EVALUATION OF THERMAL STRESSES IN
PIPING CONNECTED TO C-E DESIGNED
REACTOR COOLANT SYSTEMS

PREPARED FOR OMAHA PUBLIC POWER DISTRICT

FT. CALHOUN STATION

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TABLE OF CONTENTS

1.0 PURPOSE

The purpose of this effort is to address the NRC requests documented in NRC Bulletin 88-08, "Thermal Stresses in Piping Connected to Reactor Coolant Systems". The report is intended to support preparation of Omaha Public Power District's (OPPD) response to the bulletin for the Ft. Calhoun Station. This report has subsequently been revised to be used an integral part of the response to the NRC Bulletin.

2.0 BACKGROUND

NRC Bulletin 88-08, dated June 22, 1988, requests that licensees "(1) review their Reactor Coolant System (RCS) to identify any connected, unisolable piping that could be subjected to temperature distributions which would result in unacceptable thermal stresses and (2) take action, where such piping is identified, to ensure that the piping will not be subjected to unacceptable thermal stresses." This bulletin was prompted by a crack in a short unisolable section of Emergency Core Cooling System (ECCS) piping at an operating plant. The bulletin also mentioned a reported crack indication at Trojan in the surge line which was assumed to be caused by thermal stresses due to flow stratification. The NRC also issued a supplement to 88-08, for information only, which discusses a second crack in a short, unisolable section of ECCS piping at a Westinghouse operating unit in Belgium. In general, the issue of thermal stresses and fatigue in piping systems has been receiving increased attention from the industry. Several industry tasks including EPRI's General Fatigue Damage Management Program and INEL's Volume 2 to draft NUREG/CR-4731, "Residual Life Assessment of Major Light Water Reactor Components" have identified and qualitatively discussed a number of suspect locations in RCS connected piping that could be subjected to unusual thermal stress loadings. Specific Combustion Engineering Owners Group (CEOG) activities in this area include CEOG Task 482, "Pressurizer Spray System Thermal Fatigue Evaluation" and CEOG Task 571, "Thermal Transient Monitoring Program" (ongoing), which provides a fatigue monitoring program for primary pressure boundary piping nozzles and components. In addition, the CEOG is considering a program to resolve concerns associated with the effects of flow stratification in C-E pressurizer surge lines. All of these activities are considered to be related to NRC Bulletin 88-08 and the results to date were considered during preparation of this report.

3.0 TECHNICAL APPROACH

C-E believes the intent of NRC Bulletin 88-08 was to address two potential causes of thermal stresses in piping connected to the RCS. The first is potential leakage through valves that separate the RCS from other systems. This type of leakage would tend to be promoted by systems operations that resulted in system pressures higher than RCS pressure. The second cause for thermal stresses is flow stratification which may be caused by local stratification in "dead-ended" or valved out piping runs. For completeness, both scenarios will be examined in this report.

The first step was to review RCS piping and instrumentation diagrams for the Ft. Calhoun Station and list all piping connected to the RCS. For completeness, these lists include all penetrations to the hot and cold legs, reactor vessel, surge line, pressurizer, pressurizer spray line and the Power Operated Relief Valves (PORV)/Primary Safety Valve (PSV) piping routed to the quench tank. The surge line, main and auxiliary spray lines, and pressurizer relief lines themselves are also included. Evaluations of these lists indicated which systems are connected to the RCS. These systems are described in Section 4.0, "Systems Evaluation". This section includes a discussion of the potential impact of systems operations on the RCS.

The penetrations lists were also used to obtain isometric drawings of the applicable lines up to and including the first valve in each line. The penetrations listings for Ft. Calhoun are presented in Appendix B. Each isometric was then reviewed to determine the potential for temperature stratifications or temperature oscillation due to geometric discontinuities, routing lengths, pipe diameters etc. A discussion of this review is presented in Section 5.0, "Evaluation of Stresses in Piping Connected to the RCS".

The results of both the systems review and thermal stress evaluations are presented in Section 6.0, "Results and Conclusions".

4.0 SYSTEMS LEAKAGE EVALUATION

The RCS and connected systems were reviewed to determine whether unisolable sections of piping connected to the RCS are subjected to stresses from temperature stratification or oscillations that could be induced by leaking valves. As requested in the NRC bulletin, this review focused on operations where system pressure might potentially be higher than RCS pressure and where system temperature could potentially be cooler than RCS temperature. Such conditions could promote leakage of cool water into the RCS.

In addition it should be noted that, for the purpose of this report, the surge line, main and auxiliary spray lines, PSV's, PORVs and pressurizer are all assumed to be included within the scope of review.

The following systems are connected to or are part of the RCS:

- Reactor Coolant System
- Chemical and Volume Control System
- Safety Injection and Shutdown Cooling System
- Waste Management
- Sample System
- Refueling Water Level Indication System
- Reactor Vessel Gas Vent System

The Waste Management, Sample, Reactor Vessel Gas Vents and Refueling Water Level Indication Systems are normally valved out during power operation with no active components that would cause system pressure to increase above primary system pressure to promote valve leakage. These systems therefore, were excluded from the more detailed systems evaluation. (The penetrations themselves were not excluded, only the impact of system operation on the RCS.)

4.1 System Descriptions

The systems identified targeted for further evaluation include the Reactor Coolant System, the Chemical and Volume Control System, and the Safety Injection and Shutdown Cooling Systems. These systems were evaluated to determine the impact of system operations on piping connected to the RCS.

4.1.1 Reactor Coolant System

The Reactor Coolant System circulates borated water in a closed cycle, to remove heat from the reactor core and transfer it to a secondary (steam generating) system. The Steam Generators provide the interface and heat exchange between the Reactor Coolant (primary) System and Main Steam (secondary) System. Reactor coolant is prevented from mixing with the secondary water by the Steam Generator tubes and the Steam Generator tubesheet. The RCS is a closed system thus forming a barrier to the release of radioactive materials.

The major components of the RCS are the reactor vessel, two parallel heat transfer loops with each containing one Steam Generator and two Reactor Coolant Pumps. A Pressurizer is connected to one of the reactor vessel outlet pipes (hot leg). All components are located inside the containment.

RCS pressure is maintained by the Pressurizer, where steam and water are maintained in thermal equilibrium. Steam is formed by energizing immersion heaters in the Pressurizer, or is condensed by the Pressurizer spray to limit pressure variations caused by contraction or expansion of the reactor coolant. The average temperature of the reactor coolant varies with power level causing the fluid to expand or contract, changing the Pressurizer water level.

The Charging Pumps and Letdown Control Valves in the Chemical and Volume Control System (CVCS) are used to maintain a programmed Pressurizer water level. A continuous but variable letdown purification flow is maintained to keep the RCS chemistry within prescribed limits via a charging nozzle and a letdown nozzle on the reactor coolant piping. The charging flow is also used to alter the boron concentration and to maintain the chemical content of the reactor coolant.

The Reactor Coolant Pumps provide sufficient forced circulation flow through the RCS to assure adequate heat removal from the reactor core during power operation. A controlled bleed off flow through the Reactor Coolant Pump seals is used to cool the seals and to equalize the pressure drop across each seal. The controlled bleed off flow is collected in the Volume Control Tank of the CVCS.

4.1.2 Safety Injection and Shutdown Cooling System

The Safety Injection and Shutdown Cooling System is designed to provide emergency core cooling following reactor coolant or main steam line pipe breaks by providing rapid injection of large quantities of borated water to the RCS. The system is also designed to remove heat from the Reactor Coolant System during normal cooldown and to maintain a suitable temperature during refueling and maintenance modes of operation.

The major components of the Safety Injection System are the Safety Injection Tanks, Low Pressure Safety Injection Pumps, High Pressure Safety Injection Pumps, the Safety Injection and Refueling Water Tank, and the Shutdown Cooling Heat Exchangers.

Safety injection operates in two modes: the injection mode and the recirculation mode. The injection mode is initiated by either a low pressure signal from the pressurizer or a high containment pressure signal. The Safety Injection Tanks discharge their contents into the RCS on low RCS pressure. A Safety Injection Actuation Signal starts the High Pressure Safety Injection (HPSI) and Low Pressure Safety Injection (LPSI) Pumps which take suction from the Refueling Water Tank and discharge through the SI header isolation valves via redundant headers. Safety Injection flow reaches the Reactor Vessel through safety injection nozzles into the RCS cold legs pipes. If offsite power is unavailable, power is supplied from diesel generators (AC) in a preprogrammed timing sequence to prevent overloading. Batteries provide DC power to instrumentation when offsite power is unavailable.

The recirculation mode is initiated automatically by the Recirculation Actuation Signal (RAS) upon receipt of a low water level signal in the Safety Injection and Refueling Water Tank, or it may be manually initiated. Upon entering the recirculation mode, the containment sump isolation valves are opened, and the suction header and minimum pump flow valves used to isolate the Safety Injection and Refueling Water Tank are shut. Injection continues with water taken from the containment sump. The LPSI pumps are turned off automatically by the RAS. A portion of the cooled water from the Containment Spray System may be diverted, at operator discretion, to the suction of the HPSI Pumps. The LPSI Pumps may be used to inject cooled water when the system pressure permits.

During initiation of shutdown cooling, the LPSI pumps circulate water from the RCS through the shutdown cooling suction line off the hot leg. The LPSI pumps route the RCS water through the shutdown cooling heat exchangers for heat removal, and then back into the RCS through the safety injection nozzles located on the RCS cold legs.

4.1.3 Chemical and Volume Control System (CVCS)

The Chemical and Volume Control System (CVCS) is designed to maintain the chemistry, purity, and activity level of the reactor coolant, maintain the required volume of water in the RCS, control boron concentration, provide for the injection of concentrated boron into the RCS and provide for auxiliary pressurizer spray.

The major components of the CVCS are the Regenerative and Letdown Heat Exchangers, Purification Filters, Strainer, Ion Exchangers, Volume Control Tank and Charging Pumps.

The CVCS operates in two modes: normal operation and cooldown operation. Normal operation includes hot standby operation and power generation when the reactor system is at normal operating pressure and temperature. During normal operation letdown flow from one Reactor Vessel cold leg passes through the tube side of the Regenerative Heat Exchanger for initial temperature reduction. The final temperature reduction is made by passing flow through the tube side of the Letdown Heat Exchanger and then through the Purification Ion Exchangers. For Fort Calhoun a Deborating Ion Exchanger can be used instead of a Purification Ion Exchanger or the Ion Exchangers may be bypassed, if preferred. After leaving the Ion Exchangers, flow continues through a Strainer and one of two Purification Filters, which remove insoluble particulates, and is then sprayed into the Volume Control Tank where a hydrogen overpressure gas blanket is maintained and is absorbed by the coolant in order to remove oxygen. Flow also enters the Volume Control Tank from the Reactor Coolant Pump controlled bleed off header.

The Charging Pumps take suction from the Volume Control Tank and pump the water into the RCS. One Charging Pump is normally in operation to maintain an exact balance between letdown flow rate plus Reactor Coolant Pump bleed off flow rate and charging flow rate. The charging flow passes through the shell side of the Regenerative Heat Exchanger for recovery of heat from the letdown flow before being returned to the RCS.

During RCS cooldown, the RCS is depressurized and cooled down using auxiliary spray supplied by the Charging Pumps.

4.2 Impact of System Operation

This review focuses on systems operations where system pressure might potentially be higher than RCS pressure and system temperatures potentially cooler than RCS temperature.

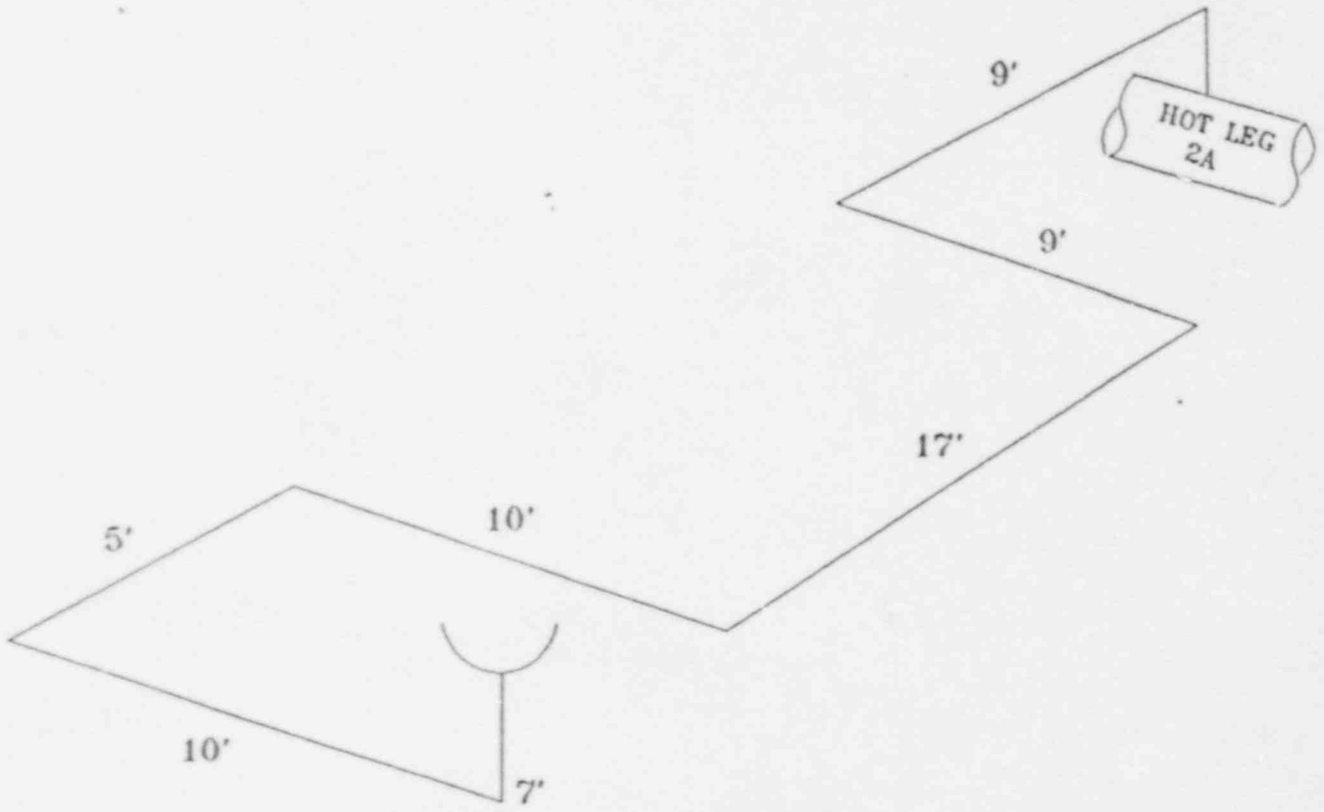
4.2.1 Reactor Coolant System

For the purpose of this evaluation, the surge line, main and auxiliary spray lines, primary safety valves, power operated relief valves and the pressurizer are all assumed to be included within the scope of the review.

Surge Line:

The pressurizer surge piping connects the bottom of the pressurizer to the hot leg primary piping. A schematic of the Ft. Calhoun surge line is shown in Figure 1. Due to the generally horizontal nature of the surge line routing and the low flow rate (7 to 15 gpm) conditions with which this system normally operates, the surge line piping and nozzles may be subjected to stratified flow loading conditions. The effect of

FIGURE 1: FT. CALHOUN SURGE LINE



these loadings on the fatigue life of the surge line is dependent on plant specific routing and support systems. Although further definition of actual in-plant thermal loadings would be needed to perform a realistic fatigue evaluation, it should be noted that no known fatigue cracking in surge piping has been confirmed. (The surge line crack noted in NRC Bulletin 88-08 was later determined not to exist by destructive testing of the crack indication.) Additionally, the heat transfer phenomena associated with the insulated heavy wall pipe would tend to minimize stratification during most phases of plant operation, except start-up where temperature stabilization has not yet occurred.

This would indicate that a fatigue life of at least eighteen years or more exists for C-E designed surge lines. (Based on a 1971 date of critical operation for the first C-E designed NSSS). In addition, the C-E Owners Group has funded actual surge line temperature data collection activities on a C-E designed NSSS. The analysis of this data is currently being considered by the C-E Owners. These ongoing CEOG activities are intended to resolve potential concerns associated with flow stratification in [illegible] plant surge lines.

PSV/PORV Piping:

The primary safety valves and power operated relief valve piping taps into the steam space at the top of the pressurizer. The piping from the pressurizer to the primary safety valve bodies is of a loop seal design that traps condensate at the bottom of the gooseneck. Excess condensation drains back into the pressurizer; this prevents a steam/water environment in this piping and greatly reduces the potential for flow stratification. The PORV inlet piping near the pressurizer is primarily vertical or near vertical such that any condensation drains back into the pressurizer. The back pressure in the piping past these valves would typically be equal to the quench tank pressure which is well below RCS operating pressure, i.e., there is no mechanism for condensate (caused by potential steam leaks) to leak back through these valves and into the RCS. In addition, the PSVs and PORVs mark the Class I break definition for the RCS boundary. Piping past these valves is therefore not considered to be part of the RCS nor within the scope of NRC Bulletin 88-08.

Pressurizer:

There are several one inch instrument taps at various locations on the pressurizer. There is no mechanism for flow through these lines into the pressurizer. In addition, the small internal diameter of these lines would not support the phenomenon of flow stratification. These lines are therefore not considered to be the subject to the concerns of NRC Bulletin 88-08.

Pressurizer Main Spray Lines:

The pressurizer main spray system acts to reduce pressurizer pressure by spraying cold leg water into the steam space. The upper portion of the spray system generally consists of a horizontal section of piping leading to the pressurizer spray nozzle. During plant heatups when less than four Reactor Coolant Pumps are operating, the normal bypass spray flowrate may be insufficient to maintain this uppermost horizontal section of spray piping full of water.

No known fatigue cracking, however, has been detected in the pressurizer spray piping. Further evaluations of stratified flow loading conditions were examined during CEOG-Task 482, "Pressurizer Spray System Thermal Fatigue Evaluation." The results of these evaluations, including recommendations were documented in a report to the C-E Owners. As a result of Task 482, Ft. Calhoun has implemented a gooseneck modification to the pressurizer spray piping which prevents the main spray header from maintaining a water/steam environment.

Pressurizer Auxiliary Spray Lines:

The auxiliary spray system acts to reduce pressurizer pressure by providing diverted charging flow to the steam space in the pressurizer. The auxiliary sprays are utilized when the main spray system is unavailable, typically when the RCPs are not operating. During normal plant operation, the auxiliary spray line is isolated from the charging system by two automatically operated valves in parallel. Although the charging system typically operates around 400°F, during transient conditions the temperature may drop as low as 120°F. The relatively cool charging system temperatures coupled with a charging pump discharge pressure higher than RCS pressure indicate the auxiliary spray line may be an unisolable section of piping connected to the RCS having temperature oscillations induced by leaking valves.

There are several general factors, however, which would tend to indicate that any potential stratified conditions in the auxiliary spray line would not be significant. The auxiliary spray line is a two inch, schedule 160 pipe. The smaller line is more flexible, and hence, more forgiving of thermal bending stresses. In addition, the smaller pipe has a higher probability of mixing due to the fact that the threshold for transition to turbulent flow is a function of pipe diameter (among other parameters). Also, the relatively thick pipe walls (compared to pipe diameter) enhance conduction around the circumference of the pipe which tends to equalize pipe wall temperatures. For this size pipe, the amount of leakage required to promote stratified flow (<.2 gpm, See Section 4.2.3) would not contain sufficient energy to provide stratified cooling.

At Ft. Calhoun, the auxiliary spray line is basically an extension of the main spray header where the main spray line turns to vertical. The gooseneck modification to the pressurizer spray piping prevents the main spray header and the auxiliary spray line from maintaining a water/steam environment. This line is therefore not a concern.

4.2.2 Safety Injection and Shutdown Cooling System

This section includes a discussion of the impact of safety injection and shutdown cooling operations on the safety injection and shutdown cooling penetrations to the RCS. During power operation, the high pressure and low pressure safety injection pumps are not active. These pumps are tested quarterly by starting the pumps and routing discharge flow through the miniflow recirculation lines to the RWT. The high pressure and low pressure pump discharge pressures are not sufficient to provide a driving head for potential leakage into the RCS.

Shutdown Cooling Lines:

The RCS shutdown cooling penetrations are isolated from the SIS by multiple valve isolation which minimizes the probability of valve leakage to the RCS. In addition, there is no direct flowpath from the CVCS to the shutdown cooling lines. Therefore, these penetrations are not a concern.

Hot Leg Injection Lines:

Ft. Calhoun credits hot leg injection to the RCS through the pressurizer via auxiliary spray so this location is not applicable to OPPD.

Safety Injection Lines:

The safety injection headers are isolated from the high pressure CVCS by two normally closed isolation valves in parallel. Although these valves are designed against leakage, Ft. Calhoun additionally has the following feature which prevents in-flow to the RCS.

There exists a connection just upstream of the safety injection check valve, from which a 1" line connects to a header and runs off to the RCS drain tank. This line serves multiple purposes. One purpose is to divert in-leakage from the check valves out of the SI header so as to maintain the correct boron concentration within the injection lines and to prevent the further leakage of reactor coolant beyond the second RCS isolation check valve into the SITs or further into the LPSI/HPSI header. These lines are isolated by control valves.

Leakage beyond the check valve is detected by a pressure transmitter, located in each injection leg between the first and second isolation check valves. As leakage occurs, the local pressure between these valves increases. When pressure exceeds a prescribed setpoint, the transmitter directly signals the line isolation control valve to open and the leakage bleeds off to the reactor coolant drain tank.

By virtue of this feature, the pressure upstream of the RCS isolation check valves can be maintained less than normal operating pressure in the RCS. This condition will preclude unintentional injection of fluid in the normal direction of flow, such as charging system leakage into the SI header. If a situation should occur whereby the charging system is leaking into the SI header though its cross connect line, the pressure in the SI header would have to exceed RCS pressure in order for flow to occur into the RCS. Before this occurred, the pressure transmitter would detect the increase and respond. Therefore, the safety injection penetrations will not be subjected to thermal stresses due to control valve leakage.

4.2.3 Chemical and Volume Control System

This section included a discussion of the impact of CVCS operations on the charging and letdown penetrations to the RCS. The auxiliary spray line was addressed in the previous section.

Letdown Line:

During normal operation the letdown line passes full flow. During letdown isolation conditions, the CVCS is isolated from the RCS letdown penetration by multiple valves which significantly reduce the probability of back leakage into the RCS. Loss of letdown with continued charging flow is an upset condition which does not frequently occur during normal operation. If charging is secured (e.g., CVCS isolation) then there is no mechanism present to provide a differential pressure towards the RCS.

Charging Line:

There are full flow conditions in the charging line during normal plant operation. During CVCS isolation the charging pumps are secured, hence there is no driving head to provide leakage past the charging throttle valve. During auxiliary spray use, the CVCS is also isolated from the RCS charging penetration by a single throttle valve. Although this configuration combined with a CVCS pressure greater than RCS pressure may allow some leakage past the charging throttle valve, several factors indicate stratified flow conditions to be unlikely. The charging line is a two inch schedule 160 pipe which results in a pipe I.D. of 1.7 inches. The relatively small diameter and thick walls promote heat conduction around the circumference of the pipe which tends to reduce thermal bending stresses. This pipe is also more flexible and, therefore, more forgiving of such stresses than a larger line. In addition, the amount of flow (even potential flow due to valve leakage) required to produce sufficient mixing to negate stratified conditions is very small for a pipe this size. The calculation presented in Appendix A demonstrates that for normal system operating temperatures, less than one quarter of a gpm is required to initiate transition flow from laminar to turbulent conditions which promote mixing. In addition, the charging throttle valve is approximately 20 feet away from the penetration. The long distance would promote mixing of any potential leakage. The line geometry enhances pipe flexibility which inherently minimizes piping stresses at a given location.

5.0 EVALUATION OF STRESSES IN PIPING CONNECTED TO THE RCS (NO LEAKAGE)

The purpose of this section is to examine potential thermal stresses which may be caused by local stratification in dead-ended or valved out piping runs. These temperature distributions may occur independent of potential valve leakage, i.e., no valve leakage is assumed to be present.

5.1 RCS Penetrations

The RCS penetrations are assumed to include the Refueling Water Level Indication System connection, the Reactor Vessel Gas Vent System connection, drain lines, instrument taps, in-core instrumentation (ICI) Nozzles, RCP seal injection lines, PORVs, PSVs, the pressurizer spray lines and the surge line.

Refueling Water Level Indication System (RWLIS) Connection:

The RWLIS connection is typically a 3/4" line. The relatively thick walls compared to the pipes inner diameter allow for significant heat conduction around the circumference of the pipe walls which tends to equalize temperatures in the metal. In addition, the small I.D. promotes mixing of fluid inside the line.

Temperature distributions due to cooling to ambient would be characteristic of fin type heat transfer, i.e., thermal gradients would act along the axial direction of the pipe rather than induce bending stresses. The RWLIS connection is therefore considered not to be a concern.

Instrument Taps:

Most instrument taps are 3/4" to 1" pipes. These pipes are not a concern for all the same reasons that apply to the RWLIS connection. In addition, these lines are typically very long with respect to the line diameter which results in flexible geometries that tend to minimize stresses from applied loading conditions.

Drain Lines:

There are four two inch drain lines; one for each cold leg. These drains are double isolated and capped off during normal operation and are not considered to be a concern for the reasons outlined for the RWLIS connection. In addition, these lines tap off the bottom of the cold legs in a vertical run, therefore, any temperature distribution would be along the axis of the pipe and would not result in significant stresses.

Reactor Vessel Gas Vent Connections:

This connection is a 3/4" - 1" connection normally filled with primary coolant. The runs are many feet long which provides large flexibility in the line and minimizes thermal induced stresses. This connection is not a concern for the reasons outlined for the RWLIS connection.

ICI Nozzles:

The ICI nozzles tap off of the reactor vessel. These lines are typically 3/4" in diameter. These connections are not a concern for the reasons outlined for the RWLIS connection.

Surge Line:

The potential for flow stratification in the surge line is addressed in Section 4.2.1.

PSV Piping:

Piping from the pressurizer to the primary safety valves is filled with condensate. Excess condensation would self drain back into the pressurizer due to the piping geometry discussed in Section 4.3.1. These connections are therefore not a concern.

PORV Piping:

The PORVs are connected to the pressurizer by an initially sloped line coming off the top of the pressurizer that is followed by long horizontal runs of 3" piping. These lines are filled with steam that may condense and lie along the bottom of the lines. Condensing steam would be replaced by pressurizer steam while the condensate along the bottom of the pipes would pool or possibly drain back to the pressurizer. Either scenario could set up a steady state condition of steam to water interface which could result in unusual top to bottom temperature gradients. Although the lines are relatively small diameter, the potential existence of two phases (steam and water) in the line could promote tendencies for top to bottom temperature differentials. Although there have been no known cracks in PORV piping to date, further definition of actual in plant loadings would be required to perform a realistic fatigue evaluation to determine the effects on the fatigue life.

Main Spray Line Connections to Cold Legs:

Main spray is drawn from the cold legs of the RCS, travels through the main sprays valves and/or the spray bypass valves, and into the main spray header to the pressurizer. Ft. Calhoun has an installed check valve to prevent auxiliary spray flow from short circuiting back to the cold legs. If leakage occurred across this check valve, it would travel down long, vertical runs before settling or passing into the cold leg. The main spray line temperatures are expected to be distributed along the axis of the piping with any leakage warming to Tc upon approaching the cold leg penetrations from near ambient conditions at the main spray valves. In addition, the auxiliary spray is normally provided at approximately 120°F (near ambient) when used during heatups and cooldowns. Therefore, there is no mechanism for significant temperature differentials to occur and these connections are not considered to be a concern.

Main Spray Line Header:

This is discussed in Section 4.2.1.

Auxiliary Spray Line:

This is discussed in Section 4.2.1

5.2 Safety Injection and Shutdown Cooling Penetrations

The subject penetrations include the safety injection lines, the hot leg injection lines and the shutdown cooling lines.

Safety Injection Penetrations:

The SIS penetrations typically tap off the tops of the cold legs at approximately a 75 degree angle from horizontal. The piping then makes a horizontal run to the safety injection check valve. The heat transfer length for this type of geometry is relatively short with respect to the diameter and length of pipe, i.e., temperatures in the pipe are expected to cool to containment ambient near or before the SI check valve. As the fluid cools it would tend to settle to the bottom of the pipe and drain back into the RCS. This volume would be replaced by warmer RCS fluid which would rise up the 75^0 inclined section into the horizontal run. Thus, a steady state natural convection loop may be initiated which would allow warmer water to flow along the top of the pipe, away from the RCS, and cooler water to flow along the bottom back towards the RCS. (See Figure 2). This flow would result in bending stresses on the pipe and SI nozzle. In addition, if the check valve were to be treated as heat source by the piping upstream of the valve, warmer water would migrate to the top of the pipe while the cooler, containment ambient fluid would stratify along the bottom. This temperature gradient would also tend to apply a bending moment to the safety injection pipe and nozzle. The potential thermal distributions would need to be more accurately defined before a realistic fatigue evaluation could be performed.

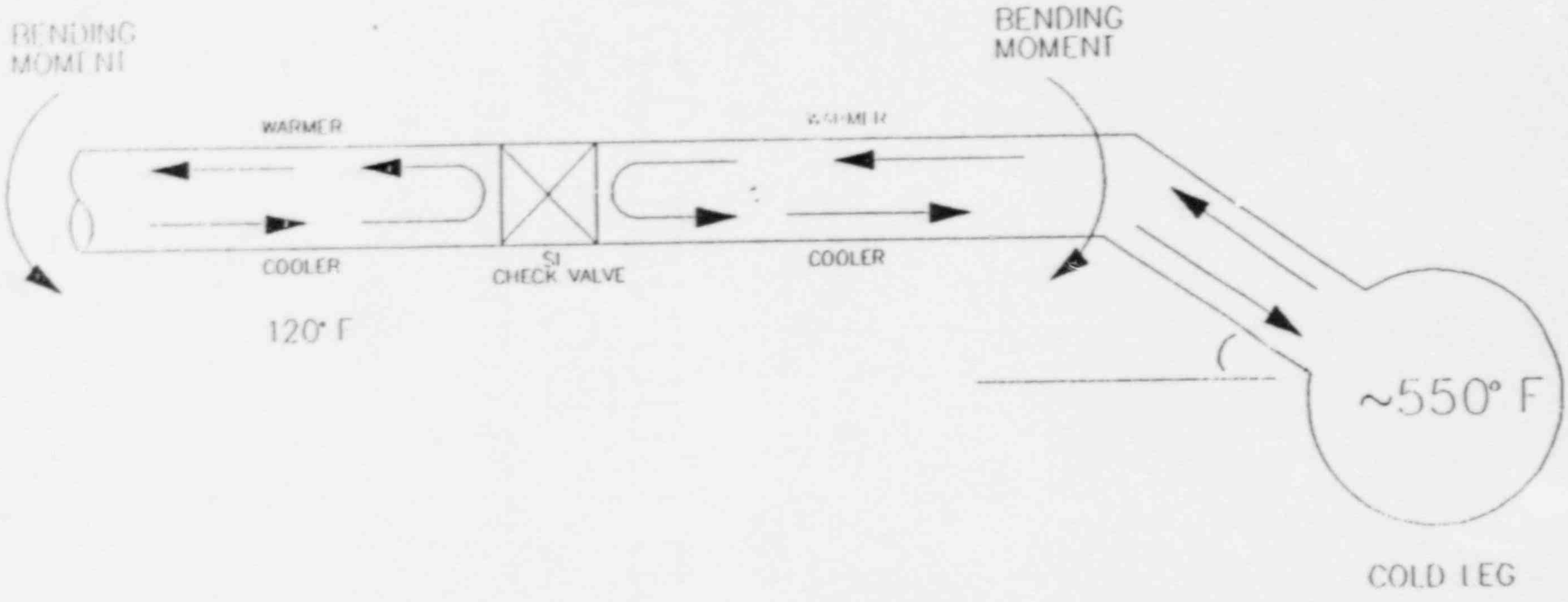


FIGURE 2: SAFETY INJECTION PENETRATION (TYPICAL)

Detracting from the potential for the above scenarios, Ft. Calhoun utilizes a butterfly check valve design that would tend to mix the flow and alleviate the potential for thermal gradients.

Shutdown Cooling Penetrations:

The shutdown cooling penetration taps off the bottom of the hot leg in a vertical drop before bending to the horizontal. The vertical run is relatively long with respect to pipe diameter, therefore the pipe exhibits fin type behavior where the thermal gradients act along the vertical axis of the pipe and induce minor axial loadings. Any cooler water would collect near the elbow and is estimated to be several degrees warmer than containment ambient. The shutdown cooling lines are therefore not considered to be a concern.

Hot Leg Injection Penetration:

Ft. Calhoun utilizes the auxiliary spray line for hot leg injection so the discussions associated with the auxiliary spray line may be referred to.

5.3 CVCS Penetrations

The CVCS penetrations include the charging and letdown line connections.

Letdown Connection:

The letdown connection is a two inch line that drops off the bottom of the cold leg. When letdown flow isolated, this initial vertical run allows cooler water to settle towards the lower end of the vertical run which results in an axial temperature distribution. This line is not a concern for the reasons outlined for the RCS drain lines in Section 5.1 (small diameter piping).

Charging Connection:

During auxiliary spray operation, the charging line penetration is isolated from the charging pump. Convection cooling could occur between the charging penetration and the first check valve, however, the small line diameter and single phase (all water) fluid conditions would not support stratified flows. The flexibility of this line due to the long piping runs also make the charging line an unlikely candidate for unusual thermal stresses.

6.0 RESULTS AND CONCLUSIONS

The results of the systems review indicate the pressurizer surge line may have the potential for flow stratification. As discussed in Section 4.2.1, potential concerns associated with temperature stratification in CEOG plant surge lines are being addressed via ongoing C-E Owners Group activities which, C-E believes, fulfills the intent of NRC Bulletin 88-08.

Stratified temperature loadings in the pressurizer spray header and auxiliary spray connection were already examined in CENPSD-261, "Pressurizer Spray System Thermal Fatigue Evaluation". The generic recommendations in this report were implemented on a plant specific basis by OPPD. At Ft. Calhoun, a gooseneck modification made to the pressurizer spray piping prevents a water/steam environment from being maintained in the auxiliary spray line.

The results of the thermal stress evaluations of stagnant lines indicates that the PORV piping from the pressurizer to the PORVs may have the potential for top to bottom temperature gradients due to the presence of two phases (steam and water) as discussed in Section 5.1. Modifications made to the pressurizer safety valve inlet lines provides the same type of thermal fatigue protection as those made to the spray piping. The safety injection penetrations may also have the potential for significant temperature differentials due to natural convection cooling as discussed in Section 5.2. More information on thermal distributions in these pipes would need to be assimilated to more accurately characterize the potential loadings.

In general, small lines with single phase all water fluid flow are not expected to be a concern for the reasons discussed in Sections 4.0 and 5.0. These include the fact that smaller pipe has a higher probability of mixing due to the low threshold for transition to turbulent flow (approximately .2 gpm). In addition, the relatively thick walls (compared to pipe diameter) enhance heat conduction around the circumference of the pipe which tends to equalize pipe wall temperatures. If small amounts (<.2 gpm) of cooler fluid are present (e.g., due to valve leakage) the energy contained in the stratified fluid would not be sufficient to provide significant stratified temperatures in a relatively thick walled pipe. Smaller lines with relatively long runs are also more flexible and therefore less susceptible to stresses induced by thermal bending loadings.

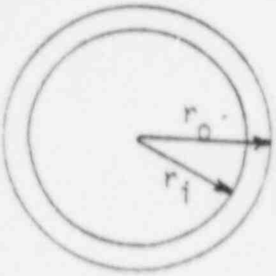
APPENDIX A

MINIMUM CRITICAL VELOCITY FLOW CALCULATION

The ability to preclude stratified flow is dependent upon fluid mixing. The mixing mechanism is highly dependent upon the turbulence of fluid and the length of pipe available for mixing (mixing length). Turbulence of a flowing fluid can be estimated by the Reynolds number for the fluid and configuration in question. The Reynolds number (Re) is proportional to the ratio of inertia force/viscous force. For relatively small Re, viscous forces predominate and the flow is laminar, whereas for the relatively large Re, the inertial forces predominate and the flow is turbulent. Hence, once a Re is established for fully turbulent flow, a lower critical velocity, Vc, can be calculated which ensures turbulence. Typically, for completely enclosed flow as in pipe, Re = 2000 establishes initially turbulent flow, however Re as great as 8000 can be laminar if velocity is slowly increased. However any small surface disturbance will disrupt the laminar layers and quickly develop into turbulent flows.

Important to fluid mixing is mixing length. Mixing lengths of approximately 75 to 100 equivalent diameters are needed to ensure complete fluid mixing.

For a typical charging line configuration the following calculation is applicable.



SCHEDULE 160 PIPE, STAINLESS STEEL
I.D. = 1.687
AREA = 2.241 IN^2

DETERMINE LOWER CRITICAL VELOCITY

CASE 1

ASSUMPTIONS:

1. WATER TEMPERATURE = 160^{0}
2. $Re = 2,000$

$$Re = \frac{DV_c}{V} \quad D = 1.687'' = .1406'$$
$$V = 4.42 \times 10^{-6} ft^2/s$$

$$V_c = \frac{ReV}{D} = \frac{(2,000)(4.42 \times 10^{-6} ft^2/s)}{(.1406\ ft)} = .062\ ft/s$$

$$Q = V_c = (.062\ ft/s)(.0156\ ft^2)(7.4805\ gal/ft^3)(60s) = .43\ gal/min$$

min

CASE 2

ASSUMPTIONS:

1. WATER TEMPERATURE = $400^{0}F$
2. $Re = 2,000$

$$V_c = \frac{ReV}{D} = \frac{(2,000)(2.105 \times 10^{-5} ft^2/s)}{(1.406\ ft)} = .03\ ft/s$$

$$Q = V_cA = (.03\ ft/s)(.0156\ ft^2)(7.4805\ gal/ft^3)(60s) = .21\ gal/min$$

min

Therefore provided flow through the charging line is approximately .21 to .43 gal/min and there is at least 75-100 equivalent pipe diameters of mixing length (14 ft), the fluid should be adequately mixed to preclude stratified flow.

APPENDIX B

FT. CALHOUN

CONNECTIONS TO RCS

Fort Calhoun Station

LINE NUMBER	DESCRIPTION
3/4" RC 2501R/RC-100	RVGVS
12" SI 2501R	Safety Injection & Shutdown Cooling Loop-2B
2" RC 2501/RC-112	To WD
RC-118/158	SG Loop 2-B Pressure Taps
RC-120/148	SG Loop 2-B Pressure Taps
RC-121/153	SG Loop 2-A Pressure Taps
RC-113/157	SG Loop 2-A Pressure Taps
2" RC 2501R	To Letdown Loop 2A
2" RC 2501R/RC-113	To WD Loop 2A
2" RC 2501R	Charging Line Loop 2A
3" RC 2501R/PCV-103-1	Spray Line Loop 2A
3/4" RC 2501R/RC-133	Bypass Spray Line Loop 2A
3/4" RC 2501R/RC-139	Sample Line Loop 2A
12" SI 2501R	Shutdown Cooling Hot Leg
12" SI 2501R	Safety Injection/Shutdown Cooling Loop 2A
12" SI 2501R	Safety Injection/Shutdown Cooling Loop 1B
3/4" RC 2501R/RC-101	RV Level Indication Loop 1A
2" RC 2501R	Charging Line Loop 1A
12" SI 2501R	Safety Injection & Shutdown Cooling Loop 1A
2" RC 2501/RC-124	To WD Loop 1A
RC-110/RC-134	S G Pressure Taps Loop 1A
RC-108/156	SG Pressure Taps Loop 1A
3" RC 2501/PCV-103-2	Spray Line Loop 1B
3/4" RC 2501/RC-131	Spray Bypass

Fort Calhoun Station

LINE NUMBER	DESCRIPTION
10" RC 2501R	Surge Line
3/4" RC 2501R/RC-138	Sample Line
2" RC 2501R/RC-128	Refueling Level Indicator Connection
RC-153/RC-109	SG Pressure Taps Loop 1B
RC-155/107	SS Pressure Taps Loop 1B
RC-103 to 106	SG Pressure Taps Loop 1B
2" RC 2501R/RC-123	To WD
RC-114 to 117	Loop 2 Pressure Instrumentation
4" RC 2507R	Spray Line Header to Pzr.
2" RC 1508R	Aux. Spray Line
1" RC 2507R/RC-143 to 146	Pzr. Instrumentation
1" RC 2507R/RC-147,149,150	Pzr. Instrumentation
4" RC 2507R/RC-141	Pzr. to PSV
4" RC 2507R/RC-142	Pzr. to PSV
6" RC 301R/RC-141	PSV to Quench Tank Header
6" RC 301R/RC-142	PSV to Quench Tank Header
8" RC 301R	Quench Tank Header
3" RC 2507R	PORV Header
3/4" RC 2507R/RC-102,126	Sample
2-1/2" RC 2507R/HCV-151	PORVs
2-1/2" RC 2507R/HCV-150	PORVs
4" RC 301R	PORV Header
6" RC 301R	PORV Header to Quench Tank
1/2" RC 301R	PORV Bypass

Fort Calhoun Station

LINE NUMBER	DESCRIPTION
8" RC 301R	Relief Header to Quench Tank
1-1/2" RC 301R	Relief Header
3/4" RC 2501R/RC-127	Sample
	ICI Nozzles