AEOD ENGINEERING EVALUATION REPORT*

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SUBJECT: BWR OVERFILL EVENTS RESULTING IN STEAM LINE FLOODING

EVENT DATES: Various

SUMMARY

Six events involving BWR overfill are described. All of the inadvertent overfill events included a reactor depressurization followed by an uncontrolled injection by condensate or condensate booster pumps or both. Although many potential safety concerns exist due to BWR overfill events, operating experience indicates that these events are infrequent and have had little actual safety significance. However, NRC should monitor licensee actions to address all potential safety concerns. Prior to plant restart, engineering evaluations and system walkdowns by the licensee should identify and correct any damage from these events to assure operability of all affected systems.

Operating experience involving BWR-6 class reactors demonstrates that relatively minor design changes may eliminate overfill events in older vintage BWRs. Furthermore, since these events usually involve some personnel error or procedural deficiency, continued training and procedural enhancements can minimize these events.

DISCUSSION

Two recent BWR overfill events, at Washington Nuclear Plant Unit 2 in March 1987 and Nine Mile Point Unit 2 in January 1988, prompted AEOD to perform a Sequence Coding Search System investigation for similar events. This search identified four additional events since 1980. All six events are described briefly in this report.

The safety concerns associated with BWR overfill events are: (1) potential for excessively rapid cooldown of the reactor pressure vessel (RPV) and internals, (2) potential for thermal shock or excessive stressing of the main steam line (MSL) and Safety/Relief Valve (SRV) piping and supports upstream of the Main Steam Isolation Valves (MSIVs) due to water hammer or hydrodynamic effects, (3) potential overstressing of the MSL piping and supports downstream of the MSIVs due to the weight of water in the MSLs if the MSIVs are open, (4) potential for cold overpressurization of the reactor vessel if the vessel were to go "solid" and then experience a subsequent reactor coolant heatup and expansion or continued water injection from CRD pumps, etc., (5) potential for MSIVs to not close on demand if water fills the MSLs, and (6) potential for water to enter rotating equipment downstream of the MSIVs.

*This document supports ongoing AEOD and NRC activities and does not represent the position or requirements of the responsible NRC program office.

The overfill events that have occurred since 1980 are:

1. Washington Nuclear Plant Unit 2 on March 22, 1987

The reactor was manually scrammed from 71% power following an observed trip of both reactor feed pumps (RFPs). Reactor water level (RWL) rapidly dropped to Level 2 and HPCS and RCIC automatically initiated to restore RWL. HPCS and RCIC injection automatically terminated, as designed, at Level 8. The operators received an erroneous report that RCIC tripped on overspeed and subsequently decided to use the condensate/feedwater system as makeup since it provides automatic level control and would allow shift resources to be used for other recovery actions. The operating crew, however, failed to complete the valving sequence necessary to establish shutdown level control. This resulted in unthrottled filling of the reactor vessel up to the level of the MSLs after an SRV was opened to reduce reactor pressure to allow the condensate system to inject.

The licensee performed an engineering evaluation of this event. The focus of the evaluation was on the MSLs, SRVs and the effect of water carryover into the MSLs during the recovery operation. As a result of the engineering evaluation, the following was determined:

° Filling of the MSLs with water to the MSIVs was analyzed as part of the original design basis of the plant. The passage of water down the lines with open MSIVs was evaluated for a previous scram recovery (1986 event described as Event 3 in this report). In that evaluation, it was shown that thermal effects on MSL piping were acceptable if the temperature difference between the water flowing and the pipe temperature was less than 144F. For this transient, the temperature differential was no greater than 81F and considered acceptable.

° Hydrodynamic effects on the MSLs were found not to be a concern. The MSLs were initially filled with the MSIVs closed and the MSIVs were opened with pressure equalized on both sides of the valves. The MSL piping inside the drywell and outside to the Main Turbine was physically inspected and no sign of support components damage or abnormal displacement was found.

° The water passage through SRV-4D was also evaluated for potential hydrodynamic effects. A physical inspection of all SRVs suspected of passing water and their associated piping, including visual examination of snubbers, spring cans, and bolting showed no sign of damage. Three snubbers were also successfully stroke tested. Inspection of the exterior of SRV-4D, which should have seen the highest load, showed no sign of unusual stressing of bolts or joints, and no sign of abnormal displacement. Based on these examinations, the SRV discharge line loads experienced during the event were considered within the design capability of the piping and piping support system. In addition, no valve leakage was observed following plant restart.

2. Nine Mile Point Unit 2 on January 21, 1988

The reactor automatically scrammed from 42% power due to low level. The event initiated when the instrument air system was incorrectly isolated. Loss of instrument air caused the RFP mini-flow/recirculation valves to go full open, causing the RFP to trip on low suction pressure. Following the scram, HPCS and RCIC injected and restored RWL and were stopped at or before Level 8. Due to the low decay heat load and injection of cold water, reactor pressure decreased and allowed condensate booster pumps to inject and overfill the reactor vessel. Water reached the MSLs with the MSIVs open. The injection was terminated when the operators closed the feedwater control and block valves.

Preliminary investigation by the licensee indicated that the PPV cooldown did not exceed 100F and that no damage occurred to any equipment.

3. Washington Nuclear Plant Unit 2 on July 25, 1986

An automatic reactor scram occurred from 71% power while performing surveillance testing. The plant operators maneuvered the plant to a safe shutdown condition. Subsequently, the main turbine bypass valves (BPVs) were inadvertently left open for approximately two and one half minutes, resulting in a rapid depressurization of the reactor. A rapid increase in RWL and flooding of the MSLs resulted from uncontrolled condensate booster pump injection.

The licensee's safety assessment determined that the effects of this event were within design margins and, based on analysis, no damage was anticipated. This conclusion was confirmed by a physical walkdown of the MSLs. However, several weaknesses in the post-scram review process were identified. There was no information available to control room personnel, in abnormal procedures or elsewhere, to provide guidance in assessing the potential for damage from a MSL flood transient. This contributed to the lack of sensitivity to this type of transient. There was a miscommunication on the part of the management team regarding whether MSIVs closed prior to the level reaching the MSLs. This significantly contributed to the incorrect decision to restart since WNP-2 is analyzed for a MSL flood transient only to the MSIVs. Further evaluations revealed that the MSIVs were definitely open during the flooding condition and closed while water was flowing in the steam lines. In retrospect, the decision to restart was made with insufficient analyses of the thermal expansion/contraction effects on the MSL piping, MSIVs, potential effects on the MSL piping supports and the potential for hydrodynamic effects. These potential effects have been evaluated by analysis and confirmatory walkdowns, and it has been concluded that no adverse effects occurred to the MSLs, piping supports, or MSIVs.

4. Oyster Creek on March 6, 1986

An automatic reactor scram occurred from 92% power while performing surveillance testing. Because the operators inadvertently left the mode switch in "RUN", the MSIVs isolated on low steam line pressure. Operator errors resulted in a RWL rise that precluded the use of the Isolation Condensers (ICs). Automatic actuation of the ICs was manually overridden by the operators due to concern for a possible water hammer since the IC steam lines were flooded. RWL was subsequently lowered and an IC placed in service.

Although this event had little apparent safety significance, it does demonstrate that high RWL can make a safety system inoperable when it is required for service. Similar events have been reported in foreign reactors.

5. Dresden Unit 2 on December 5, 1984

During the 1984 refueling outage, three MSL snubbers failed functional tests. Licensee investigation found that the most probable cause of the MSL snubber failures was the reactor vessel fast flood procedure. This procedure, which was unique to Dresden, was used at the beginning of the refueling outage to cool the RPV rapidly. Once RPV temperature was 450F or less, feedwater at approximately 130F was injected into the reactor vessel at a flow rate as high as 4500 gpm. The recirculation pumps were on minimum flow to promote mixing in the RPV. This flooding continued until RWL reached the head flanges, thus filling the MSLs down to the inboard MSIVs. It was during this period of time that a steam condensation water hammer was believed to occur in each MSL.

The MSLs have relatively long horizontal runs of between 20 to 30 feet depending on which line is examined. As water filled the horizontal run rapidly, a large surface area of subcooled water was exposed to steam within the pipe. The MSL was filled with steam since metal temperatures were still above 212F. As the large amount of water hit the first horizontal pipe elbow, a plug of water formed. The steam bubble downstream of the the plug collapsed providing a vacuum. With the approximate 20 psi vessel pressure, the plug of water was forced down the pipe rapidly until it hit the next pipe elbow. A water hammer of sufficient magnitude to damage the snubbers occurred. It is believed that this water hammer may have occurred several times dependent on the flooding flow rate and reactor pressure.

To avoid recurrence of a condensation induced water hammer, Dresden has deleted the reactor vessel flood procedure. A special procedure has been written to slowly flood the reactor vessel during shutdown conditions. This procedure limits vessel flooding to a maximum rate of 120 gpm. Strict vessel temperature and pressure limits are required during the flood up to prevent the possibility of condensation induced water hammer.

The licensee evaluated the safety significance of this event as minimal because analysis has shown that even without MSL snubbers, or with one snubber rigid per line, the piping stresses were less than yield stress.

6. LaSalle Unit 1 on March 17, 1983

Following a reactor scram, reactor pressure decayed to approximately 700 psig and the condensate booster pumps began to inject into the vessel. The RWL increase was stopped when the discharge valves of the turbine driven RFPs were closed.

The reactor cooled down from 530F to 378F in one hour. The licensee evaluated this event as having negligible effect on reactor vessel integrity since the flange bolts are the limiting components and RWL never reached the flange bolts.

FINDINGS AND CONCLUSIONS

All of the inadvertent BWR overfill events involved an RPV depressurization, caused by an open BPV, an open SRV, or cold water injection with low decay heat, which allowed uncontrolled condensate/condensate booster pump injection. BWR overfill events happen rapidly, usually following a scram when operators may have many distractions.

The safety significance of the reported BWR overfill events was generally minimal.

° Only one event (LaSalle) involved excessive (greater than 100F in one hour) RPV cooldown, and the subsequent engineering evaluation determined that the event had negligible effect on any components.

° Only one event (Dresden) involved damage to MSL piping or supports. The damage was readily detected by required surveillance. However, proper procedures and engineering evaluation and review of procedures prior to use would have prevented this event, since this event was part of a planned evolution. The Dresden and WNP-2 evaluations indicate that flooding of MSLs with cold water does have potential to damage MSL piping and supports. This damage, however, should be readily detectable by system walkdown and engineering evaluation.

° Two events involved overfilling the RPV while the MSIVs were open. In these events, no failures of MSIVs to subsequently close were reported and the weight of the water in the MSLs was not evaluated as a problem. Additionally, rotating equipment was not damaged since this equipment (RFP turbines, main turbine, HPCI and RCIC turbines) is generally tripped at Level 8 and their steam supplies are isolated.

° No events involved RPV overpressurization following vessel overfill. SRVs and operator action would probably prevent any RPV pressurization event from causing an overpressurization situation.

Relatively few (six) BWR overfill events were reported for the period 1980-1988. None of the events occurred at BWR-6 class reactors. This is probably due to additional Level 8 trips characteristic of these plants. In addition to the typical Level 8 trips of HPCS (or HPCI), RCIC, and RFPs that are typical of all BWRs, BWR-6s also have some combination of Level 8 trips of RFP discharge valves or condensate booster pumps. Their experience indicates that relatively simple and minor design modifications can minimize BWR overfill events. Another modification that should probably be considered by all BWRs is an additional annunciator that alarms above the current high RWL (Level 8) alarms but below the level of the MSLs.

Some of the BWR overfill events involved operator error, equipment failure, or procedure deficiencies. Combined with the fact that BWR overfill events continue to occur, this indicates that continued operator training, improved procedures, and perhaps, hardware changes are necessary to completely eliminate these events.

Review of operating experience did not identify any new safety concern related to BWR overfill events. However, not all LERs reporting these events were comprehensive in addressing the safety concerns. If an overfilling event should occur in the future, the NRC should assure that the licensee adequately addresses all potential safety concerns. Prior to plant restart, engineering evaluations and system walkdowns by the licensee should identify and correct any damage from these events to assure operability of all affected systems.