2-131B

USERS COPY

1 of 2

GEORGIA POWER
POWER GENERATION DEPARTMENT
VOGTLE ELECTRIC GENERATING PLANT

TRAINING STUDENT HANDOUT

TITLE:	LOSS OF RESIDUAL HEAT REMOVAL	NUMBER:	LO-HO-60315-001-02
PROGRAM:	LICENSED OPERATOR TRAINING	REVISION:	2
AUTHOR:	L. FITZWATER	DATE:	8/9/89
APPROVED:	Lloyd A. Zagorski	DATE:	9/1/89

VEGP PROCEDURE 18019-C, REV 5

SOER 88.003, LOSSES OF RHR WITH REDUCED VESSEL WATER LEVEL AT PWRs

9202190490 920116
PDR ADOCK 05000424
S PDR

MASTER COPY

SOER 88-003

ON OCTOBER 19TH AND 20TH, 1988, SOER 88-3 "LOSSES OF RESIDUAL HEAT REMOVAL WITH REDUCED REACTOR VESSEL WATER LEVEL AT PWRs," WAS MAILED TO ALL INPO MEMBERS AND PARTICIPANTS. THIS SOER IS BEING TRANSMITTED ON NETWORK FOR MEMBERS AND PARTICIPANTS THAT USE ELECTRONIC MEANS FOR DISTRIBUTION.

SIGNIFICANT OPERATING
EXPERIENCE REPORT: 88-3

YELLLOW - PROMPT ATTENTION

October 19, 1988

LOSSES OF RESIDUAL HEAT REMOVAL WITH REDUCED VESSEL WATER LEVEL AT PWRs

EVENTS:

UNIT (TYPE):	DIABLO CANYON 2 (PWR)	WATERFORD 3 (PWR)
DOC NO/LER NO:	50-323/87005	50-382/86015
EVENT DATE:	4/10/87	7/14/86, 5/12/88
NSSS/AE:	WESTINGHOUSE/PACIFIC GAS AND ELECTRIC	COMBUSTION ENGINEERING/EBASCO
UNIT (TYPE):	SAN ONOFRE 2 (PWR)	ZION 2 (PWR)
DOC NO/LER NO:	50-361/86007	50-304/85028
EVENT DATE:	3/26/86	12/14/85
NSSS/AE:	COMBUSTION ENGINEERING/ BECHTEL	WESTINGHOUSE/ SARGENT & LUNDY

REFERENCES:

1. INPO Significant Event Report (SER) 15-87, "Extended Loss of Residual Heat Removal During Steam Generator Maintenance"

2. INPO Significant Event Report (SER) 35-86, "Extended Loss of Shutdown Cooling Due to Steam Binding of Shutdown Cooling Pumps"

3. INPO Significant Event Report (SER) 17-86, "Loss of Shutdown Cooling Flow"

4. INPO Significant Operating Experience Report (SOER) 85-4, "Loss or Degradation of Residual Heat Removal Capability in PWRs"

5. INPO Significant Event Report (SER) 23-86, "Loss of Decay Heat Removal Flow Due to Inadequate Reactor Coolant System

Level Control"

6. INPO Significant Event Report (SER) 31-86, "Loss of Residual Heat Removal Flow Due to Inadvertent Draining of the Reactor Coolant System"

7. INPO Significant Event Report (SER) 2-87, "Degradation of Emergency Core Cooling"

8. INPO Operations and Maintenance Reminder (O&MR) 295, "Loss of Residual Heat Removal Flow"

9. Nuclear Safety Analysis Center Report NSAC/52 of January 1983, "Residual Heat Removal Experience Review and Safety Analysis, Pressurized Water Reactors"

10. NRC Information Notice 88-36, "Possible Sudden Loss of RCS Inventory During Low Coolant Level Operation," June 8, 1988

11. NRC Information Notice 86-101 "Loss of Decay Heat Removal Due to Loss of Fluid Levels in Reactor Coolant System," December 12, 1986

12. NUREG-1269, "Loss of Residual Heat Removal System," Diablo Canyon, Unit 2, April 10, 1987

13. NRC Letter of May 18, 1987, "Loss of Decay Heat Removal Function at Pressurized Water Reactors With Partially Drained Reactor Coolant Systems"

14. NRC Information Notice 87-23, "Loss of Decay Heat Removal During Low Reactor Coolant Level Operation," May 27, 1987

15. NRC Generic Letter 87-12, "Loss of Residual Heat Removal (RHR) While the Reactor Coolant System (RCS) is Partially Filled," July 9, 1987

16. Presentation paper entitled "An Improved Reactor Coolant Level Monitoring System to Prevent Loss of Residual Heat Removal Function in a PWR," 13th Biennial Conference on Reactor Operating Experience, August 30 - September 3, 1987, Chicago, Illinois, by Dina M. Lawrence, Commonwealth Edison

NOTE: The following terms are used interchangeably within this SOER:

- o shutdown cooling
- o residual heat removal
- o decay heat removal
- o low pressure safety injection

SUMMARY:

Significant Operating Experience Report (SOER) 85-4, "Loss or Degradation of Residual Heat Removal Capability in PWRs," issued in August 1985, discussed events involving loss or degradation of residual heat removal (RHR) capability at pressurized water reactors. The events focused on the three most common ways of losing RHR:

- o low reactor vessel level resulting in loss of RHR pump suction
- o closure of the RHR pump suction valve
- o tripping of the running RHR pump

Eighty percent of the stations have implemented most of the recommendations contained in SOER 85-4, and approximately 40 percent have implemented all the recommendations. The most frequent recommendations awaiting implementation are independent reactor vessel level indication and some procedure changes.

However, events involving loss of residual heat removal capability with reduced reactor vessel water level continue to occur at a high rate. More than 10 events involving the loss of residual heat removal capability for greater than 1 hour have occurred since August 1985. This SOER discusses five of these events, including three which resulted in boiling of water in the reactor core. These events could have been prevented through a thorough review and effective and timely implementation of the recommendations in SOER 85-4. These events demonstrate the need for increased attention to activities that require operation of the residual heat removal system with reduced reactor vessel water level at mid-loop. This SOER supplements SOER 85-4, "Loss or Degradation of Residual Heat Removal Capability in PWRs," and provides additional recommendations to prevent a loss of core cooling with reactor vessel water level at mid-loop.

These events are significant because loss of residual heat removal capability can result in the boiling of cooling water, with the potential for core uncovery and damage. The loss of residual heat removal cooling can also lead to airborne radioactivity releases, increased radiation levels due to loss of core shielding, and equipment damage.

DESCRIPTION:

DIABLO CANYON 2 (4/10/87):

The plant had been shut down for seven days. The residual heat removal system was in operation. The reactor coolant system had been drained to the mid-loop level to permit removal of the steam generator primary side manways for nozzle dam installation. The control room operator was monitoring the reactor vessel water level using a temporary water level indication system.

An engineer preparing for a local leak rate test on the reactor coolant pump seal return line to the volume control tank (VCT) opened a vent and drain valve to drain the water from a previously isolated line. The engineer then left the containment. While the line was draining, one of the boundary isolation valves leaked. This resulted in a loss of inventory from the VCT. The drain path was not monitored locally for continued leakage. The operators were unaware that a drain path had been established because the engineer preparing for the test was working under a one-day-old clearance request and had not briefed the on-duty operating shift before starting this evolution.

The resulting drop in the VCT level was observed immediately in the control room. Believing the drop in VCT level was due to decreased let down flow, the operators increased letdown flow to maintain constant VCT level, assuming that this action would also maintain reactor vessel water level constant at mid-loop. As a result, actual reactor vessel water level began to decrease slowly as indicated on the temporary water level indication system. The increased letdown flow had lowered reactor vessel water level until air entrainment occurred through a vortex at the residual heat removal suction nozzle connection to the reactor coolant system hot-leg piping. This resulted in air binding and cavitation of both the operating and the standby residual heat removal pumps.

When the decreasing reactor vessel water level was detected, the operators isolated the letdown and charging flow paths. Securing letdown flow stopped the loss of inventory from the reactor coolant system; however, because the open drain valve had not been detected, the level in the VCT continued to decrease.

When the residual heat removal pump cavitated, residual heat removal cooling capability was lost, and the reactor coolant temperature began to rise due to decay heat. The operators underestimated the heatup rate because their previous experience with a loss of residual heat removal occurred when the core had little decay heat. Because the core exit thermocouples had been disconnected in preparation for reactor closure head removal and the reactor coolant loop resistance temperature detector indications were unreliable due to lack of reactor coolant flow, the operators were unaware of the rapid temperature increase. Concerns for the safety of personnel removing the steam generator manways resulted in delays in raising reactor vessel water level. As a result, restoration of reactor vessel water level was delayed for one hour and 28 minutes. Reactor coolant system water temperature increased from 87 degrees to 220 degrees Fahrenheit, and reactor coolant system pressure increased from atmospheric to approximately 10 psig. During this period, steam was vented to containment via the reactor vessel head temporary vent line that ruptured due to the pressure increase. Water was spilled from the partially unsealed steam generator manways. Airborne radioactivity levels in containment rose, requiring evacuation of personnel.

The plant has revised its procedure for draining the reactor coolant system, providing precautions relating to residual heat removal flow and reactor coolant system level to preclude significant air entrainment due to vortex formation. A prerequisite that requires effective communications during all work activities that directly or indirectly affect reactor coolant system inventory also was included. The loss of residual heat removal flow abnormal procedure has also been revised to recognize that if an operating residual heat removal pump cavitates excessively or loses suction, the idle pump should not be started until adequate reactor vessel water level is restored. In addition, the abnormal procedure now includes a table for determining the time (based on existing water inventory, power history, and time since shutdown) until the reactor coolant system temperature will reach 200 degrees Fahrenheit without forced cooling flow. Finally, containment integrity is now required to be established prior to mid-loop operation.

Additional details of this event are provided in Reference 1.

WATERFORD UNIT 3 (7/14/86):

The plant was shut down with the shutdown cooling system in operation. The reactor vessel water level was being monitored locally by flexible vinyl tubing and in the control room by the reactor vessel water level monitoring system. The operators began draining the reactor coolant system to the mid-loop level to replace a reactor coolant pump seal. Two drain paths were being used to lower reactor vessel water level. One path was the normal drain path and was addressed in the procedure. The second path, which was not addressed in the procedure, was used to speed the draining and to conserve water by draining to the refueling water storage pool. When the desired reactor vessel water level was reached, the first drain path was secured in accordance with the procedure. However, the second path was overlooked, and water continued to drain from the reactor coolant system.

The operators were not aware of the continuing draining because a vacuum in the reactor coolant system had collapsed the flexible vinyl tubing used for level indication, causing an inaccurate reading. In addition, the reactor vessel water level monitoring system in the control room indicated only large changes in level (marked in 4 foot increments) and therefore, did not have the accuracy necessary to monitor and maintain level at mid-loop. When the water level had decreased sufficiently, the low pressure safety injection pumps started cavitating from air entrainment. The operators then identified and secured the second drain path.

Restoration of shutdown cooling was delayed for 2 1/4 hours while the mechanics working on the reactor coolant pump seals were evacuated from containment, and repeated attempts were made to vent the low pressure safety injection pumps. The low reactor vessel water level had caused a steam bubble to form between the shutdown cooling line loop seal and the pump suction. The steam could not be condensed due to saturation conditions and could not be vented due to the limited capacity of the vacuum priming system. The reactor coolant system water temperature increased from 138 to 232 degrees Fahrenheit (saturation) before shutdown cooling flow was reestablished. During this time, boiling occurred in the core region. Shutdown cooling was restored by jogging the low pressure safety injection pumps and recirculating cooler water from downstream of the shutdown cooling heat exchangers to the pump suction. In this manner, steam in the pump suction lines was cooled and condensed, allowing operation of the pumps without cavitation. The lack of guidance for restoring shutdown cooling contributed to the difficulty in recovering from this condition.

The plant revised the procedures for draining the reactor coolant system to prohibit using multiple drain paths while the pressurizer is empty and to provide details for restoring shutdown cooling.

Additional details of this event are provided in Reference 2.

WATERFORD UNIT 3 (5/12/88)

The plant was shut down with the shutdown cooling system in operation. Reactor vessel water level was being lowered to remove the steam generator nozzle dams and to test a new digital reactor vessel water level indicator. A flexible vinyl tube was used to locally monitor reactor vessel water level. The draining evolution was secured when inconsistencies developed between the digital water level indicator and the flexible vinyl tube. After water was removed from the normally dry reference leg of the digital level indicator, the digital level indicator and flexible vinyl tube were brought back into apparent agreement. The operators then resumed draining the reactor vessel.

At an indicated level of approximately 10 feet on the flexible vinyl tube and 14 feet on the digital instrument, the "A" low pressure safety injection pump began to cavitate and was secured. The operators raised reactor vessel water level and started the "B" low pressure safety injection pump in accordance with the abnormal procedure, limiting the reactor coolant system water temperature rise to a few degrees.

Low pressure safety injection pump "A" was vented and returned to service. After plant personnel inspected the installation of the two level indicators, the operators recommenced draining the reactor vessel. However, the inspection did not detect a loop seal in the flexible vinyl tube. Because of previous inaccuracies in the new digital reactor vessel water level indicator, the operators relied primarily on the flexible vinyl tube for measuring reactor vessel water level. Draining of the reactor vessel was secured when the flexible vinyl tube indicated a level of 17 feet. (The digital instrument indicated 13 feet.) Thirteen feet is below the centerline (13.38 feet) of the reactor coolant loop hot-leg piping from which the low pressure injection pumps take suction. Shortly after the draindown was secured, low pressure safety injection pump "A" again began to cavitate. The reactor vessel water level was raised, and shutdown cooling was promptly restored.

A detailed investigation of the level indication problems found that the flexible vinyl tube had been rerouted to allow for installation of the new digital level indicator. When the flexible vinyl tube was rerouted, a loop seal was created that went undetected and caused reactor vessel water level to indicate high.

The plant revised applicable procedures to minimize vinyl tubing lengths in the reactor vessel level indication system. In addition, procedures are being changed to identify the volume of water in the reactor coolant system for specific indicated reactor vessel water level heights (with and without steam generator nozzle dams in place). This provides a check of the water level indications by correlating the amount of water drained from or added to the reactor coolant system with the indicated water level change.

SAN ONOFRE 2 (3/26/86):

The plant was in a refueling outage with the reactor vessel head installed and the shutdown cooling system in operation. The heated-junction thermocouples for the reactor vessel water level indicating system and the core exit thermocouples had been removed in preparation for refueling. Water level in the reactor coolant system was being monitored by a recently installed refueling water level indication system. The system provided both narrow- and wide-range indication in the control room. The loop resistance temperature detectors were being used for reactor coolant system temperature indication.

Rather than relying solely upon a local flexible vinyl tube indicator, as had been done in previous outages, the refueling water level indication system was installed to provide increased accuracy and operator control over draining and refilling evolutions.

In preparation for repairing a leaking steam generator nozzle dam, the operators began lowering reactor vessel water level and placed the reactor coolant system eductor, which minimizes containment airborne contamination when the reactor coolant system integrity is breached, in service. Both of the control room narrow- and wide-range refueling water level indicators began oscillating after the eductor was placed in service. When plant personnel were unable to correct the oscillation problems, the flexible vinyl tube indicator was installed. The operators, who distrusted the refueling water level indication system due to the oscillations, continued draining the reactor coolant system, relying primarily on the flexible vinyl tube for level indication.

After approximately 2 1/2 minutes of draining with no apparent level change, the shutdown cooling system flow to the reactor coolant system was decreased from 3,000 to 2,000 gallons per minute to divert more drain flow to the refueling water storage tank and to reduce the potential for pump vortexing. With an indicated level of minus 78 inches on the flexible vinyl tube, reactor coolant system draining was stopped to verify level and stabilize cooling flow. Initially, the shutdown cooling system showed no sign of air entrainment, and the indicated level was 5 inches above the minimum level allowed by procedure (minus 78 inches is equivalent to 1 1/2 inches above the hot-leg piping midpoint).

A short time later, large motor current oscillations were observed on the operating low pressure safety injection pump, and the pump was stopped. Because the flexible vinyl tubing indicated adequate level, the low pressure safety injection pump was restarted. After several minutes of stable operation, motor current oscillations recurred, and the pump was stopped. The other low pressure safety injection pump was started, and stable operation was observed for several minutes before the suction pressure dropped to zero, and all shutdown cooling flow was lost. The abnormal operating procedure for loss of shutdown cooling was initiated, and an accelerated system venting scheme was employed to restore shutdown cooling system flow.

Investigation revealed that, while installing and filling the flexible vinyl tube indicator, an air bubble was trapped in the tubing, resulting in an inaccurate high reading (plus 10 1/2 inches). In addition, the reference scale for the tubing was displaced by 2 1/2 inches in the high direction, creating a total inaccuracy of plus 13 inches. Vortex air entrainment occurred when the operators used the inaccurate flexible vinyl tube indication to lower the reactor vessel water level to an indicated level of minus 78 inches (actual level was minus 91 inches, 8 inches lower than the minimum level of minus 83 inches allowed by procedure).

Subsequent utility analysis of this event showed that the reactor coolant hot-leg temperature increased from 114 to 210 degrees Fahrenheit in about 49 minutes, with local boiling in the core region. The calculated bulk reactor coolant temperature did not exceed 200 degrees Fahrenheit. Steam and approximately 2 curies of radioactivity were released to the containment via the incore flux detector nozzles in the reactor vessel head.

The plant has revised applicable procedures for draining the reactor coolant system to require operability and use of diversified level indications and has provided detailed guidance for installing the temporary flexible vinyl tube and refueling water level indication systems.

Additional details of this event are provided in Reference 3.

ZION 2 (12/14/85):

The plant was shutdown with the reactor vessel head installed, but not tensioned, and the reactor coolant system vented to atmosphere. A few days after lowering the reactor coolant level to repair an isolation valve, the 2B residual heat removal pump became airbound. After the operator tripped the residual heat removal pump, the reactor vessel water level indication in the control room became erratic and then pegged high. The operators incorrectly concluded that the residual heat removal pump or motor had failed based on no flow indication and the pump low-current readings. The 2A residual heat removal pump was started to restore cooling but soon developed abnormal current and flow indications. The operators then realized that the reactor vessel water level indication was in error and that the residual heat removal pumps had become airbound due to the low water level. Approximately 1 hour and 15 minutes was required to restore residual heat removal cooling. During this time, reactor coolant system water temperature increased 15 degrees Fahrenheit.

Because of repeated problems controlling reactor vessel water level during mid-loop operations, the plant performed a detailed review of the reactor vessel water level indicating systems. It was concluded that the accuracy of the reactor vessel water level indication could be increased by design improvements.

The 10-inch residual heat removal system discharge piping is connected to the top of one of the reactor coolant system cold legs. The water level sensing line for the reactor vessel level indicating system (refueling water level transmitter) enters a 1 1/2 inch line connected to the same reactor coolant system cold leg. Both nozzles are in the same vertical plane with the 1 1/2-inch nozzle located at 90 degrees with respect to the 10-inch nozzle. When the cold leg was partially filled and a residual heat removal pump was operating, water from the residual heat removal discharge piping impinged on the water surface close to the nozzle of the 1 1/2-inch line. Because of the dynamic effects of this impingement, the indicated water level was erratic, especially when reactor vessel water level was low. When the water level in the reactor vessel was below the nominal mid-point of the cold leg, the refueling water level transmitter would indicate erroneously that the water level was at the mid-point of the reactor coolant system hot leg.

The design of Zion's flexible vinyl tubing that connected to the refueling water level instrument also affected operational accuracy. For this reason, the visual readings on the flexible vinyl tube in containment and the refueling water level transmitter readouts in the control room were often not in agreement. These conditions made it difficult for operators to determine the correct level.

To provide dependable level indication, modifications were made to both reactor vessel water level indication systems as described in Attachment 1.

SIGNIFICANCE:

Loss of residual heat removal capability with low reactor vessel water level is significant because it can result in rapid heatup and boil-off of the reactor coolant and eventual core damage. Within 48 hours following shutdown from a high-power operating history, a loss of residual heat removal at mid-loop operation could result in boiling in the core in about 10 minutes. Even when power history and shutdown time are less restrictive, the loss of residual heat removal cooling at mid-loop could result in boiling in the core within 20 to 60 minutes with subsequent core uncovering, depending on the boil-off rate.

After the onset of boiling, the core could become completely uncovered in less than 10 minutes if a large cold-leg opening (such as an open steam generator manway) exists without an adequate reactor vessel vent path (such as the case with the reactor vessel head installed and steam generator nozzle dams in place or loop isolation valves closed). In this configuration, pressure can build up in the reactor vessel and force coolant out of the core through the cold leg opening.

ANALYSIS/DISCUSSION:

During outages, it is frequently necessary to reduce the reactor coolant level to the loop nozzle elevation for maintenance or modifications. Such operations often require maintaining the reactor vessel water level within very restrictive limits. Under these conditions, reactor vessel water level increases can result in coolant overflowing through system openings, contaminating equipment and personnel, scalding workers, and damaging equipment. Reactor vessel water level decreases of a few inches threaten core cooling by disabling the residual heat removal system through air entrainment. Because of the reduced coolant inventory at these levels, a loss of residual heat removal can result in rapid heatup rates, boil-off of reactor coolant, and eventual core damage. NSAC/52, "Residual Heat Removal Experience Review and

Safety Analysis, Pressurized Water Reactors," (Reference 9), notes that after a loss of residual heat removal cooling, increases of over 100 degrees Fahrenheit have occurred in as little as 20 minutes in partially drained PWRs.

Because of these concerns, the time spent with the reactor vessel drained to the mid-loop level should be minimized when irradiated fuel is present. This requires proper planning of maintenance activities, including having the necessary parts, equipment, personnel, and procedures available before establishing mid-loop operation. However, since mid-loop operation cannot be eliminated, additional attention is needed to ensure adequate monitoring, control, and the capability for restoration of reactor vessel water inventory and core cooling as described further below.

Loss of Coolant Inventory:

The times for boiling, core uncovery, and reactor coolant pressurization to occur following a loss of residual heat removal are dependent on reactor power history, time since shutdown, and reactor coolant system configuration. The most restrictive condition occurs for mid-loop operation 48 hours after shutdown following high-power operation and when reactor coolant temperature is above 140 degrees Fahrenheit. In this condition, boiling can occur in about 10 minutes after loss of core cooling. Even for more typically encountered conditions when reactor vessel level is lowered after a few days, boiling could still occur in 20 to 60 minutes.

Abnormal reactor coolant system configurations can result in rapid loss-of-liquid coolant inventory beyond that expected from boiling. This configuration exists when the reactor coolant hot legs are isolated (e.g., steam generator nozzle dams installed or loop isolation valves closed) in combination with a large cold leg opening (e.g., an open steam generator manway or reactor coolant pump). Under these conditions, boiling can pressurize the reactor vessel and push the coolant out of the core through the opening in the cold-leg. This can be avoided by not isolating all the hot legs with nozzle dams, not closing all isolation valves, or by providing an adequate hot-leg vent path.

Level Indication Problems:

Proper water level control requires accurate and reliable level indication. Water level indicating systems that can be collapsed by vacuum conditions or that are easily kinked are not reliable. Improper lineup of the level indicating system, inadequate installation and/or venting, and unfamiliarity with level indicating system responses can lead to water level indication and control problems. At many plants, flexible vinyl tubing used to monitor reactor vessel water level is installed and supported by draping it over various components. Consequently, the reactor vessel water level indication can be disturbed by-passing personnel, the formation of air bubbles in the liquid-filled portion, or loop seals in the vented portion.

In many of the events discussed, the recurring problems with reactor vessel water level indicating systems eroded the operators' confidence in the accuracy of the indications. In some cases, operators continued draining the reactor vessel although they suspected the indicated water level was incorrect. In the May 1988 Waterford 3 event, operators continued to drain the reactor vessel with a wide disparity between the two water-level monitoring systems. The operators chose to rely on the higher level indicating system rather than the lower, more conservative level indication. As a result, the reactor vessel was drained until a loss of shutdown cooling occurred. The lower indication was later determined to be more representative of actual reactor vessel water level.

Control of Draining Evolution:

Operating at reduced reactor vessel water levels requires continuous operator attention and a timely response to residual heat removal system problems due to the reduced water inventory. By being knowledgeable of all activities that could reduce reactor coolant inventory, operators can quickly identify and correct conditions affecting reactor vessel water level. Because monitoring for unexpected drainage depends primarily on the level detection system, stopping any intentional draining whenever the level detection system is lost or the accuracy becomes suspect will reduce the risk of lowering the level below mid-loop.

Attention is also needed to prevent conditions that could lead to the inadvertent loss of water from the reactor coolant system. In the Diablo Canyon event, a drain valve was opened without operator knowledge and was not monitored locally for continuing leakage. Therefore, when the volume control tank water level decreased, the plant operators could not properly diagnose the problem. Inappropriate action was taken that eventually resulted in a loss of residual heat removal capability and boiling in the core. In the July 1986 Waterford 3 event, two drain paths were in use, but one was not incorporated in the procedure used for draining. When securing the draining evolution, only one drain path (the one addressed in the procedure) was secured, and, unknown to the operators, reactor coolant level continued to decrease until shutdown cooling was lost.

Core Heatup Rates/Temperature Indications:

Heatup rates are affected by many factors (e.g., power history, water inventory, time since shutdown, and cooling water temperatures and flow rates) and should be reviewed whenever any of these factors change. Providing expected reactor coolant system heatup rates to operators can help them plan their response in the event of a loss of residual heat removal cooling. Use of at least two means of measuring core temperature, one of which is independent of residual heat removal flow, allows monitoring of core heatup under all conditions and will reduce the risk associated with a loss of core cooling. In the Diablo Canyon event, operators underestimated the core heatup rate when residual heat removal was lost and core temperature indication was not available. During this time, core temperature increased from 87 degrees to 220 degrees Fahrenheit, and reactor coolant system pressure increased from atmospheric to approximately 10 psig. Boiling took place in the core, and both steam and water were released to containment.

Core temperature monitoring via core thermocouples might not be feasible during evolutions such as removal or installation of the reactor vessel head. During these evolutions, maintaining core cooling with the reactor vessel water level well above the mid-loop levels can reduce the risk of losing core cooling. All evolutions that can impact reactor vessel water inventory and core cooling characteristics need to be stopped whenever a reliable core temperature indication is not available. If core thermocouple temperature monitoring will not be available for extended time periods, a backup means to monitor core temperature needs to be provided.

Restoring Inventory and Cooling:

During the referenced events, delays in restoration of core cooling occurred because the operators lacked the fundamental knowledge to assess the symptoms and understand the significance of the loss-of-cooling capability and also lacked the procedures needed to respond properly to the events.

Diagnosis and correction of residual heat removal problems requires accurate information regarding both system configurations and activities affecting reactor coolant inventory. Once the steam generator primary manways have been untorqued or removed, attempts to fill the primary system can result in a discharge from the manway unless proper controls are in place. Such a discharge of hot water endangers workers in or around the steam generators. To prevent delays in restoring residual heat removal and to avoid risks of injuries or contamination, the capability to quickly evacuate workers from the area of any reactor coolant system opening after any loss of residual heat removal cooling or reactor vessel level is needed. This requires rapid communication with personnel within the containment.

In order to make appropriate decisions regarding restoration of inventory and cooling, operators need to maintain cognizance of the following:

- o available makeup water sources
- o alternate means for injection, including gravity feed and pumped injection
- o alternate cooling schemes, such as natural circulation of steam to the steam generators
- o operational concerns for each cooling and makeup scheme

At least one source of borated makeup water to the reactor coolant system is needed at all times.

Gravity feed from the refueling water storage tank to a vented primary system can be an effective means of providing makeup water unless steam from reactor coolant system boil-off pressurizes the primary system above the available gravity head. Pumps (e.g., charging) will be necessary to inject the makeup water if the available head from the refueling water storage tank is less than reactor coolant system pressure. Decay heat rates, vent flow rates, cooling by natural circulation to the steam generators, and the amount of air in the primary system will affect the pressurization of the primary system and, thus, the feasibility of gravity feed.

Venting and Filling:

Insufficient water level is evident whenever a residual heat removal pump shows symptoms of cavitating (e.g., fluctuating current, suction pressure, or flow), even if the level detectors indicate adequate water level. Reducing residual heat removal flow can sometimes reduce air binding and help maintain some residual heat removal flow. Once air entrainment into the residual heat removal system occurs and the residual heat removal pumps are stopped, water level must be raised, and the residual heat removal pump suction must be vented to restore core cooling. Switching or starting additional residual heat removal pumps before raising water level usually will aggravate the condition by increasing the amount of air entrainment or by causing air entrainment in the second pump. In the San Onofre 2 event, both low pressure safety injection pumps became airbound, resulting in a loss of all core cooling because the operators started the pumps with the reactor vessel water level below mid-loop. Similarly, in the Zion 2 event, residual heat removal cooling was lost for approximately 75 minutes because the operators improperly diagnosed a cavitating residual heat removal pump.

Steam can collect in the suction line of residual heat removal systems designed with loop seals in the suction line. This steam cannot be condensed by saturated liquid from the hot leg or exhausted with the limited capacities of the vacuum priming system used by some plants. In the July 1986 Waterford 3 event, the operators had to repeatedly jog the low pressure safety injection pumps to condense the steam bubble that had formed in the low pressure safety injection suction line, resulting in a delay in the restoration of shutdown cooling.

Conclusion:

The causes of the events discussed in this SOER include the following:

o Involvement by managers and supervisors was not effective in providing the shut down plant with adequate, reliable core cooling as evidenced by the following:

- ineffective implementation of lessons learned from similar industry events

- inadequate design, installation, and use of both permanent and temporary systems for indicating and alarming reactor vessel water level and for measuring core temperature

- insufficient procedures and lack of procedure use for evolutions affecting reactor coolant inventory

- inadequate communications among plant personnel

- insufficient operator knowledge and training in the prevention and mitigation of loss of residual heat removal capability

- proceeding with evolutions in progress in the face of questionable information and unexpected reactor plant behavior

o Control of activities was inadequate to prevent and quickly correct unexpected coolant drainage paths and to remove personnel quickly from reactor coolant system openings when necessary.

RECOMMENDATIONS: (Applicable only to pressurized water reactors)

Management:

1. Ensure that administrative controls, procedures, and level indication and alarm systems needed to safely operate with reactor vessel water level lowered to mid-loop are in place and effective. Plant management should review with station personnel the lessons learned and potential problems associated with reduced reactor vessel water level prior to each reduction of reactor vessel water level to mid-loop.

Operations:

2. Review the procedures supporting residual heat removal system operation to ensure that procedure improvements recommended in SOER 85-4 and other procedure improvements necessary to support plant actions in response to SOER 85-4 have been incorporated. Ensure that the following specific items are included:

   a. appropriate response actions for low reactor vessel water level conditions and symptoms of pump cavitation

   b. methods to establish and maintain a hot-leg vent path to prevent pressure buildup in the reactor vessel

   c. instructions for ensuring that temporary reactor vessel water level indicating systems are properly installed, vented, calibrated and physically walked down before being used to monitor reactor vessel water level

   d. the water level band to be maintained when at mid-loop operation to prevent flooding or loss of residual heat removal pump suction

   e. actions to be taken if a leak is suspected

   f. actions to be taken if core temperature instrumentation is unavailable and residual heat removal flow is lost

   g. me[illegible]ds (such as graphs) to determine reactor core heatup and boil-off rates as a function of reactor coolant system volume and the time since shutdown, assuming worst case power history

   h. instructions to restore containment closure in situations when residual heat removal is lost

   i. methods for initiating prompt evacuation of personnel from areas in and around openings in the reactor coolant system when residual heat removal or reactor vessel water level indication is lost

Training:

3. Review initial and continuing training for operations personnel to ensure that SOER 85-4 training recommendations and other training necessary to support plant actions in response to SOER 85-4 have been incorporated. Ensure training emphasizes lessons learned from in-house and industry events involving the loss of residual heat removal capability, including the following:

a. response to discrepancies in or loss of indicated level

b. methods to determine decay heatup rates

c. indications of pump cavitation and actions needed to restore core cooling flow

d. response to a loss-of-core cooling flow with no indication of core coolant temperature

Design:

4. Review the design of the residual heat removal system and the reactor vessel level indication and alarm system to ensure that SOER 85-4 recommendations have been incorporated. Experience since 1985 corroborates the need for one of the independent reactor vessel level indicators described in SOER 85-4, recommendation 6, to provide readout and low-level alarm in the control room and have the following additional operational characteristics:

   - o indication scaled for mid-loop operation
   - o operable under conditions of vacuum and core boiling

   Based on the events described above, ensure that the following additional design features are provided:

   a. Local vents or priming pumps have the capacity to remove air and steam that can be entrained in residual heat removal suction lines.

   b. If core thermocouples are not operable, an alternate means of monitoring reactor coolant temperature exists that is indicated in the control room, independent of residual heat removal flow and operable before reactor vessel water level is lowered to mid-loop.

Utilities and participants are requested to provide feedback on similar occurrences and solutions at their plants or on their equipment to the information contact listed below.

LIMITED DISTRIBUTION

Information Contacts:

Organization and Administration Contact:	Recommendation 1 Organization & Administration Department (404) 953-7679
Operations Contact:	Recommendation 2 Operations Department (404) 951-4712
Training Contact:	Recommendation 3 Technical Development Department (404) 953-5479
Design Contact:	Recommendation 4 Design Engineering Department (404) 953-5417

KEY WORDS: Core Cooling, Decay Heat Removal, Residual Heat Removal, Reactor Vessel Level

ATTACHMENT 1

MODIFICATIONS TO ZION'S REACTOR VESSEL WATER LEVEL INDICATING SYSTEM

To improve the accuracy of reactor vessel water level indications at Zion, modifications were made (or are planned) to both water level indicating systems. Major modifications performed include the following:

- The connection points for both level indicating systems will be relocated. The new connections will be located at the reactor coolant system low points. In addition, both level indications systems are now vented to the pressurizer. Both systems will remain installed and isolated from the reactor coolant system during unit operation. The installations have been seismically designed. A new narrow-range transmitter has been added to the refueling water level indicating system for greater accuracy near the mid-loop range.

- To upgrade the flexible vinyl tubing system, the entire system was hard-piped. A hard plastic (polycarbonate) was used for a "sight glass." All other sections of the vinyl tubing were replaced with stainless steel piping and tubing. This system connects to a loop drain line immediately downstream of a steam generator.

- The electronic system for the refueling water level transmitter was also upgraded. An incore flux detector guide thimble tube is now used as the connection. The elbow connection has been made below the seal table between the second conduit weld and the seal table. Most of the remaining unused sections of conduit were left in place so they may be easily reconnected if necessary. Safety-related globe valves were installed on the new connection to provide double isolation from the reactor coolant system pressure boundary.

The following additional actions were taken to improve the reliability of the level indicating systems:

- Sensing and venting lines for the level indicators were sloped continuously to avoid intermediate high and low points that may cause air bubbles and loop seals. A walkdown was performed to verify conformance with design requirements, including design dimensions. Particular attention was given to verifying the slope of the sensing and venting lines and to determining the exact level of the transmitters for calibration purposes.

- An automatic blowdown trap was installed on the refueling water level indicating system to eliminate moisture accumulation.

- High and low-level alarms were provided in the control room, with set-points based on plant-specific data on residual heat removal operation at various flow rates and reactor vessel water levels.

- The refueling water level transmitter was calibrated prior to initial use and is recalibrated at the beginning of each refueling outage. The transmitter output will be cross-checked regularly with the hard-piped visual level indicator. The calibrations take into consideration the temperature differential between the transmitter and the reactor coolant water temperature.

Additional details on the modifications made to Zion's reactor vessel water level indicating system are provided in Reference