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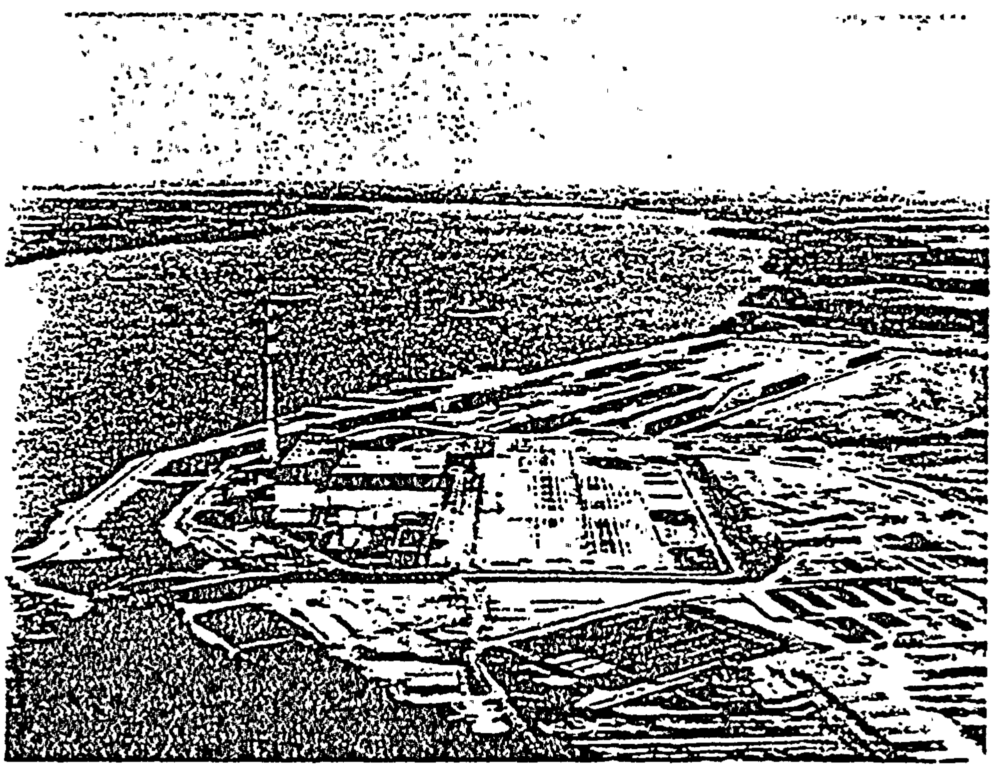
December 1980

# Analysis of Incomplete Control Rod Insertion at Browns Ferry 3



Nuclear Safety Analysis Center
Institute of Nuclear Power Operations

# Analysis of Incomplete Control Rod Insertion at Browns Ferry 3

NSAC-20/INPO-3

December 1980

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## ORDERING INFORMATION

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ABSTRACT

The failure of 77 control rods in the Browns Ferry 3 reactor to scram completely on June 28, 1980 has been analyzed. It is concluded that the cause of the incident was that one half of the scram discharge volume, which should have been empty in order to receive the water from the control rod drives, actually was almost full of water.

Any one, or a combination, of several mechanisms can contribute to accumulation of water in the SDV under certain conditions. It appears possible that there was an obstruction or a trap in the scram discharge volume exit line which impeded its drainage. Condensation of steam from other parts of the clean rad waste drain system in the scram discharge volume may also have contributed to water accumulation.

Despite extensive investigation and analysis by TVA and others a unique cause has not been established. Possible ways in which the above cited mechanisms could have been operative are pointed out, and suggested ways for guarding against them are given.

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Glossary

Analysis of
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Browns Ferry 3

## 1. Introduction

This report presents the results of a study by NSAC and INPO of the June 28, 1980 incident at the Browns Ferry Unit 3 reactor in which 77 of the full complement of 185 control rods inserted only partially when a manual scram was attempted. The purpose of this report is to present a description of the incident, and some possible causes.

In carrying out this analysis, NSAC and INPO performed a preliminary review at the site on July 3, 4, and 5. Team briefings and meetings were held with General Electric and Tennessee Valley Authority, and individual consultations were held with GE, TVA, and several utilities. NSAC and INPO also participated in several industry and NRC meetings on the incident.

NSAC/INPO contributors to this evaluation were:

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Mr. S. L. Rosen

Utility representatives who also contributed were:

Mr. B. L. Clark, Philadelphia Electric
Mr. B. B. Palagi, Commonwealth Edison
Mr. John Stetz, Northeast Utilities

## 2. Executive Summary

### Event

During a routine manual scram of the Browns Ferry 3 reactor, 77 control rods failed to insert completely.

### Background

On June 28, 1980, a manual scram of the Browns Ferry 3 reactor* was attempted in conjunction with a planned shutdown for repair of a feedwater line in the turbine building. Aside from the need for this repair, plant conditions were normal.

The shutdown procedure involved first lowering the reactor power level to 36% by reducing the recirculation flow and inserting a number of control rods to decrease the neutron chain reaction; and secondly pushing the manual scram buttons to insert all control rods completely to terminate the neutron chain reaction. Complete control rod insertion is normally accomplished in less than 3 seconds after both scram buttons are pushed. In this incident, normal control rod insertion did not occur when the scram buttons were pushed.

### Description of Event

Of 185 control rods, 10 were fully inserted prior to the manual scram. 77 rods failed to insert fully upon manual scram, with insertion ranging from position 02 (95% inserted) to position 46 (5% inserted). Observing this, the operator reset the scram; this procedure allows recharging of nitrogen-pressurized accumulators and draining of the scram discharge instrument volume. Manual scram was repeated. Insertion progressed somewhat, but 59 control rods remained only partially inserted. After a third reset and manual scram, 47 remained partially inserted.

Recharging and draining of the scram discharge instrument volume was repeated and the scram instrumentation automatically initiated a fourth scram. All rods were now fully inserted, placing the reactor in normal shutdown condition. This was accomplished within about 14 minutes of the first scram.

* Unit 3 is a 1067 Mw(e)net. General Electric boiling water reactor, in commercial operation since March 1, 1977.

The following observations are significant:

The first scram decreased the chain reaction so that the smeared average fission power level was about 2% of full power. The second scram terminated the chain reaction so that the only remaining heat generation was normal decay heat generation.

There were no indications that delay of full insertion until the fourth scram caused any damage to fuel, to the reactor, or to any other part of the plant.

Natural circulation core flow provided more than adequate overall core cooling.

General Electric calculations indicate that no fuel operating limits were exceeded.

## Scope of Analysis

This is the only known instance of a large number of control rods failing to insert completely on demand. Because of the crucial importance of being able to shut the reactor down quickly and reliably when needed, the reactor owner, the reactor designer, the NRC, and a joint NSAC-INPO team attempted to determine the causes of this failure to achieve full insertion on the first scram.

Efforts were also directed at identifying measures to prevent a repetition of this or similar failures in this and any other boiling water reactor. The failure was of further interest to NSAC and INPO as a possible precursor to more serious events.

## Findings

After the first scram attempt, the operators observed that all but one of the control rods which failed to insert were on the east half of the reactor.* This behavior of the system led plant personnel and others to believe that the east scram discharge volume (SDV), a void into which reactor water is displaced when

* The scram hydraulic system is shown diagrammatically in Fig. 1. The arrangement of the scram discharge volume is shown in Figs. 2 and 3.

high pressure water drives the east side control rods into the reactor, was for some reason already almost filled with water prior to the scram. The SDV could not accommodate the additional water discharged into it during a normal scram and therefore insertion was impeded. This conclusion has since been re-examined and stands generally accepted. Other possible causes of the incomplete scram have been analyzed and largely ruled out. The origin of the water in the SDV and the cause of its accumulation have not been firmly established, but several possible explanations have emerged. None individually can be confirmed, and a combination of them is also a possibility:

There may have been an obstruction in the 170' long 2" pipe which connects the east scram discharge volume to the scram discharge instrument volume (SDIV). This line has only a very slight slope for drainage, and a slight obstruction would have been sufficient to back up water into the scram discharge volume prior to the scram. It has been theorized that such an obstruction could have been disturbed and relocated by the violent hydraulic action in the SDV after the multiple scrams which took place. It is not possible to state with assurance, though, that such an obstruction actually did exist. It has been suggested that the obstruction could have been formed by the accumulation of solid crud. Solid crud has been found in level switches on the scram discharge instrument volume. However, no positive evidence of an obstruction in the 170' long 2" line has been found.

A combination of trapping action in the east SDV vent line and in the east SDV-SDIV 2" connector pipe, together with condensation of steam in the east SDV, may have produced a partial vacuum. The occurrence of such a partial vacuum has been observed in the SDIV of Browns Ferry 1, which is very similar in piping configuration to Browns Ferry 3, and on at least two other BWRs. There is no proof, however, that this was the cause of the incident.

Either of the foregoing may have been aggravated by momentary pressure or vacuum surges in the clean radwaste (CRW) drain system caused by large influxes of water from sources other than the SDIV. Both the SDV vent lines and the SDIV drain line discharge into the CRW drain system. This hydraulically complex system receives intermittent drainage from approximately 50 other sources. Some of that drainage is frequently hot water, which could increase pressure or suction surges.

## Conclusions

Since it has been impossible to determine whether any of these possibilities or combinations of them were responsible for the incident, corrective action recommendations should be comprehensive enough to guard against all of them. It is concluded, therefore, that appropriate steps should be taken by all BWR plants to guard against:

- An obstruction in the SDV-SDIV connection pipes.
- A configuration of the SDV-SDIV connector or vent pipes capable of producing a trap or loop seal. Such a trap or loop seal could possibly be the result of thermal expansion during hot conditions although it may not be present in a cold environment.
- Interference by the CRW drain system with the operation of the SDV-SDIV system.
- Failure of the SDV vent line valves to open.
- Too slow drainage of the SDIV due to inadequate vent or drain capacity.

The review team also examined the procedures available to the operator for an event of this type, and the response of the operators to those procedures, particularly with respect to the criteria for deciding whether to inject sodium pentaborate from the standby liquid control system. It is concluded that these criteria should provide more explicit guidance in determining the need for sodium pentaborate injection.

The conclusions outlined above are intended to apply to all BWRs with hydraulic control rod drives, operating or in construction. It is recognized that the specific corrective measures which should be taken will vary from plant to plant because of design variations and differing procedures.

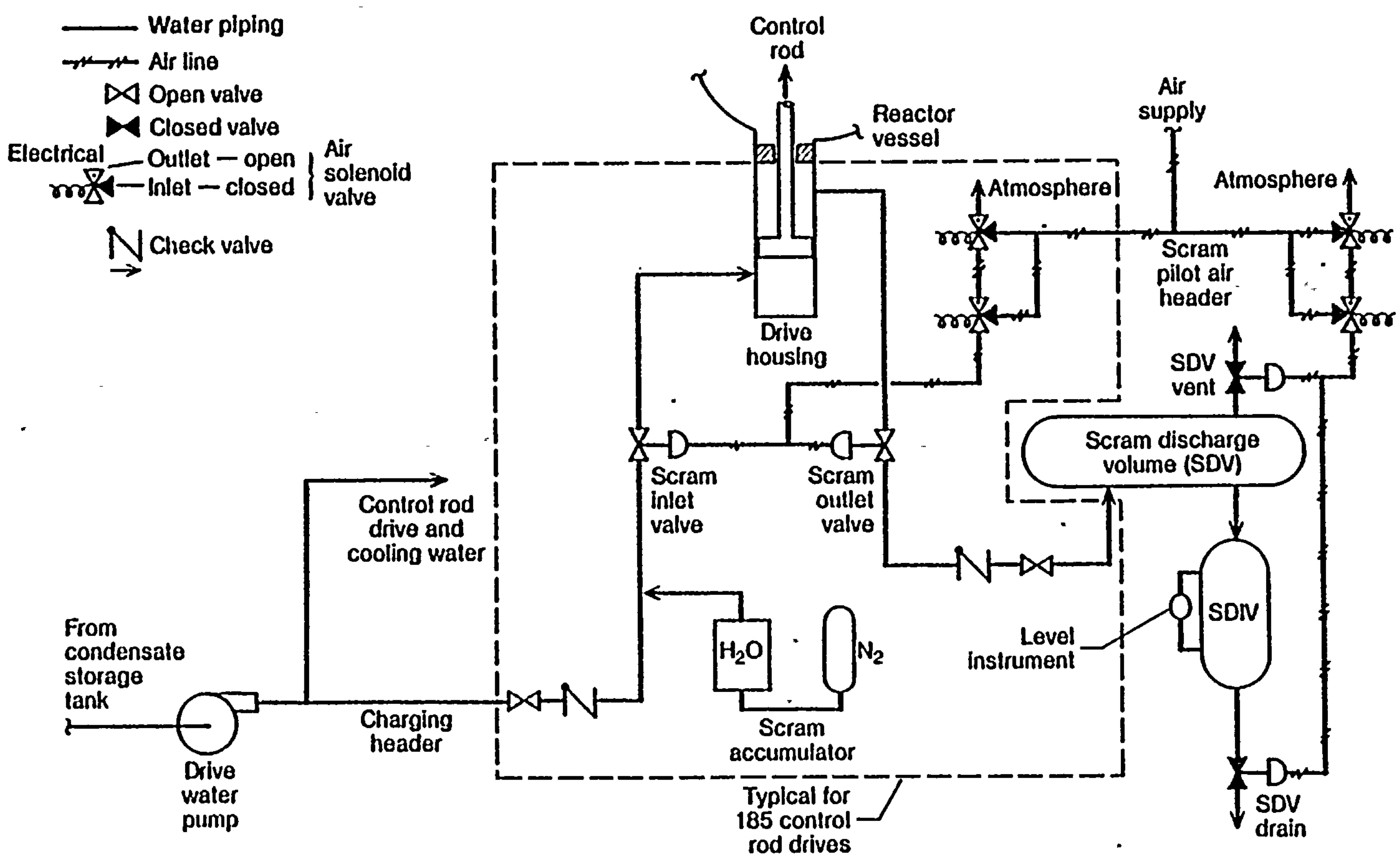


Figure 1. BWR Scram Hydraulic System (scrammed valve lineup)

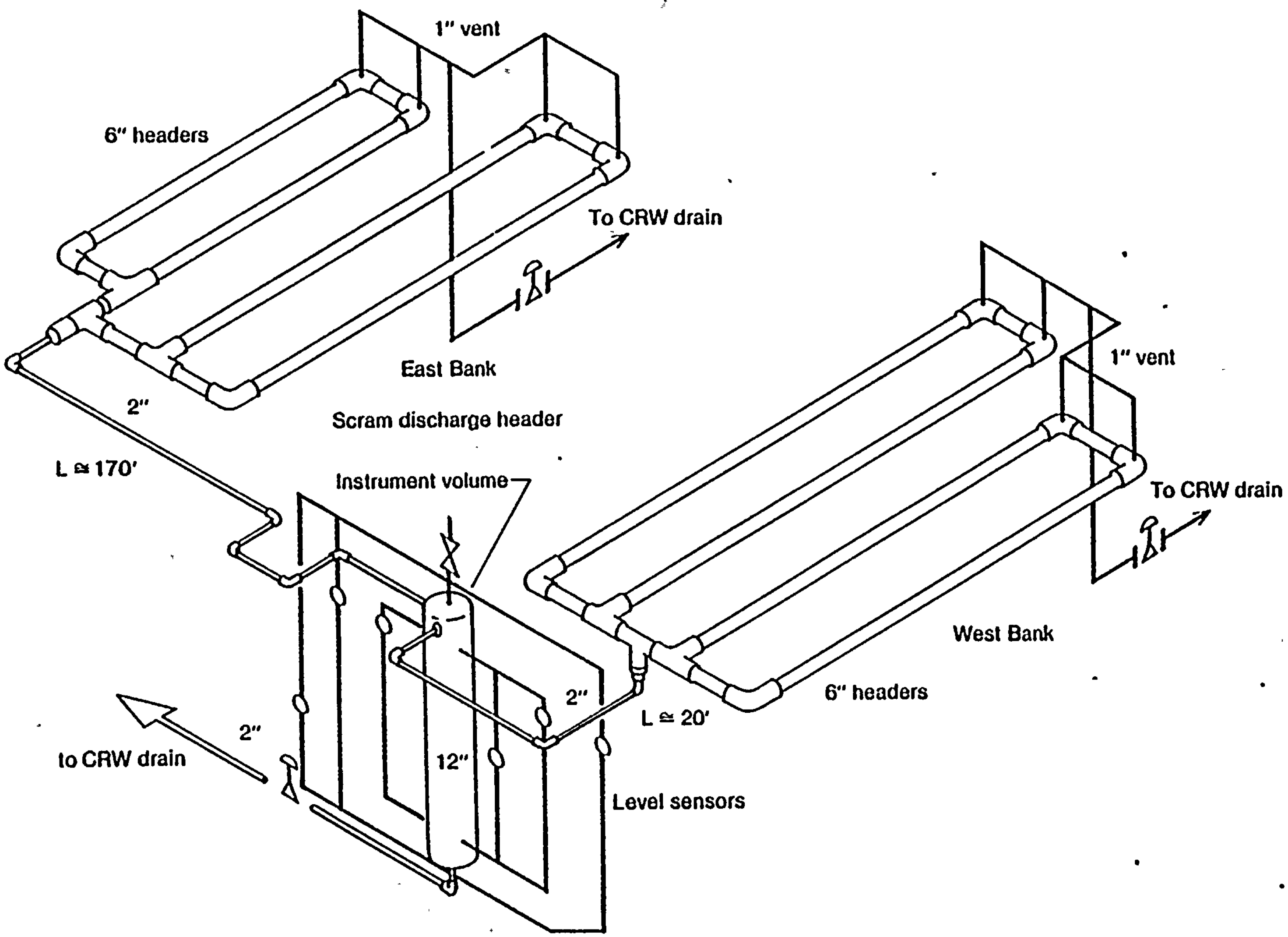


Figure 2. Browns Ferry SDV Equipment Layout (isometric view)

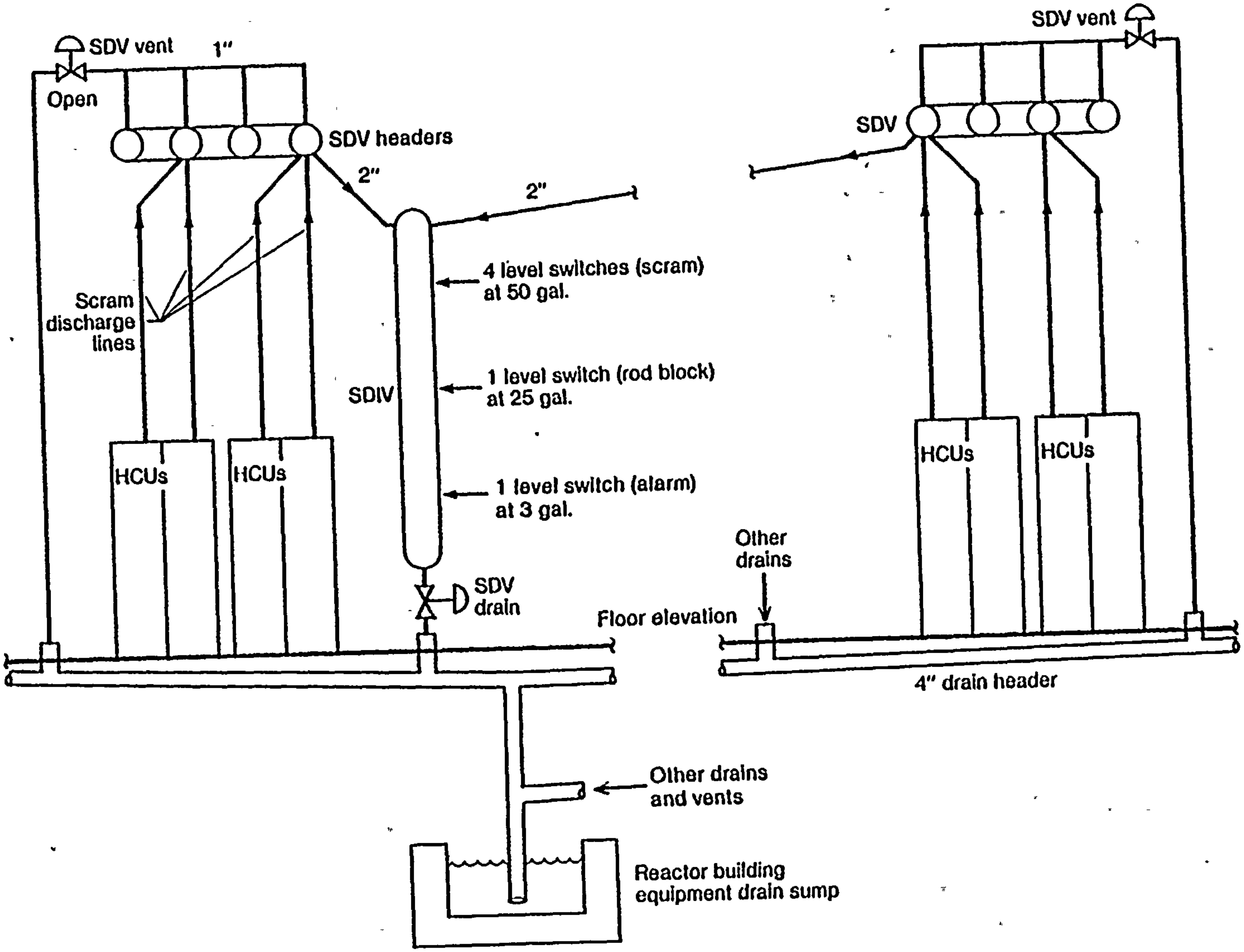


Figure 3. Sketch of Browns Ferry SDV Equipment Layout (elevation)

## 3. Summary Description of Incident

On June 28, 1980, it was necessary to shut down the Browns Ferry 3 (BF-3) reactor. This shutdown, which had been planned for a couple of days, was necessary in order to repair a feedwater line in the vicinity of one of the feedwater pumps.

The shutdown was taking place according to normal procedure. Power was first reduced to 390 Mwe (36% of rating) by decreasing recirculation flow and inserting 10 control rods. The operator then initiated a manual scram to complete the shutdown. All control rod drives received a scram signal as reported by the operators and the shift technical advisor. All 92 of the withdrawn west bank control rods inserted fully, except rod 30-23 which settled at position 02.* (It is not unusual for a rod to settle at position 02, i.e., 95% inserted, and it is of little reactivity significance since practically all the reactivity effect of the control rod is associated with the first 95% of its insertion.) However, of the 88 east bank rods withdrawn, 76 failed to insert fully, coming to rest at various positions in the range 46 (inserted 6") to 02 (inserted 138" with only 6" remaining to complete insertion). The average core fission power was reduced to less than 2% as reported by GE (Ref. 1) and as inferred from recorded LPRM (local power range monitor) readings after the first scram.

Upon observing that many rods remained only partially inserted, the operators re-set the scram after 271 seconds, resulting in opening the vent and drain valves in the scram discharge system so that water could drain from it, and at 364 seconds repeated the manual scram. All of the partially inserted rods moved inward, but some remained still only partially inserted. At 423 seconds the operators again re-set the scram, and at 476 seconds again repeated the manual scram. Again, those control rods not yet fully inserted moved inward, but some remained only partially inserted. At 682 seconds the operators again reset the scram. Upon removal of the scram discharge volume by-pass the reactor scrammed automatically** on high (50 gal.) volume in the scram discharge instrument volume. This resulted in full insertion of all the control rods which had not already fully inserted.

*Control rod travel is 144". Full in is position 00. Full out is position 48.

**Manual and automatic scrams are functionally identical, so the fact that it was an automatic scram which finally inserted all rods is not significant.

Following the fourth scram, a fifth confirmatory scram was executed and, upon ascertaining that the reactor was shut down and being cooled in a normal manner, numerous tests and observations were undertaken to ascertain the cause of the failure to achieve immediate and complete insertion of all control rods. The tests and observations included the following: (Ref.2)

- Off gas and reactor coolant analyses
- Control Rod Drive Hydraulic Control Unit valve lineup
- Control Rod Drive Accumulator re-charge
- Exercising SDIV and SDV drain and vent valves
- Disassembly and inspection of vent and drain valves
- Vent system vacuum test
- SDIV level switch calibration
- Flushing SDIV level switch taps and examination for solid material
- Review of scram history at Browns Ferry (320 scrams successful except for a few instances of latching at position 02)
- Control rod drive maintenance history review
- Review of other maintenance and modification work on BF-3
- Verification of scram actuator de-energization time
- Measurement of control rod drive stall flows and friction
- Review of CRD temperature charts (high temperature could signal excessive water leakage through the drives)
- The 170' long 2" east connector pipe was cut in six places and rodded with a metallic tape to detect any blockages
- System flushing with water (after cutting the pipe)
- SDV inspection with a boroscope (after cutting the pipe)
- Measurement of elevations at various points on the east SDV connector pipe (after cutting and re-assembling the pipe)
- Measurement of SDV slope
- Routing and configuration of air lines traced out
- Unit 3 reactor building sump (reactor building equipment drain tank, RBEDT) inspected with an underwater TV camera and also raked for solid objects
- Drainage times for the east and west SDVs, with and without the vent valves being open
- Monitoring of the equipment (CRW) drain header for possible vacuum during the drainage time tests
- Individual scrams of all rods which failed to insert normally
- Manual and automatic scrams from power

These tests and observations failed to lead to a clear understanding of the cause of the incident. The drain time tests showed that both the east and west SDVs would drain when the SDIV drain valve was opened, whether the SDV vent valves were open or not. The time required to drain the entire system with the vent valves open was about 30 minutes. With the vent valves closed the drainage time was estimated to be several hours, but drainage did occur. (The postulated blockage would not have been present during these tests.) With few exceptions these tests and observations indicated that the system was at the time of the tests capable of operating normally and as intended. The principal exceptions were that the low level (3 gal.) and rod block (25 gal.) SDIV switches did not operate during the first calibration fill, and the SDIV west vent valve operator was found to have a broken air tube and an air leak. However, recorded data and operator reports indicate that all of the SDIV level instrumentation worked during at least part of the incident. The significance of the SDIV west vent valve air leaks has not been established but is not believed to be appreciable. (On July 8 the reactor was shutdown briefly because of a bent stem on SDIV drain valve, but TVA states that this damage occurred after the incident of June 28.)

These tests established that the rate of drainage from the SDIV drain valve can exceed that from the east SDV bank. Hence, the fact that the SDIV instruments signal that little or no water is present there during drainage does not necessarily mean that the east SDV has drained completely. However, absent a trap or obstruction in the SDV connector pipe, it would not be expected that drainage of the east SDV would significantly lag drainage of the SDIV.

The reactor has operated normally since being restarted July 9, with no indications of damage to any equipment or the fuel. (See Appendix CON.)

## 4. Findings and Conclusions

### 4.1 Principal Findings and Conclusions

The review team's principal findings and conclusions are that:

a) the failure to achieve complete insertion of 76 of the control rods in the east half of the Browns Ferry Unit 3 reactor when it was manually scrammed on June 28 was due to water occupying a large part of the east bank of the scram discharge volume, and

b) the source of this water and why it was present at this particular time has not been positively determined and, due to lack of evidence, may never be determinable with certainty. However, at least three plausible explanations have been developed from the available evidence, namely:

1. There may have been a solid obstruction, at some point between the lower end of the scram discharge volume (SDV) and the scram discharge instrument volume (SDIV), of sufficient size and strength to cause water to back up in the east SDV. It has been calculated by GE (Ref. 1) that, if the SDV were 85-90% full of water, the presence of this water plus the postulated obstruction in the 2" connector pipe would be sufficient to account for the failure of 76 control rod drives (CRDs) to complete their stroke. In order to hold up the water in the SDV the postulated obstruction would have to be strong enough only to support a column of water of about 1/2' to 2 1/2' in height, depending on the location of the obstruction in the 2" line. However, it would have had to be strong enough largely to survive the first scram. The obstruction could subsequently have been dislodged and perhaps disintegrated by the build up of pressure in the SDV when the later scrams occurred. The source or sources of the water in the SDV could, in this hypothesis, have been, at least in part,

   Outlet scram valve leakage

   Normal water discharge during and following the preceding (June 6) scram

The vent system (as liquid or as vapor which condensed in the SDV)

This hypothesis has been designated as the "obstruction hypothesis".

2. Traps or loop seals may have existed in the system, particularly in the 2" connector pipe connecting the SDV to the SDIV, which, in conjunction with a partial vacuum in the SDV, would be capable of preventing drainage of water from the SDV. A particular place where, it is postulated, a trap could have existed is in the portion of the 2" line which forms an expansion loop. This loop is in the steam tunnel. No definite evidence of the presence of a trap in the 2" line is available since the line was cut apart (looking for an obstruction) before measurements to detect a trap were made. In this scenario the partial vacuum could have been created by condensation of steam in the east SDV or its vent system. The source of steam could be either the clean radwaste (CRW) sump or thermally hot discharges of CRW into the 8" piping to which the SDV vent line is also connected. The source of the water in the SDV could have been the same as in the "obstruction hypothesis".

   In particular, water may have been forced into or sucked into the scram discharge volume through the SDV vent line as a result of discharges of water from other sources into the clean radwaste drain system, and retained in the SDV by either an obstruction in the 2" SDV-SDIV connector pipe or a trap or loop seal in that line, as in hypothesis 1. This hypothesis has been designated as the "vent hypothesis".

3. The SDV vent valve may have failed in the closed position at the time of the June 6 scram, trapping water in the SDV for the intervening 3 week period. Like the "vent hypothesis", this one probably requires that there be a trap or obstruction in the 170' long 2" connector pipe since it has been demonstrated that the east SDV bank will drain (slowly) even if the vent

valve is closed. This hypothesis has been called the "stuck valve hypothesis".

It is possible that a combination of these mechanisms were operative.

It is obvious that a mechanical obstruction in the 2" line could have essentially the same effect as the hypothesized trap if the obstruction were big enough completely to seal off the pipe. Even if the obstruction were not big enough to seal off the pipe it could still, in effect, reduce the diameter of the pipe, thereby decreasing the size of the dip or hump in the pipe necessary to create the hypothesized trap. Thus, the behavior of the system is explainable by either a trap or a mechanical obstruction in the 2" line.

Our principal conclusion regarding the cause of the presence of water in a large part of the SDV is thus that this water was present due to either an obstruction or to a trapping and partial vacuum mechanism, or to some combination of these which could include failure of the vent valve to open after the June 6 scram.

These findings and conclusions raise certain questions:

- Why is it believed that the incomplete scram was due to the presence of water in the SDV?

- What is the evidence for the presence of an obstruction in the 2" connector pipe?

- What is the evidence for the presence of a loop seal or trap in the 2" connector pipe?

- What is the evidence for the existence of a partial vacuum in the east SDV?

- What is the evidence for the "stuck valve hypothesis"?

- Is there any substantial evidence which is clearly inconsistent with the three hypothesis outlined above?

Additionally the following questions were addressed:

- Did the progress of the incomplete scram subject the fuel to any unusual stress, and if so were any hazards created?

- Were the responses of the operating personnel appropriate for the situation, and were the procedures adequate?

These questions are discussed in the following subsections of this report.

4.2 Cause of the Incomplete Scram

It has been concluded that it was the presence of a large amount of water in the SDV which caused incomplete insertion of 76 control rods by hindering the free discharge of water from the east CRD units. The fault appears to have been hydraulic in nature, not due to any electrical or pneumatic malfunction, and not due to any mechanical malfunction in a CRD or a hydraulic control unit (HCU). This conclusion has been reached partly by elimination of other causes and partly by direct evidence of the hydraulic nature of the problem. The evidence bearing on this conclusion is summarized in the following paragraphs. (Ref: 2). All the tests and observations cited here are those made by GE or TVA personnel.

Electrical Failure

The electrical scram signal is applied to four discrete groups of control rods. Some rods in all groups moved inward toward full insertion. Thus the failure was not one of failure of the scram signal to reach one entire group of the rods. Moreover, all 76 of the rods which did not insert completely moved at least one notch. In tests made after the event the scram circuitry functioned normally and the electrical independence of each rod scram group was verified. The operators report that they observed that all the blue lights on the reactor control panel lighted up. This too indicates that all the individual rod scram valves opened, as required for a scram. These observations and tests show that the problem was not an electrical one concerned with the scram circuitry.

The possibility that the reactor manual control system, which controls and programs electrical power to valves in the CRD hydraulic system for normal insertion or withdrawal of control rods might have interferred with the scram, possibly by introducing a false withdrawal signal to multiple control rods, was considered. This could not cause control rod withdrawal or arrest since the insert force in a scram is about three times as large as the withdrawal force resulting from a manual control signal. It is therefore concluded that the problem was not one connected with the reactor manual control system.

<u>HCU Valve Lineup</u>

The possibility that there could have been an incorrect line up of the valves on the 76 individual hydraulic control units (HCUs) was considered, since closing of the isolation valves on the HCUs could prevent rod motion. All valve lineups were reported to be found, in two independent post-event inspections by GE and TVA personnel, to be correct, so this was not the cause of the partial scram.

<u>Lack of Accumulator Pressure</u>

The possibility that the nitrogen pressure in the scram accumulators might have been too low to get complete scram of all rods was investigated. The control room indications of accumulator pressure during and after the incident were normal. Even had the accumulator pressure been low, scram would have occurred since the design of the drives is such that reactor pressure also scrams the rods. Additionally, once charged, the accumulators are hydraulically isolated from each other and the chance of so many random failures occurring suddenly and simultaneously is very small.

<u>Excessive CRD or Scram Valve Leakage</u>

Abnormal scram valve leakage could have supplied a significant quantity of water to the east SDV bank had it been present at the time of the incident. The possibility that those drives which experienced only partial insertion had suddenly developed leakage of such size as to account for the incomplete insertion was investigated. Such leakage would have had to be very large and would have been signaled by recorded indications of wide spread high CRD temperatures. Inspection of the pertinent recorder charts shows no such indications. Post-event tests indicated that leakage thru closed scram valves from all the drives combined was about 2 gph. Post-event individual stall flow tests indicated that seal conditions were normal in the 76 drives; leakage rates were in the 1.5 - 2.0 gpm range. These results show that individual drive seal leakage was normal, and scram valve leakage was small at the time of the post-event test.

Pneumatic (Instrument Air) System Failure

The possibility of a pneumatic failure has been considered. Complete and detailed information on the layout of this system is not yet available. The available information is that each air-operated scram valve is fed from the instrument air system with no valves intervening between the closest central point of instrument air supply and the individual scram valves except for the individual maintenance valves on each HCU. The design of the system is such that each scram valve is normally held closed by air pressure. Loss of air pressure, whether intentional, by venting the scram pilot valve, or accidental, opens the scram valve causing the CRD to scram. Additionally, back-up scram valves are located on the central instrument air supply to the 370 individual scram valves. Opening of these back-up scram valves removes air pressure from all the scram valves, allowing them to open if they have not already done so. While the air supply to the east and west banks of HCUs necessarily has east and west branches, the available information discloses no way in which the air pressure in the west bank could be released without releasing the air pressure in the east bank also.

The possibility has been considered that some malfunction might have occurred on the east branch of the pneumatic system only. For example, it might be speculated that water had been introduced into part of the instrument air system through a maintenance or modification error, or that the common instrument air dryers had failed to dry the air adequately, resulting in water being accumulated more in the east than in the west branch of the HCU pneumatic system. No evidence for such events has come to light.

The possibility has been considered that the instrument air system pressure might have drifted low enough to allow the scram valves to leak excessively; air pressure is required to keep the valves closed. Such leakage from a large number of drives could have been large enough in the aggregate to cause the east SDV partially to fill with water, even if the 170' long 2" connector pipe had not been obstructed. However, there is no record of a low instrument air system pressure, and without more knowledge of the details of the instrument air system it is not clear how a pressure deficiency in that system could have affected only those scram valves on the east side of the reactor. In any event a deficiency in air pressure would have interferred with scramming only through premature filling of the SDV with water since it is loss of air pressure which causes the scram valves to open. Thus, there is no evidence that the fault was a pneumatic one. However, NSAC intends to investigate this possibility further in its longer range generic safety studies.

Presence of Water in East SDV

The possibility that the failure to insert all the rods was due to the presence of a large amount of water in the east SDV was suggested almost immediately by those who were on the scene or were notified promptly. The principal points of evidence were:

- All the control rods which failed to insert completely discharged into the east SDV. Those on the west SDV all scrammed completely, except for the one rod mentioned in section 3 of this report, which stopped at position 02.

- The time to receipt of the 50 gallon level signal from the SDIV was about 18 seconds. The fill time for the 10 preceding scrams on unit 3 fell between 42 seconds and 54 seconds. It is thus implied that a substantial volume of water was already present in the SDVs at the time of the scram although it cannot be determined whether this water was in the east or west SDV or in both.

- The scram was re-set and repeated three times after the initial scram. Each time the rods which were still not fully in moved toward and finally reached full insertion on the last scram. This behavior is consistent with the physical picture that between each re-set and the next scram water was draining out of the east SDV at a slow rate, making room for more water to enter the east SDV from the east CRDs. Subsequent measurements of water drainage rate from full SDVs indicated that the east bank drains in about 30 minutes with the vent valve open. The west bank drains in about 10 minutes. The drain times between scrams were 93, 53 and 160 seconds. Thus it would be expected that the volume voided during the drain times between scrams would be sufficient to accommodate the discharge from only a fraction of the still not inserted rods. (The discharge per full scram is about 1 gallon per rod for drives which are new or newly maintained. This is made up of 0.7 gallon displacement and 0.3 gallon leakage. With use this may be increased by seal wear to 2.5 gal/rod, full out to full in. The subsequent testing showed that the 8F-3 drive seals were in good condition.) It is evident that the time between scrams was insufficient to drain more than a small fraction of the SDV volume particularly if the SDV connector pipe were partially obstructed. Since the first scram must have essentially filled both branches of the SDV it would not be expected that the succeeding scrams would necessarily be complete if the postulated obstruction were still present.

- General Electric has calculated (Ref. 1) that the observed behavior could be accounted for if (a) the east SDV already contained about 85-90% of its volume filled with water at the time of the first scram and if (b) there were a partial obstruction in the connector pipe. GE bases these calculations on earlier tests on a single CRD and its appropriate discharge volume in a full scale test apparatus.

### 4.3 Evidence for the "Obstruction Hypothesis"

It has been theorized that the presence of water in the east bank of the scram discharge volume was due to an obstruction in the 2" schedule 160 pipe which has an I.D. of about 1.69 inches and connects the SDV and the scram discharge instrument volume. Attempts to confirm this theory have not yielded positive results either for or against the theory.

The unit 3 reactor building equipment drain sump, into which the SDIV discharges, was inspected. It contained some sludge but no object was found which could block a 2" pipe. The sump inspection did not include draining the sump completely; instead the bottom of the sump was raked, and inspected with an under-water TV camera. The examination of the sump was thus inconclusive and provided no support for the "obstruction hypothesis".

After the incident the east connector pipe was cut by TVA in six places and each section of pipe was rodded out with a metal tape. No obstruction was found. The east SDV was inspected by making cuts at each connection between the 6" SDV volumes and their respective 1" vent lines. Fiber optics and boroscopes were used to inspect the SDV 6" volumes. Small quantities of silt were observed but no larger objects were seen. It is conceivable that the silt could have accumulated and perhaps solidified at one point in the 2" line (say, at the expansion loop in the steam tunnel) to a degree such that complete or partial blockage of the line occurred. During post-incident examinations some silt or crud was observed in lines leading to the SDIV level measuring instruments, partially clogging these lines.

It has been theorized that an obstruction could have formed in the 2" connector pipe as a result of flushing of silt from the SDV banks (this had been done only once) in order to reduce local radiation levels. The flushing did little more than to push the local hot spots from the SDV 6" piping into the smaller 2" line according to TVA outage personnel. The silt is theorized to have formed a soft plug, possibly in the expansion loop in the 2" connector line. This loop is located in the steam tunnel where the high temperature may have hardened the soft plug into a hard partial obstruction.

Presumably, if such an obstruction had been present, it could have been swept out by the high pressure differential resulting from the opening of the scram discharge valves and dispersed so that little if any evidence of it would be expected to be left after five scrams in rapid succession. In any event, none has been found.

During the post-event investigation by TVA the SDV headers were again flushed out with water. Only a little silt was observed in the discharge. It was observed that the flushing produced some movement of the previously existing radioactively hot spots in the headers toward their discharge ends, i.e., in the direction of the flushing flow. Presumably the hot spots represented solid radioactive materials. However, these hot spots do not necessarily confirm the presence of materials capable of clogging the connector pipe. Also, earlier scrams, such as that on June 6, gave no hint of an obstruction. Thus, while the presence of a mechanical obstruction cannot be ruled out, no direct evidence for it has been found.

Some indirect evidence for an obstruction may exist in the following. A mathematical model of the hydraulic aspects of the CRD-SDV-SDIV complex has been devised by General Electric as earlier noted (Ref. 1). Details of the model appear in Ref. 8. This model reproduces correctly the behavior of a single CRD and its "share" of the SDV in the San Jose test facility. Accordingly the model has been used by GE to predict the behavior of the entire Browns Ferry 3 CRD-SDV-SDIV system. When this was done it was found that in order to make the model reproduce the behavior of the Browns Ferry 3 system as observed on June 28 it was necessary to assume that the east SDV was 85-90% full of water and that the frictional loss coefficient of the connector pipe was six times as large as would be expected from standard hydraulic correlations. This could be taken as indirect evidence of an obstruction in that pipe.

However, there are uncertainties which make this conclusion questionable. The two aspects of observed Browns Ferry 3 behavior which it was desired to make the model match were

a) the fact that 76 rods on the east side inserted only partially or, more precisely, that there was only 47% average insertion of those east side control rods not already fully inserted, and

b) the report that the 50 gallon SDIV signal was received 18 seconds (19 seconds by some accounts) after the first scram. If the connector pipe had had a normal loss coefficient the time to the 50 gallon signal would have been 8-10 seconds according to the model.

It is not clear that either the model or the data are sufficiently reliable to justify concluding that there was a mechanical obstruction present. The ability of the instrumentation used to measure the SDIV level to respond correctly to very rapid changes in level, such as must have occurred in this case is not known. Also, the arrangement of the instrument piping is such as to make it difficult to interpret level indications during the period of rapid filling of the SDIV, particularly if there were some partial binding or blockage of them by crud, as was reported.

## 4.4 Evidence for the "Vent Hypothesis"

The principal features of the "vent hypothesis" are that:

- The SDV, SDIV and connected piping, after each scram, could become filled with steam drawn in through the SDV vents from the complex system of drains into which other than SDV vents and the SDIV drain lines connect. (Some parts of this drain system receive relatively hot water from various sources in the reactor building. This is why there is a cooler for the RBEDT into which all these drains discharge and this is why steam can be seen rising from this tank when it is open to the reactor building atmosphere). Another possible mechanism by which the SDV could become filled with steam is the flashing of hot water, resulting from a scram, upon draining the system. It is not known whether this occurred in this incident.

- Some of the steam drawn into the SDV vent may condense on the relatively cool walls of the 1" vent pipe, the condensate flowing by gravity to the SDV vent valve which is located in a horizontal run of pipe at a level about 5' below the high point of the vent line and at that point forming a seal or trap. There is no direct evidence that this actually occurred at BF-3, but there is no way to have detected it if it had occurred. Therefore, its occurrence cannot be excluded.

- The connector pipe between the SDV and the SDIV has an overall fall of about 1'10" from end to end. (Ref. 6). This pipe is schedule 160, having a nominal I.D. of 1.69". If, at any point in the 170' run, there is either a low spot or high spot differing more than about 1.69" in elevation from the immediately adjacent piping, such a spot will constitute a trap, such that if suction is maintained in the piping above it, a water column can be stably supported in that piping even though the piping is open and free of any mechanical obstruction.

It has not been determined whether the low point (or high point) in the connector pipe and the trapping action of the vent valve necessary for this scenario were actually present. The connector pipe contains an expansion loop about 13' long in a nominally horizontal plane. This loop is the most probable site for the hypothesized high point or low point to have existed. The slope of the piping in this loop at the time of the incident is unknown since the piping was cut apart for internal inspection before any measurements were made. The I.D. of the elbows in the loop may be smaller than that of the pipe. Hence a local high point of 1.69" or possibly less would have sufficed to form a trap. It has been stated that pipe restraints are present on the loop, but the extent to which pipe movement is prevented is not known. It may be significant that the loop is located in the steam tunnel, where ambient temperatures are usually high. Thermal expansion could conceivably warp the piping out of its cold configuration sufficiently to produce the necessary trap, even if the cold configuration were not such as to produce a trap. It is concluded that definite knowledge of the slopes of parts of the loop at the time of the incident is lacking and probably can never be established.

Water can arrive in the SDV from CRD leakage as well as by condensation, and even the 2 gph leakage rate through the scram discharge valves which was measured for all the CRDs together after the incident would be sufficient essentially to fill the system in several days if none of it escaped via the SDIV drain valve.

If, as supposed in the vent hypothesis, it was sub-atmospheric pressure in the SDV which permitted the SDV to fill to about 85-90% of its volume with water, and if the trap in the connector pipe was located, as supposed, in the steam tunnel, the suction would have had to be sufficient to support a column of water of height not more than about 2'. Hot water enters one or another part of the clean radwaste drain system frequently, if not continuously. Steam from this water would be available to the SDV vents since the SDV vents connect into the same CRW drain system as those hotter streams. Visual observation of the RBEDT has shown visible currents of steam rising from it at times.

A complication in the analysis of the system vis-a-vis the venting hypothesis is the fact that there were several vents in the CRW drain system known to be open to the atmosphere. Some of these vents were of 1/2" size, but it is also reported by TVA that there is a 4" vent to the atmosphere at the reactor water clean up overflow. These vents are avenues by which air may enter the CRW system, creating an air/steam mixture which, if the CRW drain system were at sub-atomspheric pressure as hypothesized, would then tend to be drawn into the SDV and SDIV, finally filling them with air to the point that inflow of the air/steam mixture would cease. It would be thought that these vents would be sufficient to prevent the creation of any substantially sub-atmospheric pressure in the CRW system and hence in the SDV or SDIV. Yet, while conducting individual rod scram tests on the similar system at BF-1, the 3 gallon alarm on the SDIV came in shortly after the second rod scrammed and the presence of water in the SDIV was verified.

This incident occurred in Browns Ferry 1 on July 19, 1980. While conducting scram tests, the 3 gallon alarm on the SDIV came in shortly after the second rod was scrammed. The SDIV drain valve and the SDV vent valves were both open as is normal for individual rod scram timing tests. Ultrasonic testing disclosed that about 7 gallons of water was standing in the SDIV with no water indicated in the SDVs. Subsequently, a plug was removed from the bottom of the 3 gallon SDIV float switch assembly. The result was that air was drawn in to the open hole for several minutes, showing that a subatmospheric pressure existed in the SDIV. Once the subatmospheric pressure was relieved, the water in the SDIV drained successfully. Several more rods were subsequently scram-timed without repetition of the phenomenon.

NSAC and INPO have been informed (Ref. 3) that additional incidents like that of July 19 have since been observed at BF-1 again. It is reported also that the July 19 incident symptoms (receipt of the 3 gallon level signal) have since been reproduced by the expedient of restricting the entry of cold water into the CRW drain system, admitting only relatively hot water. It is reported that when this is done the 3 gallon SDIV level alarm can be received during normal operation, and that the open ½" vents on the 565' level (above referred to) have been observed to emit steam. The presence of a water column upstream from the SDIV drain valve has been detected ultrasonically under these conditions and apparently under more normal conditions also. (Ref. 3). No water was detected in the 6" SDV headers, and no standing water has been detected in any of the testing done on all U.S. BWRs since the June 28 incident at Browns Ferry 3.

The BF-1 observations show that it is possible for a subatmospheric pressure to occur in the SDIV (and presumably therefore in the SDV also) even though the vent and drain valves are open. Precise identification of the locations of the traps which permit this occurrence is not possible without more detailed analysis of the system.

## 4.5 The "Stuck Valve Hypothesis"

It has been pointed out that, if the east vent valve had failed to open following the June 6 scram, and if there were a partial or complete obstruction or a trap in the connector pipe, water from the June 6 scram could still have been in the east SDV on June 28.

After the June 28 incident the east vent valve was disassembled. Nothing abnormal was found. The operator has an indication in the control room of the status of this valve, derived from valve stem position (not solenoid energization). It is considered quite unlikely that the operator would have failed to notice the light signifying that the valve was closed for three weeks. Thus it is considered unlikely that the "stuck valve hypothesis" is valid.

A blockage at any point in the vent line would have had the same effect as if the vent valve had been closed. To investigate the question of whether the vent line was open, the plant personnel connected a small vacuum pump to the vent piping on the downstream (RBEDT) side of the vent valve.

The results of the test appeared to show that there was no blockage in the vent line. However, the conditions of the test were such that those performing them are reluctant to attach much significance to them.

### 4.6 Effect of Scram on Fuel

The fact that all the rods which failed to insert fully were in the same half of the reactor could be viewed as an out-of-sequence set of rod movements, thus raising the question of whether any unusual stress was put on the fuel.

General Electric has performed an analysis to determine whether the critical power ratio (CPR) of any of the fuel went below the licensed limit for the limiting bundle during the transient. (The critical power ratio is defined as

$$\frac{\text{Bundle power at which transition boiling starts}}{\text{Actual fuel bundle power}}).$$

Initial power, flow and rod positions were the actual ones at the start of the first scram. Prior to the scram the minimum CPR in the reactor was 2.21. At the end of the first scram the calculated minimum CPR was 9.34. (Ref. 7) There are no indications against the assumption that the change in MCPR from 2.21 to 9.34 during the transient was monotonic. The recirculation pumps continued at constant speed during the transient and the reactor pressure fell smoothly from 920 psig to 900 psig with no recorded pressure spike which might cause a power spike.

Core average fission power at the end of the first scram was estimated, from local power range monitor (LPRM) readings, to be about 2% of rated power. Decay power was also approximately 2% of rated power. Coolant flow through the core was estimated to be about 21% of full rated flow.

Recorded LPRM readings were examined in order to ascertain, if possible, whether the rod pattern resulting from the first scram had permitted the development of any local regions in which there was a sufficient mis-match of power and flow to justify concern about potential fuel damage. While this concern has not been resolved in this specific case, further analysis is planned to explore the question of whether there are partial scram conditions which could carry the potential for fuel damage.

The LPRM readings in the present case indicated that there may have been local regions where neutron power was in the range of 10-15% of rated power. While gross core coolant flow is known, the flow through those channels in the locally high power regions is not known.

Recorded coolant and off gas radioactivity levels before and after the scram, as displayed in Appendix CON, show no significant increase in released activity since June 28. It is thus implied that the fuel received no appreciable short term damage.

4.7 Operator Response

Appendix OPS contains information on the pertinent procedures which were in effect at the time of the incident. The procedures were not written to include the possibility that a large number (not just a few) of rods would fail to insert completely since they called for the operator to scram each un-inserted rod individually. It is possible that sequential individual rod insertion could have been used in the June 28 event. However, if the operator (or shift engineer) regarded the situation which he saw as one which was not covered by written procedure, it was reasonable for him to do what he did, i.e., attempt repeatedly to get a full scram of the rods en masse, rather than scramming each one individually. Under the circumstances prevailing at the time, the operators responded in an appropriate manner. In the present case it would have taken substantially longer to carry out 76 individual rod scrams than it actually took to carry out 4 en masse scrams, in spite of the fact that individual rod scrams are carried out with the drain and vent valves open, thus facilitating drainage of the SDV and SDIV.

The fact that it was necessary for the operators to deal with a situation of this type emphasizes the desirability of having procedures which have broader coverage of potential operating problems.

The review team also discussed the matter of the appropriateness of not injecting sodium pentaborate (the "Standby Liquid Control" or SLC) in this incident. It is clear that, because the reactor was brought to a safe shutdown condition without SLC, SLC injection was not necessary in this case. The procedure governing SLC injection places the responsibility for deciding to inject (or not to inject) on the shift engineer or his assistant. In this case, using the information available, an acceptable decision was made. So far as could be ascertained, no specific criteria or guidelines for making such decisions have been set down. If the condition of the reactor (e.g., power level) at the time of the scram had been different than it was, and if the scram had been one which was necessary for a reason of safety, the SLC decision might have had to be made under more adverse conditions than in this case. New procedures governing this subject are now in effect at Browns Ferry based on NUREG-0460, but their basis is not clearly defined in NUREG-0460.

## 4.8 Role of the Vent and Drain Valves

The SDV vent and the SDIV drain valves normally have only the function of retaining water resulting from a scram and, when the operator elects, of releasing that water to the reactor building drain tank. However, starting at a few seconds after the scram itself, the vent and drain valves close and become part of the primary pressure boundary. If they should fail to close they would create a small break LOCA with coolant discharge directly to the reactor building. If the coolant were highly contaminated, operator access to vital equipment could be impaired. It is likewise necessary that the vent and drain valves not fail to open when required, since, in the event of a partial scram it is necessary reliably to open these valves in order to empty the SDV in preparation for a follow-on attempt to complete the scram.

## 4.9 Ancillary Questions

In the course of the study of the BF-3 incident it has been necessary to look briefly at various aspects of the scram system not already addressed, such as the pneumatic system, the assignment of the individual rods to the two scram discharge headers, the reliability of equipment used for level indication in the SDIV, and the interaction between the turbine/condenser system and the reactor in the event of a partial scram. So far as known these features of the plant played no adverse role in the event, but additional generic study appears to be warranted. Consideration of these topics will be subject to later NSAC study and reporting.

## 4.10 Summary of Conclusions

To summarize the foregoing discussion, it is concluded that

- The June 28 partial failure to scram at Browns Ferry 3 was caused by water occupying a large fraction of the volume of the east scram discharge volume.

- The origin of this water, how it got into the east SDV bank and why it stayed there are and probably will remain obscure, although several plausible explanations have been advanced. None of these explanations is contradicted by the available evidence, but also none of them has a complete factual supporting basis. The principal explanations are:

    - There may have been an obstruction in the 170' long 2" connector pipe from the SDV to the SDIV.

    - A combination of trapping action in the vent line and SDV-SDIV connector pipe together with condensation of steam in the SDV may have occurred.

    - Any of the foregoing causes may have been aggravated by momentary pressure surges in the CRW drain system such as could be caused by large influxes of water from systems other than the SDV, particularly if that water were hot.

- Incidental examination of various parts of the BWR scram system suggests further generic study of them by NSAC.

- Re-examination of the procedures governing actions to be taken in the event of a partial failure to scram, and of the bases for deciding whether to inject sodium pentaborate, suggests further study by each utility.

APPENDIX SOE

SEQUENCE OF EVENTS

APPENDIX SOE
SEQUENCE OF EVENTS
BROWNS FERRY 3
JUNE 28, 1980

Plant Status Prior to the Start of the Event:

Browns Ferry Unit 3 commenced a routine shutdown to perform maintenance on a reactor feedwater pump discharge line. The initial power reduction was performed at a rate of 8 mwe/min from 1082 mwe to 542 mwe by reducing recirculation flow.

With the recirculation pump operating at minimum speed, additional power reduction to 390 mwe was accomplished by normal insertion of selected control rods.

The plant conditions following this power reduction were as follows:

| | |
|---|---|
| Power Level | 36% of Rated |
| Core Flow | $39 \times 10^6$ lbs. per hr. |
| Reactor Pressure | 920 psi |
| Vessel Level | 35 inches (203 inches above the top of the active fuel) |
| Generator Output | 390 MWE |
| Steam Flow | $4.9 \times 10^6$ lbs. per hr. |
| Feedwater Flow | $4.9 \times 10^6$ lbs. per hr. |
| Control Rod Pattern | 157 control rods were fully withdrawn<br>10 rods were fully inserted<br>18 rods were at intermediate position (See Reference 1) |

| Time | Event | Remarks and References |
|---|---|---|
| 01 31 16 | A manual scram was initiated to complete | Within several seconds after the scram, in accordance with |

| Time | Event | Remarks and References |
|---|---|---|
| | the shutdown. This was a normal part of the Browns Ferry shutdown procedure. | normal procedures, the scram discharge volume (SDV) bypass switch was placed in "bypass" position, the reactor mode switch was placed in "shutdown" position, and insertion of the source range monitors (SRMs) and intermediate range monitors (IRMs) were initiated. |

Within several seconds (approximately 5 to 10) after this scram, operating personnel noted that:

- The blue scram lights and the scram accumulator lights were lit as expected.
- A number of rods on the east side of the reactor were indicated to be not fully inserted.

During this entire sequence of events, operating personnel reported that they observed that key thermal hydraulic parameters (pressure, level, temperatures and flows) were well within normal limits for ordinary scrams. However a number of control rods were not fully inserted.

Subsequently, a review of plant recorders and process computer printout showed:

- A total of 77 rods did not fully insert. Of these, seven rods settled at either position 02 or 04. The extent of insertion varied from 5 percent of fully inserted to 95 percent of fully inserted for these partially inserted rods. The rod pattern at this time is shown by Fig. SOE-1.
- Many of the local power range monitors (LPRMs) in the east side of the reactor and in the upper region (level C&D) indicated above zero values (See Fig. SOE-2).
- The readings of the fully inserted IRMs were approximately mid-range on range five or six.

| Time | Event | Remarks and References |
|---|---|---|
| | | • A review of LPRM readings indicated that fission power in one or more localized regions of.the core could have been in the range of 10-15% of full rated power due to rods not being completely inserted in these regions.<br><br>• During and after this scram, no other unusual or unexplained variations in plant parameters were observed.<br><br>Total indicated steam flow dropped sharply during this scram to approximately 10 to 15 percent of the pre-scram value.<br><br>Reactor pressure decreased from 920 to approximately 900 psi (this pressure remained approximately constant throughout the remainder of the event.)<br><br>Core flow decreased to 22 x $10^6$ lbs. per hr. This decrease was due to the loss of natural circulation driving head when reactor power was reduced.<br><br>Based on steam flow indication which may be inaccurate at low scale values, the heat generation within the reactor was close to the heat generation expected from decay heat alone. The insertion of the rods had significantly reduced power level. |
| 01 31 24 | Low reactor water level trip occurred. (This corresponds to Level 3 which is 180.5 inches above the top of the active fuel.) | The water level decrease was due to void collapse following the scram. From plant recorders it was later verified that minimum water level reached during this event remained above the level required for emergency core cooling system initiation. (This corresponds to Level 2 which is 110 inches above the top of the active fuel.)<br><br>The level variation, including maximum and minimum values, was well within the expected range during a normal scram. |

| Time | Event | Remarks and References |
|---|---|---|
| 01 31 34 | The scram discharge volume "high-high" level was reached. | This occurred 18 seconds after the manual scram. This normally occurs approximately 40 seconds after a scram. Subsequent investigation confirmed that all "high-high" instrument volume level switches were properly calibrated and functioning. |
| 01 31 40 | The main turbine was tripped as part of normal procedure. | |
| 01 32 01 | The low reactor water level trip was reset. | During the interval between 01 32 01 and 01 35 43 normal water level was achieved and one feedwater pump, two condensate booster pumps and one condensate pump were then secured. |
| 01 35 43 | The scram was reset and the hydraulic control unit accumulators were recharged until the lights cleared. | Low pressure switch resets at approximately 950 psig. Normal accumulator nitrogen pressure is 1150 psig. |
| 01 37 20 | A second scram was manually initiated for the purpose of inserting the remaining 77 rods. | Within several seconds after this scram, operating personnel observed that:<br>• All blue scram lights and accumulator lights were lit and scram group pilot lights were out as expected.<br>• Rod movement was indicated, but motion appeared slower than normal.<br>• Some rods were indicated to be not fully inserted.<br>Subsequent review of plant recorders and printouts indicated that:<br>• A total of 59 rods were still not fully inserted. The rod pattern at this time is shown by Fig. SOE-3. Major plant parameters (steam flow, core flow, water level and reactor pressure) remained essentially unchanged throughout the scram. |

| Time | Event | Remarks and References |
|---|---|---|
| | | Fluctuations of IRM sensor readings prevent determination of actual effects due to the scram. |
| 01 38 19 | The scram was reset and the hydraulic control unit accumulators recharged until the lights cleared. | |
| 01 39 12 | A third manual scram was initiated. | Operating personnel observed that:<br>• All blue scram lights and accumulator lights were lit and scram group pilot lights were out.<br>• Rod movement was indicated.<br>• Some rods were indicated to be not fully inserted.<br>Information obtained later from plant recorders showed that:<br>• A total of 47 rods were still not fully inserted. The rod pattern at this time is shown in Figure SOE-4.<br>• LPRM readings all indicated "downscale" except 40-57C which was failed.<br>• All major parameters discussed above, remained approximately constant throughout this scram. |
| 01 42 37 | The scram was reset for the third time and the hydraulic control unit accumulators were recharged until the lights cleared. | |
| 01 45 17 | The operator placed the scram discharge volume (SDV) bypass switch in "normal" which resulted in a scram since the SDV was not actually fully drained. This was the fourth scram in this sequence of events. | Operating personnel observed that:<br>• Rod insertion rate appeared normal for a scram.<br>• All blue scram lights and accumulator lights were lit and scram group pilot lights were out. |

| Time | Event | Remarks and References |
|---|---|---|
| | | • All rods were indicated to be fully inserted as shown in Figure SOE-5.<br>• Plant parameters and conditions were as normally expected following a scram. |
| 01 46 30 | The operator initiated a manual scram (confirmatory). | |
| 01 46 43 | The scram was reset. | |
| 01 57 34 | The discharge volume high water level trips (50 gallon scram trips) cleared. | |

PRIOR TO SCRAM #1

| | 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 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 |
| 39 | 38 | 48 | 48 | 48 | 0 | 48 | 48 | 48 | 48 | 48 | 0 | 48 | 48 | 48 | 38 |
| 35 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 |
| 31 | 48 | 48 | 0 | 48 | 48 | 48 | 48 | 48 | 48 | 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 | | | | |

AFTER SCRAM #1

Blank Indicate Rod Full In

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

0131

Figure SOE-1. Control Rod Positions

| | 08 | 16 | 24 | 32 | 40 | 48 | 56 |
|---|---|---|---|---|---|---|---|
| 57 | | 2 | 2 | 0 | 0 | | |
| | | 0 | 0 | 0 | 20* | | |
| | | 0 | 0 | 0 | 0 | | |
| | | 0 | 0 | 0 | 0 | | |
| 49 | 2 | 4 | 4 | 0 | 0 | 0 | |
| | 0 | 2 | 0 | 0 | 0 | 0 | |
| | 0 | 0 | 0 | 0 | 0 | 0 | |
| | 0 | 0 | 0 | 0 | 0 | 0 | |
| 41 | 3 | 3 | 6 | 0 | 0 | 0 | 0 |
| | 2 | 2 | 6 | 0 | 0 | 0 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33 | 6 | 8 | 3 | 0 | 0 | 0 | 0 |
| | 3 | 4 | 2 | 0 | 0 | 0 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25 | 9 | 10 | 9 | 2 | 0 | 0 | 0 |
| | >0 | 0 | 4 | 0 | 0 | 0 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | >0 | 10 | 7 | 2 | 0 | 0 | 0 |
| | 6 | 6 | 4 | 0 | 0 | 0 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 09 | D | 4 | 4 | 0 | 0 | 0 | |
| | C | 0 | 2 | 0 | 0 | 0 | |
| | B | 0 | 0 | 0 | 0 | 0 | |
| | A | 0 | 0 | 0 | 0 | 0 | |

*Failed

Figure SOE-2. LPRM Readings Following Scram #1

PRIOR TO SCRAM #2

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

0131

AFTER SCRAM #2

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

0137

Figure SOE-3. Control Rod Positions

PRIOR TO SCRAM #3

0137

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

AFTER SCRAM #3

0139

| | 02 | 06 | 10 | 14 | 18 | 22 | 26 | 30 | 34 | 38 | 42 | 46 | 50 | 54 | 58 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 59 | | | | | 24 | | | | | | | | | | |
| 55 | | | | 20 | 40 | 22 | | | | | | | | | |
| 51 | | | | 16 | | 24 | 30 | | | | | | | | |
| 47 | | 26 | | | | 6 | | | | | | | | | |
| 43 | | 24 | 36 | | 2 | | 24 | 18 | | | | | | | |
| 39 | 2 | | 24 | | | 20 | | | | | | | | | |
| 35 | 6 | | 26 | | | | 14 | 16 | | | | | | | |
| 31 | | | | 2 | 4 | | | | | | | | | | |
| 27 | 18 | 16 | 14 | 2 | 4 | 6 | 2 | | | | | | | | |
| 23 | | | 26 | 12 | | | 2 | | | | | | | | |
| 19 | | 16 | 18 | | | | 2 | 2 | | | | | | | |
| 15 | | 4 | | 10 | | >0 | | | | | | | | | |
| 11 | | | 6 | | | 28 | 26 | 8 | | | | | | | |
| 07 | | | | | 24 | | | | | | | | | | |
| 03 | | | | | | 30 | 10 | | | | | | | | |

Figure SOE-4. Control Rod Positions

PRIOR TO SCRAM #4

0139

| | 02 | 06 | 10 | 14 | 18 | 22 | 26 | 30 | 34 | 38 | 42 | 46 | 50 | 54 | 58 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 59 | | | | | 24 | | | | | | | | | | |
| 55 | | | | 20 | 40 | 22 | | | | | | | | | |
| 51 | | | | 16 | | 24 | 30 | | | | | | | | |
| 47 | | 26 | | | | 6 | | | | | | | | | |
| 43 | | 24 | 36 | | 2 | | 24 | 18 | | | | | | | |
| 39 | 2 | | 24 | | | 20 | | | | | | | | | |
| 35 | 6 | | 26 | | | | 14 | 16 | | | | | | | |
| 31 | | | | 2 | 4 | | | | | | | | | | |
| 27 | 18 | 16 | 14 | 2 | 4 | 6 | 2 | | | | | | | | |
| 23 | | | 26 | 12 | | | 2 | | | | | | | | |
| 19 | | 16 | 18 | | | | 2 | 2 | | | | | | | |
| 15 | | 4 | | 10 | | >0 | | | | | | | | | |
| 11 | | | 6 | | | 28 | 26 | 8 | | | | | | | |
| 07 | | | | | 24 | | | | | | | | | | |
| 03 | | | | | 30 | 10 | | | | | | | | | |

AFTER SCRAM #4

0145

| | 02 | 06 | 10 | 14 | 18 | 22 | 26 | 30 | 34 | 38 | 42 | 46 | 50 | 54 | 58 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 59 | | | | | | | | | | | | | | | |
| 55 | | | | | | | | | | | | | | | |
| 51 | | | | | | | | | | | | | | | |
| 47 | | | | | | | | | | | | | | | |
| 43 | | | | | | | | | | | | | | | |
| 39 | | | | | | | | | | | | | | | |
| 35 | | | | | | | ALL | RODS | | | | | | | |
| 31 | | | | | | | | IN | | | | | | | |
| 27 | | | | | | | | | | | | | | | |
| 23 | | | | | | | | | | | | | | | |
| 19 | | | | | | | | | | | | | | | |
| 15 | | | | | | | | | | | | | | | |
| 11 | | | | | | | | | | | | | | | |
| 07 | | | | | | | | | | | | | | | |
| 03 | | | | | | | | | | | | | | | |

Figure SOE-5. Control Rod Positions

APPENDIX DES

SYSTEM DESCRIPTION

## APPENDIX DES
## SYSTEM DESCRIPTION

### CONTROL ROD DRIVE HYDRAULIC SYSTEM

I. SYSTEM FUNCTION

A. General - The control rod drive system makes changes in core reactivity by incrementally positioning neutron-absorbing control rods within the reactor core in response to manual control signals. The system is also capable of quickly shutting down the reactor (scram) in emergency situations by rapidly inserting all withdrawn control rods into the core in response to manual or automatic signals.

B. The functions of the system are to:

1. Move the control rods in either direction at controlled rates, latching the rod stationary when not requested to move.

2. Charge HCU scram accumulators.

3. Provide cooling water to drive mechanisms.

II. MAJOR SYSTEM COMPONENTS (Refer to Fig. DES-1)

A. Two 100% capacity, 5 stage, centrifugal pumps.

B. Two 100% capacity drive water (discharge) filters.

1. Parallel installed, 50 micron cartridge type.

C. Two 100% capacity flow control valves.

1. Air operated, balanced trim globe valves positioned by automatic flow control loop or local manual control stations.

2. Normally controlled in automatic mode to give approximately 60 gpm system flow.

D. One drive water pressure control valve.

1. Motor operated valve positioned by operator to maintain approximately 250 psi differential between drive water head and reactor pressure.

E. One cooling water pressure control valve.

1. Motor operated valve positioned by operator to maintain the cooling water header approximately 20 psi above reactor pressure, to provide cooling flow.

F. Two sets of solenoid operated stablizing valves.

G. Hydraulic control units (Fig. DES-2)

1. Provide control interface between hydraulic system and individual CRDs.

2. Seven hydraulic piping risers with manual shut-off valves at each HCU provided as follows:

a. Insert riser - Line connecting HCU directional control manifold to representive CRD under piston area.

b. Withdraw riser - Line connecting HCU directional control manifold to respective CRD over piston area.

c. Cooling water riser - Line connecting hydraulic system cooling header to CRD insert line.

d. Exhaust riser - Line connecting HCU directional control manifold and hydraulic system return header.

e. Drive water riser - Line connecting system drive water header to HCU directional control manifold. Provides hydraulic pressure during insert, unlatch and withdraw modes of CRD operation.

f. Charging water riser - Line connects hydraulic system charging header to water side of scram accumulator. Maintains scram accumulator at pump discharge pressure.

g. Scram discharge riser - Line connects the CRD over piston area to the Scram Discharge Volume via the withdraw riser and outlet scram valve.

3. Directional Control Manifold consists of a 4-way block manifold to port CRD hydraulic flows between the CRD mechanism via the insert and withdraw risers and the hydraulic system via the drive water supply and exhaust riser during normal rod movement.

4. Scram Section consists of the following HCU mounted components to allow rapid insertion of the control rod in response to signals from the RPS.

   a. Scram Valves - Two normally closed, air operated globe valves. Held closed by instrument air via two solenoid operated scram pilot valves, each powered from one of the two RPS trip channels and connected physically such that both solenoids must de-energize to vent air from and to open the scram valves.

      (1) Inlet Scram Valve, when open, connects the water side of the scram accumulator directly via the insert header to the CRD under piston area.

      (2) Outlet Scram Valve, when open, connects the CRD over piston area, via the withdraw riser, to the scram discharge volume.

   b. Scram Accumulator consists of piston type, 5 gal capacity, accumulator connected to a precharged $N_2$ cylinder at the bottom and the insert riser via the inlet scram valve at the top.

c. System Response During Scram - When reactor scram is initiated by the reactor protection system (RPS) the inlet and outlet scram valves open to admit the pressure in the scram accumulator to the area below the drive piston and to vent the area above the piston to the scram discharge headers. The scram discharge headers are maintained at atmospheric pressure during normal operation. The large differential pressures applied to the drive piston area produce a large upward force on the index tube and control rod, giving the rod a high initial acceleration and providing a large margin of force to overcome possible friction or binding in the drive line. The characteristics of the CRD hydraulic system are such that the CRD index tube rapidly accelerates to a scram velocity of approximately 5'/sec. As the index tube closes off ports in the cylinder wall (i.e., buffer holes in the piston tube), the increasing resistance to water flow reduces the speed of the index tube. The number, size, and spacing of the buffer holes in the CRD piston tube which are progressively closed are chosen to provide a gradual deceleration of index tube movement.

Each CRD puts approximately 2.5 gallons of water into the SDV for a maximum scram stroke; the water side of the scram accumulator holds approximately 1.5 times this volume. There is adequate capacity in the hydraulic system accumulator supplying each CRD to complete a scram stroke in the required time at low reactor pressure. At high reactor pressures, however, the accumulator provides the initial surge of water, but the normal accumulator discharge and line losses quickly reduce the pressure at the CRD to a level equal to reactor pressure. This causes the ball check valve (built into the CRD flange directly below the under-piston water port) to shift its position and admit reactor water under the drive piston, thus admitting water from the accumulator and from the reactor vessel. Reactor pressure, therefore, supplies the force required to complete the scram stroke at higher reactor pressures, while the accumulator alone supplies the force for low-pressure scrams.

## III. SCRAM DISCHARGE VOLUME (Fig. DES-3)

A. General - Provided to receive and contain the water exhausted from all CRDs during scram. During a scram the SDV becomes part of the primary system pressure boundary. Consists of header piping which connects to the HCU scram discharge risers. The east and west sections of this piping drain to a common instrument volume. The east and west headers are equipped with vent valves. Since a minimum SDV capacity is required to allow the water displaced during scram to accumulate in the SDV, a series of level switches is provided on the instrument volume to warn of diminishing capacity:

1 scram discharge volume not drained (3 gallons)
1 rod block (25 gallons)
4 SDV Hi Hi scram (50 gallons)

B. SDV Vent and Drain - Air to-open, normally open valves which maintain SDV drained and vented to atmospheric pressure during normal operation. Valves are held open by instrument air from scram pilot air header via a 3-way double solenoid dump valve. Each solenoid is normally energized from one of the two reactor protection system trip channels. When both solenoids are de-energized (scram) the valve exhausts the air header downstream allowing the vents and drain to close by spring pressure.

Both the SDV vent lines and the SDIV drain line discharge into the clean radwaste drain system. This is a complex arrangement of piping which takes drainage from about 50 points in the reactor building and collects it in the reactor building equipment drain tank, (Ref. 4) (Ref. 5), a lined rectangular concrete sump of about 6340 gallon capacity bottomed at elevation 509' in the reactor building. Except when being inspected the top of the tank is closed with a concrete plug.

The RBEDT is equipped with pumps for removal of the water and for passing the water through a cooler when necessary. Several potential sources of hot water drainage into this tank have been identified including:

- Reactor Water Clean up System Leakage
- Fuel Pool Cooling System Leakage
- Steam Tunnel Piping or Valve Drains
- Residual Heat Removal Heat Exchanger and Piping

The CRW drain system collects drainage from equipment at several elevations in the reactor building as follows: (Ref. 4)

660'6"
621'
565'

The SDV-SDIV system is located on elevation 565'. Measurements of the normal rate of CRW flow rate into the RBEDT are reported by TVA to have been made, with the result being about 4-5 gpm. These measurements have not been documented to NSAC.

The CRW drain system piping ranges in size from a few 1/2" vents to 8" iron pipe size downcomers. All discharges from that part of the system into which the SDIV drains combine in a single 8" downcomer. The design drawings for the system specify that it is to be air tight -- no funnel drains permitted, but some of the 1/2" vents have apparently been open for a long time. There is also a 4" vent at the RWCU precoat overflow line.

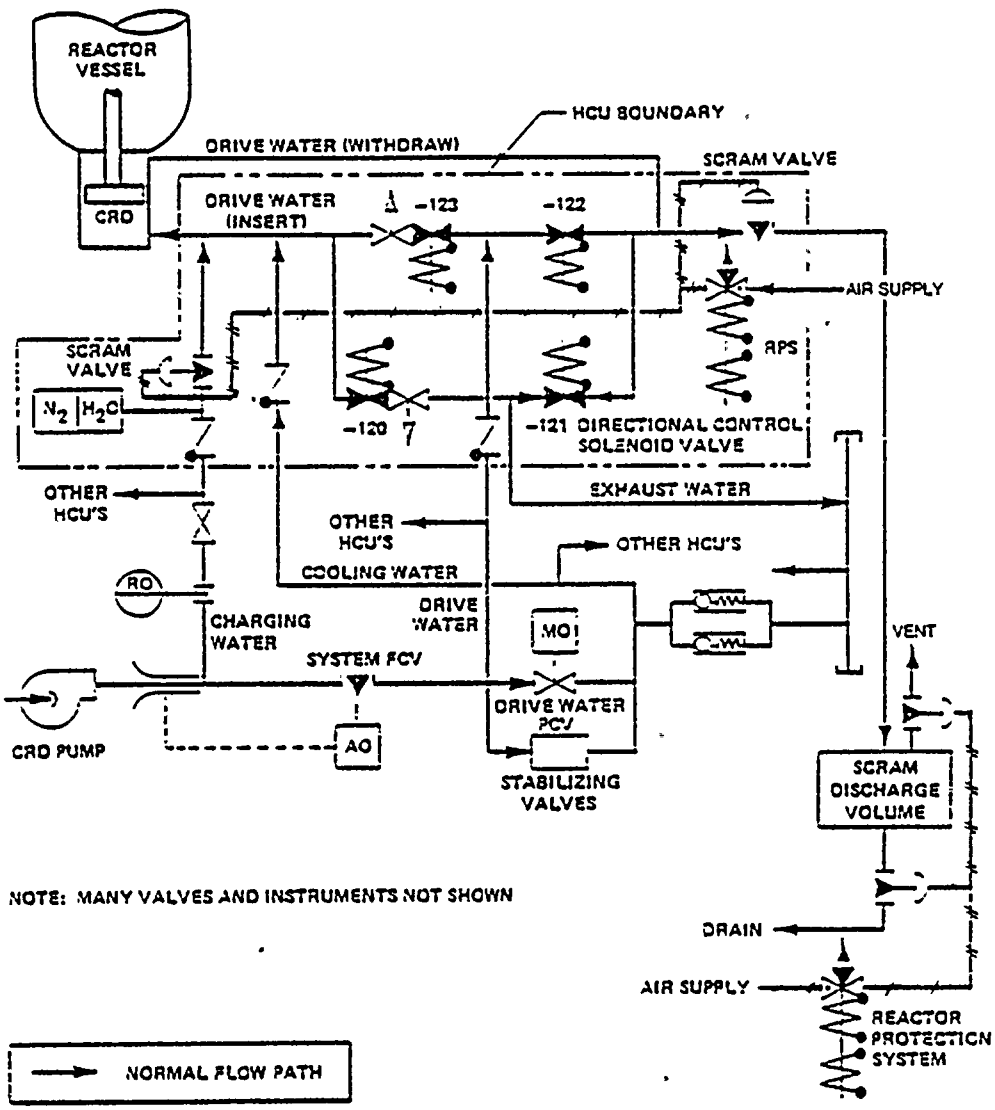


Figure DES-1. Typical CRD Hydraulic Control System (piping layout)

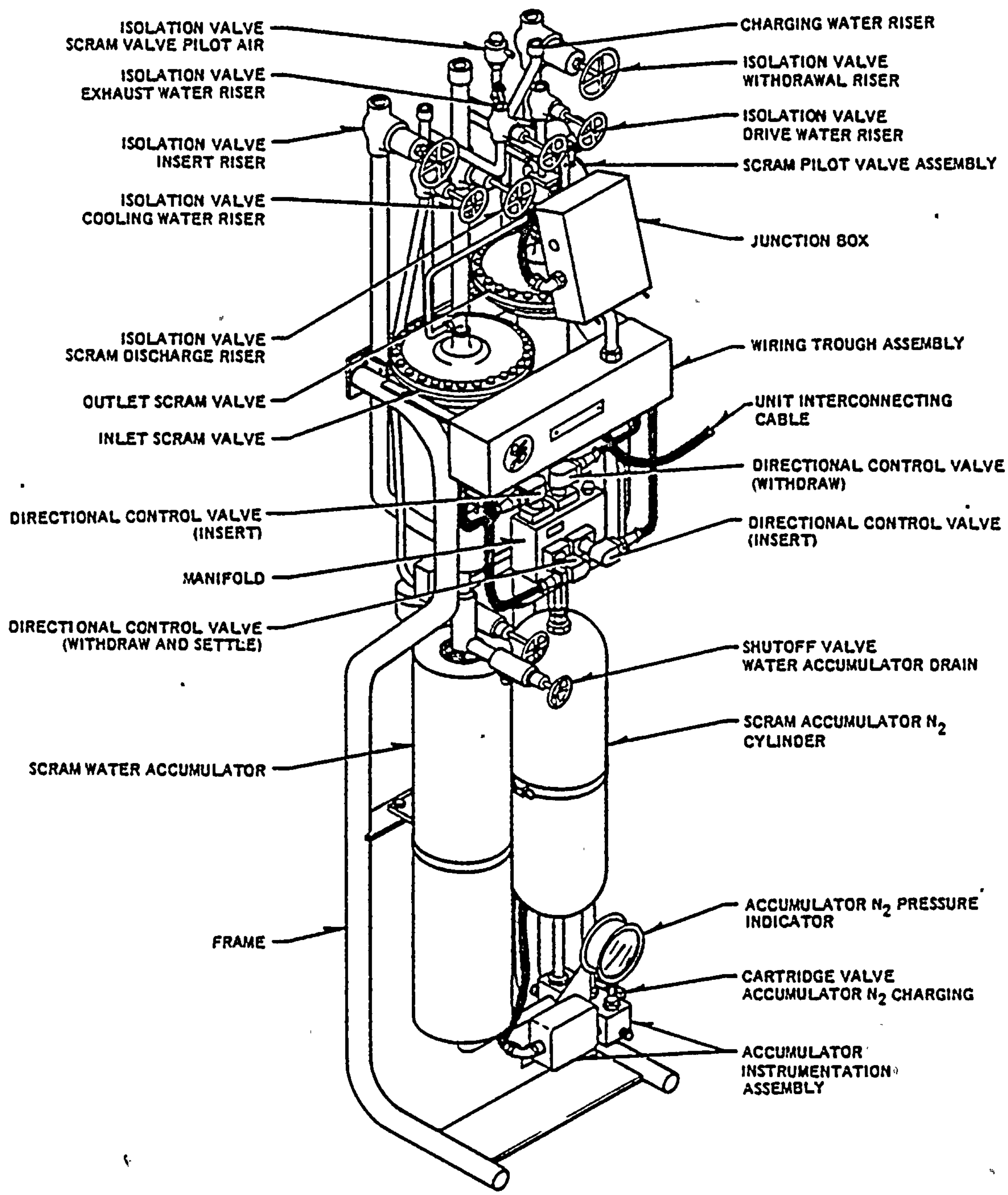


Figure DES-2. Control Rod Drive Hydraulic Control Unit (component assembly)

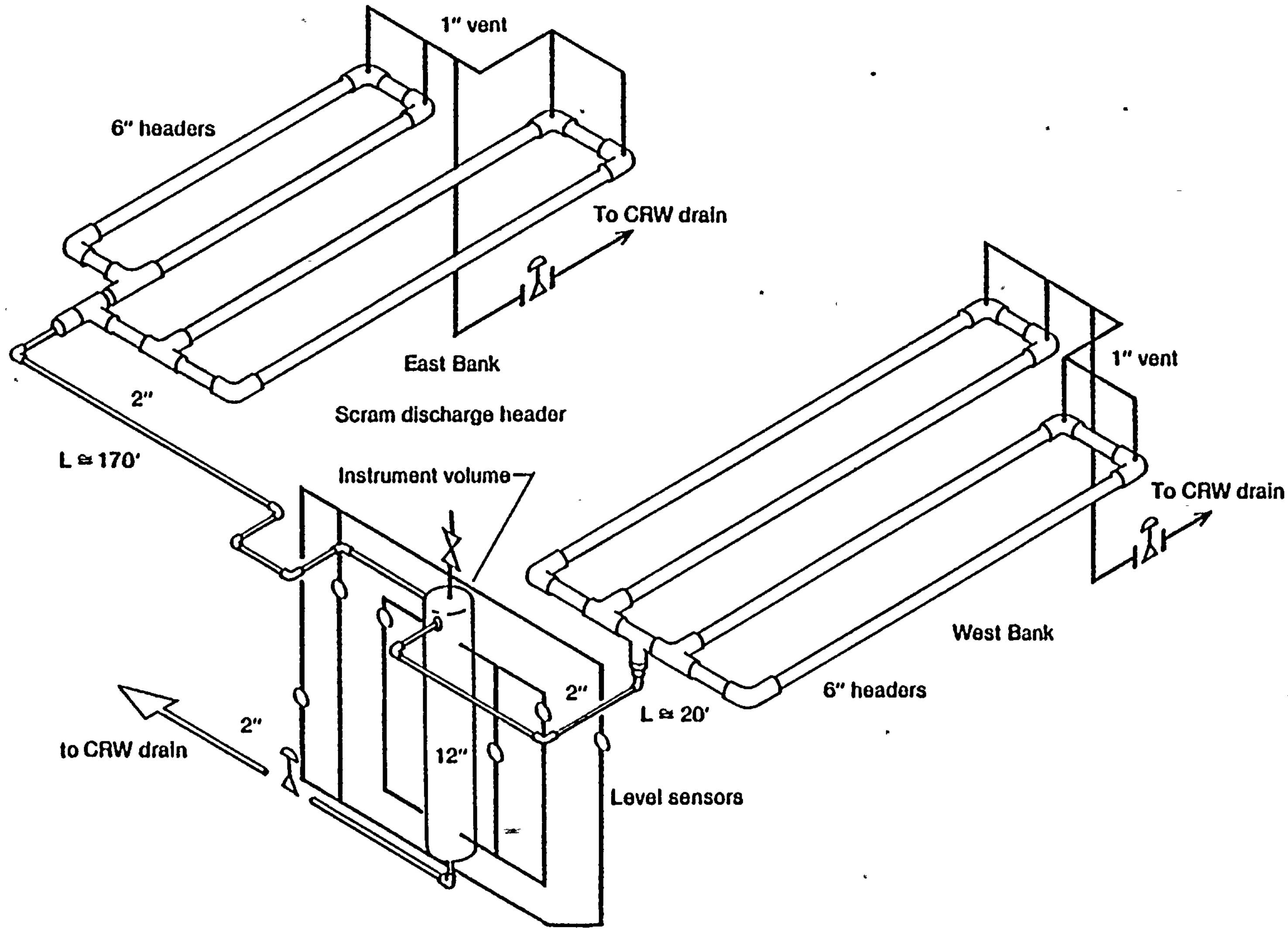


Figure DES-3. Browns Ferry SDV Equipment Layout (isometric view)

APPENDIX CON

CONSEQUENCES OF THE EVENT TO THE REACTOR

# APPENDIX CON

## CONSEQUENCES OF THE EVENT TO THE REACTOR

The fact that the first scram resulted in an out-of-sequence rod configuration with the reactor still critical at a low but not precisely known power level has raised the question of whether there could have been some part of the reactor which would have been running at a power density high enough to overstress the fuel at the existing cooling conditions.

A pragmatic answer to this question lies in the comparison of before-and-after levels of radioactivity in the primary coolant (Table CON-1) and the off-gas stream (Table CON-2). It is seen that there is no systematic change in primary coolant gross radioactivity or iodine. The off-gas activity shows a generally increasing trend in June and August, but July levels did not show such a trend. Also, July levels were not significantly different than those of June.

These data do not suggest any damage to the fuel.

TABLE CON-1

PRIMARY COOLANT CHEMISTRY

BF-3

| | | | JUNE 1980 | JULY 1980 |
|---|---|---|---|---|
| Gross Radioactivity (μ Ci/ml) | | | | |
| | | High | 9.12E-03 | 8.63E-03 |
| | Solids | Low | 2.03E-04 | 2.37E-04 |
| | | Avg. | 1.27E-03 | 1.36E-03 |
| | | High | 2.45E-01 | 1.48E-01 |
| | Filtrate | Low | 2.64E-02 | 5.43E-03 |
| | | Avg. | 1.20E-01 | 6.85E-02 |
| Iodine 131 (μ Ci/ml) | | | | |
| | | High | 1.55E-03 | 3.34E-04 |
| | | Low | 2.35E-05 | 0.75E-05 |
| | | Avg. | 7.46E-04 | 1.94E-04 |

TABLE CON-2

OFF GAS SYSTEM PERFORMANCE*

BF-3

| | JUNE 1980 | JULY 1980 | AUGUST 1980 |
|---|---|---|---|
| Off Gas Radioactivity, post-treatment monitor, μ Ci/cc | | | |
| Start of Month | 2E-03 | 3E-03 | 1.5E-03 |
| End of Month | 5E-03 | 3E-03 | 8E-03 |
| Maximum | 5E-03 | 3E-03 | 8E-03 |
| Off Gas Flow Rate, SCFM, approx. avg. | 100 | 80-90 | 80-95 |

*The values given are the result of putting a straight line through the daily readings for the month and estimating the intercepts. Hence the value at the end of one month does not necessarily agree with the value at the beginning of the next month. Also, in the case of July, values for approximately the first half of the month were not used since the reactor was shut down for most of this time and the off gas radioactivity readings were either low or erratic. However, no July readings higher than about 1E-02 were recorded.

Additionally, GE has calculated that no fuel operating limits were exceeded during the transient. Copy attached. (Also Ref. 7.)

GENERAL ELECTRIC

NUCLEAR FUEL AND SERVICES DIVISION

GENERAL ELECTRIC COMPANY, 175 CURTNER AVE., SAN JOSE, CALIFORNIA 95125

FPF-80-271

August 22, 1980

Dr. Miles Leveritt
Nuclear Safety Analysis Center
3412 Hillview
Palo Alto, CA 94303

Dear Dr. Leveritt:

The attached memo summarizes the work performed by General Electric to evaluate the condition of the Browns Ferry-3 fuel following the incomplete rod insertion on June 28. The results indicated substantial margins to any fuel limits existed. While this work has not received the engineering reviews which we would normally perform as part of our engineering evaluation efforts, the margins are so great that we believe the conclusions are accurate.

If you have any questions, please call me.

Very truly yours,

F. P. Felini

F. P. Felini, Manager
Domestic Product Service
M/C 880, 925-1257

FPF:gs

# NUCLEAR POWER SYSTEMS ENGINEERING DEPARTMENT MEMO

TO: F.P. Felini

DATE: August 22, 1980
CFSD/80-237

FROM: J.A. McGrady

REQUIRED RESPONSE
DATE: n/a

SUBJECT: THERMAL LIMITS EVALUATION OF BROWNS FERRY 3 PARTIAL SCRAM EVENT

FOR: ACTION ☐
DECISION ☐
INFORMATION ☒

---

3-D BWR simulator cases were run simulating the core conditions at Browns Ferry 3 just prior to and just after the first partial scram. The actual rod patterns and thermal-hydraulic conditions that were a combination of the best available data from the plant and best estimate (by engineering judgement) values were used in these two cases.

Based on these simulator cases, the thermal limits at Browns Ferry 3 both before and after the first partial scram, were not even close to even the technical specification operating limits on MCPR, MLHGR, and RAPLHGR (See Table below). Thus, as not even normal operating thermal limits were violated during this event, thermal limit violations are of no concern for the actual Browns Ferry 3 partial scram event.

| | Technical Specification Thermal Limit | 3-D BWR Simulator Results Before Scram | After 1st Partial Scram |
|---|---|---|---|
| MCPR | $> \sim 1.54\ (1.28 \times K_f)$ | 2.21 | 9.34 |
| MLHGR | < 13.4 Kw/ft | 6.49 | 1.81 |
| RAPLHGR* | < 1.0 | .483 | .137 |

$$*RAPLHGR = \left(\frac{MAPLHGR}{MAPLHGR\ LIMIT}\right)$$

where MAPLHGR limit varies with fuel type and exposure.

These results have not been verified, but are believed to be representative of actual core conditions to the extent necessary to justify that thermal limits were of no concern during this event.

J.A. McGrady
J.A. McGrady
Core & Fuel Systems Design
Mail Code 740 - Ext. 56136

Concurrence: Kathy Stark
K.L. Stark
Senior Engineer
Operating Core Design Management-2

---

cc.

# APPENDIX OPS

## OPERATOR ACTIONS AND PROCEDURES

## APPENDIX OPS
## OPERATOR ACTIONS AND PROCEDURES

I. PURPOSE

The purpose of this section is to review the possibly applicable procedures available at the time of the event, the procedures and/or modifications to procedures as a result of the event, and to comment on the performance of the operational staff during the event.

II. POSSIBLE APPLICABLE OPERATION PROCEDURES AVAILABLE AT THE TIME OF THE EVENT

| PROC. NO. | TITLE |
|---|---|
| 85 | Control Rod Drive Hydraulic System Section IV (Abnormal Operations) |
| 63 | Standby Liquid Control System |

A. Operating Procedure No. 85.

This was the only existing procedure at the time of the event which actually addressed the situation of rods failing to fully insert after a scram.

Basically, the operators adhered to this procedure. It does, however, specify scramming the rods individually versus performing total core scrams. The original intent of the procedure did not foresee such a large number of rods not fully inserting and, therefore, it was reasonable for the operating personnel to opt for total core scrams using the manual scram buttons.

As a result of this event, the procedure has been modified to be applicable when four or less rods fail to fully insert. The failure of five or more rods to fully insert is now addressed in a new emergency operating instruction which is detailed under Item (III) below.

B. System Operating Instruction No. 63, Standby Liquid Control System

This procedure is addressed to show only that it was available. It states that the shift engineer or assistant shift engineer has the authority to order injection.

In the case of this event, operations personnel acted in accordance with their judgment as provided in the then existing procedures. However, both the then existing and now existing procedures appear to lack adequate criteria for making such judgments. Further review is advisable.

## III. NEW PROCEDURES PREPARED AS A RESULT OF THE EVENT

The complete text of these procedures is provided below.

1. Control Rod Drive Hydraulic System Operating Instruction No. 85, Section S, Water in Discharge Header (By Ultrasonic Tests)

   S. Water in discharge header (by ultrasonic tests)

      1. Water level in scram discharge piping less than 1".

         a. Dispatch personnel to visually verify open position of SDV vent and drain valves.

         b. Check for leaking scram discharge valves.

            1. Check CRD temp recorder - high drive temperatures may indicate leaking scram outlet valves.

            2. Check temperature of the scram discharge riser at each hydraulic control unit.

            3. If any riser is found to be warm to the touch, verify scram discharge valve leakage according to GEK-9582.

      2. Water level in scram discharge piping > 1 1/2" but < 2".

         a. Immediately reduce load to minimum and scram the reactor.

3. Water level in scram discharge piping > 2".

a. Initiate a controlled shutdown to the cold shutdown condition.

2. Failure of Control Rods to Insert During a Scram (Emergency Operating Instruction No. 47)

I. SYMPTOMS

A. Parameter changes

1. Failure of all control rods to fully insert upon scram signal

2. LPRM's indicate the reactor is critical after scram

3. IRM's and SRM's indicate reactor is critical after the scram.

B. Alarms

1. Reactor auto scram channel A (B)

2. Rod withdrawal block

3. Scram discharge volume not drained

4. Sequential events print-out would give additional annunciations

II. AUTOMATIC ACTIONS
Automatic actions directly associated with the event, causing the scram would occur (i.e., low water level, high drywell pressure, turbogenerator trip and etc.)

## FAILURE OF ALL CONTROL RODS TO INSERT

III. IMMEDIATE OPERATOR ACTIONS

A. Verify existing condition by multiple indications (i.e., alarms, charts, indicating lights, gauges and other instruments).

B. Verify all automatic actions have occurred. If not, place controls in manual and make corrective manipulations.

CAUTION: DO NOT PLACE CONTROLS IN MANUAL, UNNECESSARY WHEN AUTOMATIC IS FUNCTIONING PROPERLY UNLESS UNSAFE PLANT CONDITIONS WILL RESULT.

C. Trip reactor recirculation pumps.

D. Place mode switch in shutdown. Place scram discharge volume high water level bypass switch to bypass. Verify scram discharge volume vent and drain valves open.

E. Reset reactor scram and manually scram the reactor, reset and repeat if rod motion is observed until all control rods are fully inserted.

CAUTION: CONTINUOUSLY MONITOR NEUTRON FLUX UNTIL ALL RODS ARE FULLY INSERTED.

F. Notify supervisor of events and actions taken.

## IV. SUBSEQUENT OPERATOR ACTIONS

A. If all scram valve position lights are not illuminated, isolate and vent the scram air header. Restore air when all scram valves are open.

B. Individually, from the auxiliary instrument room, scram those control rods not fully inserted. Reset each rod after it fully inserts and continue to scram rods until all rods are fully inserted. Select those rods in areas of indicated high reactivity to be scrammed first.

C. Select the control rods that did not fully insert and manually insert as RSCS permits; bypass the RWM; place the RSCS, sequence mode selector, in the insert position and select the rod group to be inserted. From the auxiliary instrument room, bypass all rods to full in position, then manually drive the rods in one at a time.

D. If the control rod system is unable to maintain the reactor in a subcritical condition; upon shift engineer's approval, initiate standby liquid control (SLC) and continue to inject until the entire contents of the standby liquid control tank is injected.

CAUTION: IF AT ANYTIME THE FOLLOWING CONDITIONS EXIST, SLC INJECTION IS MANDATORY:

1. Five (5) or more adjacent rods not inserted below 06 position and either reactor water level cannot be maintained, or suppression pool water temperature limit of 110°F is reached.

2. Thirty (30) or more rods not inserted below 06 position and either reactor water level cannot be maintained or suppression pool water temperature limit of 110°F is reached.

E. Confirm the reactor water cleanup system (RWCU) isolates or manually isolate the RWCU system.

F. Restart the reactor recirculation pump(s) at minimum flow to aid in mixing of neutron absorber.

G. Verify neutron flux decreases as SLC solution is injected into the core.

H. Log events and actions taken in daily journal.

## REFERENCES


1. Evaluation of Incomplete Control Rod Insertion Event at Browns Ferry 3. Report NEDC-24276, General Electric Co., October 1980.

2. Report and Safety Evaluation of the Browns Ferry Unit 3 Partial Scram Failure of June 28, 1980. T. D. Knight, Tennessee Valley Authority, Rev. 1, July 10, 1980.

3. Scram Discharge System Special test BF STEAR No. 80-18. Tennessee Valley Authority, Herbert Abercrombie, August 8, 1980.

4. TVA Drawing 47W852-2 Flow Diagram, Clean Radwaste and Decon Drainage Browns Ferry Units 1-3.

5. TVA Drawing 47W481-9 Mechanical - Drains and Embedded Piping Stage III and IV. Browns Ferry Units 1-3.

6. TVA Drawing CNM-5-0024 CRD Scram Discharge Header Isometric. Browns Ferry Nuclear Plant. (Unit 3).

7. GE Letter, J. A. McGrady to F. P. Felini, August 22, 1980. "Thermal Limits Evaluation of Browns Ferry 3 Partial Scram Event" (Copy in Appendix CON).

8. Internal GE report, "Analytical Studies to Simulate the Incomplete Control Rod Insertion Event at Browns Ferry 3 Using a Transient Model". OPE-0880. D. C. Rennels, August 1980.

## GLOSSARY

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|---|---|
| APRM | Average Power Range Monitor - Each APRM gives the average of 8 strings of LPRMs. There are 6 APRM channels |
| CPR | Critical Power Ratio. Bundle power at which transition boiling would start divided by actual fuel bundle power |
| CRD | Control Rod Drives - Mechnical & Hydraulic Piston devices which insert/withdraw control rods (installed directly under reactor vessel) |
| CRW | Clean Radwaste Waste - Equipment leakage is collected directly at source and sent back to storage prior to repeated usage |
| ΔP | Differential pressure |
| HCU | Hydraulic Control Units - Hydraulic, Pneumatic electrical devices which control insert/withdraw of CRD's (located outside containment) |
| Header Bank | The 4 pipes, 6" in I.D. about 50' long which make up a SDV. There are 2 header banks - east and west |
| INPO | Institute of Nuclear Power Operations (Atlanta, Georgia) |
| IRM | Intermediate Power Range Monitor. Neutron detectors capable of being inserted into reactor to measure power at intermediate levels. 0.0001% to 30% of full power. Reactor has 8 IRMs |
| LPRM | Local Power Range Monitor A neutron monitor for use in the power operating range. The core contains 172 LPRMs arranged in 43 vertical strings of 4 each |
| MCPR | Lowest value of CPR in reactor |
| NSAC | Nuclear Safety Analysis Center (Palo Alto, California) |
| SCRAM | Insertion of control rods at maximum speed to terminate chain reaction abruptly. Insertion time usually 2-3 seconds |
| SDIV | Scram Discharge Instrumentation Volume - Includes tanks and piping, fixtures and instruments which monitor water level |
| SDV | Scram Discharge Volume - includes piping fixtures from individual HCU discharge lines thru to discharge into SDIV |
| SRM | Source range power (neutron monitor). Source to about 2% of full power. Reactor has 4 SRMs. |
| TVA | Tennessee Valley Authority |

INPO/NSAC SIGNIFICANT OPERATING EXPERIENCE REPORT 80-6

DECEMBER 19, 1980

PARTIAL FAILURE OF CONTROL RODS TO INSERT

REFERENCE: UNIT - BROWNS FERRY 3
DOC NO/LER NO: 50-296/80-24
DATE: 6/28/80
NSSS/AE - GE/TVA
NSAC 20/INPO 3, Analysis of Incomplete Control Rod Insertion at Browns Ferry 3

DESCRIPTION:

While in the process of performing a normal shutdown for maintenance, a manual scram resulted in a partial failure to insert of 76 control rods, associated with the east Scram Discharge Volume (SDV). Two additional manual scrams followed by an automatic scram were required prior to attaining all rods in.

The details of this event are described in the INPO/NSAC report referenced above.

SIGNIFICANCE:

The potential exists for water to accumulate within the Scram Discharge Volume (SDV) piping in such a way as to remain undetected by the Scram Discharge Instrument Volume (SDIV) instrumentation. This water accumulation may, in turn, result in premature pressurization of the SDV and thus affect control rod motion upon a scram.

RECOMMENDATIONS:

Since designs and conditions vary from plant to plant, it is recognized that any one set of specific recommendations can not apply to all BWR plants. Therefore, these recommendations are presented as objectives which should be attained, with examples of possible ways to achieve these objectives. It is understood these examples do not necessarily represent all the acceptable ways of achieving the objectives. It should be noted that many of the examples are the same as specific fixes which have been proposed by others in the following documents:

NRC IE BULLETIN NO. 80-17
" " " " SUPPLEMENT 1
" " " " SUPPLEMENT 2
" " " " SUPPLEMENT 3

GENERAL ELECTRIC SIL NO. 331
" " " " SUPPLEMENT 4

UTILITY SUBCOMMITTEE RECOMMENDATIONS
"Long-Term Evaluation of Scram Discharge System"



| | |
|---|---|
| *RED | - IMMEDIATE ATTENTION |
| YELLOW | - PROMPT ATTENTION |
| GREEN | - NORMAL ATTENTION |

1. Guard Against Accumulation of Undetected Water In the SDV

The SDIV instrumentation can indicate the absence of water in the SDV; when, in fact, the SDV is essentially full. The SDIV water detection instrumentation should provide reliable, direct indication of water in the SDV.

2. Ensure Adequacy of Procedures on Detection of Water

Ensure that adequate procedures exist regarding action to be taken if water is detected in the SDV system when it should be free of water.

3. Guard Against Obstruction Or Trapping In The SDV-SDIV Connector Pipe.

Any obstruction of the SDV-SDIV line, whether by solid matter or by a water trap, should be guarded against. Possible ways of guarding against a solid obstruction or water trap in the line include:

- Enlarge the diameter of the line connecting the SDV to the SDIV as close as practical to the internal diameter of the SDV headers and repipe with care to eliminate locations where solids would be expected to accumulate such as dips or humps in the line, internal roughness at weld points, diameter changes, etc. Consider relocation of the SDIV to a lower level in the plant to allow for increased pitch in the line between the remote SDV and the SDIV.

-or-

- Install separate SDIVs for the two header banks, so that the line from each header bank to its SDIV will be relatively short, straight, and as close as practical to the same internal diameter as the SDV headers themselves.

4. Guard Against Trapping In The Vent Line

Any location or configuration favorable to trapping water in the vent line should be avoided. Possible ways of doing so include:

- Put vent valves in vertical, not horizontal pipe runs, and ensure that all horizontal portions of vent lines actually have sufficient slope to assure drainage without trapping.

5. Guard Against Interference From CRW Drain System

The possibility that steam or water from other drains into the CRW drain system could interfere with operation of the SDV-SDIV system by inducing a suction or producing a pressure should be guarded against. A possible way of doing this is to:

- Isolate the vent and drain lines from each other and from other CRW drainage, by running them as dedicated lines directly to the reactor building equipment drain sump.

6. Guard Against The Possibility Of The Vent Not Opening

Failure of the SDV vent valve to open should be guarded against since such failure could interfere with the SDV draining freely. Possible ways of doing this include:

- Install a redundant vent valve

-or-

- Cross connect the vents on the two header system

7. Guard Against Excessively Slow SDV Drainage

Excessively slow drainage of the SDV should be guarded against since, if successive and close-spaced scrams are necessary as in the Browns Ferry 3 case, it may be difficult to achieve them if the SDVs are essentially full of water from the preceding scram. After one scram has been attempted, the readiness of the system for a possibly needed next scram should not be limited by the SDV-SDIV drain time. One way of achieving this objective is:

- Ensure that the SDV vent valves open when the scram is re-set by installing redundant valves and ensure that the SDV vent lines are clear.
- Ensure that the SDIV drain line capacity is sized to allow prompt drainage and install redundant SDIV drain valves.

8. Guard Against Trapping In Individual Headers

In some plants each SDV header bank consists of 2 or more header pipes connected together, in parallel, to form the desired volume. The possibility that one header could fail to drain even though the other parallel header has drained should be guarded against. Ways of achieving this include:

- Ensure that the design provides an adequate slope for all headers in each bank.

9. Ensure That Failure To Scram Procedures Are Adequate

Procedures, adequate for guidance of operators and shift engineers in the event of failure to scram, should be provided. These procedures should specify under what circumstances specific measures should be taken in the event of delayed scrams or incomplete scrams.

10. Guard Against Uncontrolled Release Of Reactor Coolant To the Reactor Building

Failure to close on signal of a single vent valve or single drain valve can result in loss of reactor coolant to the reactor building sump. Redundant means to close off the drain and vent pathways during a scram should be considered.

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