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Abnormal Occurrence; Blockage of Coolant Flow to Safety-Related Systems and Components

Section 208 of the Energy Reorganization Act of 1974, as amended, requires the NRC to disseminate information on abnormal occurrences (i.e., unscheduled incidents or events which the Commission determines are significant from the standpoint of public health and safety). The following recurrance of certain incidents was determined to be an abnormal occurrence using the criteria published in the Federal Register on February 24, 1977 (42 FR 10950). Example I D.4 ("For All Licensees") in Appendix A notes that recurring incidents, and incidents with implications for similar facilities (generic incidents), which create major safety concern can be considered an abnormal occurrence. The following description of the incident also contains the remedial actions taken.

Date and Place—The NRC has received notifications from several nuclear power plant licensees indicating that the heat transfer capabilities in some safety-related and non-safety-related cooling systems were degraded by unanticipated blockage of the coolant flow paths. Table 1 lists several incidents of a generic nature with varying degrees of safety significance. The incidents are listed by date of discovery. The incident discovered at Brunswick Unit 1 was the most significant from the safety standpoint due to the total loss of both redundant trains of the residual heat removal system. The other incidents, which were of lesser safety significance, are other recent examples of the recurrent nature of flow blockage problems which have been experienced. The principal cause for the flow blockage in many of these situations was a buildup of biological organisms.

TABLE 1.—INCIDENTS INVOLVING COOLANT FLOW BLOCKAGE TO SAFETY SYSTEMS AND COMPONENTS

Date, plant, location, and licensee	Event description
1. Sept. 3, 1980; Arkansas Nuclear One; Units 1 and 2; Pope County, Arkansas; Arkansas Power and Light Company (see note 1).	Coolant flow in the service water systems was blocked due to debris from Asiatic clams growing in the system and from a buildup of silt and corrosion products. Containment coolers, high pressure safety injection pump bearing and seal coolers, and containment spray and low pressure injection pump seal water coolers were most significantly affected. Clam shells were also found in the Auxiliary Cooling Water System (ACWS) which serves non-safety-related equipment in the turbine building. Due to design differences, Unit 2 had more severe problem than Unit 1.
2. Mar. 18, 1981; Rancho Seco Unit 1; Sacramento County, California; Sacramento Municipal Utility District (see note 2).	During a refueling outage, the licensee observed that the inlet plenum of the safety-related lube oil cooler on each of the high pressure injection pumps was 80 to 90% clogged with corrosion products. The cause was attributed to excessive corrosion of the lube oil cooler cast steel heads. Routine surveillance testing did not previously verify performance of this equipment.
3. Apr. 25, 1981; Brunswick Units 1 and 2; Brunswick County, North Carolina; Carolina Power and Light Company (see note 3).	Coolant flow in the service water systems was blocked due to debris from marine organisms growing in the system. Species present included American oysters, blue mussels, barnacles, and tubeworms. The Residual Heat Removal (RHR) systems, which provide decay heat removal capability following normal shut downs and during post-accident recirculation cooling, at both units were affected. Some shells were also found in other safety and non-safety related component coolers such as the diesel generator heat exchangers, core-spray pump room cooler and the turbine building component cooling water heat exchangers. Three RHR heat exchangers (both of those on Unit 1 and one on Unit 2) had their baffle plates displaced, as a result of the high differential pressure caused by the change in flow rate, allowing the service water to bypass the heat exchanger tubes. Therefore, the heat exchangers were inoperable.
4. June 9, 1981; San Onofre Unit 1; San Diego County, California; Southern California Edison Company (see note 4).	Growth of gooseneck barnacles on the salt-water discharge pipe of the safety-related component cooling water heat exchangers caused a low coolant flow and the malfunctioning of a butterfly valve. This growth was noticed while making preparations to restart the plant following a 14-month protracted shutdown. No problems were noted previously when the plant was in normal operation with routine flushings of the system with heated water.
5. Aug. 28, 1981; Pilgrim Unit 1; Plymouth County, Massachusetts; Boston Edison Company (see note 5).	While conducting an inspection in conjunction with an NRC Information Notice 81-21, the Reactor Building Closed Cooling Water (RBCCW) heat exchanger baffle plate had deformed allowing water to bypass the heat exchanger tubes. Although the heat exchanger problem involved a design deficiency, the growth of mussels in the Salt Service Water (SSW) system contributed to the degradation of the SSW system capabilities. Pilgrim had experienced problems with mussels growing in the cooling system for several years. The RBCCW system cools both non-safety and safety-related systems. The degradation of the RBCCW heat exchanger affects the heat removal capability of the residual heat removal system, as well as safety-related pump lube oil and bearing coolers and safety-related area coolers. (Note.—The RBCCW heat exchanger design deficiency is being reviewed separately for generic implications as a possible common mode failure mechanisms.)
6. Jan. 14, 1982; Arkansas Nuclear One, Unit 2; Pope County Arkansas, Arkansas Power and Light Company (see note 1).	While the plant was shutdown a weekly surveillance flow test was being conducted of the containment fan cooler heat exchangers. For the "C" cooler, flow dropped from about 1800 gpm to 500-600 gpm within five minutes. A normal flush did not increase flow; however, a high velocity flush did get the flow through the "C" cooler back to about 1300 gpm (technical specification value is 1250 gpm). The "C" and "D" coolers were disassembled and about five gallons of Asiatic clams were removed from the "C" cooler inlet water box; some clams were also found in the "D" cooler inlet water box. Most of the clams were dead. Other coolers were inspected but no significant amount of clams were found.

Notes to table 1:

1. Arkansas Nuclear One, Units 1 and 2 utilize pressurized water reactors designed by Babcock & Wilcox and Combustion Engineering, respectively.
2. Rancho Seco Unit 1 utilizes a pressurized water reactor designed by Babcock & Wilcox.
3. Brunswick Units 1 and 2 both utilize boiling water reactors designed by General Electric.
4. San Onofre Unit 1 utilizes a pressurized water reactor designed by Westinghouse.
5. Pilgrim Unit 1 utilizes a boiling water reactor designed by General Electric.

TO BE FILED IN

SPECIAL REPORTS
3a) FEDERAL REGISTER NOTICES CONCERNING ABNORMAL OCCURRENCES & FOLLOW-UP REPORTS

NUCLEAR REGULATORY COMMISSION

Docket No. 50-400 Official Exh. No. II #12

In the matter of Shearon Harris #1

Staff

Applicant ✓ IDENTIFIED ✓

Intervenor RECEIVED ✓

Cont'g Off'r REJECTED

Contractor DATE 9-6-84

Other Witness

Reporter WRB

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Nature and Probable Consequence—In a nuclear power plant, it is imperative that the heat generated by the nuclear reactor and the components of safety systems be dissipated to the environs. This process is usually performed by transferring the heat being generated to various cooling systems via heat exchangers and then to a heat sink such as a river, lake or cooling tower. These processes are utilized during normal operations and subsequent to normal plant shutdownns or accidents. Failure to provide adequate cooling could result in severe damage to the safety-related components or systems designed to safely shut down the plant and to mitigate the consequences of a major occurrence (such as a loss of coolant accident, LOCA).

The events described in Table 1, although limited in actual consequence, clearly are precursors to a possible common cause failure that could lead to more serious consequences, particularly in conjunction with postulated accidents. The nature of aquatic fouling in piping systems is such that it may go unnoticed, or not severely degrade system performance, until the system is called upon to function following an incident. Some of the ways that this can be postulated to occur are described below.

a. During normal operation, particularly if an adequate control program is not being followed, fouling organisms can grow in large diameter piping if the flow velocity is low. A quantity of fouling organisms, sufficient to cause severe flow blockages in safety-related coolers under accident conditions, could accumulate in such piping without causing significant flow degradation under normal operating conditions. Therefore, a situation such as this could go undetected for a long time since a large accumulation of fouling organisms would be required before any noticeable flow degradation was observed. These fouling organisms may potentially be slowly swept into components requiring cooling water causing tube plugging and degraded performance. If additional service water pumps are started following an incident, the tendency for live organisms, marine shell fragments, and other debris to be swept down the piping into heat exc[illegible]ers would increase due to the high[illegible] flow velocity.

b. Fouling organisms also thrive in stagnant runs of piping in operating systems or in piping systems which have been inactive for long periods of time. Particularly during initial construction or extended maintenance outages, systems that would normally be operating may be laid-up for months or even years without the implementation of an adequate control program, allowing fouling organisms ample time to become established in systems that otherwise might be unaffected during operation. The concern here is that plants could begin operation without the operators being aware of the fouling that could exist.

An example of this, that did not go undetected by the licensee, is the described occurrence at San Onofre Unit 1. This plant had been shutdown for steam generator tube repairs for over one year. During this time, the periodic flushing of the system with heated water (heat treatment) normally used by the licensee to control the growth of marine organisms, was curtailed. Due to the lack of periodic heat treatment the licensee discovered, after observing a low saltwater coolant flow rate, that gooseneck barnacles were present on the component cooling water heat exchanger discharge tubesheet and in the saltwater discharge piping. The growth of the barnacles effectively (1) reduced the flow area of the piping causing low flow and (2) caused the malfunctioning of a butterfly valve.

Fire protection systems using service water are also prime candidates for fouling by aquatic organisms since they inherently contain stagnant branch lines that are conducive to marine growth. Branch lines in fire protection sprinkler heads generally have orifices of one-half inch. These would be susceptible to plugging. In addition, live organisms or marine shell fragments would be swept toward the open sprinkler head in the event of a fire.

c. Seismically diked emergency ponds utilized by some power plants as the ultimate heat sink could also support the growth of Asiatic clams. If make-up to the pond is from a waterbody in which the Asiatic clams are known to be present, then it is likely that the clams will be found in the ultimate heat sink and possibly in the service water supply header leading to the plant from the ultimate heat sink.

Under design heat loads (e.g., post-LOCA) ultimate heat sink temperatures could reach 110 to 120°F during summer months. This is not enough to cause a substantial mortality of the clam population. Dead clams may be more of a problem than live organisms, since they are more easily swept along by the flow. Therefore, following a LOCA that resulted in high pond temperatures, service water system performance could be gradually degraded if the dead clams are swept into the system. Even if the temperature of the ultimate heat sink does not reach the point that causes clam mortality, clams residing in the service water supply header could still be swept along the piping if the flow velocity is sufficiently high. Since the service water supply headers can be quite long, even a moderately dense infestation may translate into a large volume of clams. A small percentage of these, if swept along the piping, could overburden automatic backwash service water strainers.

d. Although all nuclear power plants are designed to withstand a seismic event, the vibratory motion induced by such an event may cause fouling organisms such as oysters, that attach themselves to piping walls by a strong but brittle bond, to be broken loose in sufficient quantities by the pipe flexure to cause flow blockage in cooling water systems. In a similar manner, during a seismic event, piping severely encrusted with corrosion products may release a substantial amount of debris which can collect in equipment bearing or seal coolers blocking the cooling water flow. In both cases, the buildup of fouling organism or corrosion products may not noticeably degrade system performance during normal operation; however, the performance of redundant systems could be simultaneously degraded following a seismic event. Since the reactor coolant system is seismically designed, a LOCA is not postulated to result from a seismic event. A degradation of the service water system, in this case, would not be an immediate safety concern but may lengthen the time required to go to cold shutdown as a result of the unavailability or diminished heat removal capacity of the shutdown cooling system.

e. Seal coolers are generally provided on pumps that may be called upon to pump heated water from the containment sump following a LOCA; for example, such pumps include the high and low pressure injection pumps, containment spray pumps or residual heat removal pumps. Surveillance testing of these pumps is, by necessity, performed with water at ambient temperature. This is not representative of the temperatures of water encountered during the post-LOCA recirculation mode of operation. Therefore, if flow blockage existed in the pump seal coolers due to the growth of fouling organisms, or a buildup of silt or corrosion products, it could go unnoticed during pump surveillance testing unless flow measurements through the coolers were part of the test. There are two reasons for this: (1) Since the pumped fluid is at ambient temperature, seal cooling may not be necessary and no seal degradation would be observed even after hours of running without cooling water; and (2) generally, surveillance testing is of such a short duration that no noticeable seal degradation would occur even if cooling flow were necessary for sustained operation. Since pumps required during the post-LOCA recirculation are generally located outside primary containment (in the auxiliary building) degraded pump seals would result in the leakage of radioactively contaminated water outside containment.

Similarly, pumps provided with bearing lube oil coolers could be susceptible to flow blockages due to fouling organisms or the accumulation of corrosion products or silt deposits. Flow blockages in these coolers could also go unnoticed during surveillance testing unless the cooling water flow was monitored. This could result in premature bearing failure when the pumps are needed to run for an extended period of time, e.g., following a LOCA.

The safety concern identified by these events is the possible degradation of the heat transfer capabilities of redundant safety systems to the point where system function is lost. Preventive measures and methods of detecting gradual degradation have been inadequate in certain areas to preclude the occurence. The above postulated events involve a common cause failure mode that can affect redundant systems. Aquatic organisms, mud silt and corrosion products have been the main source of flow blockage in the coolant piping system and associated heat exchangers where events have occurred.

Cause or Causes—A variety of causes lead to the events reported in Table 1. At Arkansas Nuclear One, the first event discovered September 3, 1980, the growth of Asiatic clams was unanticipated in the design and appropriate operational control features were not provided. The design and operational control features that did exist were inadequate to prevent the buildup of mud, silt, and corrosion products from becoming a major problem.

The second event at Arkansas Nuclear One, Unit 2 on January 14, 1982 assumes additional significance as compared to the other described events since it indicates that (1) although the corrective actions taken to prevent buildup of marine organisms may not be totally effective, the increased frequency of surveillance implemented as a result of the previous event allowed the licensee to detect the claim intrusion in its early stages,[1] and (2) the rate of accumulation of the organisms can be rapid. During the surveillance test, the flow dropped from 1800 gpm to approximately 600 gpm over a five minute interval, indicating a sizeable blockage. About six buckets of clams were removed. The event remains under investigation. The licensee is studying the service water piping to identify for inspection any portions of piping that may be conductive to Asiatic clam growth, and other long-term preventative measures; this study is planned to be complete prior to the refueling outage scheduled for October 1983.

At Rancho Seco, the corrosion occurred because the heads were cast steel. A corrosion resistant coating such as epoxy or copper/nickel cladding would have prevented the problem. Existing surveillance testing procedures, however, were also deficient in that the safety-related heat exchanger performance was not verified under appropriate accident conditions.

At Brunswick, the chlorination program, which was part of the program to control the growth of marine organisms, was stopped for approximately 14 months due to potential operational problems and environmental effects. Although operational and administrative controls were inadequate at Arkansas Nuclear One and Brunswick to detect early signs of the problem, the plants were shutdown when the technical specification limits could no longer be met. As previously discussed, the incident at Brunswick has the most safety significance of the incidents described in this report. Unit 1, which was shutdown on April 17, 1981 to begin a scheduled maintenance outage, experienced a total loss of the residual heat removal system on April 25, 1981. In order to provide residual heat removal capacity during the plant shutdown, an alternate cooling flow path had to be established. Because of the problems found on the Unit 1 RHR heat exchangers, the similar heat exchangers in the operating Unit 2 were examined. For RHR heat exchanger 2A, a higher than normal differential pressure at design flow was discovered; however, the baffle plate was not displaced. The baffle plate was found displaced for RHR heat exchanger 2B. Therefore, Unit 2 was shutdown using heat exchanger 2A at reduced capacity. After the unit was in cold shutdown, and alternate cooling flow path was established (as in Unit 1 described above) and the heat exchangers were taken out of service of repair.

[1] Inspection of other safety-related coolers showed only traces of Asiatic clams with no significant accumulation.

At San Onofre, the growth of gooseneck barnacles was attributed to the termination of a heat treatment procedure that controls their growth. The treatment was terminated during a protracted plant shutdown of 14 months. The system problems were noted during routine operational checks.

At Pilgrim, the mussels apparently grew in the Salt Service Water System even though a back flusing and cleanout program was instituted to control their growth. Routine surveillance indicated a continuing problem due to decreasing heat transfer capabilities.

In general, the causes of the incidents above related to an inadequate surveillance and monitoring of the heat exchanger performance characteristics such as flow rates, fouling factors, heat transfer coefficients, etc.

Actions Taken To Prevent Recurrence

Licensees—The licensees of Arkansas Nuclear One, Rancho Seco, Brunswick, San Onofre Unit 1 and Pilgrim have cleaned and flushed the affected cooling water systems. The licensees have also committed to improving design features and detection techniques which are intended to preclude the development of significant fouling of safety-related cooling systems in the future.

NRC—The NRC conducted special inspections regarding the events at the facilities noted above. In addition, on April 10, 1981 the NRC's Office of Inspection and Enforcement issued IE Bulletin 81-03, "Flow Blockage of Cooling Water to Safety System Components by *Corbicula* sp. (Asiatic Clam) and *Mytilus* sp. (Mussel)". The Bulletin requested licensees to determine whether either species was present in the vicinity of their station and the extent of any fouling these organisms may have caused in fire protection or safety-related systems. The responses to the Bulletin have been received from all of the operating plants. The responses received represent 48 sites. Of these, 21 sites reported positive findings either in the plant or in the source or receiving waterbody. Eight sites have seen some evidence of Asiatic Clams in the plant and six sites have seen evidence of mussels in the plant. This has ranged from occasional findings of a few shell fragments in the main condenser to major infestations. An additional seven sites have reported that while Asiatic clams were not yet present in the plant, they were present in either source or receiving waterbodies and infestations at the plant were possible in the future.

The Bulletin also asked licensees to describe their methods for preventing and detecting any future fouling at their plants. A combination of chlorination, heat treatment, flushing, backflushing and the installation of strainers were the preventative actions taken by most of the affected plants. Many of them routinely inspect the intake canal, the pump discharge strainers and the main condenser, cleaning them out as needed. Detection methods included surveillance programs comprised of visual inspections and measurements of flow, differential pressure, and temperature at various system locations. These actions by the licensees can be expected to have varying degrees of effectiveness depending on the frequency with which they are performed and the severity of the infestation present at and around the plant.

IE Bulletin 81-03 addressed fouling by Asiatic clams and musseles only. Therefore, most plants discussed only these two species in their responses. Some plants however, mentioned the presence of other fouling organisms such as other species of clams, oysters, barnacles, tubeworms and algae to name a few. In addition, a number of plants reported problems caused by mud and silt. In some cases, they claimed this to be a bigger problem at the plant than marine fouling.

In July 1981, NRC issued IE Information Notice 81-21, "Potential Loss of Direct Access to Ultimate Heat Sink". The Notice described the loss of the normal decay heat removal system at Brunswick. It also emphasized the need for licensees to initiate appropriate actions, as described in IE Bulletin 81-03, for any marine organisms that could cause fouling at their plant.

A case study entitled "Report on Service Water System Flow Blockages by Bivalve Mollusks at Arkansas Nuclear One and Brunswick", was issued by the NRC's Office for Analysis and Evaluation of Operational Data in February 1982.

The NRC's Office of Nuclear Reactor Regulation (NRR) is conducting a generic study of service water system malfunctions. This study is being assisted through the Special Studies program at the Oak Ridge National Laboratory (ORNL). In the program, ORNL will investigate licensee event reports (LERs) from January 1979 through June 1981 on the partial or complete loss of service water systems and organize these results systematically. From this collection of events, ORNL will evaluate the safety significance of service water malfunctions and provide their recommendations for any corrective measures that they believe may be needed. NRR will attempt to correlate specific plant design features, surveillance programs and preventative measures with the magnitude and types of service water problems reported in LERs and the responses to IE Bulletin 81-03. Based on the results of this study, corrective actions will be recommended in order to improve the reliability of service water systems.

In addition to the service water study, NRR is reviewing the design of baffle plates in "U" tube heat exchangers similar to those used at Brunswick. This review is to determine if a generic problem exists and if the design is appropriate for the given application.

Future reports on the findings and investigations will be made, as appropriate, in the quarterly Report to Congress on Abnormal Occurrences (NUREG-0900 series.)

Dated at Washington, D.C. this 13th day of May 1982.

Samuel J. Chilk,

Secretary of the Commission.