UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

ENCLOSURE

SAFETY EVALUATION BY THE OFFICE OF SPECIAL PROJECTS

RELATING TO THINNING OF PIPE WALLS

TENNESSEE VALLEY AUTHORITY

BROWNS FERRY NUCLEAR PLANT, UNITS 1, 2 AND 3

DOCKET NOS. 50-259, 50-260 AND 50-296

1.0 INTRODUCTION

On December 9, 1986, Unit 2 of the Surry Power Station experienced a catastrophic failure of a main feedwater pipe due to erosion/corrosion of the carbon steel pipe wall. Although erosion/corrosion pipe failures have occurred in other carbon steel systems, particularly in small diameter piping in two-phase systems and in water systems containing suspended solids, there have been no previously reported failures in large diameter systems containing high-purity water.

The basis for this evaluation is NRC Bulletin 87-01, "Thinning of Pipe Walls in Nuclear Power Plants." The bulletin requests the code of construction for the piping systems susceptible to erosion-corrosion, a description of the thickness measurement program, the criteria for selecting inspection points, a summary of the inspection results, and a description of future plans.

2.0 DISCUSSION/EVALUATION

The licensee answered these questions through their bulletin response of September 18, 1987 and Volume 3 of the Browns Ferry Nuclear Performance Plan.

2.1 Identify the codes or standards for piping design and fabrication

- The piping was designed and fabricated to the 1967 edition of ASA B31.1.

2.2 Describe the scope and extent of your programs for ensuring that pipe wall thicknesses are not reduced below the minimum allowable thickness. Include in the description the criteria that you have established for selecting thickness measurement points, frequency of examination, inspection methods and repair/replacement decisions.

- The licensee's basis for selecting areas most susceptible to erosion/corrosion in dual-phase systems is based on an EPRI Report NP-3944 entitled, "Erosion-Corrosion in Nuclear Plant Steam Piping; Causes and Inspection Program Guidelines." TVA's basis for selecting areas in single-phase systems is based on an EPRI report dated February 19, 1987. The systems selected for examination were the turbine piping, moisture separators, heater drains, steam extraction, feedwater/condensate, and emergency equipment cooling water.

- Procedures were submitted with the licensee's response that describes the scope and extent of the thickness measurement programs. Ultrasonic testing (UT) is used to measure wall thickness with supplemental assistance from visual examination. Procedure TS 09.01.01.14.02 dated March 6, 1984, "Inspection Program - Division of Nuclear Power - Steam/Water Erosion of Piping and Corrosion of Raw Water Carbon Steel Piping," describes the inspection program. Procedure N-UT-26, Revision 4 dated May 14, 1987, "Ultrasonic Examination for the Detection of I.D. Pitting, Erosion and Corrosion," describes the examination procedure in detail.

- The licensee plans to use the inspection results for trending analyses. If trending indicates that the wall thickness of the component will approach the design minimum wall thickness before the next scheduled outage, the component will be replaced or repaired.

2.3 For liquid-phase systems, state specifically whether the following factors have been considered in establishing your criteria for selecting points at which to monitor piping thickness:

a. Piping material (e.g., chromium content);

b. Piping configuration (e.g., fittings less than 10 pipe dia. apart);

c. pH of water in the system (e.g., pH less than 10);

d. System temperature (e.g., between 190° and 500°F);

e. Fluid bulk velocity (e.g., greater than 10 f/s); and

f. Oxygen content in the system (e.g., oxygen less than 50 ppb).

- The licensee stated that only plain carbon steel piping was inspected since small amounts of chromium significantly improve a material's resistance to single-phase flow erosion/corrosion as shown by Unit 2. Fittings less than 10 pipe diameters apart and piping immediately downstream of orifices and flow control valves are considered potential corrosion sites. Studies have shown that erosion/corrosion is more likely to occur in the 200° to 350°F temperature range for single-phase flow. Locations within this range are inspected as well as areas up to 500°F if other criteria warrants.

The fluid bulk velocity of the areas inspected generally exceeds 10 f/s, however inspections were not limited to those areas.

° The licensee stated that the pH and oxygen are maintained at levels less than those necessary to enhance erosion/corrosion resistance. According to the FSAR, the pH may vary from 7.5 to 8.5. Since the pH and oxygen are assumed to be constant throughout the single-phase flow, they are not criteria for selecting examination points.

2.4 Summarize the results of all inspections which were conducted for the purpose of identifying pipe wall thinning, and any other inspections where pipe wall thinning was discovered.

a. Describe the inspection program and indicate whether it was specifically intended to measure wall thickness or whether these measurements were incidental.

b. Describe what piping was examined and how (e.g., describe the inspection instruments, test method, reference thickness, locations examined, means for locating measurement points in subsequent locations).

c. Report thickness measurement results and note those that were identified as unacceptable and why.

d. Describe actions already taken or planned for piping that has been found to have a nonconforming wall thickness. Include the results of any related failure analyses that have been performed. Indicate whether the actions involve repair or replacement, including any change of materials.

° Browns Ferry Nuclear Plant (BFN) Unit 1

a. The turbine cross-under piping was inspected in 1977 and pits 60 to 80 mils deep were found. Some eroded areas were bright and others were covered with a dull, graying oxide which is associated with an actively corroding pit. An area of considerable wear was identified adjacent to moisture separator No. 3 and this and other areas were mapped for future inspections. The 1979 inspection showed additional degradation and straight lengths of pipe had the typical "tiger striping" pattern of pitting. The damage in the turbine exhaust area was completely random.

High velocity steam erosion caused the failure of a moisture separator drain pipe in 1982. Stainless steel was recommended as the replacement material.

b. The turbine cross-around piping was inspected in 1983 and there was widespread steam erosion damage. The majority of the corrosion sites were active. UT methods located one spot where the 0.625 in. pipe wall had been reduced to 0.400 in., but there was sufficient thickness for continued service. The licensee stated that the wall loss was proceeding at a constant rate, but the staff found that the data points would also justify a curve where the wall loss grew in proportion to the square of the number of hours of operation. The licensee position should be reviewed at subsequent outages.

c. The miscellaneous drain headers were examined by UT in 1984 and there was not any appreciable wall degradation. In this report, the licensee based the minimum acceptable wall thickness on the pipe diameter and internal pressure. The staff is of the opinion that this would give an unacceptably thin wall for drain pipes and there should be sufficient thickness to account for the accuracy of the ultrasonic test equipment and the pipe rigidity needed for mechanical loads. The licensee responded that degradation would be detected in the tracking program and corrective actions would be taken before the minimum wall thickness is reached.

d. In 1986, a small section was removed from a portion of pipe to verify UT results. The measured values were consistent with UT results. Tiger striping erosion/corrosion was observed.

° Browns Ferry Nuclear Plant, Unit 2

a. The heater drain lines were examined in 1978 and showed the same erosion corrosion as Unit 1, although not as deep because Unit 2 piping has a slightly higher alloy content. The 1979 inspection of the cross-under piping showed very little erosion/corrosion except in the No. 1 extraction piping and certain areas in the manway cover. Localized attack was seen in the 2B1 moisture separator.

b. The 1982 inspection of moisture separators and associated piping showed minor steam erosion damage. In February 1983, the licensee inspected the 2B2 moisture separator drain piping and found erosion-type degradation in the 8 in. tee, 4 x 8 in. increaser, 8 in. pipe and 8 x 16 in. increaser. Wall loss was measured by visual and UT methods and estimated to be 30%. Stainless steel replacement materials were recommended. This damage had not been observed in examinations of the 2A2 and 2C2 piping which have a higher alloy content.

c. An examination of the 4 in. turbine exhaust piping in May 1983, showed the maximum wall loss to be .097 in. No wall thinning was observed on cross-over piping during a 1985 examination.

d. Several reports were written in 1985 on the degradation of the extraction steam piping. UT examination showed wall losses ranging up to 60% in the No. 2 lines and up to 35% in the No. 1 lines. Calculations showed there was sufficient material remaining, but plans were made for temporary repair and replacements until better materials could be obtained.

° As a result of NRC Bulletin 87-01, 32 areas were selected on the feedwater condensate piping for wall thickness measurements using UT methods. Some minor cavitation damage was detected at the discharge of the main feed pump, but there was not any evidence of wall degradation.

° Browns Ferry Nuclear Plant, Unit 3

The cross-around piping, extraction steam piping, and emergency equipment cooling water piping were examined for wall degradation in 1984. There were few localized areas of erosion/corrosion in the 42 in. diameter cross-around piping and the moisture separators and they were not active corrosion sites. The wall thickness of the extraction steam piping from Extractor no. 2 had been reduced from .375 in. nominal to .291 in. The minimum wall thickness of the first 12 in. line off of the main line from extractor no. 2 was .301 in. while the surrounding area was .398 in. In several unrelated spots, the wall thickness of the 18 in. dia. emergency equipment cooling water piping had been reduced to .304 in. from .375 in. nominal. The 1986 inspection of the cross-over piping did not identify any wall thinning.

2.5 Describe plans for revising present programs and developing new or additional programs for monitoring pipe wall thickness.

° The licensee furnished Sequoyah Nuclear Plant surveillance instructions and indicated that Browns Ferry would have similar plans. The inspection results will be compared with previous data and serve as the basis for replacement or continued operation of degraded pipe. The licensee plans to participate in the NUMARC initiative regarding selection and inspection of piping for wall thinning. The licensee explained that these plans are not complete and will be modified based on experience.

3.0 FINDINGS

The staff reviewed Volume 3 of the Browns Ferry Nuclear Performance Plan and the licensee's response to NRC Bulletin 87-01. The systems most susceptible

to erosion/corrosion degradation have been examined by the licensee. They were the turbine piping, moisture separators, heater drains, steam extraction, feedwater/condensate, and emergency equipment cooling water.

With the exception of the Unit 3 emergency equipment cooling water piping which had localized wall thickness reductions of 19%, the licensee has reduced the number of wall thickness examinations to likely areas of vapor phase attack via cavitation, erosion and erosion/corrosion. The only reported failure was the Unit 1 moisture separator drain pipe failure. Severely degraded areas were the Unit 1 turbine cross-around piping, Unit 2 moisture separators and extraction steam piping, and Unit 3 extraction steam piping.

Surveillance instructions have been written and the licensee plans to monitor susceptible areas and trend the results. The locations of susceptible areas and frequency of inspection may change as experience is accumulated.

The minimum acceptable wall thickness is based on the minimum thickness to accommodate the internal pressure plus a corrosion allowance and the staff feels that additional thickness to account for the sensitivity and accuracy of the ultrasonic test equipment and the pipe rigidity needed for mechanical loads should also be considered. The licensee makes the assumption that degradation due to erosion/corrosion will be linear with respect to time, but the staff noted that the data also support a conclusion that the degradation will increase with the square of the operating time.

The NRC staff concluded that the licensee's inspection and surveillance program and the response to NRC Bulletin 87-01 are programmatically acceptable.

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