AEOD ENGINEERING EVALUATION REPORT [1/]

UNIT:	Salem 1	EE REPORT NO.:	AEOD/E512
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NSSS/AE: Westinghouse/Public Service Electric and Gas Company

SUBJECT: FAILURE OF SAFETY-RELATED PUMPS DUE TO DEBRIS

SUMMARY

On July 13, 1984, with Salem Unit 1 in a refueling outage, a centrifugal charging pump (CCP) seized after running for approximately thirty seconds while performing emergency core cooling system (ECCS) subsystem surveillance testing. Seizure of the CCP was attributed to metal filings which lodged between the impeller and wearing rings. The metal filings were a result of recent work performed on the common header of the CCP's vent lines. The loss of the CCP occurred when ECCS operability was not required. However, some safety concerns were identified in review of this event and related operating experience pertaining to failure or degradation of ECCS components due to debris ingestion which may warrant further action.

AEOD identified two potential ways that foreign material could enter the ECCS and possibly affect its performance when operability of the system is required. These two ways are: (1) through existing sump screens and (2) failure to close sump screen access doors.

This evaluation found that due to the design of centrifugal pumps used in high head safety injection (SI) systems, these pumps could be susceptible to mechanical problems from debris in the pumped fluid. Foreign material having characteristics similar to metal filings could potentially exist inside containment and pass through most existing sump screen designs. The SI pumps could experience mechanical problems from this foreign material because during the recirculation phase of loss-of-coolant accident (LOCA) mitigation, the RHR system provides the SI system a source of borated water. Similar problems could occur if foreign material is present in borated storage tanks from which the ECCS takes suction during the injection phase. Containment sump designs employing the use of hinged-type screen access doors or grates have a potential for these doors to fail open as a result of not being properly secured and leave large openings in the screens. This would defeat the safety function of the sump screens which could lead to potential damage and failure of multiple

1/ This report supports ongoing AEOD and NRC activities and does not represent the position or requirements of the responsible NRC program office.

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pumps in the ECCS and block flow through spray orifices in the containment spray (CS) system.

Review of boiling water reactor (BWR) safety-related systems indicate that small sized foreign material can pass through most suction strainers and into ECCS pump suctions. Due to the wide variation in pump designs used in BWR safety systems, it is difficult to determine whether these pumps are susceptible to shaft or impeller seizure from small sized abrasive foreign material. Because pumps used in BWR safety systems generally have lower pumping head requirements compared to high head SI pumps in pressurized water reactors (PWRs), pump internal tolerances should be larger and, therefore, not as susceptible to mechanical problems from foreign material. Unresolved Safety Issue (USI) A-43 has identified certain types of pumps used in BWR safety systems which could be subject to seal failure and/or bearing seizure. Current generic activities are addressing the debris issue with respect to BWR safety-related systems.

Because of the potential safety implications of degradation and/or possible failure of multiple pumps in the ECCS from debris due to improperly secured containment sump screen doors or grates, it is suggested that IE issue an information notice addressing the safety significance of sump screen integrity and the need for administratively controlling these access openings to the sump. The information notice should also notify all PWR licensees of the potential undetectable common cause failure of the ECCS due to foreign material contamination of the ECCS borated storage tanks.

Because the Salem event indicates that the high head SI pumps are susceptible to abrasive foreign material in the pumped fluid, it is suggested that the Office of Nuclear Reactor Regulation consider expanding the scope of Generic Issue 38 entitled, "Potential Recirculation System Failure as a Consequence of Ingestion of Containment Paint Flakes or Other Fine Debris," to evaluate the potential loss of the high pressure recirculation system during small-break LOCA mitigation for PWRs.

INTRODUCTION

AEOD identified an event at Salem Unit 1 (Ref. 1) as possibly having generic safety implications. That event involved a surveillance test during which a high head SI pump experienced shaft seizure due to foreign material entrained in the pumped fluid. The concern was that possible degradation of pump performance or pump failure could occur and result in a partial or total loss of the ECCS when required to operate. AEOD conducted an evaluation to determine the sources of foreign material and to identify the potential generic implications of the Salem event.

During the recirculation phase of LOCA mitigation, the SI pumps could experience mechanical problems from foreign material that is small enough to pass through sump screens inside containment and into the RHR suction lines. The high head SI system could be rendered inoperable during recirculation because the RHR system provides the SI system borated water from the sump. Operability of the SI system is essential in some small-break LOCA mitigations because the reactor coolant system (RCS) pressure would be higher than the RHR pumps shutoff head. Foreign material in the pumped fluid that could cause degradation of pump performance or failure represents a potential common mode failure of the SI system. Intermediate head SI pumps in some ECCS designs could also be susceptible to this failure mode due to similarities in pump design.

DISCUSSION

On July 13, 1984, with Salem Unit 1 in a refueling outage, one of the two CCPs seized after running for approximately thirty seconds while performing ECCS subsystem surveillance testing. Upon disassembly of the pump, a small amount of resin particles and metal filings were found in the pump casing. Further investigation revealed similar material was found in the common suction line of all makeup pumps.

At Salem, the CCP that seized serves as a charging pump in the chemical, volume, and control system (CVCS) during normal operations and as a high head SI pump in the ECCS during accident mitigation. This plant also employs intermediate head SI pumps in the ECCS for accident mitigation only. The manufacturer of the high and intermediate head SI pumps is California Pacific, model numbers 2.5 RLIJ and 2.5 JTCH, respectively. The tolerances between the impeller and wearing rings are on the order of 0.006-0.008 inch for these type pumps.

The pump that seized was installed in January 1982 and had been operating satisfactorily prior to the maintenance work performed on the CVCS during the refueling outage. The licensee did not operate the redundant CCP after the first pump had failed to avoid potential damage to it. The positive displacement charging pump (PDCP) had been operating prior to this event and did not experience any mechanical problems. The licensee indicated that due to the differences in design and internal tolerances, the PDCP is not as susceptible as the CCPs to mechanical problems from foreign material in the pumped fluid.

The licensee attributed the seizure of the CCP to metal filings lodged between the impeller and wearing rings and confirmed it through discussions with the pump vendor. The metal filings found in the suction lines of all three charging pumps were by-products of maintenance work performed on the common header of the CCP's vent lines. The maintenance involved repairing cracks in the vent and drain lines caused by stress induced vibration (Ref. 2). The cutting and grinding of vent piping produced very fine metal filings which inadvertently deposited on the inside of the CCP's common header piping. The exact amount of metal filings found inside the pump casing and common header could not be quantified, but operations personnel indicated that it was very small.

During the refueling outage, resin flushing operations took place on the mixed bed demineralizer in the CVCS, and on the spent fuel pool demineralizer. The resin beads found in the pump casings and common header came from either or both of these components. Current accounting techniques employed by the licensee are accurate to within one half cup, but the exact source of resin could not be determined. Resin could and often does collect in low sections of piping during backflushing operations and sometimes goes undetected. Salem has experienced recurring problems with resin contamination of plant systems.

The CVCS is used to supply concentrated boric acid, demineralized reactor makeup water, or a mixture of both to the RCS, and is used to refill the refueling water storage tank (RWST). It is believed that a small amount of spent resin was deposited in sections of the CVCS piping as a result of backflushing operations. Subsequent use of the CVCS caused resin to be transported to the RWST and also deposited in the suction piping to the CCPs. Some radiation "hot" spots on the piping from the RWST to the CCPs were detected.

Inspection of the RWST for Unit 1 revealed it contained approximately five to six cubic feet of resin beads and insoluble brownish rust or silt-like material. Unit 2 RWST was found to contain only a small amount of resin beads. The majority of the resin found in Unit 1 RWST was attributed to resin flushing operations that took place after the first year of plant operation. This conclusion is based on the following: (1) a large amount of resin was not accounted for during backflushing operations conducted that year, (2) radiation levels in the RWST were very low, and (3) most resin during recent backflushing operations was accounted for. No other types of foreign material or objects were found in the RWSTs during cleanup operations.

It is unlikely that the resin found in the CCP casing and common header was drawn from the bottom of the RWST during pump operation because spent resin beads are not buoyant in borated water and would settle to the bottom of the RWST. The piping connecting the RWST to the CCPs takes suction approximately 18 inches from the bottom of the RWST. Thus, the resin would have to become unsettled in order for it to reach the suction line. Flowrates during surveillance testing of CCPs are very low due to recirculation of the pump's discharge through miniflow lines and do not appear sufficient to agitate the contents of the tank.

During the plant's operating history, the licensee did not recall inspecting the inside of the RWST. After this event, the licensee suspected that there was radioactive resin contained in the RWST because of low radiation levels detected on the outside of the tank. The licensee inspected all systems which potentially could have been contaminated with resin and/or metal filings as a result of this event including the reactor vessel; however, no resin beads or metal filings were found.

ANALYSIS

The loss of the CCP occurred during the performance of required surveillance testing when the unit was in a refueling outage. This testing is necessary to prove ECCS operability prior to changing operational modes. Technical specifications require one charging pump be operable and capable of being powered from an operable emergency power source when the unit is in a refueling or cold shutdown mode of operation. The operability of one charging pump during refueling ensures that the boron injection system is available for reactivity control. With no charging pump operable or capable of being powered from an operable emergency power source, the action statement specifies that all operations involving core alterations or positive reactivity changes shall be suspended.

Prior to the CCP seizure, the PDCP had been operated on numerous occasions after the suspected intrusion of resin and metal filings into the CVCS. Also, there were no evolutions in progress involving core alterations or positive reactivity additions to the core. Since the reactor was in a stable reactivity condition and one charging pump (i.e., PDCP) was available, it was concluded that adequate reactivity control was available to maintain core shutdown margin during this event. Although the source of the metal filings was maintenance activities performed on the charging system vent and drain line piping, the potential could exist for foreign material from other sources to enter the charging system and affect the operation of the CCPs when SI system operability is required during accident mitigation. The July 13, 1984 event showed that SI pumps of this particular design could be susceptible to shaft seizure from a small amount of foreign material exhibiting hard, abrasive, and very small particle size characteristics.

During the recirculation phase of LOCA mitigation, the suction for the RHR pumps is realigned from the RWST to the containment sump when the RWST reaches its low level setpoint. In some plant procedures, manual action is then taken by the reactor operator to realign the SI pumps in series with the RHR pumps, thus, placing these pumps in the recirculation mode also. This is necessary in certain small-break LOCA mitigations when the RCS pressure remains above the shutoff head of the RHR pumps. In this situation, the SI pumps could be subjected to foreign material that is small enough to pass through sump screens and into the suction lines of the RHR system. Thus, foreign material represents a potential common mode failure for the SI pumps during the recirculation phase of a LOCA for most Westinghouse and Babcock and Wilcox designed PWRs.

Design differences between the SI pumps and pumps employed in CS and RHR systems, could make the SI pumps more susceptible to internal mechanical problems from material erosion and shaft or impeller seizure due to certain foreign material. SI pumps are primarily multi-state centrifugal designs of very low specific speed. Internal tolerances on these pumps are generally smaller compared to CS and RHR pumps due to lower capacity and higher pumping head requirements.

Metal filings and other types of foreign material could exist inside containment as a result of maintenance activities or be generated by a LOCA. Some other potential types of foreign material identified, but not necessarily exhibiting the same characteristics as metal filings are: (1) fiberglass and blanket-type insulation which has disassociated into small pieces, (2) hydroxide precipitates--products of borated water and aluminum and zinc used for insulation encapsulation, (3) paint chips, (4) concrete dust, and (5) other miscellaneous by-products from maintenance activities conducted inside containment.

The potential for foreign material to be transported to and through the sump screens is dependent on plant layout, recirculation velocity, size and specific gravity of particles, and the size of sump screen mesh. Most sump designs employ two screens to protect the sump intake, an outer trash rack and a fine mesh inner screen. The size of the openings in the fine mesh screen is based on the minimum restrictions found in systems served by the sump. Generally, the size of the mesh screen openings is set by the spray orifices in the CS system. Spray orifices typically have diameters on the order of 0.25 inch and the inner sump screens have mesh sizes of 0.25 inch or less. Thus, particle sizes less than 0.25 of an inch could pass through most sump screen designs and into RHR pump suction lines.

In order for foreign material in containment to reach the suction of the high head SI pumps during small-break LOCA mitigation, the borated water supply of the RWST would have to be exhausted requiring the ECCS to operate in the recirculation mode. Because the RCS pressure would remain above the low and intermediate head SI pump's shutoff head, only the high head pumps would be actively taking suction from the RWST. This would result in considerably extending the time the ECCS remains in the injection phase as compared to the length of time for large-break LOCA mitigation. In general, it would take approximately 24 hours for most PWRs before high pressure recirculation would be required for small-break LOCA mitigation. Thus, assuming the steam generators are available to remove heat from the RCS via feeding and bleeding of the steam generators, the likelihood of the RCS pressure remaining relatively high requiring high pressure recirculation could be considered low.

Most sump designs include access openings in order to perform sump inspection and cleaning. Some designs employ hinged-type screen access doors or grates to facilitate these needs. The containment sump design at the Catawba Nuclear Station uses two sets of screen doors for the purpose of allowing easy access to the sump for inspection, maintenance, and to facilitate personnel passage in the pipe chase. This design has the potential for the screen doors not to be securely closed or inadvertently left open (actual events are discussed in next section) following maintenance activities conducted in or around the sump area.

Hinged-type screen access doors or grates could also be susceptible to mechanical failure from forces exerted on them, such as from jet impingement, pipe whip or missiles generated from a LOCA. Our review of Catawba's sump design indicates that it would not be susceptible to mechanical failure from a LOCA due to the location of the sump with respect to the RCS in containment. However, other sump designs may not be as adequately protected as Catawba's containment sump. Failure of the screen doors would result in defeating the safety function of the sump screens and could lead to potential damage and failure of multiple pumps in the ECCS and block flow through spray orifices in the CS system.

Our review found that the containment sump screen doors are not explicitly covered by Catawba's technical specifications. We also found that the status of the sump screen doors (i.e., verified secured or locked closed) is not mentioned as a prerequisite for meeting the limiting conditions for operation. Furthermore, plant surveillance requirements for containment sump screen doors are also not explicitly mentioned as part of the surveillance requirements for the ECCS. Since the containment sump screens play a vital role in the protection of the safety-related equipment from degradation in performance or failure due to debris in containment, plant operation without sump screen integrity may present an unreviewed safety issue.

Metal filings or other types of foreign material could be entrained in resin and enter the charging system from resin flushing operations as indicated by the licensee. As previously mentioned, resin could and often does collect in low sections of system piping during backflushing operations and sometimes goes undetected. Subsequent use of the associated piping could transport this foreign material to other systems and affect their operation. Because of the relatively soft characteristics resin exhibits, resin in small quantities does not pose as significant a threat to pump performance as do metal filings. Resin intrusion into the RCS has resulted in water chemistry parameters exceeding water quality limits and has contributed to increased stress corrosion cracking or general corrosion of piping and other components (Ref. 3).

As evident by the July 13, 1984 event, the RWST is a potential collection point for foreign material to accumulate and go undetected. Even though ECCS piping from the RWST takes suction approximately 18 inches from the bottom of the tank at Salem, subsequent to a design basis seismic event or a large break LOCA, tank agitation by ground vibration or fluid motion in the tank induced by high suction from the ECCS might be sufficient to cause foreign material to become unsettled. During the injection phase of LOCA mitigation subsequent to such agitation, all pumps in the ECCS could be subjected to plugging, degradation or failure due to foreign material contained in the RWST.

It is our understanding that generally there are no requirements for licensees to perform periodic inspections of the inside of the RWST. Lack of such a requirement is predicated on the belief that makeup borated water supplied by the CVCS is debris free. However, for plants which have experienced recurring problems with resin and/or other foreign material contamination of plant systems, administrative procedures which include periodic RWST inspections could significantly increase the detectability of foreign material contamination in the RWST. Visual tank inspections could reduce the likelihood of the aforementioned common cause failure of the ECCS pumps.

Like PWRs, suction strainers are used in BWR facilities to filter coolant and preclude damage to safety-related pumps due to foreign debris. However, BWRs do not take suction from a containment sump during ECCS recirculation operation. The pressure suppression pool (PSP) serves as the source of coolant for the ECCS. Each individual ECCS train that takes suction from the PSP is supplied with a conical-shaped coarse mesh strainer that is attached to the suction intake piping. The size of the mesh openings may vary from plant to plant; however, the purpose of the strainer is to filter out relatively large sized foreign debris that may reside in the PSP recirculation water. Thus, small sized foreign material can also pass through most suction strainers and into ECCS suction lines.

There is a wider variation in rating conditions for pumps used in BWR safety systems (i.e., specifically RHR, core spray, and core injection) than their counterparts used in PWR safety systems. For example, BWR safety pumps used in RHR systems have in many cases higher flow rates than in PWRs and are of multistage designs. Pump construction features are similar to those of PWR pumps. However, in multistage pumps, internal sleeve bushings may be used between stages providing support to the pump shaft. These interstage bushings are generally cooled and lubricated by the pumped fluid. To prevent seal damage from small sized foreign particulates, cyclone separators are often used to filter the seal coolant prior to injecting it into the shaft seal. Cyclone separators could also exist in some PWR safety systems; however, their application has been predominantly in BWRs.

In a typical arrangement, the cyclone separator is attached to the pump discharge nozzle by a 0.75 inch pipe nipple. The clean water from the separator is directed to the pump shaft seals while the dirty water is discharged to the pump suction. The jet nozzle in the separator has a 0.125 inch diameter throat. The seal water is usually injected at the midpoint of the shaft seal with a portion of the flow passing upward and remainder outward.

Because some suction strainer designs may have a very coarse mesh screen compared to the small diameter in the jet nozzle throat, there is a potential for small sized debris to pass through the suction strainers and clog the jet nozzle. Also, cyclone separators are not very efficient in filtering out foreign material which has a specific gravity close to that of water. In both cases, debris could potentially pass on to the pump seals and become lodged in the seal clearances. This could result in reduced seal water flow and/or seal failure. These safety concerns have been previously raised (see Related Generic Issues section in this report).

Pumps used in PWR high head SI systems are similar to pumps in BWR safety systems in that impellers are shrouded with wearing rings to minimize leakage, and generally are of multistage design. The pumping head for most BWR pumps are much lower than for PWR SI systems and, therefore, internal pump tolerances would tend to be larger. However, due to the wide variation in pump designs used in BWR safety systems, it is unknown if certain types of designs could be more susceptible to shaft or impeller seizure from abrasive foreign particles as was Salem's high head SI pumps.

Suction strainers used in BWRs are also susceptible to damage as a result of some improper valve lineups which could cause a partial drain down of the reactor pressure vessel (RPV) during shutdown cooling operations (Ref. 4). The potential for partially draining the RPV exists with all water systems connected directly or indirectly to the RPV. Certain improper valve lineups can result in a flow path from the RPV to the PSP via the RHR system. This would cause an inadvertent gravity drain down of the RPV and result in reverse flow through the RHR system. The resulting reverse flow could produce significant loads on the interfacing components such as the containment penetration, suction strainers, and piping supports. Such loads could cause suction strainer damage and result in a loss of the suction strainers' safety function.

Selected valve interlocks are provided in BWRs for the RHR system to minimize valve misalignments and other operator errors during shutdown cooling operations. However, the RHR system is primarily manually operated during this mode, and a comprehensive valve interlock arrangement has not been provided for RHR system valves. Thus, the RHR system is subjected to operator error which could result in hydraulic and thermal conditions not specifically considered during the design process for the suction strainers.

Although the potential exists for causing suction strainer damage, the probability of this occurring and resulting in degradation in ECCS pump performance and/or pump failure during LOCA mitigation is very low. This is because of the following: (1) operator error during shutdown cooling operation would have to occur resulting in gravity drain down through the RHR system to the PSP, (2) thermal-hydraulic forces resulting from reverse flow would have to be sufficient to cause damage to each suction strainer in both RHR system trains allowing large debris to enter the suction intake piping, and

(3) suction strainer damage would have to go undetected prior to the plant returning to power operation.

General Electric has issued a service information letter (SIL) to all BWR licensees (Ref. 4), addressing the safety implications of RHR valve misalignment during shutdown cooling operations. Also, IE followed this up with an information notice (Ref. 5) describing recent events involving reductions of RPV coolant inventory at BWRs and referencing the SIL. In addition, we are unaware of any suction strainer damage occurring as a result of RHR valve misalignment. Thus, the safety implications of RHR valve misalignment potentially causing damage to the RHR suction strainers and impacting the performance of ECCS operation during LOCA mitigation is considered unlikely. However, the safety implications of possible core uncovery through valve misalignments of the RHR and other systems for BWRs is currently under review by AEOD.

OPERATING EXPERIENCE

AEOD reviewed the operating experience and found four events at U.S. facilities and one event at a foreign facility involving various system pumps in which degradation of pump performance was attributed to foreign material in the pumped fluid. An event occurred at Haddam Neck (Ref. 6), with the plant operating at 100% power when charging flow to the reactor coolant pump seals was lost, and the operating CCP indication became erratic. The CCP was secured and the redundant CCP was started. Inspection of the failed CCP revealed that the pump shaft had sheared just outside the pump casing. Preliminary causal indications upon disassembly of the pump were of severe pump binding due to foreign material becoming lodged in several stages of the pump. This pump had been installed approximately six months prior to this failure and had been operating satisfactorily. Investigation by the licensee and pump vendor (California Pacific) as to the cause of failure and source of foreign material is continuing.

An event at Davis-Besse Unit 1 (Ref. 7), involved a makeup pump which was taken out of service due to increased vibration levels and a degradation of pump performance. Upon disassembly of the pump, the first stage impeller wearing ring was found in pieces which cut a large groove in the shaft and bent the two splitters of the first stage impeller. Cause of pump failure was attributed to foreign material which lodged between the first stage impeller wearing rings and the pump casing causing the impeller wearing ring to seize and shear its set screws. The clearance between the wearing rings and the pump casing was approximately 0.015 inch. The source of foreign material could not be determined.

At Surry Unit 1 (Ref. 8), a recirculation spray pump failure was attributed to foreign material being trapped between an impeller wearing ring and pump casing, since light scoring was found on the wearing rings. Upon inspection of the pump, it was found that the second stage lower wearing ring exceeded new pump clearances by 0.003 inch. The clearance between the wearing rings and the impeller was approximately 0.011 inch. The source of foreign material was not determined.

At a BWR facility, Dresden Unit 2 (Ref. 9), during PSP cooling operations, a low head core injection pump mechanical seal was found leaking. Leakage through the seal was attributed to dirt getting in between the sealing surfaces.

An event occurred at a foreign facility involving high head SI/charging pumps which experienced seal blockage attributed to debris ingestion. The source of debris came from an overheated polypropylene filter in the CVCS caused by high letdown fluid temperature. Filter media debris was found blocking the ports to the intermediate bearing of the operating CCP causing high pump vibration. Inspection of the two redundant CCPs revealed similar blockage. We are unaware of any U.S. facilities which employ plastic filters in the CVCS.

The effect of foreign material on pump performance is highly dependent upon pump design and particle characteristics. Operating experience indicates that foreign material entrained in the pumped fluid could have significant adverse impact on pump performance, particularly centrifugal designs having small internal tolerances between the wearing rings and the pump impeller.

Although operating experience indicates that foreign material entrained in the pumped fluid could affect pump performance, SI pump failure data does not appear to support this conclusion. Lack of SI pump failure data may be due to the high head SI pumps being operated predominantly under normal plant conditions. During normal plant conditions, the high head SI pumps are supplied with relatively debris free primary grade borated water from the CVCS. Also, as demonstrated by the Salem event, surveillance testing of the high head SI pumps would not necessarily subject the pumps to possible foreign material that may be contained in the RWST. This is because of the relatively low flow rate capacity of the high head SI pumps which does not appear sufficient to agitate the contents of the RWST. Thus, it cannot be determined if the lack of reported operating experience in this regard implies that these pumps are not susceptible to failure from foreign material in the pumped fluid.

AEOD also identified two events that involved containment sump designs having screen access doors that were either inadvertently left open or were not properly secured. An event at Catawba Unit 1 (Ref. 10) involved two sets of containment sump intake screen doors, on two occasions, that were found open after the plant entered hot shutdown operations from cold shutdown conditions. The cause of the event was attributed to inadequate administrative controls to ensure that the doors were closed. Pump damage could have occurred if debris had entered the suction piping of the ECCS during the recirculation phase of accident mitigation. There were no administrative controls or locks on the screen doors. Total elapsed time the screen doors were left open was approximately 2.5 hours.

An event which occurred at Arkansas Nuclear One Unit 2 (Ref. 11), involved an inadvertent actuation of the recirculation actuation system (RAS) while the unit was at full power. The RAS automatically caused the suction for the SI pumps to be realigned from the RWST to the containment sump. During this realignment, gravity draining of approximately 50,000 gallons of borated water occurred from the RWST to the containment building sump. A containment building entry was made in order to inspect the containment floor area. The inspection revealed that the west side screen access door of the containment sump was open. The cause for the door being found open was attributed to it not being properly secured and being forced open by gravity flow from the RWST to the containment sump. This door is normally closed to prevent debris from entering the sump and the suction lines for the ECCS. There were no administrative controls or technical specification requirements to verify the sump doors are secured when the plant changes operational modes.

Operating experience has shown that it is possible for hinged-type screen doors employed in some containment sump designs to be improperly secured or left open when the ECCS is required to be operable. If a LOCA occurs when the screen doors are improperly secured, pumps could be damaged and safety systems could be degraded or fail, e.g., spray orifices could be blocked if debris enters the ECCS suction piping during the recirculation phase.

The potential exists for having debris left inside containment from maintenance activities. This can occur during all plant operating conditions because maintenance work inside containment is not necessarily restricted to only plant shutdown conditions. Operational experience has shown that debris can be left inside containment inadvertently following maintenance work which is performed while the plant is at power. Four events were identified; three occurred at the D.C. Cook Nuclear Site (Refs. 12, 13, and 14) where loose debris and unrestrained equipment were found inside containment during a quality assurance inspection. There were no plant procedures in place at this facility requiring containment inspections following the completion of work while the plant was operating. The fourth event occurred at Sequoyah Unit 2 (Ref. 15), where a routine inspection of the upper containment resulted in the discovery of loose equipment and debris. This material included three bags of ice, a drop light, two bags of foam insulation, small hand tools, a flashlight, two jars of glue, three pairs of cold weather clothing, two strips of metal, paper, and tape. Subsequent review indicated that some of this material had been inside containment for more than five days. There were administrative controls at this facility requiring that personnel inspect their work area and the path to and from the work area to ensure that no debris is left behind when exiting the containment. The employees, however, were under the assumption that material and equipment was not considered to be debris and could be left inside containment until completion of the maintenance activity.

An example of foreign material inadvertently entering the ECCS suction lines occurred at the Braidwood Nuclear Site (Ref. 16), (the plant is currently under construction). While observing the recirculation mode of the ECCS and CS pumps, the inspector noted that the cleanliness controls were being either ignored or not enforced. The inspector observed that there were no precautions posted outside of the sump area and personnel were unaware of requirements to maintain material accountability. During the test, some debris, primarily paper, in the sump and surrounding area entered the suction flow path while taking suction from the containment recirculation sumps. As a result of the poor housekeeping practices observed during the plant inspection, a severity level V violation was issued to the licensee. The issue of poor housekeeping has arisen at many nuclear power facilities in Region III, and was the subject of a NRC regional letter issued to all Region III licensees (Ref. 17).

<u>RELATED GENERIC ACTIVITIES</u>

Two generic issues presently under investigation by the Generic Issues Branch (GIB) of the Division of Safety Technology were identified to be relevant to the debris issue (Ref. 18). These two activities are: (1) Potential Recirculation System Failure As a Consequence of Ingestion of Containment Paint

Flakes or Other Fine Debris (Generic Issue 38), and (2) Containment Emergency Sump Performance (USI A-43).

Generic Issue 38 was established after AEOD expressed concerns about the use of a polymer coating manufactured by CON-CHEM Inc. inside containment which could fail when subjected to design basis accident conditions (Ref. 19). The general concern is associated with paint flakes, fibrous insulation, or other debris which can pass through sump screens, yet will not pass through the more restrictive clearances present in the systems taking suction from the sump during the recirculation phase of accident mitigation. Of particular interest are the pump seal water systems, including filters or cyclone separators and the pump seals which might become clogged. Currently, this issue is awaiting prioritization and is addressing the effect of foreign material on RHR and CS pumps for PWRs, and RHR and core spray pumps for BWRs. The principal concern of USI A-43 (Ref. 20) is that during the post LOCA recirculation phase, the ECCS emergency sump supply water be sufficiently free of debris and air, so that RHR and CS pump performance is not degraded to the point that long-term core cooling requirements cannot be met.

Our review of both generic issues indicates that the analyses performed to date have concentrated on systems which take suction from the containment sump for PWRs, or PSP for BWRs, and are required to provide long-term recirculation capability. Thus, the emphasis of the analyses were on the CS and RHR systems for PWRs, and RHR and core spray systems for BWRs. USI A-43 conducted a review of most pump designs contained in BWR safety systems and a cursory review of PWR SI systems. However, the potential for SI pump failure due to particulate ingestion during the recirculation phase of small-break LOCA mitigation for PWRs and improperly secured hinged-type sump screen doors employed in some facilities were not specifically addressed. USI A-43 concluded that the types and quantities of debris small enough to pass through most sump screens and reach the pump impeller should not impair long-term hydraulic performance of the pumps contained in the systems reviewed. Clogging or excessive wear and increased seal leakage may occur in pumps with mechanical shaft seals as a result of accumulation of soft or abrasive debris in the seal flow passages. Catastrophic failure of shaft seals in post LOCA recirculation pumps (CS, RHR, and core spray pumps), in either PWR or BWR systems as a result of debris ingestion through existing filter screens is considered unlikely. However, if pumps with water-lubricated bearings are used for post-LOCA recirculation, they may be vulnerable to seal failure and/or bearing seizure as a result of particulate ingestion.

CS and RHR systems in PWRs employ centrifugal pumps which are primarily single-stage designs of specific speeds between 800 to 1600 rpm. Radial clearances between the wearing rings and pump impeller are typically 0.008 to 0.021 inch. The designs of these pumps probably allow for some degree of foreign material in the pumped fluid. This is because these systems are designed to take suction from the containment sump during a design basis accident where some amount of foreign material could be expected to be entrained in the recirculation water. The SI system is composed of primarily multi-stage pumps with very small internal tolerances. The water source for these pumps is primarily the RWST during the initial phase of accident mitigation. This source of primary grade water is supposed to be very clean and free of foreign material. The design of these pumps probably does not allow for any appreciable amount of foreign material in the pumped fluid. This is because pump operation during normal or accident conditions results in the pumps being supplied with relatively debris free borated water except for some small-break LOCAs.

Generic Issue 71, "Failure of Resin Demineralizer Systems and Their Effects of Nuclear Power Plant Safety" (Ref. 18) is also relevant to the Salem event. This issue was established in response to recent operational experience indicating that additional licensing attention is needed for certain auxiliary power plant equipment. Operating experience has shown that failures of resin bed type demineralizer subsystems due to operator error or malfunction have occurred within the process systems. These process systems do not directly perform any safety-related functions; however, their failures have seriously impaired the capability of safety-related systems to perform their function. This issue is also in the process of being prioritized.

FINDINGS AND CONCLUSIONS

The Salem event demonstrates that CCPs could be susceptible to shaft seizure from a small amount of foreign material exhibiting hard, abrasive, and very small particle size characteristics. This is because the CCPs are primarily multi-stage pumps with very small internal tolerances. Intermediate head SI pumps could be just as susceptible due to similarities in pump design. Although, operating experience indicates that foreign material entrained in the pump fluid could have significant adverse impact on pump performance, high head SI pump failure data does not support this conclusion. Lack of SI pump failure data may be due to the high head SI pumps being operated predominantly under normal plant conditions. Thus, it cannot be determined if the lack of reported operating experience indicates that these pumps are not as susceptible to failure from foreign material in the pumped fluid, contrary to the Salem event.

The root cause for the CCP failure at Salem was a result of poor housekeeping after maintenance activities; metal filings were allowed to be inadvertently deposited on the inside of the charging system piping. Foreign material having similar characteristics could exist inside containment as a result of maintenance activities. Particle sizes similar to the metal filings that seized the Salem CCP can pass through most sump screen designs. This is because the size of the fine mesh screen openings is usually set by the spray orifices in the CS system and not by the internal tolerances of ECCS pump clearances. Whenever maintenance activities are conducted inside containment, there is a potential for foreign material to be generated and inadvertently left inside. Plant housekeeping procedures should include containment inspections following all maintenance work conducted inside the containment building. Operating experience indicates that housekeeping procedures at some plants may be deficient in this area.

The function of the containment sump intake screens is to prevent debris in containment from entering the ECCS during the recirculation phase of LOCA mitigation. If screen access doors are not properly secured, or inadvertently left open, the function of the sump intake screens would be negated. This would permit debris to enter the sump suction lines and could result in failure of multiple pumps in the ECCS and block flow through spray orifices in the CS system. Operating experience shows that there have been several occasions where these screen doors have been left open or not properly secured when operability of safety-related systems served by the sump were required.

Review of licensee technical specifications revealed there are no explicit requirements on containment sump intake screen doors or grates for meeting the limiting conditions for operation for the ECCS and CS systems. Furthermore, there are no explicit surveillance requirements on sump intake screen doors to verify that they are locked or properly secured. The containment sump screens play a vital role in the protection of safety-related equipment from failure or degradation in performance due to debris ingestion. Administrative procedures are needed to address the status of the sump screen doors prior to changing operational modes for all PWRs which have sump designs with hinged-type screen access doors or grates. Containment sump screen integrity is crucial to ECCS operability.

Current generic activities have not adequately addressed the safety concerns identified from review of the Salem CCP failure or other operating experience. Potential SI pump failure due to particulate ingestion during the recirculation phase of accident mitigation and the possible loss of containment sump screen integrity due to improperly secured hinged-type screen doors or grates were not specifically covered.

Resins in small quantities do not pose as significant a threat to pump performance as do metal filings. However, plants which have experienced recurring problems with resins and/or other foreign material contamination of plant systems may benefit greatly from administrative procedures which address the potential for foreign debris. Visual tank inspections may be needed to preclude possible degradation and/or failure of ECCS components due to foreign material contamination of the RWST.

Review of BWR safety-related pumps indicate that they could be susceptible to pump seal degradation and/or failure due to debris ingestion. Suction strainers used to preclude pump mechanical damage from possible debris in the PSP recirculation water are designed to filter out relatively large foreign particles. Thus, small foreign material could pass through most suction strainers and enter safety system intake piping. Cyclone separators used to filter out foreign debris prior to seal injection are subject to clogging and are inefficient in removing particles with specific gravities close to that of the pumped fluid. This could result in the pump seals being supplied with unfiltered recirculation water which could cause increased seal leakage and/or seal failure from accumulated debris in the seal surfaces. Review of current generic activities indicates that these safety concerns have been previously raised.

Due to the wide variation in pump designs used in BWR safety systems, it could not be determined if certain designs could be just as susceptible to shaft or impeller seizure from abrasive foreign particles as were Salem's high head SI pumps. However, BWR pump head ratings are generally much lower than PWR high head SI pumps, indicating that internal tolerances would tend to be larger. Therefore, these pumps would not be as susceptible to mechanical problems from foreign material. Current generic activities are covering the debris ingestion issue with respect to BWR safety-related systems.

Although there exists a potential to cause suction strainer damage as a result of RHR valve misalignment in BWRs, the possibility of this occurring and resulting in degradation and/or failure of multiple ECCS trains is unlikely.

It is concluded that adequate attention was focused on this issue by General Electric, IE, and the licensees.

SUGGESTIONS

AEOD suggests IE issue an information notice to address the potential undetectable common cause failure of the ECCS due to foreign material contamination of the ECCS borated storage tanks, applicable to all PWR licensees. The Salem event indicates that foreign material contamination in the RWST could go undetectable for an extended period of time under normal usage of the tank. Visual tank inspections should be sufficient to detect any foreign material contamination at the bottom of these tanks. The information notice should also remind PWR licensees of the importance of containment sump screen integrity and the need for administrative controls and maintenance procedures to ensure that they address hinged-type access openings to the sump whenever ECCS operability is required. Plant housekeeping procedures and personnel training for all licensees should also be reviewed in order to verify that they emphasize the importance of containment cleanliness and containment inspections following all maintenance work conducted inside the containment building.

AEOD also suggests that NRR consider expanding the scope of Generic Issue 38 to address the potential loss of the ECCS due to foreign material during the recirculation phase of small-break LOCA mitigation for PWRs. The purpose of this suggestion is to upgrade current NRR activities in light of the Salem event which indicates that high head SI pumps used in PWRs could be susceptible to shaft or impeller seizure from small amounts of foreign material exhibiting hard, abrasive, and small particle size characteristics.

REFERENCES

1. Licensee Event Report 84-017, Public Service Electric and Gas Company, Salem Unit 1, Docket No. 50-272, dated August 16, 1984.

2. Licensee Event Report 84-016, Public Service Electric and Gas Company, Salem Unit 2, Docket No. 50-311, dated August 3, 1984.

3. Memorandum for K.V. Seyfrit from M. El-Zeftway, NRC, "Chemical Contamination of Primary and Secondary Systems in Light Water Reactors," AEOD/T402, dated March 22, 1984.

4. Service Information Letter No. 388, "RHR Valve Misalignment During Shutdown Cooling Operation," General Electric Company, dated February 1983.

5. IE Information Notice No. 84-81, Subject: Inadvertent Reduction in Primary Coolant Inventory in Boiling Water Reactors During Shutdown and Startup, dated November 16, 1984.

6. U.S. Nuclear Regulatory Commission, Inspection and Enforcement Inspection Report Docket No. 50-213/85-07, dated June 14, 1985.

7. Licensee Event Report 79-047, Toledo Edison Company, Davis-Besse Unit 1, Docket No. 50-346, dated April 25, 1979.

8. Licensee Event Report 78-012, Virginia Electric Power Company, Surry Unit 1, Docket No. 50-280, dated June 5, 1978.

9. Licensee Event Report 80-030, Commonwealth Edison Company, Dresden Unit 2, Docket No. 50-237, dated September 18, 1980.

10. Licensee Event Report 84-022, Duke Power Company, Catawba Unit 1, Docket No. 50-413, dated December 14, 1984.

11. Licensee Event Report 85-001, Arkansas Power and Light Company, Arkansas Nuclear One Unit 2, Docket No. 50-368, dated February 6, 1985.

12. Licensee Event Report 81-008, Indiana and Michigan Electric Company, D. C. Cook Unit 1, Docket No. 50-315, dated April 15, 1981.

13. Licensee Event Report 83-032, Indiana and Michigan Electric Company, D. C. Cook Unit 1, Docket No. 50-315, dated May 6, 1983.

14. Licensee Event Report 83-041, Indiana and Michigan Electric Company, D. C. Cook Unit 2, Docket No. 50-316, dated May 6, 1983.

15. Licensee Event Report 85-005, Tennessee Valley Authority, Sequoyah Unit 2, Docket No. 50-328, dated March 14, 1985.

16. U.S. Nuclear Regulatory Commission, Inspection and Enforcement Inspection Reports Docket Nos. 50-456/85-08, 50-457/85-08, dated February 14, 1985.

17. Letter from J.G. Keppler, NRC, to J.E. Dolan, American Electric Power Service Corporation, Indiana and Michigan Electric Company, dated January 29, 1985.

18. NUREG-0933, "A Prioritization of Generic Safety Issues," dated December 1983.

19. Memorandum for H. Denton, from C. Michelson, "Concerns Relating to the Integrity of a Polymer Coating for Surfaces Inside Containment (IE Draft Bulletin No. 80-21)," AEOD/E011, dated August 29, 1980.

20. NUREG-0897 Rev. 1, "Containment Emergency Sump Performance," dated March 30, 1984.

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MEMORANDUM FOR: Gus C. Lainas, Assistant Director
for Operating Reactors
Division of Licensing

FROM: Dennis L. Ziemann, Acting Deputy Director
Division of Human Factors Safety

SUBJECT: REVISED SAFETY EVALUATION REPORT FOR SALEM, UNITS 1 AND 2, GENERIC LETTER 83-28, ITEM 1.1 (POST-TRIP REVIEW) (TAC Nos. 52795 & 52796)

Reference: Memorandum from D. Beckham to G. Lainas, "Safety Evaluation Report for Salem, Units 1 and 2, Generic Letter 83-28, Item 1.1 (Post-Trip Review)," dated April 5, 1985.

By the above referenced memorandum, we forwarded the LQB SER with regard to Generic Letter 83-28, Action Item 1.1 (Post-Trip Review) for Salem Generating Station, Units 1 and 2. In our SER, we stated that the licensee had not addressed the methods and criteria for comparing the event information with known or expected plant behavior. We further recommended that the pertinent data obtained during the post-trip review be compared to the applicable data provided in the FSAR to verify proper operation of the systems or equipment.

By letter dated August 2, 1985, the licensee provided responses for the above open issues. We have reviewed the licensee's responses and find that the above open issues have been resolved. Thus, we conclude that the Post-Trip Program and Procedures for Salem Generating Station, Units 1 and 2, are acceptable. Our revised SER and SALP evaluation are enclosed.

This review has been conducted by D. Shum (x24906). There are no known dissenting professional opinions on this matter.

Original Signed by
Dennis L. Ziemann

Dennis L. Ziemann, Acting Deputy Director
Division of Human Factors Safety

Enclosures:
1. Safety Evaluation
2. SALP Evaluation

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CF ADOCK 05000272
CF

cc: A. Bournia
S. Varga
D. Fischer
G. Holahan

DW/DHS10/REVISED MEMO FOR LAINAS-SALEM

OFFICE	LQB/DHFS	LQB/DHFS	LQB/DHFS	ActDD/DHFS			
SURNAME	DShum/br	LCrocker	HBooher	DLZiemann			
DATE	8/27/85	8/27/85	8/28/85	9/3/85			

Enclosure 1

SAFETY EVALUATION REPORT FOR
GENERIC LETTER 83-28, ITEM 1.1 - POST-TRIP REVIEW
(PROGRAM DESCRIPTION AND PROCEDURE)
SALEM GENERATING STATION, UNITS 1 AND 2
DOCKET NOS.: 50-272/311

I. INTRODUCTION

On February 25, 1983, both of the scram circuit breakers at Unit 1 of the Salem Nuclear Power Plant (SNPP) failed to open upon an automatic reactor trip signal from the reactor protection system. This incident occurred during the plant start-up and the reactor was tripped manually by the operator about 30 seconds after the initiation of the automatic trip signal. The failure of the circuit breakers has been determined to be related to the sticking of the under voltage trip attachment. On February 22, 1983, during start-up of SNPP, Unit 1, an automatic trip signal occurred as the result of steam generator low-low level. In this case, the reactor was tripped manually by the operator almost coincidentally with the automatic trip. Following these incidents, on February 28, 1983, the NRC Executive Director for Operations (EDO) directed the staff to investigate and report on the generic implications of these occurrences. The results of the staff's inquiry into these incidents are reported in NUREG-1000, "Generic Implications of ATWS Events at the Salem Nuclear Power Plant." As a result of this investigation, the Commission requested (by Generic Letter 83-28 dated July 8, 1983) all licensees of operating reactors, applicants for an operating license, and holders of construction permits to respond to certain generic concerns. These concerns are categorized into four areas: (1) Post-Trip Review, (2) Equipment Classification and Vendor Interface, (3) Post-Maintenance Testing, and (4) Reactor Trip System Reliability Improvements.

The first action item, Post-Trip Review, consists of Action Item 1.1, "Program Description and Procedure," and Action Item 1.2, "Data and Information Capability." This safety evaluation report (SER) addresses Action Item 1.1 only.

II. REVIEW GUIDELINES

The following review guidelines were developed after initial evaluation of the various utility responses to Item 1.1 of Generic Letter 83-28 and incorporate the best features of these submittals. As such, these review guidelines in effect represent a "good practices" approach to post-trip review. We have reviewed the licensee's response to Item 1.1 against these guidelines:

A. The licensee or applicant should have systematic safety assessment procedures established that will ensure that the following restart criteria are met before restart is authorized.

- The post-trip review team has determined the root cause and sequence of events resulting in the plant trip.

- Near term corrective actions have been taken to remedy the cause of the trip.

- The post-trip review team has performed an analysis and determined that the major safety systems responded to the event within specified limits of the primary system parameters.

- The post-trip review has not resulted in the discovery of a potential safety concern (e.g., the root cause of the event occurs with a frequency significantly larger than expected).

- If any of the above restart criteria are not met, then an independent assessment of the event is performed by the Plant Operations Review Committee (PORC), or another designated group with similar authority and experience.

B. The responsibilities and authorities of the personnel who will perform the review and analysis should be well defined.

- The post-trip review team leader should be a member of plant management at the shift supervisor level or above and should hold or should have held an SRO license for the plant. The team leader should be charged with overall responsibility for directing the post-trip review, including data gathering and data assessment and he/she should have the necessary authority to obtain all personnel and data needed for the post-trip review.

- A second person on the review team should be an STA or should hold a relevant engineering degree with special transient analysis training.

- The team leader and the STA (Engineer) should be responsible to concur on a decision/recommendation to restart the plant. A nonconcurrence from either of these persons should be sufficient to prevent restart until the trip has been reviewed by the PORC or equivalent organization.

C. The licensee or applicant should indicate that the plant response to the trip event will be evaluated and a determination made as to whether the plant response was within acceptable limits. The evaluation should include:

- A verification of the proper operation of plant systems and equipment by comparison of the pertinent data obtained during the post-trip review to the applicable data provided in the FSAR.

- An analysis of the sequence of events to verify the proper functioning of safety related and other important equipment. Where possible, comparisons with previous similar events should be made.

D. The licensee or applicant should have procedures to ensure that all physical evidence necessary for an independent assessment is preserved.

E. Each licensee or applicant should provide in its submittal, copies of the plant procedures which contain the information required in Items A through D. As a minimum, these should include the following:

- The criteria for determining the acceptability of restart

- The qualifications, responsibilities and authorities of key personnel involved in the post-trip review process

- The methods and criteria for determining whether the plant variables and system responses were within the limits as described in the FSAR

- The criteria for determining the need for an independent review.

III. EVALUATION AND CONCLUSION

By letters dated July 22, 1983, and August 2, 1985, the licensee of Salem Generating Station, Units 1 and 2, provided information regarding its Post-Trip Review Program and Procedures. We have evaluated the licensee's program and procedures against the review guidelines described in Section II. A brief description of the licensee's response and the staff's evaluation of the response against each of the review guidelines is provided below:

A. With regard to the criteria for determining the acceptability of restart, the licensee indicated that following an unscheduled reactor trip and prior to the request for authorization to restart, the Senior Shift Supervisor will be required to file a Post Reactor Trip/Safety Injection Report which will contain: a description of the initiating event; a verification that the reactor protection system and the engineered safety features and systems which are important to reactor safety have performed as required; and a verification of the cause of the trip and the adequacy of the subsequent corrective action taken. We find that the licensee's criteria for determining the acceptability of restart are acceptable.

B. The qualifications, responsibilities and authorities of the personnel who will perform the review and analysis have been clearly described. The licensee indicated that the Operations Manager, who bases his decision on the above cited restart acceptability criteria, shall have the final authority to grant or deny authorization of plant restart. We have reviewed the licensee's chain of command for responsibility for post-trip review and evaluation, and find it acceptable.

C. The licensee has addressed the methods and criteria for comparing the event information with known or expected plant behavior. Based on our review, we find them to be acceptable.

D. With regard to the criteria for determining the need for independent assessment of an event, the licensee indicated that the Nuclear Support Department will perform an independent review of each Reactor Trip/Safety Injection. In addition, the licensee indicated that if the cause of the trip cannot be positively determined, or performance of specified systems during the event is in question, an investigation of the event will be performed and the results will be reviewed by the Station Operations Review Committee. We find that these actions to be taken by the licensee conform to the guidelines described in Sections II.A. and D.

E. The licensee has provided for our review a systematic safety assessment program to assess unscheduled reactor trips. Based on our review, we find that this program is acceptable.

Based on our review, we conclude that the licensee's Post-Trip Review Program and Procedures for Salem Generating Station, Units 1 and 2, are acceptable.

Enclosure 2

SALP EVALUATION
SALEM GENERATING STATION, UNITS 1 AND 2
DOCKET NOS. 50-272/311
GENERIC LETTER 83-28, ITEM 1.1, POST TRIP REVIEW

A. Functional Areas: Licensing Activities - Generic Letter 83-28, Item 1.1, Post Trip Review

1. Management involvement in assuring quality

Based on our review of the licensee's response to Generic Letter 83-28, we find that the licensee's management was involved in assuring that the issues were resolved.

Rating: Category 2

2. Approach to resolution of technical issues from a safety standpoint

Rating: N/A

3. Responsive to NRC initiatives

Based on our review, we find that the licensee is responsive to NRC initiatives.

Rating: Category 2

4. Staffing

Rating: N/A

5. Reporting and analysis of reportable events

   Rating: N/A

6. Training and qualification effectiveness

   Rating: N/A

7. Overall Rating for Licensing Activity Functional Areas: Category 2