ATTACHMENT 4 TO AEP:NRC:4034-08

WESTINGHOUSE ELECTRIC COMPANY LLC

WCAP-14070-NP
Revision 0

"EVALUATION OF DONALD C. COOK UNITS 1 AND 2 AUXILIARY SPRAY PIPING PER NRC BULLETIN 88-08"

MAY 2004

NON-PROPRIETARY

Westinghouse Non-Proprietary Class 3

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1.0 INTRODUCTION AND BACKGROUND

NRC Bulletin 88-08 (Reference 1) was issued on June 22, 1988 as a result of a pipe cracking incident at Farley Unit 2, and subsequent evaluations which confirmed that valve leakage caused the failure. The purpose of the bulletin was to request that licensees review their reactor coolant systems (RCS's) to identify any connected, unisolable piping that could be subjected to adverse thermal stresses, and take action to ensure that such piping will not be subjected to unacceptable thermal stresses.

Three specific actions were requested by Bulletin 88-08:

1) Review systems connected to the RCS to determine whether unisolable sections of piping connected to the RCS can be subjected to stresses from temperature stratification or temperature oscillations that could be induced by leaking valves, and that were not evaluated in the design analysis of the piping.

2) For any unisolable sections of piping connected to the RCS that may have been subjected to excessive thermal stresses, examine nondestructively the welds, heat-affected zones and high stress locations, including geometric discontinuities, in that piping to provide assurance that there are no existing flaws.

3) Plan and implement a program to provide continuing assurance that unisolable sections of all piping connected to the RCS will not be subjected to combined cyclic and static thermal and other stresses that could cause failure during the remaining life of the unit. This assurance may be provided by redesigning and modifying these sections of piping to withstand combined stresses caused by various loads including temporal and spatial distributions of temperature resulting from leakage across valve seats; instrumenting this piping to detect adverse temperature distributions and establishing appropriate limits on temperature distributions; or providing a means for ensuring that pressure upstream from block valves which might leak is monitored and does not exceed RCS pressure.

The NRC was prompted to issue Supplement 1 to Bulletin 88-08 on June 24, 1988, following a pipe cracking incident at Tihange Unit 1 in Belgium. This crack was in the base metal of an elbow, and not in the weld or heat-affected zone, as at Farley. The purpose of this supplement was to emphasize the need for sufficient examinations of unisolable piping connected to the RCS to ensure that there are no rejectable crack or flaw indications, and that examinations of high stress locations should include the base metal, as appropriate.

Supplement 2 of Bulletin 88-08 was issued on August 4, 1988. The experience at Farley Unit 2 and Tihange Unit 1 indicated that the ultrasonic testing procedures used were unable to reliably detect thermal fatigue cracks in stainless steel piping. Therefore, the purpose of this supplement was to emphasize the need for enhanced ultrasonic techniques and experienced examination personnel to detect such cracks.

Supplement 3 of Bulletin 88-08 was issued as a result of a cracking incident in the residual heat removal suction piping at a foreign reactor on June 6, 1988. This incident was different than the Farley incident, in that this event involved "hot" leakage exiting the RCS, whereas the previous incidents involved "cold" leakage entering the RCS. Also, this event involved periodic leakage through the valve packing gland, whereas the Farley incident involved steady leakage through the isolation valve (upstream to downstream). Therefore, the purpose of this supplement was to alert utilities that periodic valve seat leakage through packing glands could result in unacceptable thermal stresses.

The incidents resulting in the issuance of NRC Bulletin 88-08 and its supplements have several common factors:

1) the thermal loading was stratified
2) the root cause was related to leakage through an isolation valve
3) the failures occurred in unisolable piping
4) the damage resulted from thermal fatigue.

To comply with the requested actions of NRC Bulletin 88-08, United States utilities and many utilities in other countries have initiated programs to identify and inspect susceptible piping, and also provide for "continuing assurance"of piping integrity. These methods have included redesign/modification, temperature or pressure monitoring, inspection methods (periodic valve inspection, leak testing or nondestructive testing), operational modifications, and structural integrity analysis. In addition to these programs, the Electric Power Research Institute's TASCS (ThermAl Stratification, Cycling and Striping) Program was initiated to study the various phenomena associated with valve leakage, and develop methods to predict and evaluate the impact on structural integrity. Westinghouse is the prime contractor for the EPRI TASCS Program. Results of this study are included in Reference 2.

In response to NRC Bulletin 88-08, American Electric Power Service Corp. (AEP) performed a systems review of the lines at Donald C. Cook Units 1 and 2 to identify possible areas where valve leakage may jeopardize piping integrity. The following unisolable sections of auxiliary piping connected to the RCS were reviewed (WCAP-12143, Reference 5):

1) Normal and Alternate Charging System

3) Pressurizes Auxiliary Spray System

In March of 1992, American Electric Power Service Corporation initiated a comprehensive program to investigate the effects of auxiliary spray line valve leaks on the structural integrity of the auxiliary spray piping and the connecting main spray piping. The program included temporary temperature monitoring, data analysis, stress and fatigue analysis. It is the purpose of this report to document those efforts.

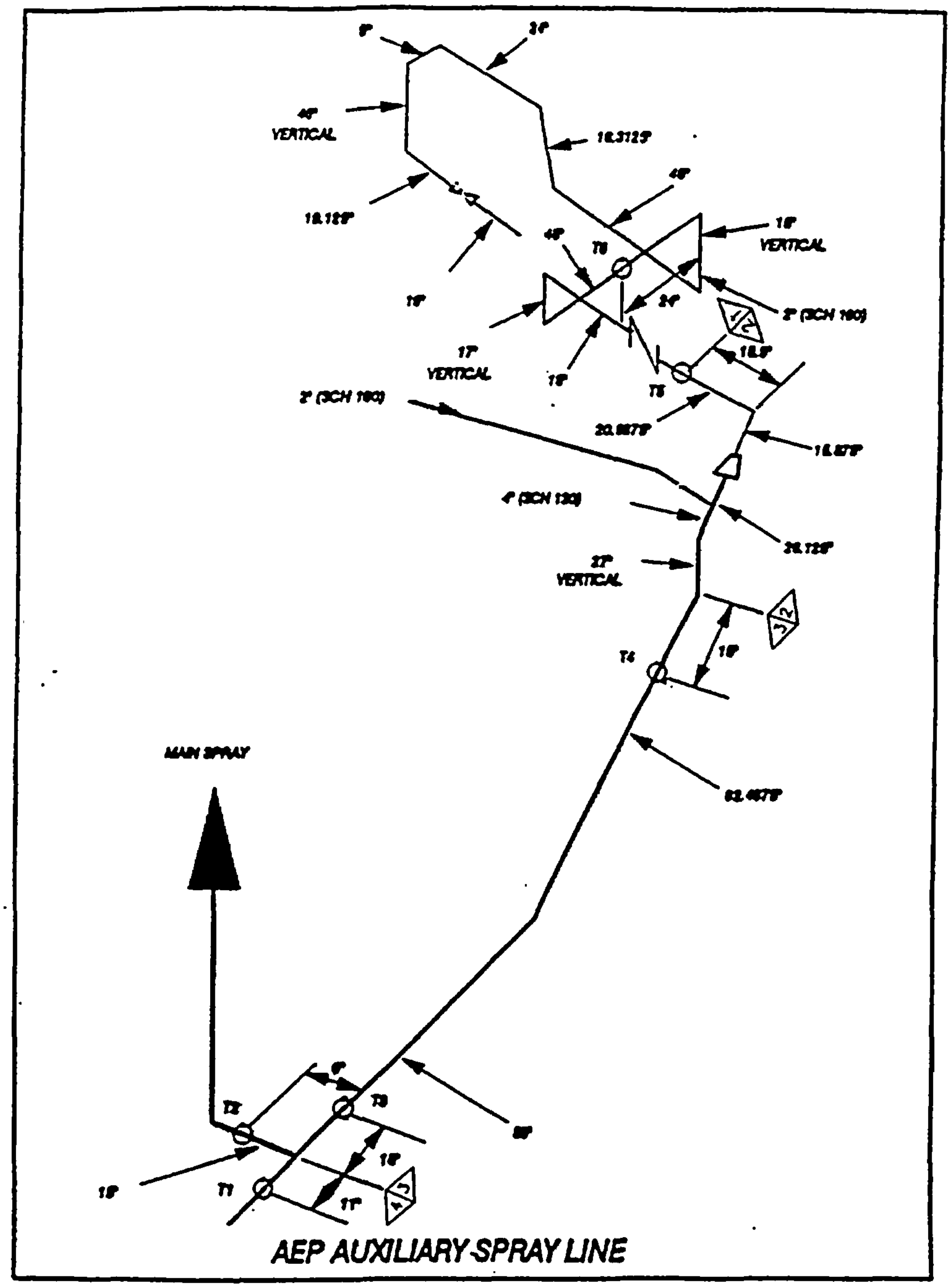
AEP has chosen to perform fatigue analysis based on the requirements of the ASME B&PV Code, 1986 Edition, Section III, Subsection NB-3653, for piping components. (The code of record for the design analysis is B31.1, 1967 which has no fatigue requirements). This analysis includes both design transients and valve leakage transients. The purpose of this report is to describe the methodology, inputs and conclusions of the isolation valve leakage analysis.

2.0 TEMPERATURE MONITORING

The temperature monitoring program utilized twelve Resistance type Temperature Detectors (RTD's) measuring top and bottom temperatures at six axial locations on the auxiliary spray and main spray piping. The specific arrangements of RTD's are shown in figure 2-1. Monitoring locations 1, 2, and 3 were concentrated on the 4" schedule 120 main spray line tee. Monitoring location 4 was on the four inch line approximately 15" from a vertical riser. Monitoring location 5 was located on the 2" schedule 160 piping just downstream of the auxiliary spray line check valve. Monitoring location 6 was located on a horizontal section of the two inch auxiliary spray piping approximately 17 feet downstream from the auxiliary spray isolation valve. In addition to the external temperature monitoring of the pipe, the following plant parameters were monitored: main spray flows; pressurizes steam and liquid space temperatures; charging temperature; RCS temperatures; and primary loop flows. The monitoring data was recorded once every two minutes, and all data were retained for analysis. The following definitions apply:

"ΔT"	=	The temperature difference between the top and bottom of the pipe.
T1-1	=	The top temperature measurement at location 1
T1-2	=	The bottom temperature measurement at location 1
T2-1	=	The top temperature measurement at location 2
T2-2	=	The bottom temperature measurement at location 2
T3-1	=	The top temperature measurement at location 3
T3-2	=	The bottom temperature measurement at location 3
T4-1	=	The top temperature measurement at location 4
T4-2	=	The bottom temperature measurement at location 4
T5-1	=	The top temperature measurement at location 5
T5-2	=	The bottom temperature measurement at location 5
T6-1	=	The top temperature measurement at location 6
T6-2	=	The bottom temperature measurement at location 6
D 1	=	The calculated ΔT at location 1
D2	=	The calculated ΔT at location 2
D3	=	The calculated ΔT at location 3
D4	=	The calculated ΔT at location 4
D5	=	The calculated ΔT at location 5
D6	=	The calculated ΔT at location 6

FIGURE 2-1 AUXILIARY SPRAY LINE MONITORING LOCATIONS



3.0 DEVELOPMENT OF ANALYTICAL MODEL

The following sections describe the analytical methods used to evaluate the various loading conditions in auxiliary spray line. Figure 3-1 illustrates the terminology used in the heat transfer discussions which follow.

3.1 Heat transfer coefficients

To evaluate the structural integrity of a pipe with a TASCS loading, the pipe wall temperature is required. To obtain the pipe wall temperature, heat transfer coefficients must be determined. These heat transfer coefficients for the water-to-pipe (h_{12}), and insulation-to-air (h_{45}) were calculated for the Donald C. Cook Units 1 and 2 auxiliary spray piping, using a combination of the methods described below.

3.1.1 Pipe Inner Surface Heat Transfer Coefficient

For the heat transfer analyses, the following heat transfer coefficient was applied to the entire pipe inner surface for the steady state solution (Reference 2).

a,c,e

This coefficient (h_{12}) is for free convection between the water and the pipe metal. Due to the low velocities involved in leakage flows, free convection has been calculated to be significantly higher than forced convection, and therefore controls the heat transfer.

3.1.2 Insulation Outer Surface Heat Transfer Coefficient

The heat transfer from the surface of the insulation follows a parallel path to the air (through convection and radiation), whereas the heat transfer from the water and through the pipe metal and insulation follows a series path. The heat transfer coefficient for the insulation outer surface (h_{45}) is comprised of free convection and radiation to the ambient air:

[ ]^{a,c,e}

The free convection heat transfer coefficient is defined as follows:

[ ]^{a,c,e}

The heat transfer is assumed to be free convection from the insulation surface.

The radiation heat transfer coefficient is defined as follows:

[ ]^{a,c,e}

Temperatures for the radiation heat transfer calculation must be in degrees Rankine.

Values for the convection and radiation heat transfer film coefficients of [ ]^{a,c,e} were calculated for the auxiliary spray piping.

3.2 Heat transfer from conduction

To determine the temperature distribution for TASCS evaluations, it is often required to perform heat transfer calculations for flows which are not stratified or for stagnant pipe sections. Generally, this is required to determine the temperature distribution in a pipe line as a boundary condition to the section of pipe with a TASCS loading.

One example of this is a case in which a leak is initially at a high temperature but must travel some distance from the original leak location to the unisolable pipe section where a TASCS evaluation is required. It must be determined if the leak can cool before it reaches the unisolable pipe. High leak rates will remain hot, and small leaks will cool down. Another example is the determination of the piping temperature distribution in the vicinity of the unisolable piping. Since the leakage flow rates in TASCS evaluations are generally low, leakage may significantly heat up before entering the unisolable piping. Therefore, the boundary temperature distribution must be quantified prior to performing leakage heatup calculations.

3.2.1 Flow without Stratification

This section provides closed form solutions to determine the axial temperature distribution in the Donald. C. Cook Units 1 and 2 auxiliary spray piping, assuming that leakage flows from the regenerative heat exchanger, through the closed isolation valves and toward the unisolable piping. From this, the temperature of the leakage near the entrance to the unisolable piping is determined. (This temperature will be used in the calculation of leakage flow heat up in Section 3.4). Assuming that the ambient temperature is [ ][a,c,e], the cooling of leakage flow which is initially hot [ ][a,c,e] is determined along the pipe length. It is assumed that stratification is not significant for this case since the pipe, at a given cross-section, will tend to reach a near-uniform temperature distribution in the steady state. The axial temperature distribution is determined by (Reference 2):

[ ] a,c,e

The overall heat transfer coefficient can be determined using the following formula:

[ ] a,c,e

Methods for calculating the heat transfer coefficients, h_{12}, and h_{45} were described in Section 3.1.

3.3 Height of a stratified flow

When thermal stratification occurs, the pipe is partially filled with hot water and partially filled with cold water. In some cases, the interface is very small and the gradient is very large. In the other extreme, the transition between the hot and cold fluid can occur over the entire pipe cross-section (see Figure 3-2). The causes of each of these two cases are related in a complex fashion to the flow rate, temperature difference, length of flow, pipe slope, pipe material and temperature (insulation characteristics), entrance conditions and exit conditions.

Once the interface height (H) has been identified, the velocity and other fluid parameters can be calculated for given volumetric flow rates. This is important because calculation of the heat transfer and stability of a stratified flow are dependent on the flow velocity.

The calculation of the stratification interface height (H) is based on the variable, y_c, the critical depth, where [ ]^{a,c,e} (Reference 2). See Figure 3-3 for geometric relationships. The method to calculate y_c follows.

The critical depth (y_c) is calculated using an iterative solution of the following equation (Reference 2):

a,c,e

Note: the same geometric parameters, A, W, and α are used to characterize H, with the subscript "y" eliminated.

This methodology was used to estimate the height of the interface of the stratified flow in the unisolable sections of the auxiliary spray piping: This approach inherently assumes that the interface is well defined, which is generally a required assumption in evaluating a stratified flow. This approach also assumes that there is flow involved in the stratified loading. In the case of the Donald. C. Cook evaluation, this flow is the leakage from the regenerative heat exchanger. (There are cases where a stratified condition can be established without a sustained flow, such as the stratification resulting from free convection currents).

3.4 Heat transfer in stratified flows

This section provides the methodology used to determine the heat transfer of the stratified fluid flow. A finite difference solution that evaluates the steady state thermal distribution of a piping section subject to low velocity fluid flows was developed. The solution was based on an overall energy balance that takes into consideration the combined effects of convection, diffusion, and ambient heat losses. The solution utilized a finite difference method to solve a system of sixty control volumes. The model considers both the pipe metal and fluid control volumes. Each cross section of the model in the x (axial) direction has six elements. The outer elements (elements in rows 1 and 6) were modeled as piping material with temperature dependent material properties of stainless steel. The inner elements (rows 2 to 5) were water elements with temperature dependent properties of water. The solution considers the effects of a convective mass transport mechanism under appropriate conditions. The basis for the solution method is developed in the following pages. The solution method utilized algorithms developed by S. V. Patankar for steady low-velocity fluid flow with negligible viscous dissipation. The initial derivation of the finite difference equations and the resulting solution method were taken from Reference 10, where the general differential equation for convection and diffusion is:

$$\partial/\partial t\cdot(\rho\Phi) + \nabla(\rho u\Phi) = \nabla(\Gamma\nabla\Phi) + S$$

Where Φ is some dependent variable, Γ represents the diffusion coefficient and S is the source term.

For the two dimensional convection and diffusion problem the equation can be written as:

$$\partial/\partial t\cdot(\rho\Phi) + \partial J_x/\partial x + \partial J_y/\partial y = S$$

Where J_x and J_y are the total (convection plus diffusion) fluxes defined by:

$$J_x \equiv \rho u\Phi - \Gamma\,(\partial\Phi/\partial x)$$

$$J_y \equiv \rho v\Phi - \Gamma\,(\partial\Phi/\partial y)$$

where u and v are the velocity components in the x and y directions.

Integration of these equations over the control volume yielded the appropriate discretization equations. The discretization equations were used to model a fixed size element array that models both the pipe material and internal fluid. There were twenty pipe elements, ten along the top of the pipe and ten along the bottom of the pipe and forty fluid elements. It is important to note that the angular sizes of the pipe elements were determined by the flow rates and the calculated values for the leak flow area per section 3.3. The primary purpose of the model was to calculate the top and bottom pipe metal temperatures along the length of the pipe. With this in mind, the development of appropriate velocity field to couple with the mass flow rates was relatively easy.

Two general cases were modeled. One is the case where the mass flow rates for both the leak flow and the process fluid flow are known. For the purposes here, the process fluid represented the existing or primary bulk fluid in the pipe which flowed opposite to the leak fluid. These definitions are necessary when defining a problem with two different initial fluid temperatures. The second general case considered heat input into the analytical section of pipe from a convective heat source. In order to estimate fluid velocity off of a convective heat source surface, the following relationship is made:

[ ] a,c,e

Friction losses are assumed as:

[ ] a,c,e

Therefore total friction losses are:

[ ] a,c,e

Therefore the maximum fluid velocity off of the hot surface (or valve face) is:

[ ] a,c,e

Additional control over the amount of energy entering the analytical boundaries for the convective heat transfer mechanism was provided by specifying the boundary fluid temperature.

For the stratified height the following relationship was used (section 3.3):

[ ] a,c,e

The solution method allows the simulation of a variety of boundary conditions. To validate the solution method, a comparison of the calculated temperatures against actual temperature measurements was made. The actual temperature data was collected during the high temperature stratification tests performed under the Westinghouse / EPRI TASCS program (Reference 2). The piping section used in the test was a 6" schedule 160, stainless steel pipe, 10 feet long with 2.5" thick mirrored insulation. The system was heated with a 320 kilowatt direct emersion electric heater with a solid state controller. The comparisons shown below are for near steady state conditions.

TASCS TEST 4 Comparison.

The first example compared the calculated values with TASCS high temperature stratification test number 4. Test number 4 was a controlled [ ]^{a,c,e} leak with an initial bulk fluid temperature in the pipe of approximately [ ]^{a,c,e} The leak fluid temperature was [ ]^{a,c,e} The temperature measurements taken at [ ]^{a,c,e} minutes from the start of the injection were used. The following boundary conditions were used to model this test:

Leak temperature [ ]^{a,c,e}

Leak rate [ ]^{a,c,e}

Process fluid temperature [ ]^{a,c,e}

Process fluid source side was considered on the same side as the leak source.

Convection was turned on with process fluid boundary node fixed at process fluid temperature

Figure 3-4 shows the calculated values with the actual test 4 results. As shown, an excellent comparison between the two was obtained.

TASCS TEST 6 Comparison

The second example compared calculated values with TASCS high temperature stratification test number 6. Test number 6 was an approximate [ ]^{a,c,e} leak with an initial bulk fluid temperature in the pipe of approximately [ ]^{a,c,e} The leak fluid temperature was approximately [ ]^{a,c,e} Temperature measurements taken at [ ]^{a,c,e} minutes from the start of the injection were used. The following boundary conditions were used to model this test:

Leak temperature [ ]^{a,c,e}

Leak rate [ ]^{a,c,e}

Process fluid temperature [ ]^{a,c,e}

Process fluid source side was considered on the same side as the leak source.

Convection was turned on with process fluid boundary node fixed at process fluid temperature

Figure 3-5 shows the calculated values with the actual test 6 results. All calculated temperatures are shown with the actual metal temperature distribution from the test. As shown, an excellent comparison between the two was obtained.

TASCS TEST 7 Comparison

The third example compared calculated values with the TASCS high temperature stratification test number 7. Test number 7 was an approximate [ ]^{a,c,e} with an initial bulk fluid temperature in the pipe of approximately [ ]^{a,c,e} The leak fluid temperature was approximately [ ]^{a,c,e} Temperature measurements taken at [ ]^{a,c,e} from the start of the injection were used. The following boundary conditions were used to model this test:

Leak temperature [ ]^{a,c,e}

Leak rate [ ]^{a,c,e}

Process fluid temperature [ ]^{a,c,e}

Process fluid source side was considered on the same side as the leak source

Convection was turned on with process fluid boundary node fixed at process fluid temperature

Figure 3-6 shows the calculated values with the actual test 7 results. All calculated temperatures are shown with the actual metal temperature distribution from the test. As shown, an excellent comparison between the two was obtained.

TASCS TEST 10 Comparison

The forth example compared calculated values with the TASCS high temperature stratification test number 10. Test number 10 was an approximate [ ]^{a,c,e} leak with an initial bulk fluid temperature in the pipe of approximately [ ]^{a,c,e} The leak fluid temperature was approximately [ ]^{a,c,e} Temperature measurements taken at [ ]^{a,c,e} from the start of injection were used. The following boundary conditions were used to model this test:

Leak temperature [ ]^{a,c,e}

Leak rate[ ]^{a,c,e}

Process fluid temperature [ ]^{a,c,e}

Process fluid source side was considered on the same side as the leak source.

Convection was turned on with process fluid boundary node fixed at process fluid temperature

Figure 3-7 shows the calculated values with the actual test 10 results. All calculated temperatures are shown with the actual metal temperature distribution from the test. As shown, an excellent comparison between the two was obtained.

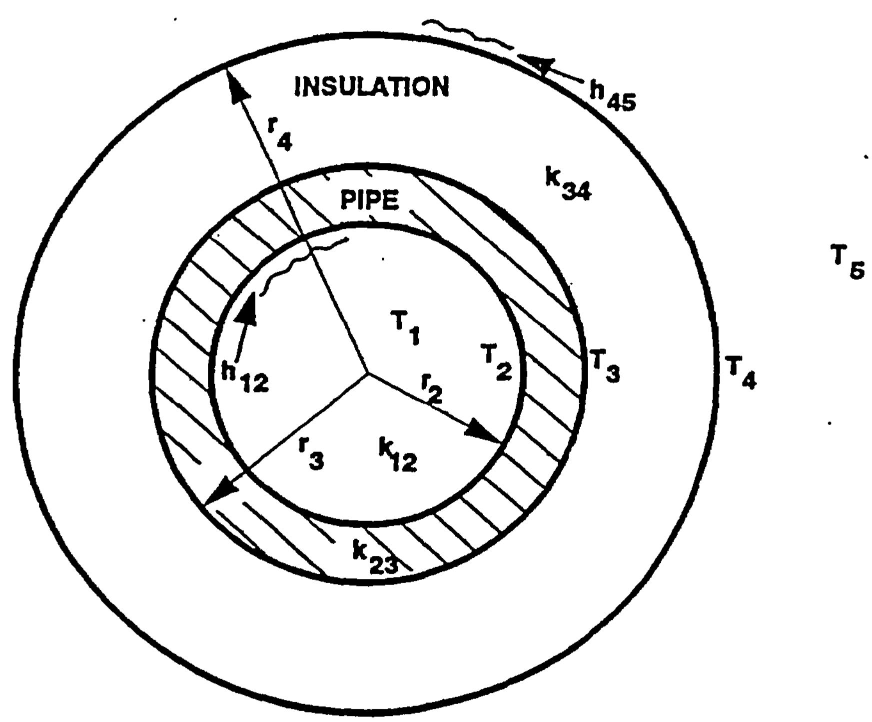
Based on the above four comparisons, the calculated temperatures show an excellent comparison with the actual temperatures for leak rates from [ ] [a,c,e] Therefore, the methodology described in this section is verified for use in the Donald C. Cook evaluation.

PIPING ANALYTICAL SECTIONS

The method described in this section was used to estimate the fluid flow conditions in the various sections of the auxiliary spray line piping. To this end, the piping was divided into four (4) analytical sections. The first analytical section is defined as the 2" schedule 160 piping from the auxiliary spray isolation valve to the auxiliary spray line check valve. This section of piping is approximately [ ] [a,c,e] with 1.5" of insulation. The insulation conductivity was estimated at [ ] [a,c,e] The second analytical section was the piping from the 2" auxiliary spray line check valve up to and including the 27" vertical section of 4" schedule 120 piping. This analytical section receives flow from the main spray by-pass lines as well as flow through the auxiliary spray valve. The third analytical section is defined as the length of 4" schedule 120 piping from the 27" vertical section to the 4" tee. This section was modeled with flows coming from both sides. The main spray flow was considered as the process flow and the combined by-pass and leak flow was considered as the leak flow. The fourth analytical section was the section of piping from the tee (where analytical section 3 ends) and the balance of the horizontal piping going back to the next tee (approximately 8 feet total). The results of the thermal analyses for these sections are discussed in section 4.0.

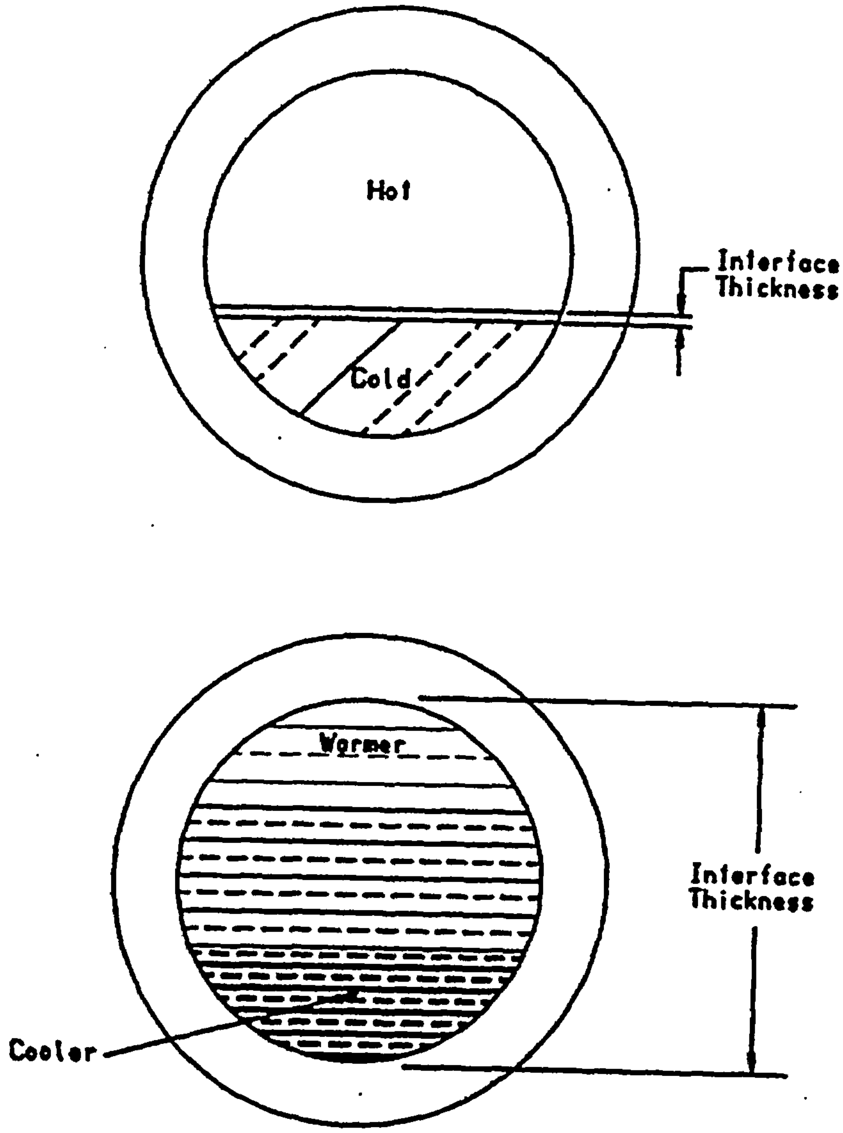
FIGURE 3-1

HEAT TRANSFER TERMINOLOGY



T_1= WATER TEMPERATURE
T_2= PIPE INNER WALL TEMPERATURE
T_3= PIPE OUTER WALL TEMPERATURE
T_4= INSULATION OUTER WALL TEMPERATURE
T_5= AMBIENT AIR TEMPERATURE

FIGURE 3-2



VARIATION OF STRATIFICATION INTERFACE

FIGURE 3-3

a,c,e

THERMAL STRATIFICATION INTERFACE TERMINOLOGY

a,c,e

FIGURE 3-4

Model comparison to Test No. 4 (.16 gpm leak)

a,c,e

FIGURE 3-5

Model comparison to Test No: 6 (.42 gpm)

a,c,e

FIGURE 3-6

Model comparison to Test No. 7 (.8 gpm)

a,c,e

FIGURE 3-7

Model Comparison to Test No. 10 (4 gpm)

4.0 TEMPERATURE MONITORING FINDINGS AND DATA ANALYSIS

The temperature monitoring data indicated the presence of thermal stratification at locations 1 through 5, as well as some cyclic thermal behavior at locations 1 and 2. Additionally, the data indicated the presence of high temperature flow coming from the auxiliary spray isolation valve. The temperature reading at location T6-1 was approximately the same as the charging flow temperature at all times. This condition indicated a potential leaking auxiliary spray isolation valve.

Initial thermal analyses of the monitoring data considered zero leak flow conditions and heat transfer by diffusion and convection. These analyses predicted a temperature of approximately [ ]^{a,c,e} at location T6-1 (see Figure 4-1), considerably lower than the [ ]^{a,c,e} observed for all normal conditions. Figure 4-2 showed the expected temperatures with a [ ]^{a,c,e} leak, again considerably less than observed. After a wide range of thermal analyses were performed in an attempt to match observed conditions, it was concluded that the auxiliary spray isolation valve was leaking. This conclusion was later substantiated on 5/21/93 when the first of two letdown isolation transients was experienced. During the letdown isolation transients, the location T6-1 temperature decreased along with the charging temperature. The temperature time history for location T6-1 and the regenerative heat exchanger outlet temperature (charging temperature) are shown in Figure 4-3. Review of the location T6-1 temperature reading and the charging flow temperature during these transients confirmed that the auxiliary spray isolation valve was leaking. During the first letdown flow isolation transient, the charging flow temperature decreased from [ ]^{a,c,e} to [ ]^{a,c,e} This change in temperature was also reflected in the location T6-1 reading as shown in the Figure 4-3. Please note that the charging temperature and location T6-1 temperature are nearly identical throughout the entire transient.

Further analyses, under various flow conditions, were performed to estimate the leak flow rate through the auxiliary spray isolation valve. These thermal analyses considered the effects of convection, diffusion and heat losses to the environment, and resulted in an estimated leak rate of approximately one gallon per minute. The results for [ ]^{a,c,e}, [ ]^{a,c,e}, and [ ]^{a,c,e} postulated leak cases compared to the measured value at T6-1 are shown in Figure 4-4. All comparisons were made to the steady state temperature at location 6, under normal operating conditions.

Once an estimate for the leak condition was established, an estimate for the spray by-pass flow had to be determined. The main spray by-pass flow enters the four inch main spray line near the reducer between the 4" and 2" auxiliary spray piping (see Figure 2-1). The by-pass flow passes through two 3/4" pipes connected to a 2" pipe that connects to the 4" piping. The two flows (by-pass & leak) are mixed in the downward leg of a 27" vertical section of four inch pipe. An overall energy balance method was used to calculate the observed temperature at the bottom of the four inch pipe at location 4 (approximately 15" downstream from the vertical section, on the horizontal portion of the 4" pipe). The temperature at T4-2 represents the combined flows of the leak from the auxiliary spray isolation valve and the main spray by-pass flow. Several combinations of by-pass and leak flow were considered. The combinations that yielded the best results had combined total flow rates between [ ]^{a,c,e} to

[ ] a,c,e gallons per minute with calculated equilibrium temperatures from [ ] a,c,e to [ ] a,c,e

The combined flows and equilibrium temperatures were then used in stratified flow analyses of analytical section 3 (the main section of four inch piping). The solutions of the stratified flow analyses were compared with the observed stratified condition with good results. Figure 4-5 shows the location 3 and 4 top and bottom temperatures along with the analytical results for the normal leak condition. An additional consideration for the analyses of section 3 was the presence of main spray flow, either by leakage past the main spray valves or directed controlled flow (initiated for pressure control). The analytical model that correlated best with the data for normal conditions was a [ ] a,c,e main spray flow that would penetrate into the section of four inch piping beyond the tee through which most of the main spray flow would travel. The temperature of the main spray flow was approximately [ ] a,c,e for the boundary conditions of the model. These results are also shown in Figure 4-5. The resulting boundary conditions from the section 3 analyses were used as part of the input boundary conditions for the section 4 analyses. The results for the normal condition with main spray leak flow compared with location 1 measured results are shown in figure 4-6.

The conclusions of these thermal analyses are:

1) A leak is occurring through the auxiliary spray isolation valve.

2) The probable leak rate is approximately [ ] a,c,e or less (a higher leak rate would yield a higher combined flow temperature in analytical section 2 and would not yield the desired match at T6-2 or T4-2 locations.

3) The main spray by-pass flow enters at temperature of approximately [ ] a,c,e. This conclusion is based on the presence of cold water (approximately [ ] a,c,e at T4-2) and the very high probability of an auxiliary spray isolation valve leak delivering water at about [ ] a,c,e through the check valve. The only mechanism available to cool the leak flow is the by-pass flow. Additionally, total combined leak flows cannot be much below those postulated, or D3 would be much lower during the normal condition and D4 would be represented by the leak flow temperature (approximately [ ] a,c,e) and the main spray flow temperature (approximately [ ] a,c,e during the low flow condition observed). Combined flow rates greater than [ ] a,c,e would tend to flush the 4" piping, resulting in lower ΔT's and more uniform steady state temperatures.

The next step in the analysis was to determine if any leak scenarios could produce higher ΔT's than those observed. A series of thermal analyses was performed considering a range of leak rates from [ ] a,c,e. In all cases, the postulated leak flow was heated up to the by-pass flow temperature before reaching the auxiliary spray line check valve. Additionally, analysis results indicate that cooling of the leak flow produced no significant stratification in the

2" piping. This led to the conclusion that the presence of the main spray by-pass flow injecting near the auxiliary spray line check valve provides sufficient preheat to prevent large ΔT's from occurring for all postulated low leak flows.

a,c,e

FIGURE 4-1

(Section 1) 2" Auxiliary Spray Line with no flow

a,c,e

FIGURE 4-2

(Section 1) .01 gpm leak case

FIGURE 4-3

a,c,e

Charging Temperature vs Location 6 Temperature 05/21/93

a,c,e

FIGURE 4-4

2" Pipe from aux spray valve to check valve

a,c,e

FIGURE 4-5

4" pipe 3gpm combined by-pass & leak flow (Section 3)

a,c,e

FIGURE 4-6

6/21/93 Section 4, .1 gpm combined penetration flow (Mc'in Spray Flow <1%)

5.0 THERMAL STRATIFICATION CYCLES

The maximum ΔT occurred at location 3 (D3). During normal operation the maximum value of D3 was approximately [ ]^{a,c,e}. The ΔT for all other locations during normal operation was less than [ ]^{a,c,e}. The maximum ΔT observed was [ ]^{a,c,e} at location 3 during an isolation of letdown that occurred on 6/15/93. See Figures 5-1 and 5-2 for the actual temperatures and Figure 5-3 for the ΔT values.

In order to postulate transients for consideration in the fatigue analysis the cyclic behavior of the data was evaluated with the CYCLEI program (Reference 9). The first step in this analysis is to determine the total cycles of thermal stratification for each location. The program CYCLEI with a filter of [ ]^{a,c,e} was used for these calculations. For this evaluation stratification cycles are counted using an overall ordered range pairing method. The this method results in count of cycle in various stratification ranges called "bins". The specific bin's are shown in the table below. Only the daily bin count totals were retained and presented for use. Cycle counting was not performed for periods when monitoring data that had no significant change in ΔT.

The results of the cycle counting effort are summarized in the table below for locations 1, 2, 3, 4, and 5. Location 6 did not have adequate data to determine if any thermal stratification had occurred.

[ ] a,c,e

The "BIN" shown in the cycle count table represents the effective range of ΔT for which the cycle count was made.

All thermal stratification cycles that had a magnitude greater than [ ] ^{a,c,e} were the result of loss of letdown transients. All of the high-cycle thermal activity occurs at locations 1 and 2. As discussed earlier, the thermal activity at these locations is influenced by two flow streams, the main spray flow, and the combined flow of the main spray by-pass flow and the leak flow from the auxiliary spray isolation valve. The cycling at locations 1 and 2 was significantly reduced when there was a small increase in main spray flows. This effect is clearly shown in Figure 5-4.

The cyclic thermal behavior was evaluated to determine if a relationship existed between the magnitude of ΔT and frequency of occurrence. The following summarizes this effort:

Typical cycling data for location 2 was evaluated to determine if a dominant frequency existed. First, a dc component (magnitude 13.5) was removed from the data, resulting in the time history shown in figure 5-5:

When converted to a frequency domain, a peak in the data was observed around [ ] ^{a,c,e} (see figures 5-6 and 5-7). Additional data processing was performed to establish a dominant magnitude of ΔT associated with the [ ] ^{a,c,e}. The data was processed with a low pass filter, a high pass filter, and a band pass filter. The low pass filter used a cut off of [ ] ^{a,c,e}. The band pass was between [ ] ^{a,c,e}. The high pass filter used a cut off of [ ] ^{a,c,e}. The effects of these filters on the data are shown in Figures 5-8, 5-9, & 5-10. Figures 5-11 through 5-13 show the filtered peaks established by CYCLEI program runs. Figures 5-14 through 5-16 show the paired cycles determined by CYCLEI. Finally, Figures 5-17 through 5-19 show the counts of cycles according to BIN's.

The results indicate very little dependency between the magnitude of the stratification cycle and the frequency (see figures 5-11 through 5-19). For the high-pass and band-pass cases, the cycles distributions are nearly identical. For the low-pass case, there is a reduction in counts but no significant change in the overall cycle distribution. In all cases, the maximum cycle magnitude was less than 40°F.

Further investigation into the cyclic behavior of the temperatures at locations 1 & 2 revealed some dependency on the spray valve demand and the presence of stratification at location l. This is shown in figure 5-20. It was finally concluded that the cycling associated with the spray valve demand was insignificant because of the low temperatures differences associated with the events.

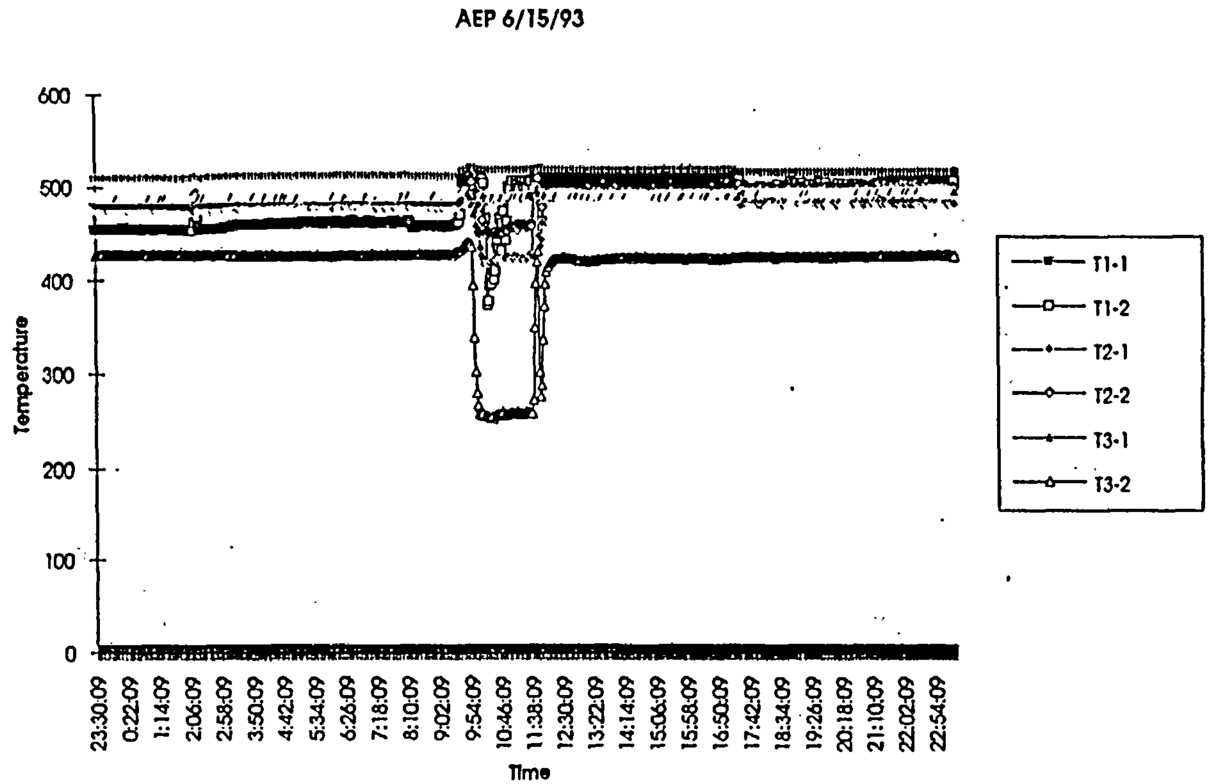

AEP 6/15/93
Temperature
600
500
400
300
200
100
0
Time
23:30:09
0:22:09
1:14:09
2:06:09
2:58:09
3:50:09
4:42:09
5:34:09
6:26:09
7:18:09
8:10:09
9:02:09
9:54:09
10:46:09
11:38:09
12:30:09
13:22:09
14:14:09
15:06:09
15:58:09
16:50:09
17:42:09
18:34:09
19:26:09
20:18:09
21:10:09
22:02:09
22:54:09
T1-1
T1-2
T2-1
T2-2
T3-1
T3-2

FIGURE 5-1

6/15/93

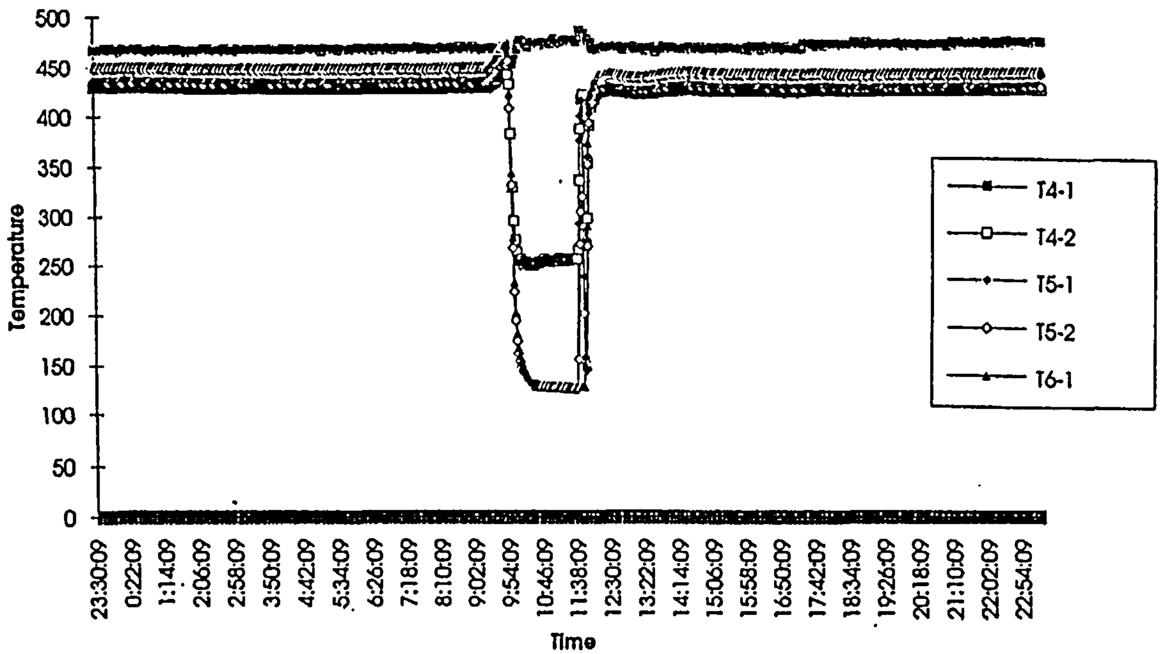


FIGURE 5-2

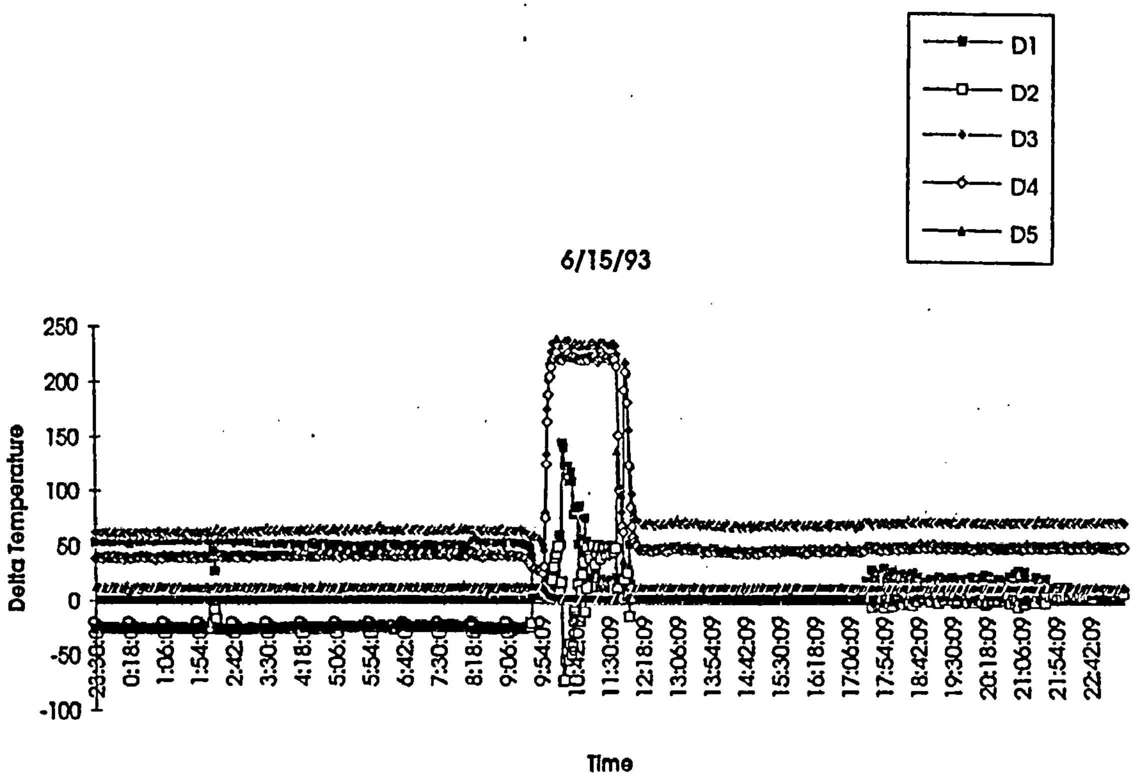

6/15/93
D1
D2
D3
D4
D5
Delta Temperature
Time
250
200
150
100
50
0
-50
-100
23:30:0
0:18:0
1:06:0
1:54:0
2:42:0
3:30:0
4:18:0
5:06:0
5:54:0
6:42:0
7:30:0
8:18:0
9:06:0
9:54:09
10:42:09
11:30:09
12:18:09
13:06:09
13:54:09
14:42:09
15:30:09
16:18:09
17:06:09
17:54:09
18:42:09
19:30:09
20:18:09
21:06:09
21:54:09
22:42:09

FIGURE 5-3

Spray Demand vs DeltaTemperature at locations 1 & 2

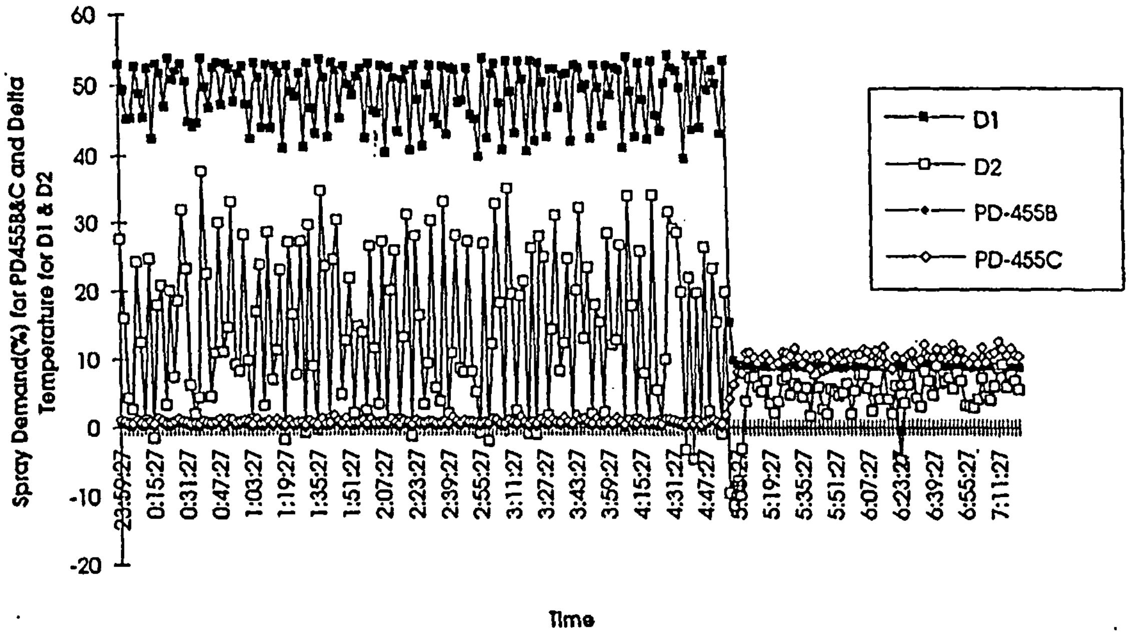


FIGURE 5-4

a,c,e

FIGURE 5-5

Location 2 DC removed

FIGURE 5-6

a,c,e

FIGURE 5-7

a,c,e

FIGURE 5-8

a,c,e

FIGURE 5-9

a,c,e

FIGURE 5-10

a,c,e

FIGURE 5-11

a,c,e

FIGURE 5-12

a,c,e

FIGURE 5-13

a,c,e

FIGURE 5-14

a,c,e

FIGURE 5-15

a,c,e

FIGURE 5-16

a,c,e

FIGURE 5-17

a,c,e

FIGURE 5-18

a,c,e

FIGURE 5-19

a,c,e

1/1/93 Spray valve demand vs location 1 dT (normalized)

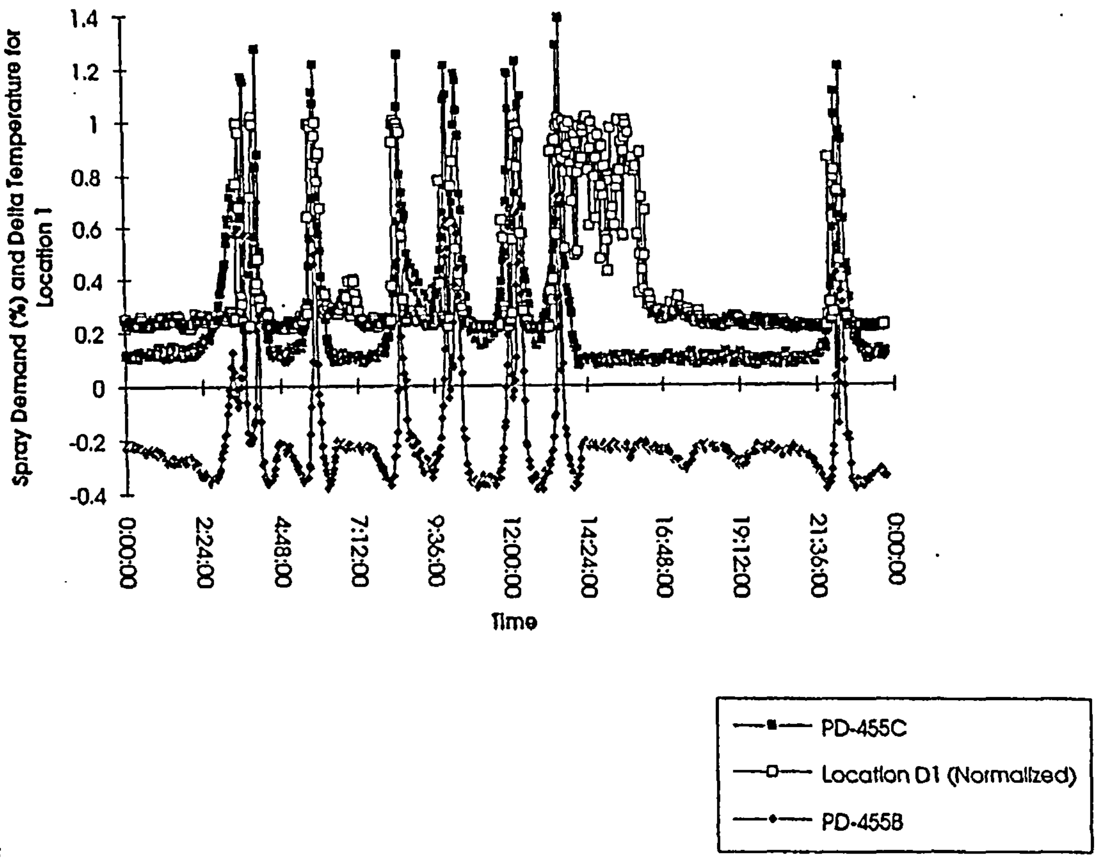


FIGURE 5-20

6.0 TRANSIENT DEVELOPMENT

This section describes the transients considered in the analysis the Donald. C. Cook units 1 and 2 auxiliary spray lines. The transients defined herein address NRC-B 88-08 and include loading conditions that contain thermal stratification, thermal cycling, and striping. The scope of the piping affected by these transients includes all of the auxiliary spray piping and some of the connected main spray piping. The transients are based, in part, on Systems Standard 1.3.X, Nuclear Steam Supply System, Auxiliary Equipment Design Transients for All Standard Plants, Revision 0, September 1978 (Reference 4). Additional information came from observations made in the monitoring program for the Donald. C. Cook Unit 1 auxiliary spray line and results from the auxiliary spray line monitoring program thermal analyses. The transients defined in this document are intended to envelope all observed loading conditions as well as address postulated design transients that may be experienced. The following terms apply to the development and definition of transients for the auxiliary spray line:

Global structural loads affect an entire analytical section, the load may be a uniform thermal load or a stratified load with a defined axial stratification profile.

Local piping loads affect only a local section of piping. Local loads result in local through-wall stress gradients. Typically these loads are defined as alternating thermal loads with the following attributes:

A. Minimum value
B. Maximum value
C. Frequency
D. Load profile
E. Total number of cycles
F. Associated Global load

Axial Stratification Profile is the variation of applied top and bottom temperature loads along the axis of the pipe.

All temperature loads are considered as metal temperatures unless stated otherwise.

The piping affected by these transients is divided into four (4) analytical sections. The analytical sections are defined as follows (refer to figure 2-1):

Section 1 = [ ] a,c,e

Section 2 =

Section 3 =

Section 4 =

[ ] a,c,e

As stated earlier, the transients provided have been developed with the aide of monitoring data collected at Donald. C. Cook Unit 1 and the AEP auxiliary spray line thermal analyses. The monitoring data reveled a leaking auxiliary spray isolation valve. The transients described below consider cases that include a continuous leak in the auxiliary spray isolation valve.

Normal Steady State (with leaking auxiliary spray isolation valve)

The normal steady state condition is defined below. The number of cycles of this condition is 200 corresponding to 200 heatup and cooldown cycles (the condition of [ ] a,c,e spray flow is used.)

Section 1 =

Section 2 =

Section 3 -

[ ] a,c,e

Section 4 = [ ] a,c,e

Note: The piping at monitoring locations 1 & 2 were also evaluated for local loads. These locations were treated as potential thermal cycling cases and analyzed for the following loads. The fluid temperatures considered were [ ] a,c,e for a combined leak flow and [ ] a,c,e for main spray flow. This resulted in a maximum fluid ΔT of [ ] a,c,e. The fluid height was [ ] a,c,e for location 1 and [ ] a,c,e for location 2. The frequency was [ ] a,c,e. The transition time between load temperatures was [ ] a,c,e seconds.

Normal Steady State (without leaking auxiliary spray isolation valve)

The normal steady state condition defined below is for the period of operations that assumes the auxiliary spray isolation valve is not leaking. The number of cycles of this condition is 200 (corresponding to 200 heatup and cooldown cycles).

Section 1 = [ ] a,c,e

Section 2 =

Section 3 =

Section 4 =

Transients Involving Charging and/or Letdown Flow Shutoff

The following transients were based on the transients defined in reference 4 for the [ ] a,c,e charging system.

Group 1 Transients: Unless stated otherwise, a cycle of each transient is defined as starting from the normal condition, and going to the defined condition and back to the normal condition.

a. Charging and letdown flow shutoff and return to service: [ ] a,c,e cycles

Isolation of charging: Same as normal case without leak

Re-start of charging flow:

a,c,e

Section 1 = [ ]

Section 2 =

Section 3 =

Section 4 =

b. Letdown flow shutoff with prompt return to service: [ ] a,c,e cycles

a,c,e

Section 1 = [ ]

Section 2 =

Section 3 =

Section 4 = [ ] a,c,e

Note: The piping near monitoring locations 1 & 2 were also evaluated for local loads.

c. Letdown flow shutoff with delayed return-to-service: [ ] a,c,e cycles

a,c,e

Section 1 =

Section 2 =

Section 3 =

Section 4 =

Note: The local sections of piping near monitoring locations 1 & 2 were also evaluated for local loads.

d. Charging flow shutoff with prompt return to service [ ] a,c,e cycles

Used the same loads as case a for "Isolation of charging".

e. Charging flow shutoff with delayed return-to-service [ ] a,c,e cycles

Used the same loads as case a. for both "Isolation of charging" and "Restart of charging flow".

Group 2 Transients

a. Charging flow step decrease and return to normal: [ ] a,c,e cycles

This transient was not considered since nothing in the monitoring data indicated that this transient was experienced.

b. Charging flow step increase and return to normal: [ ] a,c,e cycles

This transient was not considered since nothing in the monitoring data indicated that this transient was experienced.

c. Letdown flow step decrease and return to normal: [ ] a,c,e cycles

Section 1 = [ ] a,c,e

Section 2 =

Section 3 =

Section 4 =

d. Letdown flow step increase and return to normal: [ ] a,c,e cycles

Section 1 = [ ] a,c,e

Section 2 [ ]^{a,c,e}

Section 3 =

Section 4 -

7.0 STRESS AND FATIGUE EVALUATION

To evaluate the effects of valve leakage into the unisolable piping, it was necessary to consider two stress effects on the piping: a "local" effect and a "global" effect. Local stresses are obtained by modeling a section of the pipe and imposing the leakage stratification transients as defined in Section 6. Several cases were analyzed, one with no end restraints and the other with full rotational restraints. The resulting radial, circumferential and axial stresses are defined as local stresses. For the case without end restraints, the piping will "bow" and expand along the pipe axially. For the second case, the piping will expand axially but not "bow". It was determined that both local and global stresses would have to be considered.

Global stresses result from the effects of supports and pipe geometry not permitting the piping to expand and deflect as it would in the unrestrained condition. Leakage depth, stratification temperature difference and the extent of stratified pipe are important parameters in the determination of global piping stress. A leakage depth at the pipe centerline will maximize the effect of global bending. Global stresses will typically increase as the length of stratified piping increases.

7.1 Local Stress Evaluation

To determine the magnitude of local stresses resulting from the postulated stratified leakage within the pipe, a thermal solution is determined and is used as input to a stress solution. This was performed using a two-dimensional (2D) model of one-half of the pipe cross section, for each pipe size, with symmetric boundary conditions for nodes on the plane of symmetry. The Westinghouse general purpose finite element program WECAN (Ref. 3) was used to obtain both the thermal and the stress solutions. The local stresses for the postulated leakage were obtained by replacing the heat transfer elements used in the thermal analysis model with 2D isoparametric generalized plane strain elements. [

]a,c,e

7.2 Global Stress Evaluation

Global stresses are obtained by performing thermal stress analysis of the piping system with stratification postulated in the section of pipe between the main spray pipe and the adjacent check valve for the auxiliary spray line. There are periods of time when the spray valves are open, and other times when the spray valves are closed, and only trickle flow is present in the main spray line.

7.3 Fatigue Evaluation

The fatigue evaluation of the auxiliary spray lines considering auxiliary spray isolation valve leakage was based on the requirements of the ASME B&PV Code, 1986 Edition, Section III, Subsection NB-3653, for piping components. Fatigue usage was calculated at the 2 socket welded valve, 4 x 2 reducer, and 4 x 4 tee in the main spray line.

All loads was allowed to combine according to the requirements of the ASME Code until all cycles were exhausted. Alternating stress, allowable cycles, actual cycles, and usage factor were calculated for each transient loadset combination. The design fatigue curves used in the calculation of usage factor were from the 1986 ASME Code Figures 1-9.2.1 and I-9.2.2, for austenitic stainless steels. These curves were used because they include high cycle fatigue considerations. The total usage factor is the sum of usage factors for each loadset, which was shown to be less than 1.0 for forty (40) years of operation.

8.0 CONCLUSIONS AND RECOMMENDATIONS

An evaluation of the D. C. Cook Units 1 and 2 charging, alternate charging and auxiliary spray piping considering the effect of postulated isolation valve leakage transients and design transients on fatigue usage has been performed. The conclusion of this evaluation for the normal and alternate charging lines is that the cumulative fatigue usage for design transients and postulated isolation valve leakage transients is less than 1.0 for the life of the plant. The conclusion for the Units 1 and 2 auxiliary spray lines is that the cumulative fatigue usage for design transients and postulated isolation valve leakage transients is less than 1.0 for 40 calendar years. This assumes a worst case scenario of continuous isolation valve leakage the calculated leakage flow rate [ ][a,c,e]

The conclusions and recommendations include the following:

Temperature monitoring of the auxiliary spray line is no longer required and therefore should be terminated.

The structural integrity would not be challenged due to leaks in the auxiliary spray valve. The calculated fatigue usage was less than the allowable.

An adequate data base exists to evaluate any postulated leak scenario for the auxiliary spray valve.

All thermal stratification cycles that had a magnitude greater than [ ][a,c,e] were the result of loss of letdown transients and therefore few in frequency.

All of the high-cycle thermal activity occurs at locations 1 and 2.

The high cycle thermal activity can be controlled by adjusting main spray flow. The maximum ΔT observed in the high cycle thermal activity was less than [ ][a,c,e]

The maximum ΔT observed during the entire monitoring program was [ ][a,c,e].

9.0 REFERENCES

1. United States Nuclear Regulatory Commission Bulletin 88-08, "Thermal Stresses in Piping Connected to Reactor Coolant Systems", 6122188; Supplement 1, 6/24/88; Supplement 2, 8/4/88; and Supplement 3, 4/11/89.

2. "Thermal Stratification, Cycling and Striping (TASCS) Final Report", Prepared by Westinghouse Electric Corporation for Electric Power Research Institute, Research Project 3153-02, Dated October 1993.

3. Westinghouse general purpose finite element program WECAN/PLUS, Version Release 90-2 (20402403020), Westinghouse Proprietary.

4. Westinghouse Systems Standard 1.3.X, Revision 0, September 1978, "Nuclear Steam Supply System Auxiliary Equipment Design Transients for All Standard Plants", and Westinghouse Systems Standard 1.3.F, Revision 0, March 1978, "Nuclear Steam Supply System Reactor Coolant System Design Transients", Westinghouse Proprietary.

S. Westinghouse Report WCAP-12143, & Supplement 1, "Report on Evaluation of Auxiliary Piping attached to the Reactor Coolant System per NRC Bulletin 88-08 for American Electric Power Service Corporation D. C. Cook Units 1 and 2", April 1989, Westinghouse Proprietary.

6. "AEP Auxiliary Spray Line Data Reduction" by R. J. Caligirui dated 11/2/93.

7. "LEAK3 Thermal Analysis Computer Code", by E. L. Cranford, Dated 12/9/93, Westinghouse Proprietary.

8. Power Capability Parameters, Issue No. PCWG/AEP/86-3

9. "Cycle Count Computer Code for AEP Application" by E. L. Cranford, Dated 9/16/93, Westinghouse Proprietary.

10. Patankar, S, V, Numerical Heat Transfer And Fluid Flow, 1980, Hemisphere Publishing Corporation

The following AEP drawings were used:

Drawing Number	Revision
1-5435A	13
1-RC-501L4.3	4
1-RC-501L4.6	6
1-RC-10 Sheet 1 of 2	8
1-RC-10 Sheet 2 of 2	6

1-CS-780L1.2	2
1-CS-780L3.4	4
1-CS-96 Sheet 2 of 2	8