January 4, 2000

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

Before the Atomic Safety and Licensing Board

In the Matter of	)	
	)	
CAROLINA POWER & LIGHT COMPANY	)	Docket No. 50-400-LA
	)	
(Shearon Harris Nuclear Power Plant)	)	ASLBP No. 99-762-02-LA

EXHIBITS SUPPORTING THE SUMMARY OF FACTS, DATA, AND ARGUMENTS ON WHICH APPLICANT PROPOSES TO RELY AT THE SUBPART K ORAL ARGUMENT

VOLUME 5

EXHIBITS 9 - 10

EXHIBIT 9

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AFFIDAVIT OF GEORGE J. LICINA

I, George J. Licina, being first duly sworn, state as follows:

EXPERIENCE AND QUALIFICATIONS

1. I am a metallurgical engineer and have been at Structural Integrity Associates, Inc. ("Structural Integrity"), since 1986. My business address is 3315 Almaden Expressway, Suite 24, San Jose, California, 95118-1557

2. Structural Integrity is an engineering consulting firm of approximately 70 professionals. It is widely recognized for its expertise in the analysis, control, prevention, and repair of structural failures in industrial components and equipment for a broad range of industries. Its expertise spans all aspects of structural integrity including:

- fracture mechanics
- stress analysis
- corrosion, fatigue and creep analysis

- metallurgy and materials
- nondestructive testing
- structural monitoring and instrumentation
- failure analysis.

Many architect-engineering companies and metallurgical laboratories have expertise in one or another of these areas. Few companies, however, are able to provide the full scope of Structural Integrity's services: from inspection and condition assessment, to monitoring and remaining life analysis, repair or remediation (when necessary), and ultimately, total risk management of critical equipment and structures. Since it was founded in San Jose, California, in 1983, Structural Integrity's business has grown steadily. It now has branch offices in five states across the country, as well as affiliates overseas.

3. I am Structural Integrity's leading expert on corrosion. I have over 25 years' experience in evaluating environmental degradation of materials in power plant and other industrial environments, including all forms of corrosion and stress-corrosion cracking in aqueous environments, irradiation embrittlement, and Microbiologically Influenced Corrosion ("MIC"). I have performed numerous evaluations of (a) problems in the field, (b) monitoring of those problems; and (c) laboratory and field implementations of mitigation measures. I have worked closely with the Electric Power Research Institute in developing programs for combating MIC. I regularly teach two-day workshops for power-plant personnel in cooling-water corrosion and MIC. I have attached to this declaration a copy of my resume (Attachment A) and a list of my publications (Attachment B).

4. I make this affidavit to introduce my Report No. SIR-99-127 (Attachment C), explain the report's background, and summarize its principal conclusions.

OBJECTIVES OF REPORT

5. Carolina Power & Light Company ("CP&L") asked Structural Integrity to evaluate the structural integrity and suitability for service of stainless steel piping in the Spent Fuel Pool Cooling and Cleanup System for spent fuel pools C and D at the Harris Nuclear Plant ("SFP Piping"). I was in charge of that evaluation. I prepared the report attached as Attachment C. It was reviewed by Michael E. Sauby (another metallurgical engineer from our technical staff, with over 24 years experience in materials and process selection, materials evaluation, mechanical testing and non-destructive testing). I then submitted the report to CP&L as an independent, expert opinion on the structural integrity and suitability for service of the SFP Piping.

APPROACH

6. Spent fuel pools C and D have never been used to hold spent fuel, and installation of the SFP Piping has never been completed, nor has the SFP Piping been commissioned. In evaluating the structural integrity of the SFP Piping, I first evaluated its structural integrity as originally installed in the 1980s. In evaluating its present suitability for service, I assessed the worst possible degradation that the SFP Piping could have experienced since it was installed and projected all further degradation that it could potentially experience over its service life. In both respects, my review focused especially on 15 field welds in sections of the SFP Piping that are embedded in the concrete walls and floors of spent fuel pools C and D.

MATERIALS REVIEWED

7. In making this evaluation, I reviewed in detail quality-control records from the time the piping was installed, including Deficiency Disposition Reports ("DDRs") and records of hydrostatic testing of the SFP Piping done at that time, videotapes of CP&L's inspection of the welds in the SFP Piping in 1999, and the analysis of water samples taken from the SFP Piping, also in 1999. (The information I reviewed is listed in Table 1-1 of my report.)

CONCLUSIONS

8. Weld data reports for 15 field welds in the embedded sections of SFP Piping were inadvertently discarded. Nevertheless, as explained in detail in my report, the information available today allows no reasonable doubt that the SFP Piping was properly installed, has suffered no significant degradation since installation that would shorten its expected service life, and can be expected to operate under its expected service conditions for its expected service life without significant degradation.

A. The SFP Piping had good structural integrity as originally installed.

9. The SFP Piping was conservatively designed. The 12", Type 304 stainless steel SFP Piping has a design rating of 150 psi. It has a nominal wall thickness of 0.375". The calculated minimum wall thickness for 150% of the design rating of 150 psi (or 225 psi) is 0.080"; about one-fifth of the actual pipe thickness. Because the spent fuel pools are open to the atmosphere, the maximum in-service pressure inside the SFP Piping will be about 25 psi. The calculated minimum wall thickness for a service pressure of 25 psi is 0.011". Thus, the actual wall thickness is approximately 30 times the required minimum wall thickness for the maximum service pressure of the system.

10. The SFP Piping was constructed under the Harris Nuclear Plant ASME QA program. All procedures and plant construction were subject to frequent internal and external audits. This same QA program was used to successfully complete and license Harris Unit 1. While much of the documentation for the 15 embedded field welds is unavailable, the QA program did require procedures for material controls, material handling and welding procedures and qualifications, completion of weld data reports, specific QC inspections, and Authorized Nuclear Inspector (ANI) third party review. The hydrotest procedures required a QA inspector

confirmation, documented by a specific sign-off, that all weld data reports had been completed. Construction of the subject SFP Piping without those controls would have required a total breakdown of that QA program.

11. Deficiency Disposition Reports (DDRs) are quality assurance records that confirm that welds were carefully inspected during installation of the SFP Piping, specifically including the field welds in the now-embedded piping. DDRs were written for FW-408 (ANI hold point by-passed) and FW-517 (arc strikes found). The surviving hydrotest records document that weld data packages for 13 of the 15 field welds were completed and reviewed prior to the hydrotest. The satisfactory hydrotests confirm the original structural integrity of the SFP Piping and corroborate the inspections of the outside diameter of the field welds during the hydrotests that were done at that time.

12. Visual inspections (using a video camera on a pipe-crawler) in 1999 confirmed the initial structural soundness of the embedded portions of the SFP Piping, specifically including the embedded field welds. Although there are some areas on some welds where the consumable insert was not completely melted and some linear indications that appear at some field welds, those minor imperfections in the welds are not a cause for concern., Further, minor linear indications, such as at the longitudinal seam of FW-515, have been evaluated and shown to have no effect on the structural integrity of the SFP piping.

13. In evaluating the indications in the welds, it is important to keep in mind that the SFP Piping was conservatively designed in the first place. Neither volumetric inspections nor inspection of the internal diameter of the field welds is required by the ASME Code for Class 3 piping. The Code permits the use of a joint efficiency of 80% for welds in Class 3 piping that is not subjected to volumetric inspection. That joint efficiency factor was used to determine required minimum joint thicknesses in my report.FW-516 displayed the largest areas in which the consumable insert was not completely melted. Nevertheless, even in that weld, the areas in

which the insert was not completely consumed were intermittent. Fusion at the edges was complete. Even the "worst" of the embedded welds thus appears acceptable. As noted previously, very little pipe wall thickness is required to withstand operating pressures in the SFP Piping in any event.

14. In short, I conclude that the SFP Piping as originally installed had good structural integrity. It must still have good structural integrity unless it has been substantially degraded since it was installed.

B. The SFP Piping has good structural integrity now.

15. The remote visual inspection in 1999 showed that the SFP Piping and the embedded welds have not been significantly degraded since the SFP Piping was installed.

16. This result was to be expected because the conditions to which the SFP Piping has been subjected are benign. Over time, water from the spent fuel pools has leaked past "plumbers' plugs" into the SFP Piping. This water from the spent fuel pools, however, is high-purity water. There is no raw water in it, no caustic, and no other damaging chemicals. No water can leak into the embedded SFP Piping from any other system at Harris because the SFP Piping is not connected to any other system. The temperature of the water is basically the ambient temperature. There is essentially no flow within the piping, and therefore no possibility of degradation from flow-accelerated corrosion. Allowable sources of water for the hydrostatic test are defined by the hydrostatic testing procedures. The actual source of the water used for the hydrostatic test in the 1980s is unknown. However, the hydrotest water was subsequently drained and the high-purity water that was used for subsequent pool liner testing and any that has since leaked into the SFP Piping would have significantly diluted any raw water that might hypothetically have remained from the hydrostatic test.

17. In view of these benign conditions, the only mechanisms that could potentially have caused degradation of the SFP Piping are intergranular stress corrosion cracking (IGSCC), transgranular stress corrosion cracking (TGSCC), microbiologically influenced corrosion (MIC), and localized corrosion. The probability of any of these degradation mechanisms actually occurring under the conditions in the SFP Piping is extremely low. The high temperatures and aggressive chemical species required to cause IGSCC or TGSCC are simply not present in the environment of the SFP Piping. Nor can aggressive chemical species leak into the SFP Piping from other systems at Harris. The SFP Piping is not connected to any systems where aggressive chemical species might be found. The high-purity water in the spent fuel pool is too innocuous to cause localized corrosion.

18. MIC is theoretically more likely than any other form of corrosion in the SFP Piping. Water samples taken in 1999 did not, however, show the bacteria levels necessary for MIC. Although water samples do not, by themselves, confirm that there is no biofilm on piping surfaces that could promote MIC, water samples plus the visual inspections carried out in the SFP Piping at Harris provide a reliable indicator that MIC has not caused accelerated corrosion or caused leaks in the SFP Piping. MIC typically results in large mounds of organic materials in the piping, but no such large mounds were found in 1999.

19. The remote visual inspection conducted in 1999 revealed no indications of possible MIC or localized corrosion at any weld except for one. That one weld (FW-517) showed three apparent pits and some brownish deposits. CP&L recently removed and analyzed samples of those deposits. I have reviewed the results of that analysis and the remote visual examination carried out after the deposits were removed.

20. Analysis of these samples revealed that the deposits consist almost entirely of iron and oxygen. Minor amounts of chromium and silicon are also present. X-ray diffraction analysis of this deposit plus other deposits from the pipe ID revealed the presence of only hematite

(Fe_2O_3) and lepidocrocite (FeOOH).

21. In the videotapes of FW-517, taken after the corrosion deposits had been removed, the area where there had previously appeared to be two small pits continued to be discolored. There appeared to be one or two features that looked like very small entrance holes. Where the third apparent pit had previously appeared, the corrosion deposit was removed more completely, and it was not possible to make out any pits in the weld metal or base metal.

22. Based on my years of professional experience, including published analysis and confirmatory experiments on stainless steel lines with severe MIC degradation— I conclude that the observed minor pitting and corrosion at FW-517 will in no way jeopardize the structural integrity of the piping. Even severe MIC, with extensive tunneling pits in weld metal, produces only pinhole leaks. Much larger pits than those which might be present in any of the welds examined in the SFP Piping at Harris — and in a more severely stressed stainless steel weld — would have no effect on load carrying capability.

23. The tight cracks produced by IGSCC and TGSCC and the pinhole leaks produced by MIC and localized corrosion — even if they did occur — would have no significant effect on the structural integrity of the piping or the welds, especially where the SFP Piping is embedded in concrete, which both reinforces the piping and serves to impede any leaks that might otherwise occur. There is no evidence of pitting or crevice corrosion in the shallow linear indications in either field weld FW-515 or the longitudinal seam in an adjacent pipe section. The visual examinations of the piping in 1999 and the just-completed analysis of corrosion deposits at weld FW-517 have revealed no defects that would compromise the integrity of the SFP Piping in any way.

24. A significant quantity of exposed SFP piping is attached to the embedded piping, and is subject to the same internal conditions. The exposed piping is at the low point of the system. As such, it would be at least as susceptible to corrosion damage as the embedded piping

as deposition, including microbiological deposits, would be as likely or more likely in the low points. The fact that this exposed piping has been carefully inspected with no evidence of leakage or weeping being found constitutes powerful evidence that no MIC or other localized corrosion mechanisms have been operative in the SFP Piping.

25. During the visual examination of the welds in 1999, some small, broad, and apparently shallow linear indications were noted in embedded field weld FW-515. Those indications were always at the edge of the consumable insert. The longest of these indications is approximately ½" long. These small linear indications do not appear to be either evidence of corrosion or cause for concern here. Similar indications were also apparent in the longitudinal seam of one of the adjacent pipes. The Vendor Data Package for that piping segment (2-SF-144) shows that this longitudinal seam passed radiographic testing, despite the noted indication, when it was inspected in the shop after fabrication. The visual examination of the welds in 1999 showed no pitting or crevice corrosion in the shallow linear indications in either the longitudinal seam or in field weld FW-515

26. I supervised the calculation of the allowable flaw length for an axial flaw in the SFP piping, as set forth in ASME Code, Section XI, Appendix C. Even though the observed linear indications in FW-515 appear shallow, I assumed conservatively that each is a through-wall flaw. For a maximum pressure of 25 psi (hoop stress = 425 psi), a through-wall flaw as long as 102 inches would not threaten the structural integrity of the piping and would be allowable. A 102-inch through-wall flaw is over 200 times greater than the longest of the observed indications near field weld FW-515. Even if each of the observed linear indications were a through-wall flaw, the piping would still be structurally sound for the highest pressure the piping would encounter in service.

27. I conclude that the SFP Piping has not been substantially degraded since it was installed and therefore has good structural integrity now.

C. **The SFP Piping is suitable for service.**

28. The suitability of the SFP Piping for service has been verified by the facts that (a) the SFP Piping passed a hydrostatic test at pressures at least 50% higher than conditions it would experience in service, (b) no leaks of any kind have occurred under extended wet lay up conditions, (c) the overall appearance of the embedded welds is good to excellent, (d) under the expected service conditions, which are very benign, no corrosion at all is likely, and (e) pinhole leaks, even if they occurred, would have no significant effect on the structural integrity of the piping.

29. Continuing to keep the SFP Piping isolated from potential sources of contaminants and continuing to maintain the pure-water environment inside the SFP Piping will be sufficient to control any possible future degradation in the SFP Piping.

I declare under penalty of perjury that the foregoing statements and my statements in the attached report are true and correct.

G. J. Licina

George J. Licina
December 29, 1999

Subscribed and sworn to before me this
29 day of December, 1999

My commission expires Oct. 18, 2002

CALIFORNIA ALL-PURPOSE ACKNOWLEDGMENT

State of California
County of Santa Clara } ss.

On Dec. 29, 1999 (Date), before me, M. Crumb, Notary Public (Name and Title of Officer (e.g., "Jane Doe, Notary Public")), personally appeared George J. Licina (Name(s) of Signer(s)),

☐ personally known to me
☒ proved to me on the basis of satisfactory evidence

to be the person(~~s~~) whose name(~~s~~) is/~~are~~ subscribed to the within instrument and acknowledged to me that he/~~she/they~~ executed the same in his/~~her/their~~ authorized capacity(~~ies~~), and that by his/~~her/their~~ signature(~~s~~) on the instrument the person(~~s~~), or the entity upon behalf of which the person(~~s~~) acted, executed the instrument.

M. CRUMB
Comm. # 1198872
NOTARY PUBLIC - CALIFORNIA
Santa Clara County
My Comm. Expires Oct. 18, 2002

Place Notary Seal Above

WITNESS my hand and official seal.

M Crumb
Signature of Notary Public

OPTIONAL

Though the information below is not required by law, it may prove valuable to persons relying on the document and could prevent fraudulent removal and reattachment of this form to another document.

Description of Attached Document

Title or Type of Document: Affidavit of George J. Licina

Document Date: Dec. 29, 1999 Number of Pages: 10

Signer(s) Other Than Named Above: ______

Capacity(ies) Claimed by Signer

Signer's Name: ______

☒ Individual
☐ Corporate Officer — Title(s): ______
☐ Partner — ☐ Limited ☐ General
☐ Attorney in Fact
☐ Trustee
☐ Guardian or Conservator
☐ Other: ______

Signer Is Representing: ______

RIGHT THUMBPRINT OF SIGNER
Top of thumb here

George Licina
Associate

Education

BS, Metallurgical Engineering, University of Illinois (With High Honors)
Graduate Work, Materials Science, San Jose State University

Professional Associations & Awards

Alpha Sigma Mu - Metallurgy Honorary Society
Tau Beta Pi - Engineering Honorary Society
General Manager's Award - General Electric Company, Advanced Nuclear Systems Technology Operation, 1984
Patent No. 4,166,019 - Electrochemical Oxygen Meter
Patent No. 4,139,421 - Method of Determining Oxygen Content
Patent No. 5,246,560 - Apparatus for Monitoring Biofilm Activity
Patent No. 5,365,521 - Process for Monitoring Biofilm Activity

Professional Experience

1986 - present	Structural Integrity Associates, San Jose, CA Associate
1972 - 1986	General Electric Company, San Jose, CA Senior Engineer

Summary

Mr. Licina's experience at Structural Integrity Associates has dealt primarily with failure analysis and predicting the degradation and environmental compatibility of power plant materials under a variety of operating conditions. These degradation mechanisms include corrosion and environmentally assisted cracking in BWR, PWR, and various raw water environments and embrittlement of pressure vessel steels and high performance alloys. Mr. Licina is a recognized authority on microbiologically influenced corrosion and has authored reference documents on that topic for the Electric Power Research Institute and numerous utilities. Plant-specific activities have included metallurgical and fracture mechanics evaluations of nuclear steam generators, heat exchangers, valve stem cracking, BWR pipe replacement, electrical transmission lines, wind turbines and irradiation embrittlement of reactor pressure vessels, and the use of electrochemical methods for predicting and monitoring corrosion in power plant environments.

Mr. Licina has integrated technical and regulatory requirements into guidelines for field certification of materials in nuclear plants and developed a methodology and approach for nuclear life extension issues.

He has authored more than fifty publications in these technology areas and is the author of two patents involving the determination of oxygen levels in liquid sodium systems and two patents for an on-line method for monitoring biofilm activity in cooling water environments.

At the General Electric Company, Mr. Licina served as lead engineer and program manager on a number of important development programs, including Control Rod Blade Surveillance and Lifetime Evaluation in BWRs, Stress Corrosion Cracking of Cr-Mo Steels, and Carbon Transport Effects on Steels in Liquid Sodium Systems.

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Evaluation of Embedded Welds in Spent Fuel Piping at Harris Nuclear Plant

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7.0	7-1			
1.0	1-2	1		Incorporates results of additional examinations
4.0	4-1			
5.0	5-1, 5-3, 5-4, 5-8 – 5-11			
6.0	6-2			
1.0	1-2	2		Minor clarification, addition of allowable flaw size calculation
2.0	2-1, 2-2			
4.0	4-1			
5.0	5-3, 5-4			
6.0	6-2			

Table of Contents

List of Tables

Table

Page

List of Figures

1.0 INTRODUCTION

Carolina Power & Light Company (CP&L) requested Structural Integrity Associates, Inc. (SI) to evaluate the structural integrity and suitability for service of the embedded stainless steel piping, including 15 field welds, in the Spent Fuel Pool Cooling and Cleanup System for Harris Nuclear Plant (HNP) spent fuel pools C and D. The Spent Fuel Pool Piping (SFP Piping) was constructed in the early 1980s, but was never installed and has not been operational. CP&L is now commissioning C and D SFP Piping in support of activating the C and D spent fuel pools.

This report provides a review of all of the materials transmitted to SI (Table 1-1) to provide an independent, expert opinion regarding the quality of construction and suitability for purpose of the SFP Piping. This review was primarily focused on the 15 embedded field welds, described on CP&L isometric drawings 2-SF-149, -144, -143, -151, -159, -1, and –8, but also considered the overall condition of the balance of the piping.

The quality of construction assessment was focused on the as-installed structural integrity of the SFP Piping, as described by the quality records provided for this review and from the videotapes of the remote visual inspections performed during 1999. The suitability for service included an assessment of the structural integrity of the SFP Piping in its present condition, including any potential degradation that the SFP Piping has experienced since initial installation, and projections of any further degradation that stainless steel piping in that condition would possibly experience for the duration of the SFP Piping's service life.

Table 1-1

Materials Provided by CP&L

1. Vendor Data Packages for the following segments:

2-SF-149	2-SF-151	2-SF-30
2-SF-144	2-SF-1	2-SF-34
2-SF-143	2-SF-8	2-SF-159

2. Requested sections of the RAI submittal labeled "Enclosure 6 to Serial HNP-99-069" (includes CP&L weld procedures and PQRs, and DDRs).

3. Videotapes:
"Weld Hydrolasing"
"1999 CTS Power Services 1st Visit, 6/99 – Non Clear "C" Pipe"
"Weld Cleaning 2-SF-8-FW-65 & 66"
"Visual Inspections of Welds: WR/JO 99, ADUP1, 2-SF-149-FW-408, 2-SF-144-FW-515, 2-SF-144-FW-516, July 7, 1999"
"6-24-99, 99-ADUNZ WR/JO, Weld 2-SF-8-FW-66 I.D "
"Visual Inspection of Weld: 2-SF-143-FW-512, July 8, 1999"
"Visual Inspection of Weld: 2-SF-8-FW-66, 2-SF-8-FW-65, CTS Power Services"
"CP&L Tape 1" (2-SF-143-FW-513, FW-514; 2-SF-144-FW-517)
"CP&L Tape 2" (2-SF-1-FW-5, FW-4, FW-1, FW-2; 2-SF-159-FW-518, FW-519)
"SFP "D" Reinspection 2-SF-144-FW517"

4. Hydrostatic Test Records for the following segments:

2-SF-143	2-SF-159	
2-SF-149	2-SF-34	2-SF-1
2-SF-151	2-SF-144	2-SF-30

5. "Harris Nuclear Plant – Bacteria Detection in Water from the C and D Spent Fuel Pool Cooling Lines", Metallurgy Services Technical Report 99-90.

6. Isometric Drawings:

2-SF-149	2-SF-159	2-SF-1
2-SF-144	2-SF-151	2-SF-30
2-SF-143	2-SF-8	2-SF-34

7. Chemistry Sample Data Sheets –Spent Fuel Pool Drains (7), 4-27-99

2.0 BACKGROUND

Initial communications with CP&L indicated that the SFP Piping in question is embedded in concrete and is therefore not accessible for external examination or radiographic examination. However, the majority of the piping in the Spent Fuel Pool Cooling and Cleanup System is exposed and is accessible. Per CP&L, all of the stainless steel piping, embedded or exposed, was installed under the CP&L ASME N Certificate construction program which existed at the time of construction, and was spared in place when construction of HNP Units 2 & 3 was canceled.

The stainless steel SFP Piping consists of 150 psi class piping spools, 12" or 16" STD (0.375" wall), welded Type 304 stainless steel pipe, with both seamless and welded fittings, prefabricated by an authorized supplier. Vendor data records (Table 1-1, Item 1) for those spools were reviewed. Those records show that the longitudinal seam welds for the pipe itself were made by the gas tungsten arc welding (GTAW) and submerged arc welding (SAW) processes, and were radiographed and examined by liquid penetrant techniques. Pipe spool welds done by the fabricator were examined visually and by liquid penetrant testing (PT). These spools were joined by field welds made by CP&L or its contractors or assembled by flanged connections. Consistent with the piping's Code of Construction (designed to Section III, Class 3, 1971-73; constructed to 1974-76), volumetric inspection was not required for the field welds. All of the embedded field welds are in 12" lines.

Some of the records associated with the installation and field welding of the piping were discarded, including the weld data reports for the embedded field welds. All of the SFP Piping received a hydrostatic test. The hydrostatic test procedure included a review of all weld data records and a sign-off that those records were complete. The hydrostatic test procedure also required that all welded joints be visible for inspection, that the piping be pressurized to a minimum of 1.25 times the system design pressure, held at that pressure for a minimum of ten minutes, and that the piping be examined for leakage over 360° at all joints and at all regions of stress while the piping was at pressure. The examination was also witnessed by the independent authorized nuclear inspector (ANI).

Service conditions for this embedded SFP Piping will be, and have been, very mild. The rated pressure of the stainless steel SFP Piping is 150 psi; however, as noted by CP&L, the maximum service pressure, which defined the system design pressure for hydrostatic testing is only about 25 psi. The maximum service pressure is so low because the Cooling and Cleanup System takes its suction on, and discharges into, the spent fuel pool, which is open to atmospheric pressure in the Spent Fuel Handling Building. Typical operating pressure will be less than 10 psi (limited by the static head at the lowest point); design temperature is less than 200°F; and service stresses from either pressure or supports are very low. The SFP Piping experiences no high fluid velocities, and the service environment is a well controlled, benign water chemistry (borated demineralized spent fuel pool water).

Following hydrostatic testing in late 1979 (Field Welds 2-SF-1-FW-1, -2, -4, and -5) or 1981/1982 (all of the other embedded Field Welds), CP&L indicated that the SFP Piping was drained and vented, but there are no records to indicate that the piping was either rinsed or dried. No water has been introduced into the SFP Piping by in-leakage from other systems, because none of the embedded piping is connected to any other systems. Per CP&L, piping was left unconnected to other systems (e.g., Closed Cooling Water, CCW) and openings were covered with Foreign Material Exclusion covers (plywood covers prior to1989; welded-on metal covers after spent fuel pools A and B were filled). The first filling of any of the "A" and "B" spent fuel pools occurred in 1989. Later, spent fuel pools C and D were also filled to ensure that there was no drain-down event from interconnected pools A and B. Over the years, this SFP Piping has filled with water from spent fuel pools C and D, that has leaked past "plumbers plugs" installed at the pool nozzles. This leakage from the spent fuel pools to the spared-in-place SFP Piping could have begun as early as 1989 or 1990. For the purposes of this analysis, the maximum time of flooding, approximately 10 years, will be assumed for conservatism. Although the piping has been filled for a number of years with spent fuel pool borated demineralized water, no formal lay-up program has ever been implemented for the embedded SFP Piping connected to spent fuel pools C and D. The phrase "wet lay-up" will be used to describe the flooded conditions that the piping has experienced since 1989, at the earliest.

Remote visual examination of fifteen embedded field welds (2-SF-8-FW-65 and –66; 2-SF-144-FW-515, -516, and –517; 2-SF-149-FW-408; 2-SF-143-FW-512, –513, and –514; 2-SF-159-FW-518, and –519; 2-SF-1-FW-1, –2, -4, and -5) and the piping in six of the eight lines was done by a CP&L contractor using a high resolution camera mounted to a pipe crawler following draining of those lines. Those videotapes were reviewed as a part of this project. In addition, CP&L has collected and analyzed water samples from seven of the lines for water chemistry and from seven lines to characterize the microbiological nature of the water.

3.0 OBJECTIVES

The primary objective of this project was to provide an independent, expert opinion on the structural integrity and suitability for purpose of the subject SFP Piping.

This assessment includes:

- A determination of the structural integrity of the welds as installed,
- An assessment of the present condition of the SFP Piping based upon any damage that has ensued during the roughly 10 years of wet lay-up,
- Suitability for service of the SFP Piping in the benign spent fuel pool water environment, and
- Specific recommendations on any other actions that should be performed to substantiate the quality of the SFP Piping.

4.0 APPROACH

4.1 Initial Quality

The first step in this assessment involved a detailed review of the available data, listed in Table 1-1. Materials that were reviewed included:

- Piping layout information
- Specified materials of construction, including weld metals
- Actual materials of construction (or verification that the specified materials were used throughout)
- Welding procedure specification(s) for shop and field welds
- Procedure Qualification Records for shop and field welds
- Visual and PT inspection records for shop welds
- Hydrotest results
- Videotapes of the remote visual examinations of fifteen field welds in the installed SFP Piping.

4.2 Degradation Since Construction

All potentially applicable degradation mechanisms were considered. The probability for each of those mechanisms to have degraded the piping during the extended wet lay-up was evaluated against the best estimate of the conditions to which the piping was actually exposed, considering:

- All loadings
- Nominal temperature, pressure, and water chemistry conditions
- Hydrotest water chemistry, and draining or drying procedures that might have been implemented following hydrotest
- Time of immersion since initial flooding (conservatively assumed to be approximately 10 years, the time between the initial fill of spent fuel pools and the drying done for the remote visual examination)
- Verification of the exposure conditions based upon temperature, pressure, and water chemistry data from monitoring or other surveillance of the lines (water chemistry, microbiological characterization)

- Detailed review of the videotapes from the remote visual examination of fifteen of the field welds performed in 1999.

All potentially operative degradation mechanisms were considered for the SFP Piping by comparing the degradation mechanisms and the operating conditions that are associated with them to the normal operating conditions for the piping (low flow or stagnant controlled purity water at ambient temperature) plus off-normal conditions, which for the SFP Piping are no different. Those degradation mechanisms are listed in Tables 4-1 and 4-2. Both tables are from compilations of all of the potentially operative degradation mechanisms for nuclear power plant components used in either ASME Code Case N-560 [1] evaluations or the EPRI Methodology for Risk-Informed Inservice Inspection [2]. This assessment has conservatively assumed that piping residual stresses were tensile stresses at the piping inside diameter and equal to the material's yield strength. Fit up and welding can produce residual stresses that can reach the yield strength before plastic deformation relaxes them.

Table 4-1

Degradation Mechanisms and Attributes in Code Case N-560 [1]

	Mechanism	Attributes	Susceptible Regions
1	Thermal Fatigue i. Thermal Shock ii. Stratification iii. Striping	Intermittent Cold Water Injection (i, ii, iii) Low Flow, Little Fluid Mixing (ii. Iii) Notch-Like Stress Risers (ii, iii) Very Frequent Cycling (ii, iii) Unstable Turbulence Penetration into Stagnant Lines (ii, iii) Bypass leakage in valves with large ΔTs (ii, iii)	Nozzles, branch pipe connections, safe ends, welds, HAZ, and base metal regions of high stress concentration
2	Flow Accelerated Corrosion	Turbulent Flow at Sharp Radius Elbows and Tees Proximity to Pumps, Valves and Orifices Material Chromium Content Fluid pH Oxygen Temperature	
3	Erosion-Cavitation	Severe Discontinuities in Flow Path Proximity to Pump, Throttle Valve, Reducing Valve or Flow Orifice	Fittings, welds, and HAZ
4	Corrosion i. General Corrosion ii. Crevice Corrosion iii. Pitting iv. MIC	Aggressive Environment (i, iii) Oxidizing Environment (ii, iii) Material (i, iv) Temperature (i, iv) Contaminants (sulfur species, chlorides, etc.) (ii) Crevice Condition (ii) Stagnant Region (ii) Low Flow (iii) Lay up (iv)	Base metal, welds, and HAZ
5	Stress Corrosion Cracking i. IGSCC ii. TGSCC iii. PWSCC	Susceptible Material (i) Oxidizing Environment (i, ii) Stress (residual, applied) (i, ii) Initiating Contaminants (sulfur species, chlorides, etc.) (I) (aqueous halides or concentrated caustic) (ii) Temperature (i, ii) Strain Rate (environmentally assisted cracking) (i, ii) Fabrication Practice (e.g., weld ID grinding, cold work (i) Notch-like Stress Risers	Austenitic stainless steel welds and HAZ (i) Mill-annealed Alloy 600 nozzle welds and HAZ without stress relief (iii)
6	Water Hammer [Note (1)]	Potential for Fluid Voiding and Relief Valve Discharge	

NOTE:

(1) Water hammer is a rare, severe loading condition as opposed to a degradation mechanism, but its potential at a location, in conjunction with one or more of the listed degradation mechanisms, could be cause for a higher examination zone ranking.

Table 4-2

Degradation Mechanism Criteria and Susceptible Regions (from [2])

Degradation Mechanism		Criteria	Susceptible Regions
TF	TASCS	–NPS > 1 inch, and –pipe segment has a slope < 45° from horizontal (includes elbow or tee into a vertical pipe), and –potential exists for low flow in a pipe section connected to a component allowing mixing of hot and cold fluids, or potential exists for leakage flow past a valve (i.e., in-leakage, out-leakage, cross-leakage) allowing mixing of hot and cold fluids, or potential exists for convection heating in dead-ended pipe sections connected to a source of hot fluid, or potential exists for two phase (steam/water) flow, or potential exists for turbulent penetration into a relatively colder branch pipe connected to header piping containing hot fluid with turbulent flow, and –calculated or measured $\Delta T > 50°F$, and –Richardson number > 4.0	Nozzles, branch pipe connections, safe ends, welds, heat affected zones (HAZs), base metal, and regions of stress concentration
	TT	–operating temperature > 270°F for stainless steel, or operating temperature > 220°F for carbon steel, and –potential for relatively rapid temperature changes including cold fluid injection into hot pipe segment, or hot fluid injection into cold pipe segment, and –$\lvert\Delta T\rvert > 200°F$ for stainless steel, or $\lvert\Delta T\rvert > 150°F$ for carbon steel, or $\lvert\Delta T\rvert > \Delta T$ allowable (applicable to both stainless and carbon)	

Table 4-2. Degradation Mechanism Criteria and Susceptible Regions (Cont.)

Degradation Mechanism		Criteria	Susceptible Regions
SCC	IGSCC (BWR)	–evaluated in accordance with existing plant IGSCC program per NRC Generic Letter 88-01	Welds and HAZs
	IGSCC (PWR)	– austenitic stainless steel (carbon content ≥ 0.035%), and –operating temperature > 200°F, and –tensile stress (including residual stress) is present, and –oxygen or oxidizing species are present <u>OR</u> –operating temperature < 200°F, the attributes above apply, and –initiating contaminants (e.g., thiosulfate, fluoride or chloride) are also required to be present	
	TGSCC	– austenitic stainless steel, and –operating temperature > 150°F, and –tensile stress (including residual stress) is present, and –halides (e.g., fluoride or chloride) are present, and –oxygen or oxidizing species are present	Base metal, welds, and HAZs

Table 4-2. Degradation Mechanism Criteria and Susceptible Regions (Cont.)

Degradation Mechanism		Criteria	Susceptible Regions
SCC (cont.)	ECSCC	– austenitic stainless steel, and –operating temperature > 150°F, and –tensile stress is present, and –an outside piping surface is within five diameters of a probable leak path (e.g., valve stems) and is covered with non-metallic insulation that is not in compliance with Reg. Guide 1.36, or –an outside piping surface is exposed to wetting from concentrated chloride-bearing environments (i.e., sea water, brackish water, or brine)	Base metal, welds, and HAZs
	PWSCC	–piping material is Inconel (Alloy 600), and –exposed to primary water at T > 560°F, and –the material is mill-annealed and cold worked, or cold worked and welded without stress relief	Nozzles, welds, and HAZs without stress relief
LC	MIC	–operating temperature < 150°F, and –low or intermittent flow, and –pH < 10, and –presence/intrusion of organic material (e.g., Raw Water System), or –water source is not treated with biocides	Fittings, welds, HAZs, base metal, dissimilar metal joints (for example, welds and flanges), and regions containing crevices
	PIT	–potential exists for low flow, and –oxygen or oxidizing species are present, and –initiating contaminants (e.g., fluoride or chloride) are present	
	CC	–crevice condition exists (i.e., thermal sleeves), and –operating temperature > 150°F, and –oxygen or oxidizing species are present	

Table 4-2. Degradation Mechanism Criteria and Susceptible Regions (Concluded)

Degradation Mechanism		Criteria	Susceptible Regions
FS	E-C	–cavitation source, and –operating temperature < 250°F, and –flow present > 100 hrs./yr., and –velocity > 30 ft./sec., and –$(P_d - P_v) / \Delta P < 5$	Fittings, welds, HAZs, and base metal within 5D of source
	FAC	–evaluated In accordance with existing plant FAC program	per plant FAC program

5.0 RESULTS

5.1 Initial Quality

This piping was constructed (to the extent that construction was completed) under the HNP ASME QA program. All procedures and plant construction were subject to frequent internal and external audits. This same QA program was used to successfully complete and license HNP Unit 1. While much of the documentation for the fifteen embedded field welds was unavailable, the QA program did require procedures for material controls, material handling and welding procedures and qualifications, completion of weld data reports (note that hydrotest procedures required a sign-off of the completion of all weld data reports), specific QC inspections, and ANI third party review. Construction of the subject SFP Piping without those controls would have required a total breakdown of that QA program.

The presence of Deficiency Disposition Reports (DDRs) pertaining to embedded field welds (Table 1-1; Item 2) provides a clear indication that the QA program was indeed applied to the field welds. For example, Field Weld 2-SF-149-FW-408 required a DDR since an ANI hold point was bypassed on final inspection. Similarly, a DDR was written for 2-SF-144-FW-517 (arc strikes found).

In the absence of weld documentation packages for the field welds, the signed-off hydrotest records provide the only formal documentation that "all weld data records (are) complete". Those packages were provided for field welds 2-SF-149-FW-408; 2-SF143-FW-512, -513, and -514; 2-SF-144-FW-515, -516, and-517; 2-SF-159-FW-518, and –519; 2-SF-1-FW-1, -2, -4, and -5. No hydrotest packages were supplied for field welds FW-65 and –66.

The weld procedures that were reviewed as a part of this project were CP&L procedures that were in place at the time the field welds in the SFP Piping were made. Those procedures included welds in the variety of P-8 materials (per ASME Code Section IX) that would be used in nuclear construction, including the Type 304 stainless steel used for the SFP Piping. The controls on welding processes (GTAW and Shielded Metal Arc Welding, SMAW), heat inputs, purge and shielding gas, and other parameters required to make high quality welds in nuclear construction were typical of those that have been reviewed by Structural Integrity Associates for other plants, including welds for Class 1 systems. The weld procedure packages that were reviewed (Table 1-1, Item 2) also included Procedure Qualification Records that demonstrated that the weld procedures produced sounds welds with satisfactory mechanical properties.

Ebasco Services performed a calculation on the minimum piping wall thickness, t_{min}, that was required to retain the design pressures in the Spent Fuel Pool Cooling and Cleanup System, assuming a maximum allowable stress, SE, of 17,800 psi due to internal pressure [3]. That calculation, verified by Structural Integrity Associates showed that for 16" stainless steel pipe, t_{min} = 0.011" for a design service pressure of 25 psi (joint efficiency = 100%). For 12" pipe and a joint efficiency of 80%, the maximum for butt welds not subjected to volumetric examination, the calculated t_{min} was also equal to 0.011" for a design service pressure of 25 psi. The pipe's 0.375" nominal thickness is therefore approximately 30 times the required minimum thickness for the design service pressure.

The minimum wall thickness was also calculated for 150% of the 150 psi design rating of the 12" stainless steel piping, or 225 psi. The calculated t_{min} for that pressure (nine times the 25 psi design service pressure) was 0.080"; about one-fifth of the actual pipe thickness of 0.375". At a joint efficiency of 80% and pressure of 225 psi, t_{min} = 0.100". Those calculations apply to the exposed pipe. The results will be conservative for the SFP Piping embedded in concrete since the presence of the concrete effectively reinforces the pipe.

Although the fabrication requirements for the SFP Piping field welds did not require examination of the ID of pipe welds by visual or enhanced methods (such as PT), detailed visual examination results of the fifteen embedded field welds were provided by CP&L, from remote visual inspections performed during the Summer and Fall of 1999, to assess the present condition of those welds.

These visual examinations demonstrated that, in general, the piping and welds in the embedded SFP Piping were in good condition. However, there were some areas on some welds where the consumable insert was not completely consumed and some areas on most of the welds where the profile was less than ideal. The condition of a non-consumed insert was most pronounced on 2-SF-144-FW-516. Some small linear indications were observed (e.g., 2-SF-8-FW-65, 2-SF-144-FW-515 and FW-517, and 2-SF-159-FW-518) which appeared to be related to incomplete fusion. No areas were visible from the ID that would suggest that the reduction in thickness approached t_{min}. The fact that all welds passed a hydrostatic test (i.e., no visible leakage from a 360° examination) at a pressure in excess of 125% of the 25 psi system design pressure, for a minimum of ten minutes, provides a further verification of the initial quality and structural integrity of the welds.

At the ID, the appearance of the tie-in at the edges of all of the Field Welds that were examined is good to excellent. There are some weld areas, generally scattered around the circumference, where the consumable insert was not completely consumed or where the weld profile was less than ideal; not surprising for closure welds. FW-516, the worst weld in this regard, had the largest intermittent areas of incomplete consumption of its consumable insert but still exhibited complete fusion at the edges. Since there has been no volumetric examination of these welds, the overall structural integrity of the weld is assumed to be controlled by the subsurface condition resulting from small areas of the consumable insert not having been completely consumed. In the absence of a volumetric examination, that structural integrity evaluation must revert to the calculation of the required minimum thickness for the design or operating pressure, including a reduced joint efficiency. The design codes include provisions for a joint efficiency less than 100% for conditions such as these. The successful hydrotest results provide a verification that thickness exceeded t_{min} throughout FW-516 and the other welds at the time of the hydrotest, despite the non-consumed areas.

Several broad and apparently shallow linear indications were noted for 2-SF-144-FW-515. Those indications were always at the edge of the consumable insert. Similar indications were also apparent in the longitudinal seam of one of the adjacent pipes. That longitudinal seam had passed visual examination and PT as a part of its inspection following shop fabrication. No pitting or crevice corrosion were observed in the shallow linear indications in either the longitudinal seam or in field weld FW-515.

A calculation of the allowable flaw length was performed for an axial flaw, as set forth in ASME Code, Section XI, Appendix C. A through-wall flaw was conservatively assumed. For a maximum pressure of 25 psi (hoop stress = 425 psi), a total flaw length of 102 inches was determined. That means that for the 25 psi internal pressure loading, the pipe would retain its structural integrity for all axial flaws less than 102 inches. Clearly this flaw is many times greater than the observed indication near field weld FW-515.

No evidence of overheating or excessive heat tint was detected.

5.2 Degradation Since Construction

A review of all of the potentially operative degradation mechanisms listed in Table 4-1 and 4-2 identified that the only potentially operative degradation mechanisms for the SFP Piping are associated with corrosion. The flows, vibrations, and thermal conditions associated with the operation of the SFP piping, including up to ten years of wet lay-up, are far less than the conditions that can produce flow accelerated corrosion, or vibrational or thermal fatigue.

The potentially operative corrosion mechanisms include transgranular stress corrosion cracking (TGSCC), intergranular stress corrosion cracking (IGSCC), localized corrosion, and microbiologically influenced corrosion (MIC). No other corrosion mechanisms were considered to have been potentially operative for the extended lay-up conditions experienced by this piping. Other corrosion mechanisms, such as flow accelerated corrosion (FAC), are not considered operative due to the materials of construction (stainless steel), operating conditions (little or no flow; no temperatures in excess of typical ambient), and nominal environment (no caustic, raw water, or other damaging chemical species have been introduced to this piping).

The spent fuel pool cooling heat exchangers are cooled by the high purity component cooling water (CCW) system, which operates at a higher pressure than the SFP cooling water. Hence, any leakage would be from the CCW system into the SFP cooling water. Even this design condition is of no consequence for the embedded SFP Piping, since construction did not progress to the extent that any of the embedded piping was ever connected to the heat exchangers.

The SFP Piping has in effect been exposed to an extended wet lay-up with high purity water (albeit an inadvertent lay-up since no formal lay-up program was ever implemented for the lines connected to the spent fuel pools). As noted previously, over time, the piping has filled with water from the spent fuel pools which leaked past "plumbers plugs" installed at the pool nozzles, possibly beginning as early as 1989 when the "A" and "B" pools were first filled. No water has been introduced by in-leakage from other systems, because none of the embedded piping is connected to any other systems.

No regular sampling has been performed of the water in the SFP Piping. However, chemistry samples were collected from each of seven lines associated with the embedded piping (2-SF-74, -75, -212, -213, -214, -215, and –49) on 4-27-99 (Table 1-1, Item 7). Those results showed that chloride, fluoride, sulfate, and conductivity levels were very low (maximum values: chloride = 70.5 ppb; fluoride = 166 ppb; sulfate = 1027 ppb; conductivity = 103 μS/cm). Those chloride and fluoride concentrations are consistent with the specifications for spent fuel pool chemistry. Sulfate and conductivity levels are also consistent with those of a high purity water. The water samples also showed low levels of tritium; at a concentration similar to that of Spent Fuel Pool "C". The visual examinations also revealed a white crystalline substance near the bottom of some lines. That material looked very similar to boric acid crystals that form when borated water, as from the fuel pool, dries out on surfaces.

Seven water samples, from the "C" and "D" SFP Piping drains were also collected and evaluated by CP&L to provide some insight regarding the presence of active MIC bacteria in the lines (Table 1-1, Item 5). The water samples were analyzed using RapidChek™ II kits for sulfate reducing bacteria (SRB) and Hach Corporation BART™ kits for slime formers, iron related bacteria, and heterotrophic bacteria. The RapidChek tests indicated that the number of SRB was somewhere between the lower detection limit of 1000 cells/ml and 100,000 cells/ml. No slime formers, iron bacteria, or heterotrophic aerobes were detected with the BART kits. Those results are in dramatic contrast to typical bacterial counts for raw waters, providing further verification that the water in the lines was water of controlled chemistry; not untreated cooling water.

In low energy piping, the potentially operative degradation mechanisms will produce either tight cracks (TGSCC or IGSCC) or pinhole leaks (localized corrosion and MIC). For these low pressure lines, the only manifestations of those degradations will be very small leaks, of the order of a few drops per minute. In the absence of significant pressure loadings, which are absent in these lines, or significant seismic loadings, even the cracks produced by TGSCC or IGSCC would have no effect on structural integrity of the lines. Even significant pitting (i.e., over a large fraction of the circumference) confined to a narrow band, as can occur with severe MIC degradation of a weld, does not degrade the structural integrity of stainless steel weldments due to the very high toughness of those welds.

5.2.1 IGSCC

There is an extremely low probability of occurrence of IGSCC in stainless steel in the conditions and environment of the SFP Piping. While the very conservative assumption that residual stress is equal to the yield strength produces stresses sufficient to initiate and grow cracks, the controlled purity environment is not sufficiently aggressive to initiate or propagate cracks. For IGSCC driven by oxidizing conditions, the spent fuel pool temperature is far too low to produce IGSCC. Other aggressive and potential IGSCC-inducing species like thiosulfate are not present in the controlled purity environment nor is there a path that would introduce such species to the spent fuel pool environment. For example, IGSCC requires the presence of a significantly higher operating temperature (minimum of 200°F) or the presence of very aggressive chemical species such as caustic or thiosulfate.

5.2.2 TGSCC

Similarly, there is an extremely low probability of occurrence of TGSCC. As for IGSCC, the controlled purity environment is not sufficiently aggressive for either initiation or growth, even with the conservative assumption of residual stresses equal to the yield strength; a stress that would be sufficient to initiate and grow cracks if an appropriate environment were present. Chlorides are very low, limited to the levels permitted in the spent fuel pool environment (<100 ppb) or from chlorides that may have been introduced during the hydrotest (of the order of 50 to

100 ppm), with the residual chlorides subsequently diluted from the system by the spent fuel pool water.

Further, the spent fuel piping does not have any connection to coolers or other piping that can cause raw water to leak into the spent fuel pool environment.

5.2.3 Localized Corrosion

Pitting or crevice corrosion are also unlikely degradation mechanisms. The only environmental source over the long term is the very innocuous, controlled purity, spent fuel pool water. While the environment in this piping is not monitored, the spent fuel pool environment is checked by periodic water samples. All samples that have been collected from this piping, seven sample locations at one time point, as much as 10 years after initial wet-out, have confirmed that the environment inside the piping is consistent with the spent fuel pool water. The visual examinations also suggested that boric acid crystals were present in some of the lines

The chemical influence of the hydrotest water is limited by the total amount of chlorides, fluorides, and other potentially aggressive species in that water. Subsequent filling of the lines with high purity water would eliminate virtually all of those effects. The 1999 water samples have confirmed that no additional sources of water-borne chemical impurities were introduced. Dry-out and subsequent re-flooding or nearly complete dry-out of low spots would produce the most aggressive chemistry. Those locations would be expected at drains, precisely where samples were collected.

5.2.4 MIC

MIC is more likely than the other forms of localized corrosion since a minuscule population of microorganisms can grow to a diverse population of millions of microorganisms, limited only by the available nutrients. Source terms for microorganisms are hydrotest water, the spent fuel pool water, and potential intrusions of raw water from coolers. The latter item is not considered to be viable since the SFP Piping has effectively been isolated from all the coolers (more correctly, it was never connected).

Most often, MIC will produce closed, "ink bottle" shaped pits (Figure 5-1), characterized by tiny entrance holes and exit holes (if the pit goes through-wall) with a much larger area of metal loss beneath the surface. Because of the very small openings to the pit at the ID and OD, leak rates are extremely small. In stainless steels, MIC pits are far more common at weldments, either in the weld metal itself, in the heat affected zone, or beneath the heat tint. In a worst case scenario, pits in a single weld could produce a significant area of metal loss along the length of the weld such that the effective length of the flaw is large.

CP&L Test Procedure TP-30 [4] required all hydrotest water to meet Westinghouse spec PS292722. Procedure WP-115 [5] permitted hydrotests using lake water or potable water (but still water per Westinghouse spec PS292722 for piping in Westinghouse's scope of supply). The majority of the hydrotest results that were received for the embedded piping evaluated in this report were performed in accordance with WP-115.

The monitoring of the water that has been done (one data point, consisting of seven samples collected in 1999) has shown very low counts of microbial species associated with MIC. While water samples are not the best method for verifying that there is no biofilm on piping surfaces, the water sampling plus visual inspection (both ID and OD) provides a reliable indicator that MIC has not produced any leakage or accelerated corrosion in the piping

It is recognized that MIC can occur in high purity waters, in nuclear plants in systems that are nominally high purity, but that have been contaminated during initial hydrotest or during operation [8, 9]. It is also well known that water samples provide a poor representation of the biofilms on surfaces that cause MIC. The water samples that have been collected and analyzed for bacteria associated with MIC do show that the purity of the water is still very good. More importantly, no evidence of large mounds of organic materials that are typically associated with MIC was present in any of the lines that were examined in the as-found condition. All of those welds and the surrounding pipe work that were examined by the remote visual examination have been very clean, even prior to hydrolasing.

No corrosion nodules or other indications that a localized corrosion phenomenon such as MIC has occurred during the wet lay-up were revealed by the detailed remote visual inspections for all but one of the welds. A few welds exhibited some evidence of minor corrosion; limited to minor staining on those welds, except for 2-SF-144-FW-517. A very few minor discolored areas, indicative of small pits that may or may not be active any longer, were observed on those welds that exhibited evidence of corrosion. None of those indications suggests the presence of any defects that would compromise the structural integrity of these lines. No crack-like defects were noted in any of the weldments.

The remote visual examination of 2-SF-144-FW-517 revealed three apparent pits, each defined by a reddish-brown deposit. Two of those indications were located in one short section at about the 3 o'clock position; the other at about 9 o'clock.

The reddish-brown deposits and apparent entrance holes in the weld metal of 2-SF-144-FW-517 could be due to MIC, or could be from another source. In either case, the depth and morphology of the metal loss through the thickness cannot be determined from the remote visual examination of the as-found pipe. The visual examination also cannot provide a determination of whether pitting is active or not, or provide information on the source of the pitting. A definitive determination of the root cause for these small pits would require careful microbiological and chemical sampling of the deposits and the pit interior to augment the visual examination of the as-found condition, then a similarly detailed examination of the area following removal of the deposits to better characterize the pit morphology.

An additional characterization of these deposits and apparent pits was performed by CP&L and reviewed as a part of this analysis. The additional activities included mechanical removal of the deposits, two water washes of the deposits to provide an improved visual inspection, and chemical analysis of the materials that were removed. Remote visual inspection was done during or following all of the cleaning procedures.

The first remote visual examination showed the mechanical removal of the deposits by a small tool attached to the pipe crawler. The deposits were removed very easily. The material was soft and muddy with a very definite reddish-brown color. The total quantity of deposits was very small; estimated to be of the order of milligrams. The first washing of the weld removed very little additional deposit. The reddish-brown discoloration was still obvious and the location of the areas of deposit were still three dimensional. The outer portion of the corrosion nodules had been removed mechanically and during the first pressure wash. Where the two apparent pits were located, one or two features that looked like very small entrance holes were observed at the periphery of the former corrosion nodules. One was located along the centerline of the weld root. The other pit nearby exhibited two locations that may also have been entrance holes into the underlying weld material, however, those features were not as distinct.

Following the second water washing, the appearance of the two apparent pit locations barely changed at all. There, the weldment was still discolored with a reddish-brown stain and the two affected areas still appeared to be covered with a layer of an iron-based corrosion product. The single corrosion nodule located approximately 180° away from those two nodules was still discolored, but the deposited corrosion product had been removed more completely and no definite pits of the weld metal or base metal were obvious.

CP&L performed chemical analyses of solid and liquid samples removed from the locations on FW-517 described above. Liquid samples were collected from the first water washing of FW-517 and piping several feet upstream and downstream of the field weld. That fluid was collected at the nearest access point, approximately 70 feet away. The CP&L analysis included examination in the scanning electron microscope (SEM) with an energy dispersive spectrometer (EDS) attachment to determine the approximate elemental composition of the samples. X-ray diffraction (XRD), which permits a determination of the compounds present from the presence of their unique diffraction characteristics, was performed on deposits filtered from the liquid sample. All of the samples characterized by EDS were primarily iron and oxygen, with minor amounts of chromium and silicon. No other significant peaks were detected. The XRD analysis showed that the filtered solids consisted almost entirely of hematite (α-Fe_2O_3) and lepidocrocite ($FeOOH$).

Corrosion pits, even the closed, tunneling pits in weld metal that are often associated with MIC of stainless steel, would have no consequence on structural integrity. MIC can produce pinhole leaks, however, even a severe MIC condition does not impact the structural integrity of stainless steel welds, as demonstrated both by calculation [6] and confirmed by experiment [7]. As demonstrated in References 6 and 7, a distribution of much larger pits in a more severely stressed stainless steel weld had no effect on load carrying capability.

The presence of the reddish-brown deposits and apparent small pits in FW-517 is not considered to be a condition that jeopardizes the structural integrity of the SFP Piping at all.

The most powerful evidence that all welds, including the embedded welds, are structurally sound is that there have been no pinhole leaks reported for any of the exposed piping. If MIC or other localized corrosion mechanisms were operative now or had produced a problem during the 10 year period that these lines have been wet, one or more pinhole leaks might be anticipated. All of the exposed piping has been subject to external visual examination by both CP&L engineering and QC. All of the exposed field welds have been satisfactorily reexamined, both visually and by liquid penetrant testing (PT). No leakage has ever been seen in any of the exposed piping. It is noted that not all of the exposed SFP piping is connected to the embedded piping, but a significant portion of it is. CP&L has estimated that a comparable volume of exposed piping is actually connected to and communicates with the embedded piping, and has been subject to the same flooded conditions.

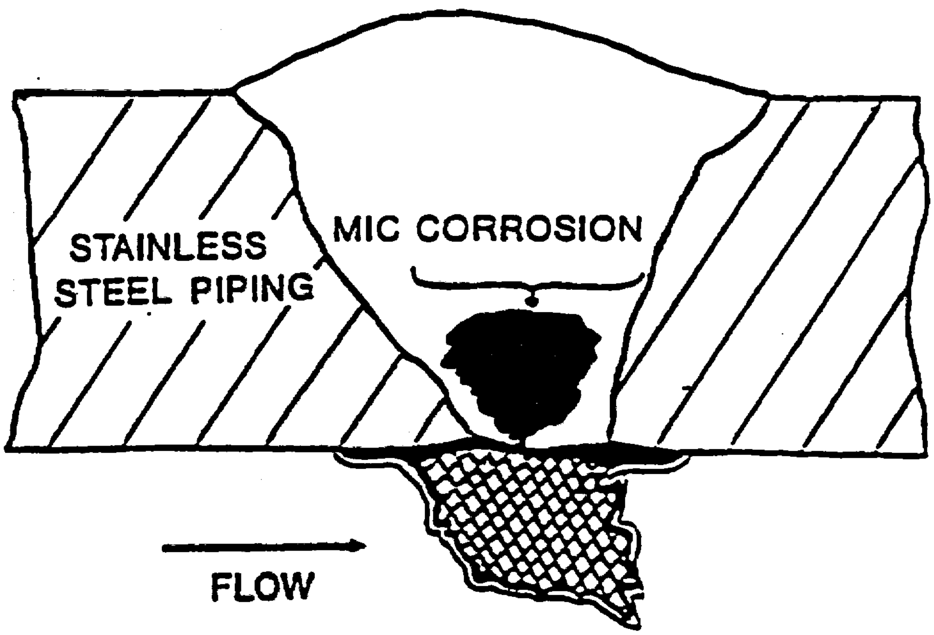

Figure 5-1. Closed Pit, Typical of MIC in Stainless Steel Piping Welds (from [7])

6.0 CONCLUSIONS

6.1 Initial Quality

The fabrication records for all of the spools in this scope were reviewed. Objective evidence was located to confirm that all components and all shop welds were of good quality.

This piping was constructed under the plant's ASME QA program; a program that was used to successfully complete and license HNP Unit 1, and which definitely appeared to have been solidly in place during the construction of all of the SFP Piping, as evidenced by QA records from that era.

No documentation was provided on the as-installed condition of field welds, except for those field welds for which hydrotest records are in hand (i.e., 2-SF-149-FW-408; 2-SF-143-FW -512,-513, and –514; 2-SF-159-FW–518, and -519; 2-SF-144-FW-515, -516, and -517; 2-SF-1-FW-1, -2, -4, and -5). For each of those welds, the hydrotest record did contain a sign-off that the weld data reports were complete, along with the successful results of the hydrotest itself, including the 360 degree visual inspection of each weld under pressure, done while the now embedded welds were still accessible.

Detailed visual examination results of embedded field welds were provided by CP&L from remote visual inspections performed for the utility during the Summer and Fall of 1999. Those inspections were used as a part of this evaluation.

The as-installed structural integrity of all of the field welds evaluated in this project (i.e., 2-SF-149-FW-408; 2-SF-143-FW-512, -513, and –514; 2-SF-159-FW–518, and -519; 2-SF-144-FW-515, -516, and -517; 2-SF-1-FW-1, -2, -4, and -5; 2-SF-8-FW-65 and, -66) was considered acceptable based upon the materials provided. The successful completion of the hydrostatic test and the detailed remote visual examination (following 10 years of exposure to a wet lay-up with high purity water) provided a conclusive demonstration of the quality of the initial welds.

6.2 Present Condition

The review of the detailed visual examinations for 2-SF-8-FW-65 and –66; 2-SF-144-FW-515, -516, and –517; 2-SF-149-FW-408; 2-SF-143-FW-512, -513, and –514; 2-SF-1-FW-1, -2, -4, and –5; and 2-SF-159-FW-518 and -519 also demonstrated that those welds were in a condition that would be very comparable to that of as-installed piping. The 10 years of wet lay-up does not appear to have degraded the structural integrity of the welds at all.

6.3 Suitability for Service as Spent Fuel Pool Piping

The assessment of the suitability for service of this SFP Piping was based upon all of the items listed above – records review and remote visual inspection.

The SFP Piping is exposed to very benign conditions. Localized corrosion, which could produce pinhole leaks, is the most likely form of degradation. None of the forms of localized corrosion, including MIC, is considered very likely at all.

No pinhole leaks have been detected in any of the exposed piping to date.

Pinholes will have no effect on structural integrity in any event.

The videotapes from the detailed remote visual examination are for six lines in a total population of eight (which include the fifteen field welds). Conclusions drawn from them assume that they are representative of the population. Per CP&L, there are no field welds in the remaining two lines.

The overall condition of the welds, including the appearance of the tie-in at the edges of the consumable insert, is good to excellent. There are some areas, generally scattered around the circumference, where the consumable insert was not completely consumed (e.g., 2-SF-144-FW-516) or where the weld profile was less than ideal. The very small thickness required to withstand design service pressure and the successful hydrotest results provide a verification that these welds are suitable for the SFP Piping's service conditions despite the non-consumed areas or imperfect profile.

The plant's best method to control degradation is to continue to keep these lines isolated from potential sources of contaminants and to assure that the only environment that the lines experience is controlled purity water. Periodic visual examination of exposed piping for the presence leaks can provide continued additional assurance of the integrity of the SFP Piping population.

7.0 REFERENCES

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