EVALUATION OF SPRAY POND
WELD CORROSION AT PVNGS

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1.0 INTRODUCTION

During a spray pond drain down in Unit 2, it was noted that water was dripping from a header weld. Based on the above observation, Unit 2 north and south ponds and Unit 1 south pond spray piping were visually inspected to determine the extent of any corrosion and leakage at the welds. Some radiography inspection was also done to help determine the cause of the leaking, and extent of any internal problem.

This report covers the inspections undertaken, the outcome of the inspections, the results of microbiological and metallographic sample analyses to determine the root cause of the problem, and testing performed to determine an ability to detect and quantify spray pond header bypass flow (leakage).

Conclusions are based on the findings from the inspections, samples analyzed, and testing. In addition, a discussion of the capability of the essential spray ponds to meet their intended safety function is presented.

2.0 CAUSE

Microbiologically Influenced Corrosion (MIC) is the probable cause of the pitting in the spray ponds. Positive identification of Gallionella, an iron bacteria, was made. This bacteria is known to cause attack on stainless steel, particularly at the weld.

These conclusions are based on:

- The positive identification of Gallionella.
- The concentric rings of corrosion product on the inside diameter of the pipe, typical of MIC.
- The selective nature of the attack. MIC preferentially attacks at or near welds along dendritic paths of the weld metal.
- The probability that untreated water remained stagnant for significant time periods in these pipes after initial flushing operations.

The pits found to date are located primarily in circumferential welds and in the bottom third. Only a small number have been identified in the base metal.

Literature and observations show that the cross sectional areas of pits are very irregular. This irregular shape and other factors make it difficult to predict the rate of growth and the final shape of the pits. The pits are expected to continue to grow because of the low pH chemistry within the pit. When pits do occur, the entrance and exit holes are almost never as large as the internal cavity observed on radiographic film. If through-wall pitting occurs, the pit will be flushed with water. This flushing action will increase the pH within the pit area and cease further growth. Because of the low pressure drop across the through wall pit, enlargement of the hole by erosion is not expected.

The spray pond piping is 316L stainless steel and the weld filler metal is 308L stainless. The 308L stainless steel weld metal was chosen for its reduced tendency to form cracks during the welding process. Although the pipe material and weld metal conform to project specifications, the 308L is less resistant to corrosion and is the area in which the pitting is found.

3.0 INSPECTION, ANALYSIS, AND TESTS

3.1 VISUAL INSPECTION

Visual inspections of the welds of Unit 1 south pond and Unit 2 north and south ponds revealed the following:

	Unit 1 So. Pond	Unit 2 No. Pond	Unit 2 So. Pond
Total Welds	316	353	272
Welds Inspected	299	353 (1)	272 (1)
Inaccessible Welds	17 (2)	2	5
Welds with Defects (3)	10	81	18
Welds with Leaks	2	42	4
Total Leaks Found	3	55	4
Welds w/Suspect Areas (4)	8	39	14

(1) Partial inspection only of the Unit 2 inaccessible welds.
(2) Inaccessible welds at pipe supports and on 4" risers above a man's height (no ladders used) were not inspected.
(3) Defects found during inspection are visual observations only.
(4) Suspect areas include inspection findings such as small pits, surface rust and non leaking holes. In some cases there were multiple defects noted on welds, but are reported only as welds with leaks or welds with suspect areas.

3.2 RADIOGRAPHIC INSPECTION

Unit 2 North and South Ponds

Twenty welds from the north and south ponds were radiographed, ten with external indications of pitting and ten with no visual indications. Radiographs of 18 of the 20 welds showed indications of pitting.

Unit 1 South Pond

Based on a statistical analysis of 625 welds in the Unit 2 spray ponds, it was determined that a total of 55 welds in one of the Unit 1 spray ponds should be radiographed to provide a 95-percent confidence level and that there will be no additional finding worse than that found in the 55 welds. A total of 57 welds were radiographed to provide additional assurance with the following results:

- 10 welds showed no indications
- 47 welds had 1142 indications

The results of the testing performed in the Unit 1 Spray Pond indicated that no further radiography was required.

3.3 SAMPLES FOR MICROBIOLOGICAL AND METALLOGRAPHIC ANALYSES

Two sections of 14-inch diameter pipe welds from the Unit 2 south pond were cut and submitted for evaluation. One was a field weld and the other was a vendor weld.

3.4 ANALYSES RESULTS

The cut sections were subjected to the following examinations and tests:

- Visual Examination
- Microbiological Examination
- Metallographic Examination
- Chemical Analysis

3.4.1 VISUAL EXAMINATION

A visual examination was performed on the as-received cut samples. To preserve the metallurgy of the surface, no cleaning was performed. The examination showed the inside surfaces of both samples discolored with a rusty corrosion product. A pattern of concentric rings was observed, which is a typical indication of MIC.

3.4.2 MICROBIOLOGICAL EXAMINATION

The sections were submitted to an outside laboratory for microbiological analysis. Scrapings were removed from the pipe sections by the microbiologist. Microscopic examination indicated the presence of Gallionella, an iron bacteria, in both pieces.

3.4.3 METALLOGRAPHIC EXAMINATION

The radiographs were used as a guide for cutting transverse to the weld and near a pit. The cut revealed a subsurface cavity. The pitting is primarily in the weld. A cross section showed approximately 60 percent through-wall penetration.

The vendor weld was sectioned twice, transverse to the weld. One cut was at a small inside diameter surface imperfection that was thought to be a likely place for a pit to initiate. It is very shallow, approximately 6 percent of the wall thickness. The interdendritic attack to the weld is indicative of MIC. The selective nature of the attack along dendritic paths is clearly evident. This selective attack, is typical of MIC pitting in stainless steel.

3.4.4 CHEMICAL ANALYSIS

The materials in the spray ponds were specified as follows:

Base metal, pipe, ASME SA-312, Type 316L
Weld filler metal, Type 308L

Chemical analysis verified that the materials met chemical requirements conforming to 316L stainless steel pipe and 308L weld filler metal.

3.5 TESTING

Testing was performed to quantify spray pond piping systems pressure drop relative to a known increase in header bypass flow area (such as through wall pitting). A pressure gauge was installed in the main header just before it enters the spray pond; the system was placed in service and pressure measurements were taken. Six spray nozzles were then removed, one at a time, and pressure measurements were taken as each nozzle was removed. This established a quantifiable relationship between system pressure drop and an increase in bypass flow area (i.e. 1.933 in^2/nozzle). To confirm the results of the test, 0.1 psig pressure drop/nozzles, pressure measurements were taken a second time as the nozzles were reinstalled. The number of nozzles removed was selected to approximate a cross sectional bypass flow area of 11.5 in^2 which is equivalent to a bypass flow of approximately 800gpm (refer to Section 4.2). The location of the removed nozzles was selected to obtain a mix of long, short, and medium pipe runs, in 14", 8", and 6" flow distribution headers.

The test results demonstrate a linear profile between system pressure drop and a increase in bypass flow area. The testing successfully established that system pressure drop can be used to detect and quantify an increase in through-wall pitting (i.e. increased by-pass flow area).

4.0 SAFETY ANALYSIS

4.1 STRUCTURAL ANALYSIS OF PIPING SYSTEM

The structural adequacy of the piping submerged in the essential spray pond was evaluated for two conditions of decreased weld material. The first condition assumed a relatively uniform loss of weld material around the total circumference of the pipe welds. Results of this evaluation show that a continuous circumferential weld loss equal to approximately 40 percent of the nominal pipe wall thickness could still accommodate existing loads and satisfy code requirements. The second condition assumed that corrosion would result in localized through-wall leaks and the remaining intermittent weld is of a thickness equal to the minimum fabricated pipe wall thickness (87.5 percent of the nominal pipe wall thickness). Results of this evaluation show that, for the most critical load condition, an intermittent loss of 30 percent of the total circumferential weld is acceptable. For most other locations, as much as 50 percent of the weld could be lost intermittently around the circumference and structural integrity would be maintained. All pitting shown on radiographs was reviewed and using the worse case of a 14 inch diameter pipe with 108 pits, and assuming 1/8 holes the structural integrity of the system would be maintained.

4.2 AMOUNT OF SPRAY NOZZLE BYPASS THAT CAN BE TOLERATED FOR PROPER SYSTEM PERFORMANCE

Leakage of circulating essential spray pond (ESP) water from the spray headers will reduce the flow through the spray nozzles and the spray pond heat rejection rate. The effect of reduced spray pond heat transfer will be to increase the pond temperature and increase the essential cooling water system circulating water temperature. Design criteria limits the temperature of essential cooling (EC) water exiting the essential cooling water system (ECWS) heat exchanger to 125°F to assure all safety systems served by the ECW systems are adequately cooled to satisfy design requirements. The limiting condition for evaluating the spray pond/ECW system performance is with a LOCA accompanied by a loss of off-site power, failure of one diesel generator and the historical worst case meterology providing high wet bulb temperature/low wind speed conditions. A review of the spray pond performance analysis under this condition shows the ECWS cooling water temperature will reach a maximum value of 122.4°F approximately 11 hours into the accident.

The impact of a 5% (800 gal/min) reduction in ESP spray flow rate on ECWS water temperature has been estimated from prior computerized performance analyses. This was done by assuming spray pond heat transfer is directly proportional to spray flow rate and that the heat load into the pond remains unchanged from the no leak case. The pond temperature will increase, resulting in a peak calculated ECWS temperature of 124.6°F. This peak value is still below the limit of 125°F. This thermal performance analysis is conservative for the following reasons:

1. Both spray trains will normally operate for the first day post LOCA with resultant lower peak pond and ECWS temperatures.

2. The calculated pond temperature increase due to reduced spray flow does not take credit for the increased spray heat transfer rate that will occur with spraying warmer water. The increase in heat transfer due to the greater spray water-to-air temperature differential will partially mitigate the increases in pond and EWCS temperatures.

3. Meteorological conditions adverse for pond heat transfer are assumed to prevail at the time of the accident.

4. The analysis includes a spent fuel pool heat load on the pond which will not exist during first cycle operation. The absence of this heat load would represent 200 gpm additional flow that can be bypassed during first cycle operation.

Finally, the thermal response of the spray pond and the ECWS water to the design basis accident is a transient situation with peak temperatures developing during the first 24 hours and then dropping as the decay heat load falls off to a level that is less than the pond capacity. Should the ECWS temperature exceed 125°F, it would only occur for a limited time interval and no catastrophic failure of any safety-related equipment would be expected.

The number of through-wall pits to leak 800 gpm and 1000 gpm for various hole diameters are shown in the table below:

Hole Diameter	800 gpm No. of Holes	1000 gpm No. of Holes	By Pass Flow Area At 800 gpm
1/8"	940	1,175	11.5 in^2
1/16"	3,755	4,695	11.5 in^2
1/32"	15,094	18,868	11.5 in^2
1/64"	60,150	75,188	11.5 in^2

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From the 57 welds radiographed in Unit 1 south pond, 1142 indications were noted. Extrapolating the indications for 316 welds in the south pond, the total indications will be 6331. A conservative assumption is that all indications develop into through-wall pits. Based on this assumption, there would be 6331 holes. Most of the through-wall pitting seen in the visual inspection has been the pinhole type (1/32", 1/64" or smaller). Once the through-wall pitting occurs, the resulting hole will be flushed with the spray pond water. This flushing action will increase the pH within the pit area and cease further growth. Therefore, considering the data in the table above, and the expected cessation of hole propagation, it follows that even with all indications leaking there would not be a significant flow reduction through the spray nozzles, and there would not be an increase in water loss from the system. Therefore, the capability of the essential spray ponds to perform their intended safety function is maintained.

5.0 CORRECTIVE ACTION

Stagnation of untreated water following the initial flushing of the spray pond piping is the cause of the pitting. The present, rigorous program for chemistry control, the regular use of biocides, and the avoidance of stagnation by operation of the spray pumps on a routine basis will prevent the initiation of such pitting in the future.

6.0 MONITORING PROGRAM

6.1 PERFORMANCE MONITORING

A performance monitoring program has been developed that calls for measuring pressure at four locations on one selected flow path of the spray pond system. Baseline pressure measurements have already been taken. In addition, pressure measurements will be taken quarterly at these locations and compared to the baseline data. If the spray pond pressure decreases while conditions upstream remain relatively unchanged, then pipe weld degradation (through wall pitting) can be concluded. The amount of bypass flow can be computed from the pressure vs flow data obtained during the testing discussed in Section 3.5.

This performance monitoring program will provide a positive means of ensuring that the spray ponds are capable of performing their intended safety function at all times.

6.2 REEXAMINATION

A second method to monitor pitting is to radiograph a sample of the previously radiographed welds at the first refueling outage. These results will provide excellent data on the growth of existing pits and confirm that new pitting has not occurred.

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7.0 OTHER SAFETY RELATED SYSTEMS

Because of the pitting found in the Units 1 and 2 Essential Spray Pond piping, examinations were performed and previous examinations rechecked for possible pitting in other safety related systems.

7.1 REMAINDER OF SPRAY POND SYSTEM

During the summer of 1984, a 100% visual examination of the balance of the Unit 2 spray pond piping was performed. Spray pond piping outside of the spray pond headers is plascite lined carbon steel pipe. Most of the piping was examined with a remote controlled television camera, and the data was stored on magnetic tape cassettes. The remainder was examined visually by removing spool pieces. No pitting was observed that could be related to bacteria. Since the stainless steel pitting in the Unit 1 spray pond was similar to the pitting found in Unit 2, the same results for the balance of the Unit 1 spray pond system should be expected.

Periodic visual examinations during maintenance of the many heat exchangers and valves have never shown evidence of bacterial related pitting. It should be noted that the type of bacteria that has been found in the spray pond system has a high tendency to cause pitting of stainless steel weld metal, and a much lower tendency to pit other metals.

7.2 AUXILIARY FEEDWATER AND CONDENSATE TRANSFER SYSTEMS

Approximately 2 years ago some minor pitting was observed in the Unit 2 auxiliary feedwater pumps. This pitting was believed to have involved bacteria. Two welds near the pumps were radiographed, and no evidence of pits was noted. The Unit 1 pumps when disassembled did not have this type of pitting. In addition, the suction strainer flanged pipe spools were removed and the piping interior was examined. Approximately 10 welds were visible in each train, and none showed any evidence of pitting or unusual deposits.

7.3 SAFETY INJECTION, CHARGING AND POOL COOLING SYSTEMS.

In the fall of 1983, during a NRC Construction Audit Team inspection, 23 piping welds and 10 socket welds on these systems were radiographed. No evidence of pitting was noted.

On March 28, 1985, a valve was removed from the Unit 1 safety injection system and 2 welds were visually examined. Neither weld showed any evidence of pitting or unusual deposits. In addition, numerous repairs, replacements, modifications, and inspections have been performed on these systems without report of corrosion.

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7.4 REACTOR COOLANT SYSTEM

Many entries into various parts of the reactor coolant system have been done in recent years, and no evidence of pitting or unusual deposits has ever been noted.

7.5 SUMMARY

Because of the above examinations, APS is convinced that the bacteria related pitting in safety related systems is confined to the spray pond stainless steel piping.

SAFETY EVALUATION

Based on the preceeding information the following can be concluded.

Under postulated worse case conditions - through wall pitting at all pit locations - the structural integrity of the piping system will be maintained and the heat rejection capability of the system will meet all design conditions. The essential spray ponds will remain capable of performing their intended safety function under all postulated conditions. In addition, means have been established to prevent further pitting initiation and to monitor bypass flow. Consequently the following determinations can be made:

1. Operation with the predicted through wall pitting of the spray pond piping will not increase the probability of occurrence or the consequences of any accident or malfunction of equipment important to safety previously evaluated in the safety analysis report.

2. This condition does not create the possibility for an accident or malfunction of a different type than any previously evaluated in the safety analysis report.

3. The margin of safety as defined in the basis for any technical specification is not reduced as a result of operating in this condition.

Based on the above conclusions, operation with the predicted through wall pitting of the spray pond piping does not constitute on unreviewed safety question.

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