instrumentation damage, but these difficulties are not the result of the SDV-IV hydraulic coupling arrangement and are overcome by other agreed upon design criteria.
3. The allowance of credit for vents would open to interpretation many hydraulic design assumptions. The adequacy of such a design would be subject to substantial uncertainties.

The owners subgroup recommended design criteria is to allow for individual plant flexibility in design. For example, some BWR plants may wish to replace the 2 inch diameter pipe from the SDV header to the IV with a larger pipe, and an improved vent system. This has an advantage, in that, it increases the volume available for scram exhaust. The disadvantages be in the fact that it is an unproven more complex design. For the entire range of possible operating conditions of this new system design, there is substantial uncertainty in predicting system response.

We've made estimates of the pipe size and protective system adequacy for the range of current slopes and lengths from the SDV headers to the IV. The maximum possible inleakage without rod motion is 5 gallons per minute (GPM). Summed over all scram discharge lines into a scram discharge header for a large BWR this amounts to about 465 GPM. For the slope of 1/8" per foot driving head, a pipe of about 8 inches in diameter would be required to pass the total inleakage. This is about the practical limit for pipe size in this application. Further, for a pipe length of about 150 ft which is the maximum it would take about 40 seconds for the inleakage to reach the IV assuming a functioning vent. At this time, inleakage may be sufficient to adversely affect scram so that the protective function response would be marginal. This calculation shows that even with an adequate vent function major system configuration changes may be required and that testing system response would be needed because of relative large uncertainties and small available margins.

Another potential source of uncertainty arises from hydrodynamic forces generated during system operation. Water hammers which damage system components and structures have been observed on SDV systems. A new design with larger pipes may also be subject to flow induced hydrodynamic forces that could damage the system and preclude its function. This also demonstrates the need for testing of system performance.

To test system response would require an extensive, elaborate test program. For example, a combination of variable inleakage rates into each SDV header over the range of possible inleakage would be required with measurement of protective instrument response and system parameters important to system function including associaged hydraulic forces on system components and structures to assure the absence of water hammer. The evaluation of such a complex test program would require a longer period of time than is considered prudent for such an important system and the risk of failure of such an undertaking are undue from a regulatory view point.

CONCLUSION

A new SDV system design, which relies on a vent system, unnecessarily complicates system function and somewhat decreases the probability of success. For such a vital safety function as provided by the SDV, the incumbant disadvantages and delays associated with potential designs which use the vent are not appropriate particularly when a solution such as proposed by GE is readily available and tested. Therefore, the independence of the SDV system from vent performance supplies a ready resolution to the hydraulic coupling problem.

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PREFACE

The findings, recommendations, and conclusions contained in this report are, for reasons of timeliness, based on information gathered through informal channels between the Tennessee Valley Authority, the General Electric Company, and the US NRC Headquarters and Regional offices. To the extent possible, the information used in the report has been verified by cross checking with other sources. The findings contained in this report, including the underlying causes of the partial scram failure which occurred at Browns Ferry Unit No. 3 (BF-3) on June 28, 1980, relate most directly to the Browns Ferry reactor. However, similarities among boiling water reactor facilities leads us to believe that the findings and recommendations may be broadly and generically applied to most if not all operating BWRs. To this end, we recommend that a plant-by-plant review, not possible in this investigation, be undertaken by others, to assess the applicability of these findings and recommendations to other BWRs and to provide analysis and evaluation of plant-unique design problems not uncovered in this investigation. Additionally, the scope of our investigation and recommendations was intentionally limited so as to address only the specific, direct and underlying causes of the partial scram failure at BF-3. We have not, therefore, taken the broader view, as could be taken by those most directly involved in the ATWS issue. We do believe, however, that some of the information presented in the report can be useful to those involved in this important generic concern. Finally, this investigation was not able to pinpoint a single precise root cause(s) which led to the BF-3 partial scram failure event, beyond to say it was caused by water in the scram discharge volume. However, we believe that, in totality, the various possible cause mechanisms discussed in this report include the actual, albeit, indeterminable root cause(s) of the event.

As a footnote, the writers wish to acknowledge the invaluable and timely information provided by the BF-3 resident inspectors, James Chase and Robert Sullivan, without whose cooperation, timely issuance of this report would not have been possible.

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1 INTRODUCTION

On June 28, 1980, the Browns Ferry 3 reactor experienced a partial failure of the scram system, while shutting down for a scheduled maintenance of the feedwater system. The reactor had been brought down to approximately 35% power by reducing recirculation flow and by manual insertion of control rods. The subject event occurred when the control room operator initiated a manual scram to make the reactor subcritical which was the next step in the normal shutdown evolution. After manual scram actuation, the control rods on the West side of the core were observed to be fully inserted. However, the control rods on the East side of the core did not fully insert. Most of the East side rods came to rest in notch positions ranging between 00 and 46 after all East side rod motion had ended. Three additional scrams and about 14 minutes were required to achieve full insertion of the partially withdrawn East side control rods. After all rods were completely inserted, the operators resumed normal shutdown operations.

On July 2, 1980, a team of NRC Headquarters representatives from IE, NRR, and AEOD went to the Browns Ferry site to gather detailed information on the event, the scram system design and operation, and the results of scram system tests which already had been performed by TVA personnel. With this initial direct contact at the plant, an independent investigation of the event cause and the recommended corrective actions was begun by the Office for Analysis and Evaluation of Operational Data (AEOD). Over the next several days, additional equipment testing was performed on the BF-3 scram system. Testing and analysis was also being conducted during this time by General Electric in San Jose, California to support TVA activities at the plant. During this period, AEOD continued to obtain, analyze, and evaluate information as it evolved from these and other sources to continue its investigation.

The purpose of this report is to provide the analysis, evaluation, findings, and recommendations which flowed from the investigation of the BF-3 event by the AEOD, US NRC. Section 2 of the report contains an event sequence. Section 3 provides a description of the design and operation of the BF-3 scram system. Section 4 discusses the possible causes of the event which were investigated and the conclusions in each case. Section 5 provides an event sequence analysis. Section 6 provides a summary of the tests and inspections performed at BF-3 which support the event sequence analysis and some of the findings. Previous operating experience and investigation findings are contained in Sections 7 and 8, respectively. Specific recommendations to correct the deficiencies discussed in the findings are provided in Section 9. The conclusions of this investigation are given in Section 10.

2 EVENT SEQUENCE

On June 28, 1980, power was being reduced by the control room operator at the Browns Ferry Unit 3 nuclear reactor in preparation for a scheduled shutdown for feedwater system maintenance. By 0131 hours, the reactor power had been brought to 390 MWe via decreased recirculation flow and manual control rod insertion. The operating personnel then initiated a manual reactor scram to complete insertion of the remaining control rods (which were at the positions shown in Figure 2-1 at the time) and thereby bring the reactor to a subcritical state.

Immediately after depressing the manual scram buttons, the operators placed the reactor mode switch in the SHUTDOWN mode. Control room personnel observed that the blue scram lights for all control rod drive scram inlet and outlet valves were illuminated, indicating that all scram valves were open. Control rod position indication also showed that all of the rods on the West side of the core were fully inserted (except for one which had stopped at position "02"). However, position indication showed that 75 rods on the East side of the core were not inserted fully. The East side control rods came to rest at positions ranging from 46 to 00 withdrawn with an average of about 23 positions withdrawn (position 48 corresponds to fully withdrawn). Rod position indications following the first manual scram are shown in Figure 2-2. At this time 18 rods on the East side were fully inserted. As estimated by the LPRM readings, power level on the East side of the core following the first scram appeared to be less than two percent.

Following scram, the Scram Instrument Volume began to fill and the Scram Instrument Volume Hi Level Scram (level switches) actuated. This occurred somewhat sooner than expected at about 19 seconds. The Hi Level scram condition was subsequently bypassed by the operator (as allowed in SHUTDOWN mode), to permit reactor protection system reset which occurred 4 minutes and 31 seconds following the first scram.

One minute and 33 seconds later a second manual scram was initiated by the operator. The time following reset allowed partial drainage of the East and West Scram Discharge Volumes. Rod positions following the second scram are shown in Figure 2-3. After this scram, 33 rods on the East side fully inserted. The second manual scram was reset after 59 seconds and the scram discharge volume was allowed to drain for 53 seconds at which time a third manual scram was actuated. Upon completion of this scram, 47 rods on the East side were fully inserted. Rod positions following the third manual scram are shown in Figure 2-4. The third scram was reset after 3 minutes and 26 seconds. The scram discharge level bypass switch was returned to normal 2 minutes and 40 seconds later. This action initiated a fourth, automatic scram due to a Scram Instrument Volume Hi Level scram condition which had not cleared. At this time all rods on the East side were fully inserted. A detailed sequence of events as provided by the event sequence recorder is shown in Table 2-1. The total elapsed time between the initial scram and final insertion of all rods was 14 minutes 2 seconds. At this time the operators continued normal shutdown operations.

3 DESIGN AND OPERATION OF THE BROWNS FERRY UNIT 3 SCRAM SYSTEM

Mechanical and Hydraulic Design of the Scram System

On a GE BWR, such as Browns Ferry Unit No. 3, the Control Rod Drive (CRD) and its associated Hydraulic Control Unit (HCU) provide the means by which each individual control rod can be rapidly inserted upward into the core during a reactor scram. A simplified drawing of the CRD mechanism is shown in Figure 3-1.

During periods of no rod motion, the collet fingers are spring loaded into a groove on the index tube to hold the drive stationary against the force of gravity. High pressure cooling water is applied below the drive piston and equalized without CRD motion via controlled inleakage past the CRD seals and into the reactor. A CRD temperature probe is provided internally to monitor each CRD to detect CRD heat-up should cooling water flow be interrupted or should excess leakage of high temperature RCS water flow out through the drive, drive insert line and scram outlet valve. Scram outlet valve leakage into the scram discharge volume on the order of 0.1 gpm would raise the probe temperature to the alarm setpoint of about 350°F.

At BF-3, water exhausted from the CRDs is routed to either an East or West header scram discharge volume. The scram discharge volume (SDV) is sized to provide a volume of approximately 3.3 gallons per CRD (approximately 600 gallons total). The SDV volume is sized to limit the total amount of hot reactor water leakage past the seals during a reactor scram (maximum volume requirement) while providing enough free space at atmospheric pressure so that back pressure on the CRDs does not increase so rapidly as to impede rod insertion speed (minimum volume requirement). In particular, the system design results in a pressure in the SDV immediately following full insertion rod motions of less than 65 psig. Low pressure in the SDV is necessary to assure that technical specification scram speeds and full-in rod motion are achieved. The volume of water exhausted through the scr outlet valve of a single normal drive for a full stroke is about 0.75 gallons, not including seal leakage and bypass flow. The leakage and bypass flow for a single drive can be in excess of 5 gallons per minute. Normal scram time from full out to 90 percent insertion is less than 3 seconds.

Although the SDV is sized for a volume of approximately 3.3 gallons per drive and the drive stroke (without bypass) is only approximately 0.75 gallons, only a single reactor scram is normally possible with respect to the scram discharge volume. Leakage of reactor water past the seals fills the SDV rapidly as long as the scram outlet valves are open which would be the case without an RPS reset. This leakage occurs even on rods that are fully inserted. The leakage is an average of 2 gpm to 3 gpm per CRD. Thus, from this source alone, the 3.3 gallons per drive of free volume available in the SDV is filled and pressurized within two minutes. Thus, more than one scram would be possible only if the operator were able to reset the scram (closing the scram outlet valves) well within this time period. Without an early reset, the SDV would be filled and the SDV would have to be drained to attempt a rescram if rod motion is to be produced.

The East and West SDV headers are each provided with a vent line and vent valve. Each header drains via a separate drain line into a scram instrument volume (SIV) where level monitoring instruments are located. The SIV, in turn, has drain piping and a drain valve.

During normal operation, the vent valves of the East and West SDV headers and the drain valve of the SIV are open. These valves are kept open to allow the leakage past the scram outlet valves entering the SDV to drain continuously into the SIV so that no build-up of water in the SDV occurs which could prevent a reactor scram. These valves close during control rod scram insertion to contain and limit the reactor water released through the scram outlet valves. During a scram, inflow of water to the SDV normally continues after control rod insertion is completed due to leakage past the CRD seals. Leakage continues until the scram is reset or until the SDV pressure equilibrates with reactor pressure.

A pressure difference of at least 550 psi must be applied between the CRD insert and withdraw lines to drive the rods in during a scram. The pressure difference applied at the beginning of a scram is provided by the 1500 psia scram accumulator and atmospheric pressure in the empty SDV. As CRD scram insertion progresses, pressure losses in the driving fluid due to line losses reduce the insert line pressure to below reactor coolant system pressure. At that time, the ball check valve, integral to the CRD, allows reactor coolant system water to come in under the piston to complete the scram, before any significant build-up in scram discharge volume pressure due to filling from leakage and bypass flow.

RPS Electrical Design

A simplified schematic of the electrical components of the Reactor Protection System (RPS) is shown in Figure 3-2. It is divided into two independent trip channels A and B. Each of the channels can be tripped (de-energized) by either the manual scram relays or the two subchannel relays. The subchannel relays are de-energized and opened whenever any one of a variety of trip conditions exist in the reactor or associated equipment. The automatic logic can be described as "one-out-of-two taken twice." For purposes of analysis of the Browns Ferry event, the automatic trip logic will not be discussed because this event occurred first with a manual scram.

With reference to Figure 3-2, both scram solenoid valves A and B must change position to provide a scram. Electrically, this requires a trip of both channel A and channel B. De-energizing the two scram solenoids changes the air flow from the control air supply to the vent path. For manual scrams, a separate scram button is provided on the control panel for each channel. A manual scram is initiated by depressing both the channel A scram button and the channel B scram button. Because of the power requirements of 185 separate scram solenoid valves on each channel, each channel is divided electrically into 4 separate scram groups. Control rods associated with the HCUs from the four groups are distributed randomly throughout the core as shown in Figure 3-3.

Scram Operation

The Reactor Protection System performs its design function by de-energizing the 370 scram solenoid air supply valves (2 for each control rod drive HCU), de-energizing the two scram discharge volume (SDV) air supply solenoid valves, and energizing the four backup scram solenoid valves in the air supply lines as shown in Figure 3-4.

Scram insertion is achieved for each individual control rod by opening the scram inlet and scram outlet valves. This applies 1500 psi accumulator pressure to the "insert" side of the control rod drive piston and vents the "withdraw" side of the piston to the SDV which is at atmospheric pressure.

For normal unscrammed conditions, the scram inlet and outlet valves are held shut by control air pressure applied through the energized scram air supply valves (S39A and S39B in Figure 3-4). The SDV vent and SIV drain valves are held open by air pressure applied through the energized discharge volume air supply valves (S37A and S37B). The air header which supplies control air to all of the 372 air supply valves (370 scram, 2 vent/drain) is pressurized through de-energized backup scram valves (S35A and S35B, S70A and S70B). The SDV vent and SIV drain valves can be operated manually from the control room.

A scram signal de-energizes both air supply valves for each rod, de-energizes the scram discharge volume air supply valves, and energizes the back-up scram valves, thus venting air pressure from the scram inlet and outlet valves and the SDV and SIV valves. This causes the scram valves to open and the SDV vent and SIV drain valves to close. In the event the individual control rod air supply valves should fail to change position (i.e., mechanical bind-up, etc.), the back-up scram valves which were energized and vented air to depressurize the air supply header assure opening of the scram valves. Thus, even if an air supply valve failed to shift, that rod would still scram. A check valve is provided around the downstream back-up scram valve in the air supply line so the upstream valve can assist in the air header venting or assume venting in case the downstream valve fails.

Physical Layout of the Scram System Hydraulic Components at Browns Ferry Unit 3

At Browns Ferry Unit No. 3, the HCUs for all of the CRDs are physically arranged in rows on the "East" and "West" sides of the reactor vessel, outside the drywell and inside the reactor building. The CRDs on the West side of the core are controlled by the West side HCUs and the CRDs on the East side of the core are controlled by the East side HCUs. Drives along the interface centerline, between the East and West sides of the core, are alternately routed to the East and West headers. A simplified diagram of the physical arrangement of the HCUs, scram discharge volume, and vent and drain system is shown in Figure 3-5.

The HCUs on each side of the reactor are arranged in 4 rows. Immediately above the 4 rows of HCUs are two cross connected "race track" shaped headers fabricated with 6" piping into which the discharge from each scram outlet valve is piped. The two connected 6" headers on the East side comprise the East bank scram discharge volume (SDV) and the two connected 6" headers on the West side comprise the West bank scram discharge volume. Each HCU insert and withdraw line is connected to the CRDs below the reactor vessel with 3/4" Schedule 80 piping through which the scram inlet and scram outlet water flows (and water for normal rod drive motion). These lines average over 50 feet in length. The lines from the HCU scram outlet valve to the SDV are fabricated with 3/4" Schedule 80 piping and are approximately 10' in length.

The Scram Instrument Volume (SIV) is located on the West side of the reactor at one end of the West side HCUs (and SDV). It is configured as a 12" diameter 10' high vertical cylinder. Single float-type level switches are installed to monitor the 3 gallon and 25 gallon levels. Four float-type level switches are provided at the 50 gallon level for the purpose of initiating a reactor scram (SIV Hi Level Scram) before the SDV begins to fill beyond the point where complete control rod insertion would be prevented.

At Browns Ferry Unit 3, the East bank and West bank SDV each drain via 2" schedule 160 pipe to a single SIV located on the West side. The drain line for the West bank is approximately 15' long while that from the East bank is approximately 150' long. In each run, the total elevation fall in the line is approximately 1' 7". On the East bank run this is an average 0.13" fall per foot of horizontal run.

The drain line piping at the bottom of the scram instrument volume and the vent line piping at the high points of the slightly inclined East bank and West bank SDV headers are routed down to the Clean Radwaste Drain (CRW) piping physically located in the reactor building floor. The CRW system is a closed drain system which discharges underwater in the Reactor Building Equipment Drain Sump at the lowest elevation in the reactor building. Many other equipments are drained and vented by this system.

4 CAUSES INVESTIGATED

Immediately following the event at Browns Ferry 3, all aspects of the scram system were investigated in an effort to find the cause. The Reactor Protection System (RPS), the air system, mechanical aspects of the CRD and various valves, the CRD and HCU hydraulics, and the possibility of air in the hydraulic system were considered. Finally, attention was focused on the East bank Scram Discharge Volume.

Electrical Investigations

Following the first manual scram, the operators verified that the blue scram lights were illuminated for all control rods. Both the scram inlet and the outlet valve stem position switches must show an open valve position to illuminate these lights. Illumination of these lights for all CRDs would indicate that the electrical portion of the RPS had successfully generated a scram signal to open all scram solenoid valves and that all scram valves had actually opened for all control rods.

The Reactor Manual Control System (RMCS) which is designed to control only one control rod at a time was reviewed to determine if there could have been possible interference with the scram function. It was determined that postulated gross failure of the RMCS and initiation of multiple control rod drive withdrawal signals would not prevent insertion during scram since upward scram forces are more than three times the magnitude of the withdrawal forces under these conditions.

By use of reference drawings, hydraulic control units from each of the four rod scram groups were verified to be randomly positioned on both sides of the core as shown in Figure 3-3. Control rod electrical signals to a group 1 rod on the East side of the core and a group 1 rod on the West side of the core would be identical. The rod insertion pattern during the event shows that on the East side a number of rods from each electrical group did not completely insert while on the West side, rods from all electrical groups did completely insert.

Based on this analysis it was concluded that the failure of rods to fully insert only on the East side was not caused by any electrical malfunction in the RPS trip logic.

TVA test (entitled SMI 150) was performed to verify that the response times for the scram actuating relays to fully de-energize were within technical specifications. Verification that they were, eliminated the concern that an electrical problem delayed opening of the East side scram valves which in turn resulted in partial insertion.

A test of the voltage on all channel A and channel B scram groups showed that all went to zero following a manual scram and all returned to 125 VAC when reset. This test was run to verify the requirements of US NRC IE Bulletin 80-17. A visual and electrical search of the scram circuitry cabinets for spurious voltage sources and loose wires (that might have provided a path for electrical power) to prevent dropout of the scram relays was performed by TVA. None was found.

CRD Tests

Various tests were run on the CRDs on the East side to verify that CRD seal integrity, friction and scram times were within allowable limits. CRD seal integrity was measured via a stall test. Results of these tests did not indicate any unusual amount of flow during stall conditions and, consequently, the CRD seals were judged to be intact. Stall tests could also have provided a means of detecting scram outlet valve leakage. However, this test was not done. Friction tests and single rod scram tests also showed no anomalies.

Non-Condensible Gas in the Hydraulic System

The effects of air or nitrogen in the CRD Hydraulic system were considered. Upon questioning, GE CRD experts stated that non-condensible gas in the hydraulic system would only cause problems with normal insert and withdraw motions but would not cause problems with scram insertion. This is because stepping the rods requires intricate timing of rod motion and latching whereas scramming is a single motion. During a stepping function any non-condensible gas would undergo compressions and expansions much different from the behavior of the non-compressible liquid.

The presence of nitrogen gas in the SDV prior to scram would be no different than the presence of air which is there routinely. Following initiation of the scram, the vent valve closes slowly enough to allow a good portion of the non-condensible gas in the SDV to be vented.

5 EVENT SEQUENCE ANALYSIS

As discussed previously, the control rod drive HCU exhausts are partitioned into East and West bank scram discharge headers. Control Rod Drives which discharge into the East header are located on the East half of the core while CRDs which exhaust into the West headers are positioned on the West side of the core.

The most notable observation of the control rod positions after the first manual scram was that all of the control rod drives exhausting into the West header inserted full-in (except for the CRD at position 30-23 which inserted to within one notch of full-in) while the control rods exhausting into the East bank header inserted an average of only 20 positions. This CRD insertion pattern provides strong evidence that the fundamental cause* of the extensive failure-to-fully-insert of the CRDs on the East side of the core was hydraulic in nature. More specifically, the rod pattern resulted from an inability of the East header CRDs to exhaust properly for some reason.

With respect to possible multiple scram outlet valve failures, all of the East header scram discharge valves were observed by the control room operators to have opened upon manual scram actuation. Additionally, all of the manual isolation valves on the scram discharge lines of the East header HCUs were inspected by the licensee immediately upon shutdown, with each found to be fully open. Accordingly, the remaining possible hydraulic causes could have been blockages in most of the CRD scram exhaust discharge lines or inadequate free volume (or high back pressure) in the East header SDV. Subsequent scram testing of numerous East header CRDs which failed to fully insert demonstrated, however, that no blockages existed in the CRD exhaust lines. Excessively rapid buildup of back pressure in the East bank SDV, due to multiple CRD seal failures, could also be postulated as a mechanism which could inhibit full-in control rod motion. However, stall tests performed on the East bank CRDs,

*See Section 4 for a discussion of other possible causes investigated.

together with individual rod and full core scram tests performed prior to restart, demonstrated that an excessively rapid increase in SDV back pressure resulting from multiple CRD seal failures was not the cause of the partial scram failure. Accordingly, it was concluded that, for some reason, the East bank SDV had inadequate free volume available to accept the full scram discharge from all East bank CRDs exhausting into the East header. Thus, the observed East bank control rod insertion behavior can best be explained on the basis that the East header SDV was at least partially filled with water when the operator manually scrammed the reactor.

As discussed in Section 3, adequate free volume must be available in both the East and West headers to accommodate water exhausted during control rod scram insertion. Furthermore, water must be exhausted into the SDV with low back pressure on the drive piston to assure that technical specification scram speeds are met. A reduction in the free volume in the SDV could tend to increase back pressure on the drive pistons too fast which could then increase the time required to complete scram insertion. Complete rod insertion would still be possible, however, even for significant reductions in the available free volume in the SDV as demonstrated in recent single CRD scram test simulations performed by GE. The GE tests showed that for a 40% decrease in the available SDV, a control rod can still fully insert over a broad range of seal leakage values. For a 70% reduction (i.e., 1.0 gal/drive remaining) in available scram discharge header free volume, the rods could still fully insert if seal leakage rates were small enough. For a reduction in SDV of this magnitude, however, increasing seal leakage rates can cause the CRD travel (number of positions inserted) to decrease. The tests show that drive travel decreases to only 36 positions (out of 48) when a 70% reduction is coupled with a seal leakage rate of 8.9 gpm. The GE test cases run for 85% reduction in free volume (.5 gal/drive remaining) showed that even with no seal leakage, the drive would insert only 28 positions and decreased to 22 positions for 5.2 gpm and 18 positions for 8.9 gpm leakage. Finally, as expected, the tests showed that the CRDs would not insert at all if there were no free volume in which to exhaust (0.0 gal/drive) regardless of seal leakage. Thus, these tests clearly demonstrate that CRD travel during scram insertions can be sharply reduced if the amount of available exhaust volume is reduced sufficiently.

Since the manual rescrams (scrams #2 and 3) occurred with East bank scram discharge volume almost full of water on each occasion, these later scrams can be used as models for back-checking the cause of the observed East bank control rod insertion behavior during the first scram. That is, the fullness of the East bank SDV during the first scram can be qualitatively and somewhat quantitatively inferred by comparing it with rod motions during the later scrams.

The available free volumes in the East bank SDV for each of the later scrams can be calculated by multiplying the drain times discussed in Section 2 by the East bank scram discharge volume drain rates discussed in Section 6. The amount of free volume which would have had to have been available during these later scrams can <u>also</u> be calculated from the observed rod motions during these scrams together with the GE test results. Comparing the volumes calculated both ways can then be used to show whether or not the observed rod motions during each scram were consistent with the amount of discharge volume made available by the drains between scrams. Once these are shown to be consistent, one can infer the limited amount of free volume which must have been present in the East bank SDV during the first scram. The East bank drain times, total number of positions inserted, and average number of positions inserted per rod used in this analysis are shown in Table 5-1.

The drain times between the first and second manual scram was 93 seconds and between the second and third manual scrams the drain time was 53 seconds. Tests at Browns Ferry show that the <u>normal</u> drain rate for the East SDV is about 11.6 gpm when East and West scram discharge volumes are draining simultaneously. Thus, by multiplying this normal drain rate times the drain time between scrams, we can calculate approximately how much water could have drained out (free volume made available) of the East bank header during the periods between scrams. Multiplying, one finds that about 18 gallons would have been made available during the first drain (between scrams 1 and 2) for the second scram while about 10.2 gallons would have been made available during the second drain (between scrams 2 and 3) for the third scram.

On the other hand, from the GE tests and the average rod motion given in Table 5-1 to a first approximation and assuming no CRD seal leakage, an average of .18 gallons per drive was available for the second scram while about .07 gallons per drive was available on average for the third scram. Thus, for 93 drives, to a first approximation and given no seal leakage, a total of about 17 gallons of free volume was available in the East SDV for the second scram while about 7 gallons was available for the third scram. However, if every East bank CRD were assumed to have a seal leakage of 5 gpm,* from the GE test results the required volume per drive would have had to have been no more than about 20 percent more than the above values. That is, about 20.5 gallons of free volume would have had to have been available during the second scram and about 9 gallons for the third scram.

Comparing the results of the above calculations, it could be concluded that the East SDV was draining normally between scrams one and two, and two and three, and that the average rod insertion during the second and third scrams was the amount which one would expect for the amount of volume made available by the drain. Thus, the insertion behavior of the East bank control rods logically could be explained on the basis of a virtually filled SDV during the second and third scrams.

This same approach can now be used to infer the cause of limited control rod motion during the first manual scram. From Figures 2-2 and 2-3, the average control rod insertion during the first scram was 20 positions. From this value we would infer (using the GE test results) that there was an average of only .35 gallons per drive available (or about 33 gallons total) in the

*Conservative based on CRD maintenance recommendations.

East scram volume during the first manual scram. This assumes no seal leakage. With a 5 gpm seal leakage, we would infer that only about .45 gallons per drive (or about 42 gallons total) had been available.

The above calculational results show that the partial scram failure during the first scram can most easily be explained by having an initially partly filled East bank SDV. Similarly, the subsequent CRD failures-to-fully-insert are explainable based on a partly filled scram discharge volume.

It should be pointed out, however, that there was considerable spread among the control rods in the number of notches inserted after the first scram. The variation from rod-to-rod could be explained by CRD-to-CRD differences in such parameters as seal leakage (which significantly effects number of notches inserted), control rod drive friction, nitrogen accumulator pressures, etc.

Finally, evidence that the East bank scram discharge volume was initially partly filled with water can be found in the elapsed time to activate the SIV Hi Level scram switches following the first manual scram. Reactor scrams at BF-3 prior to the June 28, 1980 event resulted in time delays from reactor scram actuation to SIV Hi Level scram actuation ranging from 42 to 54 seconds. The first manual scram from the June 28 event had a delay of only 19 seconds. For a normally empty SDV and SIV, the time delay would represent the time it takes for water exhausted from the CRDs to enter and begin to fill the SDV, travel down the SDV-to-SIV drain lines, and fill the SIV to the 50 gallon level. If water were already in the East SDV, water exhausted from the CRDs would almost immediately start to push water out of the East SDV and into the drain line. This would cause the SIV to fill more rapidly. Thus, an elapsed time of only 19 seconds to actuate the SIV Hi Level scram switches provides important evidence that the East SDV was already almost completely filled with water at the time of the first manual scram.

6 SCRAM DISCHARGE VOLUME/SCRAM INSTRUMENT VOLUME INSPECTIONS AND TESTS

Following the partial scram failure event at BF-3, TVA, with the assistance of GE, embarked on an extensive inspection and test program. These inspections and tests were performed to try to pinpoint what caused substantial water to be present in the East bank scram discharge volume on June 28, 1980, while the scram instrument volume level switches were indicating both headers were empty. The inspection program included physical examinations of the drain and vent piping, the scram discharge and instrument volumes, as well as the drain and vent valves. These inspections were performed in an attempt to determine if a vent or drain line blockage had caused the East bank scram discharge volume to not drain properly. Additionally, drain tests were performed on both the East and West headers to establish the drain characteristics of these components. The following paragraphs summarize the results of these inspections and tests.

Inspections

The 2" drain line between the East bank scram discharge volume and the scram instrument volume were checked for blockages. The drain piping was cut at several locations. Metal tape was then inserted through the drain piping segments. These inspections uncovered no obstructions in the piping between the SDV and SIV which could have impeded normal draining of the SDV. A fiber optics inspection of the inside of the SDV at the low point of the 6" diameter SDV (where the 2" drain line connects to the 6" SDV) revealed no foreign objects which could have blocked water from draining out of the 6" SDV into the 2" drain line. The vent piping which cross-connects the high points of the East bank scram discharge header was also cut, flushed, and inspected. No obstruction was found in these vent lines which could have impeded or prevented normal draining of the East SDV.

Following the event, the vent valve on the East header was removed and a vacuum pump connected to the Clean Radioactive waste (CRW) side of the vent line. Eight (8) inches of mercury was indicated by the 1.35 CFM vacuum pump gauge after a few minutes of pumping but fell off sharply to 2 inches shortly thereafter. Neither the validity of this vacuum reading nor the reason for the apparent and brief vacuum pull could be determined by TVA. Several days later when the 1.25 CFM vacuum pump was reconnected to the same East header common vent pipe, no vacuum could be drawn after the vent line was flushed. A test of the East header vent valve itself showed that it was operable.

The scram instrument volume was also visually examined with a boroscope by inserting it through the vent and drain line penetrations. No obstructions were found which could have prevented draining into or out of the instrument volume.

An inspection of the 6" East bank SDV and drain line showed that they sloped continuously downward toward the instrument volume, with the exception of a localized 3/4" rise in drain line at the expansion loop in the steam vault. This might have been a loop seal of greater depth when the steam vault was hot during normal reactor power operation. The overall drop in the drain line between the East SDV and instrument volume was determined to be 1' 7" over its 150 ft. length. From the inspections discussed above, TVA was not able to locate a blockage, loop seal, valve maloperation, or other impediment to draining which could be described as the root cause for holding water in East SDV.

Scram Discharge Volume Vent and Drain Tests

TVA performed a series of drain tests on both East and West SDV headers over a period of several days immediately following the partial scram failure event. The purpose of these tests was to determine the effects of a restricted vent path on East and West bank SDV drain capabilities and to quantify the normal drain characteristics of the SDV. Special test procedures were written for these tests.

Typically, these tests involved initially filling the East and West SDV discharge headers and scram instrument volume tank with room temperature demineralized water. During filling operations, the East and West header vent valves were kept open and the scram instrument volume drain valve was kept closed. Normal drain times and drain rates for the East and West SDV headers and scram instrument volume were then determined by recording the elapsed time necessary to empty these volumes with the vent and drain valves open. Vacuum hold tests (simulating vent line blockages) were performed to determine the drain capabilities of the headers with the vent valves closed. Water level in the SIV and SDV was monitored by ultrasonic equipment and verified by a clear tygon (manometer) tube attached to the scram discharge volume headers. Clearing times of the 50, 25, and 3 gallon level switches attached to the SIV tank were also recorded during the tests.

Summary of Test Results

Scram Discharge Volume Vacuum Hold Tests

East Header

With the West header drained to empty, the East header was allowed to drain into the SIV with the East header vent valve and SIV drain valve closed and the West header vent valve open. For this condition (which simulated a blocked East header vent), water drained from the East SDV into the SIV tank at a rate of only 0.6 gpm.

West Header

For this test, the East header was first drained to empty by opening its associated vent valve together with the SIV drain valve. The West header was then allowed to drain into the SIV with the West header vent valve and SIV drain valve closed. For this condition (which simulated a blocked West header vent), water drained from the West SDV into the SIV tank at a rate of about 3.2 gpm.

East and West Headers

For this test, both the East and West headers were allowed to drain simultaneously into the SIV tank with their respective vent valves closed and the SIV tank drain valve closed. After an initial water surge, the combined drain rates of the two headers into the SIV tank was 0.6 gpm.

Scram Discharge Volume Drain Tests

These tests were performed to determine the drain times and drain rates of the SDV and SIV during normal draining (open vent and drain) conditions. Drain tests were performed for both East and West headers draining at the same time. The system was first filled with the SDV vent valves open and the SIV drain valve closed. At time zero the drain valve was opened. Ultrasonics indicated that the West header emptied after about 9½ minutes while the East header emptied considerably later at about 25 minutes. Additionally, the 50 and 25 gallon switches in the scram instrument volume cleared at about 9½ minutes and 10 1/4 minutes, respectively. The SIV 3 gallon switch cleared after 11 minutes and 20 seconds had elapsed. Based on the volumes associated with the SDV headers, these tests showed the average drain rate (with both SDV headers draining together) of the East SDV header to be 11.6 gpm while the average drain rate of the West SDV header was shown to be about 35 gpm. The average drain rate for the SIV based on clearing of the SIV level switches was 24.5 gpm. However, this drain rate was with the East SDV header still draining into the SIV at an average rate of 11.6 gpm. That is, the SIV drained 24.5 gpm faster than the East SDV drained.

7 PREVIOUS BWR EXPERIENCE OF FAILURE TO FULLY INSERT

A review of previous BWR experience was performed with respect to failure to fully insert control rods and problems with the SDV. The sources of information used were NUREG-0640 and computer searches of LERs. Computer searches via the NRC LER system and the Oak Ridge Nuclear Safety Information Center data base revealed no later events more significant than those reported in NUREG-0640.

Most instances of failure of rods to fu' / insert resulted in a number of rods latching in position 02 (position 00 is fully inserted). Up to the time of publication of NUREG-0640 in April of 1978, 12 scram events where some rods failed to fully insert were tabulated. These events in general involved a relatively small number of CRDs, between 2 and 15. However, one event at Dresden 2 in November of 1974 involved 96 rods. Ninety-three stopped at position 02, one at position 04, and two at position 06. The only cause reported for the failure of rods to fully insert was damaged stop piston seals. Stop piston seal damage can cause excessive leakage past these seals during a scram which could be large enough to fill (and pressurize) the discharge volume in advance of the control rods reaching their full-in position.

8 FINDINGS

1. The partial failure to scram at BF-3 on June 28, 1980, was apparently due to the presence of water in the East scram discharge volume header. As supported by the tests, inspections and analyses discussed in Sections 4 and 5 of this report, the apparent cause of the extensive failure of control rods to fully insert on the East side of the core was the presence of water in the East scram discharge volume header.

2. <u>The BF-3 scram instrument volume Hi Level scram function did not and does not provide protection against the accumulation of water in the East scram discharge volume header (with attendant loss of East bank scram function) even for normal venting and draining conditions</u>.

Drain rate tests performed at BF-3 show that water drains out of the scram instrument volume tank considerably faster than water drains into it from the East bank scram discharge volume header even for normal, free, unobstructed venting and draining. Based on the tests, the <u>average</u> drain rate of the SIV is approximately 35 gpm while the <u>average</u> drain rate of the East bank scram discharge volume header is approximately 11.6 gpm. For these drain characteristics, water will drain out of the SIV leaving it virtually empty while water may still be present in the East bank SDV. This actually occurred in the East header drain tests. During the test, the SIV emptied about 20 minutes before the East header fully drained.

With these relative draining characteristics, if water were to leak <u>into</u> the SDV faster than 11.6 gpm, water would accumulate in and fill the East header (since water is being added faster than it can drain out). At the same time, the water draining out of the East header (i.e., at 11.6 gpm) will not accumulate in the SIV since the SIV drains at a faster rate (i.e., 35 gpm). This process would result in water filling the East header without an automatic SIV Hi Level scram ever occurring. We have also found that water drains out of the SIV so rapidly that the SIV Not Drained alarm would not alarm in the control room. Thus, there would be neither control room indication that water is filling an East SDV nor automatic reactor scram actuation to provide protection against partial loss of scram capability.

In view of the above, with regard to the SIV Hi Level automatic scram function, we have found that continuous automatic protection against filling the East bank SDV (with subsequent partial loss of scram function) never did and still does not appear to exist at BF-3. Furthermore, any BWR with a SIV normal drain rate significantly faster than its SDV normal drain rate also would be without automatic protection against filling of the SDV. Although not verified by test, it is likely that the BF-3 West SDV header also would be in this category.

The loss of automatic scram function can be explained in hydraulic head terms. The SIV is a high cylindrical tank and the 50 gallon SIV Hi Level Scram is located over 8' above the bottom of the tank. Thus, it is necessary to build up a head of 8' in the SIV before the Hi Level Trip switches can actuate. If the drain line from the SIV to CRW is a relatively short line (as is the case at BF-3) an 8' driving head, would result in a fairly rapid drain rate. On the other hand, the SDV header is a horizontal pipe with a small slope. Even when filled, the maximum head of water that can be developed above the SDV drain (at BF-3) is approximately 2½'. Thus, even with a relatively short drain line between the SDV and the SIV, the flow rate in this line would normally be low because of the low head.

Actually the SDV header drain and the SIV drain are the same size for BF-3, but the SDV drain is considerably longer. As a result, the lower available hydrostatic head in combination with the higher fluid flow resistance results in a much slower drain rate for the East SDV header than for the SIV. Such an arrangement can never detect accumulation of water in the SDV.

3. <u>A single blockage in the West header vent or drain line could completely disable the automatic reactor protection function installed to protect against a loss of scram capability for all control rods</u>.

For plants like BF-3 which have one SDV which normally drains significantly slower than the SIV, it is possible to completely disable the protection provided by the SIV Hi Level scram for both the East and West SDV by postulating a blockage on the faster draining SDV. Reduced flow from a blockage on this faster draining header SDV, when combined with the normally slower draining header flow, may total less than the scram instrument volume drain rate which would then result in the SIV emptying with both SDVs still containing water. This would be a serious and undetectable condition if water inleakage were to subsequently develop into both SDV headers such as to keep the headers full at all times. For such a situation, there would be no automatic scram to protect against a total loss of scram function due to CRD water inleakage since the SIV water level would never rise to actuate the SIV Hi Level scram switches.

4. <u>With the current scram discharge volume/scram instrument volume design, a blockage in the SDV vent or drain path can cause a partial loss of scram capability and disable the protection function installed to prevent it.</u>

As discussed in the previous sections, a blockage in the SDV header vent or drain path will drastically reduce the drain rate of the scram discharge volume. Water leaking past the scram outlet valves (or from other sources) could then cause the scram discharge volume to fill. Since the CRD temperature probes would allow about .1 gpm of undetected leakage, as much as 9 gpm could leak into the SDV header undetected from all CRDs. Thus, given a partially blocked West header drain, for example, the West header could easily start to fill with water, leaking in undetected through the West side CRD scram outlet valves. At the same time, since the drain rate of the West header with a drain line blocked could now be substantially <u>less</u> than the SIV drain rate, water would not accumulate in the SIV. Therefore, the SIV Hi Level scram switches would not actuate to prevent filling of the header. Thus, with the present SDV/SIV and Hi Level scram arrangement, a single failure such as a blockage of a SDV drain or vent can help initiate a partial loss of scram capability and disable the protective function designed to prevent the loss.

5. <u>There are numerous actual and potential mechanisms for introducing and retaining water in the SDV with no accumulation in the SIV.</u>

Review of the vent and drain paths for the scram discharge volume and the scram instrument volume has shown that there are numerous actual and potential mechanisms which could slow or even stop SDV drainage into the SIV. Since the SIV would still maintain a high drain rate, it would be possible for the SDV to retain water while SIV instrumentation indicates empty.

Possible sources of water are: water from the previous scram; multiple scram outlet valve leakage; or injection from SDV flush lines.

Mechanisms which retard free draining of water out of the SDV include: a blockage in the vent piping; a plugged SDV-to-SIV drain line; a closed SDV vent valve; a vacuum held in the SDV by a loop seal somewhere in the vent line; vent line siphon effects from water in the SDV vent line; venting to the closed CRW system in the Reactor Building Drain Sump below water without vacuum breakers; vacuum effects from fluid flows through the CRW piping system; Vacuum effects from condensing hot water in SDV from the previous scram.

Venting of the SDV to atmospheric pressure while the SIV drains into the closed CRW drain system (which could be pressurized above atmospheric pressure) could also inhibit draining of the SDV headers if there is insufficient downward slope in the SDV drain line. Since the CRW exhausts under water in the Reactor Building Drain Sump and non-condensible gases are present in the fluids draining through the CRW drain system, there is a possibility for pressure to build up in the CRW drain system. This pressure, in conjunction with a small loop seal in the drain line from the SDV to the SIV, could hold up water in the SDV even if the SDV were vented directly to atmosphere.

6. <u>The current scram discharge volume/scram instrument volume design results in the automatic Hi Level scram (safety) function being directly dependent on the nonsafety-related reactor building Clean Radioactive Waste drain system.</u> For the scram instrument volume Hi Level scram switches to activate, water must accumulate in the scram instrument volume. For water to be able to accumulate in the SIV, it must be able to drain at an adequate rate from the SDV into the SIV. However, from the drain rate tests performed at BF-3, improper venting of the SDV can sharply or totally prevent water from draining out of the SDV. Proper draining of the SDV is directly dependent on the venting function provided by the reactor building Clean Radioactive Waste drain system (a required systems interaction). Accordingly, we would conclude that operability of the SIV Hi Level scram function is dependent on the venting provided by the nonsafety-related reactor building CRW system. Unanticipated adverse venting behavior of the CRW system, which results in reduced venting of air back into the SDVs, can result in the holdup of water in the SDV with little or no accumulation of water in the SIV. This dependancy appears to be particularly inappropriate if not unacceptable for a reactor protection function which is intended to prevent the loss of reactor scram capability.

7. The BF-3 partial scram failure event, together with recent events at other BWRs, have shown that float-type water level monitoring instruments have a significant degree of unreliability.

The BF-3 partial scram failure event demonstrated on several occasions a significant unreliability of float-type level switches. As shown on the event sequence recorder printout (Table 2-1), several of the 50 gallon level instruments failed to activate on different occasions. Furthermore, during calibration testing of the SIV level switches following plant shutdown, both the 3 gallon and 25 gallon switches were found to be inoperable. After the instrument taps were flushed of residue, the switches operated satisfactorily. During drain rate testing of the BF-3 SDV, two of the four 50 gallon switches failed to activate twice in two drain tests. Additionally, inspections at Brunswick Unit No. 1, following a reactor scram on November 14, 1979, revealed inoperable alarm and rod block level switches due to bent float rods. Other surveillances and inspections at Hatch Unit 1 on June 13, 1979, found two SIV Hi Level switches inoperable due to bent floats binding against the inside of the float chamber. These recent experiences indicate a significant degree of unreliability of float-type level switches resulting from various causes.

8. <u>With the current BWR Reactor Protection System logic, the presence of certain automatic scram conditions preclude SDV draining (scram reset) to permit a rescram.</u>

In order to drain the SDV for rescram following a scram actuation, it is necessary to reopen the SDV vent and drain valves and to reclose the scram inlet and outlet valves (RPS reset). This requires the following steps: 1) place the reactor mode switch in SHUTDOWN or REFUEL; 2) actuate the DISCHARGE VOLUME HI WATER LEVEL BYPASS switch; 3) the reactor trip signal must clear or be bypassed in SHUTDOWN or REFUEL modes; and finally 4) reset the RPS. However, the following reactor trip functions cannot be bypassed by the operator in the SHUTDOWN or REFUEL mode:

Drywell High Pressure
Reactor Vessel Low Level
Main Steam Line Hi Radiation
Neutron Monitor System Trip
Reactor Vessel High Pressure
Condensor Low Vacuum*
Main Steam Line Isolation Valve Closure*

Thus, if any of the above trip conditions are present, resetting the RPS would not be possible.

For example, if a spurious MSIV closure event should occur at power with the SDV initially full of water, a reactor scram would occur with the control rods failing to fully insert. If the MSIV closure trip (or Reactor Vessel High Pressure) condition persisted, then a rescram attempt would not be possible since it cannot be bypassed in SHUTDOWN or REFUEL modes. Thus, the trip condition itself would prevent the possibility of rescram. However, we do not consider that any modification is required in the RPS trip/reset circuitry to enable the operator to reset the RPS in the presence of any automatic scram condition, since the capability to reset and rescram has not been defined as a required protective action.

*Depends on Reactor System Pressure Interlock setpoint.

9. <u>If a scram condition exists which cannot be bypassed in SHUTDOWN or REFUEL mode, then failure (to close) of a SDV vent or SIV drain valve can result in an unisolatable blowdown of reactor coolant outside primary containment.</u> With the reactor in an unscrammed state, the scram outlet valves provide both a reactor coolant pressure boundary function and a primary containment isolation function. During a reactor scram, the scram outlet valves open (one per control rod drive) and the SDV vent and SIV drain valves close. Reactor coolant pressure boundary integrity and primary containment isolation functions are then transferred to the scram discharge volume vent and SIV drain valves which seal the SDV. We have found that there are no redundant isolation valves in the vent or drain lines to provide these isolation functions for a scram condition. The failure of any one of these valves in the open position, therefore, could result in an uncontrolled blowdown of reactor water outside primary containment and into the CRW drain lines if the operator could not reset the scram. The blowdown would ultimately discharge to a drain sump which is not designed to handle the heat load or pressure buildup. With the present BWR RPS design, the operator would be able to reestablish primary containment isolation (with scram outlet valve closure) only if the RPS could be reset. However, if a reactor scram condition persists and it cannot be bypassed in SHUTDOWN or REFUEL mode (i.e., any of those listed in Finding #8) it would be impossible to reset the RPS to terminate the blowdown.

Thus, for example, a scram caused by spurious closure of the MSIVs with a failed open scram instrument volume drain valve would result in an uncontrolled blowdown of reactor coolant outside primary containment and into the drain sump room which contains the engineered safeguard pumps which are required for mitigation. Blowdown would continue as long as the MSIV closure scram condition existed (MSIVs not reopened) since this trip cannot be bypassed in SHUTDOWN or REFUEL mode. That is, the scram outlet valves could not be reclosed to isolate the blowdown until the MSIVs could be reopened. For events which result in scrams caused by conditions which cannot readily be cleared, uncontrolled blowdown into the reactor building (secondary containment) could be sustained for an indefinite period of time with possible environmental impact on the required mitigating features.

10. <u>The emergency operating instructions at BF-3 did not include a procedure or guidance for the operator to follow in the event of a partial or complete scram failure.</u>

The Browns Ferry plants, as perhaps do most (if not all) other BWRs (and probably all other LWRs), do not have emergency procedures for the operator to follow in the event of a partial or complete scram failure. We have found that, although control room operators are trained to verify that the rods have fully inserted upon a scram actuation, procedures do not exist for the operator's immediate or subsequent actions if full control rod insertion does not occur. Moreover, although operators are fully knowledgeable of the function and operation of the standby liquid control (poison) system, the plant does not have specific procedures which state when the alternate shutdown system <u>must</u> be actuated.

9 RECOMMENDATIONS

1. The operability of the Scram Instrument Volume Hi Level Scram function should be independent of the Scram Discharge Volume venting and draining requirements.

   The current BWR scram discharge volume/scram instrument volume design configuration requires proper venting of the SDV and proper SDV-to-SIV draining to assure operability of the scram instrument volume Hi Level scram function. We recommend that the operability of the Hi Level scram be made independent of SDV venting or draining requirements. We make this recommendation because of Finding Nos. 1 through 6 discussed in the previous section. That is, the hydraulic factors which control water level in the SDV and SIV should not be able to negate the response of the Hi Level protection function. We believe the acceptable configuration would be to place the SIV tank directly under the low end of the 6" SDV header and to connect the top of the SIV tank to the bottom of the low end of the SDV header by a short vertical 6" diameter pipe (rather than the current 2" diameter horizontal pipe). This arrangement should assure water spillage from the SDV directly down to the tank containing the level monitoring instruments. Furthermore, it would not depend on venting or draining phenomena which are sensitive to blockages. We also recommend two separate scram instrument volume tanks, one on each SDV header bank. Separate instrument volumes, in immediate proximity to their respective headers, should assure proper water spillage into the SIVs and provide adequate redundancy for protection against a total loss of scram capability.

   It is our firm belief that modifications which simply improve the venting of the SDV/SIV volume arrangement to assure operability of the SIV Hi Level scram function are not adequate. We recommend that this uniquely important safety function be made completely independent of any vent or drain arrangements, thereby separating the water accumulation control and protection functions. We further recommend that in situ fill tests be performed to demonstrate that the operability of the protective Hi Level scram function is insensitive to the vent or drain arrangement for the design configuration finally installed.

2. <u>Scram instrument volume water level monitoring instruments for the SIV Hi Level scram function should be both redundant and diverse.</u>

It is recommended that diversity be added to the redundancy of SIV level monitoring instruments for the SIV Hi Level scram function. Currently, there are redundant float-type level switches for each RPS channel for the Hi Level scram function. On several occasions recently, as discussed in Finding No. 7, more than one float-type level switch was observed to be inoperable at once. During and immediately following the BF-3 partial scram failure event, several float-type level switches in the instrument volume failed to actuate. In view of these experiences, we recommend that diversity be included in the level monitoring function for the SIV Hi Level scram function. The important and unique protection provided by this trip function requires that the presence of water in the SIV be monitored continuously with extremely high reliability. We are recommending that diversity be added in order to assure this reliability. Monitoring techniques, such as differential pressure cells, ultrasonic detection or conductivity probes, may be considered along with others for this purpose.

3. <u>All vent and drain paths from the scram discharge volume and scram instrument volume should have redundant automatic isolation valves</u>.

As discussed in Finding No. 9, scrams which occur as a result of automatic reactor trip conditions which cannot be cleared or bypassed in REFUEL or SHUTDOWN modes can result in unisolatable reactor system blowdowns outside of primary containment if the SDV vent or SIV drain valve fails to close. To protect against such occurrences, we recommend that redundant valves be placed on all vent and drain lines connected to these volumes. Redundant valves would also protect against equipment damage which might otherwise occur as a result of excessively slow closure or delayed closure of one of the isolation valves. These valves must be qualified and capable of closing against full reactor pressure, flow, and temperature conditions in case the lines are not isolated within normally specified time limits. The vent and drain lines and drain supports must also be designed for the hydraulic loads and instabilities associated with the blowdown of the high pressure/temperature reactor coolant to the drain system. Prolonged blowdown may be ruled out as a design basis with appropriate diverse isolation or other acceptable provisions. Blowdown instability due to isolation valve time delay is believed to be the cause of failure of the float-type level switches at Brunswick Unit No. 1.

4. <u>Emergency operating procedures and operator training should be provided for complete and partial scram failure conditions</u>.

In view of Finding No. 10, we recommend that emergency operating procedures and training be provided to control room operators to respond to partial or complete scram failure conditions. These procedures should include explicit statements regarding the conditions for which the standby liquid control system <u>must</u> be used. The procedures should include cautions regarding operator actions which should not be taken which could result in a severe transient condition (e.g., main turbine trip) being created. The procedures should provide guidance to the operator for starting up safety systems for standby readiness (e.g., HPCI on minimum flow) or for tripping other systems (e.g., recirculation pumps). The order of operator actions (i.e., immediate, subsequent) should be considered, as well as when the operator should begin attempting to insert rods manually.

We believe that such operations (human factors) aspects can and should be implemented in the near term. Such procedures and training would assure, in the near term, the most appropriate control room operator action during a scram failure event and well in advance of any ATWS modifications which may be required in the long term.

5. <u>Consider modifying the SDV vent and SIV drain arrangement to improve scram discharge volume drain reliability.</u>*

As discussed previously, scram discharge volume draining currently depends on uncertain vent and drain functions provided by the reactor building Clean Radioactive Waste drain piping, along with relatively small diameter, nonredundant vent and drain piping, which are susceptable to blockage. This current, relatively unreliable SDV venting arrangement could be improved by increasing the vent line size and by adding an alternate, reliable, and isolatable vent path. The alternate vent path could be installed with a check valve and air operated isolation valve to provide an alternate and isolatable path for air inleakage into the scram discharge volume. The alternate vent path could be vented either directly to the Reactor Building atmosphere or to a gas treatment system with a vacuum breaker. The check valve would provide automatic isolation of this redundant line upon pressurization of the scram discharge volume during a reactor scram. The drain function could also be improved by providing a second drain line from the SIV to the CRW floor drain.

We believe that modifications, such as those described above, would help improve SIV drain reliability. Improvements such as these would thus help to further reduce the number of challenges to the SIV Hi level protective scram function.

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*Although this recommendation is only for consideration, we do believe that it would further reduce the risks associated with loss of scram capability arising from water accumulation in the SDV.

10 CONCLUSIONS

The Browns Ferry Unit 3 partial scram failure event which occurred on June 28, 1980, demonstrated that the present BWR scram system can be vulnerable to loss of scram capability while operating at power. Furthermore, the event showed that the loss of scram capability can occur in a way which goes undetected by the operator and unprotected by the reactor protection system.

The information and analysis of the BF-3 partial scram failure, which is provided in this report, concludes that the cause of the loss of scram capability was the presence of water in the East scram discharge header. Furthermore, our analysis of the scram discharge volume/scram instrument volume design configuration, together with its vent and drain characteristics, leads us to conclude that numerous actual and postulated mechanisms exist which can cause the scram discharge volume to fill undetected and without protection against such filling. Our analyses also show that certain scram events can result in an unisolated reactor coolant blowdown outside of primary containment following a single isolation valve failure.

In view of these design deficiencies, we believe it necessary that modifications be made to the scram discharge volume/scram instrument volume arrangement and isolation features. Our specific recommendations for change in the SDV/SIV design which flow from our findings have been provided in this report. We believe that these recommendations should be considered along with those of others who are also reviewing the BF-3 event. We do believe, however, that the design changes described in the recommendations are necessary to adequately reduce the risks associated with the present unreliability of the BWR scram system arising from undetected accumulation of water in the scram discharge volume.

Table 2-1 Event Sequence Recorder Printout

01 31 16 A034	Reactor Scram Manual B
CY 5 34 A034	
CY 6 44 A033	Reactor Scram Manual A
01 31 24 A035	Reactor Trip Actuator A1 or A2
CY 3 38 A035	
CY 3 39 A021	Reactor Low Water Level A
CY 3 42 A023	Reactor Low Water Level C
CY 3 47 A021	Reactor Low Water Level D
CY 3 47 A036	Reactor Trip Actuator B1 or B2
CY 3 56 A022	Reactor Low Water Level B
CY 5 11 A076	REPT C Tripped
01 31 34 A003	Discharge Volume High Water Level C
CY 3 42 A003	
CY 5 01 A004	Discharge Volume High Water Level D
01 31 37 A002	Discharge Volume High Water Level B
CY 6 58 A002	
01 31 40 A001	Discharge Volume High Water Level A
CY 0 03 A001	
CY 0 18 A106	Malfunction Bus Energized
CY 0 33 A038	Turb. Stop VAlve Closure Scram Trip A
CY 0 33 A040	Turb. Stop Valve Closure Scram Trip C
CY 0 33 A041	Turb. Stop Valve Closure Scram Trip D
CY 0 34 A039	Turb. Stop Valve Closure Scram Trip B
CY 0 47 A043	Turb. Gen. Load Rejection Scram Trip B
CY 0 47 A045	Turb. Gen. Load Rejection Scram Trip D
CY 0 48 A042	Turb. Gen. Load Rejection Scram Trip A
CY 0 48 A044	Turb. Gen. Load Rejection Scram Trip C
A084	Turb. Tripped - Loss of Hydr. Trip Pressure
01 32 01 N021	Reactor Low Water Level A
CY 1 12 N021	
CY 1 57 N023	Reactor Low Water Level C
CY 2 04 N024	Reactor Low Water Level D
CY 3 35 N022	Reactor Low Water Level B
01 34 45 A058	IRM Upscale Trip on Level F
CY 4 30 A058	
01 34 48 A057	IRM Upscale Trip on Level D
CY 7 36 A057	
CY 8 07 N057	
CY 8 13 A057	

Table 2-1 Event Sequence Recorder Printout

CY 0 26 N058	IRM Upscale Trip on Level F
CY 0 49 A056	IRM Upscale Trip on Level B
CY 0 55 N056	
CY 1 01 A056	
CY 1 16 N056	
CY 1 41 A056	
CY 1 48 N056	
CY 1 56 A056	
CY 2 21 N057	IRM Upscale Trip on Level D
CY 4 14 N056	IRM Upscale Trip on Level B
01 42 00 A035	Reactor Trip Actuator A1 or A2
CY 9 23 A035	
01 42 37 N035	
CY 6 35 N035	
CY 6 36 N036	Reactor Trip Actuator B1 or B2
CY 8 05 N034	Reactor Scram Manual B
CY 8 06 N033	Reactor Scram Manual A
01 45 17 A035	Reactor Trip Actuator A1 or A2
CY 6 47 A035	
CY 47 A036	Reactor Trip Actuator B1 or B2
01 45 36 N002	Discharge Volume High Water Level B
CY 6 09 N002	
CY 6 16 A002	
01 46 30 A031	Reactor Scram Manual B
CY 9 48 A034	
CY 9 48 A033	Reactor Scram Manual A
01 47 43 N035	Reactor Trip Actuator A1 or A2
CY 2 37 N035	
CY 2 38 N036	Reactor Trip Actuator B1 or B2
CY 3 05 N033	Reactor Scram Manual A
CY 3 05 N034	Reactor Scram Manual B
01 57 04 N002	Discharge Volume High Water Level B
CY 3 22 N002	
CY 4 08 N001	Discharge Volume High Water Level A
01 57 34 N004	Discharge Volume High Water Level D
CY 4 07 N004	
CY 4 19 N003	Discharge Volume High Water Level C
02 28 06 D 80	TVA BFUP

0°

EAST | WEST

	02	06	10	14	18	22	26	30	34	38	42	46	50	54	58
59					48	48	48	48	48	48	48				
55				48	48	48	42	48	42	48	48	48			
51			48	48	48	48	48	48	48	48	48	48	48		
47		48	12	48	0	48	8	48	8	48	0	48	12	48	
43	48	48	42	48	48	48	48	48	48	48	48	48	48	48	48
39	38	48	48	48	0	48	48	48	48	48	12	48	48	48	33
35	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
31	48	48	0	48	48	48	8	48	8	48	48	48	0	48	48
27	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
23	38	48	48	48	0	48	48	48	48	48	0	48	48	48	38
19	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
15		48	12	48	0	48	8	48	8	48	0	48	12	48	
11			48	48	48	48	48	48	48	48	48	48	48		
07				48	48	48	42	48	42	48	48	48			
03					48	48	48	48	48	48	48				

180°

Figure 2-1 Control Rod Positions Before First Manual Scram

0°

EAST | WEST

	02	06	10	14	18	22	26	30	34	38	42	46	50	54	58
59					40	4	36	42	0	0	0				
55				36	46	38	2	0_W	0	0	0	0			
51			36	34	0	36	42	10	0	0	0	0	0		
47		42	0	20	0	24	0	0_W	0	0	0	0	0	0	
43	12	40	44	0	30	28	40	38	0	0	0	0	0	0	0
39	24	0	40	0	0	34	32	0_W	0	0	0	0	0	0	0
35	30	4	38	0	18	8	34	30	0	0	0	0	0	0	0
31	22	10	0	34	28	2	0	0_W	0	0	0	0	0	0	0
27	42	36	30	14	26	28	36	24	0	0	0	0	0	0	0
23	8	0	38	32	0	12	36	2_W	0	0	0	0	0	0	0
19	34	42	34	20	10	28	22	26	0	0	0	0	0	0	0
15		40	0	36	0	38	0	0_W	0	0	0	0	0	0	
11			26	6	14	40	40	24	0	0	0	0	0		
07				0	40	2	0	0_W	0	0	0	0			
03					28	42	42	30	0	0	0				

180°

Figure 2-2 Control Rod Positions After First Scram

0°

EAST | WEST

	02	06	10	14	18	22	26	30	34	38	42	46	50	54	58
59					30	0	14	18	0	0	0				
55				26	42	28	0	0	0	0	0	0			
51			12	22	0	28	34	0	0	0	0	0	0		
47		30	0	0	0	12	0	0	0	0	0	0	0	0	
43	0	30	38	0	14	4	30	26	0	0	0	0	0	0	0
39	8	0	30	0	0	26	14	0	0	0	0	0	0	0	0
35	14	0	30	0	4	0	22	20	0	0	0	0	0	0	0
31	8	0	0	14	12	0	0	0	0	0	0	0	0	0	0
27	26	22	20	2	12	12	16	2	0	0	0	0	0	0	0
23	0	0	30	20	0	0	16	0	0	0	0	0	0	0	0
19	10	26	24	0	0	8	6	4	0	0	0	0	0	0	0
15		18	0	18	0	28	0	0	0	0	0	0	0	0	
11			12	0	0	32	30	14	[illegible]	0	0	0	0		
07				0	30	0	0	0	0	0	0	0			
03					2	34	22	4	0	0	0				

180°

Figure 2-3 Control Rod Positions After Second Scram

0°

EAST | WEST

	02	06	10	14	18	22	26	30	34	38	42	46	50	54	5[illegible]
59					24	0	0	0	0	0	0				
55				20	40	22	0	[illegible]	[illegible]	0	0	0			
51			0	16	0	24	30	0	0	0	0	0	0		
[illegible]		26	0	0	0	6	0	0	0	0	0	0	0	0	
43	0	24	36	0	2	0	24	18	0	0	0	0	0	0	0
39	2	0	24	0	0	20	0	0	0	0	0	0	0	0	0
35	6	0	26	0	0	0	14	'6	0	0	0	0	0	0	0
31	0	0	0	2	4	0	0	0	0	0	0	0	0	0	0
27	18	16	14	2	4	6	2	0	0	0	0	0	0	0	0
23	0	0	26	12	0	0	2	0	0	0	0	0	0	0	0
19	0	16	18	0	0	0	2	2	0	0	0	0	0	0	0
15		4	0	10	0	0	0	0	0	0	0	0	0	0	
11			6	0	0	28	26	8	0	0	0	0	0		
07				0	24	0	0	0	0	0	0	0			
03					0	30	10	0	0	0	0				

180°

Figure 2-4 Control Rod Positions After Third Scram

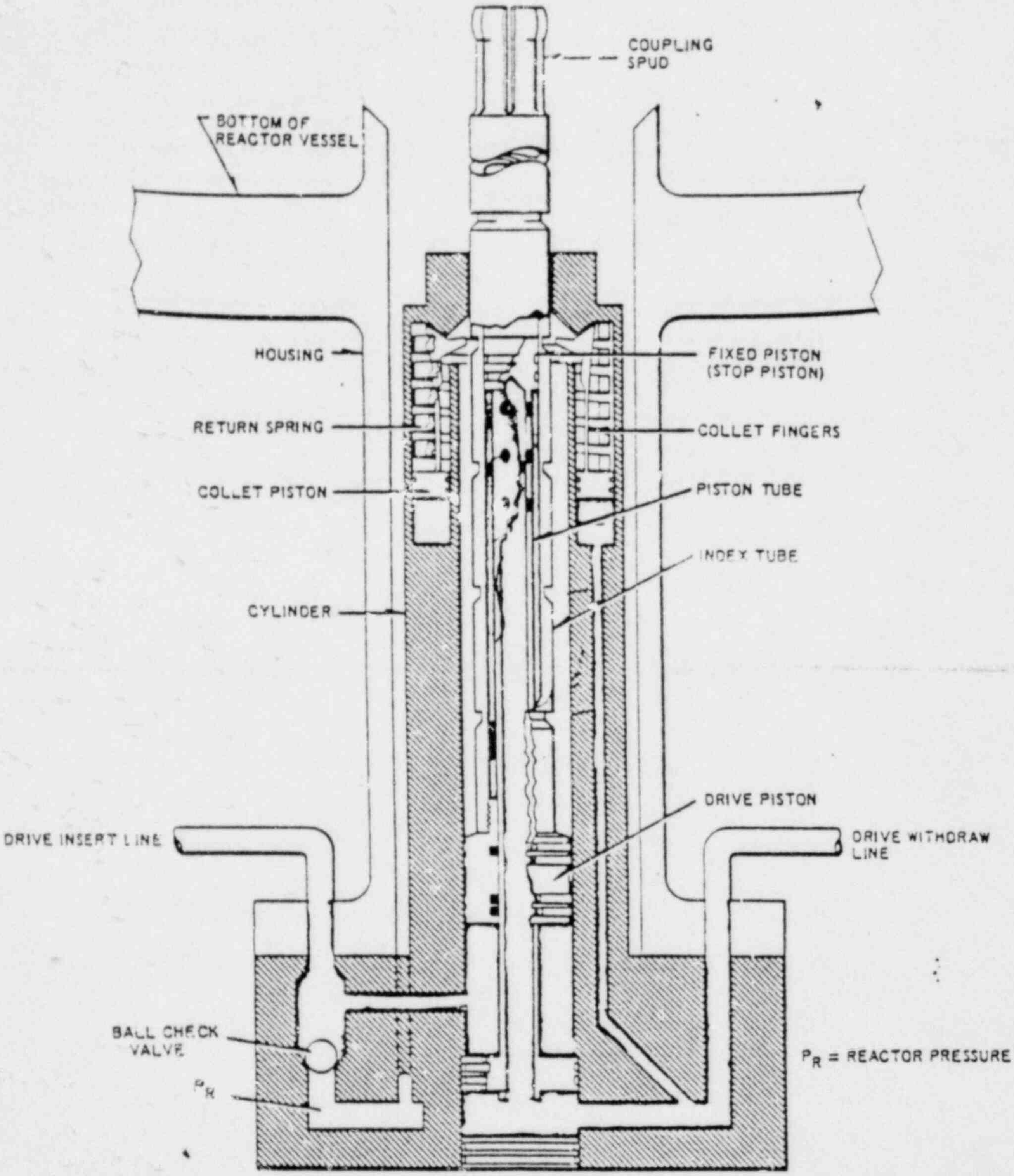


Figure 3-1 Control Rod Drive

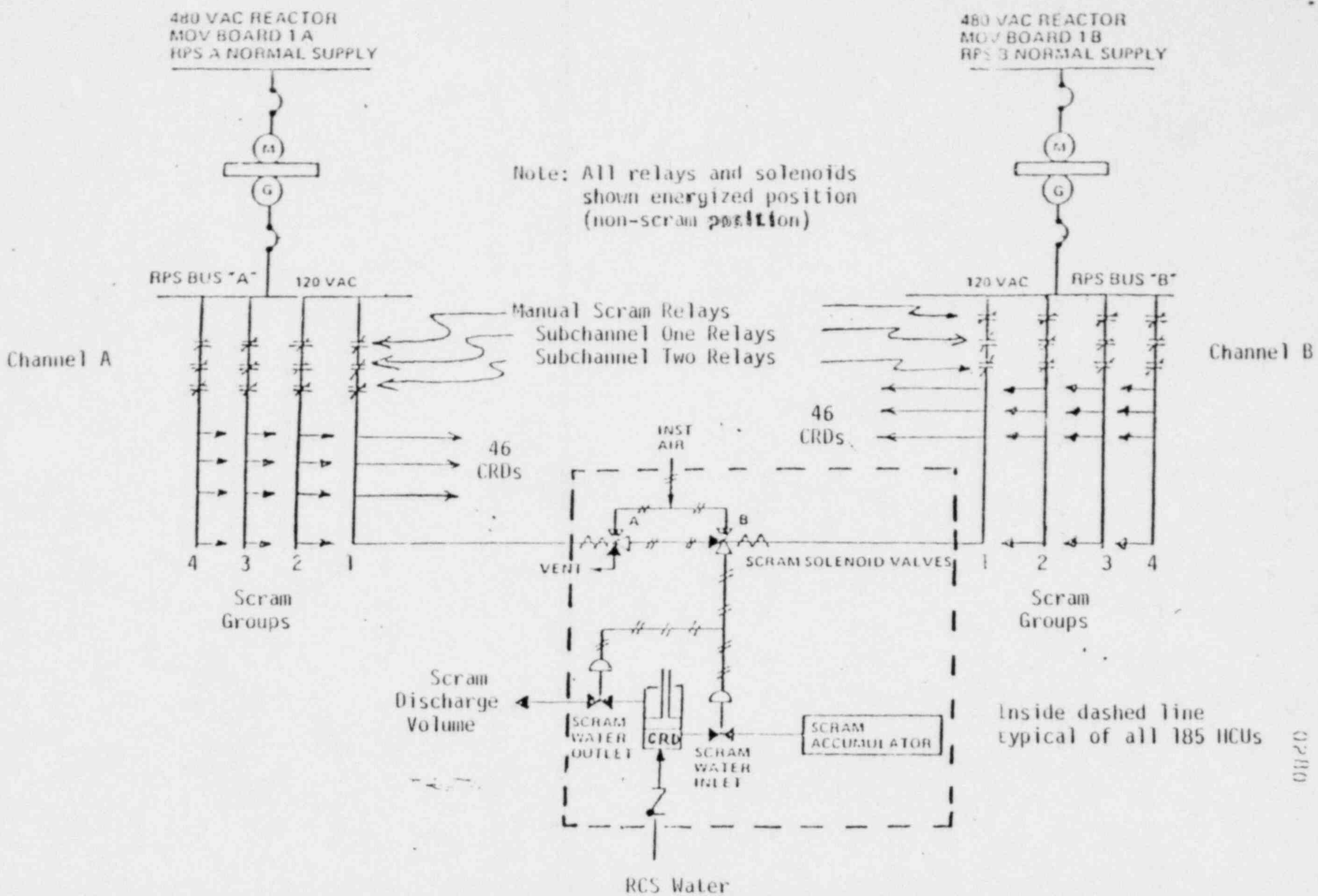


Figure 3-2 Scram Electrical Diagram

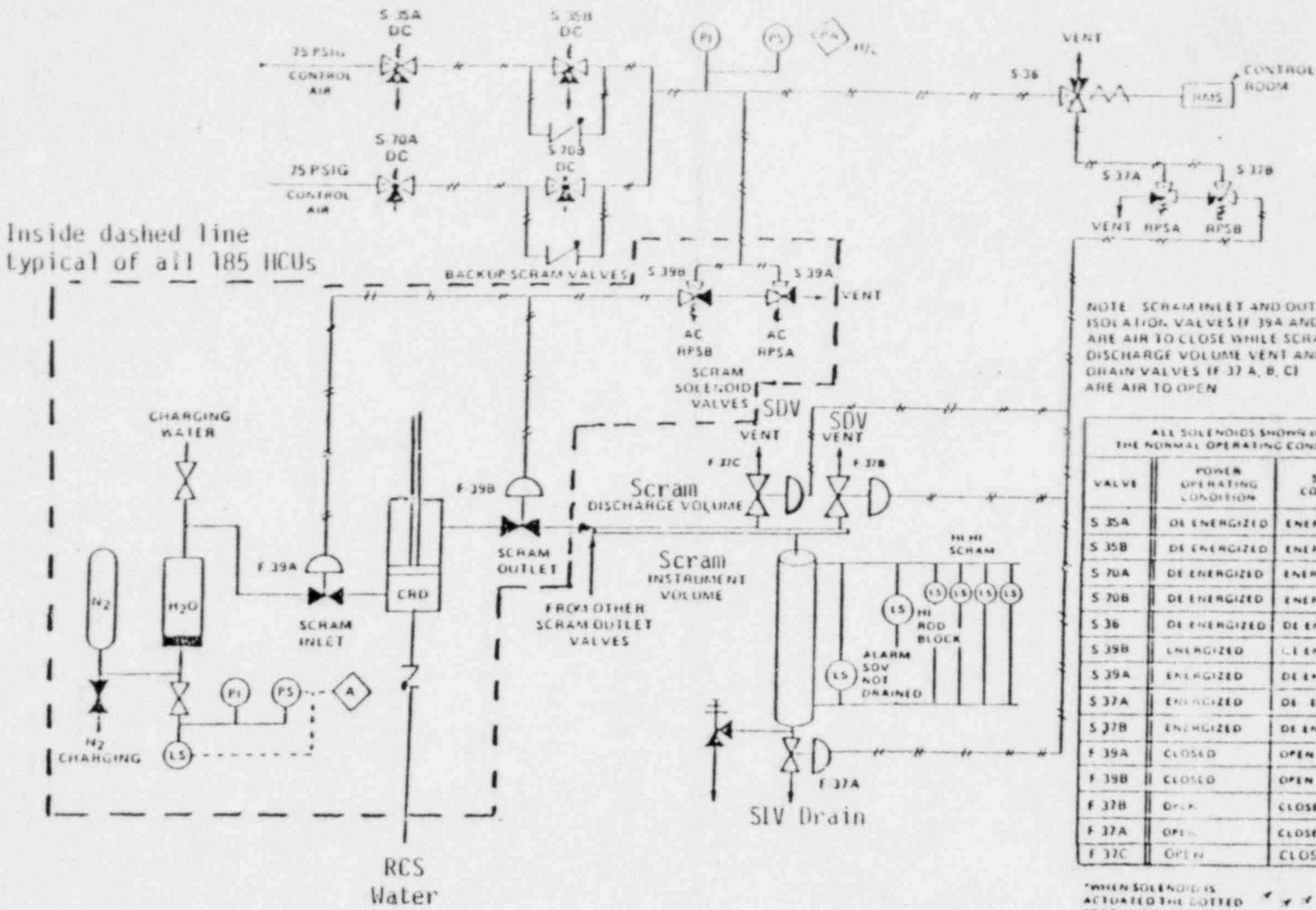
0°

East | West

	02	06	10	14	18	22	26	30	34	38	42	46	50	54	58
59					2	1	3	4	2	1	3				
55				3	4	2	1	3	4	2	1	3			
51			1	3	4	2	1	3	4	2	1	3	4		
47		1	3	4	2	1	3	4	2	1	3	4	2	1	
43	2	1	3	4	2	1	3	4	2	1	3	4	2	1	3
39	4	2	1	3	4	2	1	3	4	2	1	3	4	2	1
35	4	2	1	3	4	2	1	3	4	2	1	3	4	2	1
31	2	1	3	4	2	1	3	4	2	1	3	4	2	1	3
27	2	1	3	4	2	1	3	4	2	1	3	4	2	1	3
23	4	2	1	3	4	2	1	3	4	2	1	3	4	2	1
19	4	2	1	3	4	2	1	3	4	2	1	3	4	2	1
15		1	3	4	2	1	3	4	2	1	3	4	2	1	
11			3	4	2	1	3	4	2	1	3	4	2		
07				3	4	2	1	3	4	2	1	3			
03					4	2	1	3	4	2	1				

180°

Figure 3-3 Control Rod Scram Group Assignment



NOTE SCRAM INLET AND OUTLET ISOLATION VALVES (F 39A AND F 39B) ARE AIR TO CLOSE WHILE SCRAM DISCHARGE VOLUME VENT AND DRAIN VALVES (F 37 A, B, C) ARE AIR TO OPEN

ALL SOLENOIDS SHOWN IN THE NORMAL OPERATING CONDITION		
VALVE	POWER OPERATING CONDITION	SCRAM CONDITION
S 35A	DE ENERGIZED	ENERGIZED
S 35B	DE ENERGIZED	ENERGIZED
S 70A	DE ENERGIZED	ENERGIZED
S 70B	DE ENERGIZED	ENERGIZED
S 36	DE ENERGIZED	DE ENERGIZED
S 39B	ENERGIZED	DE ENERGIZED
S 39A	ENERGIZED	DE ENERGIZED
S 37A	ENERGIZED	DE ENERGIZED
S 37B	ENERGIZED	DE ENERGIZED
F 39A	CLOSED	OPEN
F 39B	CLOSED	OPEN
F 37B	OPEN	CLOSED
F 37A	OPEN	CLOSED
F 37C	OPEN	CLOSED

*WHEN SOLENOID IS ACTUATED THE DOTTED PORT AND THE CLOSED PORT WILL SWITCH POSITIONS

Figure 3-4 Scram Valve Arrangement

0280

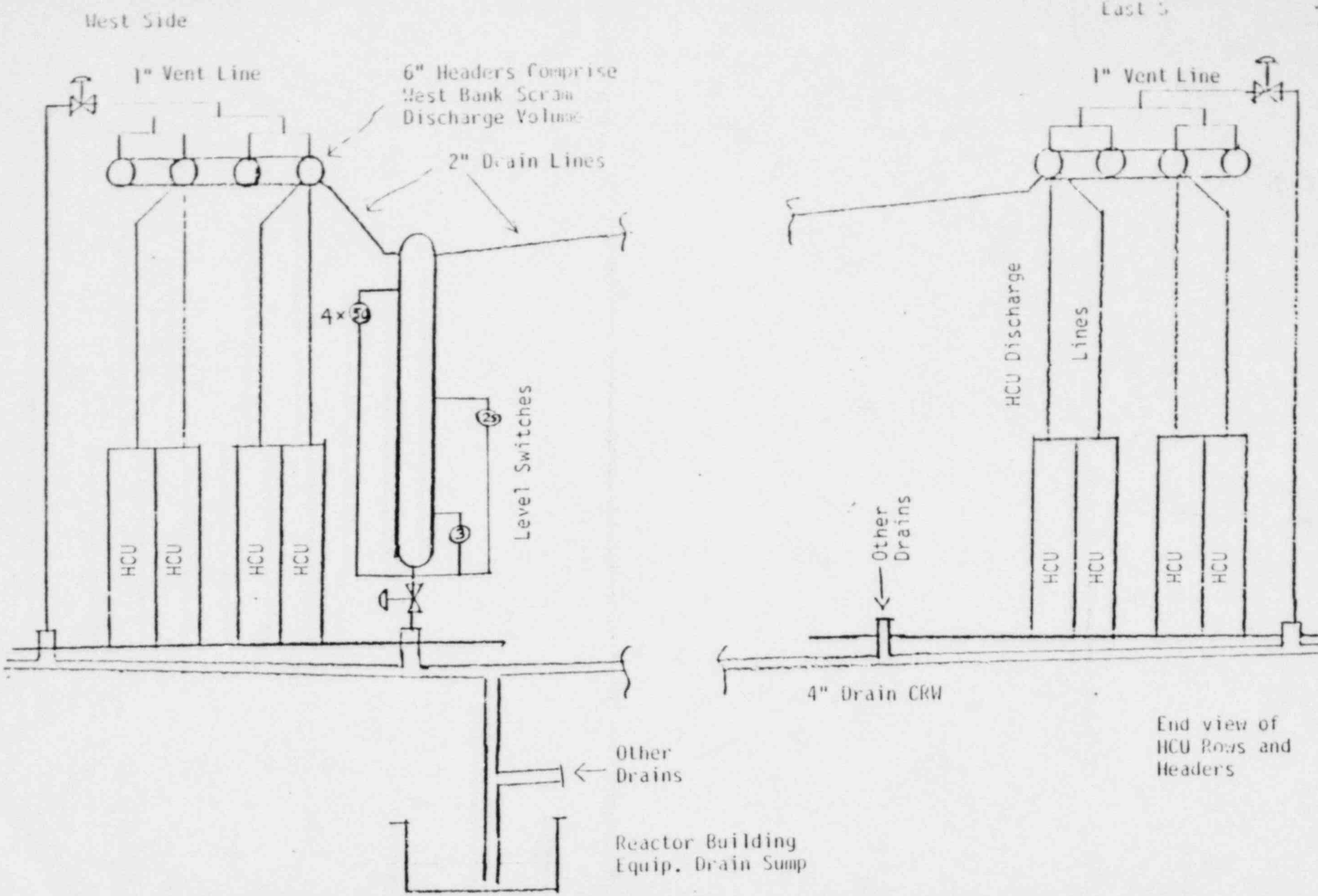
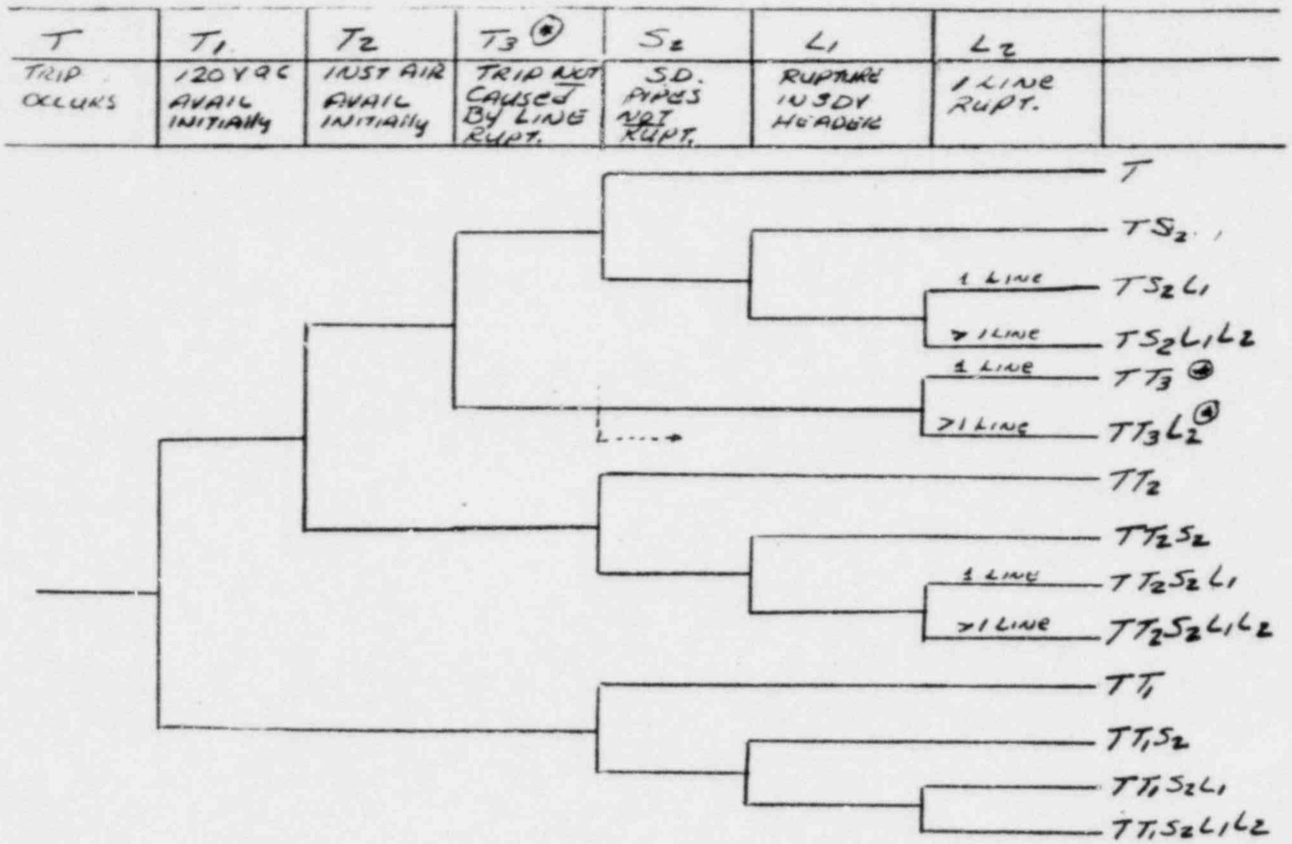


Figure 3-5 Scram Volume Drain Arrangement



24

* T_3 DENOTES PIPING FAILURE (RUPT.) UPSTREAM OF SCRAM VALVES USED FOR ISOLATION (IE. BETWEEN CONT. PENT. & SCRAM VALVE)

- BWR Rebaselined -

#	RSS - SEQ	PROB	Est. Time of Rel.	Est. Characteristics: Release Duration	Warning Time	Height of Release	Est. Heat	Est. Fract. Rel. to Atmosphere: Xe-Kr	I-Br	CsRb	Te	BaSr	Ru	LA
α_1	$AE\alpha_1$, $S_1E\alpha_1$	$\sim 5\times10^{-9}$	0.8	Puff 0.5	0.5	25	$\sim 120\times10^{6}$	1.0	.29	.57	.42	.071	.29	.00[illegible]
α_2	$AE\alpha_2$, $S_1E\alpha_2$	$\sim 10^{-9}$	←	SAME			→	1.0	.024	.04	.3	.0025	.28	.002
								SUPP. POOL DF ≈ 100						
				DIRECT TO Atms										
γ_1'	$TC\gamma'$	$\sim 2\times10^{-6}$	~1.5	~2	≲1	0	$\sim 1\times10^{-6}$	1.0	.45	.67	.64	.073	.052	.0083
γ_2'	$TW\gamma'$	$\sim 3\times10^{-6}$	~50 hr	~2	> 40 hr	0	$\lesssim 1\times10^{6}$	1.0	.098	.27	.41	.025	.028	.005
γ_3'	Σ $AE\gamma'$, $S_1E\gamma'$, $S_2E\gamma'$ etc. TQUV γ'	$\sim 3\times10^{-7}$	~2.0	Puff release 0.5	~1.0	0	$\sim .25\times10^{6}$	1.0	.095	.30	.36	.034	.027	.005
				ANNULUS (To Confinement BLDG.)										
γ_1	$TC\gamma$	$\sim 8\times10^{-6}$	~1.5	~2	1.0	25	assume Small	1.0	.07	.14	.12	.016	.01	.002
γ_2	$TW\gamma$	$\sim 1\times10^{-5}$	~50	~2	> 40 hr.	25	assume Small	1.0	.003	.11	.083	.011	.007	.001
γ_3	TQUV γ, $S_2E\gamma$, $S_1E\gamma$, $AE\gamma$ etc	$\sim 10^{-6}$	~3.5	Puff release 0.5	~1.0	25	assume Small ↑ goes thru Conf. Bldg.	1.0	.02	.055	.11	.006	.007	.0013

$T \approx 15/RY$

T_1 = LOSS of 120 Vac (ASSUME LOSS of 2 INVERTERS WILL CAUSE T_1

OPER. DATA INDICATES $\sim 4/180RY \approx 2 \times 10^{-2}/RY$

LIMITED BASE.

$T_2 \approx$ LOSS of INST AIR $\sim$ 4 CASES INDICATED IN LERS $\frac{4}{225}(.65) \approx 2.7 \times 10^{-2}/RY$

T_3