General Electric Advanced Technology Manual

Chapter 4.8

Service Water Problems

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4.8 Service Water Problems

Learning Objectives:

1. Recognize the potential consequences of Service Water System failure or degradation.
2. Identify potential causes of the Service Water System failures and / or degradation.
3. Identify the primary strategies used by Licensees to ensure adequate system reliability and piping integrity.

4.8.1 Introduction

The service water system is defined as the system or systems that transfer heat from the safety related structures, systems or components to the ultimate heat sink (UHS). For the purposes of this chapter the generic reference to service water includes the circulating water, emergency diesel generator cooling, emergency service water and fire water systems presuming they take suction from the ultimate heat sink. There have been numerous events that resulted in the full or partial blockage of service water flow of nuclear facilities. The service water intake at some nuclear facilities has been blocked by ice, debris, garbage and other sources. Mollusks have intruded into service water systems and blocked pipelines, valves and pumps. Sea life, such as jellyfish and gill bearing fish, has intruded into service water systems congesting pumps and valves. Although there are other events that reduced the effectiveness or reliability of service water systems, none have the dire implications of a complete divorce from the ultimate heat sink. As follows are descriptions of blockage events and the potential safety consequences of such events.

The service water system is designed to provide cooling water to selected safety equipment during a loss of offsite power. The lack of cooling from failure of the service water system could quickly fail operating diesel generators. Some injection system heat exchangers require service water for cooling. Low pressure emergency core cooling pumps could fail due to the loss of pump cooling or room coolers. The emergency core cooling systems and reactor core isolation cooling pumps could fail upon loss of their room cooling. Operating experience indicates that most of the service water blockage events to date would have adversely affected safety-related components or systems. About 80% of intake blockage events required the affected unit to reduce power or shutdown. Blockage events have occurred on a diverse set of water bodies. Oceans, lakes, ponds and rivers have demonstrated blockage events.

An ongoing endemic service water issue is the blocking of water intake. Frazil ice, fish, jellyfish, vegetation, clams and mussels have all disabled the water intake of service water and circulating water systems. Without access to the ultimate heat sink, the reactor can cooldown using energy exhausted to the suppression pool.

An overall analysis of service water problems yields common mechanisms that affect reactor safety and reliability that include:

- Environment and environmental changes (storm/wind effects, aquatic life, frazil ice, sand, silt, crude oil from spills)
- Inadequate Designs that do not evaluate all credible vulnerabilities
- Weaknesses in Monitoring techniques (establishing required conditions to support safety system operation, considering effects of local industrial activity)
- Material Condition Monitoring and Maintenance Programs
- Procedure and Training Deficiencies (operators/system engineers have inadequate procedural guidance and training to handle blockages)

4.8.2 Operating Experience

On January 11th, 1978 Salem Unit 1 had four of six service water pumps trip. The self-cleaning strainers for the idled pumps were filled with frazil ice. The Delaware river was coated with the slushy frazil ice. Silt had accumulated and formed walls in front of the service water pump suctions. The Delaware river was at a very low level. The combined effects allowed the ice slurry to be moved through the pumps to the strainers. The weight of the frazil ice broke the self cleaning strainer shear pins allowing the ice to concentrate and obstruct water flow. The plant continued operating on the two service water pumps that were not affected. Frazil ice is composed of very small crystals with little buoyancy. The ice crystals can be carried along in the water and form a slushy mixture that readily deposits on solid surfaces. Large accumulations of frazil ice are possible because the ice crystals readily adhere to any surface. The deposits can withstand very high differential pressures.

On September 3rd 1980, Arkansas Nuclear One (ANO) Unit 2 was shutdown when the minimum service water flow was determined to be below the minimum stipulated in the technical specifications. The low flow was due to extensive plugging by a species of non-native fresh water bivalve clams. Upon disassembling much of the service water piping, clams and clam shells were found in small diameter pipes and components. Some clams were still alive and their population was literally inside the enclosed system. Further inspection of components cooled by service water identified obstructions from silt, corrosion products and broken clam shells. Clam shells accumulated to depths of four and one half feet in some areas of the Unit 2 intake bays. Other nuclear plants had problems with this species of clam since 1957.

On April 25th, 1981 Brunswick Unit 1 had a single RHR heat exchanger failure due to the accumulation of oyster shells. When two residual heat removal (RHR) service water pumps were placed in service to one RHR heat exchanger, the deposits of shells raised differential pressure on the service water side of the heat exchanger. The high differential pressure led to a failure of the baffle plate on the waterbox of the service water side of the heat exchanger. The baffle shifted and allowed service water flow to bypass the heat exchanger. The redundant side of RHR was unavailable due to maintenance in progress. Cooling was restored using the spent fuel pool pumps and heat exchangers. An inspection at Brunswick Unit 2 revealed similar damage on a RHR heat exchanger. The Unit 2 heat exchanger had service water tubes blocked with oyster and other marine life shells. The shells came from an infestation of oysters growing primarily in one header from the intake structure to the reactor building. As the oysters died their upper shells detached and were swept into the RHR heat exchangers where they collected. Small amounts of shells were found in other heat exchangers cooled by service water.

On June 9th, 1981 San Onofre Unit 1 had aquatic biofouling in a salt water discharge line from a component cooling heat exchanger. An unspecified form of sea mollusk had reduced the effective diameter of the discharge line. A valve's movement was impaired and there was some mollusk growth into the heat exchanger. A prolonged outage with little flow in the heat exchanger allowed the mollusks to become established inside the system.

By March 1982, several reports of serious fouling events caused by mud, silt, corrosion products, or aquatic bivalve organisms in open cycle service water systems had been received. These events led to plant shutdowns, reduced power operation for repairs and modifications and degraded modes of operation. This situation forced the NRC to establish Generic Issue 51, "Improving the Reliability of Open-cycle Service Water Systems." To resolve this issue, the NRC initiated a research program to compare alternative surveillance and control programs to minimize the effects of fouling and increase plant safety.

On November 2nd 1988, Canada's Bruce 6 lost service water due to frazil ice. Service water warmup recirculation was not available due to delayed maintenance.

In December 1988, Haddam Neck found that service water flow to the containment air coolers was unacceptably low due the uniform buildup of silt and corrosion products the tubes of the coolers.

On March 21st, 1990 Peach Bottom Units 2 & 3 found that service water system performance had been degraded due to silt and corrosion product accumulation in the emergency service water piping.

On March 23rd, 1990 River Bend identified that degraded service water system performance was in part caused by microbiologically induced corrosion.

On April 11th, 1990 the Fitzpatrick power plant was in a refueling outage. The licensee reported that silt had been found in check valves in emergency service water lines to the seal coolers for two pumps in the residual heat removal system. The licensee concluded that the silt could have prevented the residual heat removal system from fulfilling its safety function.

On October 4th, 1990 Millstone Unit 1 manually tripped the reactor from 45 percent of full power because of circulating water system and service water system fouling that resulted in degraded SWS cooling, which resulted in increased containment temperature and pressure. Storm-induced high winds and seas caused an excessive amount of seaweed to accumulate on the traveling screens of the circulating water system.

On October 19th, 1990 FitzPatrick manually tripped the reactor from 45 percent of full power because the fouling rate for the circulating water traveling screens exceeded the cleaning rate of the screen wash system. A shift in wind direction contributed to an unusually large debris accumulation on the screens. Shear pins on the two operating screens failed. As the screens bowed inward because of the high differential pressure, some of the debris floated around the screens. In this event, while performing maintenance on one of the traveling screens, personnel unintentionally disabled the screen differential pressure alarm system, which would have provided early indication of fouling.

On October 19th, 1990 FitzPatrick shutdown when high winds brought debris to the travelling screens. The unusually large accumulation of debris failed two travelling screens. Then debris floated past the damaged screens.

On April 16th, 1991 Arkansas Nuclear One, Unit 2 declared both loops of the safety-related service water system inoperable with the reactor in startup conditions. Debris from the lake, the normal supply of cooling water, had bypassed the screens at the pump suctions and clogged the pump discharge strainers of both operating loops. The Licensee started an unaffected standby service water system pump. The strainers became fouled because the travelling screens were allowed to rotate without wash water flow.

On August 23rd, 1991 Haddam Neck declared service water pumps inoperable due to accumulated river silt. The silt accumulation was due to excessive suspended debris and silt from agitation when Hurricane Bob was in the area. One service water train was restored to service in less than one hour, narrowly avoiding a shutdown as required by technical specification 3.0.3.

On April 16th, 1992 Arkansas Nuclear One Unit 2 sustained service water suction blocked with debris. The unit was in startup. A standby service water train was put in service. When the obstructed trains were restored the startup continued.

On February 1993 at the James A. FitzPatrick had to shutdown when intake ice blockage dropped the intake water level to ten feet below normal water level.

On February 12th, 1994 Haddam Neck identified a through wall leak in the service water system supply piping. After removing the leaking section and examining the pipe, the licensee determined that the leak was caused by poor initial weld quality and microbiologically influenced corrosion. Lack of penetration of some welds created a crevice condition.

May 6th, 1994 Beaver Valley Unit 1 found a through-wall leak on one train of the reactor plant river water system headers to the emergency diesel generators. The licensee determined microbiologically influenced corrosion to be the cause of the pitting and through-wall leak.

On January 8th, 1996 Millstone Unit 2 had an ice plug in a service water strainer backwash drain line. The condition was attributed to a modification made without a formal engineering review. Backwash of the strainers was not restored until the ice plug was removed. Infrequent backwash during a prolonged period of freezing weather allowed the ice plug to form.

On January 30th, 1996 the Wolf Creek circulating water travelling screens became blocked with frazil ice. The travelling screens in two intake bays were frozen and the associated bay water levels were lowered to about eight feet below normal. Emergency service water was started but misaligned and the standby circulating water train was placed in service. However the freezing conditions prevailed and the reactor was tripped when intake bay levels were 12 feet below the normal height. Subsequently it was determined that the trash racks were completely frozen over. The blockage was removed by sparging with air.

On February 5th and 6th 1996, Fermi had operational difficulty with diesel generator testing. The cause was ice blockage on the intake of diesel generator service water pumps. The reservoir used to supply the service water intake was below freezing. However, some of the suction piping was above the water level. The water in the exposed pipe sections froze due to the low ambient temperature.

On January 23rd, 1997 FitzPatrick's circulating water intake became blocked by Alewives fish. Attempts were made to clean the travelling screens which had shear pin failures from the enormous collection. Power was lowered and later the unit was tripped when it was evidenced that the system restoration would take hours. Pipes, pumps, filters, strainers and valves were literally completely filled with dead fish. Alewives form large schools that flood shorelines during mating season. In this instance, an Alewives school had the misfortune to flood the FitzPatrick intake.

March 29th, 2003 Salem Unit 2 was shutdown due to circulating water intake blockage. The blockage debris consisted primarily of river grass and garbage.

On April 24th, 2003 DC Cook Units 1 & 2 service water intake was rapidly blocked by an enormous influx of Alewives fish. The fish filled piping and components. Both units were manually tripped. The weights of accumulation lead to travelling screen failures. The backwash system, strainers and one heat exchanger were damaged. Emergency diesel generators and the component cooling heat exchangers had no cooling.

On January 15th, 2004 Kewaunee found significant accumulations of silt and biological blockage from lake weed in lube oil coolers cooled by service water. 17 of the 20 tubes of a safety injection pump lube oil cooler were blocked and allowed no through flow. The licensee and the NRC believe that the small tube diameter and tube sheet design contributed to the lake weed fouling on the tube side of the lubrication oil coolers. Operating experience at Kewaunee and other operating plants show that fouling with lake weed is a concern with heat exchangers that have an inner diameter of less than ½ inch. Similar events have occurred at Point Beach, Ginna and Brunswick.

On December 2nd, 2004 Salem/Hope Creek prepared for a crude oil leak from a ship (Athos I) on the Delaware river. To mitigate the potential for oil intrusion into the cooling water systems, the licensee placed booms around the intake structures at both stations. The booms are effective at controlling oil that is at or near the surface; however, the effectiveness of the booms was lessened because the spilled oil was "heavy" crude and was suspended at varying depths in the river. On December 3, 2004, the licensee commenced shutdown of both Salem units due to the conditions on the river. There were no issues associated with the shutdowns. Hope Creek was already shut down for a refueling outage. The licensee restarted both Salem units after review of heat exchanger performance and monitoring of the oil spill.

On November 20th, 2004 Cooper's service water system was clogged with sediment, resulting in an unexpected pressure drop in both loops of service water, high differential pressure alarms on both strainers, and isolation of the nonessential service water loads. Both trains exceeded the differential pressure operability limit of 15 psid. Backwash automatically initiated and successfully cleaned the Loop A strainer, but the analogous action for Loop B did not succeed in cleaning the strainer. Operators opened the strainer bypass valve to restore service water flow and subsequently cleaned both strainers.

On November 22, 2004, Watts Bar identified that a centrifugal charging pump backup cooling line from the essential raw cooling water system was completely blocked with silt. Approximately 2.5 gallons of muddy paste passed through the 1-inch drain valve before the valve became blocked. The licensee generated 13 problem evaluation reports from early 2002 through late 2005 for blockages identified in raw cooling water lines. The licensee identified silt accumulation in portions of systems providing raw cooling water for both essential and nonessential purposes and for high pressure water for fire protection. These accumulations were identified in both stagnant and active cooling water lines, typically in system low points and in piping with low water velocity. In 1999 and 2002, clam accumulations resulted from missed biocide treatments. The licensee implemented periodic ultrasonic testing and flushing to identify and minimize blockages due to silt and clam accumulations.

On January 28th 2005 Russia's Volgondonsk Unit 1 suffered intensive frazil ice formation in their service water intake due to a sudden temperature drop and heavy snow. The debris screens at the intake rapidly froze. Intake bay level lowered and circulating and service water flows lowered. The main turbine tripped on high condenser vacuum as power was stabilized at about 5% power.

On October 20th, 2005 Cooper service water strainers had filled with silt, small rocks and debris. In 2005, the NRC Region IV office organized a special inspection based on the repetitive nature of this type of event at Cooper. In both the 2004 and 2005 events, service water flow was lost to the nonessential header was lost and greatly reduced flow to the essential headers. In each case, the successful Loop A automatic backwash precluded the need for a manual scram, which would have been required if the loss of turbine equipment cooling water had been prolonged. In each event, the Loop B filtering function was overwhelmed by the inrush of sediment. The Loop B automatic backwash function failed due to the lack of downstream pressure, which provides the motive force for the backwashing operation. The licensee believes that the contributing external factor was the low level of the Missouri River, the source of the service water system. Both of these events occurred during autumn, following the navigation season. A weir wall is installed in the river in front of the intake structure. The low river level caused an increased portion of the water that flows into the intake structure to go around (rather than over) the weir wall and jet into the service water bay. This circuitous flow entrained more sand due to the high flow and deposited it in the intake structure near the service water pump intakes in the low-flow areas.

On April 24th, 2007 Salem Unit 1 was tripped due to the reduction in circulating water flow from the accumulation of heavy river debris blocking the intake.

On September 12, 2007, Fitzpatrick's intake structure was overwhelmed by accumulating algae. Power was reduced and subsequently manually tripped. The travelling screens were overwhelmed

On October 13, 2007, FitzPatrick began to experience indications of debris accumulation on the intake traveling water screens. The debris was determined to be green fibrous algae called cladophora. Within a short period of time, the debris loading on the screens became high enough to fail the shear pins on the three circulating water system traveling screens. The licensee performed a rapid down power to approximately 35% power and secured two circulating water pumps. At that point, intake level was stable at 242 feet, two feet above the manual scram criteria and five feet above the emergency action level entry point. With no way of recovering the traveling water screens, the licensee made the decision to proceed to cold shutdown, secure all circulating water pumps, and use divers to clear the screens. The plant entered Mode 3 on the morning of October 14. As of October 15, two of the three traveling screens had been cleared of debris. The third screen sustained damage as a result of the heavy debris loading, and repairs were in progress.

On October 28th, 2007 FitzPatrick endured another algae blockage. Power was reduced and then the unit was tripped.

On January 25th, 2008 Finland's Olkiluoto Unit 2's warm water return system failed as the sea temperature was rapidly lowering. The seawater temperature dropped to nearly 31^{o}F. Without the warm water return, frazil ice formed degrading service water cooling. The reactor was manually scrammed.

On March 2nd, 2009 France's Blayais four unit's intake from the Gironde River was blocked with decomposing leaves and sediment. The blockage arose from river flooding and heavy rains which provided substantial re-suspension of debris. Unlike previous years the Gironde river had not been dredged, making sediment easier to transport. The units were tripped.

On November 24th, 2009 Argentina's Embalse plant's service water intake was blocked by debris from wildfires and mudslides produced by excessively heavy rain. Some of the service water cleaning gear was placed in manual vice automatic control. The condition did not enunciate in the control room. When the condition was revealed to the operators they entered the wrong procedure which depended on automatic features. The plant ran back to 2% power and the main turbine tripped.

On December 1st, 2009 France's Cruas Units 3 & 4 experienced service water intake blockage from a previously undetected invasive vegetation known as Canadian pondweed. Of the four plants located on the Rhone River, only Units 3 & 4 were affected. Unit 4 was shutdown and Unit 3 was operated at reduced power.

On January 5th, 2010 France's Chooz nuclear station developed frazil ice on the intake from the Meuse River. The intake blockage was identified and the ice was removed before the intake water level dropped low enough to jeopardize reactor safety.

In March and May 2010 the analogous service water intakes of the United Kingdom's two unit Torness plant became blocked with seaweed. Despite previous experience with seaweed, measures to allow early detection of blockage were not in place. Both plants were manually tripped.

On June 28th, 2011 the United Kingdom's Torness site sustained jellyfish obstructing the cooling water intake. Both Torness units were shutdown. Large groups of jellyfish, referred to as blooms, also blocked nuclear plant intake structures in Israel, Scotland and Japan in 2008.

On August 21st, 2011 the service water intake at St. Lucie Units 1 & 2 was inundated with moon jellyfish. The jellyfish event continued for four days and both St. Lucie units were shutdown for two days. When the jellyfish entered the intake structure, many were stripped of their poisonous tentacles. The accumulated tentacles killed between 50 and 75 goliath groupers. The 200 pond groupers are a protected species. Since 1984, the station has been forced to shut down or reduce power on more than 15 occasions because of jellyfish.

On September 2nd, 2011 Salem Units 1 & 2 reduced power due to partial service water intake blockage. Vegetative matter and large wood pieces were flooded into the Delaware River following Hurricane Irene.

On September 14th, 2011 Salem Unit 1's service water intake was partially blocked with debris following Hurricane Irene and Tropical Storm Lee. Flooding tributary rivers carried debris into the Delaware River. Salem Unit 1 draws suction from a marshy area. Salem Unit 2 was not appreciably affected because it uses another suction point.

4.8.3 Mitigation Strategies

The single most effective strategy for protecting service water intake is frequent observation. When obstructions are found early in their accumulation, they can be removed well before they requiring power reductions or plant shutdowns. Control of biofouling should include frequent testing. Where a lowering flow trend is identified, the affected pipe or component should be inspected. Frequent testing helps to control the flow blockages before they severely affect system operability.

4.8.3.1 Clams, Oysters and Mussels

The level of fouling at nuclear plants has been reduced to acceptable levels by using continuous chlorination during peak spawning periods, clam traps and mechanical cleaning during station outages. The results of a series of tests on mollusks performed at the Savannah River facility showed that mature clams had as much as a 10 percent survival rate after being exposed to high concentrations of free residual chlorine (10 to 40 ppm) for up to 54 hours. When the clams were allowed to remain buried in a couple of inches of mud, their survival rates were as high as 65 percent. Shelled clam larvae are very susceptible to prolonged exposure at lower concentrations of chlorine. Asiatic clams of any age have 99% mortality when exposed to high temperature (117^{o}F) water for in excess of two minutes.

Effective control of oysters in water systems has been provided by frequent and extensive observation followed by mechanical removal. Prevention methods include using continuous chlorination or other biocide. Redundant and infrequently used cooling loops should be flushed and flow tested periodically at the maximum design flow to ensure that they are not fouled or clogged.

4.8.3.2 Silt, Sand, Mud and Debris

To reduce silt and debris ingress into service water systems, some travelling screens have been replaced with screens that have much smaller holes. Sonar can be used to determine the accumulation level of silt and debris into the intake bays. Prompt investigation of degraded flow can quickly identify any blockage trend and provides the opportunity to correct problems before they imperil system operation. Warning signs for accumulations include hurricanes, major storms, excessive rain accumulation, rapid changes in ultimate heat sink water levels, mudslides and agitation by water craft.

4.8.3.3 Algae, Seaweed, Lake Weed and Pondweed

These plant forms can rapidly and unexpectedly arrive at service water intakes. Since this type of intrusion may be unexpected it is important to monitor service water system differential pressures and flow rates. Quick detection of intrusion and well managed procedures to mitigate their effect provides the best mitigation strategy.

4.8.3.4 Plant Matter Such As Leaves, Branches and Tree Wood

As with algae & weeds these obstructions can arrive with little warning; however, they do take a longer accumulation time. Visual observation on operator rounds may provide sufficient warning to take prompt action before the effects cause a complete loss of service water. Monitoring service water system differential pressures and flow rates also may provide early detection. Quick detection of intrusion and well managed procedures to mitigate their effect provides the best mitigation strategy.

4.8.3.5 Frazil Ice and Ice Plugs

Cold weather warrants anticipation of ice blocking in service water systems. Anticipation and preparation can greatly mitigate a loss of service water flow. Using discharge water recirculation can heat incoming service water enough to prevent freezing. Unlike as demonstrated in operating experience, the recirculation path should be available under cold weather conditions.

4.8.3.6 Jellyfish and Gill Bearing Fish

Like weeds and algae, jellyfish and gill bearing fish can rapidly and unexpectedly arrive at service water intakes. Since this type of intrusion may be unexpected it is important to monitor service water system differential pressures and flow rates. Quick detection of intrusion and well managed procedures to mitigate their effect provides the best mitigation strategy.

4.8.4 Regulatory Issues

Nuclear power plant facilities of licensees and applicants must meet the minimum requirements of the General Design Criteria (GDC) in 10 CFR Part 50, Appendix A. In particular, "GDC 44--Cooling Water" requires provision of a system (here called the service water system) "to transfer heat from structures, systems, and components important to safety to an ultimate heat sink" (UHS). "GDC 45--Inspection of Cooling Water System" requires the system design "to permit appropriate periodic inspection of important components, such as heat exchangers and piping, to assure the integrity and capability of the system." "GDC 46--Testing of Cooling Water System" requires the design "to permit appropriate periodic pressure and functional testing."

The Office for Analysis and Evaluation of Operational Data (AEOD) initiated a systematic and comprehensive review and evaluation of service water system failures and degradation at light water reactors from 1980 to early 1987. The results of that AEOD case study was published in "Operating Experience Feedback Report - Service Water System Failures and Degradations," NUREG-1275, Volume 3.

Of 980 operational events involving the service water system reported during this period, 276 were deemed to have potential generic safety significance. Of the 276 events with safety significance 58 percent involved system fouling. The fouling mechanisms included corrosion and erosion (27%), biofouling (10%), foreign material and debris intrusion (10%), sediment deposition (9%), and pipe coating failure and calcium carbonate deposition (1%).

Following the evaluation of service water events, several NRC requirements (Refer to Appendix A) were originated requiring licensees to:

- conduct, on a regular basis, performance testing of all heat exchangers, which are cooled by the service water system and are needed to perform a safety function. The testing performed should verify heat exchanger heat transfer capability,
- verify that their service water systems are not vulnerable to a single failure of an active component,
- inspect, on a regular basis, important portions of the service water piping for corrosion, erosion, and biofouling, and
- reduce human errors in the operation, repair, and maintenance of the service water system.

4.8.5 Summary

Service water blockage has been caused by:

- frazil ice and ice plugs,
- bivalve mollusks such as clams, oysters and mussels,
- silt, sand, mud, small rocks and corrosion products (including microbiologically induced corrosion),
- algae, seaweed, lakeweed and Canadian pondweed,

- plant matter such as leaves, branches and tree wood,
- jellyfish and gill bearing fish, and
- garbage

Some of the events described here involve instances in which sediment and / or debris has blocked flow in one or more service water lines. A number of the events described involved the failure to take adequate and timely corrective actions that could have prevented the event from occurring. Often there were multiple previous occurrences that could have alerted licensees to take more aggressive or broader corrective actions. To prevent or mitigate the effects of a loss of service water cooling, Licensees must have programs that provide vigilance to detect the beginnings of an intake blockage event. Frequent inspections of the service water system can find intrusion before it becomes severe. In events of an unexpected nature, plant actions should be directed by procedures that quickly ensure reactor safety. The importance of the service water system has been greatly underestimated at some facilities, leading to a poor response to a service water system failure. Loss of the service water system can impair reactor safety through:

- Loss of the main condenser for cooling and pressure control.
- Loss of the residual heat removal pump heat exchangers.
- Potential high area temperature effects on HPCI, LPCI and Core Spray.
- Loss of cooling to emergency diesel generators.

The worst case consequences following a prolonged complete loss of service water cooling include:

- Pressure control using safety relief valves, adding heat to the primary containment.
- Loss of emergency power to emergency core cooling systems which will require further addition of heat to the primary containment from steam driven cooling systems.
- Exceeding temperature limits for the primary containment.

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