HOPE CREEK RECIRCULATION SYSTEM
LARGE BORE PIPE CRACKING RESOLUTION

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1.0 REVISION HISTORY

12/26/95 Revision 0

2.0 PURPOSE

The purpose of this evaluation is to evaluate the potential for growth of postulated defects in the Hope Creek recirculation system large bore piping. In particular, the purpose of this evaluation is to complete the M20-92-002 & M20-92-003 ATS action items which involve growth of fabrication defects similar to those discovered during the 3R refueling outage.

3.0 SCOPE

The scope of this evaluation is the shop welded large bore piping in the Hope Creek recirculation system. The large bore piping is the 12", 22" and 28" diameter piping. The piping is evaluated for cyclic loads which may cause growth of postulated fabrication hot tear defects.

4.0 DISCUSSION

4.1 Background

Defect Discovery/Evaluation

Inservice inspections of the Hope Creek recirculation system piping during the third refueling outage (3R) detected indications on the outside diameter (OD) of two 28" diameter pipe butt welds. The circumferential defects were located in both recirculation loops at the weld joining each riser to the RHR return tee connection (see Figure 1).

The indications were identified by penetrant inspection (PT) and confirmed using ultrasonic inspections (UT). Subsequent excavation (as part of the repair) determined that the defects were circumferential with lengths up to 7½ inches and depths to about 7/16 inch. Although the largest single defect was about 7½ inches, adjacent defects resulted in total defect excavation lengths up to about 38 inches. All defects were removed and the two welds were repaired (Code Job Packages P-91-002 & P-91-003). Fracture mechanics calculations performed by General Electric (Reference 1) determined that the as-found defects were "stable" and gross failure would not occur during the highest loading condition, a seismic event.

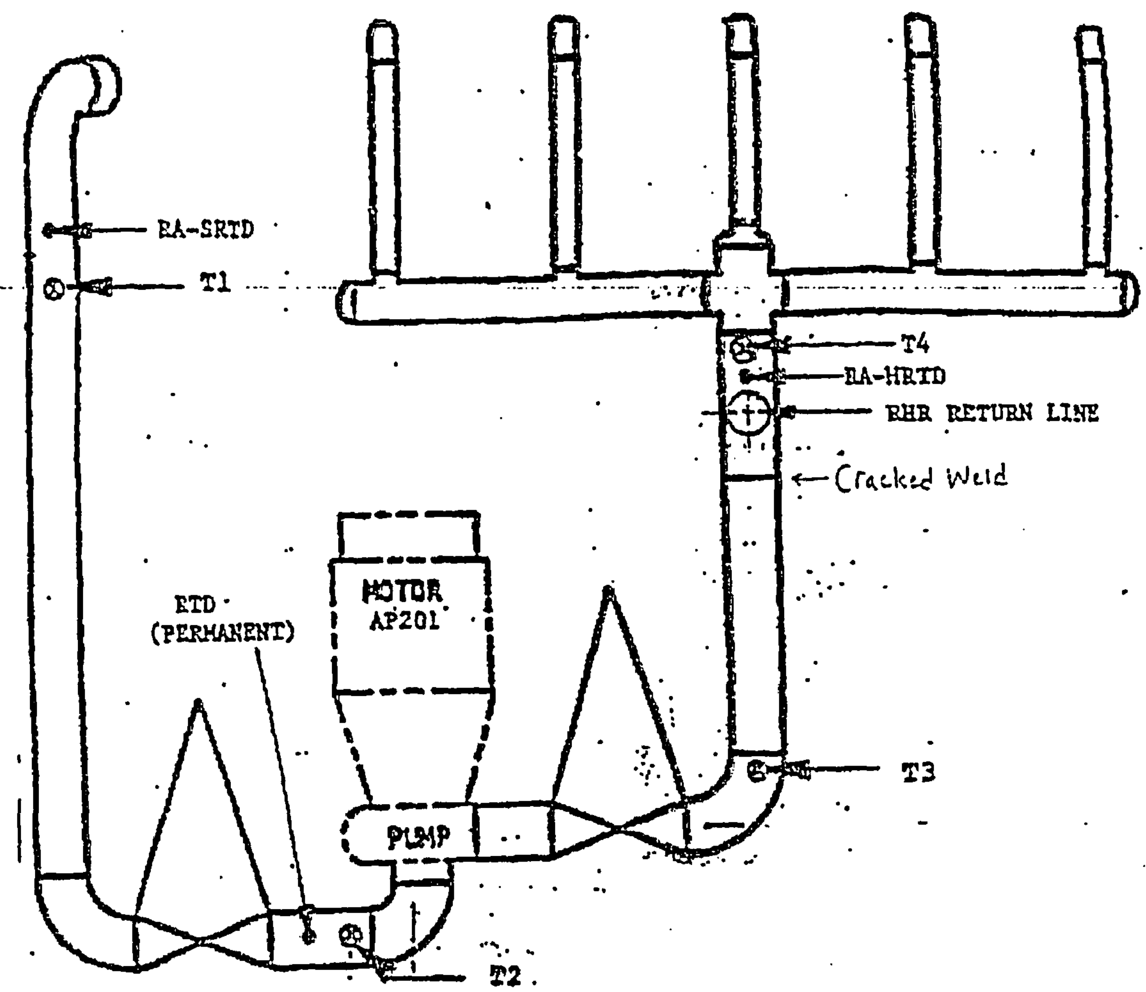

Figure 1
Hope Creek Recirculation System Geometry (Loop A)

Failure analyses determined that the defects resulted from hot tears that initiated during welding with filler metal that contained a very low amount of ferrite (Reference 1). It was concluded that the welds which may be susceptible were those shop welds fabricated by a single manufacturer using one particular welding procedure. There are a total of 50 susceptible welds in the recirculation piping.

A summary of inspection results, evaluations performed, and repair activities is provided in a "White Paper" Engineering Evaluation prepared to summarize the defect-related events (Reference 1).

Safety Review Group Assessment

The Hope Creek Onsite Safety Review Group (SRG) completed an independent assessment of the recirculation piping cracking issue (Reference 2). This assessment addressed the defects in the large diameter piping and a non-related fatigue cracking problem in the small diameter recirculation piping. In this independent assessment it was concluded that additional effort was required to fully evaluate and resolve the cracking issues. As a result, NDRAP 125-02-4003 was prepared to summarize the proposed program (Reference 3). Table 1 summarizes the status of the NDRAP action items, as follows:

- M20-92-001 - This item, which addresses the development of an NDE technique to identify fatigue cracks in small bore piping, has been completed.

- M20-92-002 and M20-92-003 - These items, which address evaluation of large bore piping for high cycle fatigue, are still open and require resolution.

The purpose of this evaluation is to close the remaining open items associated with these ATS items.

Table 1
Action Status Summary
(NDRAP-125-92-4003)

Item	Task	Description	Status
M20-92-001 Develop and implement an ultrasonic examination technique for early detection of fatigue cracks originating from inside of small bore pipes in the recirc system.	1	Prepare a specification and requisition for program development, select a contractor and verify technique.	Closed
	2	Dependent on Task 1 completion, initiate examination of small bore recirculation system pipes during planned or unplanned shutdowns.	Closed
M20-92-002 Evaluate high cycle fatigue of large bore piping in the recirculation system based on measurement and calculations.	1	Develop a calculation that can use amplitude and frequency input to calculate crack propagation in large bore piping walls.	Closed (Replaced by Task 3)
	2	Utilize the calculation developed by Task 1 to calculate the risk from crack propagation in large bore pipes related to high cycle fatigue.	Open
	3	Complete the development of a calculation that can use amplitude and frequency input to calculate crack propagation in large bore piping walls.	Open

Item	Task	Description	Status
M20-92-003 Prepare and utilize an examination and repair specification for large bore piping in the recirculation system.	1	Prepare an examination and repair specification for large bore piping in the recirculation system to replace the current program.	Closed (Replaced by Task 5)
	2	During suitable planned or unplanned shutdowns, hook up instruments to large bore pipes in the recirculation system for the purpose of measuring amplitude and frequency of vibrations during critical pump speed.	Open
	3	Start measurement of large bore pipe vibration amplitude and frequency.	Open
	4	Revise Operations procedures to record the total elapsed time the circulation pumps run at critical speed as shown in the independent assessment report.	Closed
	5	Complete an examination and repair specification as explained in 9/10/92 Memo from E. Rozovsky to D. Bhavnani (This is a repeat of Task 1).	Open

The key outstanding concern raised by the SRG is the possibility of high cycle fatigue damage in the Hope Creek large bore recirculation system piping. Specifically, the SRG expressed concern that:

- High cycle loads may cause other existing (but undiscovered) hot tear defects to grow to larger depths or lengths. These larger defects may be a safety hazard.
- High cycle loads may initiate cracks in the piping at locations other than welds. The ISI program only inspects welds, so if other cracks developed they would not be detected.

4.2 Large Bore Piping Inspections

Subsequent to the discovery of the weld defects in the 28" shop welds (during the third refueling outage), additional inspections were completed during the third, fourth and fifth refueling outages. A summary of these inspections is provided in Table 2.

No indications were discovered in any welds other than the two which were originally cracked. No further inspections are currently planned (other than those normally required by the ISI Program and Section XI of the ASME Code).

A listing of the recirculation system large bore piping welds determined to possibly be susceptible to hot tear type defects is included in Table 3. These welds are distributed throughout the piping system.

Table 2
Large Bore Piping Inspection Summary

Outage	Inspection Type	Scope[1]	Results
3R	PT	16 - 28" welds 4 - 22" welds 4 - 12" welds	No indications
	Special UT[2]	5 - 28" welds 3 - 12" welds	No indications
4R	PT Special UT	Both 28" welds with defects 4 Other welds (mixture of sizes)	Linear indication in an unrepaired section of one of the 28" welds with defects
5R	PT Special UT	Both 28" welds with defects 2 Other welds	No indications

Notes:
1. There are sixteen potentially affected 28" shop welds, four 22" welds and thirty 12" welds (see Table 3).
2. The special UT method examines the outer 1/3 of the pipe wall, where the defects have been observed.

Table 3
Shop Welds Potentially Susceptible to Hot Tear Defects

Loop	12" Welds		22" Welds	28" Welds
A	1BB12VCA-013K-1 1BB12VCA-013J-1 1BB12VCA-013H-1 1BB12VCA-013G-1 1BB12VCA-013F-1 1BB12VCA-013K-3 1BB12VCA-013J-3 1BB12VCA-013H-3	1BB12VCA-013G-3 1BB12VCA-013F-3 1BB12VCA-013K-4 1BB12VCA-013J-4 1BB12VCA-013H-4 1BB12VCA-013G-4 1BB12VCA-013F-4	1BB22VCA-013-2 1BB22VCA-013-4	1BB28VCA-012-2 1BB28VCA-012-3 1BB28VCA-012-6 1BB28VCA-012-7 1BB28VCA-012-1 1BB28VCA-013-4 1BB28VCA-013-6 1BB28VCA-013-8
B	1BB12VCA-014E-1 1BB12VCA-014D-1 1BB12VCA-014C-1 1BB12VCA-014B-1 1BB12VCA-014A-1 1BB12VCA-014E-3 1BB12VCA-014D-3 1BB12VCA-014C-3	1BB12VCA-014B-3 1BB12VCA-014A-3 1BB12VCA-014E-4 1BB12VCA-014D-4 1BB12VCA-014C-4 1BB12VCA-014B-4 1BB12VCA-014A-4	1BB22VCA-014-2 1BB22VCA-014-4	1BB28VCA-011-2 1BB28VCA-011-3 1BB28VCA-011-5 1BB28VCA-011-7 1BB28VCA-011-10 1BB28VCA-014-4 1BB28VCA-014-6 1BB28VCA-014-8

4.3 Fatigue Crack Growth

The growth of cracks under cyclic loading can be predicted using methods from linear elastic fracture mechanics (LEFM). The basic calculational method and equations (for a given defect geometry) are independent of the magnitude of the applied load, frequency of loading, and size of the defect. Thus, one set of equations can be developed which is applicable for evaluating all cyclic loadings on the piping.

A calculational method for predicting growth of postulated hot tear defects in the recirculation system large bore piping is included in Attachment 1. Attachment 1 includes the necessary equations and correlations along with the appropriate material properties. The important results from Attachment 1 are:

- The crack growth rate can be predicted based on load cycles, or if the loading is at a constant frequency, based on time.

$$\frac{da}{dN} = (10^{-19.635}) S \Delta K^{3.3}$$

$$\frac{da}{dT} = 3600 f \frac{da}{dN}$$

where:

a is the crack depth (in)
N is the number of cycles
S is a factor to account for mean stress effects
K is the stress intensity factor (ksi√in)
f is the frequency (Hz)
T is time (hr)

Details of the calculation of these parameters are included in Attachment 1.

- The welding residual stresses in the large bore piping are most likely compressive in the middle of the pipe wall and tensile at the surfaces. However, this is not necessarily true in all cases.

- There is a threshold effect for crack growth. For calculated values of effective change in stress intensity factor, $\Delta K_{eff} = S\Delta K$, less than 5 ksi√in no crack growth will occur (Reference 10).

4.4 Crack/Defect Evaluation

Method/Acceptance Criteria

Criteria for acceptance of cracks in austenitic stainless steel pressure boundary piping are provided in Section XI of the ASME Code (Reference 11). These criteria, which are based on plastic collapse (limit load) correlations, provide allowable crack depths for measured crack lengths. The application of these criteria is shown in Attachment 2.

Applied Stresses

When evaluating defects, two evaluations are performed.

- The piping is evaluated for normal conditions: pressure, deadweight and thermal expansion.
- The piping is evaluated for faulted conditions. In addition to pressure, deadweight and thermal expansion, this evaluation also includes the stresses resulting from the safe shutdown earthquake and annulus pressurization.

The faulted condition evaluation includes a lower safety factor.

4.5 Low Cycle/High Stress Loads

The predominant low cycle/high stress loads on the recirculation piping are plant startups and shutdowns and the postulated design basis earthquake. Each startup/shutdown contributes a stress cycle resulting from the differential thermal expansion stresses in the piping. The design basis earthquake does not contribute a large number of cycles of load, but has the potential to apply a large load on the cracked section.

These low cycle loads were evaluated by General Electric (Reference 13) and were found not to be a concern for defects similar to those discovered in the 3R outage. The predicted crack growth resulting from startups and shutdowns was negligible (less than 10^{-5} inches per cycle). Further, the piping was acceptable for design basis earthquake loads even with the largest identified defect.

4.6 High Cycle/Low Stress Loads

There are two primary sources of high cycle vibration in the recirculation system large bore piping. These are normal operational vibration due to pumps, flow induced vibration, etc., and a particular source of vibration at Hope Creek resulting from operation of both recirculation pumps at a critical speed of about 102% rated core flow (a condition encountered infrequently in the past during the shutdown sequence).

Normal Operation Vibration

The recirculation system piping vibrates during normal operation. Measurements of the vibration displacements were made during plant startup. Using these measurements, estimates were made of the vibration stresses and corresponding crack growth rates for postulated cracks (defects) in the recirculation system large bore piping. These calculations, which include the effects of mean stress and residual stresses are included in Attachment 3.

The primary result of those calculations is that defect growth during normal operation is a binary function. Either the defects will grow rapidly, or they will not grow. Since the residual and vibration stresses increase towards the pipe outer surface, any defect which began growing would likely grow through to the surface. It is possible that growth could occur toward the pipe inside surface and arrest as the crack tip enters an area of compressive residual stress in the center of the pipe wall.

Hope Creek has been operating for about nine years. Assuming a lifetime capacity factor of about 75%, the unit has been operating for about 2.2×10^8 seconds, at a rate of about 2.4×10^7 seconds per year. The frequency of vibration during normal operation is believed to be around 50 to 150 Hz. For a nominal frequency of 100 Hz, the recirculation piping experiences about 2×10^9 cycles per year. This is a very large number of cycles. If any defects were present and they began to grow, they would grow either through the pipe wall, or arrest, in less than several years (at the most).

These results indicate that there are no defects still growing under normal vibration loads, and that surface inspection (PT) can be used to inspect for defects.

Critical Pump Speed Vibration

It is known that there may be significant vibration of the Hope Creek recirculation piping during operation of critical pump speed at about 102% core flow (Reference 18). Plant operating procedures have been revised to adjust the pump operating conditions to preclude both pumps operating in the critical range. It is believed that these measures have eliminated the vibration. However, fatigue damage or crack growth may have occurred prior to the changes in plant operation. Measurements of the actual piping vibration during operation at critical pump speeds are not available. These data will be taken when the plant restarts after the R6 outage.

The pipe stresses during critical pump speed vibration may be large enough that there is a concern. This concern could be both growth of existing fabrication defects and, if the stress levels are great enough, development of new defects due to fatigue.

Hope Creek Operations estimates that as of June 1992, the unit has operated for about 600 to 1500 minutes in the critical pump speed range (Reference 19). As of November 1995, the unit will have spent additional time in the critical region. However, this additional time is not expected to be significant; procedure changes have been implemented to reduce the potential for operating in the critical region.

Assuming about 1000 to 1500 minutes, this duration corresponds to about $6x10^6$ to $9x10^6$ cycles (assuming a nominal 100 Hz frequency). If defects exist, there could be slow growth ($\sim 10^{-8}$ to 10^{-7} in/cycle) which would not be evident yet by leakage.

Since details of vibration stresses are not available, predicted crack growth rates cannot be determined.

4.7 Other SRG Concerns

Defect Initiation

In theory, fatigue cracks can develop at any location in the piping system which is stressed by cyclic loads. However, in practice it is very uncommon for cracks to develop at locations other than welds. In almost all instances, the most highly stressed locations in a piping system are at welds. This is because there are stress concentration effects associated with the weld and welds are typically located near highly stressed locations such as terminal ends or branch connections. As a result, the largest cracks (if any were present) would be located at welds. This concern is not considered significant; the existing practice of only inspecting welds is sufficient.

It should be noted that this issue is unrelated to the concerns of large bore recirculation piping with postulated fabrication defects, since the defects would only be located at welds. Further, it should also be noted that Section XI of the ASME Code only requires inspection of welds and immediately adjacent base metal.

Examination and Repair Specification

The main purpose of the SRG recommended examination and repair specification was to provide guidance for the data gathering, inspections and possible repairs planned for the 4R, 5R and 6R refueling outages. Inspections have been completed during the 4R and 5R outages and none are planned for the 6R outage.

The other purpose of the specification was for defining the instrumentation necessary to measure the high cycle loads. This activity is planned for the 6R outage as a separate work order.

Thus, the examination and repair specification is not necessary.

5.0 CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusions

Crack Growth Methods

A calculational method for predicting growth of postulated defects in the Hope Creek large bore recirculation piping has been developed (Attachment 1). The method can be used to predict the growth of defects in the outer one-half of the wall thickness. Methods were developed for both subsurface defects and those which penetrate the outside surface of the piping.

Acceptance criteria and methods have been developed for evaluating the acceptability of postulated defects in the Hope Creek large bore recirculation system piping (Attachment 2). The methods are based on criteria in Section XI of the ASME Boiler & Pressure Vessel Code. With knowledge of the defect size and the applied loads on the piping, the defect can be evaluated for continued service without repairs.

Low Cycle Fatigue

The recirculation piping was evaluated for low cycle loading in Reference 1 using methods similar to those developed in this evaluation. The conclusion of the evaluation was that failure of the piping from growth of similar defects due to low cycle loading was unlikely. The crack growth rate was very small and large defects could be accommodated.

High Cycle Fatigue - Normal Operation

It is concluded that there are no growing cracks in the recirculation system piping. Either no defects were present to grow, the defects and loads (stresses) were such that no growth occurred, or the defects grew until they arrested. If the defects did grow, they would likely grow through to the pipe outside surface, but would not be expected to grow completely through the pipe wall.

High Cycle Fatigue - Critical Pump Speed Operation

There is insufficient information available at this time to rule out growth of postulated defects during critical pump speed operation. This evaluation will require updating after additional information is available.

5.2 Recommendations

The following recommendations are made based on the results and conclusions discussed in this EE:

1. On the basis of this evaluation, close ATS Item M20-92-002, Task 3 (Development of Calculational Method ...). This effort has been completed.

2. On the basis of this evaluation, close ATS Item M20-92-003, Task 5 (Inspection and Repair Specification). This effort is not necessary.

3. Follow through on plans to perform tests to measure the recirculation system large bore piping vibration during operation at critical pump speeds. This is a concern not only for possible growth of fabrication defects, but also for general fatigue of the piping system.

4. Perform PT inspection of the 12 inch riser shop welds near the reactor vessel nozzles. There are ten welds (one weld per risor) on the horizontal sections of the piping adjacent to the nozzles. These welds are highly loaded, due to both steady state stresses and vibration stresses. Inspections should also be performed for any welds determined to be highly stressed during the vibration testing in recommendation 3. If defects were present in the shop weld, the defects would have grown through to the outside surface. If the PT results show no indications, there are no defects of concern. (The 28" piping has already been fully PT inspected.)

5. Update this evaluation following the completion of recommendations 3 and 4. The purpose of the update will be to incorporate an evaluation of the vibration stresses associated with pump critical speed operation.

6. Following the update of this evaluation (recommendation 5), close ATS Item M20-92-002, Task 2 (Risk From High Cycle Fatigue ...) and ATS Item M20-92-003, Tasks 2 and 3 (Measurement of Critical Pump Speed Vibration).

6.0 REFERENCES

1. H-1-BB-MHZ-0001, "Hope Creek Generating Station, Third Refueling Outage, ASME Section XI Inspections, Recirculation Piping Indications, Events, Evaluations and Actions Undertaken", PSE&G, April 2, 1991.

2. PSE&G Letter from D.E. Cooley to GM - Hope Creek Operations, HSR-92-018, 2/13/92.

3. NDRAP 125-92-4003, "Pipe Cracks in the Hope Creek Recirculation System", 3/10/92 (Attached to MEC-92-1108).

4. The Stress Analysis of Cracks Handbook, H. Tada, P. Paris and G. Irwin, Del Research Corporation, 1985.

5. ASME Boiler & Pressure Vessel Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components", Appendix A.

6. NUREG-0313, Revision 2.

7. Deleted

8. PSE&G Calculation C-0141, "Stress Report - Recirc. Loop A & RHR (Inside Drywell)", Revision 8, 4/3/95.

9. PSE&G Calculation C-0142, "Stress Report for Recirc. Loop B", Revision 8, 3/29/95.

10. "Fatigue Crack Growth Correlations for Austenitic Stainless Steels in Air", L.A. James and D.P. Jones, ASME PVP-Vol. 99, 1985.

11. ASME Boiler & Pressure Vessel Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components", Appendix C.

12. "Evaluations of Flaws in Austenitic Steel Piping", Journal of Pressure Vessel Technology, Transactions of the ASME, Vol. 108, No. 3, August 1986.

13. GE Nuclear Energy Report NEDC-31941, "Reactor Recirculation Piping System Flaw Evaluations for Normal and RHR Shutdown Cooling Operating Conditions", March 1991.

14. "Hope Creek Generating Station, Recirculation System Piping Steady State Vibration Surveillance Test", PSE&G Procedure TE-SU.BB-332(Q), Revision 2, 4/11/86. Full power data from testing 11/11/86.

15. "Piping Response, Measurement", General Electric Specification Data Sheet 22A5405AW, Revision 1, 2/7/86.

16. "Fatigue Evaluation of Piping Systems With Limited Vibration Test Data", S. N. Huang, ASME PVP-Vol 220, 1991.

17. GE Nuclear Operations Memo 123-DSB-17-0392, "Hope Creek Recirculation Snubber Reduction Analysis Preoperation and Startup Acceptability Assessment", 4/2/92.

18. PSE&G Memo NE-95-1525, from A. Kao to J. Pike, 9/28/95.

19. PSE&G Memo from Robert Hovey to Eli Rozovsky, 6/19/92.

20. NUREG-0376, "Residual Stresses at Girth-Butt Welds in Pipes and Pressure Vessels, Final Report", August 1977.

21. EPRI NP-1743, "Effect of Weld Parameters on Residual Stresses in BWR Piping Systems", March 1981.

22. EPRI NP-1413, "Measurement of Residual Stresses in Type-304 Stainless Steel Piping Butt Weldments", June 1980.

23. EPRI NP-2964, "Weld Residual Stress Redistribution Near Growing Cracks", March 1983.

7.0 IMPACT ON TECHNICAL DOCUMENTS

None

8.0 ATTACHMENTS

1. Recirculation Piping Fatigue Crack Growth Correlations
2. Recirculation Piping Crack/Defect Evaluation Procedure
3. Recirculation Piping Normal Operation Vibration Crack Growth Rates
4. MPR Calculation 108-100-01, "Bending Stresses in Elbows"

9.0 SIGNATURES

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ATTACHMENT 1

RECIRCULATION PIPING
FATIGUE CRACK GROWTH CORRELATIONS

The growth of cracks under cyclic loading can be predicted using methods from linear elastic fracture mechanics (LEFM). The basic calculational method and equations (for a given defect geometry) are independent of the magnitude of the applied load, frequency of loading, and size of the defect. Thus, one set of equations can be developed which is applicable for evaluating all cyclic loadings on the piping.

The following is a calculational method for predicting growth of postulated defects in the recirculation system piping.

A1.1 Stress Intensity Factor

The basic parameter from LEFM is the stress intensity factor K_I. The typical formula used to calculate the stress intensity factor is:

$$K_I = \sigma\sqrt{\pi a}\, g(\frac{a}{t})$$

where:

K_I is the stress intensity factor (ksi√in)
σ is the applied stress absent of crack (ksi)
a is the defect depth (in), for surface defects, a is the total defect depth, for subsurface defects, a is one-half the defect depth.
g is a function accounting for geometry and is dimensionless
t is the component thickness (in)

The stress intensity factor is essentially a measure of how rapidly the local stress field at the tip of the crack rises. The stress intensity factor is typically used in fracture toughness/brittle fracture evaluations. When the "applied" value of stress intensity factor (based on crack size, loads and geometry) exceeds the critical material limiting value, K_{IC}, sudden crack extension and failure will occur.

The g geometry factor is a function of defect geometry and component geometry. For defects similar to the fabrication hot tear defects which were discovered in the Hope Creek recirculation system large bore piping, one of two factors are applicable depending on defect location.

For surface defects which penetrate the pipe OD, the geometry factor, g, is obtained from Reference 4. The determination of the geometry factor is shown in Figure A1 (in Figure A1, g is labeled F). The values in the figure are multiplied by a parameter (based on a/t) to determine g. For the recirculation large bore piping, the ratios of inside to outside radius, r_i/r_o, are all approximately equal to 0.9. For r_i/r_o~0.9, the data in Figure A1 are relatively constant up to a/t ratios of 0.8. The average value of the span is 0.6. Thus, the geometry factor, g, is determined from:

$$g_l = Y\frac{\left[1+\left(\frac{r_o}{r_i}\right)^2\right]}{\sqrt{1-\frac{a}{t}}} \approx 0.6\frac{\left[1+\left(\frac{r_o}{r_i}\right)^2\right]}{\sqrt{1-\frac{a}{t}}}$$

where:

g_l is the geometry factor for surface defects
Y is the value from Figure A1
r_o is the outside radius (in)
r_i is the inside radius (in)

For subsurface cracks which do not penetrate the surface, the correlation from Reference 5 is used. Neglecting bending effects trough the pipe wall (the applied stress does not change significantly over the pipe wall thickness) and assuming a very long defect, the data in Figure A2 are used.

$g_2 = M_m$ (from Figure A2)

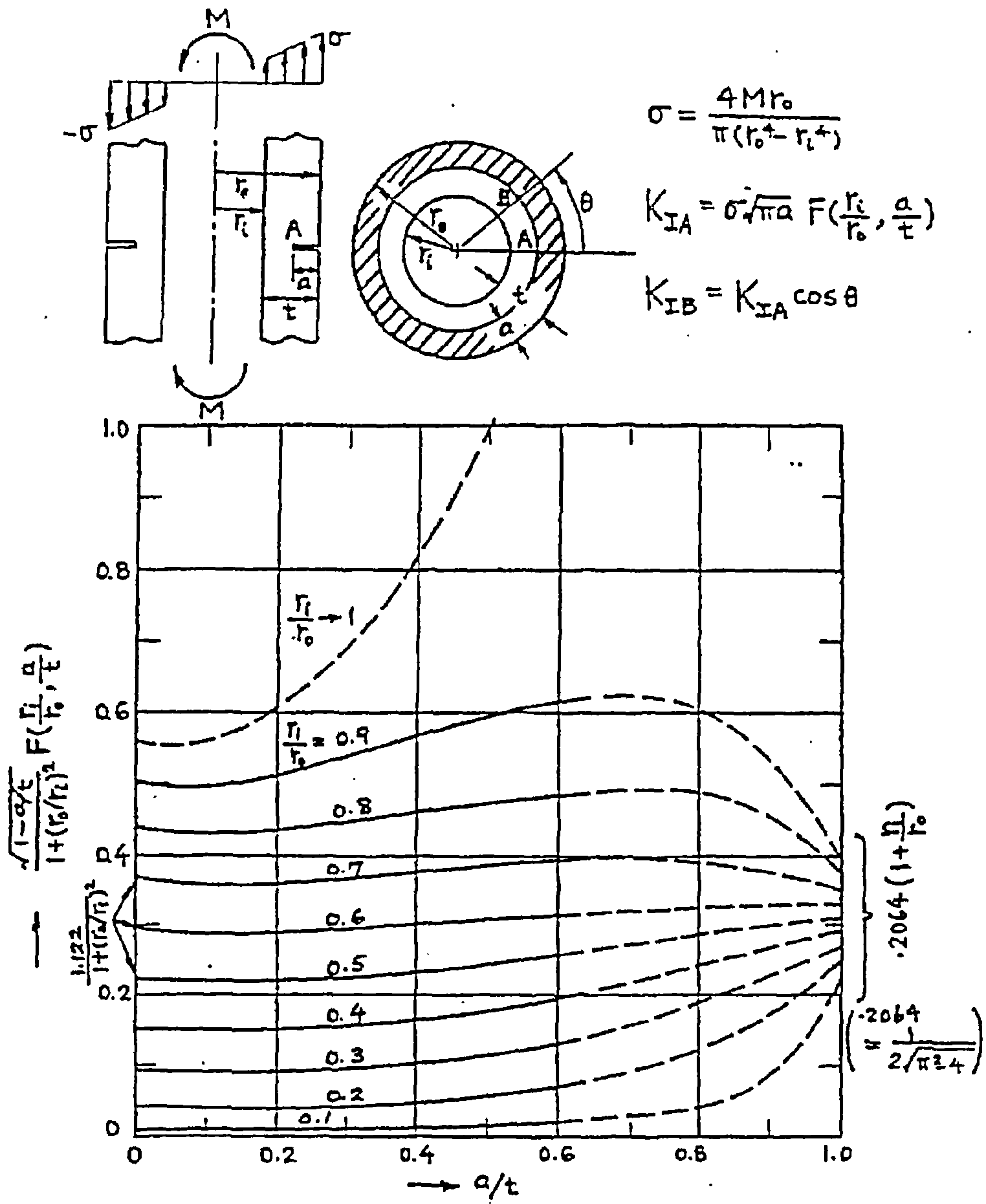

Figure A1
Surface Crack Geometry Factor

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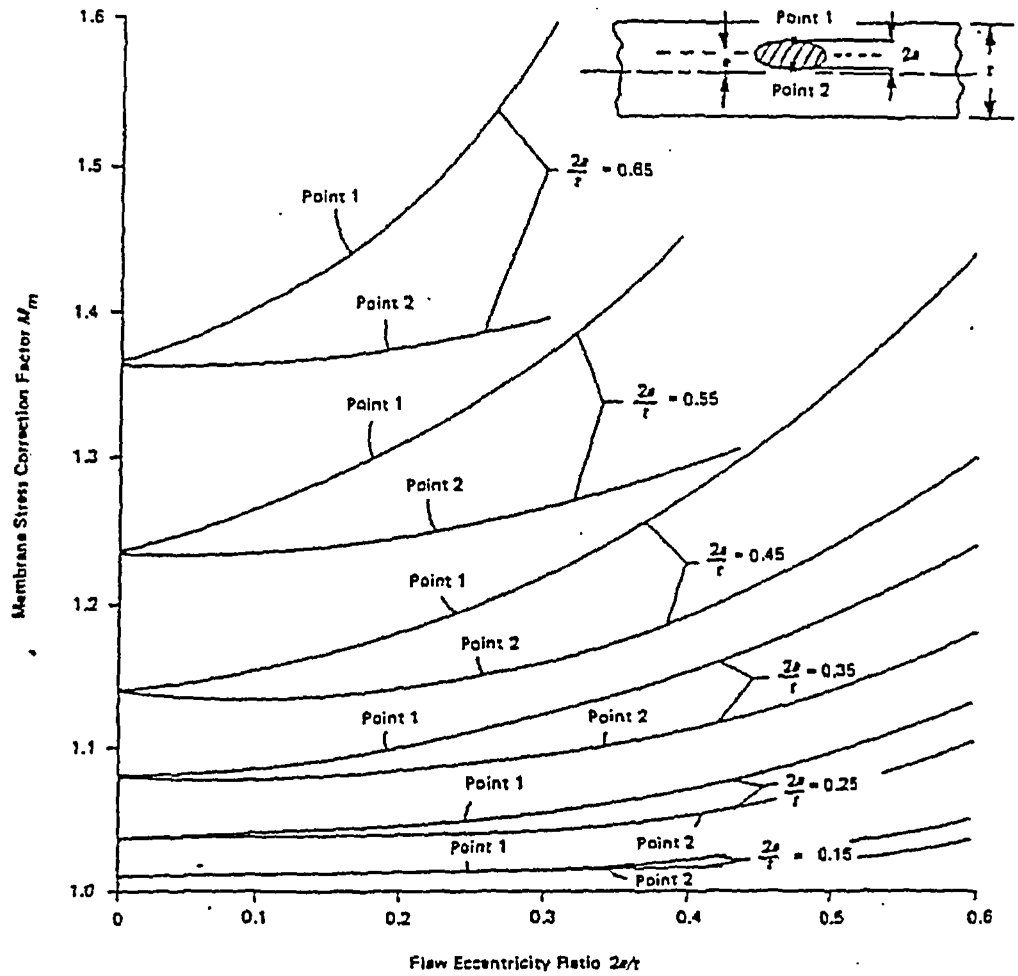

t = wall thickness
e = eccentricity
Point 1 = outer extreme of the minor diameter of ellipse (closer to surface)
Point 2 = inner extreme of the minor diameter of ellipse (further from surface)

Figure A2
Subsurface Crack Geometry Factor

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A1.2 Residual Stresses

The applied stress used in the calculation of the stress intensity factor is the total stress across the component thickness. This total stress includes not only applied stresses such as deadweight and thermal expansion, but it also includes welding residual stresses which may be present in the component.

The typical residual stress profile following welding is shown in Figure A3 for large bore piping (~26" diameter). This figure is from Reference 6, but the data in this figure are consistent with the data on residual stresses in References 20 to 23. The data are selected for locations adjacent to butt-welds. The residual stress is tensile near the yield strength at the inside surface, compressive in the middle of the pipe wall and tensile again near the outside surface. However, the data are not fully consistent. In some cases, the residual stresses are slightly tensile in the middle of the pipe wall, and near the yield strength at about 3/4 through the pipe wall.

For smaller large bore piping (~10 to 12 inch diameter), the data in References 20 to 23 show residual stress levels similar to those in larger pipes (Figure A3). However, in some cases, the residual stresses were shown to be tensile (at the yield strength) across the full thickness. In some other cases, the residual stresses were very small, almost negligible.

The hot tear defects discovered during the 3R outage were located in the outer one-half of the wall thickness. Any other hot tear fabrication defects would also be expected to be located in the outer one-half of the wall thickness. In this area, the residual stresses can not be exactly predicted. Test data shows measured tensile stresses in this area which range from strongly compressive to strongly tensile. For this evaluation, the effect of residual stress is included by considering constant residual stresses at three levels: tensile yield strength, zero, and compressive yield strength. .

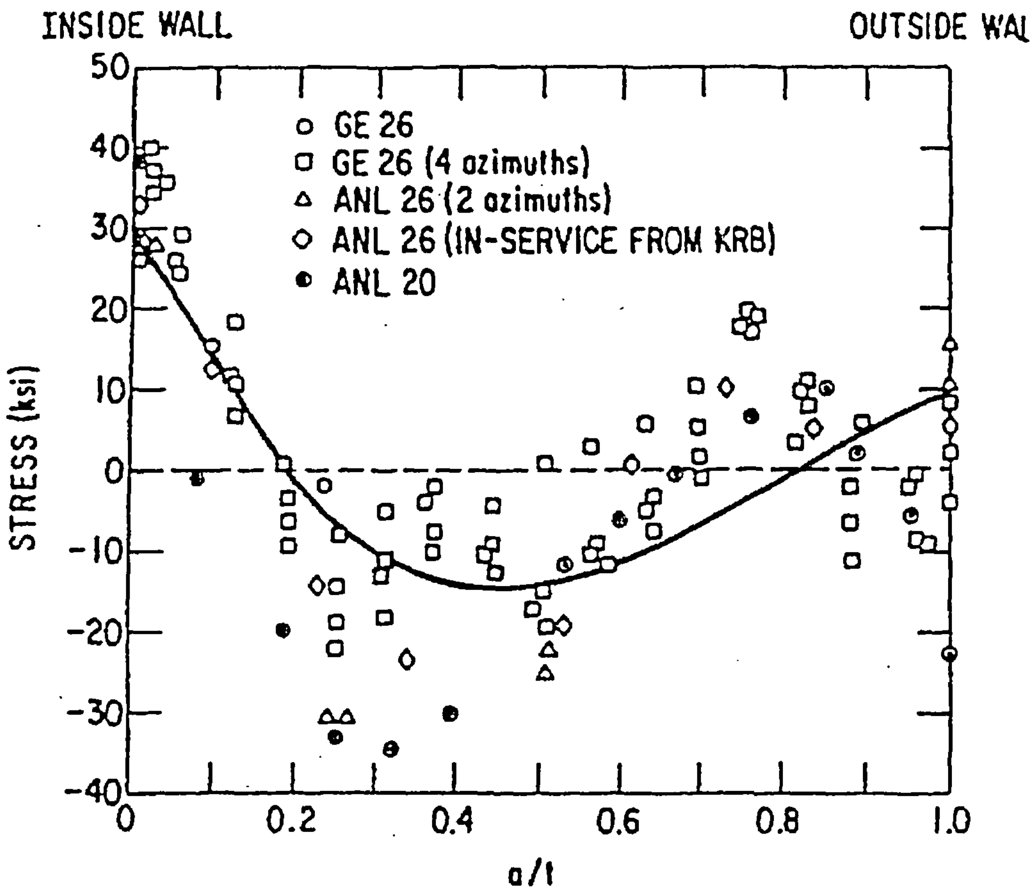

Figure A3
Large Bore Piping Axial Residual Stress Profile

A1.3 Paris Crack Growth Equation

Fatigue crack growth testing has shown that the stress intensity factor can also be used to predict crack growth rates. In particular, when the range of stress intensity factor during the stress cycle, ΔK, is plotted against the crack growth rate (in/cycle) on a log-log plot, the data are linear. This is the Paris Equation.

$$\frac{da}{dN} = C\Delta K^{n}$$

where:

- da/dN is the crack growth rate (in/cycle)
- C, n are constants depending on material, environment, and loading frequency
- ΔK is change in stress intensity factor (ksi√in)

The change in stress intensity factor, ΔK is defined as:

$$\Delta K = (K_{max} - K_{min})$$

where:

- K_{max} is the maximum value of the stress intensity factor during the cycle (ksi√in)
- K_{min} is the minimum value of the stress intensity factor during the cycle (ksi√in)

A1.4 R-Ratio

Much data has been published to demonstrate that crack growth is a function of the mean stress present during the stress cycle. This mean stress effect can be included using the "R-ratio". The R-ratio is defined as the ratio of K_{min} to K_{max}:

$$R = \frac{K_{min}}{K_{max}}$$

A1.5 Steady State Pipe Stresses

The total stress is the sum of the steady state stresses, such as deadweight, thermal expansion and residual stresses, and the high frequency cyclic stresses that might occur during operation. Thus when considering the R-ratio,

$$\sigma_{max} = \sigma_{ss} + \sigma_{cyc}$$
$$\sigma_{min} = \sigma_{ss} - \sigma_{cyc}$$

where:

σ_{max} is the maximum stress during the cycle
σ_{ss} is the steady state stress at the postulated crack location
σ_{cyc} is the cyclic stress amplitude
σ_{min} is the minimum stress during the cycle

The steady state stresses in the recirculation piping are available from the piping stress reports (References 8 and 9). The steady state stress is the axial stress resulting from internal pressure, deadweight, normal operating temperature thermal expansion and residual stresses (if applicable).

From Reference 8, the pressure plus deadweight plus thermal expansion stresses for Loop A vary from about 7000 psi to about 11500 psi. The axial stress due to internal pressure alone is between 5500 and 7500 psi, so there are some locations for which the deadweight and thermal expansion stresses are negligible. The maximum stresses are near the reactor vessel nozzles (which are the piping anchors) and at other discontinuities. For crack growth evaluations, the stresses at the location of concern should be used.

A1.6 Crack Growth Material Properties

The recirculation system large bore piping is Type 304 austenitic stainless steel. Since the postulated hot tear defects are in the outer half of the pipe wall, the defect surface is not in contact with reactor coolant. Thus, properties for Type 304 stainless steel in air should be used. Reference 10 contains a compilation of crack growth data for austenitic stainless steel in air environments, for varying loading frequencies and R-ratios.

Reference 10 shows that acceptable predictions of crack growth can be used if the following correlations are used.

$n = 3.3$

$C = C_1 F S$

where:

C_1 is the crack growth constant

$\log(C_1) = A_0 + A_1 T + A_2 T^2 + A_3 T^3$
$A_0 = -19.90901$
$A_1 = 8.118312 \times 10^{-4}$
$A_2 = -1.1321418 \times 10^{-6}$
$A_3 = 1.0240102 \times 10^{-9}$
T is the temperature (°F)

For $T = 550°F$, $C_1 = 10^{-19.635}$

F is the loading frequency correction factor = 1.0 for T<800°F

$S = 1 + 1.8R \quad (0.00 \le R \le 0.79)$
$S = -43.35 + 57.97R \quad (0.79 \le R \le 1.00)$

Thus, the fatigue crack growth of postulated defects in the recirculation piping can be predicted by:

$$\frac{da}{dN} = (10^{-19.635}) S \Delta K^{3.3}$$

Since the postulated crack growth results from vibration, the crack growth can also be predicted as a function of time using:

$$\frac{da}{dT} = 3600 f \frac{da}{dN}$$

where:

da/dT is the crack growth rate (in/hr)
f is the frequency of vibration (Hz)

Crack growth calculations are performed by numerically integrating the crack growth equations, either for crack size versus cycles or crack size versus time. The appropriate correlation for geometry factor, g, should be used based on whether the defect is considered through the outside surface.

A1.7 Crack Growth Threshold

Figure A4 is a summary of the 600°F data from Reference 10. Although it is difficult to observe on this figure, materials such as austenitic stainless steel exhibit three regions of crack growth on the da/dN data curve. At very high values of ΔK (> ~80 - 100 ksi√in), the growth rate is very high and failure occurs within a few cycles or less. At moderate values (5 - 10 ksi√in < ΔK < 80 - 100 ksi√in), the slope of the data is linear and crack growth occurs rather slowly. At very low values of ΔK (< 5 - 10 ksi√in), there is a threshold effect. For these low values of ΔK essentially no crack growth occurs. This behavior can be important in high cycle fatigue evaluations. Even if defects or cracks are present, defect growth will not occur unless the calculated range in stress intensity factor, ΔK is greater than the threshold.

It should be noted that when comparisons to the threshold stress intensity factor are made, the change in stress intensity factor should include the R-ratio effects. That is, an effective change in stress intensity factor, ΔK_{eff}, should be used. The effective change in stress intensity factor is $S(K_{max} - K_{min})$.

For conservatism, a threshold of 5 ksi√in is assumed for the recirculation system piping. Thus, no crack growth is predicted for $\Delta K_{eff} < 5$ ksi√in.

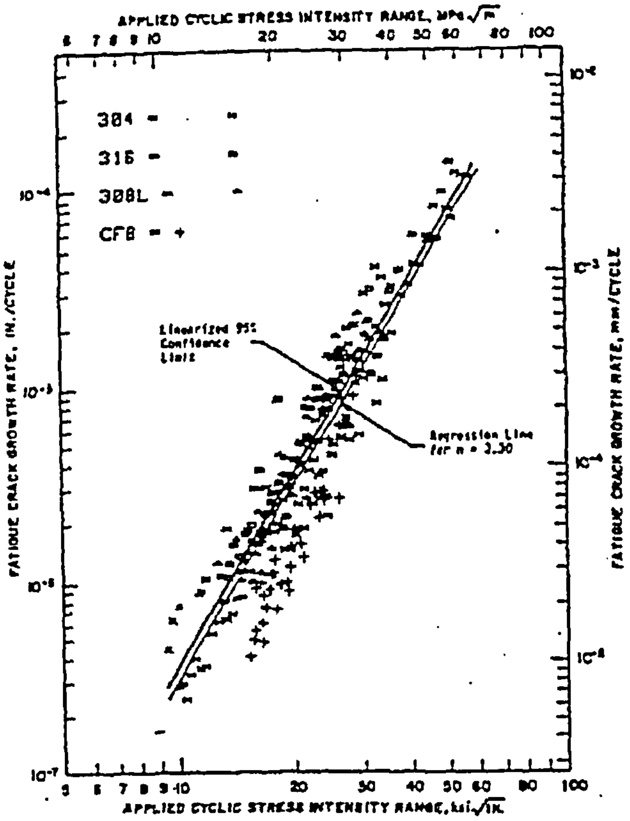

Figure A4
Type 304 Stainless Steel Crack Growth Data

ATTACHMENT 1
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CALC. NO

ATTACHMENT 2

RECIRCULATION PIPING CRACK/DEFECT EVALUATION PROCEDURE

A2.1 Method/Acceptance Criteria

Criteria for acceptance of cracks in austenitic stainless steel pressure boundary piping are provided in Section XI of the ASME Code (Reference 11). These criteria provide allowable crack depths for measured crack lengths. These criteria, which are based on the methods developed in Reference 12, are essentially plastic collapse formulations with an elastic-plastic fracture mechanics correction for certain types of welds. The allowable defect size is determined based on the load which would lead to plastic collapse of the remaining uncracked cross section (with a safety factor).

The determination of allowable defect depth and length (circumferential extent) is made by solving a set of simultaneous equations which define the stress state in the cracked condition. There are two sets of equations depending on the circumferential extent of the defect (whether the defect extends into the compressive portion of the pipe).

$(\theta + \beta) \le \pi$:

$$P'_b = \frac{6S_m}{\pi}\left(2\sin\beta - \frac{a}{t}\sin\theta\right)$$

$$\beta = \frac{1}{2}\left(\pi - \frac{a}{t}\theta - \pi\frac{P_m}{3S_m}\right)$$

$(\theta + \beta) > \pi$:

$$P'_b = \frac{6S_m}{\pi}\left(2 - \frac{a}{t}\right)\sin\beta$$

$$\beta = \frac{\pi}{2 - \frac{a}{t}}\left(1 - \frac{a}{t} - \frac{P_m}{3S_m}\right)$$

where:

- P'_b is the failure bending stress (ksi)
- S_m is the material design stress intensity (ksi)
- β is the offset (angle) of the cracked section neutral axis
- a is the defect depth (in)
- t is the pipe wall thickness (in)
- 2θ is circumferential extent of the defect
- P_m is the piping membrane stress (ksi)

The failure bending stress, P'_b is defined based on the type of material and welding methods used and the applied stresses.

Wrought Base Metal, Cast Stainless Steel, GTAW & GMAW Welds:

$$P'_b = SF(P_m + P_b) - P_m$$

SMAW & SAW Welds:

$$P'_b = Z(SF)(P_m + P_b + P_e/SF) - P_m$$

where:

- P_b is the piping bending stress (ksi)
- P_e is the piping expansion stress (ksi)
- SF = 2.77 for normal conditions
  1.39 for emergency and faulted conditions
- Z = 1.15[1 + 0.013(OD-4)] for SMAW
  1.30[1 + 0.010(OD-4)] for SAW
- OD is the nominal pipe size, but not less than 24

The above equations are solved to determine the allowable defect size (length and depth). However, in no cases shall the allowable defect depth be greater than a = 0.60t for SMAW and SAW welds or a = 0.75t for other materials and welds.

For the recirculation system large bore piping, the following data are applicable to the evaluation of defects:

- Most welds in the system include a portion made using the SAW process, so the SAW/SMAW correlations should be used.

- S_m = 17.2 ksi @ 528°F

When evaluating defects, it is important to note that the final defect size is used. The final defect size is the defect size at the end of the next operating cycle. Thus, a crack growth calculation must be performed prior to evaluating the defect. However, if the defect will be repaired and the evaluation is for the prior operating cycle, the as-found defect size should be used in the evaluation of operation with the defect (prior to repair).

A2.2 Applied Stresses

The methods and acceptance criteria for evaluating the acceptability of defects were presented above. When evaluating defects, the degraded piping must be evaluated for all postulated loading conditions. Thus, two evaluations must be performed.

- The piping must be evaluated for normal conditions using the a safety factor of 2.77. This evaluation considers pressure, deadweight and thermal expansion.

- The piping must be evaluated for faulted conditions using a safety factor of 1.39. In addition to pressure, deadweight and thermal expansion, this evaluation also includes the stresses resulting from the safe shutdown earthquake and annulus pressurization.

The allowable defect size at each location is a function of the postulated defect size and the applied loads on the piping. Since the loads are typically different at each weld, the allowable defect sizes are also different.

ATTACHMENT 3

RECIRCULATION PIPING
NORMAL OPERATION VIBRATION CRACK GROWTH RATES

A3.1 Pipe Stresses

Measurements of the recirculation system large bore piping vibration during normal operation were made during plant start-up testing. The purpose of the measurements was to verify that the stresses in the piping due to the vibration were sufficiently low that fatigue would not be a concern (i.e., the stresses are much less than the fatigue endurance limit).

The measurements of the recirculation piping vibration displacements during normal full power operation were recorded using Procedure TE-SU.BB-332(Q) (Reference 14). The full power test data was obtained at 98.6% of rated core flow. The measured peak-to-peak vibration displacements during steady state normal operation are shown in Table A3-1. As can be seen from the data in Table A3-1, the largest steady state vibration displacements are near the recirculation pumps, near both the pump inlets and outlets. Away from the pumps, the vibration is generally lower.

The vibration displacements in Table A3-1 are the steady state normal operation peak-to-peak displacements. The maximum stresses in the piping due to these displacements will be at elbows, resulting from relative motion of the elbow end points. The vibration stresses are estimated by calculating the bending stresses in elbows subjected to the relative displacements. Attachment 4 is a summary of AUTOPIPE calculations to estimate the bending stresses from small displacements in elbows of the same sizes of pipe included in the Hope Creek recirculation system.

The calculations in Attachment 4 are for displacements of the elbows welded to the reactor vessel nozzles; these will be the highest stressed locations due to the measured vibration. The stresses were calculated including the short sections of straight pipe between the nozzles and elbows. The results in Attachment 4 are for unit displacements at one end of the elbow. The calculation results are shown in Table A3-2.

Using the results in Table A3-2, estimated bending stresses in the recirculation system piping (at elbows) were calculated using the measured peak-to-peak displacements. These results are shown in Table A3-3. In Table A3-3, the axial displacements of sections of straight piping were used to estimate the total differential displacement at the elbows. The results in Table A3-3 show that the stresses range from very low values at some locations up to about 3000 psi (peak-to-peak). Most areas have stress levels of 2000 psi (peak-to-peak) or less.

As another method for estimating the vibration stresses, Reference 16 presents the results of vibration analysis and testing of power system piping. The piping system evaluated was the primary coolant piping on a Department of Energy steam generation cell. Although the piping is not identical to the Hope Creek recirculation piping, it is representative of engineered high energy safety related piping and the results in the study can be used as a qualitative assessment. One of the purposes of the study was to determine the stresses in the piping due to normal steady state vibration and operation at critical pump speeds. This study showed that the maximum stresses in the piping were around 1800 psi or less. These results are comparable to those estimated for the recirculation piping.

The vibration monitoring during startup was performed for the original configuration of the recirculation system. Since that time, PSE&G has implemented a snubber reduction program at Hope Creek which included removal of snubbers in the recirculation system. Snubbers allow thermal expansion and slow displacement of the piping, but resist large, rapid displacements such as those associated with a seismic event. In Reference 17, GE stated that the removal of the recirculation system snubbers is expected to have little impact, if any, on the normal operation steady state vibration.

Table A3-1
Startup Testing Full Power Measured Vibration Results

Piping Loop	Sensor Location	Sensor Number	Measured Vibration (mils)
A	Near the Top of 28" Pump Suction Riser	RA-SX	5
		RA-SY	2
		RA-SZ	12
	Under Pump	RA-PX	7
		RA-PY	7
		RA-PZ	7
	Bottom of Riser to Ring Header	RA-DX	10
		RA-DY	7
		RA-DZ	7
	Above RHR Return Tee	RA-HX	5
		RA-HY	12
		RA-HZ	12
B	Near the Top of 28" Pump Suction Riser	RB-SX	7
		RB-SY	7
		RB-SZ	7
	Under Pump	RB-PX	7
		RB-PY	10
		RB-PZ	7
	Bottom of Riser to Ring Header	RB-DX	10
		RB-DY	2
		RB-DZ	2
	Above RHR Return Tee	RB-HX	2
		RB-HY	2
		RB-HZ	0

Note: X displacements are in line with the pump suction, Y displacements are vertical, Z displacements are in line with the discharge risors.

Table A3-2
Normalized Pipe Elbow Bending Stresses
(From Attachment 4)

Outside Diameter (in)	Wall Thickness (in)	Deflection (mils)	Bending Stress (psi)
28.00	1.201	9	1360
28.00	1.410	7	1050
22.00	*Not evaluated since vibration stresses are small*		
12.75	0.711	28	4230

Table A3-3
Estimated Vibration Stresses - Normal Operation

Location	Diameter (in)	Wall Thickness (in)	Estimated Peak-Peak Displace.[1] (mils)	σ_{range} (psi)	$\sigma_{range}/2$ (psi)
Pump Suct. Nozzle	28.00	1.201	7	1060	530
Under Pump	28.00	1.201	14	2120	1060
Pump Discharge	28.00	1.410	19	2850	1425
Riser Supply Nozzle	12.75	0.711	12	1810	905

Note:

1. The peak-to-peak displacements were determined by adding the measured peak-to-peak displacements of the two points at each end of a run of pipe.

A3.2 Crack Growth Rates

Estimates of crack growth rates for postulated defects can be made using the stress results in Table A3-3, stresses from the piping stress report and the calculational methods described in Attachment 1. The following parameters are important.

- A review of the piping stress analysis report shows that the steady state stresses in the piping vary widely, from stresses which are essentially the pressure stress alone in some areas, to near the reactor vessel nozzles where the loads are significant. The loads and resulting stresses at highly stressed locations (near the reactor vessel nozzles and RHR return tee) are shown in Table A3-4. These results are for Loop A, which is considered typical of both loops.

- The vibration stresses range from very low levels to the estimated stresses in Table A3-3.

- The welding residual stresses can vary from compressive to tensile depending on the actual location of the defect in the pipe wall and the welding parameters.

- The size of postulated defects could be a small as 10% of the wall thickness, or less, depending on how the welds were made and what materials were used. Conversely, based on inspection results during the 3R outage, they could be up to about 30% of the wall thickness.

In order to assess the potential for crack growth for all of the potential combinations of applied stresses, defect size and residual stresses, a total of sixteen sets of calculations are performed. A set of calculations (to predict crack growth rates) is performed for each possible state for each key parameter. These results provide insight into potential growth of cracks in the highly loaded areas (e.g., near the nozzles) and other areas as well. Table A3-5 is a summary of the calculations presented in Tables A3-6 to A3-21.

A3.3 Results

There are two key results of the crack growth calculations. These are:

- Crack growth due to high frequency loads is a binary function, either the crack grows rapidly or it does not grow at all. There are two possible reasons why there are no known through-wall defects in the Hope Creek piping. These are (1) there are no remaining weld defects in the piping, and (2) defects are present in the piping and were growing at one time, but the growth has arrested (stopped) because the crack grew into the compressive residual stress region of the pipe wall.

- If sizeable defects are present (which could possibly grow), they would have already grown through to the pipe outside surface.

Table A3-5 also includes an indication whether any crack growth would have been predicted at any time during plant life. As expected, the magnitude of the vibration stresses and size of the postulated defect are most important, there is no growth predicted for the low vibration stress and 10% of the wall defect cases. The presence of large or small steady state stresses and/or tensile residual stresses can affect the potential for crack growth, but the effect is smaller.

The results of these calculations indicate that there are no defects still growing under normal vibration loads, and that surface inspection (PT) can be used to inspect for defects.

Table A3-4
Loop A Stress Analysis Results - Critical Locations

Pipe Size	Location	Loading[1]	M_A (in-kip)	M_B (in-kip)	M_C (in-kip)	M_{TOT} (in-kip)	σ (psi)
28" - 1.201"	Suction Nozzle (002N) I=2.1	P (1362 psi)					7260
		DW	63.3	-27.3	-71.4		
		TH	-1291.1	80.0	598.4		
		DW+TH	-1227.8	52.7	527	1337	2060i = 4320
		DW+TH+P					11580
28" - 1.410"	Below RHR Return (600) I=1.55	P (1643 psi)					7335
		DW	-1.8	11.7	-20.3		
		TH	171.3	1052.7	703.6		
		DW+TH	169.5	1064.4	683.3	1276	1711i = 2650
		DW+TH+P					9985
12.75"- 0.711"	Risor Nozzle (304F) I=1.80	P (1385)					5516
		DW	3.5	0.9	19.0		
		TH	160.5	2.4	-95.8		
		DW+TH	164.0	3.3	-76.8	181	2134i = 3840
		DW+TH+P					9356

Notes:

1. Operating pressure is taken from Reference 13, moment loadings are taken from Reference 8.

Table A3-5
Crack Growth Calculation Cases

Table	Steady State Stresses[1]	Vibration Stresses [2]	Residual Stresses[3]	Crack Depth (a/t)	Potential Crack Growth ?
A3-6	"High"	"High"	"Tensile"	0.1	Yes
A3-7	"High"	"High"	"Tensile"	0.3	Yes
A3-8	"High"	"High"	Negligible	0.1	Surface Cracks
A3-9	"High"	"High"	Negligible	0.3	Yes
A3-10	"High"	"Low"	"Tensile"	0.1	Pump Suction Piping Surface Cracks Only
A3-11	"High"	"Low"	"Tensile"	0.3	Yes
A3-12	"High"	"Low"	Negligible	0.1	No
A3-13	"High"	"Low"	Negligible	0.3	Surface Cracks
A3-14	"Low"	"High"	"Tensile"	0.1	Yes
A3-15	"Low"	"High"	"Tensile"	0.3	Yes
A3-16	"Low"	"High"	Negligible	0.1	Pump Suction Piping Surface Cracks Only
A3-17	"Low"	"High"	Negligible	0.3	Yes
A3-18	"Low"	"Low"	"Tensile"	0.1	Pump Suction Piping Surface Cracks Only
A3-19	"Low"	"Low"	"Tensile"	0.3	Yes
A3-20	"Low"	"Low"	Negligible	0.1	No
A3-21	"Low"	"Low"	Negligible	0.3	Surface Cracks

Notes:

1. For "high" steady state stresses, the maximum calculated normal operation stresses from Reference 8 are used. For "low" steady state stresses, only the pressure stress is used.

2. For "high" vibration stresses, the estimated maximum vibration stresses are used. For "low" vibration stresses, an assumed lower bound of 200 psi is used.

3. For "tensile" residual stresses, the residual stress is set to a constant 30 ksi. For "negligible" residual stresses, the residual stresses are neglected.

Table A3-6
Estimated Crack Growth Rates
High Steady State Stresses, High Vibration Stresses,
Tensile Residual Stresses, a/t =0.1

OD (in)	t (in)	Defect Type	a (in)	g	σ_{ss} (psi)	K_{ss} (psi√in)	σ_{cyc} (psi)	K_{cyc} (psi√in)	K_{min} (psi√in)	K_{max} (psi√in)	ΔK_{eff} (psi√in)	da/dt (in/yr)
28.00	1.201	Surface	0.120	1.39	41580	35480	1060	905	34576	36385	21234	38.55
28.00	1.201	Subsurf	0.060	1.10	41580	19866	1060	506	19359	20372	11889	5.69
28.00	1.410	Surface	0.141	1.41	39985	37643	1425	1342	36302	38985	28522	128.21
28.00	1.410	Subsurf	0.071	1.10	39985	20699	1425	738	19962	21437	15684	17.82
12.75	0.711	Surface	0.071	1.43	39356	26667	905	613	26053	27280	14734	10.94
12.75	0.711	Subsurf	0.036	1.10	39356	14468	905	333	14135	14800	7994	1.45

Table A3-7
Estimated Crack Growth Rates
High Steady State Stresses, High Vibration Stresses,
Tensile Residual Stresses, a/t =0.3

OD (in)	t (in)	Defect Type	a (in)	g	σ_{ss} (psi)	K_{ss} (psi√in)	σ_{cyc} (psi)	K_{cyc} (psi√in)	K_{min} (psi√in)	K_{max} (psi√in)	ΔK_{eff} (psi√in)	da/dt (in/yr)
28.00	1.201	Surface	0.360	1.58	41580	69682	1060	1776	67906	71458	41702	357.58
28.00	1.201	Subsurf	0.180	1.25	41580	39101	1060	997	38104	40098	23400	53.12
28.00	1.410	Surface	0.423	1.60	39985	73930	1425	2635	71295	76564	56016	1189.24
28.00	1.410	Subsurf	0.212	1.25	39985	40742	1425	1452	39290	42193	30869	166.45
12.75	0.711	Surface	0.213	1.63	39356	52372	905	1204	51168	53576	28937	101.49
12.75	0.711	Subsurf	0.107	1.25	39356	28476	905	655	27821	29131	15734	13.59

Table A3-8
Estimated Crack Growth Rates
High Steady State Stresses, High Vibration Stresses,
Negligible Residual Stresses, a/t =0.1

OD (in)	t (in)	Defect Type	a (in)	g	σ_{ss} (psi)	K_{ss} (psi√in)	σ_{cyc} (psi)	K_{cyc} (psi√in)	K_{min} (psi√in)	K_{max} (psi√in)	ΔK_{eff} (psi√in)	da/dt (in/yr)
28.00	1.201	Surface	0.120	1.39	11580	9881	1060	905	8977	10786	8859	16.08
28.00	1.201	Subsurf	0.060	1.10	11580	5533	1060	506	5026	6039	4960	0.00
28.00	1.410	Surface	0.141	1.41	9985	9400	1425	1342	8059	10742	6306	28.35
28.00	1.410	Subsurf	0.071	1.10	9985	5169	1425	738	4431	5907	3468	0.00
12.75	0.711	Surface	0.071	1.43	9356	6339	905	613	5726	6953	5389	4.00
12.75	0.711	Subsurf	0.036	1.10	9356	3439	905	333	3107	3772	2924	0.00

Table A3-9
Estimated Crack Growth Rates
High Steady State Stresses, High Vibration Stresses,
Negligible Residual Stresses, a/t =0.3

OD (in)	t (in)	Defect Type	a (in)	g	σ_{ss} (psi)	K_{ss} (psi√in)	σ_{cyc} (psi)	K_{cyc} (psi√in)	K_{min} (psi√in)	K_{max} (psi√in)	ΔK_{eff} (psi√in)	da/dt (in/yr)
28.00	1.201	Surface	0.360	1.58	11580	19406	1060	1776	17630	21183	17399	149.19
28.00	1.201	Subsurf	0.180	1.25	11580	10890	1060	997	9893	11886	9763	22.16
28.00	1.410	Surface	0.423	1.60	9985	18462	1425	2635	15827	21096	12385	262.95
28.00	1.410	Subsurf	0.212	1.25	9985	10174	1425	1452	8722	11626	6825	36.80
12.75	0.711	Surface	0.213	1.63	9356	12450	905	1204	11246	13655	10584	37.12
12.75	0.711	Subsurf	0.107	1.25	9356	6769	905	655	6115	7424	5755	4.97

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Table A3-10
Estimated Crack Growth Rates
High Steady State Stresses, Low Vibration Stresses,
Tensile Residual Stresses, a/t =0.1

OD (in)	t (in)	Defect Type	a (in)	g	σ_{ss} (psi)	K_{ss} (psi√in)	σ_{cyc} (psi)	K_{cyc} (psi√in)	K_{min} (psi√in)	K_{max} (psi√in)	ΔK_{eff} (psi√in)	da/dt (in/yr)
28.00	1.201	Surface	0.120	1.39	41580	35480	200	171	35310	35651	4801	0.00
28.00	1.201	Subsurf	0.060	1.10	41580	19866	200	96	19770	19961	2688	0.00
28.00	1.410	Surface	0.141	1.41	39985	37643	200	188	37455	37831	5288	0.26
28.00	1.410	Subsurf	0.071	1.10	39985	20699	200	104	20596	20803	2908	0.00
12.75	0.711	Surface	0.071	1.43	39356	26667	200	136	26531	26802	3804	0.00
12.75	0.711	Subsurf	0.036	1.10	39356	14468	200	74	14394	14541	2064	0.00

Table A3-11
Estimated Crack Growth Rates
High Steady State Stresses, Low Vibration Stresses,
Tensile Residual Stresses, a/t =0.3

OD (in)	t (in)	Defect Type	a (in)	g	σ_{ss} (psi)	K_{ss} (psi√in)	σ_{cyc} (psi)	K_{cyc} (psi√in)	K_{min} (psi√in)	K_{max} (psi√in)	ΔK_{eff} (psi√in)	da/dt (in/yr)
28.00	1.201	Surface	0.360	1.58	41580	69682	200	335	69347	70017	9428	1.75
28.00	1.201	Subsurf	0.180	1.25	41580	39101	200	188	38913	39289	5291	0.26
28.00	1.410	Surface	0.423	1.60	39985	73930	200	370	73560	74299	10386	2.41
28.00	1.410	Subsurf	0.212	1.25	39985	40742	200	204	40538	40945	5723	0.34
12.75	0.711	Surface	0.213	1.63	39356	52372	200	266	52106	52638	7470	0.81
12.75	0.711	Subsurf	0.107	1.25	39356	28476	200	145	28331	28621	4062	0.00

Table A3-12
Estimated Crack Growth Rates
High Steady State Stresses, Low Vibration Stresses,
Negligible Residual Stresses, a/t =0.1

OD (in)	t (in)	Defect Type	a (in)	g	σ_{ss} (psi)	K_{ss} (psi√in)	σ_{cyc} (psi)	K_{cyc} (psi√in)	K_{min} (psi√in)	K_{max} (psi√in)	ΔK_{eff} (psi√in)	da/dt (in/yr)
28.00	1.201	Surface	0.120	1.39	11580	9881	200	171	9711	10052	4318	0.00
28.00	1.201	Subsurf	0.060	1.10	11580	5533	200	96	5437	5628	2418	0.00
28.00	1.410	Surface	0.141	1.41	9985	9400	200	188	9212	9588	4648	0.00
28.00	1.410	Subsurf	0.071	1.10	9985	5169	200	104	5066	5273	2556	0.00
12.75	0.711	Surface	0.071	1.43	9356	6339	200	136	6204	6475	3305	0.00
12.75	0.711	Subsurf	0.036	1.10	9356	3439	200	74	3366	3513	1793	0.00

Table A3-13
Estimated Crack Growth Rates
High Steady State Stresses, Low Vibration Stresses,
Negligible Residual Stresses, a/t =0.3

OD (in)	t (in)	Defect Type	a (in)	g	σ_{ss} (psi)	K_{ss} (psi√in)	σ_{cyc} (psi)	K_{cyc} (psi√in)	K_{min} (psi√in)	K_{max} (psi√in)	ΔK_{eff} (psi√in)	da/dt (in/yr)
28.00	1.201	Surface	0.360	1.58	11580	19406	200	335	19071	19742	8481	1.57
28.00	1.201	Subsurf	0.180	1.25	11580	10890	200	188	10701	11078	4759	0.00
28.00	1.410	Surface	0.423	1.60	9985	18462	200	370	18092	18831	9129	2.12
28.00	1.410	Subsurf	0.212	1.25	9985	10174	200	204	9970	10378	5031	0.30
12.75	0.711	Surface	0.213	1.63	9356	12450	200	266	12184	12716	6490	0.71
12.75	0.711	Subsurf	0.107	1.25	9356	6769	200	145	6625	6914	3529	0.00

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Table A3-14
Estimated Crack Growth Rates
Low Steady State Stresses, High Vibration Stresses,
Tensile Residual Stresses, a/t =0.1

OD (in)	t (in)	Defect Type	a (in)	g	σ_{ss} (psi)	K_{ss} (psi√in)	σ_{cyc} (psi)	K_{cyc} (psi√in)	K_{min} (psi√in)	K_{max} (psi√in)	ΔK_{eff} (psi√in)	da/dt (in/yr)
28.00	1.201	Surface	0.120	1.39	37260	31794	1060	905	30890	32699	20646	37.48
28.00	1.201	Subsurf	0.060	1.10	37260	17802	1060	506	17295	18308	11560	5.53
28.00	1.410	Surface	0.141	1.41	37335	35148	1425	1342	33807	36490	27790	124.92
28.00	1.410	Subsurf	0.071	1.10	37335	19328	1425	738	18590	20065	15281	17.36
12.75	0.711	Surface	0.071	1.43	35516	24065	905	613	23451	24678	14397	10.69
12.75	0.711	Subsurf	0.036	1.10	35516	13056	905	333	12723	13389	7811	1.42

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Table A3-15
Estimated Crack Growth Rates
Low Steady State Stresses, High Vibration Stresses,
Tensile Residual Stresses, a/t =0.3

OD (in)	t (in)	Defect Type	a (in)	g	σ_{ss} (psi)	K_{ss} (psi√in)	σ_{cyc} (psi)	K_{cyc} (psi√in)	K_{min} (psi√in)	K_{max} (psi√in)	ΔK_{eff} (psi√in)	da/dt (in/yr)
28.00	1.201	Surface	0.360	1.58	37260	62442	1060	1776	60666	64219	40548	347.68
28.00	1.201	Subsurf	0.180	1.25	37260	35038	1060	997	34042	36035	22753	51.65
28.00	1.410	Surface	0.423	1.60	37335	69030	1425	2635	66395	71665	54579	1158.73
28.00	1.410	Subsurf	0.212	1.25	37335	38041	1425	1452	36589	39493	30077	162.18
12.75	0.711	Surface	0.213	1.63	35516	47262	905	1204	46058	48466	28275	99.17
12.75	0.711	Subsurf	0.107	1.25	35516	25697	905	655	25043	26352	15374	13.28

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Table A3-16
Estimated Crack Growth Rates
Low Steady State Stresses, High Vibration Stresses,
Negligible Residual Stresses, a/t =0.1

OD (in)	t (in)	Defect Type	a (in)	g	σ_{ss} (psi)	K_{ss} (psi√in)	σ_{cyc} (psi)	K_{cyc} (psi√in)	K_{min} (psi√in)	K_{max} (psi√in)	ΔK_{eff} (psi√in)	da/dt (in/yr)
28.00	1.201	Surface	0.120	1.39	7260	6195	1060	905	5290	7099	4235	0.00
28.00	1.201	Subsurf	0.060	1.10	7260	3469	1060	506	2962	3975	2372	0.00
28.00	1.410	Surface	0.141	1.41	7335	6905	1425	1342	5564	8247	5941	26.71
28.00	1.410	Subsurf	0.071	1.10	7335	3797	1425	738	3059	4535	3267	0.00
12.75	0.711	Surface	0.071	1.43	5516	3737	905	613	3124	4351	2812	0.00
12.75	0.711	Subsurf	0.036	1.10	5516	2028	905	333	1695	2360	1525	0.00

Table A3-17
Estimated Crack Growth Rates
Low Steady State Stresses, High Vibration Stresses,
Negligible Residual Stresses, a/t =0.3

OD (in)	t (in)	Defect Type	a (in)	g	σ_{ss} (psi)	K_{ss} (psi√in)	σ_{cyc} (psi)	K_{cyc} (psi√in)	K_{min} (psi√in)	K_{max} (psi√in)	ΔK_{eff} (psi√in)	da/dt (in/yr)
28.00	1.201	Surface	0.360	1.58	7260	12167	1060	1776	10390	13943	8318	71.33
28.00	1.201	Subsurf	0.180	1.25	7260	6827	1060	997	5830	7824	4668	0.00
28.00	1.410	Surface	0.423	1.60	7335	13562	1425	2635	10927	16197	11669	247.73
28.00	1.410	Subsurf	0.212	1.25	7335	7474	1425	1452	6022	8926	6430	34.67
12.75	0.711	Surface	0.213	1.63	5516	7340	905	1204	6136	8545	5522	19.37
12.75	0.711	Subsurf	0.107	1.25	5516	3991	905	655	3336	4646	3002	0.00

Table A3-18
Estimated Crack Growth Rates
Low Steady State Stresses, Low Vibration Stresses,
Tensile Residual Stresses, a/t =0.1

OD (in)	t (in)	Defect Type	a (in)	g	σ_{ss} (psi)	K_{ss} (psi√in)	σ_{cyc} (psi)	K_{cyc} (psi√in)	K_{min} (psi√in)	K_{max} (psi√in)	ΔK_{eff} (psi√in)	da/dt (in/yr)
28.00	1.201	Surface	0.120	1.39	37260	31794	200	171	31623	31965	4779	0.00
28.00	1.201	Subsurf	0.060	1.10	37260	17802	200	96	17706	17897	2676	0.00
28.00	1.410	Surface	0.141	1.41	37335	35148	200	188	34960	35337	5273	0.26
28.00	1.410	Subsurf	0.071	1.10	37335	19328	200	104	19224	19431	2899	0.00
12.75	0.711	Surface	0.071	1.43	35516	24065	200	136	23929	24200	3786	0.00
12.75	0.711	Subsurf	0.036	1.10	35516	13056	200	74	12983	13130	2054	0.00

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Table A3-19
Estimated Crack Growth Rates
Low Steady State Stresses, Low Vibration Stresses,
Tensile Residual Stresses, a/t =0.3

OD (in)	t (in)	Defect Type	a (in)	g	σ_{ss} (psi)	K_{ss} (psi√in)	σ_{cyc} (psi)	K_{cyc} (psi√in)	K_{min} (psi√in)	K_{max} (psi√in)	ΔK_{eff} (psi√in)	da/dt (in/yr)
28.00	1.201	Surface	0.360	1.58	37260	62442	200	335	62107	62777	9385	1.74
28.00	1.201	Subsurf	0.180	1.25	37260	35038	200	188	34850	35227	5266	0.26
28.00	1.410	Surface	0.423	1.60	37335	69030	200	370	68660	69400	10356	2.40
28.00	1.410	Subsurf	0.212	1.25	37335	38041	200	204	37838	38245	5707	0.34
12.75	0.711	Surface	0.213	1.63	35516	47262	200	266	46996	47528	7437	0.81
12.75	0.711	Subsurf	0.107	1.25	35516	25697	200	145	25553	25842	4043	0.00

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Table A3-20
Estimated Crack Growth Rates
Low Steady State Stresses, Low Vibration Stresses,
Negligible Residual Stresses, a/t =0.1

OD (in)	t (in)	Defect Type	a (in)	g	σ_{ss} (psi)	K_{ss} (psi√in)	σ_{cyc} (psi)	K_{cyc} (psi√in)	K_{min} (psi√in)	K_{max} (psi√in)	ΔK_{eff} (psi√in)	da/dt (in/yr)
28.00	1.201	Surface	0.120	1.39	7260	6195	200	171	6024	6366	3929	0.00
28.00	1.201	Subsurf	0.060	1.10	7260	3469	200	96	3373	3564	2200	0.00
28.00	1.410	Surface	0.141	1.41	7335	6905	200	188	6717	7094	4347	0.00
28.00	1.410	Subsurf	0.071	1.10	7335	3797	200	104	3694	3901	2390	0.00
12.75	0.711	Surface	0.071	1.43	5516	3737	200	136	3602	3873	2863	0.00
12.75	0.711	Subsurf	0.036	1.10	5516	2028	200	74	1954	2101	1553	0.00

Table A3-21
Estimated Crack Growth Rates
Low Steady State Stresses, Low Vibration Stresses,
Negligible Residual Stresses, a/t =0.3

OD (in)	t (in)	Defect Type	a (in)	g	σ_{ss} (psi)	K_{ss} (psi√in)	σ_{cyc} (psi)	K_{cyc} (psi√in)	K_{min} (psi√in)	K_{max} (psi√in)	ΔK_{eff} (psi√in)	da/dt (in/yr)
28.00	1.201	Surface	0.360	1.58	7260	12167	200	335	11832	12502	7717	1.43
28.00	1.201	Subsurf	0.180	1.25	7260	6827	200	188	6639	7015	4330	0.00
28.00	1.410	Surface	0.423	1.60	7335	13562	200	370	13192	13932	8537	1.98
28.00	1.410	Subsurf	0.212	1.25	7335	7474	200	204	7270	7678	4704	0.00
12.75	0.711	Surface	0.213	1.63	5516	7340	200	266	7074	7606	5623	0.61
12.75	0.711	Subsurf	0.107	1.25	5516	3991	200	145	3846	4136	3057	0.00

ATTACHMENT 4

BENDING STRESSES IN PIPING ELBOWS

MPR

MPR Associates, Inc.
320 King Street
Alexandria, VA 22314

CALCULATION TITLE PAGE

Client Public Service Gas and Electric	Page 1 of 9 + 45 Pages Attached
Project Hope Creek Recirculation Piping	Task No. 108-9530-100-0
Title Calculation of Piping Stresses from Unit Applied Loads	Calculation No. 108-100-CBS-01

Preparer/Date	Checker/Date	Reviewer/Date	Rev. No.
Craig B. Swanner 12/4/95	12/4/95	12/4/95	0

ATTACHMENT 4
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CALC NO. H-1-BB-MEE-1050

MPR

MPR Associates, Inc.
320 King Street
Alexandria, VA 22314

RECORD OF REVISIONS

Calculation No.	Prepared By	Checked By	Page 2
108-100-CBS-01	[signature]	[signature]	

Revision	Description
0	Initial Issue

ATTACHMENT 4
PAGE 3 OF 55
CALC. NO H-1-BB-MEE-1050

1.0 PURPOSE

The purpose of this calculation is to calculate the maximum stresses in a piping elbow for a unit applied load and moment for various pipe sizes and configurations.

The following pipe sizes are examined in this calculation:

Pipe OD (in)	Wall Thickness (in)
28.00	1.201
28.00	1.410
12.75	0.711

2.0 RESULTS

The results for each piping configuration examined are given in Table 1.

MPR Associates, Inc.
320 King Street
Alexandria, VA 22314

Table 1

Piping Elbow Stresses for a Unit Applied Force and a Unit Applied Moment

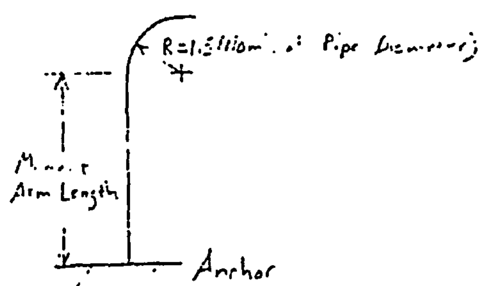
Outside Diameter (in)	Wall Thickness (in)	Unit Force Applied (lbf)	Displacement due to Force (in)	Maximum Elbow Bending Stress (ksi)	Applied Unit Moment (ft-lbf)	Maximum Elbow Bending Stress (ksi)
28.00	1.201	10,000	0.009	1.36	1,000	0.04
28.00	1.410	10,000	0.007	1.05	1,000	0.03
12.75	0.711	10,000	0.028	4.23	1,000	0.28

Notes to Table 1:

1. All stress intensities reported in Table 1 include stress intensification effects that occur at piping elbows.

3.0 CALCULATION

The maximum elbow stresses including stress intensification factors are determined using the AutoPIPE Version 4.5 piping analysis program. Each piping model consists of an anchor, a short run of piping, and a long radius elbow (i.e., elbow radius is 1.5 times the nominal pipe diameter). The piping geometry for each case is shown below.

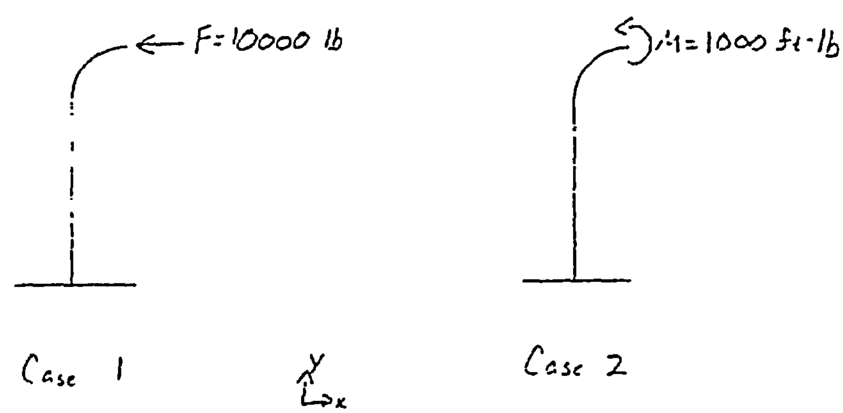


The piping model above is run for the following three cases:

Table 2
AutoPIPE Input

Piping Configuration	Outside Diameter (in)	Wall Thickness (in)	Moment Arm Length (in)	Material Properties
1	28.00	1.201	17	304 Stainless Steel
2	28.00	1.410	17	304 Stainless Steel
3	12.75	0.711	25	304 Stainless Steel

Each piping model is analyzed for two load cases. For each case the load is applied at the end of the elbow. The first case is a 10,000 lbf load applied along the pipe centerline pointing toward the elbow. The second case is a 1,000 ft-lbf moment applied so that bending occurs in the plane of the elbow. The applied loading for both cases is shown below.



Each piping model is run using AutoPIPE Version 4.5. The computer output for each case is contained in Attachments A, B, and C. The key results of each analysis are shown in Table 1.

MPR

MPR Associates, Inc.
320 King Street
Alexandria, VA 22314

Calculation No.	Prepared By	Checked By	Page 7
108-100-CBS-01	C. Swann	[signature]	

Attachment A

AutoPIPE RESULTS FOR PIPING MODEL 1

15 Pages Attached

```
*************************************************************
**                                                         **
**              AUTOPIPE SYSTEM DATA LISTING               **
**                                                         **
*************************************************************
```

SYSTEM NAME : HRECIRC1

PROJECT ID : HOPE CREEK RECIRCULATION PIPING
PIPING CONFIGURATION 1

PREPARED BY : C. Swanner
C. SWANNER

CHECKED BY :

PIPING CODE : B31.1-67

AMBIENT TEMP. (deg F) : 70.0

COMPONENT LIBRARY : AUTOPIPE

MATERIAL LIBRARY : AUTO1967

MODEL REVISION NUMBER : 11

P O I N T   D A T A   L I S T I N G

POINT NAME	TYPE	OFFSETS (ft) X	Y	Z	PIPE ID	DESCRIPTION
*** SEGMENT A						
A00	Run	0	0	0	PIPE1	
A01	Bend	0	4.92	0		Long Elbow, Radius = 42.00 inch Bend angle change = 90.00 deg SIF - In = 2.10, Out = 2.10
A02	Run	3.56	0	0		

Total weight of empty pipes : 2454 lb

COMPONENT DATA LISTING

POINT NAME	---COORDINATE(ft X	) Y	--- Z	DATA TYPE	DESCRIPTION
*** SEGMENT A					
A00	0.00	0.00	0.00	ANCHOR	Rigid Thermal movements : None
A01 N	0.00	1.42	0.00		
A01	0.00	4.92	0.00	TI	
A01 F	3.50	4.92	0.00		
A02	3.56	4.92	0.00	FORCES	Thermal 1

Number of points in the system : 5

P I P E D A T A L I S T I N G

Pipe ID/ Material	Nom/ Sch	O.D. inch	-----Thickness(inch)----- W.Th.	Corr	Mill	Insu	Ling	Spec Grav	Weight(lb/ft) Pipe	Other	Total
PIPE1 A312-TP304	NS	28.000	1.201	0	0.15	0	0	0	352	0	352

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CALC. NO H-1-BB-MEE-1050

M A T E R I A L   D A T A   L I S T I N G

Material Name	Pipe ID	Density lb/cu.ft	Pois. Ratio	Temper. deg F	Modulus E6 psi	Expans. in/100ft	Allow. psi
A312-TP304	PIPE1	501.0	0.30	70.0	28.30		18700.0

TEMPERATURE AND PRESSURE DATA

	CASE 1			CASE 2			CASE 3		
POINT NAME	PRESS. psi	TEMPER deg F	EXPAN. in/100ft	PRESS. psi	TEMPER deg F	EXPAN. in/100ft	PRESS. psi	TEMPER deg F	EXPAN. in/100ft
*** SEGMENT A									
A00	0	70.00	0.000						
A02	0	70.00	0.000						

FORCES AND DISPLACEMENTS
(Force - lb , Moment - ft-lb , Tran.- in , Rot.- deg)

POINT NAME	LOAD CASE	TYPE	X	Y	Z	XX	YY	ZZ
A02	T1	FORCE	-10000	0	0	0	0	0

A N A L Y S I S   S U M M A R Y

Current model revision number : 11

Static - Date and Time of analysis .... Dec 4, 1995 3:06 PM
Model Revision Number 11
Number of load cases 1
Load cases analyzed T1
Gaps/Friction/Yielding considered ..... No
Hanger design run .... No
Cut short included .... No
Weight of contents included .... Yes
Pressure stiffening case 0
Water elevation for buoyancy loads .... Not considered

F_x = 10,000 lbs Applied Load

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PAGE 16 OF 55
CALC. NO. H-1-BB-MEE-1050

D I S P L A C E M E N T S

Point name	Load combination	TRANSLATIONS (in) X	Y	Z	ROTATIONS (deg) X	Y	Z
*** Segment A begin ***							
A00	T1	0.000	0.000	0.000	0.000	0.000	0.000
A01 N	T1	-0.001	0.000	0.000	0.000	0.000	0.002
A01 F	T1	-0.009	0.010	0.000	0.000	0.000	0.015
A02	T1	-0.009	0.010	0.000	0.000	0.000	0.015
*** Segment A end ***							

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CALC NO. H-1-BB-MEE-1050

G L O B A L F O R C E S & M O M E N T S

Point name	Load combination	FORCES (lb) X	Y	Z	Result	MOMENTS (ft-lb) X	Y	Z	Result
*** Segment A begin ***									
A00	T1	10000	0	0	10000	0	0	-49167	49167
A01 N	T1	10000	0	0	10000	0	0	-35000	35000
A01 F	T1	10000	0	0	10000	0	0	0	0
A02	T1	10000	0	0	10000	0	0	0	0
*** Segment A end ***									

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CALC. NO. H-1-BB-MEE-1050

G E N E R A L   P I P E   S T R E S S   R E P O R T

(Stress in psi)

Point name	Load combination	Hoop Stress	Longitudinal Max	Longitudinal Min	Tors. Shear	Principal Max	Principal Min	Max Shear	Loc	Oct Shear
*** Segment A begin ***										
A00	SIFI= 1.00	SIFO= 1.00								
	T1	0	908	-908	0	908	-908	454	MT	908
A01 N-	SIFI= 1.00	SIFO= 1.00								
	T1	0	646	-646	0	646	-646	323	MT	646
A01 N+	SIFI= 2.10	SIFO= 2.10								
	T1	0	1356	-1356	0	1356	-1356	678	MT	1356
A01 F-	SIFI= 2.10	SIFO= 2.10								
	T1	0	-99	-99	0	0	-99	49	NA	99
A01 F+	SIFI= 1.00	SIFO= 1.00								
	T1	0	-99	-99	0	0	-99	49	NA	99
A02	SIFI= 1.00	SIFO= 1.00								
	T1	0	-99	-99	0	0	-99	49	NA	99
*** Segment A end ***										

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SHEET 19 OF 55
CALC. NO. H-1-BB-MEE-1050

A N A L Y S I S   S U M M A R Y

Current model revision number : 11

```
Static - Date and Time of analysis ............. Dec 4, 1995   3:07 PM
         Model Revision Number ................. 11
         Number of load cases .................. 1
         Load cases analyzed ................... T1
         Gaps/Friction/Yielding considered ..... No
         Hanger design run ..................... No
         Cut short included .................... No
         Weight of contents included ........... Yes
         Pressure stiffening case .............. 0
         Water elevation for buoyancy loads .... Not considered
```

M_z = 1000 ft-lb$_f$ Applied Moment

D I S P L A C E M E N T S

Point name	Load combination	TRANSLATIONS (in) X	Y	Z	ROTATIONS (deg) X	Y	Z
*** Segment A begin ***							
A00	T1	0.000	0.000	0.000	0.000	0.000	0.000
A01 N	T1	0.000	0.000	0.000	0.000	0.000	0.000
A01 F	T1	0.000	0.001	0.000	0.000	0.000	0.001
A02	T1	0.000	0.001	0.000	0.000	0.000	0.001
*** Segment A end ***							

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GLOBAL FORCES & MOMENTS

Point name	Load combination	FORCES (lb) X	Y	Z	Result	MOMENTS (ft-lb) X	Y	Z	Result
*** Segment A begin ***									
A00	T1	0	0	0	0	0	0	-1000	1000
A01 N	T1	0	0	0	0	0	0	-1000	1000
A01 F	T1	0	.0	0	0	0	0	-1000	1000
A02	T1	0	0	0	0	0	0	-1000	1000
*** Segment A end ***									

GENERAL PIPE STRESS REPORT
(Stress in psi)

Point name	Load combination	Hoop Stress	Longitudinal Max	Longitudinal Min	Tors. Shear	Principal Max	Principal Min	Max Shear	Loc	Oct Shear
*** Segment A begin ***										
A00	SIFI= 1.00	SIFO= 1.00								
	T1	0	18	-18	0	18	-18	9	MT	18
A01 N-	SIFI= 1.00	SIFO= 1.00								
	T1	0	18	-18	0	18	-18	9	MT	18
A01 N+	SIFI= 2.10	SIFO= 2.10								
	T1	0	39	-39	0	39	-39	19	MT	39
A01 F-	SIFI= 2.10	SIFO= 2.10								
	T1	0	39	-39	0	39	-39	19	MT	39
A01 F+	SIFI= 1.00	SIFO= 1.00								
	T1	0	18	-18	0	18	-18	9	MT	18
A02	SIFI= 1.00	SIFO= 1.00								
	T1	0	18	-18	0	18	-18	9	MT	18
*** Segment A end ***										

ATTACHMENT 4
PAGE 23 OF 55
CALC. NO. H-1-BB-MEE-1050

MPR

MPR Associates, Inc.
320 King Street
Alexandria, VA 22314

Calculation No.	Prepared By	Checked By	Page 8
108-100-CBS-01			

Attachment B

AutoPIPE RESULTS FOR PIPING MODEL 2

15 Pages Attached

```
*************************************************************
**                                                         **
**              AUTOPIPE SYSTEM DATA LISTING               **
**                                                         **
*************************************************************
```

SYSTEM NAME : HRECIRC2

PROJECT ID : HOPE CREEK RECIRCULATION PIPING
PIPING CONFIGURATION 2

PREPARED BY : ____________________
C. SWANNER

CHECKED BY : ____________________

PIPING CODE : B31.1-67

AMBIENT TEMP. (deg F) : 70.0

COMPONENT LIBRARY : AUTOPIPE

MATERIAL LIBRARY : AUTO1967

MODEL REVISION NUMBER : 1

ATTACHMENT 4
PAGE 25 OF 55
CALC. NO. H-1-BB-MEE-1050

POINT DATA LISTING

POINT NAME	TYPE	OFFSETS (ft) X	Y	Z	PIPE ID	DESCRIPTION
*** SEGMENT A						
A00	Run	0	0	0	PIPE1	
A01	Bend	0	4.92	0		Long Elbow, Radius = 42.00 inch Bend angle change = 90.00 deg SIF - In = 1.87, Out = 1.87
A02	Run	3.56	0	0		

Total weight of empty pipes : 2858 lb

ATTACHMENT 4
PAGE 26 OF 55
CALC. NO H-1-BB-MEE-1050

C O M P O N E N T   D A T A   L I S T I N G

POINT NAME	---COORDINATE(ft)--- X	Y	Z	DATA TYPE	DESCRIPTION
*** SEGMENT A					
A00	0.00	0.00	0.00	ANCHOR	Rigid
					Thermal movements : None
A01 N	0.00	1.42	0.00		
A01	0.00	4.92	0.00	TI	
A01 F	3.50	4.92	0.00		
A02	3.56	4.92	0.00	FORCES	Thermal 1

Number of points in the system : 5

4
27 55
H-1-BB-MEE-1050

P I P E D A T A L I S T I N G

Pipe ID/ Material	Nom/ Sch	O.D. inch	Thickness (inch) W.Th.	Corr	Mill	Insu	Ling	Spec Grav	Weight (lb/ft) Pipe	Other	Total
PIPE1 A312-TP304	NS	28.000	1.410	0	0.18	0	0	0	410	0	410

ATTACHMENT 1
PAGE 28 OF 55
CALC. NO H-1-BB-MEE-1050

MATERIAL DATA LISTING

Material Name	Pipe ID	Density lb/cu.ft	Pois. Ratio	Temper. deg F	Modulus E6 psi	Expans. in/100ft	Allow. psi
A312-TP304	PIPE1	501.0	0.30	70.0	28.30		18700.0

ATTACHMENT 4
19 OF 55
H-1-BB-MEE-1050

IT IS THE RESPONSIBILITY OF THE USER TO VERIFY REVISION, STATUS
PRINTED 20041108

TEMPERATURE AND PRESSURE DATA

POINT NAME	CASE 1 PRESS. psi	CASE 1 TEMPER deg F	CASE 1 EXPAN. in/100ft	CASE 2 PRESS. psi	CASE 2 TEMPER deg F	CASE 2 EXPAN. in/100ft	CASE 3 PRESS. psi	CASE 3 TEMPER deg F	CASE 3 EXPAN. in/100ft
*** SEGMENT A									
A00	0	70.00	0.000						
A02	0	70.00	0.000						

4
30 55
H-1-BB-MEE-1050

FORCES AND DISPLACEMENTS
(Force - lb , Moment - ft-lb , Tran.- in , Rot.- deg)

POINT NAME	LOAD CASE	TYPE	X	Y	Z	XX	YY	ZZ
A02	T1	FORCE	-10000	0	0	0	0	0

ATTACHMENT 4
PAGE 31 OF 55
CALC. NO. H-1-BB-MEE-1050

IT IS THE RESPONSIBILITY OF THE USER TO VERIFY REVISION, STATUS
PRINTED 20041108

A N A L Y S I S   S U M M A R Y

Current model revision number : 1

Static - Date and Time of analysis .... Dec 4, 1995 3:09 PM
Model Revision Number 1
Number of load cases 1
Load cases analyzed T1
Gaps/Friction/Yielding considered ..... No
Hanger design run .... No
Cut short included .... No
Weight of contents included .... Yes
Pressure stiffening case 0
Water elevation for buoyancy loads .... Not considered

F_x = -10.000 lbs Applied Load

4
32 55
H-1-BB-MEE-1050

D I S P L A C E M E N T S

Point name	Load combination	TRANSLATIONS (in) X	Y	Z	ROTATIONS (deg) X	Y	Z
*** Segment A begin ***							
A00	T1	0.000	0.000	0.000	0.000	0.000	0.000
A01 N	T1	-0.001	0.000	0.000	0.000	0.000	0.002
A01 F	T1	-0.007	0.008	0.000	0.000	0.000	0.011
A02	T1	-0.007	0.008	0.000	0.000	0.000	0.011
*** Segment A end ***							

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33 55
H-1-BB-MEE-1050

G L O B A L F O R C E S & M O M E N T S

Point name	Load combination	FORCES (lb) X	Y	Z	Result	MOMENTS (ft-lb) X	Y	Z	Result
*** Segment A begin ***									
A00	T1	10000	0	0	10000	0	0	-49167	49167
A01 N	T1	10000	0	0	10000	0	0	-35000	35000
A01 F	T1	10000	0	0	10000	0	0	0	0
A02	T1	10000	0	0	10000	0	0	0	0
*** Segment A end ***									

GENERAL PIPE STRESS REPORT

(Stress in psi)

Point name	Load combination	Hoop Stress	Longitudinal Max	Longitudinal Min	Tors. Shear	Principal Max	Principal Min	Max Shear	Loc	Oct Shear
*** Segment A begin ***										
A00	SIFI= 1.00	SIFO= 1.00								
	T1	0	791	-791	0	791	-791	396	MT	791
A01 N-	SIFI= 1.00	SIFO= 1.00								
	T1	0	563	-563	0	563	-563	282	MT	563
A01 N+	SIFI= 1.87	SIFO= 1.87								
	T1	0	1051	-1051	0	1051	-1051	525	MT	1051
A01 F-	SIFI= 1.87	SIFO= 1.87								
	T1	0	-85	-85	0	0	-85	42	NA	85
A01 F+	SIFI= 1.00	SIFO= 1.00								
	T1	0	-85	-85	0	0	-85	42	NA	85
A02	SIFI= 1.00	SIFO= 1.00								
	T1	0	-85	-85	0	0	-85	42	NA	85
*** Segment A end ***										

ATTACHMENT 4
PAGE 35 OF 55
CALC NO. H-1-BB-MEE-1050

A N A L Y S I S   S U M M A R Y

Current model revision number : 1

```
Static - Date and Time of analysis ............ Dec 4, 1995   3:10 PM
         Model Revision Number ................ 1
         Number of load cases ................. 1
         Load cases analyzed .................. T1
         Gaps/Friction/Yielding considered ..... No
         Hanger design run .................... No
         Cut short included ................... No
         Weight of contents included .......... Yes
         Pressure stiffening case ............. 0
         Water elevation for buoyancy loads .... Not considered
```

M_z = 1,000 ft-lbs Applied Moment

ATTACHMENT 4
PAGE 36 OF 55
CALC NO. H-1-BB-MEE-1050

D I S P L A C E M E N T S

Point name	Load combination	TRANSLATIONS (in) X	Y	Z	ROTATIONS (deg) X	Y	Z
*** Segment A begin ***							
A00	T1	0.000	0.000	0.000	0.000	0.000	0.000
A01 N	T1	0.000	0.000	0.000	0.000	0.000	0.000
A01 F	T1	0.000	0.000	0.000	0.000	0.000	0.001
A02	T1	0.000	0.000	0.000	0.000	0.000	0.001
*** Segment A end ***							

Sheet 4
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H-1-BB-MEE-1050

G L O B A L F O R C E S & M O M E N T S

Point name	Load combination	FORCES (lb) X	Y	Z	Result	MOMENTS (ft-lb) X	Y	Z	Result
*** Segment A begin ***									
A00	T1	0	0	0	0	0	0	-1000	1000
A01 N	T1	0	0	0	0	0	0	-1000	1000
A01 F	T1	0	0	0	0	0	0	-1000	1000
A02	T1	0	0	0	0	0	0	-1000	1000
*** Segment A end ***									

ATTACHMENT 4
PAGE 38 OF 55
CALC. NO. H-1-BB-MEE-1050

GENERAL PIPE STRESS REPORT
(Stress in psi)

Point name	Load combination	Hoop Stress	Longitudinal Max	Longitudinal Min	Tors. Shear	Principal Max	Principal Min	Max Shear	Loc	Oct Shear
*** Segment A begin ***										
A00	SIFI= 1.00	SIFO= 1.00								
	T1	0	16	-16	0	16	-16	8	MT	16
A01 N-	SIFI= 1.00	SIFO= 1.00								
	T1	0	16	-16	0	16	-16	8	MT	16
A01 N+	SIFI= 1.87	SIFO= 1.87								
	T1	0	30	-30	0	30	-30	15	MT	30
A01 F-	SIFI= 1.87	SIFO= 1.87								
	T1	0	30	-30	0	30	-30	15	MT	30
A01 F+	SIFI= 1.00	SIFO= 1.00								
	T1	0	16	-16	0	16	-16	8	MT	16
A02	SIFI= 1.00	SIFO= 1.00								
	T1	0	16	-16	0	16	-16	8	MT	16
*** Segment A end ***										

ATTACHMENT 4
PAGE 37 OF 55
CALC NO. H-1-BB-MEE-1050

Attachment C

AutoPIPE RESULTS FOR PIPING MODEL 3

15 Pages Attached

4
40 55
H-1-3B-MEE-1050

****
** **
** AUTOPIPE SYSTEM DATA LISTING **
** **
****

SYSTEM NAME : HRECIRC3

PROJECT ID : HOPE CREEK RECIRCULATION PIPING
PIPING CONFIGURATION 3

PREPARED BY : C. Swanner
C. SWANNER

CHECKED BY : [signature]

PIPING CODE : B31.1-67

AMBIENT TEMP. (deg F) : 70.0

COMPONENT LIBRARY : AUTOPIPE

MATERIAL LIBRARY : AUTO1967

MODEL REVISION NUMBER : 0

POINT DATA LISTING

POINT NAME	TYPE	OFFSETS (ft) X	Y	Z	PIPE ID	DESCRIPTION
*** SEGMENT A						
A00	Run	0	0	0	PIPE1	
A01	Bend	0	3.58	0		Long Elbow, Radius = 18.00 inch Bend angle change = 90.00 deg SIF - In = 1.80, Out = 1.80
A02	Run	1.50	0	0		

Total weight of empty pipes : 416 lb

ATTACHMENT 4
PAGE 42 OF 55
CALC NO. H-1-BB-MEE-1050

C O M P O N E N T   D A T A   L I S T I N G

POINT NAME	---COORDINATE(ft)--- X	Y	Z	DATA TYPE	DESCRIPTION
*** SEGMENT A					
A00	0.00	0.00	0.00	ANCHOR	Rigid
					Thermal movements : None
A01 N	0.00	2.08	0.00		
A01	0.00	3.58	0.00	TI	
A01 F	1.50	3.58	0.00		
A02	1.50	3.58	0.00	FORCES	Thermal 1

Number of points in the system : 5

ATTACHMENT 4
PAGE 43 OF 55
CALC. NO. H-1-BB-MEE-1050

P I P E   D A T A   L I S T I N G

Pipe ID/ Material	Nom/ Sch	O.D. inch	Thickness(inch) W.Th.	Corr	Mill	Insu	Ling	Spec Grav	Weight(lb/ft) Pipe	Other	Total
PIPE1 A312-TP304	NS	12.750	0.711	0	0.09	0	0	0	93.56	0	93.56

[illegible] 4
[illegible] 44 [illegible] 55
[illegible] H-1-BB-MEK-1050

M A T E R I A L   D A T A   L I S T I N G

Material Name	Pipe ID	Density lb/cu.ft	Pois. Ratio	Temper. deg F	Modulus E6 psi	Expans. in/100ft	Allow. psi
A312-TP304	PIPE1	501.0	0.30	70.0	28.30		18700.0

ATTACHMENT 4
PAGE 45 OF 55
CALC NO. H-1-BB-MEE-1050

TEMPERATURE AND PRESSURE DATA

POINT NAME	CASE 1 PRESS. psi	CASE 1 TEMPER deg F	CASE 1 EXPAN. in/100ft	CASE 2 PRESS. psi	CASE 2 TEMPER deg F	CASE 2 EXPAN. in/100ft	CASE 3 PRESS. psi	CASE 3 TEMPER deg F	CASE 3 EXPAN. in/100ft
*** SEGMENT A									
A00	0	70.00	0.000						
A02	0	70.00	0.000						

4
46 55
H-1-BB-MEE-1050

FORCES AND DISPLACEMENTS
(Force - lb , Moment - ft-lb , Tran.- in , Rot.- deg)

POINT NAME	LOAD CASE	TYPE	X	Y	Z	XX	YY	ZZ
A02	T1	FORCE	-10000	0	0	0	0	0

4
17 55
H-1-BB-MEE-1050

A N A L Y S I S S U M M A R Y

Current model revision number : 0

Static - Date and Time of analysis .... Dec 4, 1995 2:54 PM
Model Revision Number 0
Number of load cases 1
Load cases analyzed T1
Gaps/Friction/Yielding considered ..... No
Hanger design run .... No
Cut short included .... No
Weight of contents included .... Yes
Pressure stiffening case 0
Water elevation for buoyancy loads .... Not considered

F_x = -10,000 lbs Applied Force

Attachment 4
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Calc No. H-1-BB-MEE-1050

D I S P L A C E M E N T S

Point name	Load combination	TRANSLATIONS (in) X	Y	Z	ROTATIONS (deg) X	Y	Z
*** Segment A begin ***							
A00	T1	0.000	0.000	0.000	0.000	0.000	0.000
A01 N	T1	-0.010	0.000	0.000	0.000	0.000	0.032
A01 F	T1	-0.028	0.020	0.000	0.000	0.000	0.067
A02	T1	-0.028	0.020	0.000	0.000	0.000	0.067
*** Segment A end ***							

G L O B A L F O R C E S & M O M E N T S

Point name	Load combination	FORCES (lb) X	Y	Z	Result	MOMENTS (ft-lb) X	Y	Z	Result
*** Segment A begin ***									
A00	T1	10000	0	0	10000	0	0	-35823	35823
A01 N	T1	10000	0	0	10000	0	0	-14990	14990
A01 F	T1	10000	0	0	10000	0	0	0	0
A02	T1	10000	0	0	10000	0	0	0	0
*** Segment A end ***									

G E N E R A L P I P E S T R E S S R E P O R T
(Stress in psi)

Point name	Load combination	Hoop Stress	Longitudinal Max	Longitudinal Min	Tors. Shear	Principal Max	Principal Min	Max Shear	Loc	Oct Shear
*** Segment A begin ***										
A00	SIFI= 1.00	SIFO= 1.00								
	T1	0	5605	-5605	0	5605	-5605	2803	MT	5605
A01 N-	SIFI= 1.00	SIFO= 1.00								
	T1	0	2346	-2346	0	2346	-2346	1173	MT	2346
A01 N+	SIFI= 1.80	SIFO= 1.80								
	T1	0	4224	-4225	0	4224	-4225	2112	MC	4225
A01 F-	SIFI= 1.80	SIFO= 1.80								
	T1	0	-372	-372	0	0	-372	186	NA	372
A01 F+	SIFI= 1.00	SIFO= 1.00								
	T1	0	-372	-372	0	0	-372	186	NA	372
A02	SIFI= 1.00	SIFO= 1.00								
	T1	0	-372	-372	0	0	-372	186	NA	372
*** Segment A end ***										

A N A L Y S I S   S U M M A R Y

Current model revision number : 0

Static - Date and Time of analysis .... Dec 4, 1995 2:56 PM
Model Revision Number 0
Number of load cases 1
Load cases analyzed T1
Gaps/Friction/Yielding considered ..... No
Hanger design run .... No
Cut short included .... No
Weight of contents included .... Yes
Pressure stiffening case 0
Water elevation for buoyancy loads .... Not considered

M_z=1,000 ft-lbf Unit Moment

D I S P L A C E M E N T S

Point name	Load combination	TRANSLATIONS (in) X	Y	Z	ROTATIONS (deg) X	Y	Z
*** Segment A begin ***							
A00	T1	0.000	0.000	0.000	0.000	0.000	0.000
A01 N	T1	0.000	0.000	0.000	0.000	0.000	0.001
A01 F	T1	-0.001	0.002	0.000	0.000	0.000	0.008
A02	T1	-0.001	0.002	0.000	0.000	0.000	0.008
*** Segment A end ***							

G L O B A L F O R C E S & M O M E N T S

Point name	Load combination	FORCES (lb) X	Y	Z	Result	MOMENTS (ft-lb) X	Y	Z	Result
*** Segment A begin ***									
A00	T1	0	0	0	0	0	0	-1000	1000
A01 N	T1	0	0	0	0	0	0	-1000	1000
A01 F	T1	0	0	0	0	0	0	-1000	1000
A02	T1	0	0	0	0	0	0	-1000	1000
*** Segment A end ***									

G E N E R A L P I P E S T R E S S R E P O R T

(Stress in psi)

Point name	Load combination	Hoop Stress	Longitudinal Max	Longitudinal Min	Tors. Shear	Principal Max	Principal Min	Max Shear	Loc	Oct Shear
*** Segment A begin ***										
A00	SIFI= 1.00	SIFO= 1.00								
	T1	0	156	-156	0	156	-156	78	MT	156
A01 N-	SIFI= 1.00	SIFO= 1.00								
	T1	0	156	-156	0	156	-156	78	MT	156
A01 N+	SIFI= 1.80	SIFO= 1.80								
	T1	0	282	-282	0	282	-282	141	MT	282
A01 F-	SIFI= 1.80	SIFO= 1.80								
	T1	0	282	-282	0	282	-282	141	MT	282
A01 F+	SIFI= 1.00	SIFO= 1.00								
	T1	0	156	-156	0	156	-156	78	MT	156
A02	SIFI= 1.00	SIFO= 1.00								
	T1	0	156	-156	0	156	-156	78	MT	156
*** Segment A end ***										

ATTACHMENT 4
PAGE 55 of 55
CALC NO. H-1-BB-MEE-1050