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TRIP REPORT: ON-SITE ANALYSIS OF THE HUMAN FACTORS OF AN EVENT AT QUAD CITIES 2 ON OCTOBER 27, 1990

(HI-HI IRM SCRAM FROM HOT STANDBY)

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EXECUTIVE SUMMARY

At 3:39 p.m., October 27, 1990, the Quad Cities Unit 2 reactor scrammed on a Hi-Hi trip from the intermediate range monitors (IRMs). The scram occurred when the Unit 2 Nuclear Station Operator (NSO) was operating in the Hot Standby mode and attempting to control reactor pressure by means of control rod positioning. The scram occurred when the NSO withdrew rods to increase pressure. A team led by Eugene Trager, of Nuclear Regulatory Commission, Office for Analysis and Evaluation of Operational Data (NRC/AEOD), visited the site on October 31 and November 1 to conduct an analysis of the human factors involved in this event as a part of an on-going AEOD program to study the human factors of operating events. Other team members were Barry Kaufer, of NRC/AEOD, and Orville Meyer and Mark Parrish, of Idaho National Engineering Laboratory. This report provides a reconstruction and review of the details of the event and an analysis of the human factors embedded within the event.

The Quad Cities Nuclear Generating Station is located near Cordova, Illinois, and is owned and operated by the Commonwealth Edison Co. of Chicago, Illinois. The station consists of two General Electric BWR-3 reactors with Mark I containment and each plant rated at 789 MWe.

Both units are operated from a common control room, and an NSO, who is a licensed reactor operator (RO), is dedicated to the controls of each reactor. There is an NSO serving as the Center Desk Operator and an additional NSO at the panels. The NSOs for both units are under the supervision of a Shift Control Room Engineer (SCRE), who is a licensed Senior Reactor Operator (SRO). Two Shift Foremen (SF), who also hold SRO licenses, are assigned principally to supervise local operations outside the control room. All operations during the shift are supervised by a Shift Engineer (SE), who is a licensed SRO.

The objective of unit 2 operations during this event was to support the conduct of Special Test 2-95 Partial B, "Turbine Generator Torsional Response Test." The purpose of Special Test 2-95 was to precisely determine the torsional resonant frequencies of the turbine-generator rotors.

The test method was to operate the turbine at 45 to 105% of rated speed with the generator connected to a phase A line-to-neutral short circuit. The electrical load on the generator would be very small. The reactor power required would be approximately 6 to 7%. The turbine speed would be controlled by a test potentiometer in the turbine control valve EHC circuit. Reactor power would be under the control of the Unit 2 NSO.

Temporary Change 6303 was issued on 10/24/90 to normal operating Quad Cities General Procedure (QGP) 2-4, "Shutdown from Power Operation to a Standby Hot Pressurized Condition," in order to allow the use of recirculation pumps and/or control rods to reduce power and thereby provide greater flexibility during power reduction to Hot Standby. Temporary Change 6303 did not add any special instructions or cautions. QGP 2-4 with Temporary Change 6303 was the controlling procedure in use by the Unit 2 NSO during the event.

The Special Test was attempted on 9/28/90 but was not performed due to electrical problems with the EHC circuitry. An extra RO and an SRO were assigned to the control room to perform the test during the 9/28/90 attempt.

The test was attempted again on 10/27/90 beginning with shift 1 (11:00 p.m. to 7:00 a.m.). The Unit 2 NSO inserted control rods to reduce reactor pressure to shut the TBVs and permit connection of Special Test circuitry to the EHC controls.

During this maneuver the NSO experienced high control rod notch worths. The reactor had been in power operation the previous day and high xenon concentrations existed. The tips of the control rods in use were near the top of the core in a region of lower xenon concentration. Information on the high rod notch worth was passed on orally from shift 1 to 2 (7:00 a.m. to 3:00 p.m.) but not from shift 2 to 3 (3:00 to 11 p.m.). No log entry was made of the high control rod notch worths.

The shift 2 operators increased reactor power until 1 to 2 TBVs were open and warmed up the main turbine. However, the Special Test circuitry would not permit increasing the turbine speed above 571 rpm so the turbine was tripped. Unit 2 conditions during shift turnover were ~7% power, 1-1/2 TBVs open, 920 psig reactor pressure, and mode switch in Hot Standby.

When Shift 3 began their orientation, a meeting was being conducted near the SCRE's desk with use of the SCRE's phone among test engineers, the SE, and other station staff concerning the Special Test. The SCRE directed that the meeting leave the control room, and it reconvened in the SE's office. Shift 3 began operations at 3:00 p.m.

In addition to the Special Test, there were other conditions that were of concern to the SE and the SCRE: two IRM channels were in "bypass," one IRM had a spurious trip, and one IRM remote detector drive was inoperable with the detector inserted, and the drywell had been deinerted with a LCO (limiting condition for operation) that requires reinerting within 24 hours or being in Hot Shutdown.

At 3:10 p.m., the above conferencees decided to abort the Special Test and return to power. The SE phoned the SCRE and directed him to take the EHC off-line to permit removing the Special Test circuits. The SCRE directed the Unit 2 NSO to insert control rods to reduce reactor pressure to less than 800 psig.

The NSO inserted control rods a total of 84 steps while observing the reactor pressure decrease. The reactor pressure decreased to 770 psig, but at the same time the reactor power had decreased to Range 1 of the IRM (the lowest range of the IRMs; the reactor was significantly sub-critical). At 3:58 p.m., the NSO began rod withdrawal to increase pressure and withdrew one group of four rods one notch. He then withdrew one rod one notch. The reactor scrammed from an IRM Hi-Hi trip on a 25 second period at 3:59 p.m..

Task Awareness

The dominant human factor in this event was a low level of awareness by the plant staff that the reactor conditions required by the torsional test were difficult to maintain. Reactivity management requires special attention when attempting to control reactor pressure with the control rods while the TBVs are shut because the reactor is at low power (2 to 5%). In addition, high rod notch worths may be experienced if xenon peaking levels are present. This low level of task awareness began with the planning and preparation of the Special Test and carried on through all activities to culminate in the reactor scram.

Procedures

The procedures reflected the low level of task awareness, as there were no special instructions for reactivity management and no cautions for possible high rod notch worths. In addition, procedures were not followed. A test engineer, rather than the Shift 1 Unit 2 NSO, annotated and initialled a step in procedure QGP 2-4 as complete when a controlled change to the procedure would have been more appropriate, particularly since the step involved reactivity management in Hot Standby.

Training

Requalification training had not included a lesson plan for reactor operation in Hot Standby and the operators had no special training nor briefing for the Special Test. The station developed and implemented an appropriate lesson plan within three days after the event.

Dissemination of Operating Experience Information

Information on similar events at other stations had not been disseminated to the reactor operators. The high rod notch worth experienced during shift 1 had not been passed on to the shift 3 operators.

Communications

The Unit 2 NSO did not report back any information to the SCRE while executing the SCRE's comm nd to insert control rods to reduce pressure to less than 800 psig. The changes in rod positions and reactor power level were significant enough to justify supervisory overview by the SCRE.

Command and Control

The commands from the SE to the SCRE and from the SCRE to the NSO were minimal and did not contain cautions or directions to report information back. The lack of reporting from the NSO to the SCRE contributing to the SCRE's failure to direct and oversee the NSO's actions.

Knowledge-Based Versus Rule-Based Operation

The Unit 2 NSO seemed to have been in a rule-based mode of operation, as he was following the procedural rule to "insert control rods until reactor pressure is less than ..." No signal seemed to have been effective to remind the operator to use his knowledge of reactivity management and also monitor reactor power.

ACKNOWLEDGEMENTS

Appreciation is expressed for the cooperation of the Quad Cities station staff and especially for the control room operators who were on duty during shift 3 on October 27, who freely provided information concerning their observations, thinking, and actions during the event. Appreciation is also expressed for the valuable insights and contributions of Hironori Peterson, of NRC Region III, during on-site analysis.

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ACRONYMS

APRM	average power range monitor
EHC	electro-hydraulic control
IRM	intermediate range monitor
NRC/AEOD	Nuclear Regulatory Commission, Office for Analysis and Evaluation of Operational Data
NSO	Nuclear Station Operator
QGP	Quad Cities General Procedure
RO	Reactor Operator
SCRE	Shift Control Room Engineer
SE	Shift Engineer
SF	Shift Foreman
SRM	source range monitor
SRO	Senior Reactor Operator
TBV	turbine bypass valve

1. INTRODUCTION

1.1 Purpose

The purpose of the visit to the Quad Cities Nuclear Generating Station on October 31 and November 1 and of the subsequent analysis was to examine the human factors involved in the automatic reactor scram from Hot Standby that occurred on Unit 2 at 3:59 p.m., October 27, 1990. The scram originated from a Hi-Hi trip on intermediate range monitors (IRMs) 13 and 16 while the Unit 2 Nuclear Station Operator (NSO) was attempting to control reactor pressure by means of control rod positioning. The reactor scrammed on a 25 second period when the NSO withdrew control rods to increase pressure. This site visit was the sixth site visit to be conducted by the NRC staff with the assistance of INEL, for the purpose of acquiring and analyzing data on the related human factors issues of operating events.

1.2 Scope

The on-site data acquisition and analysis focused on the factors that contributed to the reactor trip: operator tasks, control room activities, and control room crew composition immediately preceding the scram. The human factors related to the preparation for the test were also analyzed: planning of the operation, preparation and review of the controlling procedures, specific training for the operation, and on-shift and shift-to-shift operator communications.

1.3 On-site Analysis Team

The on-site analysis team was led by Eugene Trager, of NRC/AEOD, and included Barry Kaufer, of NRC/AEOD, and Orville Meyer and Mark Parrish of Idaho National Engineering Laboratory.

2. DESCRIPTION OF THE EVENT ANALYSIS

2.1 Background

The Quad Cities Nuclear Generating Station is located near Cordova, Illinois, on the Mississippi River approximately 20 miles north of Moline, and is owned and operated by the Commonwealth Edison Co. of Chicago, Illinois. The station consists of two General Electric BWR-3 reactors with Mark I containment and each plant rated at 789 MWe. Unit 1 entered commercial operation on February 18, 1973; Unit 2, on March 10, 1973.

Both units are operated from a common control room, and an NSO, who is a licensed reactor operator (RO), is dedicated to the controls of each reactor. There is an NSO serving as the Center Desk Operator and an additional NSO at the panels. The NSOs for both units are under the supervision of a Shift Control Room Engineer (SCRE), who is a licensed Senior Reactor Operator (SRO). Two Shift Foremen (SF), who also hold SRO licenses, are assigned principally to supervise local operations outside the control room. All operations during the shift are under the supervision of a Shift Engineer (SE), who is a licensed SRO.

The objective of Unit 2 operations during this event was to support the conduct of Special Test 2-95 Partial B, "Turbine Generator Torsional Response Test." (Unit 1 was in commercial power generation at 90 to 100% power.) The purpose of Special Test 2-95 was to precisely determine the torsional resonant frequencies of the turbine-generator rotors. The test method was to excite the resonant frequencies by operating the turbine at 45 to 105% of rated speed with the generator disconnected from the grid and instead connected to a phase A line-to-neutral short circuit. The phase A fault current would be limited to low values by the use of a low-power dc source in place of the normal field excitation. The electrical load on the generator would be very small and the turbine load would be slightly above the no-load value. The reactor power required would be that necessary to support the turbine and the auxiliary steam loads which would total approximately 6 to 7% of full reactor power.

During the actual measurement of the resonant frequencies, the turbine speed would be controlled by a test potentiometer speed reference setting in the turbine control valve electric-hydraulic control (EHC) circuit. The potentiometer setting would be under the direction of the test director. Reactor power would be under the control of the Unit 2 NSO with the automatic pressure control adjusting the opening of the turbine bypass valves (TBVs) to maintain reactor pressure near the setpoint.

The Special Test 2-95 Partial B procedure does not specify the reactor power level for the performance of the measurement of the resonant frequencies. It does state that the Mode Switch must be in Startup/Hot Standby and the reactor power must be less than 12% to prevent a reactor scram due to an average power range monitor (APRM) Hi-Hi trip. The "Limitations and Actions" section of the Special Test procedure states that the Test Director shall order the reactor to be scrammed if any of the following conditions exist and are "not part of a controlled evolution:"

- Reactor pressure increasing above 960 psig
- Reactor pressure decreasing below 890 psig
- APRMs increasing above 11% of rated power
- APRMs decreasing below 2% of rated power.

Temporary Change 6303 was issued on 10/24/90 to normal operating procedure QGP 2-4, "Shutdown from Power Operation to a Standby Hot Pressurized Condition," in order to allow the use of recirculation pumps and/or control rods to reduce power and thereby provide greater flexibility during power reduction to Hot Standby. Temporary Change 6303 deleted certain sections of QGP 2-4 as not applicable to the Special test evolution and did not add any Special instructions or cautions. QGP 2-4 with sections deleted by Temporary Change 6303 was the controlling procedure in use by the Unit 2 NSO during the event on 10/27/90. The combination of Special Test Procedure 2-95 Partial B and Temporary Change 6303 constituted the procedures for the Special test evolution.

The on-site analysis of this event disclosed that there were five phases to this Special test evolution, as defined in Table 1.

The Special Test 2-95 Partial B procedure gave explicit instructions for reactor operation only for the fourth item in Phase 3, that is, the procedure gave no instructions for reactor operation during installation and removal of test circuits. The only applicable procedure for reactor operation for the remainder of the evolution was QGP 2-4 as modified by Temporary Change 6303. The reactor scram during the event occurred during the performance of Phase 4. There was no special training for Special Test evolutions.

2.2 Event Time Line

The following event time-line sequence was constructed based upon interviews with the station personnel listed in Table 2 and upon reviews of the control room logs and recordings and control room copies of Special Test 2-95 Partial B and Temporary Change 6303. The IRM recorders were operating on slow speed during the event and the station was attempting to decipher the recordings during the site visit (some entries in control room logs required interpretation):

9/26/90

> Safety evaluation for Special Test 2-95 Partial B approved by the Quad Cities On-site Safety Review Board. The conclusion of the safety evaluation was that the Final Safety Analysis Report and the Technical Specifications were not affected and did not need to be changed.

Table 1. Reactor operating cycle for performance of Special Test 2-95 Partial B, "Unit 2 Turbine-Generator Torsional Response Test"

Phase 1. Initial conditions

Low power operation (~10%).

Automatic reactor pressure control at ~900 psi with 1-1/2 TBVs open.

Reactor power level is high enough for the void coefficient of reactivity to provide reactor power stability.

Infrequent notching of individual control rods used to adjust power level.

Xenon at greater than equilibrium due to power history.

Phase 2. Installation of Special Test circuits on EHC controls

Requires the EHC to be taken out-of-service with main turbine secured and all TBVs shut.

Operating method selected is to reduce reactor power by inserting control rods until the automatic pressure control has shut all TBVs and then to continue reactor power reduction until the auxiliary steam loads have reduced pressure to less than 900 psig.

Reactor power reduction by rod insertion will have little effect upon pressure reduction after reactor power is reduced below the decay heat level [below the Point of Adding Heat (POAH), Range 7 on IRMs]. Pressure reduction will be determined by the auxiliary steam loads and ambient losses, which may not total much in excess of the decay heat levels.

Continued rod insertion may be required to compensate for the temperature affect on reactivity during cooldown and for possible decay of xenon.

Continued rod insertion may drive the reactor subcritical since power level is too low for the void coefficient of reactivity to have much effect.

Reactor criticality may be sensitive to rod motion on rods high in or on the periphery of the core due to xenon peaking in the central regions of the core.

Table 1. (continued)

Phase 3. Operate Turbine-generator per Special Test 2-95 Partial B.

Restore EHC.

Increase reactor power by notching out control rods until the increasing reactor pressure causes the automatic pressure control to begin to open a TBV.

Continue until in low power operation with one to two TBVs open.

Turbine-generator will be operated at very low load with speed adjusted as requested by the Test Director.

Phase 4. Remove Special test circuits on EHC controls.

Reactor operation is the same as in Phase 2.

Phase 5. Return to normal commercial operation.

Table 2. Station personnel interviewed

10/27 Shift 1: Unit 2 Nuclear Station Operator[a]
Shift Control Room Engineer[a]

10/27 Shift 3: Unit 2 Nuclear Station Operator
Shift Control Room Engineer
Shift Engineer
Shift Technical Advisor
Nuclear Engineer

Training Manager

Simulator Training Manager

a. These operators were also on-duty during the 9/28/90 attempt to perform Special Test 2-95 Partial B.

9/27/90

Validation of Special Test 2-95 Partial B was signed off as completed. The validation sign-off form offers four validation methods:

Simulator performance

Plant walk-through

Bench check

Tabletop check, which was selected.

Rev 0 of Special Test 2-95 Partial B received on-site review and approval signatures.

9/28/90

Phase 2 of Special Test 2-95 Partial B (see Table 1) was attempted but not completed due to electrical problems with the EHC circuit.

An extra RO and SRO were assigned to the shift to perform the Special Test (the extra RO and SRO were the unit 2 NSO and SCRE on duty on shift 1 on 10/27/90 later in this sequence.)

10/24/90

Temporary Change 6303 was issued against QGP 2-4, "Shutdown from Power Operation to a Standby Hot Pressurized Condition," to "allow the use of recircs [reactor coolant recirculation pumps] and/or control rods to reduce power to provide greater flexibility during power reduction to hot standby."

3:40 a.m. - Received Channel A half scram while ranging IRM 14 from range 7 to 6. This appeared to be a spurious electrical problem. A "near miss" memo was written to inform the on-coming shift.

(time approx) - The SCRE and the Unit 2 NSO could not understand step D.38.b and would not sign it as completed. The Test Director then annotated and initialled step D.38.b of operating procedure QGP 2-4 as complete.

- "Hot rod" condition experienced ["hot rod" is terminology used by station operators for unusually high rod worth]. Significant IRM increase of 1 to 2 ranges resulted from one notch rod withdrawal. The auxiliary NSO assigned to the control room was directed to help observe IRM responses.

4:20 a.m. - Unit 2 reactor pressure steady at ~830 psig. The EHC pumps were turned off.

- Technicians began to connect test circuitry to EHC controls for Special Test 2-95 Partial B.

10/27/90-Shift 2 (7:00-3:00 p.m.)

7:00 a.m. - Shift turnover.

- Unit 1 operating at 710 to 780 MWe.

10/27/90, Shift 1 (11:00 p.m. 10/26 to 7:00 a.m. 10/27)

11:00 p.m. - Shift turnover.

- Unit 1 at 95 to 100%.

- Unit 2 at 141 MWe and preparing for turbine torsional test.

11:45 p.m. - Made entry into Unit 2 drywell to disconnect drive from IRM 16 detector and manually insert detector, since remote drive was inoperable (drywell had been deinerted previously).

00:52 a.m. - Reduced Unit 2 power to 130 MWe and took turbine off line.

- Began inserting rods to come to Hot Standby.

2:40 a.m. - Unit 2 Mode Switch to Startup/Hot Standby.

- Began inserting rods to reduce reactor pressure to target value of 850-900 psi to close the TBVs and turn off EHC pumps.

- Test Director for Special Test 2-95 Partial B was present (also the individual who planned the Special Test, is a licensed SRO, and has had experience as a nuclear engineer.)

- At Hot Standby; reactor pressure ~860 psig; drywell deinerted because of entry required during Shift 1; limiting condition for operation (LCO) action statement to reinert the drywell or in shutdown within 24 hours; IRM 17 inoperable; IRM 16 remote drive for detector inoperable.

- Shift 1 operators orally advise on-coming shift 2 Unit 2 operators of the "hot rod" condition experienced. However, no written information was provided.

10:10 a.m. - Turned on Unit 2 EHC pumps and began notching rods out to increase power until 1 to 2 TBVs are open.

- Began turbine warmup.

12:20 p.m. - Closed generator field circuit breaker for turbine torsional test.

12:24 p.m. - Adjusted Unit 2 APRM gains to 7% power.

12:26 p.m. - Began turbine acceleration.

1:25 p.m. - Turbine speed seems to plateau out at 571 rpm, which is less than minimum speed required for the turbine torsional test.

- Conference begins among the Special Test Director, other utility personnel, and vendor personnel concerning the turbine speed problem.

- Opened generator field breaker and tripped the turbine.

2:30 p.m. - Shift 3 operators arrive on-site and begin preparations for assuming control at 3:00 p.m.

2:50 p.m. (approx) - SCRE directed Special Test conferees to leave the control room.

10/27/90 - Shift 3 (3:00 to 11:00 p.m.)

3:00 p.m. - Unit 1 at 710 to 780 MWe.

- Unit 2 on "hold" for Special Test 2-95 Partial B, ~7% power, 1-1/2 TBVs open, 920 psig.

- Four out of eight IRMs had problems [the A channels have one in "bypass' and one with caution tag because of 1/2 scram on Shift 1, and B channels have one on "bypass" and one (#16) with detector inserted but with inoperable remote detector drive.]

- Unit 2 was in LCO action statement to reinert drywell with approximately 12 hours remaining or be in shutdown. Withdrawal of IRM #16 would require entry into drywell. Reinerting drywell would require 10 to 11 hours elapsed time.

- No information concerning the "hot rod" experience during shift 1 was passed on to the on-coming shift 3 Unit 2 operators.

- Conference was still on-going concerning the problem with the Special Test 2-95 and was taking place near SCRE's desk with use of SCRE's phone.

- Conference resumed in SE's office.

3:10 p.m. - Decision made by conferees in SE's office to abort Special Test 2-95 Partial B and return Unit 2 to commercial power generation. The IRM 16 detector with the inoperable drive was left inserted, which would destroy (burn-out) the detector during power operation.

- SE directed the SCRE by telephone to insert control rods to take the EHC off-line and began directions to other personnel for reinerting the drywell and other preparations for disconnecting the Special Test equipment and returning Unit 2 to power operations.

- Nuclear engineer "on-call," who had been called to be present for the Special Test, left site since the test was aborted.

- SCRE directed Unit 2 NSO to insert control rods to reduce reactor pressure to less than 800 psig. (During similar maneuver on shift 1 the pressure was not reduced below ~860 psig. The purpose of the pressure reduction was to prevent an increasing pressure reaching 920 psig and signal the TBVs to open. The SCRE on shift 3 was opting for a larger pressure margin to prevent this. However, this would require more rod insertion.) Unit 2 NSO began inserting control rods per step D.38.b of QGP 2-4.

3:30 p.m. - Unit 2 NSO continued rod insertion.

- Fourteen rod groups were inserted, a total of 84 steps.

- Unit 2 NSO was observing pressure decrease with objective of decreasing pressure to less than 800 psig.

- Unit 2 NSO stopped rod insertion at ~850 psig

- IRM indications decreased from Range 6 to 1 (reactor was significantly subcritical, however, Unit 2 NSO was still focusing attention on reactor pressure).

- At 805 psig the TBVs were completely closed by the automatic pressure control and the EHC pumps were turned off. Reactor pressure was decreasing. Unit 2 NSO attempted rod withdrawal to increase pressure.

3:43 p.m. - Rod block annunciator indicated that rod withdrawal was blocked due to source range monitor (SRM) indication being less than 100 cps and SRMs not fully inserted. Unit 2 NSO began inserting SRMs to increase their indicated level.

3:57:45 p.m. - Rod block cleared as SRMs were being inserted. Reactor pressure was 770 psig.

3:58 p.m. - Unit 2 NSO began rod withdrawal to increase reactor pressure; withdrew one Group (G-7, G-9, J-9, J-7) from position 04 to 06; then withdrew rod G-7 from position 06 to 08.

3:59 p.m. - Unit 2 reactor scram from IRM Hi-Hi trip.

(Note: No significant changes in reactor feedwater flow or reactor water level occurred during the 3:30-3:59 time interval relative to reactivity.)

- Entered procedure QGP 2-3 for Hot Shutdown.

2.3 Analysis

2.3.1 Task Awareness

A dominant factor underlying all other factors of this event was a low level of awareness that the reactor operation tasks required by the Special Test 2-95 on the Unit 2 turbine generator might require special attention. Table 1 was prepared during this event analysis to identify five different phases of reactor operation that were required to perform the Special Test. This tabulation indicates that Phase 2 and 4, the installation and removal of Special Test circuits on the EHC controls, may require special attention to reactivity management to avoid either subcriticality or short reactor startup periods. However, the event analysis indicated that a low level of task awareness [illegible] reactivity management persisted through the preparation and conduct intervals for the Special Test.

The reactor was to be maintained in Hot Standby with the TBVs shut during Phase 2 and 4. Maintaining the reactor critical in Hot Standby with the TBVs shut is an infrequently performed operation of limited durations since the normal operating plans would usually call for continuing on either to Hot Shutdown or to Power Operation.

Safety Evaluation 90-601, 9/24/90, which was prepared for Special Test 2-95, Partial B, does not address reactivity management during the Special Test. Temporary Change 6303 to QGP 2-4, "Shutdown from Power Operation to a Standby Hot Pressurized Condition," was prepared by deleting those parts of QGP 2-4 that were not needed to support the Special Test 2-95 to provide greater flexibility during power reduction to hot standby. Temporary change 6303 did not add any notes or cautions to QGP 2-4. As summarized below QGP 2-4 is not explicit for reactivity management of the Phase 2 and 4 condition (Table 1) and contains no cautions for possible high rod or notch worth.

2.3.2 Procedures

The controlling procedure for reactor operations for the Special Test was Temporary Change 6303 to QGP 2-4, "Shutdown from Power Operation to a Standby Hot Pressurized Condition." As noted above, QGP 2-4 has no cautions for reactivity management. The possible need for a caution is demonstrated by the fact that QGP 1-2, "Unit Startup to Hot Standby," has a caution concerning the possibility of high rod and notch worths existing after a shutdown from power operations. QGP 1-3, "Hot Standby to Power Operation," has a similar caution that is more generally worded and is not restricted to specific, limited rod positions.

The control room copy of the controlling procedure, Temporary Change 6303 to QGP 2-4, had been initialled as complete through Step D.38.b by the Shift 1 operators. The Shift 3 Unit 2 NSO was using the marked up copy of the procedure for guidance, but was not formally following the procedure. There was no procedure covering the complete sequence of reactor operations outlined in Table 1.

At the time of the event, the Unit 2 NSO had Temporary Change 6303 on his desk and was attempting to carry out the SCRE's command to reduce pressure to less than 800 psig in accordance with Step 38 b of Temporary Change 6303. The "less than 800 psig" is a variation from the "920 psig" in step 3.8.b.:

b. Insert control rods until reactor pressure equals 920 psig and the reactor 's subcritical by at least three rods.

The Unit 2 NSO copy of Temporary Change 6303 contained an added handwritten note: "Impossible to tell exact number of rods subcrit., took pressure to 825 psig," adjacent to step 38 b and the step had been initialled off by the operating engineer on shift 1 of 10/27/90. The insertion of the control rods until the reactor power was below the range of the IRMs was consistent with the controlling procedures.

To summarize, the controlling procedure for the Special Test had no special instructions for reactor power or reactivity control or cautions for high rod or notch worth and relied instead upon the QGPs for Hot Standby. The adequacy of these QGPs in this respect is questionable and is under review by the Quad Cities Station staff.

A signal occurred on shift 1 of 10/23/90 that could have alerted the control room crew to the possibility of a problem in the use of the controlling procedure for the Special Test. That signal was the request by the SCRE and Unit 2 NSO for help in interpreting Step D.38.b of Temporary Changes 6303. The request was resolved by the operating engineer on shift 1 who discussed Step D.38.b with the SCRE and the Unit 2 NSO, annotated and initialled the step on the control room copy of Temporary Change 6303 as complete. This resolution was apparently adequate for shift 1, as no reactivity management anomaly occurred on shift 1. A preferred resolution would have been to put the test on hold and initiate a change request for the controlling procedure. The change control process may have uncovered the fact that QGP 2-4 was missing the caution with respect to high rod notch worths that existed in QGP 1-2 and QGP 1-3. However, it may not have uncovered the knowledge that central rods may have a high notch worth when these tips are near the top of the core, since that knowledge was not widely available. A full resolution to the interpretation and usage of Step D.38.b would have required a higher level of task awareness, specifically, a greater knowledge of the possible sensitivity of the reactivity management task during the test planning and procedure preparation stages.

2.3.3 Training

No special training was requested for this Special Test and there was no simulator drill, classroom instruction, or "read only" instructions for the control room operators. Further, there was no lesson plan that specifically covers reactivity management in Hot Standby conditions. Hot Standby may be transitioned during some simulator exercises but the high rod notch worths experienced on 10/27/90 would not have been simulated. Maintaining criticality in Hot Standby was not included in previous Requalification training.

On the job training or experience in reactivity management in Hot Standby is limited since this is an infrequent condition. The Unit 2 NSO operator who had experienced the scram could not recall any time since 1982 that he had been involved in Hot Standby operations.

The Requal/Remediation Lesson Plan that was issued on 10/31/90 and the Hot Standby Operations lesson plan for SRO/RO licensee training that was issued on 10/30/90 define training that would have been appropriate for supporting operations during the 10/27/90 event.

2.3.4 Dissemination of Operating Experience Information

An SRO was assigned to review the reactivity management event that occurred at La Salle on 6/23/1990. However, no written information on the significance of this event relative to Quad Cities was prepared for the reactor operators.

Special Test 2-95 had been attempted on 9/28/90 and Phase 2 and 4, installation and removal of the test circuits on the EHC controls, was performed. An extra SCRE and NSO were present at the Unit 2 controls for this trial. No written information on the reactor control experience during this 9/28/90 test run was prepared for the benefit of other reactor operators or other station staff.

Phase 2 of Special Test 2-95 was performed by the 11:00 p.m. to 7:00 a.m. shift on the morning of 10/27/90. High notch worth had been experienced and understood by the NSO and the SCRE (who incidentally were the same NSO and SCRE at the controls on 9/28/90). No written information on this experience was prepared; there was no entry in the logs. Oral information was passed on during the turnover to the 7:00 a.m. to 3:00 p.m. shift, however this shift did not pass this information on to the 3:00 to 11:00 p.m. shift who ultimately experienced the scram at 3:59 p.m.

2.3.5 Communications

The low level of awareness of the reactor operations task demands that existed during the planning of Special Test 2-95 was followed by a low level of communications that existed among the station operators as demonstrated by the following information from the on-site analysis.

The command communication from the SE to the SCRE by telephone was to reduce pressure, turn off the EHC pumps, remove the Special Test circuits, and restore the EHC to service. The command communication from the SCRE to the Unit 2 NSO was to reduce the pressure to less than 800 psig to permit turning off the EHC pumps. There was no communication from the Unit 2 NSO to the SCRE to acknowledge understanding of the command or to report progress in execution of the pressure reduction. Immediately before the scram, the SCRE realized that the Unit 2 NSO was pulling rods and that the SRMs were fully inserted, but there was no communication between the SCRE and the Unit 2 NSO.

2.3.6 Command and Control

The low level of communication among the SE, the SCRE, and the Unit 2 NSO implies a diminished level of command and control of the Unit 2 reactor, as does the absence of a brief review by the shift 3 operators of the planned operations for the shift prior to initiating a significant change in the operating mode of the reactor. There were several factors that contributed to the diminished status of command and control: (a) the continuously low level of task awareness, which perhaps was compounded by a shift turnover during which there many people in the control room; (b) the conference in the control room among the SE and other station staff concerning a decision as to whether to return to power or to shutdown; (c) the need to resolve the question concerning the time limit on an LCO which required reinerting the drywell versus the inoperable IRM detector drive which would require entry into the drywell to repair; (d) concern about the reliability of other IRM channels; and (e) when the Unit 2 NSO began to lower reactor power to reduce pressure, the SE and the SCRE were involved in reinerting the drywell and other activities pursuant to returning to power.

A command to hold the existing reactor operating mode until the situation was reviewed among the SE, the SCRE, and the Unit 2 NSO would have been appropriate. However, given the low levels of task awareness and communications and the absence of detailed operating instructions, precautions, and training for Phase 2 and 4 of the Special Test, it cannot be determined if a "hold and review" command would have prevented the reactor scram.

2.3.7 Knowledge-based Versus Rule-based Operation

The expected range of knowledge of an NSO includes the fact that Range 6 of the IRMs is below the POAH as is the heat balance principle that results in little effect on pressure reduction if the reactor power is reduced below the POAH. However, it appears that the Unit 2 NSO was in a rule-based mode of operation, as he was fixated on following step 38 b of Temporary Change 6303, "Insert control rods until reactor pressure is less than 920 psig and the reactor is subcritical," as modified by the SCRE's direction to reduce pressure to less than 800 psig. His knowledge base would have told him that it was unnecessary to reduce power below Range 6, however, a rule-based manner of operation is self-reinforcing. Once an operator is engaged in executing a set of specific rules, the operator will tend to continue until some signal alerts him to reconsider, such as an annunciator alarm, a procedural caution a cautionary principle retained from training, or a communication from another control room team member. In this event no such signal was present and the Unit 2 NSO had confidence stemming from a use of the procedure by a previous shift as attested by the initials of an experienced operating engineer.

Once the reactor power was down to the bottom of the range of the IRMs, the stage was set for obtaining a short reactor period and Hi-Hi IRM scram due to the combined effect of reactor cooldown, xenon decay, and high notch worth of the center control rods.

3. SUMMARY OF FINDINGS

There were several human factors that were evident contributors to the reactivity transient and Hi-Hi IRM scram on October 27, 1990. However, our analysis indicates that the factor that underlay all the other factors was a low level of task awareness concerning the management of reactivity by the reactor operator when operating in a post-shutdown, Hot Standby mode. Several conditions combine to present a unique challenge to the reactor operator who is executing this task: increased control rod notch worth due to post-shutdown xenon conditions, variable levels of decay heat, low level of control of heat removal, and low level of negative reactivity feedback from temperature changes or void formation. In addition, planning for the turbine torsional response test apparently did not consider the possibility that operations during preparation for and restoration from the test would be more challenging than operation during the test itself.

Given this low level of task awareness at the test planning stage, there would not have been a strong signal to review the written procedural instructions and cautions, the task specific training, and the command and control structure and staffing for the entire Special Test evolution. These were the human factors that ultimately led directly to the unanticipated, automatic scram.