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NRC BULLETIN 88-08
EVALUATION OF AUXILIARY PIPING FOR COMANCHE PEAK UNIT 2

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SECTION 1.0
EXECUTIVE SUMMARY

This report provides an evaluation of the Comanche Peak Steam Electric Station Unit 2 normal charging, alternate charging, auxiliary spray and cold leg safety injection lines for the effects of potential thermal loadings and cycling resulting from isolation valve inleakage into the Reactor Coolant System, as described in NRC Bulletin 88-08. This evaluation includes the development of bounding transients and calculation of the effect of these transients on the integrity of the unisolable piping (i.e. the sections of piping between the Reactor Coolant System, or normal spray line, and the immediate upstream check valve).

Stress, fatigue usage and fatigue crack growth evaluations were performed in order to determine the potential for cracks to occur, and the time required for cracks to propagate at the critical locations. (The critical locations were determined to be the check valve outlet welds on the charging, alternate charging and cold leg safety injection lines, and the 6" x 2" sock-o-let on the auxiliary spray line.) Results of these evaluations indicated that the crack initiation times from fatigue usage calculation are 10 years, 10 years and 7 years for charging, alternate charging and cold leg safety injection lines, respectively. Furthermore, from fatigue crack growth calculation, the minimum time required for crack propagation to 60% of the wall thickness is 1.2 years, 20 years and 7 years for the charging, alternate charging and cold leg safety injection lines, respectively. These times represent total time at power operation. Periods when the line is in service should not be included in the determination of time at power operation, since only isolated piping is of concern. (The auxiliary spray line fatigue evaluation resulted in a cumulative usage factor less than 1.0 for the design life, therefore fatigue crack growth evaluation was not performed for this line.)

Augmented inservice inspection intervals at the critical locations should be developed based on these results. All other welds in these lines should be inspected in accordance with standard ASME Section XI criteria.

SECTION 2.0

BACKGROUND AND INTRODUCTION

Following the discovery of pipe cracks in the auxiliary lines of several commercial nuclear power plants, the United States Nuclear Regulatory Commission issued Bulletin 88-08 (Reference 1). Action Item 1 of the bulletin requested utilities to identify unisolable piping connected to the Reactor Coolant System (RCS) which is susceptible to adverse temperature distributions (not considered in the design of the piping) that could be induced by leakage through isolation valves into the RCS (inleakage). TU Electric identified the following lines for Comanche Peak (Reference 2):

[

]^{a,c,e}

Action Item 2 of the bulletin requested that utilities nondestructively examine (NDE) the welds, heat-affected zones and high stress locations, including geometric discontinuities of the identified piping to ensure that there are no existing flaws. Since Comanche Peak Unit 2 has not yet begun operation, NDE was not warranted.

Action Item 3 requested that a program be implemented to provide continuing assurance that unisolable sections of piping connected to the RCS will not be subjected to combined cyclic and static thermal and other stresses that could cause fatigue failure during the remaining life of the unit. To this end, an evaluation has been performed to determine augmented inservice inspection intervals, based on fatigue usage and fatigue crack growth methodology, and assuming continuous stress cycling.

Augmented inservice inspection intervals based on conservative thermal loadings and fatigue crack growth analysis provides a strong technical justification to eliminate the need for continuous temperature monitoring of the charging, alternate charging, auxiliary spray and cold leg safety injection lines, while still satisfying the requirements of NRC Bulletin 88-08.

SECTION 3.0
OVERALL EVALUATION APPROACH

Upon reviewing the monitoring results from Unit 1 for charging, alternate charging, auxiliary spray and cold leg safety injection lines for the period from March 15, 1990 to August 6, 1991, it was found that there was no evidence of valve leakage in the unisolable piping.

For the purposes of analysis and Bulletin 88-08 requirements, it was postulated that stress cycles occur continuously in the unisolable piping during plant operation, resulting from postulated isolation valve leakage. (This valve leakage is considered herein as a postulated condition and should not be treated as a design condition).

The steps in the structural evaluation of the unisolable piping under the postulated valve leakage loadings are listed below:

[

]^{a,c,e}

Comanche Peak Unit 2 has not yet begun commercial operation. Given that the unit is new, and has experienced very little fatigue cycles, it is highly unlikely that cracks are present in the susceptible piping. Fatigue usage is calculated to determine the time required for crack initiation. Furthermore, fatigue crack growth is then calculated, [

]^{a,c,e}

Based upon the time required to initiate and to propagate cracks [ ]^{a,c,e} augmented inservice inspection intervals will be determined for the critical locations of the susceptible piping.

SECTION 4.0
CHARGING AND ALTERNATE CHARGING SYSTEM EVALUATION

4.1 Determination of Thermal Stratification Loading

There are two charging paths provided in the Comanche Peak design. The first is the normal charging line to the cold leg of RCS Loop 4; the second is the alternate charging line connected to the cold leg of Loop 1. During normal plant operation, one of these lines will be in service, with the other line isolated. When the line is isolated, the postulated leakage can induce stress cycling.

The source of postulated leakage is the outlet of the regenerative heat exchanger, which is typically at [

]^{a,c,e} before entering the unisolable piping (i.e., the piping between the RCL branch connection and the adjacent check valve. Depending on leakage flowrate and insulation characteristics, it is possible for the leakage to cool significantly over this distance, resulting in thermal stresses in the unisolable piping. [

]^{a,c,e} calculations were performed for both lines.

Heat transfer calculations were carried out to determine the leakage temperature as it enters the unisolable piping, [

]^{a,c,e}

Piping layouts for the Comanche Peak Units 1 and 2 charging and alternate charging lines are similar in the unisolable sections. Temperature monitoring of the alternate charging line on Comanche Peak Unit 1 had indicated an unisolable piping temperature of about [ ]^{a,c,e}

[ ]^{a,c,e} while the line was isolated, and no indication of valve leakage. (The normal charging line was in service during the monitoring period, therefore [ ]^{a,c,e} was also assumed for the charging line, since the charging and alternate charging lines are geometrically similar in the unisolable sections). Given an unisolable piping temperature for the line not in service and the leakage temperature, a stratification temperature difference was determined, as a function of leakage flowrate.

Using an approach presented by Ven Te Chow (Reference 3), the stratification interface depth can be related to [ ]^{a,c,e} For the purpose of this evaluation, the stratification interface depth [ ]^{a,c,e} Corresponding leakrates and stratification temperature differences (and hence through-wall thermal gradient stresses) were then determined. For the charging line, this resulted in a leakage flowrate of [ ]^{a,c,e} For the alternate charging line, the leakrate was [ ]^{a,c,e}

4.2 Stress Evaluation

A thermal stratification loading will typically have two stress effects on piping, a "local" effect and a "global" effect. Local stresses may be obtained by modeling [ ]^{a,c,e}

Global stresses result from the effects of not allowing the piping to "bow" as it would in the unrestrained condition. This restraint results from piping supports and the piping itself. [ ]^{a,c,e}

[

]^{a,c,e}

4.2.1 Local Stress Evaluation

In order to determine the magnitude of local stresses resulting from the postulated stratified leakage, the thermal distribution within the pipe must be resolved. This was done using [

]^{a,c,e} The Westinghouse general purpose finite element program WECAN (Ref. 4) was used to solve for the thermal distribution, [

]^{a,c,e}

The local stresses for the postulated leakage were obtained by replacing the heat transfer elements used in the thermal analysis model with [

]^{a,c,e} elements.

It was shown in Reference 5 that [

]^{a,c,e}

4.2.2 Global Stress Evaluation

Global stresses were obtained by performing a thermal stress analysis of the pipe with stratified fluid postulated to occur in the section of pipe between the reactor coolant loop and the adjacent check valve. Bending stresses result from [

]^{a,c,e}

This was consistent with the local stress analysis as detailed in section 4.2.1. Turbulence was assumed to extend into the charging lines from flow in the reactor coolant loop. Turbulence limits the length of stratified piping by causing mixing of hot and cold fluid. The turbulent region was assumed to extend into the alternate charging line to a distance of [ ]^{a,c,e}

The alternate charging line was determined to envelope both normal and alternate charging lines because stresses were higher [

$]^{a,c,e}$

delta T for both lines. The fluid temperature between the regenerative heat exchanger header and the check valve adjacent to the RCL was varied [

$]^{a,c,e}$ of the leaking fluid.

Two separate leakage cases were analyzed, one with fluid stratified and the other without fluid stratified. However, both cases consider the temperature [

$]^{a,c,e}$ These cases provided a range of moment stresses for cycling. The global moment stresses were combined with local effects in the fatigue evaluation to determine fatigue usage for the postulated leakage loading.

4.3 Fatigue Evaluation

The fatigue evaluation of the charging and alternate charging lines for postulated leakage was performed based on the requirements of ASME B&PV Code, (1979 Edition), Section III, Subsection NB-3653, for piping components. Fatigue usage was calculated at [

$]^{a,c,e}$ This location was judged to be the critical fatigue location because both postulated leakage stress and design usage factor were high.

The [$]^{a,c,e}$ was evaluated by considering the following transients:

[

$]^{a,c,e}$

The postulated leakage transient consisted of two loadsets. [

]^{a,c,e}

Each of the loadsets were allowed to combine according to the requirements of the ASME Code until all cycles were exhausted. [

]^{a,c,e} design were selected for use in the fatigue evaluation. The design fatigue curve used in the calculation of usage factor was presented in the 1986 ASME Code Figure I-9.2.1 and I-9.2.2, for austenitic stainless steels. These curves were used because they include high cycle fatigue considerations. Usage was calculated for all transients [

]^{a,c,e}

4.4 Fatigue Crack Growth Evaluation

The critical location for the normal and alternate charging lines was determined to be [

]^{a,c,e}

The unisolable piping will heat the leakage as it flows toward the RCL, and loop turbulence will promote mixing, thus reducing the stratification temperature difference at other locations in the unisolable piping.

A credible mechanism to initiate and terminate isolation valve leakage does not exist, therefore continuous leakage was postulated at the critical leakrate. Fatigue cycles are possible, however, [

]^{a,c,e}

[ ]^{a,c,e} The methods of fracture mechanics were then employed to determine crack propagation time.

4.4.1 Method Description

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 6. The fatigue crack growth law for stainless steel in a pressurized water environment was obtained from Reference 7. The crack growth in inches per cycle is

$$da/dn = (C)(F)(S)(E)\ \Delta K^{3.30}$$

where: $C = 2.42 \times 10^{-20}$
F = frequency factor (F = 1.0 temperatures below 800°F)
S = minimum K to maximum K ratio correction ($S = 1.0$ for $R = 0$;
$S = 1 + 1.8R$ for $0 < R < 0.8$; and $S = -43.35 + 57.97R$ for $R > 0.8$)
where R = ratio of the minimum K_I to the maximum K_I
E = environmental factor
ΔK = range of stress intensity factor, psi $\sqrt{in}$

4.4.2 Fatigue Crack Growth Results

As for the fatigue usage evaluation, the fatigue crack growth evaluation was based upon a [ ]^{a,c,e} cyclic frequency. Under this cyclic frequency, the period of time required to propagate an initial crack of [ ]^{a,c,e} was determined to be [ ]^{a,c,e} of power operation for the normal charging line and [ ]^{a,c,e} of power operation for the alternate charging line. It should be noted that periods when the line is in service should not be included in the determination of time at power operation, since only isolated piping is of concern.

a, c, e

Figure 4-1. Normal Charging Line Leakage Temperature as it Enters the Unisolable Piping

a, c, e

Figure 4-2. Alternate Charging Line Leakage Temperature as it Enters the Unisolable Piping

a, c, e

Figure 4-3. Thermal Loading for Postulated Leakage - Charging and Alternate Charging Lines

a, c, e

Figure 4-4. Steady State Temperature Distribution for Postulated Leakage Charging and Alternate Charging Lines

a, c, e

Figure 4-5. Steady State Stress Intensity for Postulated Leakage - Charging and Alternate Charging Lines

SECTION 5.0
AUXILIARY SPRAY SYSTEM EVALUATION

5.1 Determination of Bounding Transient

The auxiliary spray line provides a flow path from the regenerative heat exchanger to the main spray line, and is isolated during normal plant operation. The connection to the main spray piping is essentially a 15'-6" riser, which branches into the bottom of the horizontal main spray line.

The source of potential leakage is the outlet of the regenerative heat exchanger, which is typically at [ ]^{a,c,e} during normal plant operation. The distance from the leakage source to the unisolable piping is about [ ]^{a,c,e} therefore the temperature of the leakage flow as it enters the unisolable piping may be substantially less than the source temperature, depending on leakage flowrate and insulation characteristics.

Since the unisolable piping is essentially a long vertical riser which extends down from the main spray line, it is expected that the inlet to the unisolable piping (the check valve outlet weld) will be at containment ambient temperature, without isolation valve leakage. Such a condition is commonly termed "cold trap." The temperature in other regions of the unisolable piping are determined [ ]^{a,c,e} from the main spray line temperature.

Should isolation valve leakage occur in the auxiliary spray line, it would enter the unisolable piping in the "cold trapped" region, and gradually heat up and disperse into the bulk fluid as it flowed upward toward the main spray connection. Stratification, in the general sense, does not occur in vertical pipes, therefore it is expected that the thermal loadings would be axisymmetric and relatively small.

5.2 Stress Evaluation

Since stratification does not occur for the leakage condition, global stresses are not affected. However, it was necessary to consider an additional transient at the 6" x 2" sock-o-let. This transient consisted of the effects of leakage water flowing from the auxiliary spray line into the main spray line. This transient was conservatively [

]a,c,e A heat transfer analysis of the leakage transient was performed to determine the thermal transient effects for use in the fatigue calculations.

5.3 Fatigue Evaluation

As for the charging and alternate charging lines, no credible mechanism exists to initiate and terminate auxiliary spray line isolation valve leakage. Fatigue cycles are possible, however, during main spray operation, which creates turbulent penetration into the auxiliary spray line. (Typically, the main spray line is operated with a bypass flowrate of 1 to 5 gpm, in order to prevent thermal shock to the pressurizer spray nozzle during spray actuation. This reduced flowrate results in essentially no turbulent penetration into the auxiliary spray line.)

The fatigue evaluation of the auxiliary spray line for postulated leakage was performed based on the requirements of ASME B&PV Code (1979 Edition), Section III, Subsection NB-3653, for piping components. Fatigue usage factor was calculated at the 6 x 2" sock-o-let which connects the auxiliary spray line to the main spray line,[ ]a,c,e

The sock-o-let was evaluated by considering the following transients:

[

]a,c,e

The postulated leakage transient consisted of two loadsets. [

]a,c,e

Each of the loadsets were allowed to combine according to the requirements of the ASME Code until all cycles were used up. [

]^{a,c,e} design were selected for use in the fatigue evaluation. The design fatigue curve used in the calculatin of usage factor is the 1986 ASME Code, Figure I-9.2.1 and I-9.2.2, for austenitic stainless steels. These curves were used because they include high cycle fatigue considerations. Usage factor was calculated for all transients [

]^{a,c,e}

Fatigue crack growth evaluation was not performed, based on the fatigue usage results.

SECTION 6.0
COLD LEG SAFETY INJECTION SYSTEM EVALUATION

6.1 Determination of Bounding Transient

The 1-1/2 inch cold leg safety injection lines connect to the cold legs of each of the four RCS loops. During normal plant operation, these lines are isolated from centrifugal charging pump pressure. Under postulated isolation valve leakage, the potential for stress cycling exists in the unisolable piping sections.

In order to evaluate the effect of isolation valve leakage on the safety injection lines, plant monitoring data was reviewed for a plant which is known to have had valve leakage (Reference 8), and a leakage transient was developed based upon the most severe loading observed. This transient had an initial fluid temperature of about [ ]^{a,c,e} and the final fluid temperature was about [ ]^{a,c,e} The outer pipe wall temperature remained relatively constant prior to and after the transient. The time required for the pipe outer wall temperature to drop [ ]^{a,c,e} These parameters were used as inputs to the heat transfer analysis.

In order to define the fluid temperature transient occurring within the pipe which yields the observed outer wall temperatures, it was assumed that the fluid transient is [

]^{a,c,e}

A WECAN finite element axisymmetric model consisting of [ ]^{a,c,e} elements was used for the heat transfer analysis as well as the stress analysis. By loading the inner pipe wall of the model with the fluid transient, [ ]^{a,c,e} matched the monitored outer wall temperature.

Analyses were performed for a range of inside wall film coefficients since the film coefficient is a function of fluid velocity, which cannot be accurately determined by noninstrusive methods. The fluid velocities used in the film coefficient calculation varied from [ ]^{a,c,e} which is a reasonable range for valve leakage in a small pipe.

Two solutions were found which matched the outside wall temperatures of the monitored transient [ ]^{a,c,e} A smaller film coefficient was attempted, but a match with the monitored data could not be obtained. Matches could also be obtained using [ ]^{a,c,e}

These fluid transients were used as the basis for the stress and fatigue analysis.

6.2 Stress Evaluation

6.2.1 Local Stress Evaluation

In order to verify that the simplified [ ]^{a,c,e} finite element model was valid for stress analysis, the model was analyzed with a typical boron injection design transient (560°F to 70°F portion only). The results were compared to the design analysis, which used a more detailed [ ]^{a,c,e} model. The simplified model correlated well with the detailed model.

The simplified finite element stress model was loaded with the [ ]^{a,c,e} transients from Section 6.1. Peak stresses were shown to maximize at approximately [ ]^{a,c,e} For the inleakage local stress, it was conservatively assumed that all inleakage transients occur at a ΔT of [ ]^{a,c,e} Values for other components were obtained by multiplying the straight pipe peak stress intensity by the appropriate ratio developed from the original detailed design analysis.

6.2.2 Global Stress Analysis

Global stresses were obtained by performing a thermal stress analysis of the pipe with stratified fluid postulated to occur in the section of pipe between the reactor coolant loop and the first check valve. Although it is unlikely for stratification to occur in such a small diameter pipe, stratification was conservatively considered in the global stress analysis. Bending stresses result from the effects of pipe routing, supports and restraints which counteract the bowing effects of stratified fluid in the pipe. [

]^{a,c,e}

The delta T between stratified fluid was chosen to be [

]^{a,c,c}

The global moment stresses were combined with local effects in the fatigue evaluation to determine usage for postulated leakage.

6.3 Fatigue Evaluation

The fatigue evaluation of the boron injection lines for postulated leakage was performed based on the requirements of ASME B&PV Code (1979 Edition), Section III, Subsection NB-3653, for piping components. Fatigue usage was calculated [

]^{a,c,e} These locations were judged to be the critical fatigue locations because both local leakage stress and design usage factor were high.

[

]^{a,c,e}

The postulated leakage transient consisted of two loadsets. [

]^{a,c,e}

Each of the loadsets were allowed to combine according to the requirements of the ASME code until all cycles were used up. [
]^{a,c,e} design were selected for use in the fatigue evaluation. The design fatigue curve used in the calculation of usage was presented in the 1986 ASME Code Figure I-9.2.1 and I-9.2.2, for austenitic stainless steels. These curves were used because they include high cycle fatigue considerations. Usage was calculated for all transients involving design effects [

]^{a,c,e}

6.4 Fatigue Crack Growth Evaluation

The critical location for the cold leg safety injection lines was determined to be the [
]^{a,c,e} The unisolable piping will heat the leakage as it flows toward the RCS, and loop turbulence will promote mixing, thus reducing the stratification temperature difference at other locations in the unisolable piping.

A credible mechanism to initiate and terminate isolation valve leakage does not exist. However, fatigue cycles were postulated [

]^{a,c,e} The methods of fatigue crack growth were then used to determine crack propagation time.

Fatigue crack growth evaluation resulted [

]^{a,c,e}

SECTION 7.0

SUMMARY AND CONCLUSIONS

A detailed evaluation has been completed for the Comanche Peak Unit 2 normal charging, alternate charging, auxiliary spray and cold leg safety injection lines in response to concerns raised in NRC Bulletin 88-08.

Conservative assumptions were made to develop postulated isolation valve leakage transients. Subsequent calculations of stress, fatigue usage and fatigue crack growth were performed, in order to determine the potential for cracks to occur and the time required for cracks to propagate.

Results of this evaluation are presented below.

Line	Critical Location	Initiation Time	Propagation Time**

[

]^{a,c,e}

It is concluded that the requirements of NRC Bulletin 88-08 are satisfied based on the following:

- Conservative technical evaluations provided in this report
- Augmented inservice inspection intervals, and
- Implementation of the CPSES Unit 2 long-term transient and fatigue cycle monitoring program

Augmented inservice inspection intervals at the critical locations should be developed based on these results. All other welds in these lines should be inspected in accordance with standard ASME Section XI criteria.

SECTION 8.0
REFERENCES

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