WCAP-13245

EVALUATION OF BYRON AND BRAIDWOOD UNITS 1 AND 2 AUXILIARY SPRAY LINES PER NRC BULLETIN 88-08

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TABLE OF CONTENTS

SECTION 1.0
EXECUTIVE SUMMARY

This report provides an evaluation of the pressurizer auxiliary spray line for the effects of potential thermal stratification and cycling as described in NRC Bulletin 88-08 (reference 1). This evaluation included monitoring data review, transient development, structural integrity and fatigue analysis, and inservice inspection recommendations.

The monitoring data did not provide any indication of unanalyzed thermal transients, including thermal cycling or inleakage of cold fluid from the auxiliary spray line. However, for this evaluation, a conservative thermal transient was postulated, based on the experience of the safety injection piping at Farley Unit 2. A structural integrity analysis was performed including fatigue crack growth to determine an acceptable period of operation, assuming that the postulated transient occurs. This analysis determined an acceptable period of power operation of approximately 39 months.

In conclusion, an inservice inspection interval of 39 months of power operation is recommended to provide continued assurance of the structural integrity of the pressurizer auxiliary spray piping. Therefore, it is judged that future monitoring of the auxiliary spray piping is not necessary.

SECTION 2.0
BACKGROUND AND INTRODUCTION

Following the discovery of pipe cracks in the auxiliary lines of several nuclear power plants, the United States Nuclear Regulatory Commission issued Bulletin 88-08 (Ref. 1). Action Item 1 of the Bulletin requested utilities to identify systems connected to the Reactor Coolant System which are susceptible to adverse temperature distributions (not considered in the design analysis of the piping) that could be induced by leaking valves. The auxiliary pressurizer spray line was identified as one such system at the Byron and Braidwood Units (Ref. 2).

Action Item 2 of Bulletin 88-08 requested that the identified systems be nondestructively examined to provide assurance that there are no existing flaws. Recent inspection of the auxiliary spray lines at Byron Units 1 and 2 resulted in no indications of flaws. (The Braidwood Units are scheduled for inspection during the upcoming refueling outage).

Action Item 3 of the Bulletin requested that a program be implemented to provide continuous assurance that adverse temperature distributions are not occurring in unisolable piping sections. Accordingly, Commonwealth Edison Company has instrumented the auxiliary spray line at Byron Units 1 and 2 with surface-mounted temperature sensors.

Data from the Byron Unit 1 auxiliary spray line has been evaluated for evidence of adverse temperature distributions. Temperatures at the two monitored locations are steady, with no cycling observed. The temperatures are also within the expected range of temperatures during mode 1, therefore inleakage of cold fluid from the auxiliary spray line into the hot main spray line is not occurring.

Plant operating practices have also been evaluated to determine the potential impact on fatigue life of the auxiliary spray line and main spray line in the vicinity of the auxiliary spray/main spray connection if leakage as identified in the Bulletin occurs.

Based on the results of inservice inspection, temperature monitoring, plant operating practices and fatigue analysis (assuming postulated transient), this evaluation provides justification for the elimination of monitoring the Byron and Braidwood auxiliary spray lines per NRC Bulletin 88-08 Item 3. Instead, periodic inservice inspection (with frequency determined by analysis results) will be performed.

SECTION 3.0
THERMAL TRANSIENT DEVELOPMENT

Adverse temperature distributions could occur in the auxiliary spray line and connecting main spray line if the auxiliary spray isolation valve admits leakage flow under certain thermal hydraulic conditions.

Several possible scenarios must be considered for transient evaluation. The first, and most likely condition, considers no leakage through valve 2IAB8RE (see figure 3-1). This condition has been evaluated in the original design analysis, and therefore further consideration is not required. A second condition assumes [

]^{a,c,e} This unlikely condition will not result in significant abnormal thermal transients, due to the small temperature difference between the two fluids. A third condition is possible in which [

]^{a,c,e} Due to the potential for excessive fatigue, this condition is evaluated in this report.

To develop a thermal transient for the assumed condition of cold leakage, it was necessary to evaluate the actual operating conditions of the spray line and determine the potential for thermal stratification, cycling and mixing.

3.1 Pressurizer Spray Line Operation

The flow rate in the main spray piping must be determined in order to evaluate the potential for thermal stratification and cycling in the potentially affected piping. Typical flow conditions in the main spray piping are summarized in this section, based on actual operating experience at the Byron and Braidwood Units.

The Byron and Braidwood pressurizer spray systems are typically operated with a 10 to 20 percent demand on spray valves 455B and 455C during 90 to 95 percent of the total time that the units are at normal operating conditions. There is a direct correlation between percent demand and percent of rated travel and therefore typical flowrates may be calculated using figure 3-2.

The design flowrate for the main spray line is [

]^{a,c,e}

Therefore, during 90 to 95 percent of the normal operating period, the main spray line flow rate is typically [ ]^{a,c,e}

During the remaining 5 to 10 percent of the normal operating period, the main spray flow rate will vary depending on plant conditions. While this flow may be sufficient to cause turbulent mixing of the potential inleakage from the auxiliary spray line (thus eliminating the potential for thermal cycling), it will be conservatively assumed that the flow conditions are such that thermal stratification and cycling will occur.

3.2 Stratification Thermal Hydraulics

Thermal stratification can occur in horizontal pipes when hot and cold fluids are present under certain thermal hydraulic conditions, including temperature, flowrate and pipe size. A measure of the potential for two fluids to stratify is given by the Richardson number, which is defined as follows:

$$Ri = gB\Delta TD/V^2$$

where: g = acceleration of gravity
B = volumetric expansion coefficient
ΔT = fluid temperature difference
D = pipe inside diameter
V = fluid velocity

Test data (reference 9) indicates that stratification is likely if the Richardson number is greater than or equal to approximately 1.0. Values much less than [ ]a,c,e It is assumed that a Richardson number of approximately [

]a,c,e

Since the most likely location of thermal cycling is [

]a,c,e This will provide the flow rate, and hence, fluid velocity for the calculation of the Richardson number.

In addition to flow rate, it is necessary to determine the fluid temperature difference (ΔT). This will be used in the Richardson number calculation and the thermal transient definition for the fatigue analyses.

An evaluation of the thermal transient which caused the Farley pipe crack (reference 8) resulted in a maximum temperature difference [

]a,c,e

The maximum potential temperature difference for the auxiliary spray piping is [

]a,c,e

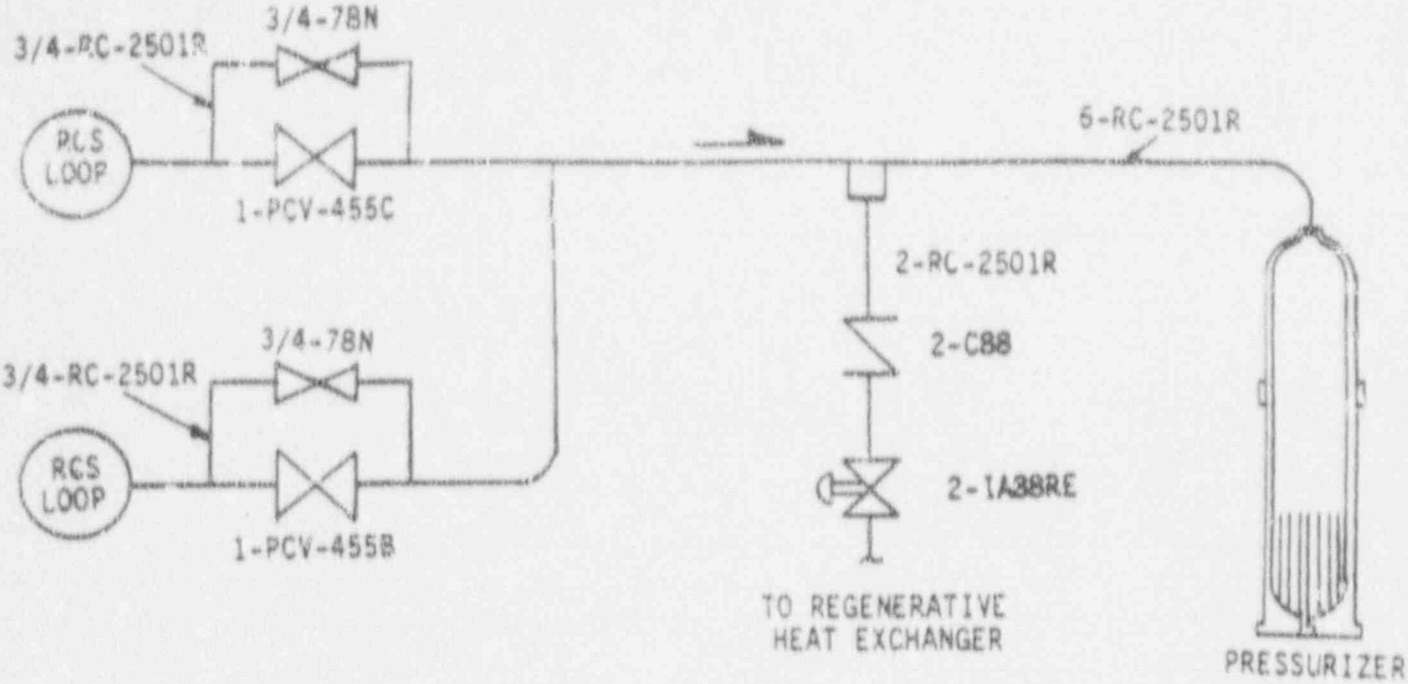
Based on a comparison of the maximum potential temperature differences for the Farley safety injection line and the Byron/Braidwood auxiliary spray lines, a temperature difference of [ ]a,c,e is conservatively assumed for thermal transients on the auxiliary spray line.

The potential for thermal stratification and cycling will be determined based upon the operating conditions defined in section 3.1 and the postulated transient, using the Richardson number.

For 90 percent of the operating time, the flowrate of [

]a,c,e Therefore, fatigue is not a concern for at least 90 percent of the normal operating period.

For the remaining 10 percent of the time, a [ ]a,c,e stratification transient will be considered in the fatigue evaluation.



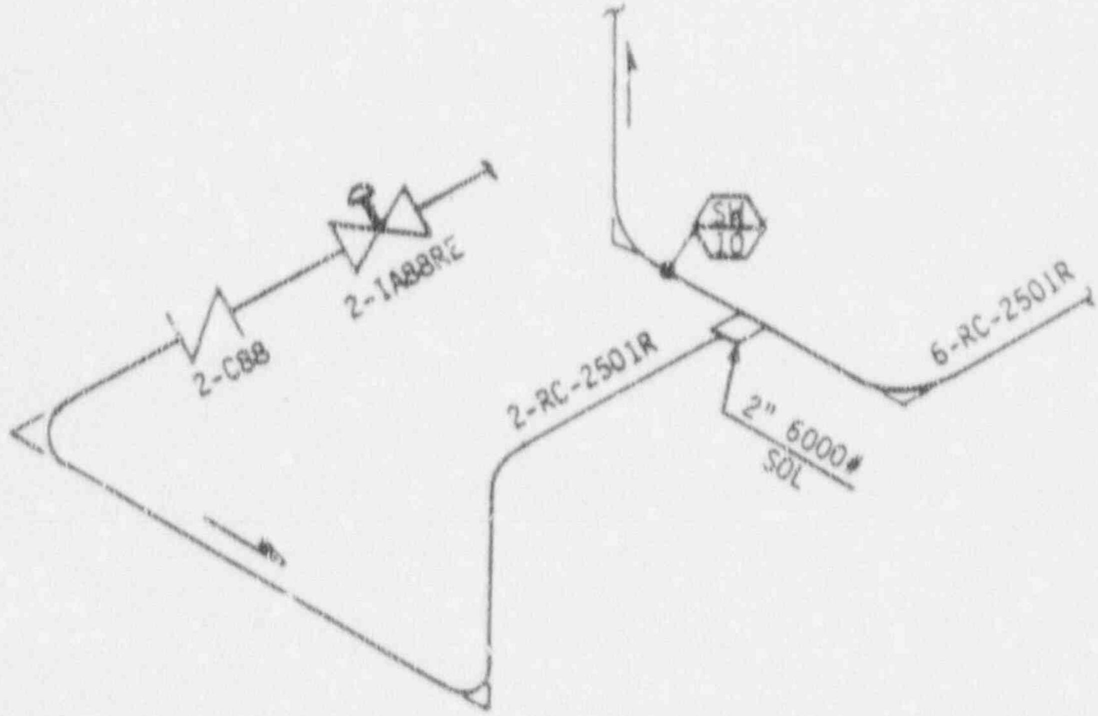


Figure 3-1. Flow Schematic and Typical Isometric Layout of Spray Piping

a,c,e

Figure 3-2. Valve % Rated Travel Versus % of Rated Flow for Main Spray Valve

SECTION 4.0
STRUCTURAL INTEGRITY AND FATIGUE ANALYSES

As described in the previous section, thermal cycling is possible during as much as ten percent of the time the Byron and Braidwood units are at normal operating conditions, should worst case auxiliary spray isolation valve leakage occur.

4.1 Thermal Loading

Since the transient for the assumed auxiliary spray line leakage is postulated, rather than actual, a conservative transient, based on the Farley safety injection experience was used in this evaluation. Based on temperature data from Farley and the expected low flow leakage conditions, a thermal profile was defined to be used in finite element thermal and stress analysis (see figure 4-1).

Assuming the thermal conditions shown in figure 4-1 are [

][a,c,e]

This temperature loading assumed a conservative transient period of [ ][a,c,e] minutes per cycle. Finite element analysis has shown that if the actual cycle time is shorter than [ ][a,c,e] minutes, the resulting stresses will be less severe, since heat transfer through the pipe thickness requires a certain amount of time. If the cycle time is longer than [ ][a,c,e] minutes, the local thermal stresses will be identical to the [ ][a,c,e] minute cycle, but the piping will be subjected to fewer cycles.

4.2 Stress Analysis

A thermal stratification loading will typically have two stress effects on piping, a "local" effect and a "global" effect. Local stresses can be obtained [

]^{a,c,e}

Global stresses result from [
]^{a,c,e}

[

]^{a,c,e}

The local stress for this evaluation is conservatively obtained using the [ ]^{a,c,e} The heat transfer elements used in the thermal analysis model were replaced with [
]^{a,c,e} and loaded with nodal temperature input from the heat transfer analysis.

4.3 Fatigue Analysis

A fatigue analysis was performed using fatigue crack growth methods, to ensure the structural integrity of the auxiliary spray and main spray piping, should the postulated transient occur. This fatigue evaluation will be used only to determine an acceptable period of operation between inservice inspection intervals.

The ASME Section XI method is based on stress analysis results and material crack growth laws. The stress intensity factor (K_I) required for the fatigue crack growth calculations is obtained from the K_I expression given

in reference 3 for an aspect ratio (2a/ℓ) of 1:6. The fatigue crack growth law for stainless steel in a pressurized water environment was obtained from reference 4. The crack growth per cycle da/dN (inches/cycles) is

[ ]^{a,c,e}

The stress intensity range input to the fatigue crack growth analysis was obtained from the maximum axial stress.

The results of the fatigue crack growth analysis indicate that approximately [ ]^{a,c,e} cycles of the postulated transient would be required to propagate an initial [ ]^{a,c,e} percent through wall crack to [ ]^{a,c,e} percent of the wall thickness. This cycling has been postulated to occur only during a maximum of ten percent of the time the plant is at normal operating conditions, should auxiliary spray line isolation valve leakage occur. Based upon the conservative transient period of [ ]^{a,c,e} minutes, this translates to 39 months of power operation. The inservice inspection interval is therefore recommended to be two refueling cycles, or approximately 39 months of power operation.

a,c,e

Figure 4-1. Thermal Loading Based on Farley SI Pipe Incident

a,c,e

Figure 4-2. Transient Loading on Inside Pipe Surface Used for Thermal Analysis

4014s/101989 10

a,c,e

Figure 4-3. Temperature Distribution in Pipe

SECTION 5.0

INSERVICE INSPECTION RECOMMENDATIONS

This section summarizes recommendations for inservice inspection on the Byron and Braidwood pressurizer spray and auxiliary spray lines for those locations susceptible to culd inleakage from the auxiliary spray line. This updates the recommendations provided in letter CAE-88-324 (reference 7), based on the evaluation summarized in this report.

5.1 Inservice Inspection Locations

Figure 5-1 illustrates the two general locations required for inservice inspection. The location labeled as [

]a,c,e

The other location is a [ ]a,c,e Figure 5-2 illustrates the most critical zones for potential crack indications in the vicinity [

]a,c,e

[

]a,c,e

5.2 Inservice Inspection Guidelines

The type of indications expected from this type of loading are generally ID initiated and circumferentially oriented cracks. For zone B, the orientation of potential indications is not known, except that they are expected to be ID initiated.

The following general UT guidelines previously provided in reference 7 reflect the experience of the inspection of the Farley Unit 2 safety injection line as discussed in NRC Bulletin 88-08, Supplement 2.

Larger Diameter Lines (4 to 6 inch)

Performing a 45 degree refracted shear wave examination using a 2.25 MHz 0.5 to 0.25 inch diameter transducer, calibrating out to a one and one-half vee exam for all of the above welds.

Performing an additional 60 degree refracted shear wave examination using a 0.50 to 0.25 inch diameter, 1.5 MHz transducer, calibrating out to a one and one-half vee exam for all of the above welds.

Scanning sensitivities should be at 14 dB above reference sensitivity with a noise level of less than 10% full screen height for the 45 and 60 degree exams. If the noise level exceeds the above limit, reduce the scanning sensitivity in one dB increments until the noise level drops to below the above level, and record this [illegible] on on the applicable data sheet.

Record and evaluate all indications that traveled in time, are not attributed to component geometry and have an amplitude of greater than or equal to 20% of the distance amplitude correction curved.

Smaller Diameter Lines (less than 4 inches)

As a result of the NRC bulletin 88-08, a number of smaller diameter pipes are now requiring inspection. It should be noted that these lines were not

designed for such inspection, and some locations may require advanced volumetric inspection techniques. Volumetric inspection can be either ultrasonic testing or radiographic testing.

1. Ultrasonic testing may involve use of miniature or specialized transducers with specific procedures for examining the volume of interest.

2. Radiographic techniques should be considered when unusual component geometry or large areas require inspection. These techniques should be qualified to ensure that proper coverage of the component volume of concern. Access for positioning the radioactive source is also an important consideration.

In some cases, it may be practical to use a combination of radiographic and ultrasonic testing techniques.

If any indications or suspect indications are detected during the above examinations, it is recommended that supplemental radiographic examination of that weld be performed.

a,c,e

Figure 5-1. Inservice Inspection Locations*

a,c,e

Figure 5-2. Inservice Inspection Location - Branch Connection

SECTION 6.0
REFERENCES

1. United States NRC Bulletin 88-08, "Thermal Stresses in Piping Connected to Reactor Coolant Systems," 6/22/88; Supplement 1, 6/24/88; Supplement 2, 8/4/88 and Supplement 3, 4/11/89.

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3. McGowan, J. J. and Raymund, M. "Stress Intensity Factor Solutions for Internal Longitudinal Semi-Elliptical Surface Flaws in a Cylinder Under Arbitrary Loadings," Fracture Mechanics, ASTM STP 677, 1979, pp. 365-380.

4. James, L. A., and Jones, D. P., "Predictive Capabilities in Environmentally Assisting Cracking," Special Publications, PVP-Vol. 99, ASME, Nov. 1985.

5. Program WECAN, version date 9/3/02A, cycle 22, 4/11/89, Westinghouse Proprietary.

6. Program FCG, cycle 3, 8/2/89, Westinghouse Proprietary.

7. Westinghouse letter CAE88-324, 9/21/88, "Commonwealth Edison Company, Byron/Braidwood Nuclear Stations, Response to NRC Bulletin 88-08."

8. WCAP-11786, Rev. 1, "J. M. Farley Unit 2, Engineering Evaluation of the Weld Joint Crack in the Six Inch Safety Injection and Residual Heat Removal Piping," July, 1989, Westinghouse Proprietary.

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11. Bamford, W. H., "Fatigue Crack Growth of Stainless Steel Reactor Coolant Piping in a Pressurized Water Reactor Environment," ASME Trans. Journal of Pressure Vessel Technology, Feb. 1979.