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AEP
INDIANA
MICHIGAN
POWER

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C0801-05

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U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Mail Stop O-P1-17
Washington, DC 20555-0001

Donald C. Cook Nuclear Plant Units 1 and 2
NRC GENERIC LETTER (GL) 96-06
ASSURANCE OF EQUIPMENT OPERABILITY AND CONTAINMENT
INTEGRITY DURING DESIGN BASIS ACCIDENT CONDITIONS
RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION
(TAC NOS. M96801 AND M96802)

References:

1. Letter from A. C. Bakken III, Indiana Michigan Power Company to Nuclear Regulatory Commission Document Control Desk, "NRC Generic Letter (GL) 96-06, Assurance of Equipment Operability and Containment Integrity During Design Basis Accident Conditions, (TAC Nos. M96801 and M96802)," submittal C0800-10, dated August 15, 2000.

2. Letter from M. W. Rencheck, Indiana Michigan Power Company, to Nuclear Regulatory Commission Document Control Desk, "Donald C. Cook Nuclear Plant Unit 1, NRC Generic Letter (GL) 96-06, Assurance of Equipment Operability and Containment Integrity During Design Basis Accident Conditions, (TAC Nos. M96801 and M96802)," submittal C1100-01, dated November 7, 2000.

3. Letter from John F. Stang, Nuclear Regulatory Commission, to Robert P. Powers, Indiana Michigan Power Company, "Donald C. Cook Nuclear Plant, Units 1 and 2 – Request for Additional Information, 'Responses to Generic Letter (GL) 96-06 Assurance of Equipment Operability and Containment Integrity During Design-Basis Accident Conditions,' (TAC Nos. M96801 and M96802)," dated June 6, 2001.

A072

In GL 96-06, the Nuclear Regulatory Commission (NRC) requested licensees to review their plant designs to determine if isolated piping sections inside of containment could be subjected to overpressurization following a design-basis accident. Additionally, the NRC requested licensees to determine if piping inside of containment could be subjected to either two-phase flow or waterhammer following a design-basis accident. Indiana Michigan Power Company responded to the GL in References 1 and 2, stating that there were piping sections inside containment that could be subjected to overpressurization and waterhammer following a design-basis accident.

In Reference 3, the NRC requested additional information regarding the evaluations that were performed in responding to the GL. This letter provides a response to the request for additional information.

This letter contains no new commitments. Should you have any questions, please contact Mr. Ronald W. Gaston, Manager of Regulatory Affairs, at (616) 697-5020.

Sincerely,

M. W. Rencheck
Vice President Nuclear Engineering

/dmb

c: J. E. Dyer
MDEQ - DW & RPD, w/o attachments
NRC Resident Inspector
R. Whale, w/o attachments

AFFIRMATION

I, Michael W. Rencheck, being duly sworn, state that I am Vice President of Indiana Michigan Power Company (I&M), that I am authorized to sign and file this request with the Nuclear Regulatory Commission on behalf of I&M, and that the statements made and the matters set forth herein pertaining to I&M are true and correct to the best of my knowledge, information, and belief.

Indiana Michigan Power Company

MW Rencheck

M. W. Rencheck
Vice President Nuclear Engineering

SWORN TO AND SUBSCRIBED BEFORE ME

THIS 31 DAY OF August, 2001

Jennifer L Kernosky
Notary Public

My Commission Expires 05/26/05

JENNIFER L KERNOSKY
Notary Public, Berrien County, Michigan
My Commission Expires May 26, 2005

ATTACHMENT 1 TO C0801-05

RESPONSE TO GENERIC LETTER (GL) 96-06
REQUEST FOR ADDITIONAL INFORMATION

In GL 96-06, the Nuclear Regulatory Commission (NRC) requested licensees to review their plant designs and determine if piping inside of containment would be subject to overpressurization, waterhammer, or two-phase flow following a design basis accident. Indiana Michigan Power Company (I&M) responded to the GL in letters from A. C. Bakken III, I&M, to NRC Document Control Desk, dated August 15, 2000, and M. W. Rencheck, I&M, to NRC Document Control Desk, dated November 7, 2000. The NRC in a letter from J. F. Stang, Jr. to Robert P. Powers, I&M, dated June 6, 2001, requested additional information. The following responds to the NRC's request for additional information.

NRC Question 1

"If a methodology other than that discussed in NUREG/CR-05220, 'Diagnosis of Condensation-induced Waterhammer,' was used in evaluating the effects of waterhammer, describe this alternate methodology in detail. Also, explain why this methodology is applicable and gives conservative results (typically accomplished through rigorous plant-specific modeling, testing, and analysis)."

I&M Response

NUREG/CR-05220 describes an approach for waterhammer analysis that is based on several primary steps. These are: (1) determine what type of waterhammer is possible, (2) perform analysis to determine the water velocity at collapse of the void or impact of two water slugs, (3) determine the waterhammer pressures using the impact velocity and the speed of sound, and (4) using the waterhammer pressure, determine the waterhammer loads and evaluate the impact of the loads on the system. These steps were followed in the non-essential service water (NESW) system evaluation.

Waterhammer was analyzed using a transient hydraulic computer code that includes the thermodynamic equations of state for water (both liquid and vapor); therefore, the code identifies the locations of voids and water slugs in the piping system, including their transient behavior. This is consistent with the methodology discussed in NUREG/CR-05220. For the NESW system, the primary waterhammer events are trapped void collapse and saturated water slug acceleration. The impact velocity and waterhammer pressure are calculated by the analysis code. Stress analyses were performed to evaluate the impact of the waterhammer loads on the piping and pipe supports. The stress analyses are discussed in the response to Question 2(d).

Additional details on the methodology used, its applicability, and its conservatisms, are described in detail in the Question 2 response.

NRC Question 2

"For both the waterhammer and two-phase flow analyses, provide the following information:

NRC Question 2(a)

Identify any computer codes that were used in the waterhammer and two-phase flow analyses and describe the methods used to benchmark the codes for the specific loading conditions involved (see Standard Review Plan Section 3.9.1)."

I&M Response

The transient hydraulic computer code SYSFLOW, which was developed by MPR Associates, Incorporated, was used to analyze the waterhammer events. The transient thermal hydraulic analysis computer program uses a fully implicit numerical technique to solve the integrated mass, energy, and momentum conservation equations over a set of control volumes connected by fluid connectors. The piping is divided into control volumes that contain mass and energy. Mass and energy are transferred between the control volumes via connections between the centroid of one control volume and the centroid of another control volume. The transient flow rate in the connector is determined by the integrated momentum conservation equation, and the transient behavior of the mass and energy in the control volumes is determined by the integrated mass and energy conservation equations. The pressure, temperature, enthalpy, density, and void fraction are all determined from the mass and energy in a control volume.

Since the analytic approach described above is based on the conservation of mass, energy, and momentum and includes the complete thermodynamic equations of state of steam/water, acoustic phenomena are included implicitly in the solution of the conservation equations. For example, the velocity at which sound propagates can be determined from the properties of steam/water from the partial derivative of pressure with respect to density at constant entropy and the wave equation which controls the propagation of sound waves can be derived directly from the conservation equations.

The computer code was verified by using it to analyze piping configurations for which the answers are known, including problems involving pressure waves traveling through the piping at the speed of sound.

In addition, the results of the computer code were compared with the steady state results calculated with a Proto-Flo steady state computer model of the NESW system. The results of these comparisons show that the calculated results of the transient computer code are acceptable.

The two-phase flow analysis was limited to hand calculations to demonstrate that boiling does not occur in the containment ventilation coolers. A transient analysis computer code was not used for this evaluation.

NRC Question 2(b)

"Describe and justify all assumptions and input parameters (including those used in any computer codes) such as amplifications due to fluid structure interaction, speed of sound, force reductions, and mesh sizes, and explain why the values selected give conservative results. Also, provide justification for omitting any effects that may be relevant to the analysis (e.g., fluid structure interaction, flow induced-vibration, erosion)."

I&M Response

A number of assumptions were made in developing the analysis model and performing the hydraulic and stress analyses. The key assumptions made in the analyses and modeling included:

Waterhammer Analysis - Several key assumptions are built into the analysis methodology and computer code. The most important are:

- No credit is taken for the cushioning effect of any entrained air in the NESW system. This maximizes the magnitude of any resulting pressure pulses.
- The computer code and model neglect fluid structure interaction and the reduction in speed of sound due to pipe expansion. This overestimates the calculated waterhammer pressures.
- The analytic technique overestimates waterhammer pressures. When a void collapses and becomes water solid in the model, the computer code overestimates the mass in the control volume and overestimates the resulting pressure.

Other assumptions made in performing the waterhammer hydraulic analyses included:

- The geometrically similar piping inside containment was modeled as a single line with flow properties of the combined lines as the response would be similar to the response of the two lines individually.
- Several turbine building flow loads were modeled as a single flow connector and resistance. This approach has negligible impact on the analysis results.

Two-Phase Flow

- The containment ventilation coolers are assumed to have zero fouling. This increases the heat transfer rate from the containment atmosphere to the NESW system and increases the possibility of two-phase flow.

Stress Analysis

- A model of a single upper containment ventilation unit line was constructed. It was assumed that this line would provide results comparable to other lines because of the low loads, the ample margin, and the similarity in the piping designs.

NRC Question 2(c)

"Provide a detailed description of the 'worst case' scenarios for waterhammer and two-phase flow (i.e., scenarios that lead to most severe consequences when considering design-basis assumptions such as single-failure, loss of offsite power, etc.), taking into consideration the complete range of event possibilities, system configurations, and parameters. For example, all waterhammer types and water slug scenarios should be considered, as well as temperatures, pressures, flow rates, load combinations, and potential component failures. Additional examples include:

- the effect of void fraction on flow balance and heat transfer;
- the consequences of steam formation, transport, and accumulation;
- cavitation, resonance, and fatigue effects; and
- erosion consideration."

I&M Response

The most severe two-phase conditions that develop in the system result from column separation effects as pumping power is lost during loss-of-offsite power (LOOP) events. Thus, the waterhammer events associated with collapse or compression of steam pockets are not considered. The worst case scenarios for waterhammer in the NESW containment piping were determined by a failure modes and effects analysis (FMEA). These scenarios are:

A dual unit LOOP waterhammer event occurring in the upper-containment-ventilation unit's piping without a loss-of-coolant accident (LOCA). This event results in the maximum voiding in the NESW system, with the containment isolation valves remaining open. This is a classic column separation waterhammer scenario. The worst case pressures result from assuming the void collapses without air present (to cushion the impact) and with cold water in the system. The largest voids are in the upper containment ventilation unit piping. The FMEA determined that the limiting case is a LOOP with a lower containment ventilation unit isolation valve failing closed. This would direct more flow towards the upper containment ventilation units and increase the impact velocity.

A dual unit LOOP waterhammer event occurring in the lower-containment-ventilation unit's piping with a small break LOCA. Although the voids in the lower ventilation unit piping would not be as large as in the upper ventilation unit piping, it is possible that the refill velocity could be higher, since the system will preferentially fill the lower unit's piping before filling the upper unit's piping. This is also a classic column separation waterhammer scenario, with the same assumptions as the previous case (no air cushioning, cold water, etc.). The FMEA determined that the limiting case is a LOOP with a lower containment ventilation unit isolation valve failing closed. This would direct more flow towards the open lower containment ventilation units and increase the impact velocity.

In summary, the worst case scenarios are classic column separation configurations, using traditional limiting assumptions.

The containment ventilation units are not used for accident mitigation. Thus, the effect on the heat transfer coefficients is not a concern, as the ventilation units are not credited with removing heat from containment following an accident.

NRC Question 2(d)

"Please provide the limiting piping loads for the bounding waterhammer and provide comparisons to the allowable limits for these loads. Please include results demonstrating integrity of the non-essential-service water (NESW) system inside containment and the results demonstrating the integrity of the system outside of the containment. Include consideration of containment isolation valves and penetrations."

I&M Response

The maximum piping stress due to the waterhammer loads was calculated to be 10 ksi. The calculated support loads varied, but were typically very small. The maximum support load due to the waterhammer loads was 570 lb.

Full design stress analyses were not performed for the NESW piping for the waterhammer loads. This was because of the very low calculated stresses and support loads. Additionally, the system is not required to remain operational (there are no safe-shutdown required functions). The only requirement is that any failures will not adversely affect safety-related equipment or prevent containment isolation. The appropriate acceptance criteria for this loading are those defined in the Appendix F to Section III of the American Society of Mechanical Engineers (ASME) Code. These criteria provide ample margin, and a qualitative evaluation was performed to determine that the calculated loads and stresses, even when combined with gravity and other applicable loads, would still be considerably less than the code acceptance criteria.

The calculated pipe stresses were determined assuming no pipe supports were present. The maximum stress of 10 ksi is not a concern for significant piping damage or detrimental impact on isolation valve performance as this stress is well below the ASME Code, Appendix F limits. The NESW system is not safety related, so detailed design analyses of all piping segments and pipe supports were not performed. However, the maximum pipe support load of 570 lbs. is comparable to the available normal design loads. These loads were considered acceptable even if some support damage occurred, particularly since the piping is acceptable even without the supports.

NRC Question 2(e)

"Confirm that the analyses included a complete failure modes and effects analysis (FMEA) for all components (including electrical and pneumatic failures) that could impact performance of the cooling water system and confirm that the FMEA is documented and available for review, or explain why a complete and fully documented FMEA was not performed."

I&M Response

A FMEA has been performed. The FMEA considered all postulated failures, including electrical, pneumatic and mechanical. The results of the FMEA are summarized in Table 1.

NRC Question 2(f)

"Explain and justify all uses of 'engineering judgement'"

I&M Response

Engineering judgement was used in several instances in performing the hydraulic analysis and the piping stress analysis. The most significant use of judgement was in the selection of the basic analysis approach. It was judged that a full, detailed design analysis of all NESW piping inside containment for waterhammer loads is not required. Rather, an analysis of a single containment cooler and its associated piping is adequate. The analysis approach used, and key judgements made, are as follows:

- The hydraulic modeling was performed using two models. A coarse model of the piping inside and outside containment was used to calculate the magnitude and duration of the waterhammer pressure pulse. The profile of this pulse was used as input to a detailed model of a containment cooler and its associated piping to calculate the time history response of the pressure pulse traveling through the cooler's piping. This approach was judged to provide sufficiently accurate results for the NESW system analysis. This conclusion is based on the large margin that exists between the calculated stresses and the applicable acceptance criteria (ASME Code, Appendix F).

- Stress analyses using the hydraulic loads as inputs were performed for a single containment cooler piping segment. A typical cooler line was selected for detailed modeling. This was judged to be acceptable because of the common design approach used for all NESW piping inside containment (e.g., span lengths between supports, routing through the containment, etc.). The stress analyses were performed for two conditions of pipe support stiffness (1 x 10^6 lb/ft, and supports not active). These two conditions were judged to sufficiently represent the expected piping stresses and pipe support loads. This conclusion is based on the large margin that exists between the calculated stresses and the applicable acceptance criteria (ASME Code, Appendix F). The calculated support loads and piping stresses were judged sufficiently low that additional, detailed analyses considering all postulated design loads is not required.

- Judgement was used in several instances in developing the details of the hydraulic models and the stress analysis models previously discussed. These uses of judgement are typically used by the vendor who performed the analysis. The modeling techniques were implemented under a 10 CFR 50, Appendix B program and have been used in previous applications.

Overall, the use of engineering judgement as described above is considered acceptable for the NESW piping evaluation. The results of the analysis support the judgement. The calculated maximum waterhammer pressure pulses are very low, between 50 and 150 psi, and the associated piping loads are low. The calculated piping stresses were much less than the ASME Section III, Appendix F allowable limits. The postulated waterhammer events would be fairly benign events for the NESW system, and the use of the selected evaluation approach is acceptable.

NRC Question 3

"Was condensation induced waterhammer (CIWH) analyzed? Are there any long horizontal piping runs in the NESW system where CIWH could occur during system drain down following a loss of offsite power or during the refill after power was reestablished?"

I&M Response

CIWH is caused when water slugs are trapped between two steam pockets, with incoming cold water on one side and high-pressure steam on the other side. The presence of the cold water causes a sudden collapse (condensation) of the steam pocket, creating a situation with low pressure on one side of the slug (due to the rapid condensation), and high pressure on the other side. The water slug accelerates through the low-pressure pocket into the incoming water. This condition does not occur in the NESW piping. Although water slugs and steam pockets may form in the piping during drain down, there is always very low pressure on the downstream side of the water slugs (the NESW system is an open loop system). It is impractical to consider that significant CIWH events could occur in these situations. Any CIWH events in the horizontal piping are considered bounded by the column separation waterhammer analysis.

NRC Question 4

"Determine the uncertainty in the waterhammer and two-phase flow analyses, explain how the uncertainty was determined, and how it was accounted for in the analyses to assure conservative results."

I&M Response

The analyses of waterhammer and two-phase flow do not include a formal uncertainty analysis. The results are based on bounding scenarios and conservative modeling approaches; therefore, the calculated results for waterhammer pressures, pipe stresses, and pipe supports are considered conservative. The overall conclusion of the evaluation was that the waterhammer loads are very small and would not cause gross failure of the piping and pipe supports. This conclusion was based on comparisons of calculated pipe stresses and pipe support loads to applicable acceptance criteria (ASME Code, Appendix F). The margins between calculated stresses and allowable stresses were sufficiently large to allow judgement to be used in place of a detailed design analysis of the entire system. Any expected uncertainties in the analysis methodology and results would not change this conclusion.

NRC Question 5

"Confirm that the waterhammer and two-phase flow loading conditions do not exceed any design specifications or recommended service conditions for the piping system and components, including those stated by equipment vendors; and confirm that the system will continue to perform its design-isolation functions as assumed in the safety analysis report for the facility."

I&M Response

The NESW system is a non-safety-related system, and its only safety-related function is to isolate the NESW piping following an accident signal. The NESW system is not required to operate to reach safe shutdown following an accident. Direct comparisons to design specifications, code acceptance criteria, etc., were not performed. Sufficient analyses were performed to provide support for the conclusion that the waterhammer loading is small and would not significantly damage or affect the NESW piping and pipe supports. The potential waterhammer events do not jeopardize the integrity of the containment isolation valves or safety related equipment installed inside containment, nor do they have a detrimental impact on isolation valve performance.

NRC Question 6

"With respect to the waterhammer and two-phase flow issue, provide a simplified diagram of the systems analyzed, showing major components, active components, relative elevations, lengths of piping runs, and the location of any orifices and flow restrictions."

I&M Response

Flow diagrams and isometric drawings of the NESW system are provided in Attachment 2.

NRC Question 7

"Describe in detail any plant modifications or procedural changes that have been made or are planned to be made to resolve the waterhammer and two-phase flow issues. Consider the circumstance by which the NESW would be isolated following a loss-of-coolant accident or steamline break, voided within the containment as the result of internal steam formation and subsequent opening of the isolations valves by operators for post accident containment cooldown. Would waterhammer occur under such a scenario? What procedural safeguards are provided?"

I&M Response

No plant modifications or procedural changes have been made, and none are planned. The NESW system is not used (or required) for post-accident containment cooldown.

NRC Question 8

"In the submittal of November 7, 2000, you identified 21 lines installed in Unit 1 that have no relief valves and are susceptible to thermally-induced pressurization. You classified three lines under category E1 and the remaining 18 lines under category E2 depending on the method you used for calculating peak pressure inside the affected line. You also stated that the 21 lines have been analyzed based on the inelastic analysis criteria in Appendix F to Section III of the American Society of Mechanical Engineers (ASME) Code."

NRC Question 8(a)

"Provide the maximum-calculated temperature and pressure for the pipe run. Describe in detail, the method used to calculate temperature and pressure values for the affected lines. This should include a discussion on the heat transfer model and the basis for the heat transfer coefficients used in the analysis."

I&M Response

Table 2 lists the maximum temperature and pressure for each Category E1 pipe, and the maximum pressure in each Category E2 pipe line.

For lines classified as Category E1, the temperature increase for the water inside the pipe and the associated pressure were determined. The water temperature is calculated by considering either forced convection or condensation heat transfer on the pipe's outer surface, conduction through the pipe walls, and natural convection heat transfer on the pipe's inner surface. The calculation uses standard correlations for heat transfer coefficients. A sample calculation, whose methodology is applicable to both Unit 1 and Unit 2, is provided in Attachment 3.

The calculated water temperature is used as an input to a stress analysis in which the system pressure is calculated. The stress analysis evaluates system expansion, calculates a specific volume for the water inside the pipe and determines the pressure based on the water's equation of state. A sample calculation, whose methodology is applicable to both Unit 1 and Unit 2, is provided in Attachment 4.

For lines classified as Category E2, the pressure at which certain diaphragm valves in the pipe system would lift off their seats to provide a momentary relief path was calculated. The calculation determines the system pressure required to open the valve a distance equal to 10% of its full-stroke length. Factors considered in this calculation are the diaphragm area exposed to the pressure in the isolated section and the valve's spring constant. The system pressure at which the valve is considered to open is the value at which the pressure force equals the spring force when the valve has opened a distance equal to 10% of it full-stroke length. Details of the calculation are provided in Attachment 5.

NRC Question 8(b)

"Describe the applicable design criteria for the piping and the valves. Include the required load combinations and the methodology for calculating primary membrane stress intensity for combined loads. Identify the licensing basis code edition of Appendix F to Section III of the ASME Code. Provide the maximum calculated and allowable stress and stain in the carbon steel and/or stainless steel penetrations."

I&M Response

The code of record for the valves is USAS B31.1.0-1967, which references USA Standards B16.1, B16.5 and B16.1. Where these acceptance criteria were exceeded, the 1989 version of the ASME Code, Section III, Appendix F was used.

Load combinations analyzed include overpressure, deadweight, and seismic induced loads. The methodology is fully described in Attachment 6.

The code of record for the piping systems is USAS B31.1.0-1967. Table 126.1 of this code references the ASME Boiler and Pressure Vessel Code, although Appendix F was not yet a part of Section III of the ASME Code at that time.

Where B31.1 code criteria were exceeded, piping segments were evaluated to Appendix F to Section III of the 1989 ASME Code. Use of Appendix F is consistent with the recommendations in Supplement 1 to Generic Letter 96-06. As a check, design stress intensity and yield strength

values from the 1989 ASME Code were compared to the values from the 1968 version, as shown in Attachment 6. This comparison showed that the 1989 edition material properties are comparable to the 1968 edition properties. Accordingly, the 1989 ASME Code version is appropriate to use for this evaluation.
The maximum stresses and strains in the piping are listed in Table 3. All lines are acceptable for overpressurization based on Appendix F criteria.

NRC Question 8(c)

"Based on the results of inelastic analysis of the 21 lines, provide the calculation for the line that has the maximum calculated stress/strain. The calculation should clearly indicate all design input parameters including material stress-strain curve and justification thereof, and the methodology for inelastic analysis including the analysis results. Provide the detailed calculation of maximum primary membrane stress intensity, membrane hoop strain, and the peak strain at local discontinuity. Acceptance criteria for stress and strain limits and its justification should also be provided along with the reference to specific articles of Appendix F to Section III of the ASME Code."

I&M Response

The reactor coolant pump (RCP) Seal Bypass line has the highest stress. The manner in which the stress and strain was calculated during overpressurization conditions is described in detail in Attachment 7 (which includes the calculation of peak pressure and shows the stress strain curves) and Attachment 6 (which includes stress and strain calculations and acceptance criteria).

NRC Question 8(d)

"For piping in E2 category, you indicated that credit for the momentary lifting of diaphragm valves was taken in the calculation of peak pressure that are listed in the submittal. Describe the method used to estimate the valve lift off pressure. Discuss any source of uncertainty associated with the calculation of the valve lift off pressure."

I&M Response

The method used to estimate the valve lift off pressure is discussed in the Question 8(a) response. The calculation to determine the valve lift off pressure did not credit leakage that would occur prior to the valve's opening by 10% of its full stroke. This conservatism was used to bound any uncertainty in the vendor supplied values used to calculate the opening pressure as the valves would begin to leak once the trapped water pressure was sufficient to just start lifting the valve.

NRC Question 9

"In the submittal of August 15, 2000, you identified four lines installed in Unit 2 that have no relief valves and are susceptible to thermally-induced pressurization. You stated that the four lines were analyzed based on the inelastic analysis criteria in Appendix F to Section III of the ASME Code."

NRC Question 9(a)

"Provide the maximum calculated temperature and pressure values for the pipe run. Describe in detail, the method to calculate temperature and pressure, if different from that provided in response to question 8(a)."

I&M Response

The maximum pressures and temperatures for each Unit 2-pipe segment are listed in Table 4. The methodology was previously discussed in the Question 8(a) response.

NRC Question 9(b)

"Provide the maximum calculated stress and strain in the carbon steel and/or stainless steel penetrations. Describe the design criteria, if different from that provided in response to question 8(b)."

I&M Response

The maximum stresses and strains in the piping are listed in Table 5. All lines are acceptable for overpressurization based on Appendix F criteria.

Unit 2 segments were evaluated to the requirements of ASME Code Section III Appendix F. Load combinations analyzed include hoop stresses due to overpressure, and longitudinal stresses due to pressure, deadweight and seismic induced loads. Longitudinal stresses were conservatively assumed to be equal to the allowable material stress to simplify the analysis. The methodology is fully described in Attachment 8.

NRC Question 9(c)

"Provide the calculation for the line with the maximum calculated stress/strain, if the maximum calculated stress/strain are not enveloped by and/or the calculation process is different from the sample calculation provided in response to question 8(c)."

I&M Response

The RCP Seal Bypass line has the highest stress. The manner in which the stress and strain was calculated during overpressurization conditions is described in detail in Attachment 8.

Table 1
Limiting Configurations of Donald C. Cook Nuclear Plant NESW System During Scenarios Considered for GL 96-06

Parameter	Scenario		
	Max Potential for Column Separation in Upper Containment Ventilation Units	Max Potential for Column Separation in Lower Containment Ventilation Units	Max Potential for Two-Phase Flow
Plant Condition	LOOP without LOCA	LOOP with Small Break LOCA	LOOP with Small Break LOCA
Number of NESW Pumps Running	All four pumps are assumed to operate to maximize flow (2 pumps per unit)	All four pumps are assumed to operate to maximize flow (2 pumps per unit)	Only the two pumps in the other unit are assumed to operate to minimize flow
Status of NESW Discharge Header Cross-Tie	Open	Open	Open
Number of NESW Flow Paths Open in Containment			
--Upper Containment Ventilation Units (4 total)	4	0	4
--Lower Containment Ventilation Units (4 total)	3	3	4
--Instrument Room	2	0	2
--RCP Coolers	0	0	4
Status of Other NESW Loads Outside of Containment			
-- Air Compressors	Open	Open	Closed
-- Other Loads	Closed	Closed	Open

Table 2

Donald C. Cook Nuclear Plant Unit 1 Piping Segments Maximum-Calculated Temperature and Pressure

Segment	Description	Maximum Temperature (°F)	Maximum Pressure (psig)
NESW Cooling for Instrumentation Room Ventilation Units (2 segments)	Piping between NESW supply and return isolation valves located outside of containment.	NA*	325
NESW Cooling for Upper Containment Ventilation Units (4 segments)	Piping between NESW supply and return isolation valves located outside of containment.	NA*	711
NESW Cooling for RCP Motor Air Coolers (4 segments)	Piping between NESW supply and return isolation valves located outside of containment.	NA*	711
NESW Cooling for Lower Containment Ventilation Units (4 segments)	Piping between NESW supply and return isolation valves located outside of containment.	NA*	215
Primary Water Supply to RCPs and pressurizer relief tank (PRT) (CPN 33)	Piping between Primary Water Supply line isolation valve outside containment to RCP and PRT isolation valves inside containment.	NA*	212
Demineralized Water Supply to Refueling Cavity Scrub Down Hose Connections (CPN 36)	Piping between Demineralized Water Supply line isolation valves outside containment to manual isolation valves for hose connections inside containment.	NA*	325
Reactor Coolant Drain Tank Pump Suction (CPN 40)	Piping from PRT drain line isolation valve and reactor coolant drain tank (RCDT) drain line check valve inside containment to isolation valves outside containment.	NA*	262
Containment Sump Pump Discharge (CPN 41)	Piping between sump pump discharge check valves inside containment and discharge isolation valves outside containment.	NA*	212
Safety Injection Test Line and Accumulator Fill Line (CPN 32)	Piping between accumulator isolation valves and fill line isolation valves.	235	15,310
RCP Seal Bypass Line	Piping between RCP seal bypass check valves and RCP seal bypass isolation valve, all inside containment.	235	16,940
RCP Seal Leakoff Return Line (CPN 37)	Piping between isolation valves located inside and outside of containment.	240	1,800

* No temperature was calculated for these lines since they have diaphragm valves that will open under overpressure conditions.

Table 3

Donald C. Cook Nuclear Plant Unit 1 Piping Segments
Maximum-Calculated Pipe Stress and Strain

	Per Appendix F		
Segment	**Stress Intensity (SI) / Allowable Stress (0.7 S_u) (psi)**	**Maximum Stress Index (equal to SI/0.7S_u)**	**Maximum Strain (in/in) (5% Permitted)**
NESW Cooling for Instrumentation Room Ventilation Units (2 segments)	27,902 / 42,000	0.66	0.0081%
NESW Cooling for Upper Containment Ventilation Units (4 segments)	29,466 / 42,000	0.70	0.0185%
NESW Cooling for RCP Motor Air Coolers (4 segments)	29,466 / 42,000	0.70	0.0185%
NESW Cooling for Lower Containment Ventilation Units (4 segments)	27,625 / 42,000	0.66	0.0085%
Primary Water Supply to RCPs and PRT (CPN 33)	29,545 / 47,950	0.62	0.011%
Demineralized Water Supply to Refueling Cavity Scrub Down Hose Connections (CPN 36)	30,238 / 47,950	0.63	0.016%
Reactor Coolant Drain Tank Pump Suction (CPN 40)	30,483 / 47,950	0.64	0.017%
Containment Sump Pump Discharge (CPN 41)	30,043 / 47,950	0.63	0.011%
Safety Injection Test Line and Accumulator Fill Line (CPN 32)	45,825 / 47,950	0.96	0.371%
RCP Seal Bypass Line	47,354 / 47,950	0.99	0.996%
RCP Seal Leakoff Return Line (CPN 37)	44,470 / 47,950	0.93	2.016%

Table 4

Donald C. Cook Nuclear Plant Unit 2 Piping Segments Maximum Calculated Temperatures and Pressures

Segment	Description	Maximum Temperature (°F)	Maximum Pressure (psig)
RCP Seal Leak-off Return Line (CPN 37)	Penetration piping between inside and outside containment isolation valves, including test connections.	250	15,300
Accumulator Fill Lines (CPN 32)	Piping from outside containment isolation valve to normally closed "inlet" valves at each accumulator and, the normally closed valves in the flow paths to the low head SI hot leg loops.	240	1,890
RCP Seal Bypass Lines	Piping from the seal bypass line check valves to the normally closed QRV-150 valve in the common discharge header.	250	1,890
PRT and RCDT Drain Piping (CPN 40)	Piping from the normally closed PRT drain line and the RCDT drain line check valve inside containment to the normally closed isolation valves outside containment.	250	17,100

Table 5

Donald C. Cook Nuclear Plant Unit 2 Piping Segments Maximum Calculated Pipe Stresses and Strains

	Per Appendix F		
Segment	**Stress Intensity (SI) / Allowable Stress ($0.7\ S_u$) (psi)**	**Maximum Stress Index (equal to $SI/0.7S_u$)**	**Maximum Strain (in/in) (5% Permitted)**
RCP Seal Leak-off Return Line (CPN 37)	38,200 / 47,950	0.80	2.614%
Accumulator Fill Lines (CPN 32)	40,200 / 47,950	0.84	0.422%
RCP Seal Bypass Lines	42,643 / 47,950	0.89	1.147%
PRT and RCDT Drain Piping (CPN 40)	38,200 / 47,950	0.80	2.629%

ATTACHMENT 2 TO C0801-05

NON-ESSENTIAL-SERVICE WATER SYSTEM DRAWINGS

The following drawings provide an overview of the non-essential-service water (NESW) system and the details of the NESW piping for components located inside the containment that were modeled in the waterhammer analysis.

Unit 1 Drawings

Inside Containment

OP-1-5114-82	Flow Diagram Non-Essential Service Water Unit 1
OP-1-5114A-25	Flow Diagram Non-Essential Service Water
1-NSW-65	Upper Containment Ventilation Unit 4 Supply Line
1-NSW-66	Upper Containment Ventilation Unit 3 Supply Line
1-NSW-67	Upper Containment Ventilation Unit 2 Supply Line
1-NSW-68	Upper Containment Ventilation Unit 1 Supply Line
1-NSW-69	Upper Containment Ventilation Unit 4 Return Line
1-NSW-70	Upper Containment Ventilation Unit 3 Return Line
1-NSW-71	Upper Containment Ventilation Unit 2 Return Line
1-NSW-72	Upper Containment Ventilation Unit 1 Return Line
1-NSW-174	Instrument Room Ventilation Unit 3 Supply Line
1-NSW-175	Instrument Room Ventilation Unit 4 Supply Line
1-NSW-176	Instrument Room Ventilation Unit 3 Return Line
1-NSW-177	Instrument Room Ventilation Unit 4 Return Line
1-NSW-178	Lower Containment Ventilation Unit 1 Supply Line
1-NSW-179	Lower Containment Ventilation Unit 2 Supply Line
1-NSW-180	Lower Containment Ventilation Unit 3 Supply Line
1-NSW-181	Lower Containment Ventilation Unit 4 Supply Line
1-NSW-182	Lower Containment Ventilation Unit 1 Return Line
1-NSW-183	Lower Containment Ventilation Unit 2 Return Line
1-NSW-184	Lower Containment Ventilation Unit 3 Return Line
1-NSW-185	Lower Containment Ventilation Unit 4 Return Line

Outside Containment

1-NSW-37	Lower Containment Ventilation Unit 2 Supply Line
1-NSW-38	Lower Containment Ventilation Unit 3 Supply Line
1-NSW-39	Upper Containment Ventilation Unit 2 Supply Line
1-NSW-42	Upper Containment Ventilation Unit 3 Supply Line
1-NSW-44	Upper Containment Ventilation Unit 2 Return Line
1-NSW-45	Lower Containment Ventilation Unit 2 Return Line
1-NSW-46	Lower Containment Ventilation Unit 3 Return Line
1-NSW-47	Upper Containment Ventilation Unit 3 Return Line
1-NSW-49	Instrument Room Ventilation Unit 3 Supply Line
1-NSW-50	Instrument Room Ventilation Unit 4 Return Line

1-NSW-51	Instrument Room Ventilation Unit 3 Return Line
1-NSW-52	Instrument Room Ventilation Unit 4 Supply Line
1-NSW-54	Upper Containment Ventilation Unit 1 Supply Line
1-NSW-55	Lower Containment Ventilation Unit 1 Supply Line
1-NSW-57	Upper Containment Ventilation Unit 4 Supply Line
1-NSW-58	Lower Containment Ventilation Unit 4 Supply Line
1-NSW-59	Lower Containment Ventilation Unit 1 Return Line
1-NSW-60	Upper Containment Ventilation Unit 1 Return Line
1-NSW-62	Lower Containment Ventilation Unit 4 Return Line
1-NSW-63	Upper Containment Ventilation Unit 4 Return Line

Unit 2 Drawings

Inside Containment

OP-2-5114-50	Flow Diagram Non-Essential Service Water Unit No. 2
OP-2-5114A-29	Flow Diagram Non-Essential Service Water
2-NSW-130	Upper Containment Ventilation Unit 1 Supply Line
2-NSW-131	Upper Containment Ventilation Unit 2 Supply Line
2-NSW-132	Upper Containment Ventilation Unit 3 Supply Line
2-NSW-133	Upper Containment Ventilation Unit 4 Supply Line
2-NSW-138	Upper Containment Ventilation Unit 1 Return Line
2-NSW-139	Upper Containment Ventilation Unit 2 Return Line
2-NSW-140	Upper Containment Ventilation Unit 3 Return Line
2-NSW-141	Upper Containment Ventilation Unit 4 Return Line
2-NSW-186	Instrument Room Ventilation Unit 3 Supply Line
2-NSW-187	Instrument Room Ventilation Unit 4 Supply Line
2-NSW-188	Instrument Room Ventilation Unit 3 Return Line
2-NSW-189	Instrument Room Ventilation Unit 4 Return Line
2-NSW-192	Lower Containment Ventilation Unit 1 Supply Line
2-NSW-193	Lower Containment Ventilation Unit 2 Supply Line
2-NSW-194	Lower Containment Ventilation Unit 3 Supply Line
2-NSW-195	Lower Containment Ventilation Unit 4 Supply Line
2-NSW-196	Lower Containment Ventilation Unit 1 Return Line
2-NSW-197	Lower Containment Ventilation Unit 2 Return Line
2-NSW-198	Lower Containment Ventilation Unit 3 Return Line
2-NSW-199	Lower Containment Ventilation Unit 4 Return Line

Outside Containment

2-NSW-100	Lower Containment Ventilation Unit 2 Supply Line
2-NSW-101	Lower Containment Ventilation Unit 3 Supply Line
2-NSW-102	Upper Containment Ventilation Unit 2 Supply Line

2-NSW-105	Upper Containment Ventilation Unit 3 Supply Line
2-NSW-106	Instrument Room Ventilation Unit 3 Supply Line
2-NSW-107	Instrument Room Ventilation Unit 4 Supply Line
2-NSW-108	Upper Containment Ventilation Unit 4 Supply Line
2-NSW-111	Upper Containment Ventilation Unit 1 Supply Line
2-NSW-112	Lower Containment Ventilation Unit 1 Supply Line
2-NSW-114	Upper Containment Ventilation Unit 2 Return Line
2-NSW-115	Lower Containment Ventilation Unit 3 Return Line
2-NSW-116	Lower Containment Ventilation Unit 1 Return Line
2-NSW-117	Upper Containment Ventilation Unit 3 Return Line
2-NSW-119	Instrument Room Ventilation Unit 3 Return Line
2-NSW-120	Instrument Room Ventilation Unit 4 Return Line
2-NSW-122	Upper Containment Ventilation Unit 4 Return Line
2-NSW-123	Lower Containment Ventilation Unit 2 Return Line
2-NSW-124	Lower Containment Ventilation Unit 4 Return Line
2-NSW-125	Upper Containment Ventilation Unit 1 Return Line
2-NSW-146	Lower Containment Ventilation Unit 4 Supply Line

In accordance with the restrictions stated on drawings OP-1-5114-82, OP-1-5114A-25, OP-25114-50 and OP-2-5114A-29, Indiana Michigan Power Company (I&M) hereby releases these documents to the Nuclear Regulatory Commission (NRC) for its information and use in connection with the review of I&M's submittal. I&M also permits the NRC to reproduce the drawings as necessary to facilitate the review and distribution of the submittal to meet NRC requirements.

ATTACHMENT 3 TO C0801-05

MPR CALCULATION 025-065-04

“DETERMINATION OF WATER TEMPERATURE IN D. C. COOK UNIT 1 RCP SEAL WATER LINE (CPN-37)”

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

CALCULATION TITLE PAGE

Client American Electric Power	Page 1 of 22
Project Evaluation of D.C. Cook Unit 1 Piping Segments for Potential Thermal Overpressurization	Task No. 025-0013-065-0
Title Determination of Water Temperature in D.C. Cook Unit 1 RCP Seal Water Line (CPN-37)	Calculation No. 025-065-04

Preparer/Date	Checker/Date	Reviewer/Approver/Date	Rev. No.
S R Harp 9/7/00	R C Sanders 9/7/00	R C Sanders 9/7/00	0

QUALITY ASSURANCE DOCUMENT

This document has been prepared, checked and reviewed/approved in accordance with the Quality Assurance requirements of 10CFR50, Appendix B, as specified in the MPR Quality Assurance Manual.

MPR

MPR-2169 Appendix A.4

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

RECORD OF REVISIONS

Calculation No.	Prepared By	Checked By	Page 2
025-065-04	S R Harp	RC Landers	

Revision	Description
0	Original Issue.

CONTENTS

1.0 PURPOSE

The purpose of this calculation is to predict the water temperatures reached in the CPN-37 piping system following pipe break accidents inside containment at DC Cook Unit 1. Two cases are considered. In the first, a steam jet from a hole in the nearest steam pipe directly impinges on the CPN-37 piping system. In the second, the steam jet does not directly impinge on the CPN-37 pipe system. Instead, the compartment containing the CPN-37 system is assumed to be passively filled with steam that condenses on the pipe. The containment temperatures during the accidents are those predicted for steam line break and loss of coolant accidents, as provided in Reference 3.

2.0 SUMMARY

One-dimensional, transient thermal analyses for the pipes in CPN-37 were performed to determine the temperature of water trapped in the segment during accident conditions. The water in the piping system was assumed to be initially 160°F and the containment temperatures were obtained as a function of time from Reference 3. The steam line break transients, AFW runout and MSIV failure, are considered to be significant for three minutes. The LOCA containment temperature transient remains significant for 15 hours.

Maximum water temperatures were calculated for the case of a steam jet directly impinging on the pipe and for the case of steam condensation on the OD. The maximum water temperature in the piping system for each transient is listed in Table 1. All of the temperatures are bounded by 240 °F.

Table 1. Maximum Water Temperatures (^{O}F)

Transient Considered		4" Schedule 10S	4" Schedule 40S
Steam Jet	AFW	235	235
	MSIV	235	235
	LOCA	207	207
Condensation	AFW	213	213
	MSIV	213	213
	LOCA	237	237

3.0 CALCULATION

3.1 Temperature Transients

The containment temperatures for the lower containment are plotted for the AFW Runout and MSIV failure steam line break scenarios (hereinafter referred to as "AFW" and "MSIV") in Figure 1 and the LOCA in Figure 2. These temperatures are taken from Reference 3.

These containment temperature profiles are used as the steam jet temperatures when considering direct impingement. They are not used when considering condensation since the vapor saturation pressure determines the temperature at which condensation will occur. In this study, the containment pressure is assumed to be 9 psig, the maximum pressure during an MSIV accident (Reference 3). The saturation temperature at 9 psig is 237 °F.

Note that the LOCA transient is much longer than the steam line break transients and that its compartment temperatures are much lower. As a result, the forced convection heat transfer during the LOCA will be much less than the convective heat transfer during the steam line break accidents. However, the LOCA is included in this study because condensation heat transfer will be more significant during a LOCA than during AFW and MSIV accidents. This is because the compartment pressure during a LOCA (Reference 3) stays consistently higher (6 psig+) for a longer period of time than in the steam line breaks and therefore the saturation temperature of the vapor surrounding the pipe will remain higher for a longer period of time in a LOCA accident than in the other accidents.

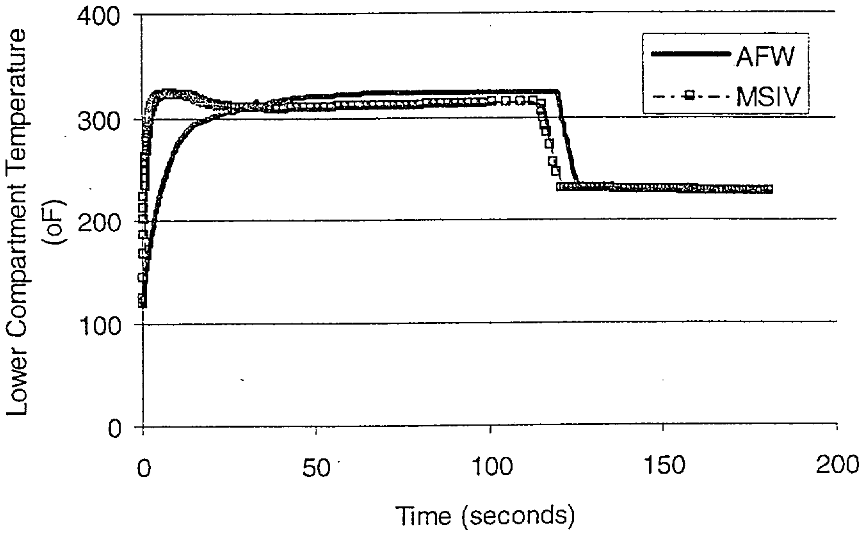


Figure 1. AFW and MSIV Lower Containment Temperatures

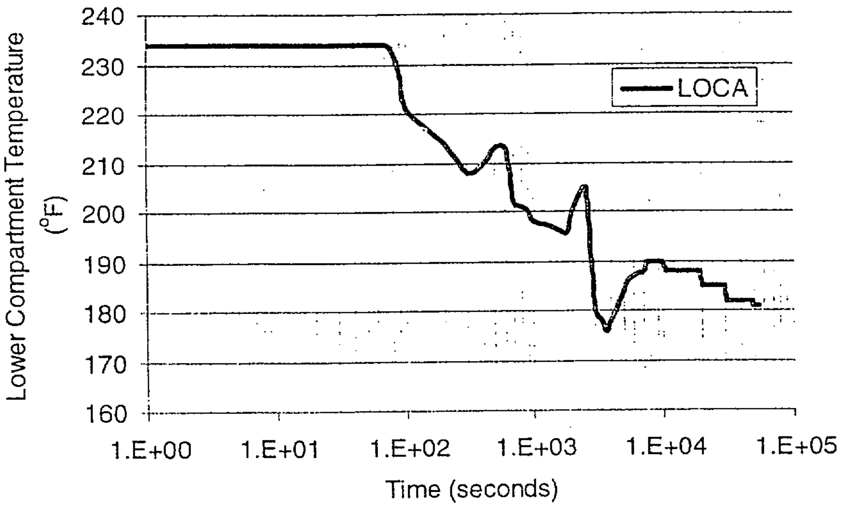


Figure 2. LOCA Lower Containment Temperatures

3.2 Pipe Sizes

CPN-37 consists of three different combinations of pipe sizes and schedules as listed in Table 2. Lengths are from Reference 1. Sizes, schedules, and materials are from References 12 and 13.

Table 2. Pipe Sizes and Schedules

Pipe Size (in.)	Schedule	OD (in.)	Thickness (in.)	ID (in.)	Length[1] (ft) (Ref. 1)	Material
1	40S	1.315	0.133	1.05	3	A-312 GR TP 304
4	10S	4.5	0.12	4.26	14	A-312 GR TP 304
4	40S	4.5	0.237	4.026	10	A-312 GR TP 304

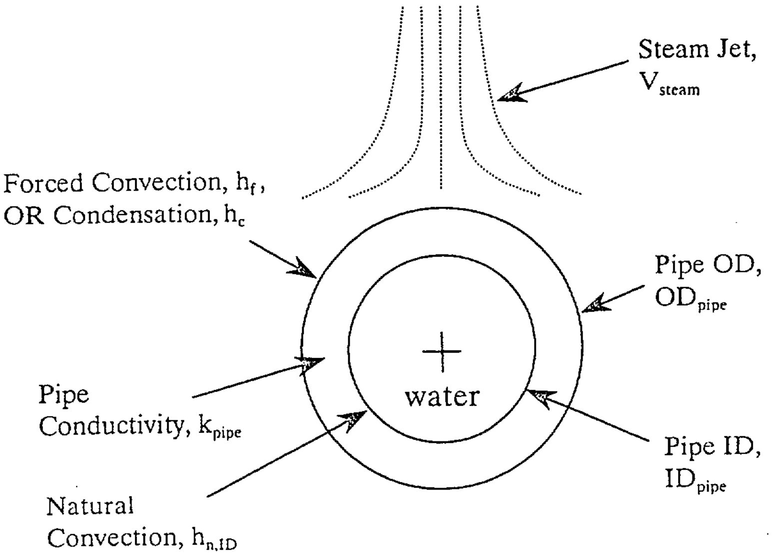
Note: 1. Only piping inside containment is considered since the piping outside containment is not heated during the accidents.

Since the length of the 1" pipe is short compared to the 4" pipe, heating of the 1" pipe will not significantly contribute to the bulk temperature of the piping system and it is therefore neglected. Insulation is also conservatively neglected as it could be blown off the pipe during the accidents.

3.3 Problem Set-up and Solution Procedure

The nomenclature used in this calculation is depicted in Figure 3.

Figure 3. Depiction of the System to be Modeled



When a steam jet directly impinges on the pipe, heat is transferred to the pipe OD by forced convection (heat transfer coefficient h_f). If instead the steam reaches the pipe passively, heat is transferred to the pipe OD by condensation (heat transfer coefficient h_c).

Heat is transferred by conduction from the pipe OD to the pipe ID. At the pipe-water interface, heat is transferred to the water by natural convection (heat transfer coefficient $h_{n,ID}$).

The temperature of the water is found by equating the heat transfer rate per unit pipe length to the rate of energy storage in the water per unit pipe length. This conservatively over estimates the water temperature because the energy stored in the pipe is neglected.

$$\frac{dE'}{dt} = q''\pi\, OD_{pipe} \tag{1}$$

The right hand side of Equation (1), the rate of heat transfer per unit length, depends on whether a steam jet is impacting the pipe or, instead, the containment is passively filled with steam,

$q_f'' = U_f\,(T_{comp} - T_{water})$ for an impinging steam jet (2a)

$q_c'' = U_c\,(T_v - T_{water})$ for a containment passively filled with steam (2b)

where:

q_f''=heat transfer rate per unit area for forced convection (steam jet)
U_f= overall heat transfer coefficient for forced convection (steam jet)
T_{comp}=temperature of the containment compartment as a function of time (Figures 1 and 2)
T_{water}= temperature of water in the pipe
q_c''= heat transfer rate per unit area for condensation
U_c= overall heat transfer coefficient for condensation
T_v=saturation vapor temperature at 9 psig (237°F)

Each overall heat transfer coefficient is a combination of the materials' thermal conductivities and the heat transfer coefficients at the pipe's OD and ID as described in section 3.4.

Energy storage is only considered to occur in water since the specific heat of the pipe is much less than that of water. For a unit length of pipe, the rate of energy storage with changing temperature is

$$\frac{dE'}{dt} = \frac{\pi}{4}\left[\rho_{water} ID_{pipe}{}^{2} C_{p,water}\right]\frac{dT_{water}}{dt} \qquad (3)$$

where

$C_{p,\,water}$ = heat capacity of water, 1BTU/(lbm F)

Equating Equations (2a) and (3) for the case of a steam jet impinging on the pipe

$$\frac{\pi}{4}\left[\ \rho_{water} ID_{pipe}{}^{2} C_{p,water}\ \right]\frac{dT_{water}}{dt} = U_f\ (T_{cont} - T_{water})\pi\, OD_{pipe} \qquad (4)$$

Using a forward discretization approach, Equation (4) becomes,

$$\frac{\pi}{4}\left[\ \rho_{water} ID_{pipe}{}^{2} C_{p,water}\ \right]\frac{\left(T_{water}^{j+1} - T_{water}^{j}\right)}{t^{j+1} - t^{j}} = U_f\ (T^{j}{}_{cont} - T^{j}{}_{water})\pi\, OD_{pipe} \qquad (5)$$

where the superscript j refers to the current time and the superscript j+1 refers to the next point in time that is considered.

Solving for the temperature at the future time t^{j+1},

$$T_{water}^{j+1} = T_{water}^{j} + \frac{4U_f\ (T^j{}_{cont} - T^j{}_{water})OD_{pipe}\left(t^{j+1} - t^j\right)}{[\ \rho_{water} ID_{pipe}{}^2 C_{p,water}\ ]} \qquad (6)$$

In the case of vapor condensation on a pipe instead of a steam jet,

$$T_{water}^{j+1} = T_{water}^{j} + \frac{4U_c\ (T_v - T^j{}_{water})OD_{pipe}\left(t^{j+1} - t^j\right)}{[\ \rho_{water} ID_{pipe}{}^2 C_{p,water}\ ]} \qquad (7)$$

These equations are solved given the water in the pipe is originally at 160 °F. The containment temperatures change as shown in Figures 1 and 2 and the saturation vapor temperature is 237°F at 9 psig.

3.4 Overall Heat Transfer Coefficients

The combined resistance of the convection coefficients and the pipe's conductivity is found with a circuit analogy. From Equation 2.44 in Reference 10, the universal heat transfer coefficient for the circuit in Figure 3 is,

$$U = \frac{1}{\dfrac{1}{h_{n,ID}}\dfrac{OD_{pipe}}{ID_{pipe}} + \dfrac{OD_{pipe}}{2\,k_{pipe}}\ln\dfrac{OD_{pipe}}{ID_{pipe}} + \dfrac{1}{h_{OD}}} \qquad (8)$$

In the case of an impinging steam jet, the heat transfer coefficient at the outer diameter is the forced convection heat transfer coefficient

$$h_{OD} = h_f$$

and the universal heat transfer coefficient is,

$$U_f = \frac{1}{\dfrac{1}{h_{n,ID}}\dfrac{OD_{pipe}}{ID_{pipe}} + \dfrac{OD_{pipe}}{2\,k_{pipe}}\ln\dfrac{OD_{pipe}}{ID_{pipe}} + \dfrac{1}{h_f}} \qquad (9)$$

When the jet does not impinge directly on the pipe, but the pipe is surrounded by steam,

$h_{OD} = h_c$

and the heat transfer coefficient is equal to the condensation heat transfer coefficient.

$$U_c = \frac{1}{\frac{1}{h_{n,ID}}\frac{OD_{pipe}}{ID_{pipe}} + \frac{OD_{pipe}}{2\,k_{pipe}}\ln\frac{OD_{pipe}}{ID_{pipe}} + \frac{1}{h_c}} \qquad (10)$$

The formulas for calculation of the forced heat transfer coefficient, h_f, are in Sections 3.5 and 3.6. The calculation description for the condensation heat transfer coefficient is in Section 3.7. The natural convection heat transfer coefficient at the pipe OD is found by the formula in Section 3.8. Properties of the pipe and water, including thermal conductivities, are in Section 3.9.

3.5 Forced Convection Heat Transfer Coefficient

The following heat transfer coefficient relation describes forced convection over a cylinder (Reference 7).

$$h_f = \frac{k_{steam}}{OD_{pipe}}\left[0.3 + \frac{0.62\,Re^{\frac{1}{2}}\,Pr^{\frac{1}{3}}}{\left[1+\left(\frac{0.4}{Pr}\right)^{\frac{2}{3}}\right]^{\frac{1}{4}}}\left[1+\left(\frac{Re}{282000}\right)^{\frac{5}{8}}\right]^{\frac{4}{5}}\right] \qquad (11)$$

where: $Re = \dfrac{\rho_{steam}\overline{V}\,OD_{pipe}}{\mu_{steam}}$ $\qquad Pr = \dfrac{C_{p,steam}\,\mu_{steam}}{k_{steam}}$

and where

h_f = forced convection heat transfer coefficient
ρ_{steam} = density of the steam jet
μ_{steam} = viscosity of the steam jet
k_{steam} = thermal conductivity of the steam jet
C_{p_steam} = specific heat of the steam jet
$\overline{V}$ = average velocity of the steam jet 40 feet from the break (see Section 3.6)
OD_{pipe} = outer diameter of the pipe

The maximum temperature in the lower containment is 325°F. Steam properties at this temperature are Reference (5),

ρ_{steam} = 0.2174 lbm/ft^3
μ_{steam} = 9.7E-6 lbm / (ft s)
k_{steam} = 0.0189 BTU/(hr ft F)
C_{p_steam} = 0.579 BTU/(lbm F)

The average jet velocity from Section 3.6 is,

$\overline{V}$ = 444 ft/s (from Section 3.6)

For a 4 inch pipe schedule 10S

OD_{ins}=4.5 in.

With these values,

Re=3.73E6 Pr=1.07 h_f=234 BTU/ (hr ft^2 F)

The heat transfer rate at the outer surface of the pipe is described in these calculations as

$$q'' = h_f\,(T_{cont} - T_{OD,pipe}) \qquad (12)$$

where

q'' = heat transfer rate per unit surface area
h_f = forced convection heat transfer coefficient
T_{cont} = containment temperature
$T_{OD,pipe}$ = pipe OD temperature

3.6 Steam Jet Velocity

In order to calculate the forced convection coefficient associated with the steam jet in Section 3.5, the velocity at which the steam jet impinges on the pipe must be determined.

From References 1 and 2, the closest a Cook Unit 1 steam pipe comes to the pipe associated with CPN-37 is about 40 feet.

$$L = 40 \text{ ft}$$

For an AFW runout steam line break, Figure 6 of Reference 3 indicates the steam pipe break area is,

$$A = 0.86 \text{ ft}^2$$

The corresponding break radius is,

$$r_j = \sqrt{\frac{A}{\pi}} = 6.3 \text{ in.}$$

Reference 4 provides the steam jet centerline velocity as a function of distance from the break given sonic conditions at the break and the value of a dimensionless constant φ,

$$\varphi = 0.074\, x_c \sqrt{\rho_c} \qquad (13)$$

where:
x_c = dimensionless axial distance, L/r_j
L = axial distance from the pipe break
r_j = radius of the hole in the steam pipe
ρ_c = dimensionless density, ρ_e/ρ_j
ρ_j = density of the steam jet exiting the hole
ρ_e = density of the jet steam at impact

The density of steam exiting the pipe is taken at 1025 psig and 550°F. From Reference 9 at those conditions,

$$\rho_j = \frac{1}{0.43084} \frac{\text{lb}}{\text{ft}^3}$$

The density of the jet when it impacts the wall is taken at 9 psig and 325 °F, the peak containment pressure and temperatures during an accident. From Reference 9 at those conditions,

$$\rho_e = \frac{1}{19.481}\frac{\text{lb}}{\text{ft}^3}$$

With the above properties and dimensions,

$$\varphi = 0.84$$

Figure 2 of Reference 4 indicates that the centerline speed of a jet at this value of φ is 100% of its choke flow velocity,

$$V_{center} = V_{choke}$$

where V_{center}= centerline velocity of jet 40 ft from steam pipe break
V_{choke}= choke flow velocity

From Figure 12 of Reference 5, the choke flow velocity of the steam exiting the hole is,

$$V_{choke} = 1455 \text{ ft/s}$$

This is assuming the jet pressure is equal to the 9 psig containment pressure.

The centerline velocity is then

$$V_{center} = 1455 \text{ ft/s}$$

The radial velocity of a steam jet from Reference 6, Table 5.5 is,

$$\log\left(\frac{V_{cent}}{V_r}\right) = 40\left(\frac{r}{L}\right)^2 \qquad (14)$$

where: V_r = velocity at distance r from centerline
r = radial distance from jet centerline

Solving for velocity as a function of radial position at a distance L,

$$V(r) = V_{center}\, 10^{-40\left(\frac{r}{L}\right)^2} \qquad (15)$$

A plot of the jet speed as a function of radius for L = 40 ft is in Figure 4.

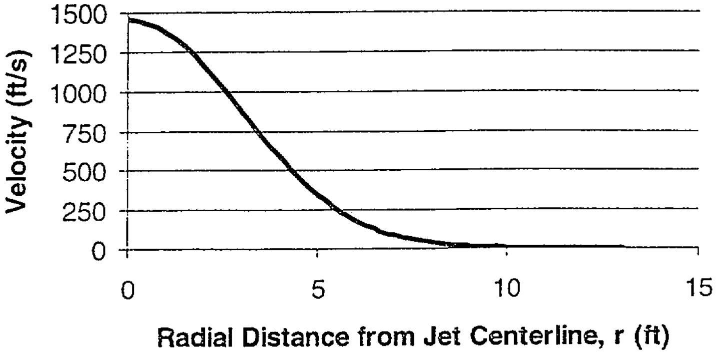


Figure 4. Velocity Distribution of Steam Jet

Since the jet diameter is approximately 25 ft wide (radius 12.5 ft in Figure 4) and the piping segment is approximately 25 ft wide (Reference 1), the jet will impact the entire length of the piping system.

An average of the jet velocity when it impacts the CPN-37 piping, at a distance of 40 ft from the steam line break, is used to calculate the forced convection heat transfer coefficient. The average velocity is used so that the heat transfer coefficient is in its average form. The average of the velocity at which the steam jet impacts the pipe is found by averaging the curve in Figure 4 over the radius of the steam jet, 12.5 ft,

$$\overline{V} = \frac{1}{12.5\,\text{ft}} \int_{0\,\text{ft}}^{12.5\,\text{ft}} V(r)\, dr = 444\,\frac{\text{ft}}{\text{s}} \qquad (16)$$

3.7 Condensation Heat Transfer Coefficient

When the containment is passively filled with steam, the steam will condense on the pipe if the pipe temperature is lower than the saturation temperature of the steam. Under such conditions, the appropriate heat transfer coefficient is of the form (Reference 10, Equation 10-23),

$$h_{cond} = 0.725 \left[\frac{\rho_l(\rho_l - \rho_v)\ g\, h_{fg}\, k_w^{\ 3}}{OD_{pipe}\ \mu_l\ (T_v - T_{OD,pipe})} \right]^{\frac{1}{4}} \tag{17}$$

where h_{cond}=condensation heat transfer coefficient
ρ_l=condensate density
ρ_v=vapor density
h_{fg}=latent heat of vaporization
k_w=condensate thermal conductivity
OD_{pipe}=od of the pipe
μ_l=condensate viscosity
T_v=vapor temperature
$T_{OD,pipe}$=temperature at the od of the pipe

The maximum pressure in containment during an accident, 9 psig, is used to determine the properties of the steam vapor and condensate. From References 7 and 11,

ρ_l=59.16 lbm/ft^3
ρ_v=0.058 lbm/ft^3
h_{fg}=954 BTU/lbm
k_w=0.394 BTU/(hr ft F)
μ_l=1.65E-4 lbm/(ft s)
T_v=237 F

For a 4 inch schedule 10S pipe

OD_{pipe}=4.5 in.

The temperature of the pipe is not explicitly evaluated in this study. Instead, the following conservative estimate is used,

$$T_{OD,pipe} = \qquad T_{water}$$

where : T_{water} = temperature of the water in the pipe

For demonstration of the order of magnitude of the condensation heat transfer coefficient, the water temperature will be taken as,

$$T_{OD,ins} = T_{water} = 200°F$$

With the above values,

$$h_{cond} = 1300 \text{ BTU/(hr ft}^2\text{°F)}$$

The heat transfer rate associated with condensation is then

$$q'' = h_{cond}\,(T_v - T_{OD,pipe}) \qquad (18)$$

where

q'' = heat transfer rate per unit surface area
h_{cond} = forced convection heat transfer coefficient
T_v = Saturation temperature at 9 psig (237 °F)
$T_{OD,pipe}$ = pipe temperature

3.8 Natural Convection Heat Transfer Coefficient

The heat transfer at the inner diameter of the pipe is governed by natural convection. 18 ft of the 24 ft inside of containment is horizontally oriented as is 7 feet of the 10 feet outside of containment (Reference 1). Since the majority of the pipe is horizontally oriented, the heat transfer coefficient applied to this boundary is for a horizontal pipe. Based on experimental evidence, Reference 8 recommends that the natural heat transfer coefficient for natural convection about the OD of a horizontal pipe be used at the inner diameter of a pipe as well. The recommended heat transfer coefficient is of the form,

$$h_{n,ID,\,horizontal} = \frac{k_{water}}{ID_{pipe}}\left[0.56\,(Gr\,Pr)^{0.25}\right] \qquad (19)$$

where:
$$Gr = \frac{\rho^2 \beta_{water}\; g\; ID_{pipe}^{\;3}\; (T_{ID,pipe} - T_{water})}{\mu_{water}^{\;2}} \qquad Pr = \frac{C_{p,water}\,\mu_{water}}{k_{water}}$$

for $10 < GrPr < 10^9$

where:

k_{water} = thermal conductivity of the water
μ_{water} = viscosity of the water
ρ_{water} = density of the water
$C_{p,water}$ = specific heat of the water
β_{water} = volumetric expansion coefficient of the water
ID_{pipe} = inner diameter of the pipe
$T_{ID,pipe}$ = temperature at the pipe id
T_{water} = temperature of the water

For water at 200°F (References 7 and 10):

k_{water} = 0.39 BTU/(hr ft F)
μ_{water} = 2.05E-4 lbm /(ft s)
ρ_{water} = 60.1 lbm / ft^3
$C_{p,water}$ = 1.005 BTU/(lbm F)
β_{water} = 4.8E-4 1/F

The temperature at the pipe ID, $T_{ID,pipe}$, is not explicitly evaluated in this model. Instead, the temperature at the pipe ID is conservatively assumed to be the containment temperature

$$T_{ID,pipe} = T_{comp}$$

For a 4" schedule 10S pipe,

$$ID_{pipe} = 4.26 \text{ in.}$$

and the temperatures,

$$T_{ID,pipe} = T_{comp} = 237°F$$
$$T_{water} = 170°F$$

the dimensionless numbers are,

$$Gr=4.0\text{ E}9 \quad Pr=1.9 \quad Gr\,Pr=7.6\text{ E}10$$

GrPr is still of the order of 1E9, so the natural convection coefficient of Equation 19 should be valid. The heat transfer coefficient is,

$$h_{n,ID,horizontal}=182 \text{ BTU/(hr ft}^2\text{°F)}$$

3.9 Material Properties

The material properties of the pipe and water are evaluated at 200°F (References 7, 10, 12, 13) and are listed in Table 3.

Table 3. Material Properties of Pipe, and Water at 200°F

Property	Water	Pipe 304 SS
k Btu/(hr ft °F)	0.391	10.7
Cp Btu/ (lbm °F)	1.005	na
ρ lbm/ft^3	60.1	na
β 1/ °F	4.8e-4	na
μ lbm/(ft s)	2.05e-4	na

3.10 Results- Transient Water Temperature

The temperature of the water in the 4" schedule 10S piping is shown in Figure 5 for the AFW accident and in Figure 6 for the LOCA accident. The AFW and MSIV results are within 2 percent of each other, so only a curve for the more limiting AFW accident results are shown (Figure 5). The results for the 4" schedule 40S pipe are within 2 percent of results for the 4" schedule 10S pipe shown in Figures 5 and 6, and so plots of the less limiting 4" schedule 40S pipe results are not included either.

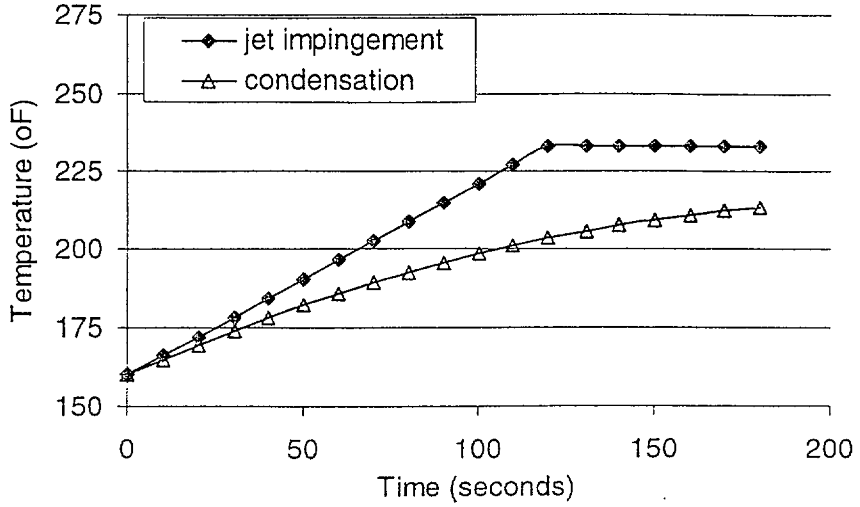


Figure 5. Water Temperature in 4" Schedule 10S pipe during AFW Failure

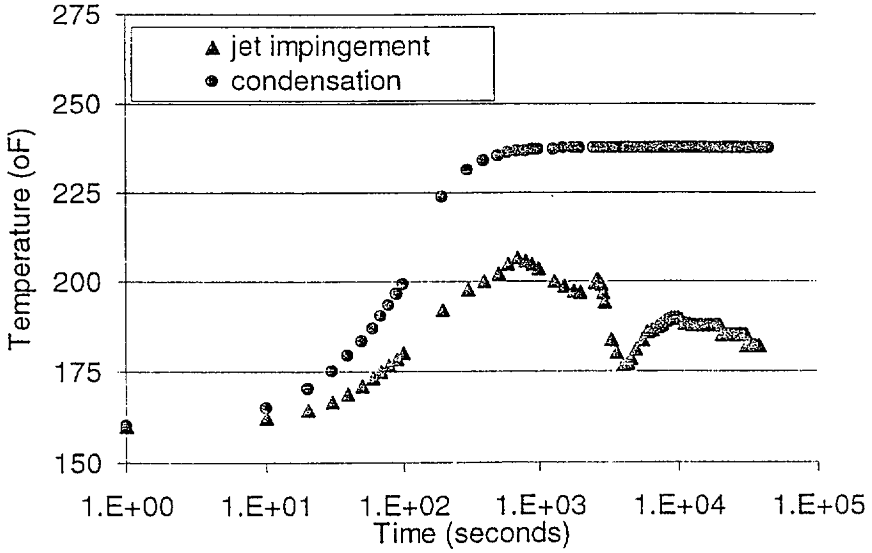


Figure 6. Water Temperature in 4" Schedule 10S pipe during LOCA

The results of Figure 5 indicate that the maximum water temperature during AFW (and MSIV), 235 °F, is produced by forced convection. This is the maximum temperature reached due to forced convection during the entire accident because the containment temperature never rises above 235 °F beyond the 3 minutes considered in this study for MSIV or AFW accidents (Reference 3).

The maximum condensation temperature is 213 °F at 3 minutes for AFW (and MSIV) (Figure 5). The temperature due to condensation may increase further over the next few minutes because the saturation temperature will remain above 213 °F for at least the first ten minutes of the MSIV and AFW accidents (based on the saturation temperatures of the compartment pressures shown in Reference 3). However, the water temperature after ten minutes will be less than 235 °F since the compartment temperature is less than 235 °F and the compartment pressure is less than 7 psig (T_{sat} =235 °F) for the remainder of the transients shown in Reference 5. As a result, 235 °F bounds the temperature of the water in the pipes during MSIV and AFW accidents.

In contrast to the MSIV and AFW accidents, condensation produces the highest water temperature, 237 °F, for the LOCA (Figure 6). This is because the convective heat transfer is lower for the LOCA than it is for the MSIV or AFW. In addition, the LOCA transient is much longer than the MSIV and AFW accident, and therefor the water in the pipe has time to reach the saturation temperature (237 °F at 9 psig) during the LOCA when condensation is the primary heat transfer mechanism.

The predicted water temperatures in the CPN-37 piping system during MSIV, AFW, or LOCA accidents are summarized in Table 4. Based on these results, the maximum temperature during an AFW, MSIV, or LOCA accident should be no higher than 240 °F

Table 1. Maximum Water Temperatures (°F)

Transient Considered		4" Schedule 10S	4" Schedule 40S
Steam Jet	AFW	235	235
	MSIV	235	235
	LOCA	207	207
Condensation	AFW	213	213
	MSIV	213	213
	LOCA	237	237

4.0 REFERENCES

1. Drawings of Containment Penetration CPN-37
    - D.C. Cook Drawing Number 1-CS-93, Revision 7.
    - D.C. Cook Drawing Number 1-CS-42, Revision 12.
2. Drawings of Main Steam Pipe Penetrations CPN 2-5
    - D.C. Cook Drawing Number 1-MS-14, Revision 16 (CPN 1).
    - D.C. Cook Drawing Number 1-MS-1, Revision 17 (CPN 2).
    - D.C. Cook Drawing Number 1-MS-6, Revision 13 (CPN 3 or 4) (Closest to CPN-37 pipe)
    - D.C. Cook Drawing Number 1-MS-10, Revision 14 (CPN 3 or 4).
3. "Containment Pressure and Temperature Figures and Tabular Data for UFSAR Limiting Cases," AEP-99-408, November 10, 1999.
4. P. Witze, "Centerline Velocity Decay of Compressivle Free Jets," AIAA Journal, Vol. 12:4 (4/74) p. 417-418.
5. "ASME Steam Tables," ASME, 6th Edition.
6. Perry and Chilton, "Chemical Engineers' Handbook," McGraw-Hill, 6th Edition.
7. F.P. Incropera and D.P. DeWitt, "Fundamentals of Heat and Mass Transfer," John Wiley and Sons, 3rd Edition.
8. EPRI Report TR-103581, "Thermal Stratification, Cycling, and Striping (TASCS)," prepared by Westinghouse Electric Corp., March 1994.
9. "Properties of Steam and Water," ASME Electronic Steam Tables, 1992.
10. F. Kreith and M. Bohn, "Principles of Heat Transfer," PWS Publishing Company, 5th Edition.
11. G.J. Van Wylen and R.E. Sonntag, "Fundamentals of Classical Thermodynamics," John Wiley and Sons, 3rd Edition
12. "Pipe Material Specification," AEP Specification No. ES-Pipe-1013-QCN-CS3, Revision 1.
13. "Pipe Material Specification," AEP Specification No. ES-Pipe-1000-WCS, Revision 1.

ATTACHMENT 4 TO C0801-05

MPR CALCULATION 025-065-05

"DETERMINATION OF PEAK PRESSURE IN D. C. COOK UNIT 1 RCP SEAL WATER LINE (CPN-37)"

MPR	MPR-2169 Appendix A.5	MPR Associates, Inc. 320 King Street Alexandria, VA 22314

CALCULATION TITLE PAGE

Client American Electric Power	Page 1 of 14
Project Evaluation of D.C. Cook Unit 1 Piping Segments for Potential Thermal Overpressurization	Task No. 025-0013-065-0
Title Determination of Peak Pressure in D.C. Cook Unit 1 RCP Seal Water Line (CPN-37)	Calculation No. 025-065-05

Preparer/Date	Checker/Date	Reviewer/Approver/Date	Rev. No.
S R Harp 9/7/00	9/7/2000	9/7/2000	0

QUALITY ASSURANCE DOCUMENT

This document has been prepared, checked and reviewed/approved in accordance with the Quality Assurance requirements of 10CFR50, Appendix B, as specified in the MPR Quality Assurance Manual.

RECORD OF REVISIONS

Calculation No.	Prepared By	Checked By	Page 2
025-065-05	S A Harp		

Revision	Description
0	Original Issue.

CONTENTS

1.0 PURPOSE

The purpose of this calculation is to determine the pressure in the CPN-37 piping segment at D. C. Cook Nuclear Power Station, Unit 1 during accident conditions. The evaluation addresses the concern identified in NRC Generic Letter 96-06, which states that during a design basis accident, isolated piping segments within containment may become over-pressurized by the thermal expansion of the contained water. CPN-37 is the RCP seal leak-off return line.

2.0 RESULTS

The maximum pressure reached in the CPN-37 line is 1795 psig.

This result will be used in separate evaluations for the pipe and valves in this segment.

3.0 CALCULATION

3.1 Approach

This pressure calculation assumes the piping segment is initially at 165 psia and 150°F prior to the LOCA or steam-line break. 165 psia is the pipe design pressure per the piping specification (Reference 1). 150°F is a conservative estimate of the pipe temperature since the design temperature is 200°F.

Reference 2 determined the maximum temperature of the water in the CPN-37 pipes during loss-of-coolant and steam line break accidents. The bounding water temperature is 240°F for all accidents.

The pressure calculation method used in MPR Calculation 025-065-02 (Reference 3) will be used here to determine the pressure increase as the water heats from 150°F to 240°F. Parameters used in the analysis are described in the following sections.

3.2 Geometry and Material Data

In this calculation, the CPN-37 piping is divided into three different segments corresponding to the three different sizes of pipe that make up this pipe segment. The data required for each cross section are the pipe diameter, wall thickness and material properties. The piping geometry is found in Reference 4 and the pipe dimensions are from Reference 5. The material data includes: material class and material type (References 1 and 4), design stress intensity (S_m), yield stress (S_y), ultimate strength (S_u), elastic modulus (E), and plastic modulus (E_p). The plastic modulus is found in Reference 6 and the associated stress-strain curve is shown in Figure 1. The remaining material properties are obtained from the 1989 ASME Code (Reference 7). Material properties are evaluated at 240°F, the bounding water temperature calculated in Reference 2. The geometry and material data for the piping segments is listed in Table 1. Nominal pipe wall thickness was used for the evaluations. The lengths of each pipe cross section in the segment are listed in Table 2 (from Reference 4).

Table 1: Geometry and Material Properties, CPN-37, 240°F

Pipe Size	Sched.	Geometry Data		Material Data							
		OD (in)	Wall (in)	Class	Type	S_m (ksi)	S_y (ksi)	S_u (ksi)	E (10^6 psi)	E_p (10^6 psi)
4 in	10S	4.500	0.120	B-14	SA312 TP304	20.0	24.0	69.0	27.4	0.425
4 in	40S	4.500	0.237	B-14	SA312 TP304	20.0	24.0	69.0	27.4	0.425
1 in	40S	1.315	0.133	B-14	SA312 TP304	20.0	24.0	69.0	27.4	0.425

Table 2: Piping Segment Lengths

Segment	Pipe Geometry			Length*
CPN-37	4 in	SCH 10S	SA312 TP304	14 ft
	4 in	SCH 40S	SA312 TP304	10 ft
	1 in	SCH 40S	SA312 TP304	3 ft

* Note: Only piping in containment is considered for conservatism.

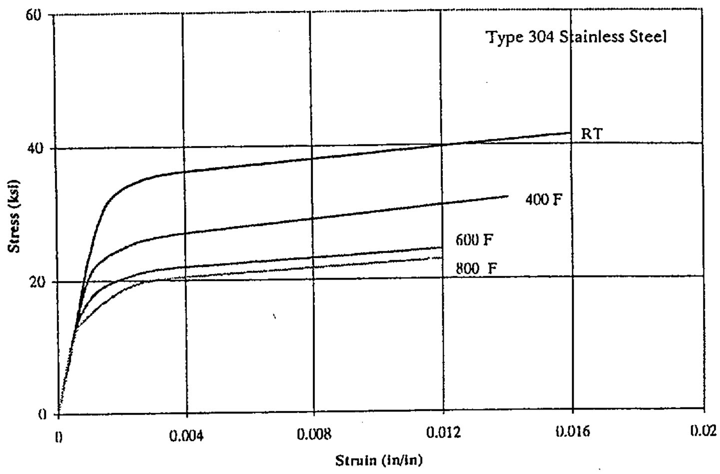


Figure 1: Type 304 Stainless Steel Stress-Strain Curve. (Reference 6)

3.3 Fluid Properties

Figure 2 shows the relationship between pressure and specific volume at a temperature of 240°F (from Reference 8). A polynomial curve fit, which represent the equations of state for the fluid, is also shown. This equation will be used in the determination of fluid pressure during the heat up. The specific volume for the initial conditions (165 psia, 150°F) is $\upsilon = 0.0163343$ ft^3/lb.

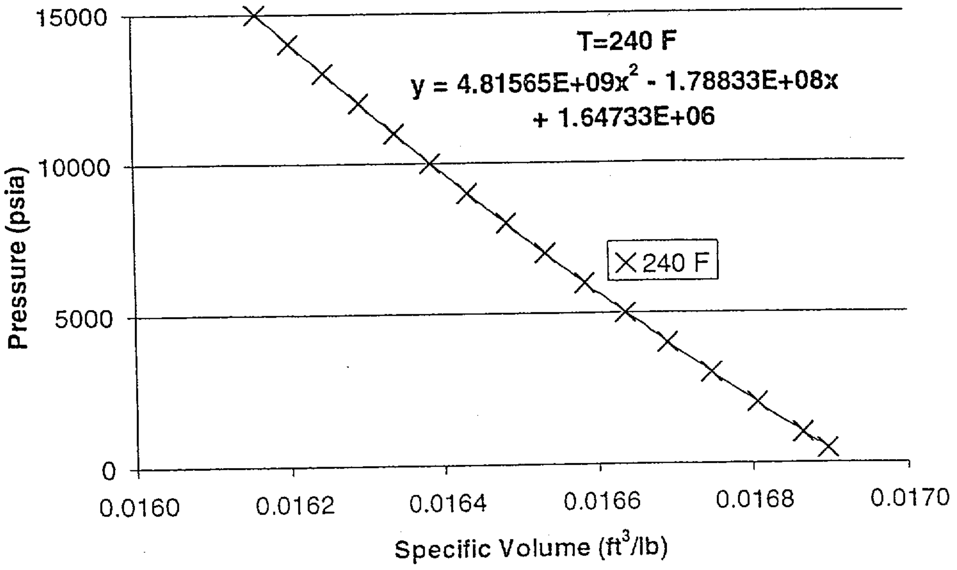


Figure 2: Equation of State for Water at 240°F

3.4 Solution Method and Results

The method of Reference 2 is used to calculate pressure given the inputs in sections 3.2 and 3.3. Attachment A contains a MathCAD program printout showing the equations used and the results. The calculation shows that the pressure reached in CPN-37 at 240°F is 1810 psia (1795 psig).

4.0 REFERENCES

1. D.C. Cook Piping Specification ES-PIPE-1013-QCN-CS3, Revision 1, "Pipe Material Specification: Safety Related."
2. MPR Calculation 025-065-04, "Determination of Water Temperature in D.C. Cook Unit 1 CPN-37," Revision 0.
3. MPR Calculation 025-065-02, "Determination of Peak Pressures in D.C. Cook Unit 1 Piping Segments Isolated by Air Operated Globe Valves," Revision 0.
4. Drawings for Containment Penetration CPN-37:
   - D.C. Cook Drawing No. OP-1-5129A, Revision 28, "CVCS – Reactor Letdown & Charging."
   - D.C. Cook Drawing No. 1-CS-93, Revision 7.
   - D.C. Cook Drawing No. 1-CS-42, Revision 12.
5. Crane Technical Paper No. 410, "Flow of Fluids," 1986.
6. Aerospace Structural Metals Handbook, Volume 2, 1990, Code 1303, Figure 3.03112, Type 304 Stainless Steel.
7. 1989 ASME Code, Section III Division 1- Appendices– Properties.
8. ASME Steam Tables, 6th Edition.

Attachment A
Pressure in CPN-37

PURPOSE:

The purpose of this calculation is to determine the pressure reached in CPN-37 at D.C. Cook, Unit 1 when the pipe heats to 240F.

CALCULATION:

The expected temperature of the water during a LOCA and the ambient temperature are

$T_{LOCA} := 240$ $\quad T_{amb} := 150$ $\quad T_{ambo} := 70$

The mean coefficient of thermal expansion for SA-312 Gr TP304 from 70 to 150 F (Reference 8) is

$\alpha_{To} := 8.67 \cdot 10^{-6}$

And the initial strain due to thermal expansion from 70F to 150 F is

$\varepsilon_{tho} := \alpha_{To} \cdot (T_{amb} - T_{ambo})$ $\quad \varepsilon_{tho} = 6.94 \cdot 10^{-4}$ in/in

The conversion for psi to ksi is

$ksi := 1000\ psi$

For penetration CPN-37, there are three different types of pipes in the system. Geometry and material properties are listed below. Note that the diameters are the cold diameters at 70F. These diameters will be adjusted for thermal expansion to 150 F in the next section.

The first pipe is 4" Sch 10S, pipe specification B-14

$ID_{4B14} := 4.260\ in$ $\quad S_{m4B14} := 20\ ksi$ $\quad E_{4B14} := 27.4 \cdot 10^{6}\ psi$

$t_{4B14} := 0.120\ in$ $\quad S_{y4B14} := 24\ ksi$ $\quad E_{p4B14} := 0.425 \cdot 10^{6}\ psi$

$OD_{4B14} := ID_{4B14} + 2 \cdot t_{4B14}$ $\quad S_{u4B14} := 69\ ksi$ $\quad$ SA-312 Gr TP304

$OD_{4B14} = 4.5\ in$

The second pipe is 1" Sch 40S, pipe specification B-14

$ID_{1B14} := 1.049\ in$ $\quad S_{m1B14} := 20\ ksi$ $\quad E_{1B14} := 27.4 \cdot 10^{6}\ psi$

$t_{1B14} := 0.133\ in$ $\quad S_{y1B14} := 24\ ksi$ $\quad E_{p1B14} := 0.425 \cdot 10^{6}\ psi$

$OD_{1B14} := ID_{1B14} + 2 \cdot t_{1B14}$ $\quad S_{u1B14} := 69\ ksi$ $\quad$ SA-312 Gr TP304

$OD_{1B14} = 1.315\ in$

The third pipe is 4" Sch 40S, pipe specification B-14

$ID_{4B1440} := 4.026\ \text{in}$ $\quad S_{m4B1440} := 20\ \text{ksi}$ $\quad E_{4B1440} := 27.4 \cdot 10^{6}\ \text{psi}$

$t_{4B1440} := 0.237\ \text{in}$ $\quad S_{y4B1440} := 24\ \text{ksi}$ $\quad E_{p4B1440} := 0.425 \cdot 10^{6}\ \text{psi}$

$OD_{4B1440} := ID_{4B1440} + 2 \cdot t_{4B1440}$ $\quad S_{u4B1440} := 69\ \text{ksi}$ $\quad$ SA-312 Gr TP304

$OD_{4B1440} = 4.5 \cdot \text{in}$

Note: Inverse units used in these equations result from MathCad format requirements and do not represent errors.

The lengths of the three different pipes are as follows:

$L_1 := (14\ \text{ft}) \cdot \text{in}^{-1}$ $\quad L_2 := (3\ \text{ft}) \cdot \text{in}^{-1}$ $\quad L_3 := (10\ \text{ft}) \cdot \text{in}^{-1}$

$L_1 = 168$ inches $\quad L_2 = 36$ inches $\quad L_3 = 120$ inches

For the first pipe (4" Sch 10S, B-14), the specific material parameters used in the calculation are

$t_1 := t_{4B14} \cdot \text{in}^{-1}$ $\qquad t_1 = 0.12$ inches

$$r_{01} := \left[\left(\frac{OD_{4B14} \cdot \text{in}^{-1}}{2} \right) - t_1 \right] \cdot \left(1 + \varepsilon_{tho}\right) \qquad r_{01} = 2.131 \text{ inches}$$

$$r_{01\_ini} := \left[\left(\frac{OD_{4B14} \cdot \text{in}^{-1}}{2} \right) - t_1 \right] \qquad r_{01\_ini} = 2.130 \text{ inches}$$

$S_{y1} := S_{y4B14} \cdot \text{psi}^{-1}$ $\qquad S_{y1} = 2.4 \cdot 10^{4}$ psi

$E_1 := E_{4B14} \cdot \text{psi}^{-1}$ $\qquad E_1 = 2.74 \cdot 10^{7}$ psi

$E_{p1} := E_{p4B14} \cdot \text{psi}^{-1}$ $\qquad E_{p1} = 4.25 \cdot 10^{5}$ psi

$$\varepsilon_{y1} := \frac{S_{y1}}{E_1} \qquad \varepsilon_{y1} = 8.759 \cdot 10^{-4} \text{ in/in}$$

$S_{m1} := S_{m4B14}$ $\qquad S_{m1} = 2 \cdot 10^{4} \cdot \text{psi}$

$S_{u1} := S_{u4B14}$ $\qquad S_{u1} = 6.9 \cdot 10^{4} \cdot \text{psi}$

For the second pipe (1" Sch 40S, B-14), the specific material parameters for the calculation are

$t_2 := t_{1B14}\cdot in^{-1}$ $t_2 = 0.133$ inches

$r_{02} := \left[\left(\frac{OD_{1B14}\cdot in^{-1}}{2}\right) - t_2\right]\cdot\left(1+\varepsilon_{tho}\right)$ $r_{02} = 0.525$ inches

$r_{02\_ini} := \left[\left(\frac{OD_{1B14}\cdot in^{-1}}{2}\right) - t_2\right]$ $r_{02\_ini} = 0.524$ inches

$S_{y2} := S_{y1B14}\cdot psi^{-1}$ $S_{y2} = 2.4\cdot 10^{4}$ psi

$E_2 := E_{1B14}\cdot psi^{-1}$ $E_2 = 2.74\cdot 10^{7}$ psi

$E_{p2} := E_{p1B14}\cdot psi^{-1}$ $E_{p2} = 4.25\cdot 10^{5}$ psi

$\varepsilon_{y2} := \frac{S_{y2}}{E_2}$ $\varepsilon_{y2} = 8.759\cdot 10^{-4}$ in/in

$S_{m2} := S_{m1B14}$ $S_{m2} = 2\cdot 10^{4}\cdot psi$

$S_{u2} := S_{u1B14}$ $S_{u2} = 6.9\cdot 10^{4}\cdot psi$

For the third pipe (4" Sch 40S, B-14), the specific material parameters used in the calculation are

$t_3 := t_{4B1440}\cdot in^{-1}$ $t_3 = 0.237$ inches

$r_{03} := \left[\left(\frac{OD_{4B1440}\cdot in^{-1}}{2}\right) - t_3\right]\cdot\left(1+\varepsilon_{tho}\right)$ $r_{03} = 2.014$ inches

$r_{03\_ini} := \left[\left(\frac{OD_{4B1440}\cdot in^{-1}}{2}\right) - t_3\right]$ $r_{03\_ini} = 2.013$ inches

$S_{y3} := S_{y4B1440}\cdot psi^{-1}$ $S_{y3} = 2.4\cdot 10^{4}$ psi

$E_3 := E_{4B1440}\cdot psi^{-1}$ $E_3 = 2.7\cdot 10^{7}$ psi

$E_{p3} := E_{p4B1440}\cdot psi^{-1}$ $E_{p3} = 4.25\cdot 10^{5}$ psi

$\varepsilon_{y3} := \frac{S_{y3}}{E_3}$ $\varepsilon_{y3} = 8.759\cdot 10^{-4}$ in/in

$S_{m3} := S_{m4B1440}$ $S_{m3} = 2\cdot 10^{4}\cdot psi$

$S_{u3} := S_{u4B14}$ $S_{u3} = 6.9\cdot 10^{4}\cdot psi$

At 150 F 165 psia, the water has a specific volume

$$v_{initial} = 0.0163343\ ft^3 \cdot lb^{-1}$$

Therefore, the mass of water in a unit length (1 inch) of pipe is

$$m_{w1i} := \frac{\pi \cdot r_{01}^{2} \cdot 1}{\left(v_{initial} \cdot lb \cdot in^{-3}\right)} \qquad m_{w1i} = 0.506$$ lb per unit length (4" Sch 10S)

$$m_{w2i} := \frac{\pi \cdot r_{02}^{2} \cdot 1}{\left(v_{initial} \cdot lb \cdot in^{-3}\right)} \qquad m_{w2i} = 0.031$$ lb per unit length (1" Sch 40S)

$$m_{w3i} := \frac{\pi \cdot r_{03}^{2} \cdot 1}{\left(v_{initial} \cdot lb \cdot in^{-3}\right)} \qquad m_{w3i} = 0.452$$ lb per unit length (4" Sch 40S)

The mean coefficient of thermal expansion for SA-312 Gr TP304 from 70 to 240 F is

$$\alpha_T := 8.88 \cdot 10^{-6}$$

And the strain due to thermal expansion is

$$\varepsilon_{th} := \alpha_T \cdot \left(T_{LOCA} - T_{ambo}\right) \qquad \varepsilon_{th} = 1.51 \cdot 10^{-3}$$ in/in

The total mass of the water in the piping, assuming that the pipe is filled, is

$$m_{tot} := \left(m_{w1i} \cdot L_1 + m_{w2i} \cdot L_2 + m_{w3i} \cdot L_3\right) \cdot \left(1 + \varepsilon_{tho}\right) \qquad m_{tot} = 140$$ lb

To solve the equations for the system with both pipe sizes, we must guess initial values for the variables.

$P := 3000$

$v := 0.016$

$\varepsilon_{p1} := 0.01$

$\varepsilon_{p2} := 0.01$

$\varepsilon_{p3} := 0.01$

$vol_1 := 1$

$vol_2 := 1$

$vol_3 := 1$

$\sigma_{h1} := 100$

$\sigma_{h2} := 100$

$\sigma_{h3} := 100$

$r_1 := 1.0$

$r_2 := 1.0$

$r_3 := 1.0$

$m_{w1} := 1$

$m_{w2} := 1$

$m_{w3} := 1$

Assign a function to represent the change from elastic strain to plastic strain as follows:

$$f_1(\sigma_{h1}, S_{y1}, E_1, E_{p1}, \varepsilon_{y1}) := \text{if}\left(\sigma_{h1} > S_{y1}, \frac{\sigma_{h1} - S_{y1}}{E_{p1}} + \varepsilon_{y1}, \frac{\sigma_{h1}}{E_1}\right)$$

$$f_2(\sigma_{h2}, S_{y2}, E_2, E_{p2}, \varepsilon_{y2}) := \text{if}\left(\sigma_{h2} > S_{y2}, \frac{\sigma_{h2} - S_{y2}}{E_{p2}} + \varepsilon_{y2}, \frac{\sigma_{h2}}{E_2}\right)$$

$$f_3(\sigma_{h3}, S_{y3}, E_3, E_{p3}, \varepsilon_{y3}) := \text{if}\left(\sigma_{h3} > S_{y3}, \frac{\sigma_{h3} - S_{y3}}{E_{p3}} + \varepsilon_{y3}, \frac{\sigma_{h3}}{E_3}\right)$$

Given

$$r_1 = (1 + \varepsilon_{p1}) \cdot r_{01\_ini}(1 + \varepsilon_{th}) \qquad r_2 = (1 + \varepsilon_{p2}) \cdot r_{02\_ini}(1 + \varepsilon_{th}) \qquad r_3 = (1 + \varepsilon_{p3}) \cdot r_{03\_ini}(1 + \varepsilon_{th})$$

$$vol_1 = \frac{\pi \cdot {r_1}^2 \cdot (1 + \varepsilon_{th}) \cdot L_1}{(12^3)} \qquad vol_2 = \frac{\pi \cdot {r_2}^2 \cdot (1 + \varepsilon_{th}) \cdot L_2}{(12^3)} \qquad vol_3 = \frac{\pi \cdot {r_3}^2 \cdot (1 + \varepsilon_{th}) \cdot L_3}{(12^3)}$$

$$v = \frac{vol_1}{m_{w1}} \qquad v = \frac{vol_2}{m_{w2}} \qquad v = \frac{vol_3}{m_{w3}}$$

$$P = (4.81565 \cdot 10^9) \cdot v^2 - (1.78833 \cdot 10^8) \cdot v + 1.64733 \cdot 10^6 \qquad m_{tot} = m_{w1} + m_{w2} + m_{w3}$$

$$\sigma_{h1} = P \cdot \frac{r_1}{t_1} \qquad \sigma_{h2} = P \cdot \frac{r_2}{t_2} \qquad \sigma_{h3} = P \cdot \frac{r_3}{t_3}$$

$$\varepsilon_{p1} = f_1(\sigma_{h1}, S_{y1}, E_1, E_{p1}, \varepsilon_{y1}) \qquad \varepsilon_{p2} = f_2(\sigma_{h2}, S_{y2}, E_2, E_{p2}, \varepsilon_{y2}) \qquad \varepsilon_{p3} = f_3(\sigma_{h3}, S_{y3}, E_3, E_{p3}, \varepsilon_{y3})$$

Solving the equations.

$AA := \mathrm{Find}(r_1, r_2, r_3, \varepsilon_{p1}, \varepsilon_{p2}, \varepsilon_{p3}, vol_1, vol_2, vol_3, v, P, \sigma_{h1}, \sigma_{h2}, \sigma_{h3}, m_{w1}, m_{w2}, m_{w3})$

$r_1 := AA_{0,0} \cdot in$ $\quad r_1 = 2.18 \cdot in$

$r_2 := AA_{1,0} \cdot in$ $\quad r_2 = 0.53 \cdot in$

$r_3 := AA_{2,0} \cdot in$ $\quad r_3 = 2.02 \cdot in$

$\varepsilon_{p1} := AA_{3,0}$ $\quad \varepsilon_{p1} = 2.1741 \cdot \%$

$\varepsilon_{p2} := AA_{4,0}$ $\quad \varepsilon_{p2} = 0.02609 \cdot \%$

$\varepsilon_{p3} := AA_{5,0}$ $\quad \varepsilon_{p3} = 0.05621 \cdot \%$

$vol_1 := AA_{6,0} \cdot ft^3$ $\quad vol_1 = 1.45 \cdot ft^3$

$vol_2 := AA_{7,0} \cdot ft^3$ $\quad vol_2 = 0.02 \cdot ft^3$

$vol_3 := AA_{8,0} \cdot ft^3$ $\quad vol_3 = 0.89 \cdot ft^3$

$v := AA_{9,0} \cdot ft^3 \cdot lb^{-1}$ $\quad v = 0.016817 \cdot ft^3 \cdot lb^{-1}$

$P := AA_{10,0} \cdot psi$ $\quad P = 1.81 \cdot 10^3 \cdot psi$ (psia)

$\sigma_{h1} := AA_{11,0} \cdot psi$ $\quad \sigma_{h1} = 33 \cdot ksi$

$\sigma_{h2} := AA_{12,0} \cdot psi$ $\quad \sigma_{h2} = 7 \cdot ksi$

$\sigma_{h3} := AA_{13,0} \cdot psi$ $\quad \sigma_{h3} = 15 \cdot ksi$

$m_{w1} := AA_{14,0} \cdot lb$ $\quad m_{w1} = 86 \cdot lb$

$m_{w2} := AA_{15,0} \cdot lb$ $\quad m_{w2} = 1 \cdot lb$

$m_{w3} := AA_{16,0} \cdot lb$ $\quad m_{w3} = 53 \cdot lb$

AA =

	0
0	2.18
1	0.53
2	2.02
3	0.02
4	0
5	0
6	1.45
7	0.02
8	0.89
9	0.02
10	1809.57
11	32867.64
12	7148.86
13	15401.71
14	86.41
15	1.08

ATTACHMENT 5 TO C0801-05

MPR CALCULATION 025-065-01

"DETERMINATION OF PEAK PRESSURES IN D. C. COOK UNIT 1 PIPING SEGMENTS ISOLATED BY AIR OPERATED DIAPHRAGM VALVES"

MPR

MPR-2169 Appendix A.1

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

CALCULATION TITLE PAGE

Client American Electric Power	Page 1 of 20
Project Evaluation of D.C. Cook Unit 1 Piping Segments for Potential Thermal Overpressurization	Task No. 025-0013-065-0
Title Determination of Peak Pressures in D.C. Cook Unit 1 Piping Segments Isolated by Air Operated Diaphragm Valves	Calculation No. 025-065-01

Preparer/Date	Checker/Date	Reviewer/Approver/Date	Rev. No.
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QUALITY ASSURANCE DOCUMENT

This document has been prepared, checked and reviewed/approved in accordance with the Quality Assurance requirements of 10CFR50, Appendix B, as specified in the MPR Quality Assurance Manual.

RECORD OF REVISIONS

Calculation No.	Prepared By	Checked By	
025-065-01			Page 2

Revision	Description
0	Original Issue.

CONTENTS

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025-065-01			

1.0 PURPOSE

The purpose of this calculation is to determine the peak pressures that can be obtained in piping segments susceptible to thermal overpressurization that are isolated by air operated diaphragm valves at the D. C. Cook Nuclear Power Station, Unit 1. The pressures determined in this calculation are used in a separate stress analysis of the piping segments. The piping segments isolated by diaphragm valves are listed in Table 1 of Section 2 of this calculation.

The maximum pressure is taken as the pressure at which the air operated diaphragm valves installed in the segments will open. This calculation also demonstrates that the diaphragm integrity is maintained up to this opening pressure.

2.0 SUMMARY

The segment pressures required to begin to open the diaphragm valves in each system are in Table 1.

Table 1. Segment Pressures Required to Open Air Operated Diaphragm

System	NESW			PW	DEMIN	WDS	SDCON
CPN	Multiple	Multiple	Multiple	33	36	40	41
Valve Size	2”	3”	6”	3”	2”	4”	3”
Line Pressure to Begin to Open (psig), $p_{segment,o}$	325	711	215	212	325	262	212

The EPDM diaphragms will remain intact at these pressures. The diaphragm elongation is limited to 90% by the compressor and finger plate. EPDM will not rupture until it reaches 500% elongation.

These pressure results will be used in separate evaluations for the pipe and valves in these segments.

3.0 CALCULATION

This calculation will be performed in the following steps:

- Determination of the types and configuration of valves installed in Cook Unit 1 piping segments of interest (Section 3.1).
- Calculation of the water pressure inside the piping segments that would be required to force open a closed diaphragm valve (Section 3.2).
- Demonstration that diaphragms can withstand the calculated segment pressure (Section 3).

3.1 Diaphragm Valves Installed in Piping Segments at Cook Unit 1

Each of the segments considered in this calculation is isolated using air operated diaphragm valves. These valves are air to open, spring to close valves provided by Grinnell (now ITT Engineered Valves).

The valves installed in each segment are listed in Table 2, along with configuration information. Configuration information was assumed based on information available from plant records. To verify this information, a walkdown was performed for these valves, and data obtained was compared to data from plant records and from the vendor. Walkdown data was documented in Reference 10. The discussion below shows how diaphragm valve model information was validated by results of the walkdown.

NESW Instrument Room CVU Valves 1-WCR-960 through 1-WCR-967

Plant records indicate that ITT Grinnell Valve Company Drawing SD-C-109700 applies to these valves. Key information from this drawing includes the following:

Valves are 2"
Actuator = 3250L Air Motor
Actuator diameter = 14.5" at outer edge
Spring number 97 is installed

This corresponds to a Series 3253 valve in the ITT Industries, Dia-Flo valve catalog (Reference 6). Dimensional information for that catalog item matches data recorded during the walkdown (specifically actuator circumference, actuator housing height, and presence of tie rods holding the actuator housing to upper cover). Further, these valves are operated off the 50 psi control air header per control air header drawing OP-1-5120J (Reference 11); per the ITT catalog, the air pressure required to operate the 3253 series valve is 30 psi.

Accordingly, the walkdown information confirmed that these valves are as shown in drawing SD-C-109700 and therefore have the #97 spring installed.

NESW Upper CVU Valves 1-WCR-920 through 1-WCR-935

Plant records indicate that ITT Grinnell Valve Company Drawing SD-C-109701 applies to these valves. Key information from this drawing includes the following:

Valves are 3"
Actuator = 32101 Air Motor
Actuator diameter = 17-1/8" at outer edge
Spring number 130 is installed

Walkdown data showed that each valve has a Grinnell Air Motor Number 101. This corresponds to a Series 32108 valve in the ITT Industries, Dia-Flo valve catalog (Reference 6). Dimensional information for that catalog item matches data recorded during the walkdown (specifically actuator circumference and actuator housing height). Further, only the Series 32108 with 101 air motor has a housing height on the order of 24".

Accordingly, the walkdown information confirmed that these valves are as shown in drawing SD-C-109701 and therefore have the #130 spring installed.

NESW RCP Air Motor Cooler CVU Valves 1-WCR-941 through 1-WCR-958

Same as above. Valves are as shown in drawing SD-C-109701 and have the #130 spring installed.

NESW Lower CVU Valves 1-WCR-900 through 1-WCR-915

Plant records indicate that ITT Grinnell Valve Company Drawing SD-C-109702 applies to these valves. Key information from this drawing includes the following:

Valves are 6"
Actuator = 32130 Air Motor
Actuator diameter = 19" at outer edge
Spring number 130 is installed

Walkdown data showed that each valve has a Grinnell Air Motor Number 130. This corresponds to a Series 32138 valve in the ITT Industries, Dia-Flo valve catalog (Reference 6). Dimensional information for that catalog item matches data recorded during the walkdown (specifically actuator circumference and actuator housing height). Further, only the Series 32138 with 130 air motor has a housing height on the order of 24".

Accordingly, the walkdown information confirmed that these valves are as shown in drawing SD-C-109702 and therefore have the #130 spring installed.

Valves 1-NRV-251, 1-DCR-600 and 1-DCR-601

Plant records indicate that Drawing WAPD-CV-SS-8R Revision 3 applies to these valves. Key information from this drawing includes the following:

Valves are 3", Item Number 3DA42R
Actuator = 3250 Air Motor
Actuator diameter = 14.5" at outer edge
Spring number 96 and 97 are installed

This corresponds to a Series 3255 valve in the ITT Industries, Dia-Flo valve catalog (Reference 6). Dimensional information for that catalog item matches data recorded during the walkdown (specifically actuator circumference and actuator housing height). Further, the walkdown found tags on each valve that indicated the valves are model 3DA42R and contain springs #96 and #97, with spring rates of 236 and 135 pounds per inch, respectively.

Accordingly, the walkdown information confirmed that these valves are as shown in drawing WAPD-CV-SS-8R and therefore have the #96 and #97 springs installed.

Valves 1-QCR-919 and 1-QCR-920

Walkdown data showed that these valves have the same dimensions as the valves shown in ITT Grinnell Valve Company Drawing SD-C-109700. Key information from this drawing includes the following:

Valves are 2"
Actuator = 3250L Air Motor
Actuator diameter = 14.5" at outer edge
Spring number 97 is installed
Air pressure to open = 35 psig

This corresponds to a Series 3253 valve in the ITT Industries, Dia-Flo valve catalog (Reference 6). Dimensional information for that catalog item matches data recorded during the walkdown (specifically actuator circumference, actuator housing height, and presence of tie rods holding the actuator housing to upper cover). Further, the drawing shows that the air pressure to open these is 35 psig, which is comparable to the air pressure required to operate the 3253 series valve of 30 psi, per the Reference 6 vendor catalog. Further, it is noted that these valves are operated off the 50 psi control air header per control air header drawing 1-OP-5120J (Reference 11).

Accordingly, the walkdown information concluded that these valves are as shown in drawing SD-C-109700 and therefore have the #97 spring installed.

Valves 1-DCR-205, 1-DCR-206 and 1-DRV-001

Plant records indicate that Drawing WAPD-CV-SS-9R Revision 3 applies to these valves. Key information from this drawing includes the following:

Valves are 4", Item Number 4DA42R
Actuator = 32100 Air Motor
Actuator diameter = 16-11/16" at outer edge
Spring number 96 and 98 are installed

During the walkdown tags were found on the valves indicating these were item 4DA42R. In addition, the spring rates for these valves were found by inspection of stamped markings on the actuator housings. Specifically, the spring rates stamped were 236 pounds per inch for the #96 spring and 342 pounds per inch for the #98 spring.

Accordingly, the walkdown information confirmed that these valves are as shown in drawing WAPD-CV-SS-9R and therefore have the #96 and #98 springs installed.

3.2 Calculation of Segment Pressure Required to Open Diaphragm Valves

During thermal overpressurization incidents (such as might occur when segments are isolated during pipe breaks in containment), water pressure will build in the isolated segment until the force on the diaphragm overcomes the spring force holding the valve closed. At this point the valve will begin to open, and relieve the trapped water.

This calculation will determine the segment water pressure which would be required to overcome the spring force and hence permit the trapped water to escape through the opened valve. To ensure the trapped water can escape the volume, the calculation will determine the system pressure needed to open the valve 10 percent of its full stroke. A check will be made to ensure that pressure can be relieved at this opening position. The method used is as follows:

1) During normal operation, air pressure acting on the actuator plate is sufficient to compress the spring and force the actuator plate up. The actuator pulls the stem and diaphragm up, thus permitting flow of water through the valve. The force required to fully open the valve ($F_{open,full}$)is equal to the air pressure required to fully open the valve (p_a) times the effective actuator area (A_a):

$$F_{open,full} = p_a\ A_a$$

2) Opening the valve to its full open position requires compressing the actuator spring(s) by an amount equal to the valve stroke. The spring force required to fully open the valve ($\Delta F_{spring,full}$) is calculated by multiplying the spring constant (k_{spring}) by the stem travel (Δh_{stem}) as follows:

$$\Delta F_{spring,full} = k_{spring}\ \Delta h_{stem}$$

3) The spring force required to begin to open a valve (F_o) is the force required to fully open the valve minus the change in the spring force from closed to full stroke,

$$F_o = F_{open,full} - \Delta F_{spring,full}$$

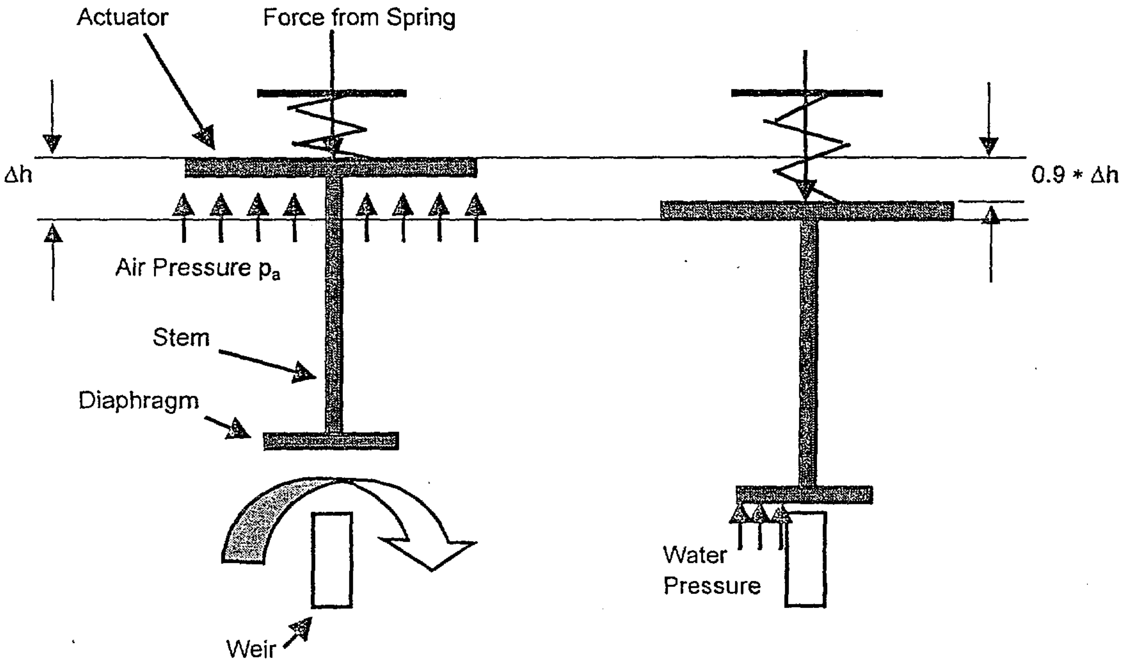
4) The spring force required to open the valve an additional 10 percent is equal to the opening force plus the force required to compress the spring by 10 percent of the valve stroke:

$$F_{10\%} = F_o + (0.1)\,k\ \Delta h_{stem}$$

Combining the above equations gives:

$$F_{10\%} = (p_a\ A_a) - 0.9\ \Delta h_{stem}\ k_{spring}$$

This is shown in Figure 1 below.



Valve Open Due to Air Pressure p_a

Valve Open 10% Due to Segment Pressure

Force from spring = $p_a A_a$

Force from spring = $(p_a A_a) - 0.9 (\Delta h) k_{spring}$

Figure 1. Force Applied by Spring on Actuator

5) The segment water pressure required to open the valve by 10% when there is no air supplied to the motor ($p_{segment}$) is:

$$p_{segment} = \frac{F_{10\%}}{A_{segment}}$$

where $A_{segment}$ is the effective area of the diaphragm that the water acts upon, equal to one half of the diaphragm area minus half the area in contact with the weir,

$$A_{segment} = \frac{1}{2}\left[\frac{\pi}{4} d_d^{\ 2} - w_w\, d_w\right]$$

where d_d = diaphragm diameter, w_w = weir width and d_w = weir length.

6) Table 3 lists this information for the valves installed in the piping segments considered in this calculation.

Using the information in Table 3 and the equations listed previously, opening pressure can be calculated for each valve. Results of this calculation are shown in Table 4.

Note that in every case the segment pressure required to open the valves by 10 percent is in excess of 200 psig. Reference 6, page 70 shows that the flow coefficient Cv for 2" to 6" ITT weir valves ranges from 12 to 105. Assuming the minimum Cv value, the flow through these valves at 200 psig pressure differential is calculated using the method of Reference 6:

$$\text{Actual flow} = Cv * (\Delta P/sg)^{1/2} = 12 * (200 / 1.0)^{1/2} = 170 \text{ gpm}$$

where "sg" = the specific gravity of water (1.0).

Since only a small volume of water (on the order of several gallons maximum) must be discharged to reduce the pressure in the trapped piping segments, this flow rate is sufficient to relieve the pressure in the segment.

Table 2. List of Air Operated Diaphragm Valves in Segments Considered

Segment	**NESW**			**PW**	**DEMIN**	**WDS**	**SDCON**
CPN	Multiple	Multiple	Multiple	33	36	40	41
Valve Size	2"	3"	6"	3"	2"	4"	3"
Diaphragm Valve Tag Numbers	1-WCR-960 to 1-WCR-967	1-WCR-920 to 1-WCR-935 1-WCR-941 to 1-WCR–948 1-WCR-951 to 1-WCR–958	1-WCR-900 to 1-WCR-915	1-NRV-251	1-QCR-919 1-QCR-920	1-DCR-205 1-DCR-206 1-DRV-001	1-DCR-600 1-DCR-601
Vendor Drawing	SD-C-109700	SD-C-109701	SD-C-109702	WAPD-CV-SS-8R	SD-C-109700	WAPD-CV-SS-9R	WAPD-CV-SS-8R
Type of Actuator	3250L	32101	32130	3250	3250L	32100 (Note 2)	3250
Spring(s) Installed	#97	#130	#130	#96 & #97	#97	#96 & #98	#96 & #97

1. Valve drawing numbers and springs were determined based on walkdown data as described in Section 4 of this calculation. Drawings are listed in Reference 1.

2. Drawing indicates a "32100" motor, with a 16-11/16" diameter actuator flange. The ITT model 32101 has a slightly larger actuator of 17.12" (see Reference 6, pages 96-97) , with an effective actuator area of 100 square inches. This calculation assumes that the effective actuator area for the 32100 actuator is the same as the 32101 actuator.

Table 3. Valve Data Used to Calculate Opening Pressure

System	NESW			PW	DEMIN	WDS	SDCON
CPN	Multiple	Multiple	Multiple	33	36	40	41
Valve Size	2”	3”	6”	3”	2”	4”	3”
Actuator	3250L	32101	32130	3250	Same as 2” NESW valve.	32100	Same as 3” PW valve.
Air Required at Full Stroke (psig), p_a (1)	35	90	75	58		55	
Effective Actuator Area (in.), A_a (2)	50	100	130	50		100	
Springs(3)	#97	#130	#130	#96 & #97		#96 & #98	
Total Spring Rate (lbf/in.), k_{spring} (4)	135	740	740	371		578	
Full Stroke Stem Travel (in.), Δh_{stem} (2)	1.125	1.625	3.125	1.625		2.125	
Diaphragm Diameter (in.), d_d (5)	3.6875	5.5	9.812	5.5		6.81	
Weir Width at Peak (in.), w_w (6)	0.25	0.31	0.50	0.31		0.50	
Weir Depth (in.), d_w (6)	3.0	4.76	8.5	4.76		5.76	

References are as follows:

(1) Air required – Reference 1 drawings. Note that these values are maximum pressures which the vendor recommended will be needed to fully open the valves; valves will begin opening at lower pressures and be fully open at this (or lower) pressure.

(2) Actuator area and full stroke – Reference 2, pages 9 and 6, respectively

(3) Springs – See Table 2

(4) Total Spring Rate – From Section 4 for CPN-33 and CPN-40; Reference 3 for others (sum if more than one spring)

(5) Diaphragm diameter – Reference 4 drawings

(6) Weir width and depth – Reference 5 drawings

Table 4. Calculated Opening Pressures

System	NESW			PW	DEMIN	WDS	SDCON
CPN	Multiple	Multiple	Multiple	33	36	40	41
Valve Size	2”	3”	6”	3”	2”	4”	3”
Force to Open Fully (lbf), $F_{open,full}$	1,750	9,000	9,750	2,900	Same as 2” NESW valve.	5,500	Same as 3” PW valve.
Spring Force (lbf), $\Delta F_{spring,full}$	152	1,203	2,313	603		1,228	
Force to Begin to Open (lbf), F_o	1,598	7,798	7,438	2,297		4,272	
Force to Open by 10% (lbf), $F_{10\%}$	1,613	7,918	7,669	2,357		4,395	
Effective Area of Diaphragm (in^2), $A_{segment}$	4.96	11.14	35.68	11.14		16.77	
Line Pressure to Open by 10% (psig), $p_{segment,o}$	325	711	215	212		262	

3.3 Ability of Diaphragm to Withstand Pressure

For each valve the diaphragm is supported by a compressor. This section will consider the ability of the diaphragm in a closed valve to withstand the calculated pressures.

Based on the results in Section 3.2, the three inch valve experiences the highest pressure. This calculation will address the ability of this size valve to withstand pressure. Larger valves experience lower pressures and so will not be limiting.

When the valve is closed the diaphragm is supported in part by the compressor. The portion of the diaphragm not supported will stretch under pressure at most until it lays along the boundary created by the compressor and the finger plate.

The elongation of the diaphragm is evaluated by looking at the length of a diaphragm before and after pressure loading. Prior to loading, the 3" diaphragm is in an unstretched state since the distance along the diaphragm between the flange and the lower portion of the compressor is very nearly equal to the distance between the flange and the top of the weir (see Figure 2 below; valve and diaphragm dimensions from References 4 and 5). In addition, the radius of curvature of the diaphragm is larger than the radius of curvature of the compressor finger (compare references 4 and 7). Figure 2a shows the original shape of a cross section of the diaphragm, compressor and finger plate in the unloaded condition.

Figure 2b shows the maximum possible deformation of the diaphragm under pressure. The diaphragm will not protrude between the small 0.36" gap between the compressor and the finger plate since the diaphragm thickness is 0.3" (more than half the gap width). A calculation of the diaphragm length before and after deformation is provided below.

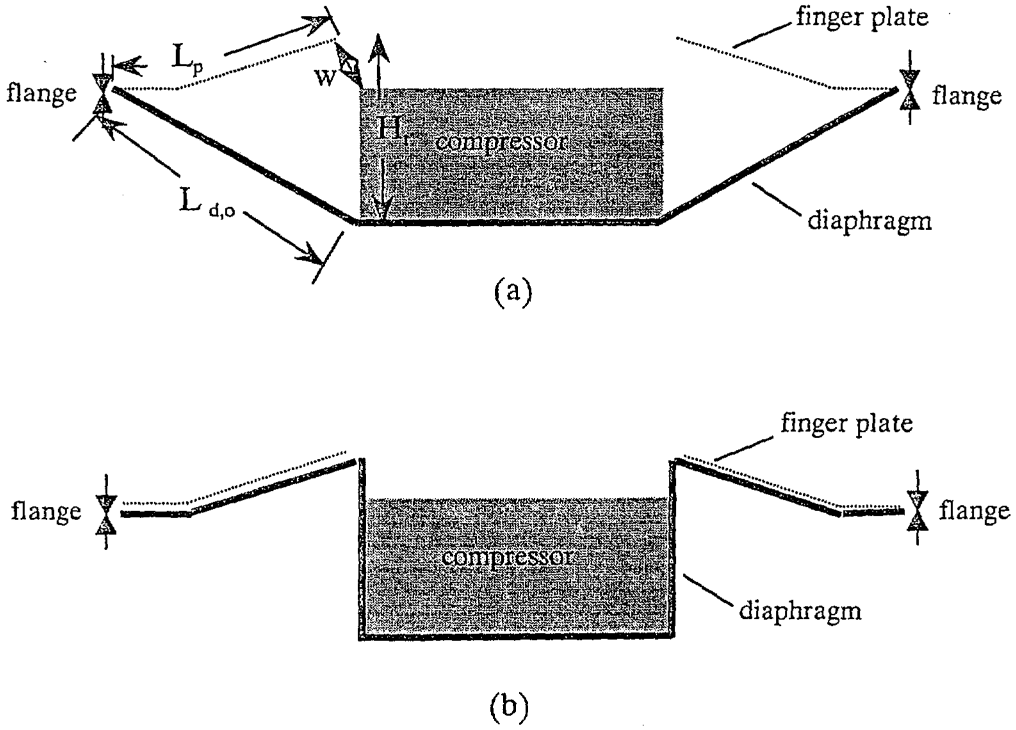
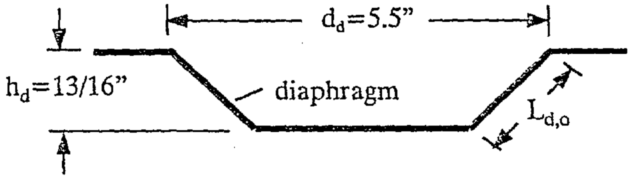
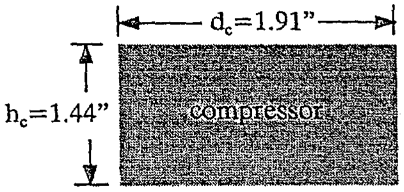


Figure 2. Diaphragm Geometry, (a) undeformed (b) deformed

The original depths and heights of the diaphragm and compressor are,

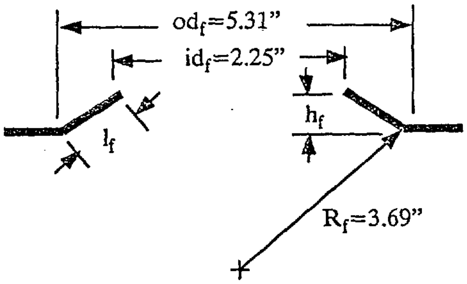




The original length of the diaphragm prior to deformation is,

$$L_{d,o} = \sqrt{\left(\frac{d_d}{2} - \frac{d_c}{2}\right)^2 + (h_d)^2} = \sqrt{\left(\frac{5.5}{2} - \frac{1.91}{2}\right)^2 + \left(\frac{13}{16}\right)^2} = 1.97 \text{ in.}$$

The finger plate dimensions are,



The height of a finger is,

$$h_f = \sqrt{R_f^2 - \left(\frac{id_f}{2}\right)^2} - \sqrt{R_f^2 - \left(\frac{od_f}{2}\right)^2} = \sqrt{3.69^2 - \left(\frac{2.25}{2}\right)^2} - \sqrt{3.69^2 - \left(\frac{5.31}{2}\right)^2} = 0.95\text{ in.}$$

The total height from the bottom of the compressor to the fingers, H_t in Figure 1a, is,

$$H_t = h_d + h_f = 1.76"$$

The diameter of the finger plate is less than the diameter of the diaphragm. The length of the finger plate that extends over the diaphragm is the length of the horizontal extension, $l_{p,h}$, plus the length of a finger, l_f. The horizontal length of the finger plate that extends over the diaphragm is

$$l_{p,h} = 0.5\ (d_d - od_f) = 0.1"$$

The length of a finger is,

$$l_f = \sqrt{\left(\frac{od_f}{2} - \frac{id_f}{2}\right)^2 + h_f^2} = \sqrt{\left(\frac{5.31}{2} - \frac{2.25}{2}\right)^2 + 0.95^2} = 1.8\text{ in.}$$

Thus, the total length of the finger plate that will contact the diaphragm is

$$L_p = l_{p,h} + l_f = 1.9"$$

The final deformed length of the diaphragm chord, $L_{d,f}$, is equal to the sum of the length of the finger plate and the height to the finger plate,

$$L_{d,f} = L_p + H_c = 3.66"$$

A summary of the original length of the diaphragm, the length of the finger plate, the height to the finger plate and the deformed diaphragm length is presented in Table 5. Based on these dimensions, the elongation of the diaphragm chord is

$$\text{Elongation} = (L_{d,f} - L_{d,o}) / L_{d,o} * 100\% = 86\%$$

The diaphragm material in the three-inch diaphragm valve is EPDM. According to Reference 9, the elongation of reinforced EPDM at break is 500%. Since the diaphragm only elongates 86%, the diaphragm should not rupture even at high pressures.

Table 5. Diaphragm Elongation

Parameter	**Value**
Original Length of Diaphragm Chord, $L_{d,o}$, in.	1.97
Length of Finger Plate, L_p, in.	1.90
Height to Finger Plate, H_c, in.	1.76
Deformed Length of Diaphragm Chord, $L_{d,f}$, in.	3.66
Percent Chord Elongation	86%

Note that there is a small gap, w, between the top of the finger plate and the top of the compressor. The length of the gap, w, between the top of the compressor and the top of the finger plate is,

$$w = \sqrt{\left(\frac{id_f - d_c}{2}\right)^2 + (H_t - h_c)^2} = \sqrt{\left(\frac{2.25 - 1.91}{2}\right)^2 + (1.76 - 1.44)^2} = 0.36\,\text{in.}$$

The diaphragm is not expected to protrude through this gap since the diaphragm thickness is 0.36".

4.0 REFERENCES

1. ITT Engineered Valves Drawings
   - Drawing Number SD-C-109700, 2" Nuclear Diaphragm Valve w/ 3250L Air Motor
   - Drawing Number SD-C-109701, 3" Nuclear Diaphragm Valve w/ 32101 Air Motor
   - Drawing Number SD-C-109702, 6" Nuclear Diaphragm Valve w/ 32130 Air Motor
   - Drawing Number WAPD-CV-SS-8R Rev. 3, 3" Grinnell Air Motor Diaphragm Valve 3250
   - Drawing Number WAPD-CV-SS-9R Rev. 3, 4" Grinnell Air Motor Diaphragm Valve 32100

2. Vendor Technical Manual VTM-ITEV-0002, VTD-ITEV-0009, Revision 1.

3. ITT Industries Drawing 117346, Revision B, Spring Specification Sheet.

4. ITT Industries Drawings for Diaphragms:
   - Drawing Number 3958 Rev. L, Diaphragm Weir 2.000
   - Drawing Number 3072 Rev. L, Diaphragm Weir 3.000
   - Drawing Number 3073 Rev. L, Diaphragm Weir 4.000
   - Diaphragm Weirs Drawing (undated)

5. ITT Industries Drawings for Weirs:
   - Drawing Number 103567 Rev. F, Body, Weir 02.00 Butt Weld End (pipe) Code, Non Code and Commercial
   - Drawing Number 100730 Rev. G, Body, Weir 03.00 Butt Weld End (pipe) Code, Non Code and Commercial
   - Drawing Number 1014177 Rev. C, Body, Weir 04.00 Butt Weld End (pipe) Code, Non Code and Commercial
   - Drawing Number 106666 Rev. E, Body, Weir 06.00 Butt Weld End (pipe) Code, Non Code and Commercial

6. "DIA FLO® Industrial Diaphragm Valves, Technical Manual and Service Guide" ITT Industries, 1999.

7. ITT Industries Drawing for Compressor:
   - Drawing Number 139 Rev. F, Compressor Weir 03.00

8. ITT Industries Drawing for Finger Plate:
   - Drawing Number 101034 Rev. G, Plate-Finger Weir 03.00

9. Freakley, P.K. and A.R. Payne, "Theory and Practice of Engineering with Rubber," Applied Science Publishers, London, 1978.

10. AEP Design Input Transmittal Number DIT B-01518-00.

11. AEP Drawing OP-1-5120J, Rev. 0, “Flow Diagram, 50# Control Air System Header, Auxiliary System Plan View, Unit #1.”

ATTACHMENT 6 TO C0801-05

MPR CALCULATION 025-065-06

"PIPING STRESS SUMMARY CALCULATION FOR OVERPRESSURIZATION IN D. C. COOK UNIT 1 PIPING SEGMENTS"

MPR-2169 Appendix A.6

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CALCULATION TITLE PAGE

Client American Electric Power	Page 1 of 38
Project Evaluation of D.C. Cook Unit 1 Piping Segments for Potential Thermal Overpressurization	Task No. 025-0013-065-0
Title Piping Stress Summary Calculation for Overpressurization in D.C. Cook Unit 1 Piping Segments	Calculation No. 025-065-06

Preparer/Date	Checker/Date	Reviewer/Approver/Date	Rev. No.
R C 9/8/00	9/8/00	9/8/00	0

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This document has been prepared, checked and reviewed/approved in accordance with the Quality Assurance requirements of 10CFR50, Appendix B, as specified in the MPR Quality Assurance Manual.

RECORD OF REVISIONS

Calculation No.	Prepared By	Checked By	Page 2
025-065-06			

Revision	Description
0	Original Issue.

CONTENTS

1.0 PURPOSE

This calculation summarizes Generic Letter 96-06 thermal overpressurization piping stress evaluations for 24 piping segments located partially or completely within the containment building at D. C. Cook Unit 1. The segments are listed in Section 2.

2.0 RESULTS

Table 1 on the next page summarizes the results of this calculation. In brief, the results are as follows:

- Internal pressures and piping stresses in the following segments **are acceptable per the plant design basis** for conditions that would occur during thermal overpressurization:

– NESW Cooling for Upper Containment Ventilation Units (4 segments)	Multiple CPNs
– NESW Cooling for RCP Motor air Coolers (4 segments)	Multiple CPNs
– NESW Cooling for Instrumentation Room Ventilation Units (2 segments)	Multiple CPNs
– NESW Cooling for Lower Containment Ventilation Units (4 segments)	Multiple CPNs

- Piping stresses in the following segments **are acceptable per criteria of Appendix F** of the ASME Code, Section III for conditions that would occur during thermal overpressurization:

– Primary Water Supply to RCPs and PRT	CPN-33
– Demineralized Water Supply to Hose Connections	CPN-36
– Reactor Coolant Drain Tank Pump Suction	CPN-40
– Containment Sump Pump Discharge	CPN-41
– Safety Injection Test Line and Accumulator Fill Line	CPN-32
– RCP Seal Water and Excess Letdown Heat Exchanger	CPN-37
– RCP Seal Bypass Line	(No CPN)

- Piping stresses in the following segments **are not acceptable per the original code criteria nor the criteria of Appendix F** of the ASME Code, Section III. These segments require further evaluation or provision of a means to relieve thermal overpressurization.

– Pressurizer Liquid Space Sample Line	CPN-66
– Hot Leg Sample Line	CPN-66
– Accumulator Sample Line	CPN-81

Table 1
Summary of Pipe Stress Evaluation

Segment		Containment Penetrations	Peak Pressure (psi)	Piping Stress Index (≤1.0 OK)		Strain Limit (≤5% OK)
				Per B31.1	Per App. F	
Non-Essential Service Water System	Instr. Rm	Multiple	325	0.93	0.66	<0.1%
	RCP&CUV	Multiple	711	0.98	0.70	<0.1%
	CLV	Multiple	215	0.93	0.66	<0.1%
Safety Injection Test Line and Accumulator Fill Line		32	15,310	**1.40**	0.96	0.4%
Primary Water Supply to the PRT		33	212	N/A	0.62	<0.1%
Demineralized Water Supply		36	325	N/A	0.63	<0.1%
RCP Seal Water and Excess Letdown Heat Exchanger		37	1,800	**1.57**	0.93	2.0%
Reactor Coolant Drain Tank Pump Suction		40	262	N/A	0.64	<0.1%
Containment Sump Pump Discharge to Waste Disposal		41	212	N/A	0.63	<0.1%
Sample Line from Hot Legs		66	17,800	**2.75**	**1.15**	**5.9%**
Sample Line from Pressurizer Liquid Space		66	17,800	**2.75**	**1.15**	**5.9%**
Sample Line from Accumulators		81	17,400	**2.69**	**1.16**	**5.6%**
RCP Seal Bypass		N/A	16,940	**1.55**	0.988	1.0%

Entries which are not acceptable are shown in bold.

3.0 CALCULATION

Reference 1 of this calculation lists MPR calculations prepared to determine the maximum pressure in piping segments at Cook Unit 1 that would occur during the thermal overpressurization concern addressed by Generic Letter 96-06. This calculation will evaluate whether the pressures and resulting piping stresses in these segments are acceptable at these pressures. This will be performed as follows:

- Given the maximum pressure, the first check is for compliance of the piping itself with the code of record, which, per the piping specifications (References 2 and 3), is USAS B31.1.0-1967 (Reference 4) for all 24 segments. See Section 3.1 for the method used to make this determination.

- For those segments where the piping stresses exceed the original code acceptance criteria, an evaluation is performed to determine if the segment would meet the acceptance criteria of Appendix F of ASME Code, Section III (Reference 5). Generic Letter 96-06, Supplement 1 (Reference 6) states that use of this code appendix is acceptable for justifying short-term operability until a permanent solution is implemented. See Section 3.2 for the method used to make this determination.

3.1 Check of Piping Compliance with Original Code Acceptance Criteria

Pressures calculated for each pipe from Reference 1 are listed in Table 1. These are the maximum pressures that each segment could reach. These maximum pressures exceed the design pressures listed for each system in the piping design specifications. Pressures, and piping stresses resulting from these pressures, will be evaluated for acceptability with regard to the original design code in this section.

Calculation Method

Per the piping specifications, the code of record for these segments is USAS B31.1.0-1967. This code has two requirements for pressure: first, that the calculated stress due to internal pressure not exceed the allowable stress (Section 102.3.2(a)); and second, that the sum of longitudinal stresses due to pressure, weight, and other sustained loads shall not exceed the allowable stress in the hot condition (Section 102.3.2 (d)). The Cook USFAR (Reference 7), Tables 2.9-1 and 2.9-2, summarize the stress limits in pressure piping required for analysis for pressure-induced loads as follows:

For Normal Conditions (Deadweight Plus Pressure Loads),
(a) $P_m \leq S_h$
(b) $P_L + P_B \leq S_h$
For Upset Conditions (Deadweight Plus Pressure Plus Operating Basis Earthquake Loads),
(a) $P_m \leq 1.2\ S_h$
(b) $P_L + P_B \leq 1.2\ S_h$
For Emergency Conditions (Deadweight Plus Pressure Plus Design Basis Earthquake Loads),
(a) $P_m \leq 1.2\ S_h$
(b) $P_L + P_B \leq 1.8\ S_h$

where

P_m = primary hoop membrane stress due to pressure
P_L = primary longitudinal membrane stress due to pressure
P_B = primary longitudinal bending stress due to deadweight and seismic loads
S_h = allowable stress at 70°F from USAS B31.1 Code for Pressure Piping, 1967

Accordingly, both hoop stress and longitudinal stress due to overpressurization must be analyzed. Further, the longitudinal stress analysis must consider the combined effects of overpressurization, deadweight and seismic loads.

To check acceptability of primary hoop membrane stress (P_m) due to overpressurization, the hoop stress is calculated using the following formula:

$$P_m = (\text{Pressure})\ (\text{Inside Diameter}) / (2 * \text{Thickness}) \leq 1.2\ S_h$$

A stress index for hoop stress can be calculated by dividing the hoop stress by the allowable stress as follows:

Stress Index for Hoop Stress = $P_m / 1.2\ S_h$

In addition, for internal pressure considerations, B31.1 Section 104.1.2 provides the following equation for allowable pressure (P, psig) for piping:

Allowable Pressure $P = [2(1.2)SE\ (t_m - A)\ ] / [D_o - 2y(t_m - A)]$

where

1.2 SE = maximum allowable stress for upset and emergency conditions, psi
t_m = minimum wall thickness, inches
A = additional thickness, inches.
    For 3.5" and smaller diameter pipe, A = 0.065"
    For 4"and larger diameter pipe, A = 0.0"
    For tubing in NESW heat exchangers, A = 0.0"
D_o = outside diameter of pipe, inches
y = 0.4 (for nonferrous materials, and for austenitic and ferritic materials less than 900°F)

Accordingly, for overpressure to be acceptable per the hoop stress criteria, two criteria must be satisfied:

(1) $P_m \leq 1.2\ S_h$
(2) Overpressure ≤ Allowable Pressure

Checking the acceptability of longitudinal stresses requires consideration of longitudinal bending stresses due to seismic and deadweight loads. These stresses are dependent on the support arrangement for the piping segments. Many of the piping segments at Cook were designed using span criteria developed in Reference 8. These criteria were intended to ensure that the piping was adequately supported so as to meet the stress limits of the code. For simplicity, the span criteria considered that the longitudinal pressure stress in all segments was bounded by 3,000 psi. Accordingly, for all segments designed using these span criteria, if the longitudinal pressure stress is less than or equal to 3,000 psi during overpressure, then the segment meets the original code requirements for combined longitudinal stress for combined overpressure, seismic and deadweight loads.

The span criteria apply to specified seismic classes, pipe sizes, schedules (40, 80 and 160), and materials. Review of the characteristics of the piping segments subject to overpressurization shows that the following segments meet these specifications:

NESW segments (14 total)
Safety Injection Test Line and Accumulator Fill Line
RCP Seal Bypass Line

Accordingly, these 16 segments are acceptable per the code requirements for longitudinal stresses for combined overpressure seismic and deadweight loads if the longitudinal pressure stress due to overpressure is less than 3,000 psi. Longitudinal stress due to overpressure is calculated as follows:

$$\sigma_{L,\text{ overpressure}} = (\text{Overpressure})\ (d^2\ )\ /\ (D_o^2 - d^2)$$

where D_o = nominal outside diameter of pipe and d = nominal inside diameter of pipe.

A stress index is calculated for these segments by dividing the total longitudinal stress (overpressure plus max permitted bending due to seismic and deadweight) by the permitted stress as follows:

$$\text{Stress Index for Longitudinal Stress} = [(1.8\ S_h) - 3{,}000 + \sigma_{L,\text{ overpressure}}\ ]\ /\ [1.8\ S_h\ ]$$

The other eight segments contain sections with Schedule 10 piping or materials not covered by the span criteria document. Since longitudinal stresses in these segments due to earthquake and deadweight are not known, acceptability of combined overpressure, seismic and deadweight stresses cannot be determined. For conservatism, these segments will be considered to be unacceptable per the original code for the overpressure load case.

Inputs

From the above, the following inputs are used in this calculation:

- Pressures used are from Reference 1 and are listed in Table 1.
- Pipe material, size and schedule are obtained for most segments by review of the drawings listed in References 9-11 and the piping specifications. For the sampling lines, tubing geometry and material were obtained from the pipe specification (Reference 3).
- Allowable stress values are listed in Table 2 at the end of Section 3 of this calculation.

Results

Attachment A, Table A-1 is a spreadsheet that calculates the allowable pressure for each segment. Table A-2 calculates the longitudinal stress for each segment and compares that stress to the limit of 3,000 psi for those segments which meet the span criteria document specifications.

Key results are summarized in Table 1 and presented below.

- The 14 NESW segments and CPN-33, 36, 40 and 41 are acceptable for hoop stress and allowable pressure. One or more piping sections in the other segments exceed the permitted hoop stress or pressure; hence, these segments do not meet the code acceptance criteria.

- The 14 NESW segments are acceptable for longitudinal stress due to combined overpressure, seismic and deadweight stresses. CPN-32, CPN-37, the RCP Seal Bypass Line and the sampling lines do not meet the longitudinal stress limit.

- Longitudinal stresses due to seismic and deadweight loads have not been determined for CPN-33, 36, 40 and 41. For conservatism, longitudinal stresses in these segments are considered unacceptable for the combined overpressure, seismic and deadweight case.

3.2 Check of Pipe Compliance with Appendix F Criteria

This section checks for compliance with the stress acceptance criteria of ASME Code, Section III, Appendix F (Reference 5) for inelastic analysis. Results are compared to Level D service limits to determine acceptability. The analysis method and results are provided below.

Applicability of Appendix F to Cook Thermal Overpressurization Analyses

Use of Appendix F is consistent with the recommendations in Supplement 1 to Generic Letter 96-06. Note that the design code for the evaluated segments is USAS B31.1.0-1967. Table 126.1 of this code references the ASME Boiler and Pressure Vessel Code, although Appendix F was not yet a part of Section III of the ASME Code at that time. The evaluations in this calculation are therefore performed using the 1989 version of the ASME Code, which has been accepted by the USNRC. In addition, material properties from the 1989 version of the ASME Code are used. Design stress intensity and yield strength values from the 1989 ASME Code are compared to the values from the 1968 version (Reference 12) below. Values are selected for 250°F from each code for consistency.

Material	Design Stress Intensity (ksi)		Yield Strength (ksi)	
	1968 Code	1989 Code	1968 Code	1989 Code
A106 Grade B	20.0	20.0	31.45	31.45
SA376 Type 304	19.9	20.0	23.8	23.75
SA312 Type 304	19.9	20.0	23.8	23.75
SA213 Type 316	20.0	20.0	24.6	24.55

This comparison shows that the 1989 edition material properties are comparable to the 1968 edition properties. Accordingly, the 1989 ASME Code version is appropriate to use for this evaluation.

Appendix F Stress Calculation Method

Pressures in the segments cause stresses in the hoop, longitudinal and radial directions. The piping could also be subjected to loads from deadweight, thermal expansion and seismic events, which could result in longitudinal pipe stresses that would either add or subtract from the pressure-induced longitudinal stresses. For Appendix F evaluations (that is, ASME Code Service Level D evaluations), only the primary loads due to deadweight and seismic events need to be considered in addition to the pressure loads. For this analysis, it is conservatively assumed that the longitudinal stresses (S_L) from both deadweight and seismic loads are equivalent to the following:

$$S_L = 1.8\,(S_h) - \sigma_{L,\ \text{design pressure}}$$

This is a simplification and a conservatism for those segments designed per the span criteria; for those segments, 3,000 psi could be used in the above equation instead of $\sigma_{L,\ \text{design pressure}}$.

where

$$\sigma_{L,\text{ design pressure}} = (\text{Design pressure})\,(d^2)\,/\,(D_o^2 - d^2)$$

The deadweight and seismic load stresses are longitudinal stresses and they are also principal stresses. There is also a longitudinal stress due to pressure, which is one-half the hoop stress. Since the deadweight and seismic stresses are bending stresses, acting in tension on one side and compression on the other, the three principal stresses are:

$S_1 = Pr/t$
$S_2 = Pr/2t \pm S_L$ where $S_L = 1.8\,(S_h) - \sigma_{L,\text{ design pressure}}$
$S_3 = -P/2$

The second principal stress has two variations:

$S_{2+} = Pr/2t + S_L$
$S_{2-} = Pr/2t - S_L$

The stress intensity is calculated as the maximum of the absolute values of the following stress differences (in accordance with the ASME Code):

$$SI = \text{Maximum of } |(S_1 - S_{2+})|,\ |(S_1 - S_{2-})|,\ |(S_{2+} - S_3)|,\ |(S_{2-} - S_3)|,\ \text{and } |(S_3 - S_1)|$$

The acceptance criterion in Section III, Appendix F, paragraph F-1341.2 of the ASME is:

$$SI < 0.7\,S_u$$

where SI is the calculated general primary membrane stress intensity. A stress index is defined as the ratio of the calculated general primary membrane stress intensity to allowable stress, as follows:

$$\text{Stress Index for Appendix F} = SI\,/\,(0.7\,S_u)$$

It should be noted that the plastic analysis method of Appendix F-1340 only requires consideration of primary membrane stresses. The secondary stresses that would be present at branch connections, elbows and valves are not evaluated.

In addition to the stress limit specified in the ASME Code, this analysis places a limit on the calculated strain. Article F-1322.5 of Appendix F states that:

> *"...in addition to the limits given in this Appendix, the strain or deformation limits (if any) provided in the Design Specification shall be satisfied."*

While none of the applicable Design Specifications identify a material strain limit, it is important that calculated strain remains low enough to ensure that failure will not occur. For this analysis, a limit of 5% strain is applied. Based on engineering judgment, none of the piping materials will fail at strains of less than 10%; so the limit of 5% provides a safety factor of two. It should be noted, however, that the primary acceptance criterion used in this analysis is the stress limit specified in Appendix F. The specified strain limit is included only for completeness.

Strain is calculated from the following relationships:

$$\epsilon_p = \sigma_h / E \qquad \text{for } \sigma_h \leq S_y$$
$$\epsilon_p = (\sigma_h - S_y) / E_p + \epsilon_y \qquad \text{for } \sigma_h > S_y$$

where

σ_h = hoop stress, psi
S_y = yield strength, psi
E = elastic modulus, psi
E_p = plastic modulus, psi
ϵ_p = plastic strain, in/in
ϵ_y = Pipe yield strain, in/in (= S_y / E)

Calculation of stress intensity is performed for all pipe segments, not just those that exceed original design code pipe stress acceptance criteria, since this information may be useful in evaluating acceptability of valves for the overpressure conditions.

Inputs

From the above, the following inputs are used in this evaluation:

- Pressures used are listed in Table 1.
- Pipe material, size and schedule are obtained for each segment by review of the drawings listed in References 9-11 and from the piping specification.
- Material property values used are listed in Table 2.

Results

Attachment A, Tables A-3 and A-4 contain spreadsheets that calculate the stress index and strain for the peak segment pressure for all segments. Key results are summarized in Table 1. In brief, the calculation shows the following:

- Stresses in the all piping segments meet Appendix F piping stress acceptance criteria with the exception of the sample lines from pressurizer liquid space, hot legs, and accumulators (CPN-66 and 81).

- Strains are less than the 5% acceptance criterion for all segments with the exception of the sample lines from pressurizer liquid space, hot legs, and accumulators (CPN-66 and 81).

Accordingly, with the exception of the sample lines, all segments meet Appendix F criteria.

Table 2
Material Properties Used in Pipe Stress Evaluation

Material Property	Material				
	A 106 Grade B	**SA312 Type 304**	**SA376 Type 304**	**SA213 Type 316**	**ASTM B75**
B31.1 Allowable Stress (ksi)	15.0(1)	16.05(2)	14.88(2)	15.35(2)	5.125(1)
Yield Strength, S_y (ksi)	31.45(3)	23.75(3)	23.75(3)	24.55(3)	Not Used
Tensile Strength, S_u (ksi)	60.0(3)	68.5(3)	68.5(3)	74.2(3)	Not Used
Elastic Modulus, psi	28.55E6(3)	27.3E6(3)	27.3E6(3)	27.3E6(3)	Not Used
Plastic Modulus, psi	Not Used	425,000(4)	425,000(4)	450,000(5)	Not Used

All material properties are for 250°F, which is judged to be the maximum metal temperature reached at high pressure conditions. References for material properties are as follows:

(1) From USAS B31.1-1967, Tables A-1 and A-2.
(2) Per USAS B31.1-1967, Table A-1, General Note d, value obtained from Section I of ASME code. Table PG-23 values used from 1968 version of Section I (Reference 13).
(3) Values obtained from 1989 version of ASME Code, Section III Appendices Tables I-2.1, I-2.2, I-3.1, I-3.2, and I-6.0.
(4) From Reference 1, Calculation 025-065-02.
(5) From Reference 1, Calculation 025-065-03.

4.0 REFERENCES

1. MPR Calculations for Segment Pressures
   - MPR Calculation 025-065-01, "Determination of Peak Pressures in D.C. Cook Unit 1 Piping Segments Isolated by Air Operated Diaphragm Valves," Revision 0.
   - MPR Calculation 025-065-02, "Determination of Peak Pressures in D.C. Cook Unit 1 Piping Segments Isolated by Air Operated Globe Valves," Revision 0.
   - MPR Calculation 025-065-03, "Determination of Peak Pressures in D.C. Cook Unit 1 Nuclear Sampling Lines," Revision 0.
   - MPR Calculation 025-065-05, "Determination of Peak Pressure in D.C. Cook Unit 1 RCP Seal Water Line (CPN-37)," Revision 0.

2. D.C. Cook Piping Specification ES-PIPE-1000-QCS, Rev 1, "Pipe Material Specification: Non-Safety Related."

3. D.C. Cook Piping Specification ES-PIPE-1013-QCN-CS3, Rev 1, "Pipe Material Specification: Safety Related."

4. USAS B31.1.0-1967, Power Piping.

5. 1989 ASME Code, Section III, Division 1 – Appendix F.

6. Generic Letter 96-06, Supplement 1 "Assurance of Equipment Operability and Containment Integrity During Design-Basis Accident Conditions," November 13, 1997.

7. Donald C. Cook Nuclear Plant Updated FSAR, Section 2, Revision 16.

8. Alternate Piping Analysis Criteria for Earthquake and Gravity Loads for Donald C. Cook Nuclear Plant, Indiana and Michigan Electric Company, American Electric Power System, New York, September 1971.

9. Drawings of Piping Segments used in Calculation:

NESW Segments
  OP-1-5114A-24
  OP-12-5152M-6

NESW UPPER 1
  1-NSW-54, Sheet 2, Revision 6
  1-NSW-68, Sheet 2, Revision 6
  1-NSW-72, Sheet 2, Revision 6
  1-NSW-68, Sheet 1, Revision 2
  1-NSW-72, Sheet 1, Revision 4
  1-NSW-60, Revision 7

NESW - UPPER 2
- 1-NSW-39, Sheet 2, Revision 7
- 1-NSW-67, Sheet 2, Revision 6
- 1-NSW-71, Sheet 2, Revision 4
- 1-NSW-67, Sheet 1, Revision 3
- 1-NSW-71, Sheet 1, Revision 5
- 1-NSW-44, Revision 6

NESW - UPPER 3
- 1-NSW-42, Sheet 2, Revision 8
- 1-NSW-66, Sheet 2, Revision 7
- 1-NSW-70, Sheet 2, Revision 5
- 1-NSW-66, Sheet 1, Revision 4
- 1-NSW-70, Sheet 1, Revision 5
- 1-NSW-47, Revision 4

NESW - UPPER 4
- 1-NSW-57, Sheet 2, Revision 6
- 1-NSW-65, Sheet 2, Revision 7
- 1-NSW-69, Sheet 2, Revision 6
- 1-NSW-63, Sheet 2, Revision 3
- 1-NSW-65, Sheet 1, Revision 3
- 1-NSW-69, Sheet 1, Revision 4
- 1-NSW-63, Sheet 1, Revision 1

NESW - LOWER 1
- 1-NSW-55, Sheet 2, Revision 5
- 1-NSW-182, Revision 4
- 1-NSW-178, Revision 4
- 1-NSW-59, Sheet 1, Revision 4

NESW - LOWER 2
- 1-NSW-37, Sheet 2, Revision 5
- 1-NSW-183, Revision 4
- 1-NSW-179, Revision 4
- 1-NSW-45, Revision 5

NESW - LOWER 3
- 1-NSW-38, Sheet 2, Revision 7
- 1-NSW-184, Revision 5
- 1-NSW-180, Revision 4
- 1-NSW-46, Revision 6

NESW - LOWER 4
- 1-NSW-58, Sheet 2, Revision 5
- 1-NSW-185, Revision 4
- 1-NSW-181, Revision 4
- 1-NSW-62, Sheet 1, Revision 4

NESW - RCP1
- 1-NSW-53, Sheet 2, Revision 6
- 1-NSW-76, Sheet 2, Revision 2
- 1-NSW-80, Sheet 2, Revision 1
- 1-NSW-76, Sheet 1, Revision 3
- 1-NSW-80, Sheet 1, Revision 1
- 1-NSW-61, Sheet 1, Revision 2

NESW - RCP 2
- 1-NSW-40, Sheet 2, Revision 5
- 1-NSW-75, Sheet 2, Revision 2
- 1-NSW-75, Sheet 1, Revision 4
- 1-NSW-79, Sheet 1, Revision 1

1-NSW-79, Sheet 2, Revision 2
1-NSW-43, Revision 3

NESW - RCP 3
- 1-NSW-41, Revision 5
- 1-NSW-74, Sheet 2, Revision 5
- 1-NSW-78, Sheet 2, Revision 4
- 1-NSW-74, Sheet 1, Revision 5
- 1-NSW-78, Sheet 1, Revision 5
- 1-NSW-48, Revision 2

NESW -RCP 4
- 1-NSW-56, Sheet 2, Revision 3
- 1-NSW-73, Sheet 2, Revision 3
- 1-NSW-77, Sheet 2, Revision 2
- 1-NSW-73, Sheet 1, Revision 3
- 1-NSW-77, Sheet 1, Revision 2
- 1-NSW-64, Revision 3

NESW - INST. RM 3
- 1-NSW-49, Revision 6
- 1-NSW-176, Revision 2
- 1-NSW-49, Revision 5
- 1-NSW-174, Revision 4
- 1-NSW-50, Revision 5

NESW - INST RM 4
- 1-NSW-52, Revision 7
- 1-NSW-177, Revision 1
- 1-NSW-175, Revision 3
- 1-NSW-51, Revision 5

CPN-32, Accumulator Fill Line.
- OP-1-5143A-4
- 1-SI-507L1.6, Revision 2
- 1-SI-508L4.6, Revision 1
- 1-SI-537-L5, Revision 1
- 1-SI-537-L9.11, Revision 2
- 1-SI-537-L16.19, Revision 1
- 1-SI-538-L1.4, Revision 5
- 1-SI-539.L2.3, Revision 0
- 1-SI-540-L4.5, Revision 2
- 1-SI-452.L1, Revision 0
- 1-SI-543-L1.3, Revision 3
- 1-SI-544.L1, Revision 1
- 1-SI-547-L1.4, Revision 2
- 1-SI-547.L9.11, Revision 2
- OP-1-5142-35
- 1-SI-508L1.3A, Revision 6
- 1-SI-537-L1.4, Revision 2
- 1-SI537-L6.8, Revision 2
- 1-SI-537-L12.15, Revision 2
- 1-SI-537-L20.21, Revision 0
- 1-SI-539.L1, Revision 0
- 1-SI-540-L1.3, Revision 3
- 1-SI-541-L1, Revision 1
- 1-SI-542.L2.3, Revision 1
- 1-SI-543-L4.6, Revision 3
- 1-SI-544.L2.3, Revision 0
- 1-SI-547-L5.8, Revision 0
- 1-SI-601L1, Revision 0

CPN-33, Primary Water Supply
- OP-1-5128A-42
- 1-PW-17, Revision 5
- 1-PW-556-L4.8, Revision 1
- 1-PW-12, Sheet 2, Revision 3
- 1-PW-556-L1.3, Revision 1
- 1-PW-556-L9.15, Revision 0

1-PW-557-L1.2, Revision 1
1-PW-557-L6.7, Revision 0
1-PW-559-L1.7, Revision 1
1-PW-557-L3.5, Revision 1
1-PW-558-L1.5, Revision 0
12-PW-4, Revision 3

CPN-36, Demin Water Supply
- OP-12-5115D-22
- 1-DW-541L1.4, Revision 1
- 1-DW-541L8.10, Revision 3
- 0-DW-500L1.4a, Revision 3
- 1-DW-541L5.7, Revision 2
- 1-DW-541L11.15, Revision 3

CPN-37, RCP Seal Water Supply
- OP-1-5129A-28
- 1-CS-93, Revision 7
- 1-CS-42, Revision 12

CPN-40, RX Coolent Drain Tank Pump Suction
- OP-12-5137A-18
- 1-WD-36, Revision 2
- 1-WD-661L1.7, Revision 0
- 1-WD-807.L1.2, Revision 0
- OP-1-5128A-42
- 1-WD-37, Revision 4
- 1-WD-66, Revision 1
- 12-WD-3, Revision 7

CPN-41, Containment Sump Pump Discharge
- OP-1-5124-22
- 1-DR-193, Revision 3
- 1-DR-519-L-1.3, Revision 2
- 1-DR-521-L1, Revision 1
- 1-DR-523-L1, Revision 1
- 1-DR-523-L5.8, Revision 1
- 1-DR-523-L12, Revision 0
- OP-12-5123B-21
- 1-DR-224, Revision 2
- 1-DR-520-L1, Revision 1
- 1-DR-522-L1, Revision 1
- 1-DR-523-L2.4, Revision 0
- 1-DR-523-L9.11, Revision 0
- 1-DR-524-L1, Revision 1

CPN-66 and 81, Sampling Lines
- 1-5141-37

Drawings of RCP Seal Bypass
- OP-1-5128A-42
- 1-CS-766-L2, Revision 1
- 1-CS-766L5.7, Revision 0
- 1-CS-771-L1, Revision 1
- 1-CS-771-L5.6, Revision 0
- 1-CS-773L1, Revision 1
- 1-CS-773-L5.11, Revision 1
- 1-CS-775L1.5, Revision 4
- 1-CS-775L11.12B, Revision 1
- 1-CS-766-L1, Revision 0
- 1-CS-766-L3.4, Revision 1
- 1-CS-766-L8.11, Revision 1
- 1-CS-771-L2.4, Revision 2
- 1-CS-771-L7.10, Revision 1
- 1-CS-73-L2.4, Revision 2
- 1-CS-775L1A.1B, Revision 1
- 1-CS-775L6.10, Revision 1
- 1-CS-775L13, Revision 1

1-CS-775L14.15, Revision 1 1-CS-775L16.21, Revision 1

10. Containment Penetration Drawings:
    1-5336-5, "Containment Unit 1 Piping Penetration Schedule Containment Wall"
    1-5337-14, "Containment Unit 1 Piping Penetration Schedule Containment Wall"

11. NESW Heat Exchanger Drawings
    American Air Filter Company Drawing MC-129-492F, "4-Row Water Coil."
    American Air Filter Company Drawing MC-129-493F, "4-Row Water Coil."
    American Air Filter Company Drawing 910349, "Coil Assembly, Cooling (Donald C. Cook Nuclear Plant)."

12. 1968 ASME Code, Section III.

13. 1968 ASME Code, Section I.

14. Crane Technical Paper 410, 1991.

Attachment A

Spreadsheets for Piping Stress Evaluation

Prepared by:
Checked by:

Table A-1:
Allowable Pressure and Hoop Stress Evaluation

Pipe Segment	CPN	Maximum Pipe Pressure (psi)	Pipe Material	Nominal Pipe Size (inch)	Pipe Schedule	Thickness (inch)	Actual Pipe Size (inch)	Inside Diameter (inch)	Design Pressure (psig)	Design Allowable Stress (psi)	Design Temperature (°F)	A (inch)	Allowable Pressure (psig)	Allowable Pressure Greater than Maximum Pressure?	Primary Hoop Stress Due to Over Pressure (psi)	Stress Index for Hoop Stress
See Note:		1	2	2	2	3	4	5	6	7	6	8	8		8	8
NESW Cooling for Lower Containment Ventilation Units (4 segments)	Multiple	215	A106 Gr B	6	40	0.280	6.625	6.065	125	15,000	150	0.000	1,575	YES	2,329	0.13
		215	A106 Gr B	4	40	0.237	4.5	4.026	125	15,000	150	0.000	1,979	YES	1,826	0.10
		215	A106 Gr B	2.5	40	0.203	2.875	2.469	125	15,000	150	0.065	1,797	YES	1,307	0.07
		215	A106 Gr B	1	80	0.179	1.315	0.957	125	15,000	150	0.065	3,353	YES	575	0.03
		215	A106 Gr B	0.5	80	0.147	0.84	0.546	125	15,000	150	0.065	3,812	YES	399	0.02
		215	SA312 TP304	6	40S	0.280	6.625	6.065	125	16,050	150	0.000	1,685	YES	2,329	0.12
		215	SA312 TP304	0.5	40S	0.109	0.84	0.622	125	16,050	150	0.065	2,106	YES	613	0.03
		215	ASTM B75	0.625	--	0.035	0.625	0.555	125	5,125	150	0.000	721	YES	1,705	0.28
NESW Cooling for Upper Containment Ventilation Units (4 segments)	Multiple	711	A106 Gr B	3	40	0.216	3.5	3.068	125	15,000	150	0.065	1,609	YES	5,049	0.28
		711	A106 Gr B	2	80	0.218	2.375	1.939	125	15,000	150	0.065	2,445	YES	3,162	0.18
		711	A106 Gr B	1.5	80	0.200	1.9	1.500	125	15,000	150	0.065	2,712	YES	2,666	0.15
		711	A106 Gr B	1	80	0.179	1.315	0.957	125	15,000	150	0.065	3,353	YES	1,901	0.11
		711	A106 Gr B	0.5	80	0.147	0.84	0.546	125	15,000	150	0.065	3,812	YES	1,320	0.07
		711	SA312 TP304	3	40S	0.216	3.5	3.068	125	16,050	150	0.065	1,721	YES	5,049	0.26
		711	SA312 TP304	0.5	40S	0.109	0.84	0.622	125	16,050	150	0.065	2,106	YES	2,029	0.11
		711	ASTM B75	0.625	--	0.035	0.625	0.555	125	5,125	150	0.000	721	YES	5,637	0.92

Prepared by:
Checked by:

Table A-1:
Allowable Pressure and Hoop Stress Evaluation

Pipe Segment	CPN	Maximum Pipe Pressure (psi)	Pipe Material	Nominal Pipe Size (inch)	Pipe Schedule	Thickness (inch)	Actual Pipe Size (inch)	Inside Diameter (inch)	Design Pressure (psig)	Design Allowable Stress (psi)	Design Temperature (°F)	A (inch)	Allowable Pressure (psig)	Allowable Pressure Greater than Maximum Pressure?	Primary Hoop Stress Due to Over Pressure (psi)	Stress Index for Hoop Stress
See Note:		1	2	2	2	3	4	5	6	7	6	8	8		8	8
NESW Cooling for RCP Motor Air Coolers (4 segments)	Multiple	711	A106 Gr B	3	40	0.216	3.5	3.068	125	15,000	150	0.065	1,609	YES	5,049	0.28
		711	A106 Gr B	2.5	40	0.203	2.875	2.469	125	15,000	150	0.065	1,797	YES	4,324	0.24
		711	A106 Gr B	1	80	0.179	1.315	0.957	125	15,000	150	0.065	3,353	YES	1,901	0.11
		711	A106 Gr B	0.5	80	0.147	0.84	0.546	125	15,000	150	0.065	3,812	YES	1,320	0.07
		711	SA312 TP304	3	40S	0.216	3.5	3.068	125	16,050	150	0.065	1,721	YES	5,049	0.26
		711	SA312 TP304	0.5	40S	0.109	0.84	0.622	125	16,050	150	0.065	2,106	YES	2,029	0.11
		711	ASTM B75	0.625	--	0.035	0.625	0.555	125	5,125	150	0.000	721	YES	5,637	0.92
NESW Cooling for Instrumentation Room Ventilation Units (2 segments)	Multiple	325	A106 Gr B	3	40	0.216	3.5	3.068	125	15,000	150	0.065	1,609	YES	2,308	0.13
		325	A106 Gr B	2.5	40	0.203	2.875	2.469	125	15,000	150	0.065	1,797	YES	1,976	0.11
		325	A106 Gr B	2	80	0.218	2.375	1.939	125	15,000	150	0.065	2,445	YES	1,445	0.08
		325	A106 Gr B	1.5	80	0.200	1.9	1.500	125	15,000	150	0.065	2,712	YES	1,219	0.07
		325	A106 Gr B	1	80	0.179	1.315	0.957	125	15,000	150	0.065	3,353	YES	869	0.05
		325	A106 Gr B	0.5	80	0.147	0.84	0.546	125	15,000	150	0.065	3,812	YES	604	0.03
		325	SA312 TP304	2	40	0.154	2.375	2.067	125	16,050	150	0.065	1,488	YES	2,181	0.11
		325	SA312 TP304	0.5	80	0.147	0.84	0.546	125	16,050	150	0.065	4,079	YES	604	0.03
		325	ASTM B75	0.625	--	0.035	0.625	0.555	125	5,125	150	0.000	721	YES	2,577	0.42

Prepared by:
Checked by:

Table A-1:
Allowable Pressure and Hoop Stress Evaluation

Pipe Segment	CPN	Maximum Pipe Pressure (psi)	Pipe Material	Nominal Pipe Size (inch)	Pipe Schedule	Thickness (inch)	Actual Pipe Size (inch)	Inside Diameter (inch)	Design Pressure (psig)	Design Allowable Stress (psi)	Design Temperature (°F)	A (inch)	Allowable Pressure (psig)	Allowable Pressure Greater than Maximum Pressure?	Primary Hoop Stress Due to Over Pressure (psi)	Stress Index for Hoop Stress
See Note:		1	2	2	2	3	4	5	6	7	6	8	8		8	8
Accumulator Fill Line	32	15,310	SA376 TP304	1	160	0.250	1.315	0.815	1750	14,880	120	0.065	5,661	NO	24,955	1.40
		15,310	SA376 TP304	0.75	160	0.219	1.05	0.612	1750	14,880	120	0.065	5,934	NO	21,392	1.20
Primary Water Supply to RCPs and PRT	33	212	SA312 TP304	3	10S	0.120	3.5	3.260	136	16,050	100	0.065	613	YES	2,880	0.15
		212	SA312 TP304	2.5	10S	0.120	2.875	2.635	136	16,050	100	0.065	748	YES	2,328	0.12
		212	SA312 TP304	1	40S	0.133	1.315	1.049	136	16,050	100	0.065	2,078	YES	836	0.04
		212	SA312 TP304	0.75	40S	0.113	1.05	0.824	136	16,050	100	0.065	1,828	YES	773	0.04
		212	SA312 TP304	0.5	40S	0.109	0.84	0.622	100	16,050	340	0.065	2,106	YES	605	0.03
Demineralized Water Supply to Refueling Cavity Scrub Down Hose Connections	36	325	SA312 TP304	3	10S	0.120	3.5	3.260	156	16,050	100	0.065	613	YES	4,415	0.23
		325	SA312 TP304	2	40S	0.154	2.375	2.067	156	16,050	100	0.065	1,488	YES	2,181	0.11
		325	SA312 TP304	1	40S	0.133	1.315	1.049	156	16,050	100	0.065	2,078	YES	1,282	0.07

Prepared by:
Checked by:

Table A-1:
Allowable Pressure and Hoop Stress Evaluation

Pipe Segment	CPN	Maximum Pipe Pressure (psi)	Pipe Material	Nominal Pipe Size (inch)	Pipe Schedule	Thickness (inch)	Actual Pipe Size (inch)	Inside Diameter (inch)	Design Pressure (psig)	Design Allowable Stress (psi)	Design Temperature (°F)	A (inch)	Allowable Pressure (psig)	Allowable Pressure Greater than Maximum Pressure?	Primary Hoop Stress Due to Over Pressure (psi)	Stress Index for Hoop Stress
See Note:		1	2	2	2	3	4	5	6	7	6	8	8		8	8
RCP Seal Water Line	37	1,800	SA312 TP304	4	10S	0.120	4.5	4.260	150	16,050	200	0.000	1,050	NO	31,950	1.66
		1,800	SA312 TP304	1	40S	0.133	1.315	1.049	150	16,050	200	0.065	2,078	YES	7,098	0.37
Reacor Coolant Drain Tank Pump Suction	40	262	SA312 TP304	4	10S	0.120	4.5	4.260	100	16,050	340	0.000	1,050	YES	4,651	0.24
		262	SA312 TP304	2	40S	0.154	2.375	2.067	100	16,050	340	0.065	1,488	YES	1,758	0.09
		262	SA312 TP304	1	40S	0.133	1.315	1.049	100	16,050	340	0.065	2,078	YES	1,033	0.05
		262	SA312 TP304	0.75	40S	0.113	1.05	0.824	100	16,050	340	0.065	1,828	YES	955	0.05
Containment Sump Pump Discharge	41	212	SA312 TP304	3	10S	0.120	3.5	3.260	60	16,050	160	0.065	613	YES	2,880	0.15
		212	SA312 TP304	2	40S	0.154	2.375	2.067	60	16,050	160	0.065	1,488	YES	1,423	0.07
		212	SA312 TP304	1	40S	0.133	1.315	1.049	60	16,050	160	0.065	2,078	YES	836	0.04
Sample Line From Pressurizer Liquid Space	66	17,800	SA213 TP316	0.5	--	0.065	0.5	0.370	2485	15,350	680	0.000	5,345	NO	50,662	2.75
Sample Line From Accumulators	81	17,400	SA213 TP316	0.5	--	0.065	0.5	0.370	600	15,350	400	0.000	5,345	NO	49,523	2.69
Sample Line From Hot Legs	66	17,800	SA213 TP316	0.5	--	0.065	0.5	0.370	2485	15,350	650	0.000	5,345	NO	50,662	2.75
RCP Seal Bypass Line	N/A	16,940	SA376 TP304	1	160	0.250	1.315	0.815	2735	14,880	200	0.065	5,661	NO	27,612	1.55
		16,940	SA376 TP304	0.75	160	0.219	1.05	0.612	2735	14,880	200	0.065	5,934	NO	23,670	1.33

Prepared by:
Checked by:

Table A-2:
Longitudinal Stress Evaluation

Pipe Segment	CPN	Maximum Pipe Pressure (psi)	Pipe Material	Nominal Pipe Size (inch)	Pipe Schedule	Thickness (inch)	Actual Pipe Size (inch)	Inside Diameter (inch)	Design Pressure (psig)	Design Allowable Stress (psi)	Design Pressure Longitudinal Stress (psi)	Over-Pressure Longitudinal Stress (psi)	Max Permitted Longitudinal Stresses (psi)	Stress Index for Longitudinal Stress
See Note:		1	2	2	2	3	4	5	6	7	8	8	8	8
NESW Cooling for Lower Containment Ventilation Units (4 segments)	Multiple	215	A106 Gr B	6	40	0.280	6.625	6.065	125	15,000	647	1,113	3,000	0.93
		215	A106 Gr B	4	40	0.237	4.5	4.026	125	15,000	501	862	3,000	0.92
		215	A106 Gr B	2.5	40	0.203	2.875	2.469	125	15,000	351	604	3,000	0.91
		215	A106 Gr B	1	80	0.179	1.315	0.957	125	15,000	141	242	3,000	0.90
		215	A106 Gr B	0.5	80	0.147	0.84	0.546	125	15,000	91	157	3,000	0.89
		215	SA312 TP304	6	40S	0.280	6.625	6.065	125	16,050	647	1,113	3,000	0.93
		215	SA312 TP304	0.5	40S	0.109	0.84	0.622	125	16,050	152	261	3,000	0.91
		215	ASTM B75	0.625	--	0.035	0.625	0.555	125	5,125	466	802	-	N/A
NESW Cooling for Upper Containment Ventilation Units (4 segments)	Multiple	711	A106 Gr B	3	40	0.216	3.5	3.068	125	15,000	415	2,359	3,000	0.98
		711	A106 Gr B	2	80	0.218	2.375	1.939	125	15,000	250	1,421	3,000	0.94
		711	A106 Gr B	1.5	80	0.200	1.9	1.500	125	15,000	207	1,176	3,000	0.93
		711	A106 Gr B	1	80	0.179	1.315	0.957	125	15,000	141	801	3,000	0.92
		711	A106 Gr B	0.5	80	0.147	0.84	0.546	125	15,000	91	520	3,000	0.91
		711	SA312 TP304	3	40S	0.216	3.5	3.068	125	16,050	415	2,359	3,000	0.98
		711	SA312 TP304	0.5	40S	0.109	0.84	0.622	125	16,050	152	863	3,000	0.93
		711	ASTM B75	0.625	--	0.035	0.625	0.555	125	5,125	466	2,651	-	N/A

Table A-2:
Longitudinal Stress Evaluation

Pipe Segment	CPN	Maximum Pipe Pressure (psi)	Pipe Material	Nominal Pipe Size (inch)	Pipe Schedule	Thickness (inch)	Actual Pipe Size (inch)	Inside Diameter (inch)	Design Pressure (psig)	Design Allowable Stress (psi)	Design Pressure Longitudinal Stress (psi)	Over-Pressure Longitudinal Stress (psi)	Max Permitted Longitudinal Stresses (psi)	Stress Index for Longitudinal Stress
See Note:		1	2	2	2	3	4	5	6	7	8	8	8	8
NESW Cooling for RCP Motor Air Coolers (4 segments)	Multiple	711	A106 Gr B	3	40	0.216	3.5	3.068	125	15,000	415	2,359	3,000	0.98
		711	A106 Gr B	2.5	40	0.203	2.875	2.469	125	15,000	351	1,998	3,000	0.96
		711	A106 Gr B	1	80	0.179	1.315	0.957	125	15,000	141	801	3,000	0.92
		711	A106 Gr B	0.5	80	0.147	0.84	0.546	125	15,000	91	520	3,000	0.91
		711	SA312 TP304	3	40S	0.216	3.5	3.068	125	16,050	415	2,359	3,000	0.98
		711	SA312 TP304	0.5	40S	0.109	0.84	0.622	125	16,050	152	863	3,000	0.93
		711	ASTM B75	0.625	--	0.035	0.625	0.555	125	5,125	466	2,651	-	N/A
NESW Cooling for Instrumentation Room Ventilation Units (2 segments)	Multiple	325	A106 Gr B	3	40	0.216	3.5	3.068	125	15,000	415	1,078	3,000	0.93
		325	A106 Gr B	2.5	40	0.203	2.875	2.469	125	15,000	351	913	3,000	0.92
		325	A106 Gr B	2	80	0.218	2.375	1.939	125	15,000	250	650	3,000	0.91
		325	A106 Gr B	1.5	80	0.200	1.9	1.500	125	15,000	207	538	3,000	0.91
		325	A106 Gr B	1	80	0.179	1.315	0.957	125	15,000	141	366	3,000	0.90
		325	A106 Gr B	0.5	80	0.147	0.84	0.546	125	15,000	91	238	3,000	0.90
		325	SA312 TP304	2	40	0.154	2.375	2.067	125	16,050	390	1,015	3,000	0.93
		325	SA312 TP304	0.5	80	0.147	0.84	0.546	125	16,050	91	238	3,000	0.90
		325	ASTM B75	0.625	--	0.035	0.625	0.555	125	5,125	466	1,212	-	N/A

Prepared by:
Checked by:

Table A-2:
Longitudinal Stress Evaluation

Pipe Segment	CPN	Maximum Pipe Pressure (psi)	Pipe Material	Nominal Pipe Size (inch)	Pipe Schedule	Thickness (inch)	Actual Pipe Size (inch)	Inside Diameter (inch)	Design Pressure (psig)	Design Allowable Stress (psi)	Design Pressure Longitudinal Stress (psi)	Over-Pressure Longitudinal Stress (psi)	Max Permitted Longitudinal Stresses (psi)	Stress Index for Longitudinal Stress
See Note:		1	2	2	2	3	4	5	6	7	8	8	8	8
Accumulator Fill Line	32	15,310	SA376 TP304	1	160	0.250	1.315	0.815	1750	14,880	1,091	9,549	3,000	1.24
		15,310	SA376 TP304	0.75	160	0.219	1.05	0.612	1750	14,880	900	7,877	3,000	1.18
Primary Water Supply to RCPs and PRT	33	212	SA312 TP304	3	10S	0.120	3.5	3.260	136	16,050	891	1,389	-	N/A
		212	SA312 TP304	2.5	10S	0.120	2.875	2.635	136	16,050	714	1,113	-	N/A
		212	SA312 TP304	1	40S	0.133	1.315	1.049	136	16,050	238	371	-	N/A
		212	SA312 TP304	0.75	40S	0.113	1.05	0.824	136	16,050	218	340	-	N/A
		212	SA312 TP304	0.5	40S	0.109	0.84	0.622	100	16,050	121	257	-	N/A
Demineralized Water Supply to Refueling Cavity Scrub Down Hose Connections	36	325	SA312 TP304	3	10S	0.120	3.5	3.260	156	16,050	1,022	2,129	-	N/A
		325	SA312 TP304	2	40S	0.154	2.375	2.067	156	16,050	487	1,015	-	N/A
		325	SA312 TP304	1	40S	0.133	1.315	1.049	156	16,050	273	569	-	N/A

Prepared by:
Checked by:

Table A-2:
Longitudinal Stress Evaluation

Pipe Segment	CPN	Maximum Pipe Pressure (psi)	Pipe Material	Nominal Pipe Size (inch)	Pipe Schedule	Thickness (inch)	Actual Pipe Size (inch)	Inside Diameter (inch)	Design Pressure (psig)	Design Allowable Stress (psi)	Design Pressure Longitudinal Stress (psi)	Over-Pressure Longitudinal Stress (psi)	Max Permitted Longitudinal Stresses (psi)	Stress Index for Longitudinal Stress
See Note:		1	2	2	2	3	4	5	6	7	8	8	8	8
RCP Seal Water Line	37	1,800	SA312 TP304	4	10S	0.120	4.5	4.260	150	16,050	1,295	15,537	-	N/A
		1,800	SA312 TP304	1	40S	0.133	1.315	1.049	150	16,050	262	3,150	-	N/A
Reacor Coolant Drain Tank Pump Suction	40	262	SA312 TP304	4	10S	0.120	4.5	4.260	100	16,050	863	2,262	-	N/A
		262	SA312 TP304	2	40S	0.154	2.375	2.067	100	16,050	312	818	-	N/A
		262	SA312 TP304	1	40S	0.133	1.315	1.049	100	16,050	175	458	-	N/A
		262	SA312 TP304	0.75	40S	0.113	1.05	0.824	100	16,050	160	420	-	N/A
Containment Sump Pump Discharge	41	212	SA312 TP304	3	10S	0.120	3.5	3.260	60	16,050	393	1,389	-	N/A
		212	SA312 TP304	2	40S	0.154	2.375	2.067	60	16,050	187	662	-	N/A
		212	SA312 TP304	1	40S	0.133	1.315	1.049	60	16,050	105	371	-	N/A
Sample Line From Pressurizer Liquid Space	66	17,800	SA213 TP316	0.5	--	0.065	0.5	0.370	2485	15,350	3,008	21,546	-	N/A
Sample Line From Accumulators	81	17,400	SA213 TP316	0.5	--	0.065	0.5	0.370	600	15,350	726	21,062	-	N/A
Sample Line From Hot Legs	66	17,800	SA213 TP316	0.5	--	0.065	0.5	0.370	2485	15,350	3,008	21,546	-	N/A
RCP Seal Bypass Line	N/A	16,940	SA376 TP304	1	160	0.250	1.315	0.815	2735	14,880	1,706	10,565	3,000	1.28
		16,940	SA376 TP304	0.75	160	0.219	1.05	0.612	2735	14,880	1,407	8,716	3,000	1.21

Prepared by:
Checked by:

Table A-3:
Appendix F Stress Evaluation

Pipe Segment	CPN	Maximum Pipe Pressure (psi)	Pipe Material	Nominal Pipe Size (inch)	Pipe Schedule	Thickness (inch)	Actual Pipe Size (inch)	Inside Diameter (inch)	Design Pressure (psig)	Design Allowable Stress (psi)	Max Bending Stress Due to DW + Seismic, Pb (psi)	Su (psi)	S1 (psi)	S2+ (psi)	S2- (psi)	S3 (psi)	SI (psi)	0.7 Su (psi)	Apendix F Stress Index
See Note:		1	2	2	2	3	4	5	6	7	9	7	9	9	9	9	9	9	9
NESW Cooling for Lower Containment Ventilation Units (4 segments)	Multiple	215	A106 Gr B	6	40	0.280	6.625	6.065	125	15,000	26,353	60,000	2,329	27,517	-25,189	-108	27,625	42,000	0.66
		215	A106 Gr B	4	40	0.237	4.5	4.026	125	15,000	26,499	60,000	1,826	27,412	-25,586	-108	27,519	42,000	0.66
		215	A106 Gr B	2.5	40	0.203	2.875	2.469	125	15,000	26,396	60,000	1,307	27,050	-25,742	-108	27,157	42,000	0.65
		215	A106 Gr B	1	80	0.179	1.315	0.957	125	15,000	26,859	60,000	575	27,147	-26,572	-108	27,254	42,000	0.65
		215	A106 Gr B	0.5	80	0.147	0.84	0.546	125	15,000	26,909	60,000	399	27,108	-26,709	-108	27,216	42,000	0.65
		215	SA312 TP304	6	40S	0.280	6.625	6.065	125	16,050	28,243	68,500	2,329	29,407	-27,079	-108	29,515	47,950	0.62
		215	SA312 TP304	0.5	40S	0.109	0.84	0.622	125	16,050	28,738	68,500	613	29,045	-28,432	-108	29,152	47,950	0.61
		215	ASTM B75	0.625	--	0.035	0.625	0.555	125	5,125	8,759	--	--	--	--	--	--	--	--
NESW Cooling for Upper Containment Ventilation Units (4 segments)	Multiple	711	A106 Gr B	3	40	0.216	3.5	3.068	125	15,000	26,585	60,000	5,049	29,110	-24,061	-356	29,466	42,000	0.70
		711	A106 Gr B	2	80	0.218	2.375	1.939	125	15,000	26,750	60,000	3,162	28,331	-25,169	-356	28,687	42,000	0.68
		711	A106 Gr B	1.5	80	0.200	1.9	1.500	125	15,000	26,793	60,000	2,666	28,126	-25,460	-356	28,482	42,000	0.68
		711	A106 Gr B	1	80	0.179	1.315	0.957	125	15,000	26,859	60,000	1,901	27,810	-25,909	-356	28,165	42,000	0.67
		711	A106 Gr B	0.5	80	0.147	0.84	0.546	125	15,000	26,909	60,000	1,320	27,569	-26,248	-356	27,924	42,000	0.66
		711	SA312 TP304	3	40S	0.216	3.5	3.068	125	16,050	28,475	68,500	5,049	31,000	-25,951	-356	31,356	47,950	0.65
		711	SA312 TP304	0.5	40S	0.109	0.84	0.622	125	16,050	28,738	68,500	2,029	29,753	-27,724	-356	30,108	47,950	0.63
		711	ASTM B75	0.625	--	0.035	0.625	0.555	125	5,125	8,759	--	--	--	--	--	--	--	--

Prepared by:
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Table A-3:
Appendix F Stress Evaluation

Pipe Segment	CPN	Maximum Pipe Pressure (psi)	Pipe Material	Nominal Pipe Size (inch)	Pipe Schedule	Thickness (inch)	Actual Pipe Size (inch)	Inside Diameter (inch)	Design Pressure (psig)	Design Allowable Stress (psi)	Max Bending Stress Due to DW + Seismic, Pb (psi)	Su (psi)	S1 (psi)	S2+ (psi)	S2- (psi)	S3 (psi)	SI (psi)	0.7 Su (psi)	Apendix F Stress Index
See Note:		1	2	2	2	3	4	5	6	7	9	7	9	9	9	9	9	9	9
NESW Cooling for RCP Motor Air Coolers (4 segments)	Multiple	711	A106 Gr B	3	40	0.216	3.5	3.068	125	15,000	26,585	60,000	5,049	29,110	-24,061	-356	29,466	42,000	0.70
		711	A106 Gr B	2.5	40	0.203	2.875	2.469	125	15,000	26,649	60,000	4,324	28,811	-24,487	-356	29,166	42,000	0.69
		711	A106 Gr B	1	80	0.179	1.315	0.957	125	15,000	26,859	60,000	1,901	27,810	-25,909	-356	28,165	42,000	0.67
		711	A106 Gr B	0.5	80	0.147	0.84	0.546	125	15,000	26,909	60,000	1,320	27,569	-26,248	-356	27,924	42,000	0.66
		711	SA312 TP304	3	40S	0.216	3.5	3.068	125	16,050	28,475	68,500	5,049	31,000	-25,951	-356	31,356	47,950	0.65
		711	SA312 TP304	0.5	40S	0.109	0.84	0.622	125	16,050	28,738	68,500	2,029	29,753	-27,724	-356	30,108	47,950	0.63
		711	ASTM B75	0.625	--	0.035	0.625	0.555	125	5,125	8,759	--	--	--	--	--	--	--	--
NESW Cooling for Instrumentation Room Ventilation Units (2 segments)	Multiple	325	A106 Gr B	3	40	0.216	3.5	3.068	125	15,000	26,585	60,000	2,308	27,739	-25,431	-163	27,902	42,000	0.66
		325	A106 Gr B	2.5	40	0.203	2.875	2.469	125	15,000	26,649	60,000	1,976	27,637	-25,661	-163	27,800	42,000	0.66
		325	A106 Gr B	2	80	0.218	2.375	1.939	125	15,000	26,750	60,000	1,445	27,473	-26,027	-163	27,635	42,000	0.66
		325	A106 Gr B	1.5	80	0.200	1.9	1.500	125	15,000	26,793	60,000	1,219	27,403	-26,184	-163	27,565	42,000	0.66
		325	A106 Gr B	1	80	0.179	1.315	0.957	125	15,000	26,859	60,000	869	27,294	-26,425	-163	27,456	42,000	0.65
		325	A106 Gr B	0.5	80	0.147	0.84	0.546	125	15,000	26,909	60,000	604	27,210	-26,607	-163	27,373	42,000	0.65
		325	SA312 TP304	2	40	0.154	2.375	2.067	125	16,050	28,500	68,500	2,181	29,590	-27,409	-163	29,753	47,950	0.62
		325	SA312 TP304	0.5	80	0.147	0.84	0.546	125	16,050	28,799	68,500	604	29,100	-28,497	-163	29,263	47,950	0.61
		325	ASTM B75	0.625	--	0.035	0.625	0.555	125	5,125	8,759	–	--	–	--	--	--	--	--

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Table A-3:
Appendix F Stress Evaluation

Pipe Segment	CPN	Maximum Pipe Pressure (psi)	Pipe Material	Nominal Pipe Size (inch)	Pipe Schedule	Thickness (inch)	Actual Pipe Size (inch)	Inside Diameter (inch)	Design Pressure (psig)	Design Allowable Stress (psi)	Max Bending Stress Due to DW + Seismic, Pb (psi)	Su (psi)	S1 (psi)	S2+ (psi)	S2- (psi)	S3 (psi)	SI (psi)	0.7 Su (psi)	Apendix F Stress Index
See Note:		1	2	2	2	3	4	5	6	7	9	7	9	9	9	9	9	9	9
Accumulator Fill Line	32	15,310	SA376 TP304	1	160	0.250	1.315	0.815	1750	14,880	25,693	68,500	24,955	38,170	-13,215	-7,655	45,825	47,950	0.96
		15,310	SA376 TP304	0.75	160	0.219	1.05	0.612	1750	14,880	25,884	68,500	21,392	36,580	-15,188	-7,655	44,235	47,950	0.92
Primary Water Supply to RCPs and PRT	33	212	SA312 TP304	3	10S	0.120	3.5	3.260	136	16,050	27,999	68,500	2,880	29,439	-26,559	-106	29,545	47,950	0.62
		212	SA312 TP304	2.5	10S	0.120	2.875	2.635	136	16,050	28,176	68,500	2,328	29,340	-27,012	-106	29,446	47,950	0.61
		212	SA312 TP304	1	40S	0.133	1.315	1.049	136	16,050	28,652	68,500	836	29,070	-28,234	-106	29,176	47,950	0.61
		212	SA312 TP304	0.75	40S	0.113	1.05	0.824	136	16,050	28,672	68,500	773	29,058	-28,285	-106	29,164	47,950	0.61
		212	SA312 TP304	0.5	40S	0.109	0.84	0.622	100	16,050	28,769	68,500	605	29,071	-28,466	-106	29,177	47,950	0.61
Demineralized Water Supply to Refueling Cavity Scrub Down Hose Connections	36	325	SA312 TP304	3	10S	0.120	3.5	3.260	156	16,050	27,868	68,500	4,415	30,075	-25,661	-163	30,238	47,950	0.63
		325	SA312 TP304	2	40S	0.154	2.375	2.067	156	16,050	28,403	68,500	2,181	29,493	-27,312	-163	29,656	47,950	0.62
		325	SA312 TP304	1	40S	0.133	1.315	1.049	156	16,050	28,617	68,500	1,282	29,258	-27,976	-163	29,420	47,950	0.61

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Table A-3:
Appendix F Stress Evaluation

Pipe Segment	CPN	Maximum Pipe Pressure (psi)	Pipe Material	Nominal Pipe Size (inch)	Pipe Schedule	Thickness (inch)	Actual Pipe Size (inch)	Inside Diameter (inch)	Design Pressure (psig)	Design Allowable Stress (psi)	Max Bending Stress Due to DW + Seismic, Pb (psi)	Su (psi)	S1 (psi)	S2+ (psi)	S2- (psi)	S3 (psi)	SI (psi)	0.7 Su (psi)	Apendix F Stress Index
See Note:		1	2	2	2	3	4	5	6	7	9	7	9	9	9	9	9	9	9
RCP Seal Water Line	37	1,800	SA312 TP304	4	10S	0.120	4.5	4.260	150	16,050	27,595	68,500	31,950	43,570	-11,620	-900	44,470	47,950	0.93
		1,800	SA312 TP304	1	40S	0.133	1.315	1.049	150	16,050	28,628	68,500	7,098	32,177	-25,078	-900	33,077	47,950	0.69
Reacor Coolant Drain Tank Pump Suction	40	262	SA312 TP304	4	10S	0.120	4.5	4.260	100	16,050	28,027	68,500	4,651	30,352	-25,702	-131	30,483	47,950	0.64
		262	SA312 TP304	2	40S	0.154	2.375	2.067	100	16,050	28,578	68,500	1,758	29,457	-27,699	-131	29,588	47,950	0.62
		262	SA312 TP304	1	40S	0.133	1.315	1.049	100	16,050	28,715	68,500	1,033	29,232	-28,198	-131	29,363	47,950	0.61
		262	SA312 TP304	0.75	40S	0.113	1.05	0.824	100	16,050	28,730	68,500	955	29,207	-28,252	-131	29,338	47,950	0.61
Containment Sump Pump Discharge	41	212	SA312 TP304	3	10S	0.120	3.5	3.260	60	16,050	28,497	68,500	2,880	29,937	-27,057	-106	30,043	47,950	0.63
		212	SA312 TP304	2	40S	0.154	2.375	2.067	60	16,050	28,703	68,500	1,423	29,414	-27,991	-106	29,520	47,950	0.62
		212	SA312 TP304	1	40S	0.133	1.315	1.049	60	16,050	28,785	68,500	836	29,203	-28,367	-106	29,309	47,950	0.61
Sample Line From Pressurizer Liquid Space	66	17,800	SA213 TP316	0.5	--	0.065	0.5	0.370	2485	15,350	24,622	74,200	50,662	49,953	709	-8,900	59,562	51,940	1.15
Sample Line From Accumulators	81	17,400	SA213 TP316	0.5	--	0.065	0.5	0.370	600	15,350	26,904	74,200	49,523	51,665	-2,142	-8,700	60,365	51,940	1.16
Sample Line From Hot Legs	66	17,800	SA213 TP316	0.5	--	0.065	0.5	0.370	2485	15,350	24,622	74,200	50,662	49,953	709	-8,900	59,562	51,940	1.15
RCP Seal Bypass Line	N/A	16,940	SA376 TP304	1	160	0.250	1.315	0.815	2735	14,880	25,078	68,500	27,612	38,884	-11,272	-8,470	47,354	47,950	0.988
		16,940	SA376 TP304	0.75	160	0.219	1.05	0.612	2735	14,880	25,377	68,500	23,670	37,212	-13,542	-8,470	45,682	47,950	0.95

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Table A-4:
Strain Evaluation

Pipe Segment	CPN	Maximum Pipe Pressure (psi)	Pipe Material	Nominal Pipe Size (inch)	Pipe Schedule	Thickness (inch)	Actual Pipe Size (inch)	Inside Diameter (inch)	Design Pressure (psig)	Design Allowable Stress (psi)	Hoop Stress (psi)	Yield Strength (psi)	Elastic Modulus (psi)	Plastic Modulus (psi)	Yield Strain (in/in)	Total Strain (in/in)	Permitted Strain (in/in)
See Note:		1	2	2	2	3	4	5	6	7	10	7	7	7	11	12	13
NESW Cooling for Lower Containment Ventilation Units (4 segments)	Multiple	215	A106 Gr B	6	40	0.280	6.625	6.065	125	15,000	2,329	31,450	28.6E+6	Not Used	1.10E-03	0.0082%	5.0%
		215	A106 Gr B	4	40	0.237	4.5	4.026	125	15,000	1,826	31,450	28.6E+6	Not Used	1.10E-03	0.0064%	5.0%
		215	A106 Gr B	2.5	40	0.203	2.875	2.469	125	15,000	1,307	31,450	28.6E+6	Not Used	1.10E-03	0.0046%	5.0%
		215	A106 Gr B	1	80	0.179	1.315	0.957	125	15,000	575	31,450	28.6E+6	Not Used	1.10E-03	0.0020%	5.0%
		215	A106 Gr B	0.5	80	0.147	0.84	0.546	125	15,000	399	31,450	28.6E+6	Not Used	1.10E-03	0.0014%	5.0%
		215	SA312 TP304	6	40S	0.280	6.625	6.065	125	16,050	2,329	23,750	27.3E+6	425,000	8.70E-04	0.0085%	5.0%
		215	SA312 TP304	0.5	40S	0.109	0.84	0.622	125	16,050	613	23,750	27.3E+6	425,000	8.70E-04	0.0022%	5.0%
		215	ASTM B75	0.625	--	0.035	0.625	0.555	125	5,125	--	--	--	--	--	--	--
NESW Cooling for Upper Containment Ventilation Units (4 segments)	Multiple	711	A106 Gr B	3	40	0.216	3.5	3.068	125	15,000	5,049	31,450	28.6E+6	Not Used	1.10E-03	0.0177%	5.0%
		711	A106 Gr B	2	80	0.218	2.375	1.939	125	15,000	3,162	31,450	28.6E+6	Not Used	1.10E-03	0.0111%	5.0%
		711	A106 Gr B	1.5	80	0.200	1.9	1.500	125	15,000	2,666	31,450	28.6E+6	Not Used	1.10E-03	0.0093%	5.0%
		711	A106 Gr B	1	80	0.179	1.315	0.957	125	15,000	1,901	31,450	28.6E+6	Not Used	1.10E-03	0.0067%	5.0%
		711	A106 Gr B	0.5	80	0.147	0.84	0.546	125	15,000	1,320	31,450	28.6E+6	Not Used	1.10E-03	0.0046%	5.0%
		711	SA312 TP304	3	40S	0.216	3.5	3.068	125	16,050	5,049	23,750	27.3E+6	425,000	8.70E-04	0.0185%	5.0%
		711	SA312 TP304	0.5	40S	0.109	0.84	0.622	125	16,050	2,029	23,750	27.3E+6	425,000	8.70E-04	0.0074%	5.0%
		711	ASTM B75	0.625	--	0.035	0.625	0.555	125	5,125	--	--	--	--	--	--	--

Table A-4: Strain Evaluation

Pipe Segment	CPN	Maximum Pipe Pressure (psi)	Pipe Material	Nominal Pipe Size (inch)	Pipe Schedule	Thickness (inch)	Actual Pipe Size (inch)	Inside Diameter (inch)	Design Pressure (psig)	Design Allowable Stress (psi)	Hoop Stress (psi)	Yield Strength (psi)	Elastic Modulus (psi)	Plastic Modulus (psi)	Yield Strain (in/in)	Total Strain (in/in)	Permitted Strain (in/in)
See Note:		1	2	2	2	3	4	5	6	7	10	7	7	7	11	12	13
NESW Cooling for RCP Motor Air Coolers (4 segments)	Multiple	711	A106 Gr B	3	40	0.216	3.5	3.068	125	15,000	5,049	31,450	28.6E+6	Not Used	1.10E-03	0.0177%	5.0%
		711	A106 Gr B	2.5	40	0.203	2.875	2.469	125	15,000	4,324	31,450	28.6E+6	Not Used	1.10E-03	0.0151%	5.0%
		711	A106 Gr B	1	80	0.179	1.315	0.957	125	15,000	1,901	31,450	28.6E+6	Not Used	1.10E-03	0.0067%	5.0%
		711	A106 Gr B	0.5	80	0.147	0.84	0.546	125	15,000	1,320	31,450	28.6E+6	Not Used	1.10E-03	0.0046%	5.0%
		711	SA312 TP304	3	40S	0.216	3.5	3.068	125	16,050	5,049	23,750	27.3E+6	425,000	8.70E-04	0.0185%	5.0%
		711	SA312 TP304	0.5	40S	0.109	0.84	0.622	125	16,050	2,029	23,750	27.3E+6	425,000	8.70E-04	0.0074%	5.0%
		711	ASTM B75	0.625	--	0.035	0.625	0.555	125	5,125	--	--	--	--	--	--	--
NESW Cooling for Instrumentation Room Ventilation Units (2 segments)	Multiple	325	A106 Gr B	3	40	0.216	3.5	3.068	125	15,000	2,308	31,450	28.6E+6	Not Used	1.10E-03	0.0081%	5.0%
		325	A106 Gr B	2.5	40	0.203	2.875	2.469	125	15,000	1,976	31,450	28.6E+6	Not Used	1.10E-03	0.0069%	5.0%
		325	A106 Gr B	2	80	0.218	2.375	1.939	125	15,000	1,445	31,450	28.6E+6	Not Used	1.10E-03	0.0051%	5.0%
		325	A106 Gr B	1.5	80	0.200	1.9	1.500	125	15,000	1,219	31,450	28.6E+6	Not Used	1.10E-03	0.0043%	5.0%
		325	A106 Gr B	1	80	0.179	1.315	0.957	125	15,000	869	31,450	28.6E+6	Not Used	1.10E-03	0.0030%	5.0%
		325	A106 Gr B	0.5	80	0.147	0.84	0.546	125	15,000	604	31,450	28.6E+6	Not Used	1.10E-03	0.0021%	5.0%
		325	SA312 TP304	2	40	0.154	2.375	2.067	125	16,050	2,181	23,750	27.3E+6	425,000	8.70E-04	0.0080%	5.0%
		325	SA312 TP304	0.5	80	0.147	0.84	0.546	125	16,050	604	23,750	27.3E+6	425,000	8.70E-04	0.0022%	5.0%
		325	ASTM B75	0.625	--	0.035	0.625	0.555	125	5,125	--	--	--	--	--	--	--

Table A-4:
Strain Evaluation

Pipe Segment	CPN	Maximum Pipe Pressure (psi)	Pipe Material	Nominal Pipe Size (inch)	Pipe Schedule	Thickness (inch)	Actual Pipe Size (inch)	Inside Diameter (inch)	Design Pressure (psig)	Design Allowable Stress (psi)	Hoop Stress (psi)	Yield Strength (psi)	Elastic Modulus (psi)	Plastic Modulus (psi)	Yield Strain (in/in)	Total Strain (in/in)	Permitted Strain (in/in)
See Note:		1	2	2	2	3	4	5	6	7	10	7	7	7	11	12	13
Accumulator Fill Line	32	15,310	SA376 TP304	1	160	0.250	1.315	0.815	1750	14,880	24,955	23,750	27.3E+6	425,000	8.70E-04	0.3706%	5.0%
		15,310	SA376 TP304	0.75	160	0.219	1.05	0.612	1750	14,880	21,392	23,750	27.3E+6	425,000	8.70E-04	0.0784%	5.0%
Primary Water Supply to RCPs and PRT	33	212	SA312 TP304	3	10S	0.120	3.5	3.260	136	16,050	2,880	23,750	27.3E+6	425,000	8.70E-04	0.0105%	5.0%
		212	SA312 TP304	2.5	10S	0.120	2.875	2.635	136	16,050	2,328	23,750	27.3E+6	425,000	8.70E-04	0.0085%	5.0%
		212	SA312 TP304	1	40S	0.133	1.315	1.049	136	16,050	836	23,750	27.3E+6	425,000	8.70E-04	0.0031%	5.0%
		212	SA312 TP304	0.75	40S	0.113	1.05	0.824	136	16,050	773	23,750	27.3E+6	425,000	8.70E-04	0.0028%	5.0%
		212	SA312 TP304	0.5	40S	0.109	0.84	0.622	100	16,050	605	23,750	27.3E+6	425,000	8.70E-04	0.0022%	5.0%
Demineralized Water Supply to Refueling Cavity Scrub Down Hose Connections	36	325	SA312 TP304	3	10S	0.120	3.5	3.260	156	16,050	4,415	23,750	27.3E+6	425,000	8.70E-04	0.0162%	5.0%
		325	SA312 TP304	2	40S	0.154	2.375	2.067	156	16,050	2,181	23,750	27.3E+6	425,000	8.70E-04	0.0080%	5.0%
		325	SA312 TP304	1	40S	0.133	1.315	1.049	156	16,050	1,282	23,750	27.3E+6	425,000	8.70E-04	0.0047%	5.0%

Table A-4:
Strain Evaluation

Pipe Segment	CPN	Maximum Pipe Pressure (psi)	Pipe Material	Nominal Pipe Size (inch)	Pipe Schedule	Thickness (inch)	Actual Pipe Size (inch)	Inside Diameter (inch)	Design Pressure (psig)	Design Allowable Stress (psi)	Hoop Stress (psi)	Yield Strength (psi)	Elastic Modulus (psi)	Plastic Modulus (psi)	Yield Strain (in/in)	Total Strain (in/in)	Permitted Strain (in/in)
See Note:		1	2	2	2	3	4	5	6	7	10	7	7	7	11	12	13
RCP Seal Water Line	37	1,800	SA312 TP304	4	10S	0.120	4.5	4.260	150	16,050	31,950	23,750	27.3E+6	425,000	8.70E-04	2.0164%	5.0%
		1,800	SA312 TP304	1	40S	0.133	1.315	1.049	150	16,050	7,098	23,750	27.3E+6	425,000	8.70E-04	0.0260%	5.0%
Reacor Coolant Drain Tank Pump Suction	40	262	SA312 TP304	4	10S	0.120	4.5	4.260	100	16,050	4,651	23,750	27.3E+6	425,000	8.70E-04	0.0170%	5.0%
		262	SA312 TP304	2	40S	0.154	2.375	2.067	100	16,050	1,758	23,750	27.3E+6	425,000	8.70E-04	0.0064%	5.0%
		262	SA312 TP304	1	40S	0.133	1.315	1.049	100	16,050	1,033	23,750	27.3E+6	425,000	8.70E-04	0.0038%	5.0%
		262	SA312 TP304	0.75	40S	0.113	1.05	0.824	100	16,050	955	23,750	27.3E+6	425,000	8.70E-04	0.0035%	5.0%
Containment Sump Pump Discharge	41	212	SA312 TP304	3	10S	0.120	3.5	3.260	60	16,050	2,880	23,750	27.3E+6	425,000	8.70E-04	0.0105%	5.0%
		212	SA312 TP304	2	40S	0.154	2.375	2.067	60	16,050	1,423	23,750	27.3E+6	425,000	8.70E-04	0.0052%	5.0%
		212	SA312 TP304	1	40S	0.133	1.315	1.049	60	16,050	836	23,750	27.3E+6	425,000	8.70E-04	0.0031%	5.0%
Sample Line From Pressurizer Liquid Space	66	17,800	SA213 TP316	0.5	--	0.065	0.5	0.370	2485	15,350	50,662	24,550	27.3E+6	450,000	8.99E-04	5.8925%	5.0%
Sample Line From Accumulators	81	17,400	SA213 TP316	0.5	--	0.065	0.5	0.370	600	15,350	49,523	24,550	27.3E+6	450,000	8.99E-04	5.6395%	5.0%
Sample Line From Hot Legs	66	17,800	SA213 TP316	0.5	--	0.065	0.5	0.370	2485	15,350	50,662	24,550	27.3E+6	450,000	8.99E-04	5.8925%	5.0%
RCP Seal Bypass Line	N/A	16,940	SA376 TP304	1	160	0.250	1.315	0.815	2735	14,880	27,612	23,750	27.3E+6	425,000	8.70E-04	0.9957%	5.0%
		16,940	SA376 TP304	0.75	160	0.219	1.05	0.612	2735	14,880	23,670	23,750	27.3E+6	425,000	8.70E-04	0.0867%	5.0%

Prepared by:
Checked by:

Notes to Tables:

1. Max pressures are from Reference 1 calculations.
2. Pipe materials, sizes and schedules are from drawings in References 9-11.
   Where multiple schedules are installed, only the thinner schedule is considered.
3. Thicknesses for pipe are from Crane (Reference 14) for corresponding pipe schedules.
   Thickness for NESW heat exchanger tubing is from Reference 11 (same for all coils).
   Thickness for sample line tubing is from Reference 3 for Class O-14 tube.
4. Actual pipe sizes are from Crane.
5. ID = Actual OD - 2*thickness.
6. Pipe design pressures and temperatures from References 2 and 3.
7. From Table 2 of calculation.
8. From equations in Section 3.1.
9. From equations in Section 3.2.
10. Hoop stress = S1 from Table A-2.
11. Yield strain = yield stress / elastic modulus.
12. If S1 < yield strength, strain = S1 / elastic modulus.
    If S1 > yield strength, strain = (S1 - yield strength) / plastic modulus + yield strain.
13. Permitted strain from Section 3.2 of calculation.

ATTACHMENT 7 TO C0801-05

MPR CALCULATION 025-065-02

“DETERMINATION OF PEAK PRESSURES IN D. C. COOK UNIT 1 PIPING SEGMENTS ISOLATED BY AIR OPERATED GLOBE VALVES”

MPR-2169 Appendix A.2

MPR Associates, Inc.
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CALCULATION TITLE PAGE

Client American Electric Power	Page 1 of 49
Project Evaluation of D.C. Cook Unit 1 Piping Segments for Potential Thermal Overpressurization	Task No. 025-0013-065-0
Title Determination of Peak Pressures in D.C. Cook Unit 1 Piping Segments Isolated by Air Operated Globe Valves	Calculation No. 025-065-02

Preparer/Date	Checker/Date	Reviewer/Approver/Date	Rev. No.
9/8/00	S R Harp 9/8/00	9-8-00	0

QUALITY ASSURANCE DOCUMENT

This document has been prepared, checked and reviewed/approved in accordance with the Quality Assurance requirements of 10CFR50, Appendix B, as specified in the MPR Quality Assurance Manual.

RECORD OF REVISIONS

Calculation No.	Prepared By	Checked By	Page 2
025-065-02	M E T	S R Harp	

Revision	Description
0	Original Issue.

CONTENTS

1.0 PURPOSE

The purpose of this calculation is to determine the peak pressures that can be obtained in piping segments susceptible to thermal overpressurization that are isolated by air operated globe valves at the D. C. Cook Nuclear Power Station, Unit 1. The pressures determined in this calculation are to be used in a separate stress analysis of the piping segments. The lines that contain globe valves are the accumulator fill line (CPN 32) and the RCP seal bypass line.

Two separate calculations of peak pressure will be made, as follows:

- The peak pressure is taken as the pressure at which valves installed in the segments will open. This is the maximum pressure that can be achieved in the line for the case where the valves are installed such that system pressure is applied under the valve plug during overpressurization.
- The peak pressure is also calculated assuming no leakage through the valves.

2.0 RESULTS

The pressures listed below will force the valves open.

Table 1: Results Summary

Segment	Case 1: Maximum Line Pressure to Open Valves (psig)	Case 2: Line Pressure With No Valve Leakage (psig)
RCP Seal Bypass Line	12,310	16,940
Accumulator Fill Line	6,930	15,310

For Case 1:

> Segment pressures equal to those shown will cause one or more valves to open. The forces generated by these pressures are equivalent to the opening force applied by the air operator at the nominal control air header supply pressure. This is a conservative calculation because the valves will begin to open at pressures lower than those above.
>
> These results are based on inputs that require verification; specifically, the plug area exposed to segment pressure for the accumulator fill line, and the valve flow direction for both lines. Refer to Section 4.0 for the information that requires verification.

For Case 2:

> Segment pressures are calculated assuming no leakage through the isolation valves.

These results will be used in separate evaluations for the pipe and valves in these segments.

3.0 CALCULATION

3.1 Globe Valves Installed in Piping Segments at Cook Unit 1

Each of the segments considered in this calculation is isolated using one or more air operated globe valve. These valves are air to open, spring to close valves.

The valves installed in each segment are listed in Table 2, along with configuration information obtained from various plant sources. Each of these valves is shut during isolation and each is subject to the segment internal pressure.

Table 2. List of Air Operated Globe Valves in Segments Considered

Segment	CPN	Globe Valve Tag Numbers	Valve Size	Drawing
RCP Seal Bypass Line	N/A	1-QRV-150	¾”	Copes Vulcan Inc. Model D100-100 Operator ¾”-1500 LB U.S.A STD DWG. No. L-137857 (Ref. 1)
Accumulator Fill Line	32	1-IRV-050, 1-IRV-060 1-IRV-111, 1-IRV-121 1-IRV-131, 1-IRV-141	1”	Copes Vulcan Inc. Model D100-100 Operator 1”-1500 LB U.S.A STD DWG. No. L-137968 (Ref. 2)
		1-IRV-115, 1-IRV-116 1-IRV-125, 1-IRV-126 1-IRV-135, 1-IRV-136 1-IRV-145, 1-IRV-146 1-IRV-147, 1-IRV-148	¾”	Copes Vulcan Inc. Model D100-100 Operator ¾”-1500 LB U.S.A STD DWG. No. L-140209 (Ref. 3)
		1-IRV-149, 1-IRV-150	¾”	2-AEP-MASN-CP1-18-55 (Ref. 4)

3.2 Case 1: Segment Pressure Acts to Open System Valves

During thermal overpressurization incidents (such as might occur when segments are isolated during pipe breaks in containment), water pressure will build in the isolated segment until the force on the valve plug overcomes the forces holding the valve closed – provided the valve is installed such that this pressure acts on the plug in a direction that would cause the plug to lift off the seat. At this point the valve will begin to open, and relieve the trapped water.

This calculation will determine the segment water pressure which would be required to overcome the spring force and hence permit the trapped water to escape through the opened valve. Separate calculations are provided for each segment.

3.2.1 RCP Seal Bypass Line

To determine the required system pressure under this plug to overcome the spring force keeping the valve closed, the following steps are taken.

1. First, calculate the force needed to open the valve (F_{open}). To simplify this analysis, this force will be determined by multiplying the nominal control air header pressure supplied to the valve (p_a) by the actuator area (A_a):

   $$F_{open} = p_a A_a$$

   This is conservative because the valve will begin to open at a lower air actuator pressure than the full control air header nominal pressure. The control air header flow diagrams listed in Reference 5 show that the nominal control air header pressure supplied to this valve is 85 psig. The actuator area for this type of valve is 100 square inches as shown in Reference 6. Accordingly, the maximum force that the air can apply to the actuator to open the valve is 8500 pounds. Since based on plant experience it is known that the valve will open when this 85 psig air pressure is applied, this pressure must be sufficient to overcome the actuator spring, stem friction, and the effects of system pressure on the other side of the plug.

2. Calculate the plug area subject to system pressure acting to open the valve, A_{plug}.

   $$A_{plug} = d_{seat\ opening}{}^2\pi/4$$

   Per Reference 11, the cage inside diameter for valve 1-QRV-150 is 15/16". The corresponding plug area subject to pressure is then 0.69 in^2.

3. For globe valves with flow up from under the seat, the segment pressure required to open the valve, without the aid of the actuator, is the opening force divided by the area of the plug,

   $$p_{open} = F_{open} / A_{plug} = 8500\ \text{lbs} / 0.69\ \text{in}^2 = 12{,}310\ \text{psig}$$

3.2.2 Accumulator Fill Line

As shown in Table 2, there are three types of valves installed in this system. The drawing for the ¾" valve types show a small seat opening dimension, so these valves will not be likely to open during pressurization. Accordingly, only the 1" Copes Vulcan valve type will be considered.

The 1" valves shown on L-137968 are shown with a wide plug and valve seat. The plug fits over the stem. Per valve packing calculations for valve 1-IRV-111 (Reference 8) the stem diameter is 0.75". Per the vendor drawing the plug is significantly larger than the stem; in this calculation the assumed plug diameter is 1.25", which must be verified (see Section 4). The plug area is therefore 1.23 in^2 for these valves. Per the control air header flow diagrams (References 5 and 9), these valves are supplied with 85 psig air to open. Since the valves have 100 in^2 actuators, an opening force of 8500 pounds is considered in this calculation. The system pressure required to open the valve is then

$$p_{open} = F_{open} / A_{plug} = 8500 \text{ lb} / 1.23 \text{ in}^2 = 6{,}930 \text{ psig}$$

3.3 Case 2: Segment Pressure Assuming No Valve Leakage

If the valves do not leak, the pressure inside the isolated pipe segment will increase as the pipe heats up in the hot containment atmosphere. The peak pressure reached will depend on the peak temperature achieved in the piping. This peak temperature is in turn a function of the heat transfer between the containment atmosphere and the water inside the piping.

Accordingly, calculation of peak temperature and the resulting pressure is described in the following sections.

3.3.1 Calculation of Peak Temperature

Review of lower compartment temperature data (from Reference 12) for the LOCA and main steam line break scenarios shows the following:

- For LOCAs, the temperature rises quickly to nearly 235°F initially, after which the temperature drops significantly. During the first part of the accident the containment pressure is 7-8 psig. Since saturation temperature at these pressures is about 235°F, it is conservative to assume that the steam will condense on the metal pipe surface. Since condensation heat transfer is very effective at transferring heat, this calculation will assume that the piping immediately reaches the peak temperature of 235°F during LOCA.

- For main steam line breaks, the lower compartment temperature peaks at about 325°F for a brief time following the break, during which time the containment pressure drops from a maximum of about 9 psig to about 7 psig. Since the 325°F temperature exceeds the saturation temperature of steam at this pressure (roughly 235°F), heat transfer during this time is by forced convection rather than condensation. Forced convection heat transfer rates are dependent on flow velocity and are less than condensation heat transfer rates. Attachment A to this calculation provides a conservative estimate of the heatup of the pipe under main steam line break conditions. Results show that under worst case conditions the bulk of the piping in these two segments will not reach 235°F while the temperature in the containment is 325°F; following that time, the containment temperature drops below 235°F. Accordingly, use of 235°F as the peak temperature of the piping conservatively bounds the temperature main steam line break scenario.

3.3.2 Calculation of Resulting Pressure

The analysis approach uses the maximum water temperature, the pipe stiffness and pipe material properties to calculate the resulting internal pressure and material stress-strain state for a postulated increase in temperature scenario. The specific steps in the analysis procedure are described below.

- The isolated piping segment arrangement is reviewed to determine the pipe sections and materials. The information on each pipe is required to determine the pressure in the entire piping segment.

- A bi-linear stress-strain curve for the specific pipe material (Type 304 stainless steel) is developed. Both the elastic stretching of the pipe wall as well as the plastic deformation of the pipe with strain hardening is considered.

- An equation of state for the water in the isolated piping segments is developed, which relates pressure to specific volume at the given temperature. The equation of state is developed from the ASME Steam Tables (Reference 13).

- A set of simultaneous equations relating pipe stress and strain to the water mass, specific volume and pressure is developed. The solution of the equations provides the final water pressure and piping segment pressure stress.

Geometry and Material Data

The data required for each piping segment are the pipe diameter, wall thickness and material properties for each cross section included in the isolated segment. The piping geometry is found in isometric drawings listed in References 18 and 19. The material data include: material class and material type (Reference 15), design stress intensity (S_m), yield stress (S_y), ultimate strength (S_u), elastic modulus (E), and plastic modulus (E_p). The plastic modulus is determined based on the stress-strain curve shown in Figure 1 (from Reference 16). The remaining material properties are extracted from the 1989 ASME Code (Reference 17). Material properties are evaluated at 235°F.

Review of isometric drawings (References 18 and 19) shows that the two segments of interest are constructed of ¾" and 1" schedule 160, SA376 type 304 stainless steel. The geometry and material data for these pipe materials are listed in Table 3. Nominal pipe wall thickness was used for the evaluations.

Table 3: Geometry and Material Properties, 235°F

Pipe Size	Sched.	Geometry Data		Material Data						
		OD (in)	Wall (in)	Class	Type	S_m (ksi)	S_y (ksi)	S_u (ksi)	E (10^6 psi)	E_p (10^6 psi)
1 in	160	1.315	0.25	M-14	SA376 TP304	20.0	24.13	69.25	27.4	0.425
3/4 in	160	1.050	0.219	M-14	SA376 TP304	20.0	24.13	69.25	27.4	0.425

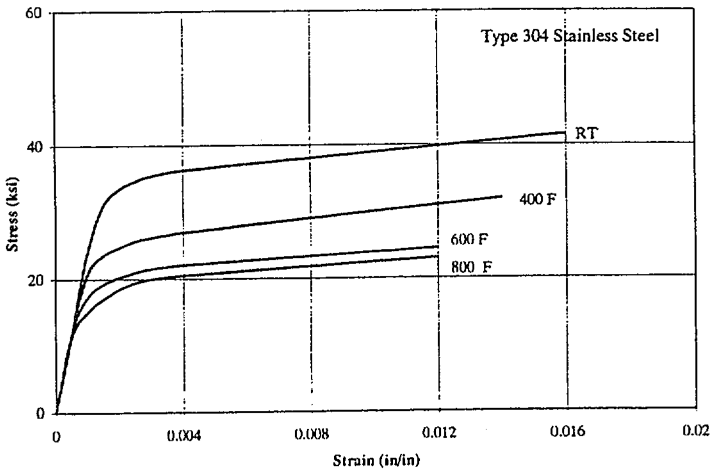


Figure 1: Type 304 Stainless Steel Stress-Strain Curve.

Note that the values from Table 3 are used in the calculation for yield strength.

Fluid Properties

The calculations to determine maximum internal pressure are performed for the maximum bounding piping segment water temperature of 235°F. These piping stress calculations assume the piping segments are initially at their maximum pressures and at minimum containment ambient conditions:

Accumulator Fill Line:	70°F, 1750 psig, ν= 0.015963 ft^3/lbm
RCP Seal Bypass Line:	70°F, 2480 psig, ν= 0.015928 ft^3/lbm

where specific volumes (ν) are obtained from the ASME Steam Tables. Maximum pressure for the accumulator fill line is the design pressure for the system per the piping specification; the RCP seal bypass pressure is the maximum operating pressure from the specification.

Figure 2 shows the relationship between pressure and specific volume at a temperature of 235°F (from the ASME Steam Tables). A polynomial curve fit is also shown of the equation of state for the fluid. This equation will be used in the determination of fluid pressure for the maximum temperature conditions.

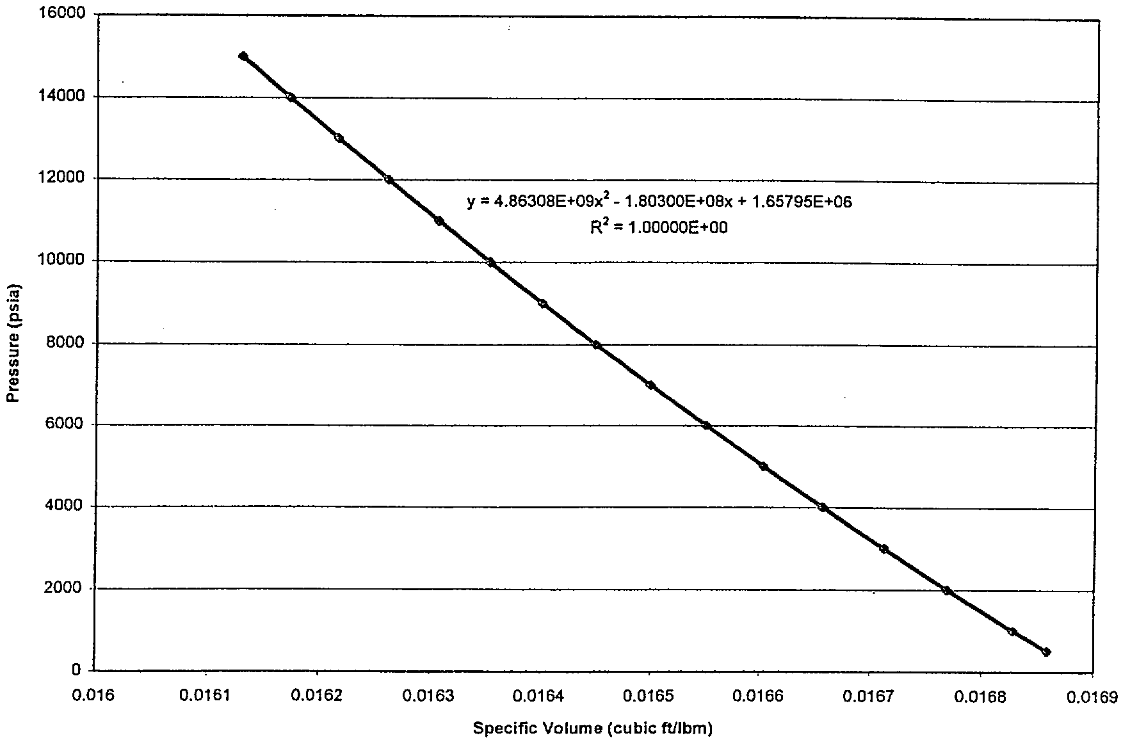


Figure 2: Equation of State for Water at 235°F

Pressure Calculation

For the general case in which a piping segment has a single pipe size and material, the fluid pressure and piping stress-strain solution are determined by solving a set of six simultaneous equations with six unknowns. The six unknowns representing the pressurized condition in the isolated segment are:

P = Internal pressure (psia)
ν = Specific volume (ft^3/lb)
σ_h = Pipe hoop stress (psi)
ϵ_p = Pipe hoop strain (in/in)
r = Pipe inside radius (in)
vol = Volume of water (ft^3)

The following constants are used to solve for the unknown variables:

t = Pipe wall thickness (in)
m_w = Mass of water (lb)
ϵ_y = Pipe yield strain (in/in) (= S_y/E)
α_T = Therm. expansion coeff. (in/in/°F)
r_0 = Initial pipe inside radius (inch)
S_y = Pipe yield stress (psi)
E = Pipe elastic modulus (psi)
E_p = Pipe plastic modulus (psi)

The set of equations that define the fluid state and stress-strain state are:

Membrane Stress:	$\sigma_h = (P\ r)/(t)$	
Volume (per unit length):	$vol = \pi(r^2)$	
Stress - Strain:	$\sigma_h = S_y + (\epsilon_p - \epsilon_y)\ E_p$	for $\sigma_h > S_y$
	$\sigma_h = \epsilon_p\ E$	for $\sigma_h < S_y$
Specific Volume:	$\nu = vol / m_w$	
Equation of State (235°F):	$P(\nu) = 4.86308x10^9\ \nu^2 - 1.80300x10^8\ \nu + 1.65795x10^6$	
Radius:	$r = (1 + \epsilon_p)\ r_0$	

In addition, the thermal expansion of the material in the circumferential and longitudinal directions is considered. The mean coefficient of thermal expansion for the piping material (SA-376 TP304) is used to calculate the material expansion due to heat up from 70°F to 235°F. The value for this heatup is 8.83E-6 in/in-°F per Reference 17, Table I-5.0.

The strain due to thermal expansion is

$$\epsilon_{th} = \alpha_T(\Delta T)$$

The equation for the pipe radius is modified to incorporate the thermal expansion:

$$r = (1 + \epsilon_p)\ (1 + \epsilon_{th})\ (r_0)$$

The set of equations listed above can be solved for a segment with a single material and single pipe cross section. For piping segments with multiple cross sections, the set of equations must be extended to account for the potential expansion of fluid from one section of pipe into another. Specifically, each segment contains lengths of ¾" and 1" Schedule 160 piping. The ¾" pipe is stiffer and stronger than the 1" pipe. Hence, as the fluid is heated and pressurized, the ¾" pipe would strain less than the 1" pipe. As a result, the fluid expansion in the ¾" pipe would result in a net flow into the 1" pipe. In other words, the net increase in volume in the 1" pipe section must include the expansion of the fluid initially in the ¾" pipe section.

In order to address multiple cross sections, the basic equation set is extended to include each section of pipe. The resulting set of unknowns is:

P	= Internal pressure (psia)	(one pressure for all pipes)
ν	= Specific volume (ft^3/lb)	(one specific volume for all pipes)
σ_{hi}	= Pipe *i* hoop stress (psi)	(one for each pipe)
ϵ_{pi}	= Pipe *i* hoop strain (in/in)	(one for each pipe)
r_i	= Pipe *i* inside radius (in)	(one for each pipe)

vol_i = Volume pipe i (ft^3) (one for each pipe)
m_{wi} = Mass of water pipe i (lb) (one for each pipe)

The additional unknowns (the mass of water in each pipe section) require two additional constants to be defined. The total mass of water is conserved for all cases because the piping segments are bounded by isolation valves.

L_i = Length of pipe i (ft) (one for each pipe)
m_{tot} = Total mass of water (lb) (total mass of all pipes)

Both the accumulator fill line and RCP seal bypass line are constructed of 1" and ¾" schedule 160 pipe in the region of interest. The lengths of different cross section pipe are determined from the drawings listed in References 18 and 19 and are as follows:

Pipe Segment	Length of 1" Pipe	Length of ¾" Pipe
Accumulator Fill Line	290 ft	20 ft
RCP Seal Bypass Line	170 ft	450 ft

Thus, the following set of equations is used to determine the conditions of a piping segment with multiple pipe cross sections.

Membrane Stress: $\sigma_{hi} = (P\ r_i)/(t_i)$
Volume: $vol_i = \pi(r_i^{\ 2})(L_i)$
Stress - Strain: $\sigma_{hi} = S_{yi} + (\epsilon_{pi} - \epsilon_{yi})\ E_{pi}$ for $\sigma_{hi} > S_{yi}$
$\sigma_{hi} = \epsilon_{pi}\ E_i$ for $\sigma_{hi} < S_{yi}$
Specific Volume: $\nu = vol_i / m_{wi}$
Equation of State: $P(\nu) = 4.86308\text{x}10^9\ \nu^2 - 1.80300\text{x}10^8\ \nu + 1.65795\text{x}10^6$
Radius: $r_i = (1 + \epsilon_p)\ (r_0)\ (\epsilon_{th}+1)$
Mass: $m_{tot} = \sum m_{wi}$

The equations and methods listed above are used to determine the fluid pressure and material stress-strain state for the segments isolated with air operated globe valves at D.C. Cook, Unit 1. The calculations are performed using MathCAD and the equations and results are shown in Attachment B. The results of these calculations are as follows:

Peak Pressure in Accumulator Fill Line:	15,310 psig
Peak Pressure in RCP Seal Bypass Line:	16,940 psig

Note that values shown above have been converted to psig.

In performing these calculations, several simplifying assumptions are made. These assumptions, which are conservative and are not considered to affect the calculation results, are as follows:

- The piping is bounded on each end by isolation valves. The isolation valve walls are thicker and stronger than the main piping. As a result, the strain in the valves will be less than the piping. The amount of water in the valves is assumed very small compared to the main piping. Thus, the expansion of this water (in the valve) and the possible strain of the valve body are neglected.

- The stronger valves will restrain the piping deflection at valve connections, preventing the piping from fully yielding and straining at that point (compared to the calculated values). The localized pipe strain at valve connections is neglected when calculating the pressure and stress/strain state of the piping.

- For conservatism, the expansion of the piping in the longitudinal direction due to pressure has been neglected.

4.0 INPUTS REQUIRING VERIFICATION

The calculation of valve opening pressure requires that the following information should be verified or determined:

For valve 1-QRV-150,
- Determine whether valve is installed such that trapped water would flow under the plug

For ONE of the 1" valves in the accumulator fill line (see table below),
- Determine whether valve is installed such that trapped water would flow under the plug
- Determine the area under the plug exposed to pressure

System	Model Number	Tag Numbers
Accumulator Fill Line	Copes Vulcan Inc. Model D100-100 Operator 1"-1500 LB U.S.A STD DWG. No. L-137968	1-IRV-050, 1-IRV-060 1-IRV-111, 1-IRV-121 1-IRV-131, 1-IRV-141

Until verification is provided, use the higher (more bounding) pressures calculated in Section 3.3 of this calculation, since those pressures are not dependent on information that requires verification.

5.0 REFERENCES

1. DWG. No. L-137857 Rev. 2 ,Copes Vulcan Inc. , Model D100-100 Operator, ¾”-1500 LB U.S.A STD.
2. DWG. No. L-137968 Rev. 2, Copes Vulcan Inc., Model D100-100 Operator, 1”-1500 LB U.S.A STD.
3. DWG. No. L-140209 Rev. 2, Copes Vulcan Inc., Model D100-100 Operator, 3/4”-1500 LB U.S.A STD.
4. DIT Number DIT-S-00335-00, dated 3/2/2000.
5. AEP Drawing OP-1-5120E, Rev. 12, “Flow Diagram, Containment Control Air 85# and 50# Ring Headers, Unit #1.”
6. AEP Procedure 12 EHP 5073.AOV.001, Revision 0.
7. Not used.
8. Valve Packing Configuration Data Sheet (12-EHP 5043.VLV.001) for valve 1-IRV-111, 3/14/2000.
9. AEP Drawing OP-1-5120D, Rev. 27, “Flow Diagram, Containment Control Air 85# and 50# Ring Headers, Unit #1.”
10. Not used.
11. AEP Design Input Transmittal Number DIT B-01518-00.
12. “Containment Pressure and Temperature Figures and Tabular Data for UFSAR Limiting Cases,” AEP-99-408, November 10, 1999.
13. “ASME Steam Tables,” ASME, 6th Edition.
14. Not used.
15. “Pipe Material Specification,” AEP Specification No. ES-Pipe-1013-QCN-CS3, Revision 1.
16. Aerospace Structural Metal Handbook, Volume 2, 1990, Code 1303, Figure 3.03112, Type 304 Stainless Steel.
17. 1989 ASME Code, Section III, Division I - Appendices.

18. Drawings of Containment Penetration CPN-32, Accumulator Fill Line.
    - OP-1-5143A-4
    - 1-SI-507L1.6, Revision 2
    - 1-SI-508L4.6, Revision 1
    - 1-SI-537-L5, Revision 1
    - 1-SI-537-L9.11, Revision 2
    - 1-SI-537-L16.19, Revision 1
    - 1-SI-538-L1.4, Revision 5
    - 1-SI-539.L2.3, Revision 0
    - 1-SI-540-L4.5, Revision 2
    - 1-SI-452.L1, Revision 0
    - 1-SI-543-L1.3, Revision 3
    - 1-SI-544.L1, Revision 1
    - 1-SI-547-L1.4, Revision 2
    - 1-SI-547.L9.11, Revision 2
    - OP-1-5142-35
    - 1-SI-508L1.3A, Revision 6
    - 1-SI-537-L1.4, Revision 2
    - 1-SI537-L6.8, Revision 2
    - 1-SI-537-L12.15, Revision 2
    - 1-SI-537-L20.21, Revision 0
    - 1-SI-539.L1, Revision 0
    - 1-SI-540-L1.3, Revision 3
    - 1-SI-541-L1, Revision 1
    - 1-SI-542.L2.3, Revision 1
    - 1-SI-543-L4.6, Revision 3
    - 1-SI-544.L2.3, Revision 0
    - 1-SI-547-L5.8, Revision 0
    - 1-SI-601L1, Revision 0

19. Drawings of RCP Seal Bypass
    - OP-1-5128A-42
    - 1-CS-766-L2, Revision 1
    - 1-CS-766L5.7, Revision 0
    - 1-CS-771-L1, Revision 1
    - 1-CS-771-L5.6, Revision 0
    - 1-CS-773L1, Revision 1
    - 1-CS-773-L5.11, Revision 1
    - 1-CS-775L1.5, Revision 4
    - 1-CS-775L11.12B, Revision 1
    - 1-CS-775L14.15, Revision 1
    - 1-CS-766-L1, Revision 0
    - 1-CS-766-L3.4, Revision 1
    - 1-CS-766-L8.11, Revision 1
    - 1-CS-771-L2.4, Revision 2
    - 1-CS-771-L7.10, Revision 1
    - 1-CS-773-L2.4, Revision 2
    - 1-CS-775L1A.1B, Revision 1
    - 1-CS-775L6.10, Revision 1
    - 1-CS-775L13, Revision 1
    - 1-CS-775L16.21, Revision 1

20. F.P. Incropera and D.P. DeWitt, "Fundamentals of Heat and Mass Transfer," John Wiley and Sons, 3rd Edition.

21. Cook UFSAR, Chapter 5.

22. AEP Drawing 12-5163-9, "Plant Arrangement Sections G-G, H-H, & K-K Units 1 & 2."

23. Crane Technical Paper No. 410, "Flow of Fluids," 1986.

Attachment A

Calculation of Maximum Temperature Achieved in Piping During Steam Line Break

PURPOSE

The purpose of this attachment is to document that the accumulator fill and RCP bypass seal lines do not heat above 235°F during main steam line break conditions in containment.

APPROACH

Forced convection heat transfer from the containment atmosphere to exposed piping is calculated as:

$$q_f'' = h\,A\,(T_{cont} - T_{pipe})$$

where:

q_f'' = heat transfer rate
h = convective heat transfer coefficient
T_{cont} = temperature of the containment as a function of time
T_{pipe} = temperature of water in the pipe

To determine the peak temperature during steam line break, the convective heat transfer coefficient is determined and used in the equation above.

A.1 Calculation of Heat Transfer Coefficient

For a cylinder in cross flow the heat transfer coefficient is calculated as follows (from Reference 20, page 344):

$$h = (k / D)\,C\,(Re)^m\,(Pr)^{1/3}$$

Where:

Re = Fluid Reynolds Number
Pr = Fluid Prandtl Number
k = Fluid thermal conductivity (Btu/hr-ft-°F)
D = Outer diameter of cylinder (ft)
C, m = Correlation constants as follows:

Re	C	m
0.4-4	0.989	0.330
4-40	0.911	0.385
40-4,000	0.683	0.466
4,000-40,000	0.193	0.618
40,000-400,000	0.027	0.805

The Reynolds Number is equal to:

$$Re = (V\,D)/\nu'$$

Where:

V = Fluid velocity (ft/sec)
ν' = Fluid kinematic viscosity (ft^2/sec)

From the above the heat transfer coefficient is dependent on the cylinder diameter, the fluid properties, and the velocity of flow over the cylinder. Conservative values for these parameters are used in this calculation, as follows:

Cylinder Diameter

The heat transfer correlation shows that heat transfer coefficient varies inversely with the diameter. Accordingly, a small diameter will be assumed. The smallest pipe in these lines is ¾" nominal, equal to 1.05" actual outside diameter; this value will be used in this calculation.

Fluid Properties

- Prandtl Number. The equation shows that heat transfer coefficient varies with the cube root of Prandtl number. Review of Appendix A of Reference 20 shows that the Prandtl number for both air and saturated water vapor is less than 1.0 at the temperature range of interest for this calculation. For simplicity and conservatism, use $(Pr)^{1/3} = 1.0$.
- Thermal Conductivity. The equation shows that heat transfer coefficient varies linearly with thermal conductivity. For conservatism, a high k value is used. From Appendix A of Reference 20, the peak value of k for air or water vapor over the temperature range of 70°F to 325°F is 0.037 W/m-K, which is equal to 0.021 BTU/hr-ft-°F.
- Kinematic Viscosity. The equation shows that heat transfer coefficient varies inversely with kinematic viscosity, which in turn varies directly with temperature and inversely with pressure. For conservatism and simplicity, one value of kinematic viscosity will be assumed for the duration of the accident. The

value chosen is the kinematic viscosity of air at 9 psig and 200°F of 1.47E-4 ft^2/sec (calculated by dividing the viscosity of air from Reference 20, Appendix A by the density at these conditions).

Velocity

Review of isometric drawings (References 18 and 19) shows that almost all piping in both lines is located in the containment pipe tunnel. This volume is located outside of the crane wall and is shielded from the jet effects of the steam line break by the floor at Elevation 612' per plant arrangement drawings (Reference 21). Accordingly, velocities in this volume will likely be small relative to velocities near a postulated steam line break location.

However, steam/air from the break may migrate to the pipe tunnel through leaks and penetrations. As the steam/air mass enters the volume, it will flow around and over these pipe segments and transfer heat by convection. An estimate may be made of the flow velocity by assuming a leak rate from adjacent higher pressure volumes into the pipe tunnel using Darcy's Law:

$$\Delta P = (\rho/144)\,(f\,L\,/\,D)(V^2\,/\,2g_c)$$

where ΔP = the pressure difference across the leak path, psi; ρ = density of flowing fluid, lbm/ft^3; f, L and D describe the flow resistance of the leak path; and V = flow velocity through the leak path, ft/sec.

Mass flow rate ($\underline{M}$) is related to velocity as follows:

$$\underline{M} = \rho V A$$

where A = flow area of the leak path. Rearranging and combining,

$$\underline{M} = [(\rho\,\Delta P)\,(288\,A^2\,D\,g_c\,/\,f\,L)]^{1/2}$$

The second term in the above equation reflects the parameters of the leak path and several constants. Replacing this parameter with a hole flow resistance coefficient K gives:

$$\underline{M} = [(\rho\,\Delta P)\,/\,K\,]^{1/2}$$

Here, K has the units of psi-$(lbm/ft^3)/(lbm/sec)^2$.

Note the following:

- If the flow path between the high pressure and low pressure volumes has a low flow resistance (K value), then the mass flow rate will be high and the volumes will quickly reach equal pressures. In this case the flow velocity will initially be high and then rapidly drop off.

- Conversely, if the flow resistance is high, then the mass flow rates will be lower and the time required to equilibrate in pressure will increase.

Mass entering the containment pipe tunnel will flow around the annulus and over the pipe segments. The velocity of flow can be calculated as a function of time as follows:

Step 1: Calculate the initial number of moles of gas in the pipe tunnel. For initial conditions, assume pipe tunnel is at 120°F initially and 14.7 psia. This minimizes the number of moles of air in containment, which will prolong the transient. Moles (n) are calculated from the ideal gas law as follows:

$$n = P\,(Vol) / (R\,T)$$

where

P = pressure in the volume, psia
Vol = containment volume, ft^3
R = universal gas constant, 10.73 psia- ft^3 / lbmole-°R
T = absolute temperature, °R

The volume of the dead-ended lower containment space is 61,702 ft^3 per Table 5.3-1 of the Cook UFSAR (Reference 22).

Step 2: Calculate the mass transferred over a time step into the volume from the higher pressure source. To do this, assume a hole flow resistance parameter K and use the following equation to find a mass flow rate:

$$\underline{M} = [(\rho\, \Delta P) / K\,]^{1/2}$$

using the upstream fluid density.

Step 3: Calculate the mass and pressure in the volume at the end of the time step. Use the ideal gas law to calculate pressure. For conservatism and simplicity, calculate this pressure assuming the temperature in the volume stays constant at the initial condition. (This is conservative because in reality the pressure would increase with temperature, slowing the flow rate into the volume.)

Step 4: Calculate the velocity in the pipe tunnel using the following equation:

$$V = \underline{M} / (\rho\, A_{cross})$$

where A_{cross} = cross sectional flow area of the pipe tunnel. Since the volume is an annular region with an outer diameter of 115', the average cross sectional area (A_{cross}) of this space is calculated as shown below:

$$A_{cross} = \text{Vol} / (\pi \text{ Diameter}) = 61{,}702 \text{ ft}^3 / (\pi\ 115') = 171 \text{ ft}^2$$

For conservatism, assume that all flow entering the tunnel flows in one direction.

These steps are repeated until the pressure inside the tunnel equals the pressure outside the tunnel, at which time the flow velocity will drop.

The Attachment A, Part 1 spreadsheets attached show the calculation of flow velocity for a range of K values assumed so as to cover the spectrum of flow resistances from large (slow pressurization rate, low velocity for a long duration) to small (high pressurization rate, high velocity for a short duration). Results show that after the first 2-3 seconds the flow velocities in the pipe tunnel are less than 20 feet per second for all ranges of hole resistance parameter. Hence, for conservatism, a value of 20 ft/sec will be assumed for bulk velocity in the pipe tunnel. Further, to account for local variations and the presence of flow obstructions, this value will be doubled:

$$V_{local} = 40 \text{ ft/sec}$$

This velocity is judged to bound the overall velocity through the pipe tunnel due to other effects as well (natural circulation, ventilation system discharge, etc.).

Heat Transfer Coefficient Calculation

Using the velocity and other parameters calculated above gives the following value for Reynolds Number:

$$Re = (V\,D) / \nu' = (40 \text{ ft/sec})\,(1.05")(1 \text{ ft}/12 \text{ inches})/(1.47\text{E-}4 \text{ ft}^2\text{/sec}) = 23{,}000$$

Using this value for Reynolds Number and the corresponding values for C and m gives the following value for heat transfer coefficient:

$$\begin{aligned} h &= (k / D)\, C\, (Re)^m\, (Pr)^{1/3} \\ &= [(0.021 \text{ BTU/hr-ft-°F})\,(12 \text{ inch} / 1 \text{ ft}) / (1.05")]\,(0.193)\,(23{,}000)^{0.618}\,(1.0) \\ &= 23 \text{ BTU/hr-ft}^2\text{-°F} \end{aligned}$$

A.2 Calculation of Temperature During Break Conditions

The heat transferred (Q, in BTU's) during a time step (dt) from the containment atmosphere to a pipe is calculated as follows:

$$Q = h\,A\,(T_{cont} - T_{pipe})\,(dt)$$

The heat transferred will heat up the pipe and water as follows:

$$\Delta T = Q / [(m_W C_{p,W}) + (m_P C_{p,P})]$$

where

ΔT = temperature increase (°F) due to transfer of Q BTU's
m_W, m_P = mass of water and pipe, lbm
$C_{p,W}$, $C_{p,P}$ = specific heat of water and pipe, BTU/lbm-°F

Per Crane (Reference 23), for the ¾" schedule 160 pipe:

Mass of metal = 1.94 pounds/ft
Mass of water = 0.128 pounds/ft
Surface area per foot = 0.275 square feet per foot

Also:

Heat capacity of metal = 477 J/kg K = 0.11 BTU/lbm-°F (per Reference 20, Table A.1 for 304)
Heat capacity of water = 1.0 BTU/lbm-°F

Therefore:

$$\begin{aligned}\Delta T &= Q / [(m_W C_{p,W}) + (m_P C_{p,P})] \\ &= Q / [(0.128 \text{ pounds/ft})(1.0 \text{ BTU/lbm-°F}) + (1.94 \text{ pounds/ft})(0.11 \text{ BTU/lbm-°F})] \\ &= Q / (0.341 \text{ BTU/°F-ft})\end{aligned}$$

Combining the above,

$$\Delta T \text{ per time step} = Q / [(m_W C_{p,W}) + (m_P C_{p,P})] = [h\ A\ (T_{cont} - T_{pipe})\ (dt)] / [(m_W C_{p,W}) + (m_P C_{p,P})]$$

The Attachment A, Part 2 spreadsheet calculates the peak temperature for the main steam line break using this equation and incrementing over the 127 second interval when the containment temperature is above 235°F. For conservatism and simplicity:

- The containment temperature is assumed to be constant at 325°F for the first 127 seconds following the accident. This bounds the temperature profiles for the two main steam line breaks considered in Reference 12.

- The heat transfer coefficient is conservatively set to 25 BTU/hr-ft^2-°F. Note that this heat transfer coefficient is for cross flow across a cylinder. This value is conservative because it exceeds the heat transfer coefficient calculated for almost the entire accident scenario, and since it represents cross flow heat transfer (whereas most piping in these two segments runs parallel to the flow in the annulus, and thus experiences less effective heat transfer).

- Only the ¾" pipe is considered, since it has a more limiting ratio of surface area to mass per unit length, and will therefore heat more quickly than larger pipes.

RESULTS

Results from the Attachment A, Part 2 spreadsheet indicate that the peak temperature achieved during steam line breaks is less than the 235°F assumed for LOCA events; accordingly, 235°F is the appropriate peak temperature in these segments.

Velocity Calculation as a Function of Hole Resistance Parameter K

Constants Used in Calculation:

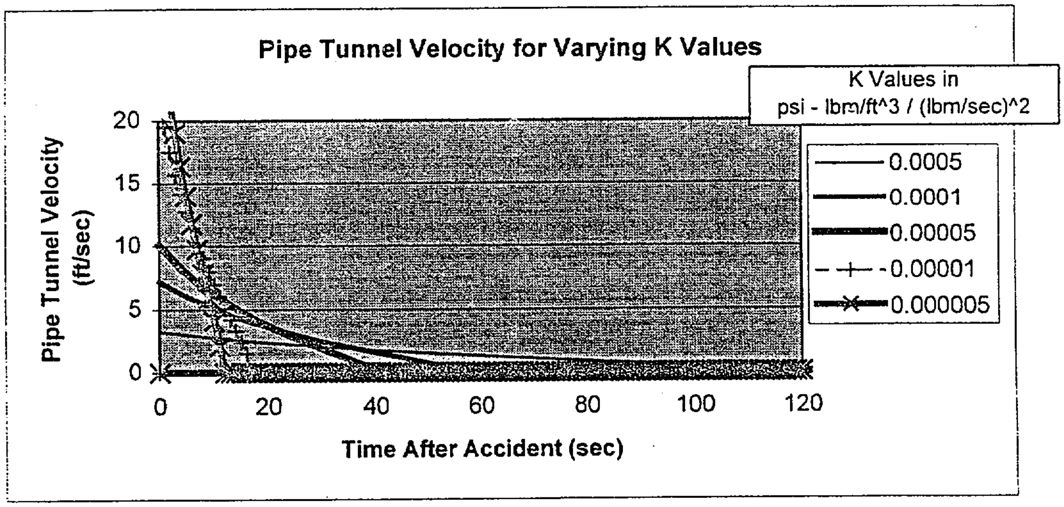
Total Volume of Pipe Tunnel:	61,702 ft^3
Mean Diameter of Pipe Tunnel:	115 ft
Cross Sectional Area of Pipe Tunnel:	171 ft^2 [= Volume / (pi * Diameter)]
Mole Weight of Upstream Gas (air):	29 lb/lbmole
Temperature of Upstream Gas:	325 deg F
Size of Time Step:	1 sec
Universal Gas Constant (R):	10.73 psia-ft^3/lbmole deg R

Calculation of Velocity versus Time:

See spreadsheets on following pages for various values of flow resistance parameter (K) for leakage path from the lower containment volume into the pipe tunnel.

Results:

The figure below shows velocity as a function of flow resistance parameter (K) over the course of the main steam line break transient.



Velocity Calculation as a Function of Hole Resistance Parameter K

Prepared by:
Checked by:

K = 0.0005 psi-lb/ft^3/(lbm/sec)^2

Time	Initial Annulus Pressure	Initial Annulus Temp	Initial Annulus Mass	Upstream Press	Upstream Density	Mass Flow Rate	Mass xferred	New Annulus Mass	New Annulus Press	New Annulus Density	Annulus Velocity
sec	psia	deg F	lbmoles	psia	lbm/ft^3	lbm/sec	lbmole	lbmole	psia	lbm/ft^3	ft/sec
0.0	14.7	120	145.74	23.7	0.081598						
1.0	14.7	120	145.74	23.7	0.081598	38.324	1.322	147.065	14.833	0.06912	3.25
2.0	14.833	120	147.06	23.7	0.081598	38.039	1.312	148.377	14.966	0.06974	3.19
3.0	14.966	120	148.38	23.7	0.081598	37.755	1.302	149.679	15.097	0.07035	3.14
4.0	15.097	120	149.68	23.7	0.081598	37.470	1.292	150.971	15.227	0.07096	3.09
5.0	15.227	120	150.97	23.7	0.081598	37.185	1.282	152.253	15.357	0.07156	3.04
6.0	15.357	120	152.25	23.7	0.081598	36.900	1.272	153.525	15.485	0.07216	2.99
7.0	15.485	120	153.53	23.7	0.081598	36.615	1.263	154.788	15.612	0.07275	2.95
8.0	15.612	120	154.79	23.7	0.081598	36.330	1.253	156.041	15.739	0.07334	2.90
9.0	15.739	120	156.04	23.7	0.081598	36.045	1.243	157.284	15.864	0.07392	2.86
10.0	15.864	120	157.28	23.7	0.081598	35.760	1.233	158.517	15.988	0.07450	2.81
11.0	15.988	120	158.52	23.7	0.081598	35.475	1.223	159.740	16.112	0.07508	2.77
12.0	16.112	120	159.74	23.7	0.081598	35.190	1.213	160.953	16.234	0.07565	2.72
13.0	16.234	120	160.95	23.7	0.081598	34.906	1.204	162.157	16.356	0.07621	2.68
14.0	16.356	120	162.16	23.7	0.081598	34.621	1.194	163.351	16.476	0.07678	2.64
15.0	16.476	120	163.35	23.7	0.081598	34.336	1.184	164.535	16.595	0.07733	2.60
16.0	16.595	120	164.53	23.7	0.081598	34.051	1.174	165.709	16.714	0.07788	2.56
17.0	16.714	120	165.71	23.7	0.081598	33.766	1.164	166.873	16.831	0.07843	2.52
18.0	16.831	120	166.87	23.7	0.081598	33.481	1.155	168.028	16.948	0.07897	2.48
19.0	16.948	120	168.03	23.7	0.081598	33.196	1.145	169.172	17.063	0.07951	2.44
20.0	17.063	120	169.17	23.7	0.081598	32.911	1.135	170.307	17.178	0.08004	2.41
21.0	17.178	120	170.31	23.7	0.081598	32.626	1.125	171.432	17.291	0.08057	2.37
22.0	17.291	120	171.43	23.7	0.081598	32.341	1.115	172.548	17.404	0.08110	2.34
23.0	17.404	120	172.55	23.7	0.081598	32.055	1.105	173.653	17.515	0.08162	2.30
24.0	17.515	120	173.65	23.7	0.081598	31.770	1.096	174.748	17.626	0.08213	2.26
25.0	17.626	120	174.75	23.7	0.081598	31.485	1.086	175.834	17.735	0.08264	2.23
26.0	17.735	120	175.83	23.7	0.081598	31.200	1.076	176.910	17.844	0.08315	2.20
27.0	17.844	120	176.91	23.7	0.081598	30.915	1.066	177.976	17.951	0.08365	2.16
28.0	17.951	120	177.98	23.7	0.081598	30.630	1.056	179.032	18.058	0.08415	2.13
29.0	18.058	120	179.03	23.7	0.081598	30.345	1.046	180.079	18.163	0.08464	2.10
30.0	18.163	120	180.08	23.7	0.081598	30.060	1.037	181.115	18.268	0.08512	2.07
31.0	18.268	120	181.12	23.7	0.081598	29.775	1.027	182.142	18.371	0.08561	2.04
32.0	18.371	120	182.14	23.7	0.081598	29.489	1.017	183.159	18.474	0.08608	2.01
33.0	18.474	120	183.16	23.7	0.081598	29.204	1.007	184.166	18.575	0.08656	1.98
34.0	18.575	120	184.17	23.7	0.081598	28.919	0.997	185.163	18.676	0.08703	1.95
35.0	18.676	120	185.16	23.7	0.081598	28.634	0.987	186.150	18.776	0.08749	1.92
36.0	18.776	120	186.15	23.7	0.081598	28.349	0.978	187.128	18.874	0.08795	1.89
37.0	18.874	120	187.13	23.7	0.081598	28.063	0.968	188.096	18.972	0.08841	1.86
38.0	18.972	120	188.10	23.7	0.081598	27.778	0.958	189.054	19.068	0.08886	1.83
39.0	19.068	120	189.05	23.7	0.081598	27.493	0.948	190.002	19.164	0.08930	1.80
40.0	19.164	120	190.00	23.7	0.081598	27.208	0.938	190.940	19.259	0.08974	1.78
41.0	19.259	120	190.94	23.7	0.081598	26.922	0.928	191.868	19.352	0.09018	1.75
42.0	19.352	120	191.87	23.7	0.081598	26.637	0.919	192.787	19.445	0.09061	1.72
43.0	19.445	120	192.79	23.7	0.081598	26.352	0.909	193.695	19.537	0.09104	1.69
44.0	19.537	120	193.70	23.7	0.081598	26.066	0.899	194.594	19.627	0.09146	1.67
45.0	19.627	120	194.59	23.7	0.081598	25.781	0.889	195.483	19.717	0.09188	1.64
46.0	19.717	120	195.48	23.7	0.081598	25.496	0.879	196.362	19.806	0.09229	1.62
47.0	19.806	120	196.36	23.7	0.081598	25.210	0.869	197.232	19.893	0.09270	1.59
48.0	19.893	120	197.23	23.7	0.081598	24.925	0.859	198.091	19.980	0.09310	1.57
49.0	19.980	120	198.09	23.7	0.081598	24.639	0.850	198.941	20.066	0.09350	1.54
50.0	20.066	120	198.94	23.7	0.081598	24.354	0.840	199.781	20.150	0.09390	1.52
51.0	20.150	120	199.78	23.7	0.081598	24.068	0.830	200.610	20.234	0.09429	1.49
52.0	20.234	120	200.61	23.7	0.081598	23.783	0.820	201.431	20.317	0.09467	1.47
53.0	20.317	120	201.43	23.7	0.081598	23.497	0.810	202.241	20.398	0.09505	1.45
54.0	20.398	120	202.24	23.7	0.081598	23.212	0.800	203.041	20.479	0.09543	1.42
55.0	20.479	120	203.04	23.7	0.081598	22.926	0.791	203.832	20.559	0.09580	1.40
56.0	20.559	120	203.83	23.7	0.081598	22.641	0.781	204.613	20.638	0.09617	1.38
57.0	20.638	120	204.61	23.7	0.081598	22.355	0.771	205.383	20.715	0.09653	1.36
58.0	20.715	120	205.38	23.7	0.081598	22.070	0.761	206.144	20.792	0.09689	1.33
59.0	20.792	120	206.14	23.7	0.081598	21.784	0.751	206.896	20.868	0.09724	1.31
60.0	20.868	120	206.90	23.7	0.081598	21.498	0.741	207.637	20.943	0.09759	1.29
61.0	20.943	120	207.64	23.7	0.081598	21.213	0.731	208.368	21.016	0.09793	1.27
62.0	21.016	120	208.37	23.7	0.081598	20.927	0.722	209.090	21.089	0.09827	1.25
63.0	21.089	120	209.09	23.7	0.081598	20.641	0.712	209.802	21.161	0.09861	1.23
64.0	21.161	120	209.80	23.7	0.081598	20.355	0.702	210.504	21.232	0.09894	1.20
65.0	21.232	120	210.50	23.7	0.081598	20.070	0.692	211.196	21.302	0.09926	1.18
66.0	21.302	120	211.20	23.7	0.081598	19.784	0.682	211.878	21.370	0.09958	1.16
67.0	21.370	120	211.88	23.7	0.081598	19.498	0.672	212.550	21.438	0.09990	1.14

Velocity Calculation as a Function of Hole Resistance Parameter K

Prepared by:
Checked by:

K = 0.0005 psi-lb/ft^3/(lbm/sec)^2

Time	Initial Annulus Pressure	Initial Annulus Temp	Initial Annulus Mass	Upstream Press	Upstream Density	Mass Flow Rate	Mass xferred	New Annulus Mass	New Annulus Press	New Annulus Density	Annulus Velocity
sec	psia	deg F	lbmoles	psia	lbm/ft^3	lbm/sec	lbmole	lbmole	psia	lbm/ft^3	ft/sec
68.0	21.438	120	212.55	23.7	0.081598	19.212	0.662	213.213	21.505	0.10021	1.12
69.0	21.505	120	213.21	23.7	0.081598	18.926	0.653	213.865	21.571	0.10052	1.10
70.0	21.571	120	213.87	23.7	0.081598	18.640	0.643	214.508	21.636	0.10082	1.08
71.0	21.636	120	214.51	23.7	0.081598	18.354	0.633	215.141	21.700	0.10112	1.06
72.0	21.700	120	215.14	23.7	0.081598	18.068	0.623	215.764	21.762	0.10141	1.04
73.0	21.762	120	215.76	23.7	0.081598	17.782	0.613	216.377	21.824	0.10170	1.02
74.0	21.824	120	216.38	23.7	0.081598	17.496	0.603	216.981	21.885	0.10198	1.00
75.0	21.885	120	216.98	23.7	0.081598	17.210	0.593	217.574	21.945	0.10226	0.99
76.0	21.945	120	217.57	23.7	0.081598	16.924	0.584	218.158	22.004	0.10253	0.97
77.0	22.004	120	218.16	23.7	0.081598	16.637	0.574	218.731	22.062	0.10280	0.95
78.0	22.062	120	218.73	23.7	0.081598	16.351	0.564	219.295	22.119	0.10307	0.93
79.0	22.119	120	219.30	23.7	0.081598	16.065	0.554	219.849	22.174	0.10333	0.91
80.0	22.174	120	219.85	23.7	0.081598	15.778	0.544	220.393	22.229	0.10358	0.89
81.0	22.229	120	220.39	23.7	0.081598	15.492	0.534	220.927	22.283	0.10384	0.87
82.0	22.283	120	220.93	23.7	0.081598	15.206	0.524	221.452	22.336	0.10408	0.86
83.0	22.336	120	221.45	23.7	0.081598	14.919	0.514	221.966	22.388	0.10432	0.84
84.0	22.388	120	221.97	23.7	0.081598	14.633	0.505	222.471	22.439	0.10456	0.82
85.0	22.439	120	222.47	23.7	0.081598	14.346	0.495	222.965	22.489	0.10479	0.80
86.0	22.489	120	222.97	23.7	0.081598	14.059	0.485	223.450	22.538	0.10502	0.78
87.0	22.538	120	223.45	23.7	0.081598	13.773	0.475	223.925	22.586	0.10525	0.77
88.0	22.586	120	223.93	23.7	0.081598	13.486	0.465	224.390	22.632	0.10546	0.75
89.0	22.632	120	224.39	23.7	0.081598	13.199	0.455	224.845	22.678	0.10568	0.73
90.0	22.678	120	224.85	23.7	0.081598	12.912	0.445	225.291	22.723	0.10589	0.71
91.0	22.723	120	225.29	23.7	0.081598	12.625	0.435	225.726	22.767	0.10609	0.70
92.0	22.767	120	225.73	23.7	0.081598	12.338	0.425	226.151	22.810	0.10629	0.68
93.0	22.810	120	226.15	23.7	0.081598	12.051	0.416	226.567	22.852	0.10649	0.66
94.0	22.852	120	226.57	23.7	0.081598	11.764	0.406	226.973	22.893	0.10668	0.65
95.0	22.893	120	226.97	23.7	0.081598	11.476	0.396	227.368	22.933	0.10686	0.63
96.0	22.933	120	227.37	23.7	0.081598	11.189	0.386	227.754	22.972	0.10704	0.61
97.0	22.972	120	227.75	23.7	0.081598	10.901	0.376	228.130	23.010	0.10722	0.60
98.0	23.010	120	228.13	23.7	0.081598	10.614	0.366	228.496	23.047	0.10739	0.58
99.0	23.047	120	228.50	23.7	0.081598	10.326	0.356	228.852	23.083	0.10756	0.56
100.0	23.083	120	228.85	23.7	0.081598	10.038	0.346	229.198	23.117	0.10772	0.55
101.0	23.117	120	229.20	23.7	0.081598	9.750	0.336	229.534	23.151	0.10788	0.53
102.0	23.151	120	229.53	23.7	0.081598	9.462	0.326	229.861	23.184	0.10803	0.51
103.0	23.184	120	229.86	23.7	0.081598	9.174	0.316	230.177	23.216	0.10818	0.50
104.0	23.216	120	230.18	23.7	0.081598	8.886	0.306	230.483	23.247	0.10833	0.48
105.0	23.247	120	230.48	23.7	0.081598	8.597	0.296	230.780	23.277	0.10847	0.46
106.0	23.277	120	230.78	23.7	0.081598	8.309	0.287	231.066	23.306	0.10860	0.45
107.0	23.306	120	231.07	23.7	0.081598	8.020	0.277	231.343	23.334	0.10873	0.43
108.0	23.334	120	231.34	23.7	0.081598	7.731	0.267	231.610	23.361	0.10886	0.42
109.0	23.361	120	231.61	23.7	0.081598	7.442	0.257	231.866	23.387	0.10898	0.40
110.0	23.387	120	231.87	23.7	0.081598	7.152	0.247	232.113	23.411	0.10909	0.38
111.0	23.411	120	232.11	23.7	0.081598	6.863	0.237	232.349	23.435	0.10920	0.37
112.0	23.435	120	232.35	23.7	0.081598	6.573	0.227	232.576	23.458	0.10931	0.35
113.0	23.458	120	232.58	23.7	0.081598	6.283	0.217	232.793	23.480	0.10941	0.34
114.0	23.480	120	232.79	23.7	0.081598	5.992	0.207	232.999	23.501	0.10951	0.32
115.0	23.501	120	233.00	23.7	0.081598	5.701	0.197	233.196	23.521	0.10960	0.30
116.0	23.521	120	233.20	23.7	0.081598	5.410	0.187	233.383	23.539	0.10969	0.29
117.0	23.539	120	233.38	23.7	0.081598	5.118	0.176	233.559	23.557	0.10977	0.27
118.0	23.557	120	233.56	23.7	0.081598	4.826	0.166	233.725	23.574	0.10985	0.26
119.0	23.574	120	233.73	23.7	0.081598	4.533	0.156	233.882	23.590	0.10992	0.24
120.0	23.590	120	233.88	23.7	0.081598	4.240	0.146	234.028	23.605	0.10999	0.23
121.0	23.605	120	234.03	23.7	0.081598	3.946	0.136	234.164	23.618	0.11006	0.21
122.0	23.618	120	234.16	23.7	0.081598	3.651	0.126	234.290	23.631	0.11012	0.19
123.0	23.631	120	234.29	23.7	0.081598	3.356	0.116	234.406	23.643	0.11017	0.18
124.0	23.643	120	234.41	23.7	0.081598	3.059	0.105	234.511	23.653	0.11022	0.16
125.0	23.653	120	234.51	23.7	0.081598	2.760	0.095	234.606	23.663	0.11027	0.15
126.0	23.663	120	234.61	23.7	0.081598	2.460	0.085	234.691	23.671	0.11031	0.13
127.0	23.671	120	234.69	23.7	0.081598	2.158	0.074	234.766	23.679	0.11034	0.11
128.0	23.679	120	234.77	23.7	0.081598	1.852	0.064	234.829	23.685	0.11037	0.10
129.0	23.685	120	234.83	23.7	0.081598	1.543	0.053	234.883	23.691	0.11040	0.08
130.0	23.691	120	234.88	23.7	0.081598	1.227	0.042	234.925	23.695	0.11041	0.07

From Previous Time Step

Assumed Constant

=PV/RT

Assumed Constant

= SQRT(rho*dP/K)

=(mass flow)*dt/MW

=Initial Mass + Transferred Mass

=nRT/V

=P(MW)/RT

$= \frac{\text{mass flow}}{(\text{rho*Area})}$

MPR-2169 Appendix A.2
Calculation 025-065-02
Attachment A, Part 1

Velocity Calculation as a Function of Hole Resistance Parameter K

Prepared by:
Checked by:

K = 0.0001 psi-lb/ft^3/(lbm/sec)^2

Time	Initial Annulus Pressure	Initial Annulus Temp	Initial Annulus Mass	Upstream Press	Upstream Density	Mass Flow Rate	Mass xferred	New Annulus Mass	New Annulus Press	New Annulus Density	Annulus Velocity
sec	psia	deg F	lbmoles	psia	lbm/ft^3	lbm/sec	lbmole	lbmole	psia	lbm/ft^3	ft/sec
0.0	14.7	120	145.74	23.7	0.081598						
1.0	14.7	120	145.74	23.7	0.081598	85.696	2.955	148.698	14.998	0.06989	7.18
2.0	14.998	120	148.70	23.7	0.081598	84.265	2.906	151.604	15.291	0.07125	6.92
3.0	15.291	120	151.60	23.7	0.081598	82.834	2.856	154.460	15.579	0.07260	6.68
4.0	15.579	120	154.46	23.7	0.081598	81.402	2.807	157.267	15.862	0.07392	6.45
5.0	15.862	120	157.27	23.7	0.081598	79.971	2.758	160.025	16.140	0.07521	6.23
6.0	16.140	120	160.03	23.7	0.081598	78.539	2.708	162.733	16.414	0.07648	6.01
7.0	16.414	120	162.73	23.7	0.081598	77.107	2.659	165.392	16.682	0.07773	5.81
8.0	16.682	120	165.39	23.7	0.081598	75.675	2.609	168.002	16.945	0.07896	5.61
9.0	16.945	120	168.00	23.7	0.081598	74.242	2.560	170.562	17.203	0.08016	5.42
10.0	17.203	120	170.56	23.7	0.081598	72.809	2.511	173.072	17.456	0.08134	5.24
11.0	17.456	120	173.07	23.7	0.081598	71.376	2.461	175.534	17.705	0.08250	5.07
12.0	17.705	120	175.53	23.7	0.081598	69.943	2.412	177.945	17.948	0.08363	4.90
13.0	17.948	120	177.95	23.7	0.081598	68.509	2.362	180.308	18.186	0.08474	4.73
14.0	18.186	120	180.31	23.7	0.081598	67.075	2.313	182.621	18.420	0.08583	4.58
15.0	18.420	120	182.62	23.7	0.081598	65.641	2.263	184.884	18.648	0.08690	4.42
16.0	18.648	120	184.88	23.7	0.081598	64.206	2.214	187.098	18.871	0.08794	4.28
17.0	18.871	120	187.10	23.7	0.081598	62.771	2.165	189.263	19.089	0.08895	4.13
18.0	19.089	120	189.26	23.7	0.081598	61.336	2.115	191.378	19.303	0.08995	3.99
19.0	19.303	120	191.38	23.7	0.081598	59.900	2.066	193.443	19.511	0.09092	3.86
20.0	19.511	120	193.44	23.7	0.081598	58.464	2.016	195.459	19.714	0.09187	3.73
21.0	19.714	120	195.46	23.7	0.081598	57.027	1.966	197.426	19.913	0.09279	3.60
22.0	19.913	120	197.43	23.7	0.081598	55.590	1.917	199.343	20.106	0.09369	3.47
23.0	20.106	120	199.34	23.7	0.081598	54.153	1.867	201.210	20.294	0.09457	3.35
24.0	20.294	120	201.21	23.7	0.081598	52.714	1.818	203.028	20.478	0.09542	3.23
25.0	20.478	120	203.03	23.7	0.081598	51.276	1.768	204.796	20.656	0.09625	3.12
26.0	20.656	120	204.80	23.7	0.081598	49.837	1.719	206.514	20.829	0.09706	3.01
27.0	20.829	120	206.51	23.7	0.081598	48.397	1.669	208.183	20.998	0.09785	2.90
28.0	20.998	120	208.18	23.7	0.081598	46.956	1.619	209.802	21.161	0.09861	2.79
29.0	21.161	120	209.80	23.7	0.081598	45.515	1.569	211.372	21.319	0.09935	2.68
30.0	21.319	120	211.37	23.7	0.081598	44.074	1.520	212.892	21.473	0.10006	2.58
31.0	21.473	120	212.89	23.7	0.081598	42.631	1.470	214.362	21.621	0.10075	2.48
32.0	21.621	120	214.36	23.7	0.081598	41.188	1.420	215.782	21.764	0.10142	2.38
33.0	21.764	120	215.78	23.7	0.081598	39.743	1.370	217.152	21.902	0.10206	2.28
34.0	21.902	120	217.15	23.7	0.081598	38.298	1.321	218.473	22.036	0.10268	2.18
35.0	22.036	120	218.47	23.7	0.081598	36.852	1.271	219.744	22.164	0.10328	2.09
36.0	22.164	120	219.74	23.7	0.081598	35.404	1.221	220.965	22.287	0.10385	2.00
37.0	22.287	120	220.96	23.7	0.081598	33.956	1.171	222.136	22.405	0.10440	1.90
38.0	22.405	120	222.14	23.7	0.081598	32.506	1.121	223.256	22.518	0.10493	1.81
39.0	22.518	120	223.26	23.7	0.081598	31.054	1.071	224.327	22.626	0.10543	1.72
40.0	22.626	120	224.33	23.7	0.081598	29.601	1.021	225.348	22.729	0.10591	1.64
41.0	22.729	120	225.35	23.7	0.081598	28.147	0.971	226.319	22.827	0.10637	1.55
42.0	22.827	120	226.32	23.7	0.081598	26.690	0.920	227.239	22.920	0.10680	1.46
43.0	22.920	120	227.24	23.7	0.081598	25.231	0.870	228.109	23.008	0.10721	1.38
44.0	23.008	120	228.11	23.7	0.081598	23.770	0.820	228.929	23.090	0.10760	1.29
45.0	23.090	120	228.93	23.7	0.081598	22.306	0.769	229.698	23.168	0.10796	1.21
46.0	23.168	120	229.70	23.7	0.081598	20.838	0.719	230.416	23.240	0.10830	1.13
47.0	23.240	120	230.42	23.7	0.081598	19.368	0.668	231.084	23.308	0.10861	1.04
48.0	23.308	120	231.08	23.7	0.081598	17.892	0.617	231.701	23.370	0.10890	0.96
49.0	23.370	120	231.70	23.7	0.081598	16.412	0.566	232.267	23.427	0.10917	0.88
50.0	23.427	120	232.27	23.7	0.081598	14.926	0.515	232.782	23.479	0.10941	0.80
51.0	23.479	120	232.78	23.7	0.081598	13.432	0.463	233.245	23.526	0.10963	0.72
52.0	23.526	120	233.24	23.7	0.081598	11.929	0.411	233.656	23.567	0.10982	0.64
53.0	23.567	120	233.66	23.7	0.081598	10.414	0.359	234.015	23.603	0.10999	0.55
54.0	23.603	120	234.02	23.7	0.081598	8.882	0.306	234.322	23.634	0.11013	0.47
55.0	23.634	120	234.32	23.7	0.081598	7.327	0.253	234.574	23.660	0.11025	0.39
56.0	23.660	120	234.57	23.7	0.081598	5.735	0.198	234.772	23.680	0.11034	0.30
57.0	23.680	120	234.77	23.7	0.081598	4.076	0.141	234.913	23.694	0.11041	0.22
58.0	23.694	120	234.91	23.7	0.081598	2.247	0.077	234.990	23.702	0.11045	0.12
59.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
60.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
61.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
62.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
63.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
64.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
65.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
66.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
67.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00

K = 0.0001 psi-lb/ft^3/(lbm/sec)^2

Time	Initial Annulus Pressure	Initial Annulus Temp	Initial Annulus Mass	Upstream Press	Upstream Density	Mass Flow Rate	Mass xferred	New Annulus Mass	New Annulus Press	New Annulus Density	Annulus Velocity
sec	psia	deg F	lbmoles	psia	lbm/ft^3	lbm/sec	lbmole	lbmole	psia	lbm/ft^3	ft/sec
68.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
69.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
70.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
71.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
72.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
73.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
74.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
75.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
76.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
77.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
78.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
79.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
80.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
81.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
82.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
83.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
84.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
85.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
86.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
87.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
88.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
89.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
90.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
91.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
92.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
93.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
94.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
95.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
96.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
97.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
98.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
99.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
100.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
101.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
102.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
103.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
104.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
105.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
106.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
107.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
108.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
109.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
110.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
111.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
112.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
113.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
114.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
115.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
116.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
117.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
118.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
119.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
120.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
121.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
122.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
123.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
124.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
125.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
126.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
127.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
128.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
129.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00
130.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.990	23.702	0.11045	0.00

Velocity Calculation as a Function of Hole Resistance Parameter K

Prepared by:
Checked by:

K = 0.00005 psi-lb/ft^3/(lbm/sec)^2

Time	Initial Annulus Pressure	Initial Annulus Temp	Initial Annulus Mass	Upstream Press	Upstream Density	Mass Flow Rate	Mass xferred	New Annulus Mass	New Annulus Press	New Annulus Density	Annulus Velocity
sec	psia	deg F	lbmoles	psia	lbm/ft^3	lbm/sec	lbmole	lbmole	psia	lbm/ft^3	ft/sec
0.0	14.7	120	145.74	23.7	0.081598						
1.0	14.7	120	145.74	23.7	0.081598	121.192	4.179	149.922	15.122	0.07046	10.07
2.0	15.122	120	149.92	23.7	0.081598	118.320	4.080	154.002	15.533	0.07238	9.57
3.0	15.533	120	154.00	23.7	0.081598	115.447	3.981	157.983	15.935	0.07425	9.10
4.0	15.935	120	157.98	23.7	0.081598	112.574	3.882	161.865	16.326	0.07608	8.66
5.0	16.326	120	161.87	23.7	0.081598	109.699	3.783	165.648	16.708	0.07785	8.25
6.0	16.708	120	165.65	23.7	0.081598	106.823	3.684	169.332	17.079	0.07959	7.86
7.0	17.079	120	169.33	23.7	0.081598	103.947	3.584	172.916	17.441	0.08127	7.49
8.0	17.441	120	172.92	23.7	0.081598	101.069	3.485	176.401	17.792	0.08291	7.14
9.0	17.792	120	176.40	23.7	0.081598	98.190	3.386	179.787	18.134	0.08450	6.80
10.0	18.134	120	179.79	23.7	0.081598	95.310	3.287	183.073	18.465	0.08604	6.49
11.0	18.465	120	183.07	23.7	0.081598	92.428	3.187	186.261	18.787	0.08754	6.18
12.0	18.787	120	186.26	23.7	0.081598	89.545	3.088	189.348	19.098	0.08899	5.89
13.0	19.098	120	189.35	23.7	0.081598	86.661	2.988	192.337	19.399	0.09040	5.61
14.0	19.399	120	192.34	23.7	0.081598	83.775	2.889	195.225	19.691	0.09176	5.35
15.0	19.691	120	195.23	23.7	0.081598	80.887	2.789	198.015	19.972	0.09307	5.09
16.0	19.972	120	198.01	23.7	0.081598	77.997	2.690	200.704	20.243	0.09433	4.84
17.0	20.243	120	200.70	23.7	0.081598	75.106	2.590	203.294	20.505	0.09555	4.60
18.0	20.505	120	203.29	23.7	0.081598	72.212	2.490	205.784	20.756	0.09672	4.37
19.0	20.756	120	205.78	23.7	0.081598	69.316	2.390	208.174	20.997	0.09784	4.15
20.0	20.997	120	208.17	23.7	0.081598	66.418	2.290	210.465	21.228	0.09892	3.93
21.0	21.228	120	210.46	23.7	0.081598	63.516	2.190	212.655	21.449	0.09995	3.72
22.0	21.449	120	212.65	23.7	0.081598	60.612	2.090	214.745	21.660	0.10093	3.52
23.0	21.660	120	214.74	23.7	0.081598	57.704	1.990	216.735	21.860	0.10187	3.32
24.0	21.860	120	216.73	23.7	0.081598	54.793	1.889	218.624	22.051	0.10275	3.12
25.0	22.051	120	218.62	23.7	0.081598	51.877	1.789	220.413	22.231	0.10359	2.93
26.0	22.231	120	220.41	23.7	0.081598	48.957	1.688	222.101	22.402	0.10439	2.75
27.0	22.402	120	222.10	23.7	0.081598	46.032	1.587	223.688	22.562	0.10513	2.56
28.0	22.562	120	223.69	23.7	0.081598	43.100	1.486	225.175	22.712	0.10583	2.38
29.0	22.712	120	225.17	23.7	0.081598	40.162	1.385	226.560	22.851	0.10648	2.21
30.0	22.851	120	226.56	23.7	0.081598	37.216	1.283	227.843	22.981	0.10709	2.03
31.0	22.981	120	227.84	23.7	0.081598	34.261	1.181	229.024	23.100	0.10764	1.86
32.0	23.100	120	229.02	23.7	0.081598	31.294	1.079	230.103	23.209	0.10815	1.69
33.0	23.209	120	230.10	23.7	0.081598	28.315	0.976	231.080	23.307	0.10861	1.53
34.0	23.307	120	231.08	23.7	0.081598	25.318	0.873	231.953	23.395	0.10902	1.36
35.0	23.395	120	231.95	23.7	0.081598	22.300	0.769	232.722	23.473	0.10938	1.19
36.0	23.473	120	232.72	23.7	0.081598	19.254	0.664	233.386	23.540	0.10969	1.03
37.0	23.540	120	233.39	23.7	0.081598	16.169	0.558	233.943	23.596	0.10995	0.86
38.0	23.596	120	233.94	23.7	0.081598	13.026	0.449	234.392	23.641	0.11016	0.69
39.0	23.641	120	234.39	23.7	0.081598	9.784	0.337	234.730	23.675	0.11032	0.52
40.0	23.675	120	234.73	23.7	0.081598	6.340	0.219	234.948	23.697	0.11043	0.34
41.0	23.697	120	234.95	23.7	0.081598	2.052	0.071	235.019	23.705	0.11046	0.11
42.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
43.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
44.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
45.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
46.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
47.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
48.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
49.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
50.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
51.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
52.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
53.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
54.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
55.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
56.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
57.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
58.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
59.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
60.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
61.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
62.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
63.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
64.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
65.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
66.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
67.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00

Velocity Calculation as a Function of Hole Resistance Parameter K

Prepared by:
Checked by:

K = 0.00005 psi-lb/ft^3/(lbm/sec)^2

Time	Initial Annulus Pressure	Initial Annulus Temp	Initial Annulus Mass	Upstream Press	Upstream Density	Mass Flow Rate	Mass xferred	New Annulus Mass	New Annulus Press	New Annulus Density	Annulus Velocity
sec	psia	deg F	lbmoles	psia	lbm/ft^3	lbm/sec	lbmole	lbmole	psia	lbm/ft^3	ft/sec
68.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
69.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
70.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
71.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
72.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
73.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
74.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
75.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
76.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
77.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
78.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
79.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
80.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
81.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
82.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
83.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
84.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
85.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
86.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
87.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
88.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
89.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
90.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
91.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
92.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
93.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
94.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
95.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
96.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
97.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
98.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
99.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
100.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
101.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
102.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
103.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
104.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
105.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
106.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
107.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
108.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
109.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
110.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
111.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
112.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
113.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
114.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
115.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
116.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
117.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
118.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
119.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
120.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
121.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
122.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
123.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
124.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
125.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
126.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
127.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
128.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
129.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00
130.0	23.705	120	235.02	23.7	0.081598	0.000	0.000	235.019	23.705	0.11046	0.00

MPR-2169 Appendix A.2
Calculation 025-065-02
Attachment A, Part 1

Velocity Calculation as a Function of Hole Resistance Parameter K

Prepared by:
Checked by:

K = 0.00001 psi-lb/ft^3/(lbm/sec)^2

Time	Initial Annulus Pressure	Initial Annulus Temp	Initial Annulus Mass	Upstream Press	Upstream Density	Mass Flow Rate	Mass xferred	New Annulus Mass	New Annulus Press	New Annulus Density	Annulus Velocity
sec	psia	deg F	lbmoles	psia	lbm/ft^3	lbm/sec	lbmole	lbmole	psia	lbm/ft^3	ft/sec
0.0	14.7	120	145.74	23.7	0.081598						
1.0	14.7	120	145.74	23.7	0.081598	270.994	9.345	155.088	15.643	0.07289	21.77
2.0	15.643	120	155.09	23.7	0.081598	256.412	8.842	163.930	16.534	0.07705	19.49
3.0	16.534	120	163.93	23.7	0.081598	241.806	8.338	172.268	17.375	0.08097	17.49
4.0	17.375	120	172.27	23.7	0.081598	227.173	7.834	180.102	18.165	0.08465	15.71
5.0	18.165	120	180.10	23.7	0.081598	212.510	7.328	187.429	18.905	0.08809	14.13
6.0	18.905	120	187.43	23.7	0.081598	197.812	6.821	194.251	19.593	0.09130	12.69
7.0	19.593	120	194.25	23.7	0.081598	183.073	6.313	200.563	20.229	0.09427	11.37
8.0	20.229	120	200.56	23.7	0.081598	168.286	5.803	206.366	20.815	0.09699	10.16
9.0	20.815	120	206.37	23.7	0.081598	153.442	5.291	211.658	21.348	0.09948	9.03
10.0	21.348	120	211.66	23.7	0.081598	138.527	4.777	216.434	21.830	0.10172	7.97
11.0	21.830	120	216.43	23.7	0.081598	123.525	4.259	220.694	22.260	0.10373	6.97
12.0	22.260	120	220.69	23.7	0.081598	108.410	3.738	224.432	22.637	0.10548	6.02
13.0	22.637	120	224.43	23.7	0.081598	93.146	3.212	227.644	22.961	0.10699	5.10
14.0	22.961	120	227.64	23.7	0.081598	77.670	2.678	230.322	23.231	0.10825	4.20
15.0	23.231	120	230.32	23.7	0.081598	61.874	2.134	232.456	23.446	0.10925	3.32
16.0	23.446	120	232.46	23.7	0.081598	45.524	1.570	234.026	23.604	0.10999	2.42
17.0	23.604	120	234.03	23.7	0.081598	27.937	0.963	234.989	23.702	0.11045	1.48
18.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
19.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
20.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
21.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
22.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
23.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
24.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
25.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
26.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
27.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
28.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
29.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
30.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
31.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
32.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
33.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
34.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
35.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
36.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
37.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
38.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
39.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
40.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
41.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
42.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
43.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
44.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
45.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
46.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
47.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
48.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
49.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
50.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
51.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
52.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
53.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
54.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
55.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
56.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
57.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
58.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
59.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
60.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
61.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
62.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
63.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
64.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
65.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
66.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
67.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00

Velocity Calculation as a Function of Hole Resistance Parameter K

Prepared by:
Checked by:

K = 0.00001 psi-lb/ft^3/(lbm/sec)^2

Time	Initial Annulus Pressure	Initial Annulus Temp	Initial Annulus Mass	Upstream Press	Upstream Density	Mass Flow Rate	Mass xferred	New Annulus Mass	New Annulus Press	New Annulus Density	Annulus Velocity
sec	psia	deg F	lbmoles	psia	lbm/ft^3	lbm/sec	lbmole	lbmole	psia	lbm/ft^3	ft/sec
68.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
69.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
70.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
71.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
72.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
73.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
74.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
75.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
76.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
77.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
78.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
79.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
80.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
81.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
82.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
83.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
84.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
85.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
86.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
87.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
88.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
89.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
90.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
91.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
92.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
93.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
94.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
95.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
96.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
97.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
98.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
99.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
100.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
101.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
102.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
103.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
104.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
105.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
106.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
107.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
108.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
109.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
110.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
111.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
112.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
113.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
114.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
115.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
116.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
117.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
118.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
119.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
120.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
121.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
122.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
123.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
124.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
125.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
126.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
127.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
128.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
129.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00
130.0	23.702	120	234.99	23.7	0.081598	0.000	0.000	234.989	23.702	0.11045	0.00

MPR-2169 Appendix A.2
Calculation 025-065-02
Attachment A, Part 1

Velocity Calculation as a Function of Hole Resistance Parameter K

Prepared by:
Checked by:

K = 0.000005 psi-lb/ft^3/(lbm/sec)^2

Time	Initial Annulus Pressure	Initial Annulus Temp	Initial Annulus Mass	Upstream Press	Upstream Density	Mass Flow Rate	Mass xferred	New Annulus Mass	New Annulus Press	New Annulus Density	Annulus Velocity
sec	psia	deg F	lbmoles	psia	lbm/ft^3	lbm/sec	lbmole	lbmole	psia	lbm/ft^3	ft/sec
0.0	14.7	120	145.74	23.7	0.081598						
1.0	14.7	120	145.74	23.7	0.081598	383.243	13.215	158.959	16.033	0.07471	30.04
2.0	16.033	120	158.96	23.7	0.081598	353.727	12.197	171.156	17.263	0.08044	25.75
3.0	17.263	120	171.16	23.7	0.081598	324.107	11.176	182.332	18.390	0.08570	22.14
4.0	18.390	120	182.33	23.7	0.081598	294.363	10.150	192.483	19.414	0.09047	19.05
5.0	19.414	120	192.48	23.7	0.081598	264.465	9.119	201.602	20.334	0.09475	16.34
6.0	20.334	120	201.60	23.7	0.081598	234.373	8.082	209.684	21.149	0.09855	13.92
7.0	21.149	120	209.68	23.7	0.081598	204.029	7.035	216.720	21.859	0.10186	11.73
8.0	21.859	120	216.72	23.7	0.081598	173.342	5.977	222.697	22.462	0.10467	9.70
9.0	22.462	120	222.70	23.7	0.081598	142.157	4.902	227.599	22.956	0.10697	7.78
10.0	22.956	120	227.60	23.7	0.081598	110.181	3.799	231.398	23.339	0.10876	5.93
11.0	23.339	120	231.40	23.7	0.081598	76.721	2.646	234.044	23.606	0.11000	4.08
12.0	23.606	120	234.04	23.7	0.081598	39.134	1.349	235.393	23.742	0.11063	2.07
13.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
14.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
15.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
16.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
17.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
18.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
19.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
20.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
21.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
22.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
23.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
24.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
25.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
26.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
27.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
28.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
29.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
30.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
31.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
32.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
33.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
34.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
35.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
36.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
37.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
38.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
39.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
40.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
41.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
42.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
43.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
44.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
45.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
46.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
47.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
48.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
49.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
50.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
51.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
52.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
53.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
54.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
55.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
56.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
57.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
58.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
59.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
60.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
61.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
62.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
63.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
64.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
65.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
66.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
67.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00

Velocity Calculation as a Function of Hole Resistance Parameter K

Prepared by:
Checked by:

K = 0.000005 psi-lb/ft^3/(lbm/sec)^2

Time sec	Initial Annulus Pressure psia	Initial Annulus Temp deg F	Initial Annulus Mass lbmoles	Upstream Press psia	Upstream Density lbm/ft^3	Mass Flow Rate lbm/sec	Mass xferred lbmole	New Annulus Mass lbmole	New Annulus Press psia	New Annulus Density lbm/ft^3	Annulus Velocity ft/sec
68.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
69.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
70.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
71.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
72.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
73.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
74.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
75.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
76.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
77.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
78.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
79.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
80.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
81.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
82.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
83.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
84.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
85.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
86.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
87.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
88.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
89.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
90.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
91.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
92.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
93.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
94.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
95.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
96.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
97.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
98.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
99.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
100.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
101.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
102.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
103.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
104.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
105.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
106.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
107.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
108.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
109.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
110.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
111.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
112.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
113.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
114.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
115.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
116.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
117.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
118.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
119.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
120.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
121.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
122.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
123.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
124.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
125.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
126.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
127.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
128.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
129.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00
130.0	23.742	120	235.39	23.7	0.081598	0.000	0.000	235.393	23.742	0.11063	0.00

Pipe Heatup Calculation

Prepared by:
Checked by:

Pipe OD	1.05	in
Pipe Wall	0.219	in
dt	1	sec

	Mass	Heat Capacity	mCp
	lbm	BTU/lbm-deg F	BTU/F-ft
Metal	1.940	0.11	0.213
Water	0.128	1.0	0.128
		Total	0.341

Time	Initial Pipe Temp	Air Temp	Heat Transfer Coefficient (h	Pipe Surface Area (A)	Heat Transfer Rate	BTU's Transferred	Pipe Temp Increase	New Pipe Temp
sec	deg F	deg F	BTU/hr-ft^2-F	ft^2 per ft	BTU/hr per ft	BTU/ft	deg F	deg F
0.0								
1.0	120.000	325	25	0.275	1408.808	0.391	1.146	121.146
2.0	121.146	325	25	0.275	1400.931	0.389	1.140	122.286
3.0	122.286	325	25	0.275	1393.097	0.387	1.133	123.420
4.0	123.420	325	25	0.275	1385.308	0.385	1.127	124.547
5.0	124.547	325	25	0.275	1377.562	0.383	1.121	125.668
6.0	125.668	325	25	0.275	1369.859	0.381	1.115	126.782
7.0	126.782	325	25	0.275	1362.199	0.378	1.108	127.891
8.0	127.891	325	25	0.275	1354.582	0.376	1.102	128.993
9.0	128.993	325	25	0.275	1347.008	0.374	1.096	130.089
10.0	130.089	325	25	0.275	1339.476	0.372	1.090	131.179
11.0	131.179	325	25	0.275	1331.987	0.370	1.084	132.262
12.0	132.262	325	25	0.275	1324.539	0.368	1.078	133.340
13.0	133.340	325	25	0.275	1317.133	0.366	1.072	134.412
14.0	134.412	325	25	0.275	1309.768	0.364	1.066	135.477
15.0	135.477	325	25	0.275	1302.444	0.362	1.060	136.537
16.0	136.537	325	25	0.275	1295.161	0.360	1.054	137.591
17.0	137.591	325	25	0.275	1287.920	0.358	1.048	138.639
18.0	138.639	325	25	0.275	1280.718	0.356	1.042	139.681
19.0	139.681	325	25	0.275	1273.557	0.354	1.036	140.717
20.0	140.717	325	25	0.275	1266.436	0.352	1.030	141.747
21.0	141.747	325	25	0.275	1259.354	0.350	1.025	142.772
22.0	142.772	325	25	0.275	1252.313	0.348	1.019	143.791
23.0	143.791	325	25	0.275	1245.310	0.346	1.013	144.804
24.0	144.804	325	25	0.275	1238.347	0.344	1.008	145.812
25.0	145.812	325	25	0.275	1231.423	0.342	1.002	146.814
26.0	146.814	325	25	0.275	1224.537	0.340	0.996	147.810
27.0	147.810	325	25	0.275	1217.690	0.338	0.991	148.801
28.0	148.801	325	25	0.275	1210.881	0.336	0.985	149.786
29.0	149.786	325	25	0.275	1204.111	0.334	0.980	150.766
30.0	150.766	325	25	0.275	1197.378	0.333	0.974	151.740
31.0	151.740	325	25	0.275	1190.683	0.331	0.969	152.709
32.0	152.709	325	25	0.275	1184.025	0.329	0.963	153.672
33.0	153.672	325	25	0.275	1177.404	0.327	0.958	154.630
34.0	154.630	325	25	0.275	1170.821	0.325	0.953	155.583
35.0	155.583	325	25	0.275	1164.274	0.323	0.947	156.530
36.0	156.530	325	25	0.275	1157.764	0.322	0.942	157.472
37.0	157.472	325	25	0.275	1151.290	0.320	0.937	158.409
38.0	158.409	325	25	0.275	1144.853	0.318	0.932	159.340
39.0	159.340	325	25	0.275	1138.451	0.316	0.926	160.267
40.0	160.267	325	25	0.275	1132.086	0.314	0.921	161.188
41.0	161.188	325	25	0.275	1125.756	0.313	0.916	162.104
42.0	162.104	325	25	0.275	1119.461	0.311	0.911	163.015
43.0	163.015	325	25	0.275	1113.201	0.309	0.906	163.920
44.0	163.920	325	25	0.275	1106.977	0.307	0.901	164.821
45.0	164.821	325	25	0.275	1100.787	0.306	0.896	165.717
46.0	165.717	325	25	0.275	1094.632	0.304	0.891	166.607
47.0	166.607	325	25	0.275	1088.511	0.302	0.886	167.493
48.0	167.493	325	25	0.275	1082.425	0.301	0.881	168.374
49.0	168.374	325	25	0.275	1076.372	0.299	0.876	169.250
50.0	169.250	325	25	0.275	1070.354	0.297	0.871	170.120
51.0	170.120	325	25	0.275	1064.369	0.296	0.866	170.986
52.0	170.986	325	25	0.275	1058.417	0.294	0.861	171.848
53.0	171.848	325	25	0.275	1052.499	0.292	0.856	172.704
54.0	172.704	325	25	0.275	1046.614	0.291	0.852	173.556
55.0	173.556	325	25	0.275	1040.762	0.289	0.847	174.402
56.0	174.402	325	25	0.275	1034.942	0.287	0.842	175.244
57.0	175.244	325	25	0.275	1029.156	0.286	0.837	176.082
58.0	176.082	325	25	0.275	1023.401	0.284	0.833	176.914
59.0	176.914	325	25	0.275	1017.679	0.283	0.828	177.742
60.0	177.742	325	25	0.275	1011.988	0.281	0.823	178.566
61.0	178.566	325	25	0.275	1006.330	0.280	0.819	179.385
62.0	179.385	325	25	0.275	1000.703	0.278	0.814	180.199

Pipe Heatup Calculation

Prepared by:
Checked by:

Pipe OD	1.05	in
Pipe Wall	0.219	in
dt	1	sec

	Mass	Heat Capacity	mCp
	lbm	BTU/lbm-deg F	BTU/F-ft
Metal	1.940	0.11	0.213
Water	0.128	1.0	0.128
		Total	0.341

Time	Initial Pipe Temp	Air Temp	Heat Transfer Coefficient (h	Pipe Surface Area (A)	Heat Transfer Rate	BTU's Transferred	Pipe Temp Increase	New Pipe Temp
sec	deg F	deg F	BTU/hr-ft^2-F	ft^2 per ft	BTU/hr per ft	BTU/ft	deg F	deg F
63.0	180.199	325	25	0.275	995.107	0.276	0.810	181.009
64.0	181.009	325	25	0.275	989.543	0.275	0.805	181.814
65.0	181.814	325	25	0.275	984.010	0.273	0.801	182.614
66.0	182.614	325	25	0.275	978.508	0.272	0.796	183.410
67.0	183.410	325	25	0.275	973.036	0.270	0.792	184.202
68.0	184.202	325	25	0.275	967.596	0.269	0.787	184.989
69.0	184.989	325	25	0.275	962.185	0.267	0.783	185.772
70.0	185.772	325	25	0.275	956.805	0.266	0.778	186.551
71.0	186.551	325	25	0.275	951.455	0.264	0.774	187.325
72.0	187.325	325	25	0.275	946.135	0.263	0.770	188.095
73.0	188.095	325	25	0.275	940.845	0.261	0.766	188.860
74.0	188.860	325	25	0.275	935.584	0.260	0.761	189.622
75.0	189.622	325	25	0.275	930.353	0.258	0.757	190.378
76.0	190.378	325	25	0.275	925.150	0.257	0.753	191.131
77.0	191.131	325	25	0.275	919.977	0.256	0.749	191.880
78.0	191.880	325	25	0.275	914.833	0.254	0.744	192.624
79.0	192.624	325	25	0.275	909.718	0.253	0.740	193.364
80.0	193.364	325	25	0.275	904.631	0.251	0.736	194.100
81.0	194.100	325	25	0.275	899.573	0.250	0.732	194.832
82.0	194.832	325	25	0.275	894.543	0.248	0.728	195.560
83.0	195.560	325	25	0.275	889.541	0.247	0.724	196.284
84.0	196.284	325	25	0.275	884.567	0.246	0.720	197.004
85.0	197.004	325	25	0.275	879.621	0.244	0.716	197.719
86.0	197.719	325	25	0.275	874.703	0.243	0.712	198.431
87.0	198.431	325	25	0.275	869.812	0.242	0.708	199.139
88.0	199.139	325	25	0.275	864.948	0.240	0.704	199.842
89.0	199.842	325	25	0.275	860.112	0.239	0.700	200.542
90.0	200.542	325	25	0.275	855.302	0.238	0.696	201.238
91.0	201.238	325	25	0.275	850.520	0.236	0.692	201.930
92.0	201.930	325	25	0.275	845.764	0.235	0.688	202.618
93.0	202.618	325	25	0.275	841.035	0.234	0.684	203.303
94.0	203.303	325	25	0.275	836.332	0.232	0.680	203.983
95.0	203.983	325	25	0.275	831.656	0.231	0.677	204.660
96.0	204.660	325	25	0.275	827.006	0.230	0.673	205.333
97.0	205.333	325	25	0.275	822.382	0.228	0.669	206.002
98.0	206.002	325	25	0.275	817.783	0.227	0.665	206.667
99.0	206.667	325	25	0.275	813.210	0.226	0.662	207.329
100.0	207.329	325	25	0.275	808.663	0.225	0.658	207.987
101.0	207.987	325	25	0.275	804.142	0.223	0.654	208.641
102.0	208.641	325	25	0.275	799.645	0.222	0.651	209.292
103.0	209.292	325	25	0.275	795.174	0.221	0.647	209.939
104.0	209.939	325	25	0.275	790.728	0.220	0.643	210.582
105.0	210.582	325	25	0.275	786.306	0.218	0.640	211.222
106.0	211.222	325	25	0.275	781.910	0.217	0.636	211.858
107.0	211.858	325	25	0.275	777.538	0.216	0.633	212.491
108.0	212.491	325	25	0.275	773.190	0.215	0.629	213.120
109.0	213.120	325	25	0.275	768.867	0.214	0.626	213.745
110.0	213.745	325	25	0.275	764.568	0.212	0.622	214.368
111.0	214.368	325	25	0.275	760.292	0.211	0.619	214.986
112.0	214.986	325	25	0.275	756.041	0.210	0.615	215.601
113.0	215.601	325	25	0.275	751.814	0.209	0.612	216.213
114.0	216.213	325	25	0.275	747.610	0.208	0.608	216.821
115.0	216.821	325	25	0.275	743.430	0.207	0.605	217.426
116.0	217.426	325	25	0.275	739.273	0.205	0.602	218.028
117.0	218.028	325	25	0.275	735.139	0.204	0.598	218.626
118.0	218.626	325	25	0.275	731.028	0.203	0.595	219.221
119.0	219.221	325	25	0.275	726.941	0.202	0.591	219.812
120.0	219.812	325	25	0.275	722.876	0.201	0.588	220.400
121.0	220.400	325	25	0.275	718.834	0.200	0.585	220.985
122.0	220.985	325	25	0.275	714.815	0.199	0.582	221.567
123.0	221.567	325	25	0.275	710.818	0.197	0.578	222.145
124.0	222.145	325	25	0.275	706.843	0.196	0.575	222.720
125.0	222.720	325	25	0.275	702.891	0.195	0.572	223.292
126.0	223.292	325	25	0.275	698.961	0.194	0.569	223.861

MPR-2169 Appendix A.2
Calculation 025-065-02
Attachment A, Part 2

Pipe Heatup Calculation

Prepared by:
Checked by:

Pipe OD	1.05	in
Pipe Wall	0.219	in
dt	1	sec

	Mass	Heat Capacity	mCp
	lbm	BTU/lbm-deg F	BTU/F-ft
Metal	1.940	0.11	0.213
Water	0.128	1.0	0.128
		Total	0.341

Time	Initial Pipe Temp	Air Temp	Heat Transfer Coefficient (h	Pipe Surface Area (A)	Heat Transfer Rate	BTU's Transferred	Pipe Temp Increase	New Pipe Temp
sec	deg F	deg F	BTU/hr-ft^2-F	ft^2 per ft	BTU/hr per ft	BTU/ft	deg F	deg F
127.0	223.861	230	25	0.275	42.190	0.012	0.034	223.895
128.0	223.895	230	25	0.275	41.954	0.012	0.034	223.929
129.0	223.929	230	25	0.275	41.720	0.012	0.034	223.963
130.0	223.963	230	25	0.275	41.486	0.012	0.034	223.997
131.0	223.997	230	25	0.275	41.254	0.011	0.034	224.031
132.0	224.031	230	25	0.275	41.024	0.011	0.033	224.064
133.0	224.064	230	25	0.275	40.794	0.011	0.033	224.097
134.0	224.097	230	25	0.275	40.566	0.011	0.033	224.130
135.0	224.130	230	25	0.275	40.339	0.011	0.033	224.163
136.0	224.163	230	25	0.275	40.114	0.011	0.033	224.196
137.0	224.196	230	25	0.275	39.890	0.011	0.032	224.228
138.0	224.228	230	25	0.275	39.667	0.011	0.032	224.260
139.0	224.260	230	25	0.275	39.445	0.011	0.032	224.292
140.0	224.292	230	25	0.275	39.224	0.011	0.032	224.324
141.0	224.324	230	25	0.275	39.005	0.011	0.032	224.356
142.0	224.356	230	25	0.275	38.787	0.011	0.032	224.388
143.0	224.388	230	25	0.275	38.570	0.011	0.031	224.419
144.0	224.419	230	25	0.275	38.354	0.011	0.031	224.450
145.0	224.450	230	25	0.275	38.140	0.011	0.031	224.481
146.0	224.481	230	25	0.275	37.927	0.011	0.031	224.512
147.0	224.512	230	25	0.275	37.714	0.010	0.031	224.543
148.0	224.543	230	25	0.275	37.504	0.010	0.031	224.573
149.0	224.573	230	25	0.275	37.294	0.010	0.030	224.604
150.0	224.604	230	25	0.275	37.085	0.010	0.030	224.634
151.0	224.634	230	25	0.275	36.878	0.010	0.030	224.664
152.0	224.664	230	25	0.275	36.672	0.010	0.030	224.694
153.0	224.694	230	25	0.275	36.467	0.010	0.030	224.723
154.0	224.723	230	25	0.275	36.263	0.010	0.030	224.753
155.0	224.753	230	25	0.275	36.060	0.010	0.029	224.782
156.0	224.782	230	25	0.275	35.858	0.010	0.029	224.811
157.0	224.811	230	25	0.275	35.658	0.010	0.029	224.840
158.0	224.840	230	25	0.275	35.459	0.010	0.029	224.869
159.0	224.869	230	25	0.275	35.260	0.010	0.029	224.898
160.0	224.898	230	25	0.275	35.063	0.010	0.029	224.926
161.0	224.926	230	25	0.275	34.867	0.010	0.028	224.955
162.0	224.955	230	25	0.275	34.672	0.010	0.028	224.983
163.0	224.983	230	25	0.275	34.478	0.010	0.028	225.011
164.0	225.011	230	25	0.275	34.285	0.010	0.028	225.039
165.0	225.039	230	25	0.275	34.094	0.009	0.028	225.067
166.0	225.067	230	25	0.275	33.903	0.009	0.028	225.094
167.0	225.094	230	25	0.275	33.714	0.009	0.027	225.122
168.0	225.122	230	25	0.275	33.525	0.009	0.027	225.149
169.0	225.149	230	25	0.275	33.338	0.009	0.027	225.176
170.0	225.176	230	25	0.275	33.151	0.009	0.027	225.203
171.0	225.203	230	25	0.275	32.966	0.009	0.027	225.230
172.0	225.230	230	25	0.275	32.781	0.009	0.027	225.257
173.0	225.257	230	25	0.275	32.598	0.009	0.027	225.283
174.0	225.283	230	25	0.275	32.416	0.009	0.026	225.309
175.0	225.309	230	25	0.275	32.235	0.009	0.026	225.336
176.0	225.336	230	25	0.275	32.054	0.009	0.026	225.362
177.0	225.362	230	25	0.275	31.875	0.009	0.026	225.388
178.0	225.388	230	25	0.275	31.697	0.009	0.026	225.413
179.0	225.413	230	25	0.275	31.520	0.009	0.026	225.439
180.0	225.439	230	25	0.275	31.343	0.009	0.026	225.465
181.0	225.465	230	25	0.275	31.168	0.009	0.025	225.490
182.0	225.490	230	25	0.275	30.994	0.009	0.025	225.515
183.0	225.515	230	25	0.275	30.821	0.009	0.025	225.540
184.0	225.540	230	25	0.275	30.648	0.009	0.025	225.565
185.0	225.565	230	25	0.275	30.477	0.008	0.025	225.590
186.0	225.590	230	25	0.275	30.306	0.008	0.025	225.615
187.0	225.615	230	25	0.275	30.137	0.008	0.025	225.639
188.0	225.639	230	25	0.275	29.968	0.008	0.024	225.664
189.0	225.664	230	25	0.275	29.801	0.008	0.024	225.688
190.0	225.688	230	25	0.275	29.634	0.008	0.024	225.712

Pipe Heatup Calculation

Pipe OD	1.05	in
Pipe Wall	0.219	in
dt	1	sec

	Mass	Heat Capacity	mCp
	lbm	BTU/lbm-deg F	BTU/F-ft
Metal	1.940	0.11	0.213
Water	0.128	1.0	0.128
		Total	0.341

Time	Initial Pipe Temp	Air Temp	Heat Transfer Coefficient (h	Pipe Surface Area (A)	Heat Transfer Rate	BTU's Transferred	Pipe Temp Increase	New Pipe Temp
sec	deg F	deg F	BTU/hr-ft^2-F	ft^2 per ft	BTU/hr per ft	BTU/ft	deg F	deg F
191.0	225.712	230	25	0.275	29.469	0.008	0.024	225.736
192.0	225.736	230	25	0.275	29.304	0.008	0.024	225.760
193.0	225.760	230	25	0.275	29.140	0.008	0.024	225.783
194.0	225.783	230	25	0.275	28.977	0.008	0.024	225.807
195.0	225.807	230	25	0.275	28.815	0.008	0.023	225.830
196.0	225.830	230	25	0.275	28.654	0.008	0.023	225.854
197.0	225.854	230	25	0.275	28.494	0.008	0.023	225.877
198.0	225.877	230	25	0.275	28.334	0.008	0.023	225.900
199.0	225.900	230	25	0.275	28.176	0.008	0.023	225.923
200.0	225.923	230	25	0.275	28.018	0.008	0.023	225.946
201.0	225.946	230	25	0.275	27.862	0.008	0.023	225.968
202.0	225.968	230	25	0.275	27.706	0.008	0.023	225.991
203.0	225.991	230	25	0.275	27.551	0.008	0.022	226.013
204.0	226.013	230	25	0.275	27.397	0.008	0.022	226.036
205.0	226.036	230	25	0.275	27.244	0.008	0.022	226.058
206.0	226.058	230	25	0.275	27.091	0.008	0.022	226.080
207.0	226.080	230	25	0.275	26.940	0.007	0.022	226.102
208.0	226.102	230	25	0.275	26.789	0.007	0.022	226.124
209.0	226.124	230	25	0.275	26.639	0.007	0.022	226.145
210.0	226.145	230	25	0.275	26.491	0.007	0.022	226.167
211.0	226.167	230	25	0.275	26.342	0.007	0.021	226.188
212.0	226.188	230	25	0.275	26.195	0.007	0.021	226.210
213.0	226.210	230	25	0.275	26.049	0.007	0.021	226.231
214.0	226.231	230	25	0.275	25.903	0.007	0.021	226.252
215.0	226.252	230	25	0.275	25.758	0.007	0.021	226.273
216.0	226.273	230	25	0.275	25.614	0.007	0.021	226.294
217.0	226.294	230	25	0.275	25.471	0.007	0.021	226.314
218.0	226.314	230	25	0.275	25.328	0.007	0.021	226.335
219.0	226.335	230	25	0.275	25.187	0.007	0.020	226.355
220.0	226.355	230	25	0.275	25.046	0.007	0.020	226.376
221.0	226.376	230	25	0.275	24.906	0.007	0.020	226.396
222.0	226.396	230	25	0.275	24.767	0.007	0.020	226.416
223.0	226.416	230	25	0.275	24.628	0.007	0.020	226.436
224.0	226.436	230	25	0.275	24.491	0.007	0.020	226.456
225.0	226.456	230	25	0.275	24.354	0.007	0.020	226.476
226.0	226.476	230	25	0.275	24.217	0.007	0.020	226.496
227.0	226.496	230	25	0.275	24.082	0.007	0.020	226.515
228.0	226.515	230	25	0.275	23.947	0.007	0.019	226.535
229.0	226.535	230	25	0.275	23.813	0.007	0.019	226.554
230.0	226.554	230	25	0.275	23.680	0.007	0.019	226.573
231.0	226.573	230	25	0.275	23.548	0.007	0.019	226.593
232.0	226.593	230	25	0.275	23.416	0.007	0.019	226.612
233.0	226.612	230	25	0.275	23.285	0.006	0.019	226.631
234.0	226.631	230	25	0.275	23.155	0.006	0.019	226.649
235.0	226.649	230	25	0.275	23.026	0.006	0.019	226.668
236.0	226.668	230	25	0.275	22.897	0.006	0.019	226.687
237.0	226.687	230	25	0.275	22.769	0.006	0.019	226.705
238.0	226.705	230	25	0.275	22.642	0.006	0.018	226.724
239.0	226.724	230	25	0.275	22.515	0.006	0.018	226.742
240.0	226.742	230	25	0.275	22.389	0.006	0.018	226.760
241.0	226.760	230	25	0.275	22.264	0.006	0.018	226.778
242.0	226.778	230	25	0.275	22.139	0.006	0.018	226.796
243.0	226.796	230	25	0.275	22.016	0.006	0.018	226.814
244.0	226.814	230	25	0.275	21.892	0.006	0.018	226.832
245.0	226.832	230	25	0.275	21.770	0.006	0.018	226.850
246.0	226.850	230	25	0.275	21.648	0.006	0.018	226.868
247.0	226.868	230	25	0.275	21.527	0.006	0.018	226.885
248.0	226.885	230	25	0.275	21.407	0.006	0.017	226.902
249.0	226.902	230	25	0.275	21.287	0.006	0.017	226.920
250.0	226.920	230	25	0.275	21.168	0.006	0.017	226.937
251.0	226.937	230	25	0.275	21.050	0.006	0.017	226.954
252.0	226.954	230	25	0.275	20.932	0.006	0.017	226.971
253.0	226.971	230	25	0.275	20.815	0.006	0.017	226.988
254.0	226.988	230	25	0.275	20.699	0.006	0.017	227.005

Pipe Heatup Calculation

Prepared by: R C Russell
Checked by: S R Haas

Pipe OD	1.05	in
Pipe Wall	0.219	in
dt	1	sec

	Mass	Heat Capacity	mCp
	lbm	BTU/lbm-deg F	BTU/F-ft
Metal	1.940	0.11	0.213
Water	0.128	1.0	0.128
		Total	0.341

Time	Initial Pipe Temp	Air Temp	Heat Transfer Coefficient (h	Pipe Surface Area (A)	Heat Transfer Rate	BTU's Transferred	Pipe Temp Increase	New Pipe Temp
sec	deg F	deg F	BTU/hr-ft^2-F	ft^2 per ft	BTU/hr per ft	BTU/ft	deg F	deg F
255.0	227.005	230	25	0.275	20.583	0.006	0.017	227.022
256.0	227.022	230	25	0.275	20.468	0.006	0.017	227.038
257.0	227.038	230	25	0.275	20.353	0.006	0.017	227.055
258.0	227.055	230	25	0.275	20.240	0.006	0.016	227.071
259.0	227.071	230	25	0.275	20.126	0.006	0.016	227.088
260.0	227.088	230	25	0.275	20.014	0.006	0.016	227.104
261.0	227.104	230	25	0.275	19.902	0.006	0.016	227.120
262.0	227.120	230	25	0.275	19.791	0.005	0.016	227.136
263.0	227.136	230	25	0.275	19.680	0.005	0.016	227.152
264.0	227.152	230	25	0.275	19.570	0.005	0.016	227.168
265.0	227.168	230	25	0.275	19.461	0.005	0.016	227.184
266.0	227.184	230	25	0.275	19.352	0.005	0.016	227.200
267.0	227.200	230	25	0.275	19.244	0.005	0.016	227.215
268.0	227.215	230	25	0.275	19.136	0.005	0.016	227.231
269.0	227.231	230	25	0.275	19.029	0.005	0.015	227.247
270.0	227.247	230	25	0.275	18.923	0.005	0.015	227.262
271.0	227.262	230	25	0.275	18.817	0.005	0.015	227.277
272.0	227.277	230	25	0.275	18.712	0.005	0.015	227.292
273.0	227.292	230	25	0.275	18.607	0.005	0.015	227.308
274.0	227.308	230	25	0.275	18.503	0.005	0.015	227.323
275.0	227.323	230	25	0.275	18.399	0.005	0.015	227.338
276.0	227.338	230	25	0.275	18.297	0.005	0.015	227.353
277.0	227.353	230	25	0.275	18.194	0.005	0.015	227.367
278.0	227.367	230	25	0.275	18.092	0.005	0.015	227.382
279.0	227.382	230	25	0.275	17.991	0.005	0.015	227.397
280.0	227.397	230	25	0.275	17.891	0.005	0.015	227.411

Initial Pipe Temp: From Previous Time Step

Air Temp: Varies with time; 325 deg F at start, drops to 230 after 127 seconds

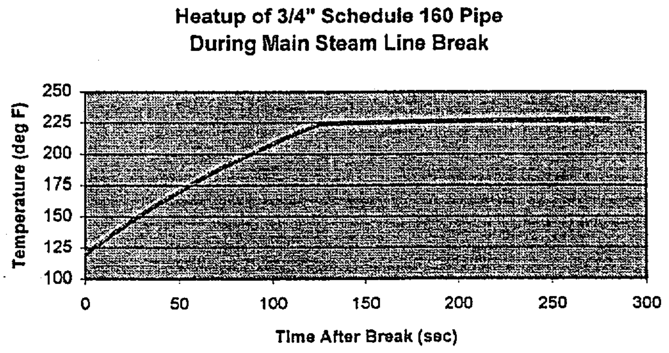
Heat Transfer Coefficient: h is assumed constant at this value over the transient

Heat Transfer Rate: q = hA (Tair - Tpipe)

BTU's Transferred: Q = (q/3600)(dt)

Pipe Temp Increase: dT = Q/(Total mCp)

New Pipe Temp: Tnew = Tinitial + dT



Attachment B
Peak Pressure in CPN-32

PURPOSE:

The purpose of this attachment is to calculate the peak pressure attained during a design basis accident in the Cook Unit 1 accumulator fill line connected to CPN-32.

CALCULATION:

The expected temperature of the water during a LOCA and the ambient temperature are

$T_{LOCA} := 235$ $\qquad$ $T_{amb} := 70$

The conversion for psi to ksi is

$ksi := 1000\ psi$

For penetration CPN-32, there are two different types of pipes in the system.

The first pipe is 1" Sch 160, pipe specification M-14

$ID_{1M14} := 0.815\ in$ $\qquad$ $S_{m1M14} := 20\ ksi$ $\qquad$ $E_{1M14} := 27.4 \cdot 10^6\ psi$

$t_{1M14} := 0.250\ in$ $\qquad$ $S_{y1M14} := 24.13\ ksi$ $\qquad$ $E_{p1M14} := 0.425 \cdot 10^6\ psi$

$OD_{1M14} := ID_{1M14} + 2 \cdot t_{1M14}$ $\qquad$ $S_{u1M14} := 69.25\ ksi$ $\qquad$ SA-376 Gr TP304

$OD_{1M14} = 1.315 \cdot in$

The second pipe is 3/4" Sch 160, pipe specification M-14

$ID_{34M14} := 0.612\ in$ $\qquad$ $S_{m34M14} := 20\ ksi$ $\qquad$ $E_{34M14} := 27.4 \cdot 10^6\ psi$

$t_{34M14} := 0.219\ in$ $\qquad$ $S_{y34M14} := 24.13\ ksi$ $\qquad$ $E_{p34M14} := 0.425 \cdot 10^6\ psi$

$OD_{34M14} := ID_{34M14} + 2 \cdot t_{34M14}$ $\qquad$ $S_{u34M14} := 69.25\ ksi$ $\qquad$ SA-376 Gr TP304

$OD_{34M14} = 1.05 \cdot in$

The lengths of the two different pipes are as follows:

Note: Inverse units used in these equations result from MathCad format requirements and do not represent errors.

$L_1 := (290\ ft) \cdot in^{-1}$ $\qquad$ $L_2 := (170\ ft) \cdot in^{-1}$

$L_1 = 3.48 \cdot 10^3$ inches $\qquad$ $L_2 = 2.04 \cdot 10^3$ inches

For the first pipe (1" Sch 160, M-14), the specific material parameters used in the calculation are

$t_1 := t_{1M14} \cdot in^{-1}$ $\qquad t_1 = 0.25$ inches

$r_{01} := \left(\frac{OD_{1M14} \cdot in^{-1}}{2} \right) - t_1$ $\qquad r_{01} = 0.408$ inches

$S_{y1} := S_{y1M14} \cdot psi^{-1}$ $\qquad S_{y1} = 2.413 \cdot 10^4$ psi

$E_1 := E_{1M14} \cdot psi^{-1}$ $\qquad E_1 = 2.74 \cdot 10^7$ psi

$E_{p1} := E_{p1M14} \cdot psi^{-1}$ $\qquad E_{p1} = 4.25 \cdot 10^5$ psi

$\varepsilon_{y1} := \frac{S_{y1}}{E_1}$ $\qquad \varepsilon_{y1} = 8.807 \cdot 10^{-4}$ in/in

$S_{m1} := S_{m1M14}$ $\qquad S_{m1} = 2 \cdot 10^4 \, psi$

$S_{u1} := S_{u1M14}$ $\qquad S_{u1} = 6.925 \cdot 10^4 \, psi$

For the second pipe (3/4" Sch 160, M-14), the specific material parameters for the calculation are

$t_2 := t_{34M14} \cdot in^{-1}$ $\qquad t_2 = 0.219$ inches

$r_{02} := \left(\frac{OD_{34M14} \cdot in^{-1}}{2} \right) - t_2$ $\qquad r_{02} = 0.306$ inches

$S_{y2} := S_{y34M14} \cdot psi^{-1}$ $\qquad S_{y2} = 2.413 \cdot 10^4$ psi

$E_2 := E_{34M14} \cdot psi^{-1}$ $\qquad E_2 = 2.74 \cdot 10^7$ psi

$E_{p2} := E_{p34M14} \cdot psi^{-1}$ $\qquad E_{p2} = 4.25 \cdot 10^5$ psi

$\varepsilon_{y2} := \frac{S_{y2}}{E_2}$ $\qquad \varepsilon_{y2} = 8.807 \cdot 10^{-4}$ in/in

$S_{m2} := S_{m34M14}$ $\qquad S_{m2} = 2 \cdot 10^4 \, psi$

$S_{u2} := S_{u34M14}$ $\qquad S_{u2} = 6.925 \cdot 10^4 \, psi$

At the initial conditions, the trapped water has a specific volume of

$v_{initial} := 0.015963 \, ft^3 \cdot lb^{-1}$

Therefore, the mass of water in a unit length (1 inch) of pipe is

$$m_{w1i} := \frac{\pi \cdot r_{01}^{2} \cdot 1}{\left(v_{initial} \cdot lb \cdot in^{-3}\right)} \qquad m_{w1i} = 0.019$$ lb per unit length in inches (1" Sch 160)

$$m_{w2i} := \frac{\pi \cdot r_{02}^{2} \cdot 1}{\left(v_{initial} \cdot lb \cdot in^{-3}\right)} \qquad m_{w2i} = 0.011$$ lb per unit length in inches (3/4" Sch 160)

The mean coefficient of thermal expansion for SA-376 Gr TP304 at 235 F is

$$\alpha_T := 8.83 \cdot 10^{-6}$$

And the strain due to thermal expansion is

$$\varepsilon_{th} := \alpha_T \cdot \left(T_{LOCA} - T_{amb}\right) \qquad \varepsilon_{th} = 1.457 \cdot 10^{-3}$$ in/in

The total mass of the water in the piping, assuming that the pipe is filled, is

$$m_{tot} := m_{w1i} \cdot L_1 + m_{w2i} \cdot L_2 \qquad m_{tot} = 87.57$$ lb

To solve the equations for the system with both pipe sizes, we must guess inital values for the variables.

$P := 3000$ $\qquad \varepsilon_{p1} := 0.01$ $\qquad vol_1 := 1$

$v := 0.016$ $\qquad \varepsilon_{p2} := 0.01$ $\qquad vol_2 := 1$

$\sigma_{h1} := 100$ $\qquad r_1 := 1$ $\qquad m_{w1} := 1$

$\sigma_{h2} := 100$ $\qquad r_2 := 1$ $\qquad m_{w2} := 1$

Assign a function to represent the change from elastic strain to plastic strain as follows:

$$f_1\left(\sigma_{h1}, S_{y1}, E_1, E_{p1}, \varepsilon_{y1}\right) := \mathrm{if}\left(\sigma_{h1} > S_{y1}, \frac{\sigma_{h1} - S_{y1}}{E_{p1}} + \varepsilon_{y1}, \frac{\sigma_{h1}}{E_1}\right)$$

$$f_2\left(\sigma_{h2}, S_{y2}, E_2, E_{p2}, \varepsilon_{y2}\right) := \mathrm{if}\left(\sigma_{h2} > S_{y2}, \frac{\sigma_{h2} - S_{y2}}{E_{p2}} + \varepsilon_{y2}, \frac{\sigma_{h2}}{E_2}\right)$$

Given

$r_1 = (1+\varepsilon_{p1})\cdot r_{01}\cdot(1+\varepsilon_{th})$

$r_2 = (1+\varepsilon_{p2})\cdot r_{02}\cdot(1+\varepsilon_{th})$

$vol_1 = \dfrac{\pi\cdot r_1^2\cdot(1+\varepsilon_{th})\cdot L_1}{(12^3)}$

$vol_2 = \dfrac{\pi\cdot r_2^2\cdot(1+\varepsilon_{th})\cdot L_2}{(12^3)}$

$v = \dfrac{vol_1}{m_{w1}}$

$v = \dfrac{vol_2}{m_{w2}}$

$P = (4.86308\cdot10^9)\cdot v^2 - (1.80300\cdot10^8)\cdot v + 1.65795\cdot10^6$

$m_{tot} = m_{w1} + m_{w2}$

$\sigma_{h1} = P\cdot\dfrac{r_1}{t_1}$

$\sigma_{h2} = P\cdot\dfrac{r_2}{t_2}$

$\varepsilon_{p1} = f_1(\sigma_{h1}, S_{y1}, E_1, E_{p1}, \varepsilon_{y1})$

$\varepsilon_{p2} = f_2(\sigma_{h2}, S_{y2}, E_2, E_{p2}, \varepsilon_{y2})$

Solving the equations.

$AA := \mathrm{Find}(r_1, r_2, \varepsilon_{p1}, \varepsilon_{p2}, vol_1, vol_2, v, P, \sigma_{h1}, \sigma_{h2}, m_{w1}, m_{w2})$

$r_1 := AA_{0,0}\cdot in$ $\qquad r_1 = 0.409\,in$

$r_2 := AA_{1,0}\cdot in$ $\qquad r_2 = 0.307\,in$

$\varepsilon_{p1} := AA_{2,0}$ $\qquad \varepsilon_{p1} = 0.315\,\%$

$\varepsilon_{p2} := AA_{3,0}$ $\qquad \varepsilon_{p2} = 0.078\,\%$

$vol_1 := AA_{4,0}\cdot ft^3$ $\qquad vol_1 = 1.062\,ft^3$

$vol_2 := AA_{5,0}\cdot ft^3$ $\qquad vol_2 = 0.349\,ft^3$

$v := AA_{6,0}\cdot ft^3\cdot lb^{-1}$ $\qquad v = 0.016115\,ft^3\cdot lb^{-1}$

$P := AA_{7,0}\cdot psi$ $\qquad P = 1.5324\cdot10^4\,psi$

$\sigma_{h1} := AA_{8,0}\cdot psi$ $\qquad \sigma_{h1} = 25.092\,ksi$

$\sigma_{h2} := AA_{9,0}\cdot psi$ $\qquad \sigma_{h2} = 21.459\,ksi$

$m_{w1} := AA_{10,0}\cdot lb$ $\qquad m_{w1} = 65.892\,lb$

$m_{w2} := AA_{11,0}\cdot lb$ $\qquad m_{w2} = 21.678\,lb$

AA =

	0
0	0.409
1	0.307
2	$3.145\cdot10^{-3}$
3	$7.832\cdot10^{-4}$
4	1.062
5	0.349
6	0.016
7	$1.532\cdot10^{4}$
8	$2.509\cdot10^{4}$
9	$2.146\cdot10^{4}$
10	65.892
11	21.678

Attachment C
Peak Pressure in RCP Seal Bypass Line

PURPOSE:

The purpose of this attachment is to calculate the peak pressure attained during a design basis accident in the Cook Unit 1 RCP seal bypass line inside the containment.

CALCULATION:

The expected temperature of the water during a LOCA and the ambient temperature are

$T_{LOCA} := 235$ $\quad$ $T_{amb} := 70$

The conversion for psi to ksi is

$ksi := 1000\ psi$

For penetration RCP Seal, there are two different pipes in the system -- very short lengths of 1" pipe and relatively longer 3/4" pipe. For conservatism, assumed a 1:100 length ratio.

The first pipe is 1" Sch 160, pipe specification M-14

$ID_{1M14} := 0.815\ in$ $\quad$ $S_{m1M14} := 20\ ksi$ $\quad$ $E_{1M14} := 27.4\cdot 10^{6}\ psi$

$t_{1M14} := 0.250\ in$ $\quad$ $S_{y1M14} := 24.13\ ksi$ $\quad$ $E_{p1M14} := 0.425\cdot 10^{6}\ psi$

$OD_{1M14} := ID_{1M14} + 2\cdot t_{1M14}$ $\quad$ $S_{u1M14} := 69.25\ ksi$ $\quad$ SA-376 Gr TP304

$OD_{1M14} = 1.315\circ in$

The second pipe is 3/4" Sch 160, pipe specification M-14

$ID_{34M14} := 0.612\ in$ $\quad$ $S_{m34M14} := 20\ ksi$ $\quad$ $E_{34M14} := 27.4\cdot 10^{6}\ psi$

$t_{34M14} := 0.219\ in$ $\quad$ $S_{y34M14} := 24.13\ ksi$ $\quad$ $E_{p34M14} := 0.425\cdot 10^{6}\ psi$

$OD_{34M14} := ID_{34M14} + 2\cdot t_{34M1}$ $\quad$ $S_{u34M14} := 69.25\ ksi$ $\quad$ SA-376 Gr TP304

$OD_{34M14} = 1.05\circ in$

The lengths of the two different pipes are conservatively represented as follows:

$L_{1} := (20\ ft)\cdot in^{-1}$ $\quad$ $L_{2} := (450\ ft)\cdot in^{-1}$

$L_{1} = 240$ inches $\quad$ $L_{2} = 5.4\cdot 10^{3}$ inches

> Note: Inverse units used in these equations result from MathCad format requirements and do not represent errors.

For the first pipe (1" Sch 160, M-14), the specific material parameters used in the calculation are

$t_1 := t_{1M14} \cdot in^{-1}$ $\quad t_1 = 0.25$ inches

$r_{01} := \left(\frac{OD_{1M14} \cdot in^{-1}}{2}\right) - t_1$ $\quad r_{01} = 0.408$ inches

$S_{y1} := S_{y1M14} \cdot psi^{-1}$ $\quad S_{y1} = 2.413 \cdot 10^4$ psi

$E_1 := E_{1M14} \cdot psi^{-1}$ $\quad E_1 = 2.74 \cdot 10^7$ psi

$E_{p1} := E_{p1M14} \cdot psi^{-1}$ $\quad E_{p1} = 4.25 \cdot 10^5$ psi

$\varepsilon_{y1} := \frac{S_{y1}}{E_1}$ $\quad \varepsilon_{y1} = 8.807 \cdot 10^{-4}$ in/in

$S_{m1} := S_{m1M14}$ $\quad S_{m1} = 2 \cdot 10^4 \, psi$

$S_{u1} := S_{u1M14}$ $\quad S_{u1} = 6.925 \cdot 10^4 \, psi$

For the second pipe (3/4" Sch 160, M-14), the specific material parameters for the calculation are

$t_2 := t_{34M14} \cdot in^{-1}$ $\quad t_2 = 0.219$ inches

$r_{02} := \left(\frac{OD_{34M14} \cdot in^{-1}}{2}\right) - t_2$ $\quad r_{02} = 0.306$ inches

$S_{y2} := S_{y34M14} \cdot psi^{-1}$ $\quad S_{y2} = 2.413 \cdot 10^4$ psi

$E_2 := E_{34M14} \cdot psi^{-1}$ $\quad E_2 = 2.74 \cdot 10^7$ psi

$E_{p2} := E_{p34M14} \cdot psi^{-1}$ $\quad E_{p2} = 4.25 \cdot 10^5$ psi

$\varepsilon_{y2} := \frac{S_{y2}}{E_2}$ $\quad \varepsilon_{y2} = 8.807 \cdot 10^{-4}$ in/in

$S_{m2} := S_{m34M14}$ $\quad S_{m2} = 2 \cdot 10^4 \, psi$

$S_{u2} := S_{u34M14}$ $\quad S_{u2} = 6.925 \cdot 10^4 \, psi$

At the initial conditions, the trapped water has a specific volume of:

$v_{initial} := 0.015928 \, ft^3 \cdot lb^{-1}$

Therefore, the mass of water in a unit length (1 inch) of pipe is

$m_{w1i} := \dfrac{\pi \cdot r_{01}{}^{2} \cdot 1}{\left(v_{initial} \cdot lb \cdot in^{-3}\right)}$ $\qquad m_{w1i} = 0.019$ lb per unit length in inches (1" Sch 160)

$m_{w2i} := \dfrac{\pi \cdot r_{02}{}^{2} \cdot 1}{\left(v_{initial} \cdot lb \cdot in^{-3}\right)}$ $\qquad m_{w2i} = 0.011$ lb per unit length in inches (3/4" Sch 160)

The mean coefficient of thermal expansion for SA-376 Gr TP304 at 235 F is

$\alpha_T := 8.83 \cdot 10^{-6}$

And the strain due to thermal expansion is

$\varepsilon_{th} := \alpha_T \cdot \left(T_{LOCA} - T_{amb}\right)$ $\qquad \varepsilon_{th} = 1.457 \cdot 10^{-3}$ in/in

The total mass of the water in the piping, assuming that the pipe is filled, is

$m_{tot} := m_{w1i} \cdot L_1 + m_{w2i} \cdot L_2$ $\qquad m_{tot} = 62.263$ lb

To solve the equations for the system with both pipe sizes, we must guess inital values for the variables.

$P := 3000$ $\qquad \varepsilon_{p1} := 0.01$ $\qquad vol_1 := 1$

$v := 0.016$ $\qquad \varepsilon_{p2} := 0.01$ $\qquad vol_2 := 1$

$\sigma_{h1} := 100$ $\qquad r_1 := 1$ $\qquad m_{w1} := 1$

$\sigma_{h2} := 100$ $\qquad r_2 := 1$ $\qquad m_{w2} := 1$

Assign a function to represent the change from elastic strain to plastic strain as follows:

$$f_1\left(\sigma_{h1}, S_{y1}, E_1, E_{p1}, \varepsilon_{y1}\right) := \mathrm{if}\left(\sigma_{h1} > S_{y1}, \frac{\sigma_{h1} - S_{y1}}{E_{p1}} + \varepsilon_{y1}, \frac{\sigma_{h1}}{E_1}\right)$$

$$f_2\left(\sigma_{h2}, S_{y2}, E_2, E_{p2}, \varepsilon_{y2}\right) := \mathrm{if}\left(\sigma_{h2} > S_{y2}, \frac{\sigma_{h2} - S_{y2}}{E_{p2}} + \varepsilon_{y2}, \frac{\sigma_{h2}}{E_2}\right)$$

Given

$r_1 = (1+\varepsilon_{p1})\cdot r_{01}\cdot(1+\varepsilon_{th})$ $\qquad$ $r_2 = (1+\varepsilon_{p2})\cdot r_{02}\cdot(1+\varepsilon_{th})$

$vol_1 = \dfrac{\pi\cdot r_1{}^2\cdot(1+\varepsilon_{th})\cdot L_1}{(12^3)}$ $\qquad$ $vol_2 = \dfrac{\pi\cdot r_2{}^2\cdot(1+\varepsilon_{th})\cdot L_2}{(12^3)}$

$v = \dfrac{vol_1}{m_{w1}}$ $\qquad$ $v = \dfrac{vol_2}{m_{w2}}$

$P = (4.86308\cdot10^9)\cdot v^2 - (1.80300\cdot10^8)\cdot v + 1.65795\cdot10^6$ $\qquad$ $m_{tot} = m_{w1} + m_{w2}$

$\sigma_{h1} = P\cdot\dfrac{r_1}{t_1}$ $\qquad$ $\sigma_{h2} = P\cdot\dfrac{r_2}{t_2}$

$\varepsilon_{p1} = f_1(\sigma_{h1}, S_{y1}, E_1, E_{p1}, \varepsilon_{y1})$ $\qquad$ $\varepsilon_{p2} = f_2(\sigma_{h2}, S_{y2}, E_2, E_{p2}, \varepsilon_{y2})$

Solving the equations.

$AA := \mathrm{Find}(r_1, r_2, \varepsilon_{p1}, \varepsilon_{p2}, vol_1, vol_2, v, P, \sigma_{h1}, \sigma_{h2}, m_{w1}, m_{w2})$

$r_1 := AA_{0,0}\cdot in$ $\qquad$ $r_1 = 0.412\,in$

$r_2 := AA_{1,0}\cdot in$ $\qquad$ $r_2 = 0.307\,in$

$\varepsilon_{p1} := AA_{2,0}$ $\qquad$ $\varepsilon_{p1} = 0.988\,\%$

$\varepsilon_{p2} := AA_{3,0}$ $\qquad$ $\varepsilon_{p2} = 0.087\,\%$

$vol_1 := AA_{4,0}\cdot ft^3$ $\qquad$ $vol_1 = 0.074\,ft^3$

$vol_2 := AA_{5,0}\cdot ft^3$ $\qquad$ $vol_2 = 0.925\,ft^3$

$v := AA_{6,0}\cdot ft^3\cdot lb^{-1}$ $\qquad$ $v = 0.016047\,ft^3\cdot lb^{-1}$

$P := AA_{7,0}\cdot psi$ $\qquad$ $P = 1.6958\cdot10^4\,psi$

$\sigma_{h1} := AA_{8,0}\cdot psi$ $\qquad$ $\sigma_{h1} = 27.955\,ksi$

$\sigma_{h2} := AA_{9,0}\cdot psi$ $\qquad$ $\sigma_{h2} = 23.749\,ksi$

$m_{w1} := AA_{10,0}\cdot lb$ $\qquad$ $m_{w1} = 4.625\,lb$

$m_{w2} := AA_{11,0}\cdot lb$ $\qquad$ $m_{w2} = 57.638\,lb$

AA =

	0
0	0.412
1	0.307
2	$9.88\cdot10^{-3}$
3	$8.668\cdot10^{-4}$
4	0.074
5	0.925
6	0.016
7	$1.696\cdot10^{4}$
8	$2.795\cdot10^{4}$
9	$2.375\cdot10^{4}$
10	4.625
11	57.638

ATTACHMENT 8 TO C0801-05

MPR CALCULATION 025-057-01

STRUCTURAL EVALUATION FOR SELECTED PIPING SEGMENTS, REVISION 3

MPR

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

CALCULATION TITLE PAGE

Client
American Electric Power

Page 1 of 54
(including attachments)

Project
Generic Letter 96-06: Thermal Over-pressurization Operability Evaluation

Task No.
025-0004-0570

Title
Structural Evaluation for Selected Piping Segments

Calculation No.
025-057-01

Preparer/Date	Checker/Date	Reviewer/Approver/Date	Rev. No.
Mark Gillespie 2/18/2000	Amol Limaye 2/18/2000	R. C. Trench 2/18/2000	0
Ralph S. Paul 2/29/2000	Amol Limaye 2/29/2000	R. C. Trench 2/29/2000	1
Ralph S. Paul 3/17/2000	Amol Limaye 3/17/2000	R. C. Trench 3/17/2000	2
Mark Gillespie (MSG) 3/27/2000	Amol Limaye 3/27/2000	R C Trench 3/27/2000	3

QUALITY ASSURANCE DOCUMENT

This document has been prepared, checked and reviewed/approved in accordance with the Quality Assurance requirements of 10CFR50, Appendix B, as specified in the MPR Quality Assurance Manual.

RECORD OF REVISIONS

Calculation No.	Prepared By	Checked By	Page 2
025-057-01	MBG		

Revision	Description
0	Original Issue
1	Revised to incorporate AEP comments and to update references to include the DIT that transmitted design input data to MPR. Only pages 1, 2, 4, 5, 6, 14, 15, and 16 were revised. All other pages are still Revision 0.
2	Revised to incorporate DRB comments. Only pages 1, 2, 3, 6, and 12 were revised. Appendix E was added. Pages 4, 5, 14, 15 and 16 are Revision 1. All other pages are Revision 0.
3	Revised to incorporate DRB comments. Changed initial pressure and final temperature for CPN-32. Reprinted pages 1-17 to accommodate added text, and revised Appendices D and E for the new conditions.

CONTENTS

1.0 PURPOSE

The purpose of this calculation is to perform an evaluation of four (4) piping segments that are located partially or completely within the containment building at D. C. Cook Nuclear Power Station, Unit 2. The evaluation addresses the concern identified in NRC Generic Letter 96-06, which states that during a design basis accident, isolated piping segments within containment may become over-pressurized by the thermal expansion of the contained water.

The four containment pipe segments are listed below.

1.	CPN-40	PRT and RCDT Drain Piping
2.	RCP Seal	RCP Seal Bypass Lines
3.	CPN-37	RCP Seal Leak-off Return Line
4.	CPN-32	Accumulator Fill Lines

2.0 RESULTS

The results from this calculation, including stress intensities and material strains, are presented in Table 1. The reported stress intensity is the primary membrane stress intensity due to pressure combined with the bounding longitudinal stress. The allowable stress is taken as 70% of the material ultimate strength, consistent with the acceptance criteria in Section III, Appendix F of the 1989 ASME Code (Reference 1). The maximum allowable strain is assumed to be 5%. The calculated stress intensities and strains are less than the allowable values for all segments.

Table 1: Results Summary

Segment	Pipe Size	Fluid Pressure (psia)	Material Strain (%)	Stress Intensity (ksi)	Allowable Stress (ksi)	Stress Index
CPN-40	4 in.	1,891	2.63	38.2	47.95	0.80
	2 in.		0.05	27.3		0.57
	¾ in.		0.02	24.4		0.51
RCP Seal	1 in.	17,081	1.15	42.6	47.95	0.89
	¾ in.		0.14	40.5		0.84
CPN-37	4 in.	1,888	2.61	38.2	47.95	0.80
	1 in.		0.03	24.7		0.52
CPN-32	1 in.	15,326	0.42	40.2	47.95	0.84
	¾ in.		0.08	38.4		0.80

3.0 CALCULATION

3.1 Approach

If a segment of piping containing water is heated, following a LOCA or steam-line break for example, the water will expand. Furthermore, if the piping segment is isolated (i.e. there is no leakage out of the piping), the constrained expansion will cause an increase in the internal pressure. Depending on the pipe geometry, pipe material and the increase in water temperature, the pressure rise could ultimately lead to an over-pressurization failure of the piping. This concern for a thermal over-pressurization failure is identified in NRC Generic Letter 96-06. The purpose of this calculation is to evaluate the possibility of failure of four potentially isolated segments of piping at D.C. Cook, Unit 2.

The analysis approach is based on the requirements and acceptance criteria for inelastic analyses in Section III, Appendix F of the 1989 ASME Code (Reference 1). In general, the analysis approach uses the maximum water temperature, the pipe stiffness and pipe material properties to calculate the resulting internal pressure and material stress-strain state for a postulated increase in temperature scenario. The specific steps in the analysis procedure are described below.

1. The isolated piping segment arrangement is reviewed to determine all of the pipe sections and materials. This review includes the main piping run as well as branch lines, vents and drains. The information on each pipe is required to determine the pressure and stresses in the entire piping segment.

2. The maximum piping segment temperature is based on conditions during a loss-of-coolant accident or steam line break. Under these conditions, Reference 2 calculates a maximum bounding piping segment water temperature of 250°F for penetrations CPN-40, the RCP Seal and CPN-37. The bounding water temperature for penetration CPN-32 is 240°F as defined in Reference 2.

3. A bi-linear stress-strain curve for the specific pipe material (Type 304 stainless steel) is developed. Both the elastic stretching of the pipe wall as well as the plastic deformation of the pipe with strain hardening is considered.

4. An equation of state for the water in the isolated piping segments is developed, which relates pressure to specific volume at a given temperature. The equation of state is developed from the ASME Steam Tables (Reference 11).

5. A set of simultaneous equations relating pipe stress and strain and the water mass, specific volume and pressure is developed. The solution of the equations provides the final water pressure and piping segment pressure stress.

6. The calculated pressure stresses are combined with the longitudinal stresses from deadweight and seismic loads to determine the stress intensity for each section of pipe.

7. The calculated stress intensity is compared to the corresponding Section III, Appendix F (Reference 1) allowable stress.

8. Secondary stresses at anchor points and transitions are not considered because a Level D analysis does not require an evaluation of secondary stresses.

9. Pipe fittings are assumed to be at least as strong as the piping segments to which they are attached. The valve bodies are evaluated in MPR Calculation 025-057-02 (Reference 9) and they are also assumed to be at least as strong as the piping segments.

3.2 Geometry and Material Data

The data required for each piping segment are the pipe diameter, wall thickness and material properties for each cross section included in the isolated segment between the isolation valves. The piping geometry is found in References 3-6 and 13. AEP DIT No. DIT-B-00842-00 (Reference 14) provides the list of references from which the design inputs were obtained. The material data include: Material Class and Material Type (References 7 and 8), design stress intensity (S_m), yield stress (S_y), ultimate strength (S_u), elastic modulus (E), and plastic modulus (E_p). The plastic modulus is found in Reference 10 and the associated stress-strain curve is shown on Figure 1. The remaining material properties are extracted from the 1989 ASME Code (Reference 12). All material properties are evaluated at 250°F, the highest piping segment water temperature calculated in Reference 2. The geometry and material data for each piping segment are summarized below and listed in Table 2. Nominal pipe wall thickness was used for the evaluations. Appendix E presents a sensitivity analysis of the effect of pipe wall thickness variation on calculated piping pressure and stress.

CPN-40: PRT and RCDT Drain Piping

Containment penetration 40 (CPN-40) consists of piping from the normally closed Pressurizer Relief Tank (PRT) drain line and the Reactor Coolant Drain Tank (RCDT) drain line check valve to the normally closed isolation valves outside containment. The system includes SA-312 Type 304 stainless steel piping of three different sizes: 4-inch schedule 10, 2-inch schedule 40 and ¾-inch schedule 40 (Reference 3).

RCP Seal Bypass Line

The Reactor Coolant Pump (RCP Seal) penetration consists of piping from the seal bypass line check valves to the normally closed QRV-150 valve in the common discharge header. The system includes SA-376 Type 304 stainless steel piping of two different sizes: 1-inch schedule 160 and ¾-inch schedule 160 (Reference 4).

CPN-37: RCP Seal Leak-off Return Line

Containment penetration 37 (CPN-37) consists of piping between containment isolation valves, including test connections. The system includes SA-312 Type 304 stainless steel piping of two different sizes: 4-inch schedule 10 and 1-inch schedule 40 (Reference 5).

CPN-32: Accumulator Fill Lines

Containment penetration 32 (CPN-32) consists of piping from outside the containment isolation valves to the normally closed accumulator "inlet" valves and the normally closed valves in the flow paths to the low head Safety Injection (SI) hot leg loops. The system includes SA-376 Type 304 stainless steel piping of two different sizes: 1-inch schedule 160 and ¾-inch schedule 160 (Reference 6).

Table 2: Geometry and Material Properties

ID	Pipe Size	Geometry Data		Material Data						
		OD (in)	Wall (in)	Class	Type	S_m (ksi)	S_y (ksi)	S_u (ksi)	E (10^6 psi)	E_p (10^6 psi)
CPN-40	4 in	4.500	0.120	B-23	SA312 TP304	20.0	23.75	68.5	27.3	0.425
	2 in	2.375	0.154	B-23	SA312 TP304	20.0	23.75	68.5	27.3	0.425
	¾ in	1.050	0.113	B-23	SA312 TP304	20.0	23.75	68.5	27.3	0.425
	4 in	4.500	0.120	B-14	SA312 TP304	20.0	23.75	68.5	27.3	0.425
RCP Seal	1 in	1.315	0.250	M-14	SA376 TP304	20.0	23.75	68.5	27.3	0.425
	¾ in	1.050	0.219	M-14	SA376 TP304	20.0	23.75	68.5	27.3	0.425
CPN-37	4 in	4.500	0.120	B-14	SA312 TP304	20.0	23.75	68.5	27.3	0.425
	1 in	1.315	0.133	B-14	SA312 TP304	20.0	23.75	68.5	27.3	0.425
CPN-32	1 in	1.315	0.250	M-14	SA376 TP304	20.0	23.75	68.5	27.3	0.425
	¾ in	1.050	0.219	M-14	SA376 TP304	20.0	23.75	68.5	27.3	0.425

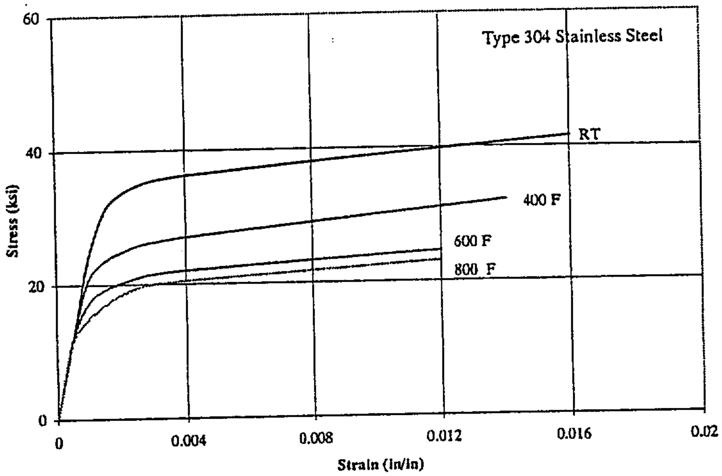


Figure 1: Type 304 Stainless Steel Stress-Strain Curve.

3.3 Fluid Properties

The calculations to determine maximum internal pressure and corresponding pipe stresses for CPN-40, the RCP Seal line and CPN-37 are performed for the maximum bounding piping segment water temperature of 250°F. These piping stress calculations assume the piping segments are initially at 15 psia and 70°F prior to the LOCA or steam-line break. This initial temperature is considered conservative since the containment temperature would likely be higher. If valve leakage resulted in a higher initial pressure and temperature, the valve leakage would preclude pressurization due to thermal expansion of the contained fluid.

Figure 2 shows the relationship between pressure and specific volume at a temperature of 250°F (from Reference 11); Table 3 provides the data for the graph. A polynomial curve fit is also shown which represents the equation of state for the fluid. This equation will be used in the determination of fluid pressure for the maximum temperature conditions. The specific volume for the initial conditions (15 psia, 70°F) is $\nu = 0.01605$ ft³/lb.

Table 3: Specific Volume versus Pressure at 250°F

Pressure (psia)	Specific Volume (ft³/lb)	Pressure (psia)	Specific Volume (ft³/lb)
1000	0.016944	6000	0.016655
2000	0.016883	7000	0.016602
3000	0.016823	8000	0.016550
4000	0.016766	9000	0.016500
5000	0.016710	10000	0.016451

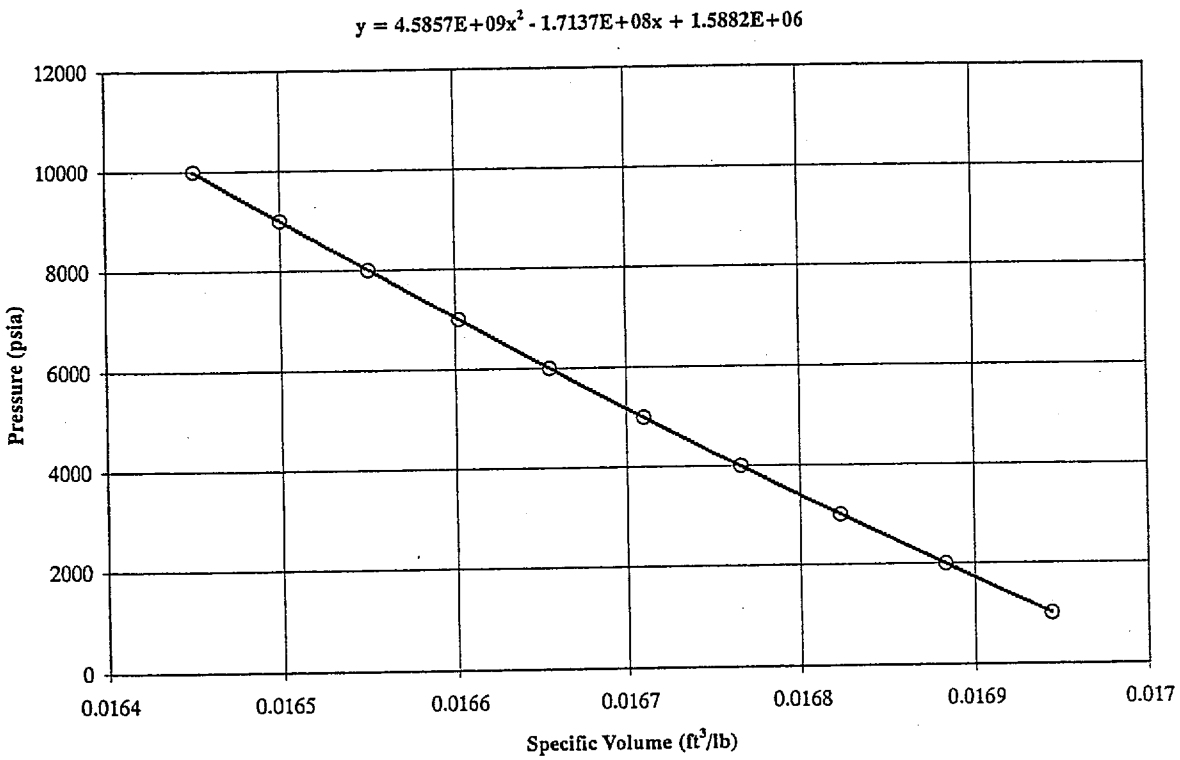


Figure 2: Equation of State for Water at 250°F.

The calculations to determine maximum internal pressure and corresponding pipe stresses for CPN-32 are performed for a maximum bounding piping segment water temperature of 240°F. These piping stress calculations assume the piping segments are initially at 1800 psia and 70°F prior to the LOCA or steam-line break. This pressure is significantly higher than for the other penetrations because the accumulator fill line has the potential of being pressurized with the maximum head of 3790 feet, or 1650 psia (Reference 15). The total line pressure used in this calculation is 1800 psia, which bounds the maximum head plus the inlet suction pressure of the pump.

Figure 3 shows the relationship between pressure and specific volume at a temperature of 240°F (from Reference 11); Table 4 provides the data for the graph. The polynomial curve fit represents the equation of state for the fluid and will be used in the determination of fluid pressure for the maximum temperature conditions. The specific volume for the initial conditions (1800 psia, 70°F) is $v = 0.015961$ ft³/lb.

Table 4: Specific Volume versus Pressure at 240°F

Pressure (psia)	Specific Volume (ft³/lb)	Pressure (psia)	Specific Volume (ft³/lb)
1000	0.016866	6000	0.016584
2000	0.016806	7000	0.016533
3000	0.016748	8000	0.016482
4000	0.016692	9000	0.016433
5000	0.016637	10000	0.016385

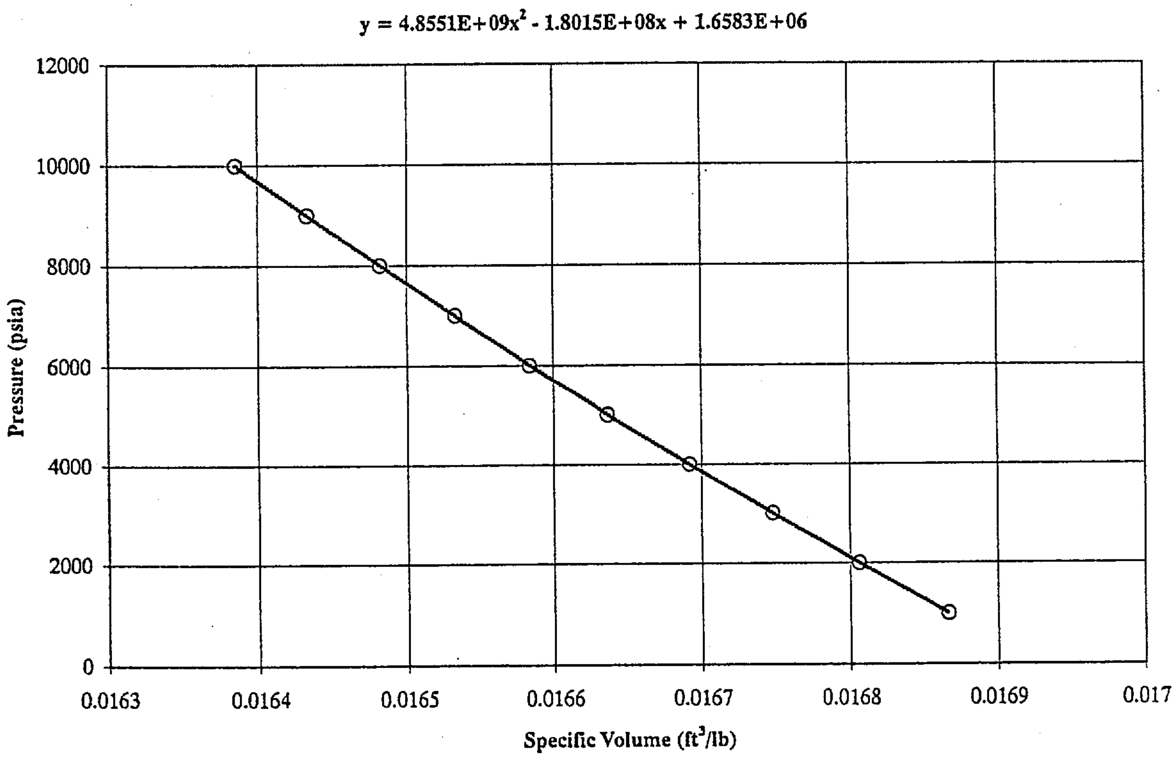


Figure 3: Equation of State for Water at 240°F.

3.4 Pressure Stress

For the general case in which a piping segment has a single pipe size and material, the fluid pressure and piping stress-strain solution are determined by solving a set of six simultaneous equations with six unknowns. The stress-state resulting from pressure loads is then combined with other stresses in Section 3.5 below as part of the ASME Code evaluation.

The six unknowns representing the pressurized condition in the isolated segment are:

$P \equiv$ Internal pressure (psia)
$\upsilon \equiv$ Specific volume (ft^3/lb)
$\sigma_h \equiv$ Pipe hoop stress (psi)
$\epsilon_p \equiv$ Pipe hoop strain (in/in)
$r \equiv$ Pipe inside radius (in)
vol $\equiv$ Volume of water (ft^3)

The following constants are used to solve for the unknown variables:

$t \equiv$ Pipe wall thickness (in)
$m_w \equiv$ Mass of water (lb)
$\varepsilon_y \equiv$ Pipe yield strain (in/in) ($= S_y/E$)
$\alpha_T \equiv$ Therm. expansion coeff. (in/in/°F)
$r_0 \equiv$ Initial pipe inside radius (inch)
$S_y \equiv$ Pipe yield stress (psi)
$E \equiv$ Pipe elastic modulus (psi)
$E_p \equiv$ Pipe plastic modulus (psi)

The set of equations that define the fluid state and stress-strain state are:

Membrane Stress: $\sigma_h = (P\,r)/(t)$
Volume (per unit length): $\text{vol} = \pi(r^2)$
Stress - Strain: $\sigma_h = S_y + (\epsilon_p - \epsilon_y)\,E_p$ for $\sigma_h > S_y$
$\sigma_h = \varepsilon_p\,E$ for $\sigma_h < S_y$
Specific Volume: $\nu = \text{vol} / m_w$
Equation of State: $P(\nu) = 4.5857\text{x}10^9\,\nu^2 - 1.7137\text{x}10^8\,\nu + 1.5882\text{x}10^6$
Radius: $r = (1 + \varepsilon_p)\,r_0$

In addition, the thermal expansion of the material in the circumferential and longitudinal directions is considered. The mean coefficient of thermal expansion for the piping material (SA-312 TP304 and SA-376 TP304) is used to calculate the material expansion due to heat up from 70°F to 250°F ($\Delta T = 180°F$).

Then, using $\alpha_T = 8.90\text{x}10^{-6}$ in/in/°F (Reference 12), the strain due to thermal expansion is

$$\varepsilon_{th} = \alpha_T(\Delta T) = 8.90\text{x}10^{-6}\ \text{in/in/°F}\ (180°\text{F}) = 0.001602\ \text{in/in}$$

The equation for the pipe radius is modified to incorporate the thermal expansion:

$$r = (1 + \epsilon_p)\,(r_0)\,(\varepsilon_{th} + 1)$$

The set of equations listed above can be solved for a segment with a single material and single pipe cross section. For piping segments with multiple cross sections, the set of equations must be extended to account for the potential expansion of fluid from one section of pipe into another. For example, if a segment includes a length of 1-inch pipe and a length of 4-inch pipe (same pipe schedule), the 1-inch pipe is stiffer and stronger than the 4-inch pipe. Hence, as the fluid is heated and pressurized, the 1-inch pipe would likely remain elastic and yield very little while the 4-inch pipe would yield and "balloon" to allow the fluid to expand. As a result, the fluid expansion in the 1-inch pipe would result in a net flow into the 4-inch pipe. In other words, the net increase in volume in the 4-inch pipe section must include the expansion of the fluid initially in the 1-inch pipe section.

In order to address multiple cross sections, the basic equation set is extended to include each section of pipe. The resulting set of unknowns is:

$P \equiv$ Internal pressure (psia) (one pressure for all pipes)
$\nu \equiv$ Specific volume (ft^3/lb) (one specific volume for all pipes)
$\sigma_{hi} \equiv$ Pipe *i* hoop stress (psi) (one for each pipe)
$\varepsilon_{pi} \equiv$ Pipe *i* hoop strain (in/in) (one for each pipe)
$r_i \equiv$ Pipe *i* inside radius (in) (one for each pipe)
$vol_i \equiv$ Volume pipe *i* (ft^3) (one for each pipe)
$m_{wi} \equiv$ Mass of water pipe *i* (lb) (one for each pipe)

The additional unknowns (the mass of water in each pipe section) require two additional constants to be defined. The total mass of water is conserved for all cases because the piping segments are bounded by isolation valves.

L_i = Length of pipe *i* (ft) (one for each pipe)
m_{tot} = Total mass of water (lb) (total mass of all pipes)

For the containment penetrations at D.C. Cook Unit 2, the lengths of different cross section pipe for each piping segment are shown in Table 4.

Table 5: Piping Segment Lengths

Segment	Pipe Geometry			Length
CPN-40	4 in	SCH 10S	SA312 TP304	159 ft
	2 in	SCH 40	SA312 TP304	4 ft
	¾ in	SCH 40	SA312 TP304	24 ft
RCP Seal	1 in	SCH 160	SA376 TP304	20 ft
	¾ in	SCH 160	SA376 TP304	450 ft
CPN-37	4 in	SCH 10S	SA312 TP304	34 ft
	1 in	SCH 40	SA312 TP304	3 ft
CPN-32	1 in	SCH 160	SA376 TP304	270 ft
	¾ in	SCH 160	SA376 TP304	138 ft

Thus, the following set of equations is used to determine the conditions of a piping segment with multiple pipe cross sections.

Membrane Stress: $\sigma_{hi} = (P\, r_i)/(t_i)$
Volume: $vol_i = \pi(r_i^2)(L_i)$
Stress - Strain: $\sigma_{hi} = S_{yi} + (\varepsilon_{pi} - \varepsilon_{yi})\, E_{pi}$ for $\sigma_{hi} > S_{yi}$
$\sigma_{hi} = \varepsilon_{pi}\, E_i$ for $\sigma_{hi} < S_{yi}$
Specific Volume: $\nu = vol_i / m_{wi}$
Equation of State: $P(\nu) = 4.5857\text{x}10^9\, \nu^2 - 1.7137\text{x}10^8\, \nu + 1.5882\text{x}10^6$
Radius: $r_i = (1 + \varepsilon_{pi})\, r_{0i}$
Mass: $m_{tot} = \sum m_{wi}$

The equations and methods listed above are used to determine the fluid pressure and material stress-strain state for the four piping segments at D.C. Cook, Unit 2. The calculations are performed using MathCAD and the equations and results are shown in Appendices A-D. The results of these calculations are shown in Table 5.

In performing the calculations shown in Table 5, several simplifying assumptions are made. These assumptions, which are conservative and are not considered to affect the calculation results, are as follows:

- The piping is bounded on each end by isolation valves. The isolation valve walls are thicker and stronger than the main piping. As a result, the strain in the valves will be less than the piping. The amount of water in the valves is assumed very small compared to the main piping. Thus, the expansion of this water (in the valve) and the possible strain of the valve body are neglected.

- The stronger valves will restrain the piping deflection at valve connections, preventing the piping from fully yielding and straining at that point (compared to the calculated values). The localized pipe strain at valve connections is neglected when calculating the pressure and stress/strain state of the piping.

- Absolute pressure is used to calculate piping pressure stress rather than gauge pressure for simplicity and conservatism.

- For conservatism, the expansion of the piping in the longitudinal direction due to pressure has been neglected.

Table 6: Pressure and Stress Results

Segment	Pipe Size	P (psia)	ν (ft^3/lb)	σ_h (ksi)	ε_p (in/in)	vol (ft^3)	r (in)	m_w (lb)
CPN-40	4 in	1,891	0.016977	34.5	0.02629	16.66	2.19	981.1
	2 in			12.7	0.00047	0.094	1.04	5.522
	¾ in			6.9	0.00025	0.089	0.41	5.263
RCP Seal	1 in	17,081	0.016197	28.2	0.01147	0.074	0.41	4.599
	¾ in			23.9	0.00143	0.926	0.31	57.19
CPN-37	4 in	1,888	0.016977	34.4	0.02614	3.561	2.19	209.7
	1 in			7.5	0.00027	0.018	0.52	1.066
CPN-32	1 in	15,326	0.016144	25.1	0.00422	0.991	0.41	61.38
	¾ in			21.5	0.00079	0.284	0.31	17.57

3.5 ASME Code Stress Analysis

The pressure hoop stresses calculated in the previous section are just one load applied to the piping segment. The piping could also be subjected to loads from deadweight, thermal expansion and seismic events, which could result in longitudinal pipe stresses that would either add or subtract from the pressure-induced longitudinal stresses. For a Level D evaluation, only the primary loads due to deadweight and seismic events need to be considered in addition to the pressure loads. For this analysis, it is conservatively assumed that the longitudinal stresses (S_L) from both deadweight and seismic loads are equivalent to the material design stress intensity, S_m.

The acceptance criteria in Section III, Appendix F of the ASME Code are based on calculated stress intensity. The acceptance criterion is:

$$SI < 0.7\, S_u$$

where SI is the calculated stress intensity.

In addition to the stress limit specified in the ASME Code, this analysis places a limit on the calculated strain. Article F-1322.5 of Appendix F states that "in addition to the limits given in this Appendix, the strain or deformation limits (if any) provided in the Design Specification shall be satisfied." While none of the applicable Design Specifications identify a material strain limit, it is important that calculated strain remains low enough to ensure that failure will not occur. For this analysis, a limit of 5% strain is applied. Based on engineering judgment, none of the materials used in the pipe segments will fail at strains of less than 10%; so the limit of 5% provides a safety factor of two. It should be noted, however, that the primary acceptance criterion used in this analysis is the stress limit specified in Appendix F. The specified strain limit is included only for completeness.

The stresses calculated in Section 3.4 are in the hoop direction and they are principal stresses. The deadweight and seismic load stresses are longitudinal stresses and they are also principal stresses. There is also a longitudinal stress due to pressure, which is one-half the hoop stress. Since the deadweight and seismic stresses are bending stresses, acting in tension on one side and compression on the other, the three principal stresses are:

$S_1 = Pr/t$
$S_2 = Pr/2t \pm S_L$ where $S_L = S_m$
$S_3 = -P/2$

The second principal stress has two variations:

$S_{2+} = Pr/2t + S_L$
$S_{2-} = Pr/2t - S_L$

The stress intensity is calculated as the maximum of the absolute values of the following stress differences (in accordance with the ASME Code):

$SI = \text{Maximum of } (S_1 - S_{2+}), (S_1 - S_{2-}), (S_{2+} - S_3), (S_{2-} - S_3), \text{ or } (S_3 - S_1)$

The results of the calculations for principal stresses and stress intensity are summarized below.

Table 7: Principal Stresses and Stress Intensity

Segment	Pipe Size	S1 (ksi)	S2 (ksi)	S3 (ksi)	SI (ksi)
CPN-40	4 in	34.5	37.2 / -2.75	-0.95	38.2
	2 in	12.7	26.4 / -13.6	-0.95	27.3
	¾ in	6.91	23.4 / -16.5	-0.95	24.4
RCP Seal	1 in	28.2	34.1 / -5.90	-8.54	42.6
	¾ in	23.9	32.0 / -8.03	-8.54	40.5
CPN-37	4 in	34.4	37.2 / -2.78	-0.94	38.2
	1 in	7.46	23.7 / -16.3	-0.94	24.7
CPN-32	1 in	25.1	32.6 / -7.44	-7.66	40.2
	¾ in	21.5	30.7 / -9.27	-7.66	38.4

The calculated stress intensities are compared to the ASME Section III, Appendix F criteria of $0.7S_u$ (= 47.95 ksi). It should be noted that the plastic analysis method of Appendix F-1340 only requires consideration of primary membrane stresses. The secondary stresses that would be present at branch connections, elbows and valves are not evaluated.

4.0 REFERENCES

1. 1989 ASME Code, Section III, Division 1 – Appendix F.
2. MPR Calculation 025-057-03, "Documentation of Isolated Piping Temperature for GL 96-06 Evaluation," Rev 1.
3. Drawings for Containment Penetration CPN-40:
   - D.C. Cook Drawing No. OP-12-5137A, Rev 18, "WDS Vents & Drains."
   - D.C. Cook Drawing No. 12-WD-3, Rev 7.
   - D.C. Cook Drawing No. 2-WD-80, Sh. 1 of 3, Rev 1.
   - D.C. Cook Drawing No. 2-WD-80, Sh. 2 of 3, Rev 1.
   - D.C. Cook Drawing No. 2-WD-80, Sh. 3 of 3, Rev 1.
   - D.C. Cook Drawing No. 2-WD-538, Rev 0.
   - D.C. Cook Drawing No. 2-WD-539, Rev 0.
4. Drawings for Containment Piping Segment RCP Seal:
   - D.C. Cook Drawing No. OP-2-5128A, Rev 45, "Reactor Coolant."
   - D.C. Cook Drawing No. 2-CS-711, Sh. 1 of 7, Rev 2.
   - D.C. Cook Drawing No. 2-CS-711, Sh. 2 of 7, Rev 2.
   - D.C. Cook Drawing No. 2-CS-711, Sh. 3 of 7, Rev 2.
   - D.C. Cook Drawing No. 2-CS-711, Sh. 4 of 7, Rev 1.
   - D.C. Cook Drawing No. 2-CS-711, Sh. 5 of 7, Rev 1.
   - D.C. Cook Drawing No. 2-CS-711, Sh. 6 of 7, Rev 1.
   - D.C. Cook Drawing No. 2-CS-711, Sh. 7 of 7, Rev 5.
   - D.C. Cook Drawing No. 2-CS-712, Sh. 1 of 2, Rev 1.
   - D.C. Cook Drawing No. 2-CS-712, Sh. 2 of 2, Rev 3.
   - D.C. Cook Drawing No. 2-CS-713, Sh. 1 of 2, Rev 2.
   - D.C. Cook Drawing No. 2-CS-713, Sh. 2 of 2, Rev 2.
   - D.C. Cook Drawing No. 2-CS-714, Rev 2.
5. Drawings for Containment Penetration CPN-37:
   - D.C. Cook Drawing No. OP-2-5129A, Rev 30, "CVCS – Reactor Letdown & Charging."
   - D.C. Cook Drawing No. 2-CS-90, Sh. 1 of 2, Rev 6.
   - D.C. Cook Drawing No. 2-CS-90, Sh. 2 of 2, Rev 9.
   - D.C. Cook Drawing No. 2-CS-122, Sh. 1 of 3, Rev 5.
   - D.C. Cook Drawing No. 2-CS-122, Sh. 2 of 3, Rev 6.
   - D.C. Cook Drawing No. 2-CS-122, Sh. 3 of 3, Rev 8.

6. Drawings for Containment Penetration CPN-32:
    - D.C. Cook Drawing No. OP-2-5143A, Rev 1, "Emerg. Core Cooling (RHR) Accumulator Piping."
    - D.C. Cook Drawing No. OP-2-5142A, Rev 41, "Emergency Core Cooling (SIS)."
    - D.C. Cook Drawing No. 2-SI-532, Sh. 2, Rev 1.
    - D.C. Cook Drawing No. 2-SI-604, Rev 0.
    - D.C. Cook Drawing No. 2-SI-570, Sh. 1 of 6, Rev 1.
    - D.C. Cook Drawing No. 2-SI-570, Sh. 2 of 6, Rev 0.
    - D.C. Cook Drawing No. 2-SI-570, Sh. 3 of 6, Rev 1.
    - D.C. Cook Drawing No. 2-SI-570, Sh. 4 of 6, Rev 1.
    - D.C. Cook Drawing No. 2-SI-570, Sh. 5 of 6, Rev 0.
    - D.C. Cook Drawing No. 2-SI-570, Sh. 6 of 6, Rev 0.
    - D.C. Cook Drawing No. 2-SI-571, Rev 4.
    - D.C. Cook Drawing No. 2-SI-572, Sh. 1 of 2, Rev 3.
    - D.C. Cook Drawing No. 2-SI-572, Sh. 2 of 2, Rev 2.
    - D.C. Cook Drawing No. 2-SI-573, Rev 2.
    - D.C. Cook Drawing No. 2-SI-574, Sh. 1 of 2, Rev 2.
    - D.C. Cook Drawing No. 2-SI-574, Sh. 2 of 2, Rev 1.
    - D.C. Cook Drawing No. 2-SI-575, Sh. 1 of 2, Rev 0.
    - D.C. Cook Drawing No. 2-SI-575, Sh. 2 of 2, Rev 0.
    - D.C. Cook Drawing No. 2-SI-576, Rev 3.
    - D.C. Cook Drawing No. 2-SI-577, Sh. 1 of 2, Rev 0.
    - D.C. Cook Drawing No. 2-SI-577, Sh. 2 of 2, Rev 0.
    - D.C. Cook Drawing No. 2-SI-578, Sh. 1 of 2, Rev 4.
    - D.C. Cook Drawing No. 2-SI-578, Sh. 2 of 2, Rev 4.
    - D.C. Cook Drawing No. 2-SI-579, Sh. 1 of 2, Rev 0.
    - D.C. Cook Drawing No. 2-SI-579, Sh. 2 of 2, Rev 1.
    - D.C. Cook Drawing No. 2-SI-580, Rev 2.
7. D.C. Cook Piping Specification ES-PIPE-1000-QCS, Rev 1, "Pipe Material Specification: Non-Safety Related."
8. D.C. Cook Piping Specification ES-PIPE-1013-QCN-CS3, Rev 1, "Pipe Material Specification: Safety Related."
9. MPR Calculation 025-057-02, "Evaluation of Valve Structural Adequacy," Rev 1.
10. Aerospace Structural Metal Handbook, Volume 2, 1990, Code 1303, Figure 3.03112, Type 304 Stainless Steel.
11. ASME Steam Tables, 6th Edition.
12. 1989 ASME Code, Section II: Part D – Properties.
13. Crane Technical Paper No. 410, "Flow of Fluids," 1986.
14. AEP DIT-B-00842-00, Input for MPR Report No. MPR-2131.
15. AEP DIT-B-00966-00, Input for MPR Report No. MPR-2131.

APPENDIX A

PURPOSE:

The purpose of this calculation is to perform an evaluation of isolated piping segments that penetrate the containment to determine the effect of thermal over-pressurization during a design basis accident by the thermal expansion of the contained water. The results of this calculation represent piping segment CPN-40 at D.C. Cook, Unit 2.

CALCULATION:

The expected temperature of the water during a LOCA and the ambient temperature are

$T_{LOCA} := 250$ $\qquad$ $T_{amb} := 70$

The conversion for psi to ksi is

$\mathrm{ksi} := 1000\ \mathrm{psi}$

For penetration CPN-40, there are three different pipes in the system. Using References 3, 12 and 13, the pipe material propoerties and geometry were determined.

The first pipe is 4" Sch 10, pipe specification B-14/B-23

$ID_{4B14} := 4.260\ \mathrm{in}$ $\qquad$ $S_{m4B14} := 20\ \mathrm{ksi}$ $\qquad$ $E_{4B14} := 27.3 \cdot 10^{6}\ \mathrm{psi}$

$t_{4B14} := 0.120\ \mathrm{in}$ $\qquad$ $S_{y4B14} := 23.7\ \mathrm{ksi}$ $\qquad$ $E_{p4B14} := 0.425 \cdot 10^{6}\ \mathrm{psi}$

$OD_{4B14} := ID_{4B14} + 2 \cdot t_{4B14}$ $\qquad$ $S_{u4B14} := 68.5\ \mathrm{ksi}$ $\qquad$ SA-312 Gr TP304

$OD_{4B14} = 4.5 \circ \mathrm{in}$

The second pipe is 2" Sch 40, pipe specification B-23

$ID_{2B23} := 2.067\ \mathrm{in}$ $\qquad$ $S_{m2B23} := 20\ \mathrm{ksi}$ $\qquad$ $E_{2B23} := 27.3 \cdot 10^{6}\ \mathrm{psi}$

$t_{2B23} := 0.154\ \mathrm{in}$ $\qquad$ $S_{y2B23} := 23.7\ \mathrm{ksi}$ $\qquad$ $E_{p2B23} := 0.425 \cdot 10^{6}\ \mathrm{psi}$

$OD_{2B23} := ID_{2B23} + 2 \cdot t_{2B23}$ $\qquad$ $S_{u2B23} := 68.5\ \mathrm{ksi}$ $\qquad$ SA-312 Gr TP304

$OD_{2B23} = 2.375 \circ \mathrm{in}$

The third pipe is 3/4" Sch 40, pipe specification B-23

$ID_{34B23} := 0.824\ \mathrm{in}$ $\qquad$ $S_{m34B23} := 20\ \mathrm{ksi}$ $\qquad$ $E_{34B23} := 27.3 \cdot 10^{6}\ \mathrm{psi}$

$t_{34B23} := 0.113\ \mathrm{in}$ $\qquad$ $S_{y34B23} := 23.7\ \mathrm{ksi}$ $\qquad$ $E_{p34B23} := 0.425 \cdot 10^{6}\ \mathrm{psi}$

$OD_{34B23} := ID_{34B23} + 2 \cdot t_{34B23}$ $\qquad$ $S_{u34B23} := 68.5\ \mathrm{ksi}$ $\qquad$ SA-312 Gr TP304

$OD_{34B23} = 1.05 \circ \mathrm{in}$

The lengths of the three different pipes are determined from the drawings in Reference 3. The 4" pipe has a total length of approximately 159 ft., the 2" pipe has a total length of approximately 4 ft., and the 3/4" pipe has a total length of approximately 24 ft.

$L_1 := (159\ \text{ft})\cdot\text{in}^{-1}$ $L_2 := (4\ \text{ft})\cdot\text{in}^{-1}$ $L_3 := (24\ \text{ft})\cdot\text{in}^{-1}$

$L_1 = 1.908\cdot10^{3}$ inches $L_2 = 48$ inches $L_3 = 288$ inches

For the first pipe (4" Sch 10, B-14/B-23), the specific material parameters used in the calculation are

$t_1 := t_{4B14}\cdot\text{in}^{-1}$ $t_1 = 0.12$ inches

$r_{01} := \left(\dfrac{OD_{4B14}\cdot\text{in}^{-1}}{2}\right) - t_1$ $r_{01} = 2.13$ inches

$S_{y1} := S_{y4B14}\cdot\text{psi}^{-1}$ $S_{y1} = 2.37\cdot10^{4}$ psi

$E_1 := E_{4B14}\cdot\text{psi}^{-1}$ $E_1 = 2.73\cdot10^{7}$ psi

$E_{p1} := E_{p4B14}\cdot\text{psi}^{-1}$ $E_{p1} = 4.25\cdot10^{5}$ psi

$\varepsilon_{y1} := \dfrac{S_{y1}}{E_1}$ $\varepsilon_{y1} = 8.681\cdot10^{-4}$ in/in

$S_{m1} := S_{m4B14}$ $S_{m1} = 2\cdot10^{4}\cdot\text{psi}$

$S_{u1} := S_{u4B14}$ $S_{u1} = 6.85\cdot10^{4}\cdot\text{psi}$

For the second pipe (2" Sch 40, B-23), the specific material parameters for the calculation are

$t_2 := t_{2B23}\cdot\text{in}^{-1}$ $t_2 = 0.154$ inches

$r_{02} := \left(\dfrac{OD_{2B23}\cdot\text{in}^{-1}}{2}\right) - t_2$ $r_{02} = 1.034$ inches

$S_{y2} := S_{y2B23}\cdot\text{psi}^{-1}$ $S_{y2} = 2.37\cdot10^{4}$ psi

$E_2 := E_{2B23}\cdot\text{psi}^{-1}$ $E_2 = 2.73\cdot10^{7}$ psi

$E_{p2} := E_{p2B23}\cdot\text{psi}^{-1}$ $E_{p2} = 4.25\cdot10^{5}$ psi

$\varepsilon_{y2} := \dfrac{S_{y2}}{E_2}$ $\varepsilon_{y2} = 8.681\cdot10^{-4}$ in/in

$S_{m2} := S_{m2B23}$ $S_{m2} = 2\cdot10^{4}\cdot\text{psi}$

$S_{u2} := S_{u2B23}$ $S_{u2} = 6.85\cdot10^{4}\cdot\text{psi}$

For the third pipe (3/4" Sch 40, B-23), the specific material parameters for the calculation are

$t_3 := t_{34B23} \cdot in^{-1}$ $\quad t_3 = 0.113$ inches

$r_{03} := \left(\frac{OD_{34B23} \cdot in^{-1}}{2}\right) - t_3$ $\quad r_{03} = 0.412$ inches

$S_{y3} := S_{y34B23} \cdot psi^{-1}$ $\quad S_{y3} = 2.37 \cdot 10^4$ psi

$E_3 := E_{34B23} \cdot psi^{-1}$ $\quad E_3 = 2.73 \cdot 10^7$ psi

$E_{p3} := E_{p34B23} \cdot psi^{-1}$ $\quad E_{p3} = 4.25 \cdot 10^5$ psi

$\varepsilon_{y3} := \frac{S_{y3}}{E_3}$ $\quad \varepsilon_{y3} = 8.681 \cdot 10^{-4}$ in/in

$S_{m3} := S_{m34B23}$ $\quad S_{m3} = 2 \cdot 10^4 \circ psi$

$S_{u3} := S_{u34B23}$ $\quad S_{u3} = 6.85 \cdot 10^4 \circ psi$

At the ambient condition of 70 F, the water has a specific volume

$v_{initial} := 0.01605\ ft^3 \cdot lb^{-1}$

Therefore, the mass of water in a unit length (1 inch) of pipe is

$m_{w1i} := \frac{\pi \cdot r_{01}{}^2 \cdot 1}{\left(v_{initial} \cdot lb \cdot in^{-3}\right)}$ $\quad m_{w1i} = 0.514$ lb per unit length (4" Sch 10)

$m_{w2i} := \frac{\pi \cdot r_{02}{}^2 \cdot 1}{\left(v_{initial} \cdot lb \cdot in^{-3}\right)}$ $\quad m_{w2i} = 0.121$ lb per unit length (2" Sch 40)

$m_{w3i} := \frac{\pi \cdot r_{03}{}^2 \cdot 1}{\left(v_{initial} \cdot lb \cdot in^{-3}\right)}$ $\quad m_{w3i} = 0.019$ lb per unit length (3/4" Sch 40)

The mean coefficient of thermal expansion for SA-312 Gr TP304 at 250 F (Reference 12) is

$\alpha_T := 8.90 \cdot 10^{-6}$

And the strain due to thermal expansion is

$\varepsilon_{th} := \alpha_T \cdot \left(T_{LOCA} - T_{amb}\right)$ $\quad \varepsilon_{th} = 1.602 \cdot 10^{-3}$ in/in

The total mass of the water in the piping, assuming that the pipe is filled, is

$m_{tot} := m_{w1i} \cdot L_1 + m_{w2i} \cdot L_2 + m_{w3i} \cdot L_3$ $\qquad m_{tot} = 991.893$ lb

To solve the equations for the system with both pipe sizes, we must guess inital values for the variables.

$P := 3000$

$v := 0.016$

$\sigma_{h1} := 100$

$\sigma_{h2} := 100$

$\sigma_{h3} := 100$

$\varepsilon_{p1} := 0.01$

$\varepsilon_{p2} := 0.01$

$\varepsilon_{p3} := 0.01$

$r_1 := 1$

$r_2 := 1$

$r_3 := 1$

$vol_1 := 1$

$vol_2 := 1$

$vol_3 := 1$

$m_{w1} := 1$

$m_{w2} := 1$

$m_{w3} := 1$

Assign a function to represent the change from elastic strain to plastic strain as follows:

$$f_1(\sigma_{h1}, S_{y1}, E_1, E_{p1}, \varepsilon_{y1}) := if\left(\sigma_{h1} > S_{y1}, \frac{\sigma_{h1} - S_{y1}}{E_{p1}} + \varepsilon_{y1}, \frac{\sigma_{h1}}{E_1}\right)$$

$$f_2(\sigma_{h2}, S_{y2}, E_2, E_{p2}, \varepsilon_{y2}) := if\left(\sigma_{h2} > S_{y2}, \frac{\sigma_{h2} - S_{y2}}{E_{p2}} + \varepsilon_{y2}, \frac{\sigma_{h2}}{E_2}\right)$$

$$f_3(\sigma_{h3}, S_{y3}, E_3, E_{p3}, \varepsilon_{y3}) := if\left(\sigma_{h3} > S_{y3}, \frac{\sigma_{h3} - S_{y3}}{E_{p3}} + \varepsilon_{y3}, \frac{\sigma_{h3}}{E_3}\right)$$

Given

$$r_1 = (1 + \varepsilon_{p1}) \cdot r_{01} \cdot (1 + \varepsilon_{th}) \qquad r_2 = (1 + \varepsilon_{p2}) \cdot r_{02} \cdot (1 + \varepsilon_{th}) \qquad r_3 = (1 + \varepsilon_{p3}) \cdot r_{03} \cdot (1 + \varepsilon_{th})$$

$$vol_1 = \frac{\pi \cdot r_1^{2} \cdot (1 + \varepsilon_{th}) \cdot L_1}{(12^3)} \qquad vol_2 = \frac{\pi \cdot r_2^{2} \cdot (1 + \varepsilon_{th}) \cdot L_2}{(12^3)} \qquad vol_3 = \frac{\pi \cdot r_3^{2} \cdot (1 + \varepsilon_{th}) \cdot L_3}{(12^3)}$$

$$v = \frac{vol_1}{m_{w1}} \qquad v = \frac{vol_2}{m_{w2}} \qquad v = \frac{vol_3}{m_{w3}} \qquad \sigma_{h1} = P \cdot \frac{r_1}{t_1} \qquad \sigma_{h2} = P \cdot \frac{r_2}{t_2} \qquad \sigma_{h3} = P \cdot \frac{r_3}{t_3}$$

$$P = (4.507 \cdot 10^9) \cdot v^2 - (1.690 \cdot 10^8) \cdot v + 1.572 \cdot 10^6 \qquad m_{tot} = m_{w1} + m_{w2} + m_{w3}$$

$\varepsilon_{p1}=f_1(\sigma_{h1},S_{y1},E_1,E_{p1},\varepsilon_{y1})$ $\varepsilon_{p2}=f_2(\sigma_{h2},S_{y2},E_2,E_{p2},\varepsilon_{y2})$

$\varepsilon_{p3}=f_3(\sigma_{h3},S_{y3},E_3,E_{p3},\varepsilon_{y3})$

Solving the equations.

$AA := \mathrm{Find}(r_1,r_2,r_3,\varepsilon_{p1},\varepsilon_{p2},\varepsilon_{p3},vol_1,vol_2,vol_3,v,P,\sigma_{h1},\sigma_{h2},\sigma_{h3},m_{w1},m_{w2},m_{w3})$

$r_1 := AA_{0,0}\cdot in$ $r_1 = 2.19\,in$

$r_2 := AA_{1,0}\cdot in$ $r_2 = 1.036\,in$

$r_3 := AA_{2,0}\cdot in$ $r_3 = 0.413\,in$

$\varepsilon_{p1} := AA_{3,0}$ $\varepsilon_{p1} = 2.629\,\%$

$\varepsilon_{p2} := AA_{4,0}$ $\varepsilon_{p2} = 0.047\,\%$

$\varepsilon_{p3} := AA_{5,0}$ $\varepsilon_{p3} = 0.025\,\%$

$vol_1 := AA_{6,0}\cdot ft^3$ $vol_1 = 16.656\,ft^3$

$vol_2 := AA_{7,0}\cdot ft^3$ $vol_2 = 0.094\,ft^3$

$vol_3 := AA_{8,0}\cdot ft^3$ $vol_3 = 0.089\,ft^3$

$v := AA_{9,0}\cdot ft^3\cdot lb^{-1}$ $v = 0.016977\,ft^3\cdot lb^{-1}$

$P := AA_{10,0}\cdot psi$ $P = 1.891\cdot10^3\,psi$

$\sigma_{h1} := AA_{11,0}\cdot psi$ $\sigma_{h1} = 34.506\,ksi$

$\sigma_{h2} := AA_{12,0}\cdot psi$ $\sigma_{h2} = 12.718\,ksi$

$\sigma_{h3} := AA_{13,0}\cdot psi$ $\sigma_{h3} = 6.908\,ksi$

$m_{w1} := AA_{14,0}\cdot lb$ $m_{w1} = 981.108\,lb$

$m_{w2} := AA_{15,0}\cdot lb$ $m_{w2} = 5.522\,lb$

$m_{w3} := AA_{16,0}\cdot lb$ $m_{w3} = 5.263\,lb$

AA =

	0
0	2.19
1	1.036
2	0.413
3	0.026
4	$4.659\cdot10^{-4}$
5	$2.53\cdot10^{-4}$
6	16.656
7	0.094
8	0.089
9	0.017
10	$1.891\cdot10^{3}$
11	$3.451\cdot10^{4}$
12	$1.272\cdot10^{4}$
13	$6.908\cdot10^{3}$
14	981.108
15	5.522

The principal stresses for the first pipe are calculated

$S_{11} := \frac{P \cdot r_1}{t_1 \cdot in}$ $\qquad S_{11} = 34.506 \cdot ksi$

$S_{2p1} := \frac{P \cdot r_1}{2 \cdot t_1 \cdot in} + S_{m1}$ $\qquad S_{2p1} = 37.253 \cdot ksi$

$S_{2m1} := \frac{P \cdot r_1}{2 \cdot t_1 \cdot in} - S_{m1}$ $\qquad S_{2m1} = -2.747 \cdot ksi$

$S_{31} := \frac{-P}{2}$ $\qquad S_{31} = -0.946 \cdot ksi$

$$BB_1 := \begin{bmatrix} \left| S_{11} - S_{2p1} \right| \\ \left| S_{11} - S_{2m1} \right| \\ \left| S_{2p1} - S_{31} \right| \\ \left| S_{2m1} - S_{31} \right| \\ \left| S_{31} - S_{11} \right| \end{bmatrix} \qquad BB_1 = \begin{bmatrix} 2.747 \\ 37.253 \\ 38.198 \\ 1.802 \\ 35.451 \end{bmatrix} \cdot ksi$$

The stress intensity

$SI := \max(BB_1)$ $\qquad SI = 38.198 \cdot ksi$

The allowable stress is

$S_{allowable} := 0.7 \cdot S_{u1}$ $\qquad S_{allowable} = 47.95 \cdot ksi$

The stress index is

$Index := \frac{SI}{S_{allowable}}$ $\qquad Index = 0.797$

The principal stresses for the second pipe are calculated

$$S_{12} := \frac{P \cdot r_2}{t_2 \cdot in} \qquad S_{12} = 12.718 \cdot ksi$$

$$S_{2p2} := \frac{P \cdot r_2}{2 \cdot t_2 \cdot in} + S_{m2} \qquad S_{2p2} = 26.359 \cdot ksi$$

$$S_{2m2} := \frac{P \cdot r_2}{2 \cdot t_2 \cdot in} - S_{m2} \qquad S_{2m2} = -13.641 \cdot ksi$$

$$S_{32} := \frac{-P}{2} \qquad S_{32} = -0.946 \cdot ksi$$

$$BB_2 := \begin{bmatrix} \left| S_{12} - S_{2p2} \right| \\ \left| S_{12} - S_{2m2} \right| \\ \left| S_{2p2} - S_{32} \right| \\ \left| S_{2m2} - S_{32} \right| \\ \left| S_{32} - S_{12} \right| \end{bmatrix} \qquad BB_2 = \begin{bmatrix} 13.641 \\ 26.359 \\ 27.304 \\ 12.696 \\ 13.663 \end{bmatrix} \cdot ksi$$

The stress intensity

$$SI := \max(BB_2) \qquad SI = 27.304 \cdot ksi$$

The allowable stress is

$$S_{allowable} := 0.7 \cdot S_{u2} \qquad S_{allowable} = 47.95 \cdot ksi$$

The stress index is

$$Index := \frac{SI}{S_{allowable}} \qquad Index = 0.569$$

The principal stresses for the third pipe are calculated

$$S_{13} := \frac{P \cdot r_3}{t_3 \cdot in} \qquad S_{13} = 6.908 \cdot ksi$$

$$S_{2p3} := \frac{P \cdot r_3}{2 \cdot t_3 \cdot in} + S_{m3} \qquad S_{2p3} = 23.454 \cdot ksi$$

$$S_{2m3} := \frac{P \cdot r_3}{2 \cdot t_3 \cdot in} - S_{m3} \qquad S_{2m3} = -16.546 \cdot ksi$$

$$S_{33} := \frac{-P}{2} \qquad S_{33} = -0.946 \cdot ksi$$

$$BB_3 := \begin{bmatrix} |S_{13} - S_{2p3}| \\ |S_{13} - S_{2m3}| \\ |S_{2p3} - S_{33}| \\ |S_{2m3} - S_{33}| \\ |S_{33} - S_{13}| \end{bmatrix} \qquad BB_3 = \begin{bmatrix} 16.546 \\ 23.454 \\ 24.4 \\ 15.6 \\ 7.854 \end{bmatrix} \cdot ksi$$

The stress intensity

$$SI := \max(BB_3) \qquad SI = 24.4 \cdot ksi$$

The allowable stress is

$$S_{allowable} := 0.7 \cdot S_{u3} \qquad S_{allowable} = 47.95 \cdot ksi$$

The stress index is

$$Index := \frac{SI}{S_{allowable}} \qquad Index = 0.509$$

APPENDIX B

PURPOSE:

The purpose of this calculation is to perform an evaluation of isolated piping segments that penetrate the containment to determine the effect of thermal over-pressurization during a design basis accident by the thermal expansion of the contained water. The results of this calculation represent penetration RCP Seal at D.C. Cook, Unit 2.

CALCULATION:

The expected temperature of the water during a LOCA and the ambient temperature are

$T_{LOCA} := 250$ $\qquad$ $T_{amb} := 70$

The conversion for psi to ksi is

$ksi := 1000\ psi$

For penetration RCP Seal, there are two different pipes in the system. Using References 4, 12 and 13, the pipe material properties and geometry were determined, respectively.

The first pipe is 1" Sch 160, pipe specification M-14

$ID_{1M14} := 0.815\ in$ $\qquad$ $S_{m1M14} := 20\ ksi$ $\qquad$ $E_{1M14} := 27.3 \cdot 10^{6}\ psi$

$t_{1M14} := 0.250\ in$ $\qquad$ $S_{y1M14} := 23.7\ ksi$ $\qquad$ $E_{p1M14} := 0.425 \cdot 10^{6}\ psi$

$OD_{1M14} := ID_{1M14} + 2 \cdot t_{1M14}$ $\qquad$ $S_{u1M14} := 68.5\ ksi$ $\qquad$ SA-376 Gr TP304

$OD_{1M14} = 1.315 \circ in$

The second pipe is 3/4" Sch 160, pipe specification M-14

$ID_{34M14} := 0.612\ in$ $\qquad$ $S_{m34M14} := 20\ ksi$ $\qquad$ $E_{34M14} := 27.3 \cdot 10^{6}\ psi$

$t_{34M14} := 0.219\ in$ $\qquad$ $S_{y34M14} := 23.7\ ksi$ $\qquad$ $E_{p34M14} := 0.425 \cdot 10^{6}\ psi$

$OD_{34M14} := ID_{34M14} + 2 \cdot t_{34M14}$ $\qquad$ $S_{u34M14} := 68.5\ ksi$ $\qquad$ SA-376 Gr TP304

$OD_{34M14} = 1.05 \circ in$

The lengths of the two different pipes are determined from the drawings in Reference 4. The 1" pipe has a total length of approximately 20 ft. while the 3/4" pipe has a total length of approximately 450 ft.

$L_{1} := (20\ ft) \cdot in^{-1}$ $\qquad$ $L_{2} := (450\ ft) \cdot in^{-1}$

$L_{1} = 240$ inches $\qquad$ $L_{2} = 5.4 \cdot 10^{3}$ inches

For the first pipe (1" Sch 160, M-14), the specific material parameters used in the calculation are

$t_1 := t_{1M14}\cdot in^{-1}$ $t_1 = 0.25$ inches

$r_{01} := \left(\frac{OD_{1M14}\cdot in^{-1}}{2}\right) - t_1$ $r_{01} = 0.408$ inches

$S_{y1} := S_{y1M14}\cdot psi^{-1}$ $S_{y1} = 2.37\cdot 10^{4}$ psi

$E_1 := E_{1M14}\cdot psi^{-1}$ $E_1 = 2.73\cdot 10^{7}$ psi

$E_{p1} := E_{p1M14}\cdot psi^{-1}$ $E_{p1} = 4.25\cdot 10^{5}$ psi

$\varepsilon_{y1} := \frac{S_{y1}}{E_1}$ $\varepsilon_{y1} = 8.681\cdot 10^{-4}$ in/in

$S_{m1} := S_{m1M14}$ $S_{m1} = 2\cdot 10^{4}\cdot psi$

$S_{u1} := S_{u1M14}$ $S_{u1} = 6.85\cdot 10^{4}\cdot psi$

For the second pipe (3/4" Sch 160, M-14), the specific material parameters for the calculation are

$t_2 := t_{34M14}\cdot in^{-1}$ $t_2 = 0.219$ inches

$r_{02} := \left(\frac{OD_{34M14}\cdot in^{-1}}{2}\right) - t_2$ $r_{02} = 0.306$ inches

$S_{y2} := S_{y34M14}\cdot psi^{-1}$ $S_{y2} = 2.37\cdot 10^{4}$ psi

$E_2 := E_{34M14}\cdot psi^{-1}$ $E_2 = 2.73\cdot 10^{7}$ psi

$E_{p2} := E_{p34M14}\cdot psi^{-1}$ $E_{p2} = 4.25\cdot 10^{5}$ psi

$\varepsilon_{y2} := \frac{S_{y2}}{E_2}$ $\varepsilon_{y2} = 8.681\cdot 10^{-4}$ in/in

$S_{m2} := S_{m34M14}$ $S_{m2} = 2\cdot 10^{4}\cdot psi$

$S_{u2} := S_{u34M14}$ $S_{u2} = 6.85\cdot 10^{4}\cdot psi$

At the ambient condition of 70 F, the water has a specific volume

$v_{initial} := 0.01605\ ft^{3}\cdot lb^{-1}$

Therefore, the mass of water in a unit length (1 inch) of pipe is

$$m_{w1i} := \frac{\pi \cdot r_{01}^{2} \cdot 1}{\left(v_{initial} \cdot lb \cdot in^{-3}\right)} \qquad m_{w1i} = 0.019 \quad \text{lb per unit length (1" Sch 160)}$$

$$m_{w2i} := \frac{\pi \cdot r_{02}^{2} \cdot 1}{\left(v_{initial} \cdot lb \cdot in^{-3}\right)} \qquad m_{w2i} = 0.011 \quad \text{lb per unit length (3/4" Sch 160)}$$

The mean coefficient of thermal expansion for SA-376 Gr TP304 at 250 F (Reference 12) is

$$\alpha_T := 8.90 \cdot 10^{-6}$$

And the strain due to thermal expansion is

$$\varepsilon_{th} := \alpha_T \cdot \left(T_{LOCA} - T_{amb}\right) \qquad \varepsilon_{th} = 1.602 \cdot 10^{-3} \quad \text{in/in}$$

The total mass of the water in the piping, assuming that the pipe is filled, is

$$m_{tot} := m_{w1i} \cdot L_1 + m_{w2i} \cdot L_2 \qquad m_{tot} = 61.79 \quad \text{lb}$$

To solve the equations for the system with both pipe sizes, we must guess inital values for the variables.

$P := 3000$ $\qquad \varepsilon_{p1} := 0.01$ $\qquad vol_1 := 1$

$v := 0.016$ $\qquad \varepsilon_{p2} := 0.01$ $\qquad vol_2 := 1$

$\sigma_{h1} := 100$ $\qquad r_1 := 1$ $\qquad m_{w1} := 1$

$\sigma_{h2} := 100$ $\qquad r_2 := 1$ $\qquad m_{w2} := 1$

Assign a function to represent the change from elastic strain to plastic strain as follows:

$$f_1\left(\sigma_{h1}, S_{y1}, E_1, E_{p1}, \varepsilon_{y1}\right) := \mathrm{if}\left(\sigma_{h1} > S_{y1}, \frac{\sigma_{h1} - S_{y1}}{E_{p1}} + \varepsilon_{y1}, \frac{\sigma_{h1}}{E_1}\right)$$

$$f_2\left(\sigma_{h2}, S_{y2}, E_2, E_{p2}, \varepsilon_{y2}\right) := \mathrm{if}\left(\sigma_{h2} > S_{y2}, \frac{\sigma_{h2} - S_{y2}}{E_{p2}} + \varepsilon_{y2}, \frac{\sigma_{h2}}{E_2}\right)$$

Given

$$r_1 = (1+\varepsilon_{p1}) \cdot r_{01} \cdot (1+\varepsilon_{th}) \qquad r_2 = (1+\varepsilon_{p2}) \cdot r_{02} \cdot (1+\varepsilon_{th})$$

$$vol_1 = \frac{\pi \cdot r_1^{2} \cdot (1+\varepsilon_{th}) \cdot L_1}{(12^3)} \qquad vol_2 = \frac{\pi \cdot r_2^{2} \cdot (1+\varepsilon_{th}) \cdot L_2}{(12^3)}$$

$$v = \frac{vol_1}{m_{w1}} \qquad v = \frac{vol_2}{m_{w2}}$$

$$P = (4.507 \cdot 10^9) \cdot v^2 - (1.690 \cdot 10^8) \cdot v + 1.572 \cdot 10^6 \qquad m_{tot} = m_{w1} + m_{w2}$$

$$\sigma_{h1} = P \cdot \frac{r_1}{t_1} \qquad \sigma_{h2} = P \cdot \frac{r_2}{t_2}$$

$$\varepsilon_{p1} = f_1(\sigma_{h1}, S_{y1}, E_1, E_{p1}, \varepsilon_{y1}) \qquad \varepsilon_{p2} = f_2(\sigma_{h2}, S_{y2}, E_2, E_{p2}, \varepsilon_{y2})$$

Solving the equations.

$$AA := \mathrm{Find}(r_1, r_2, \varepsilon_{p1}, \varepsilon_{p2}, vol_1, vol_2, v, P, \sigma_{h1}, \sigma_{h2}, m_{w1}, m_{w2})$$

$r_1 := AA_{0,0} \cdot in$ $\qquad r_1 = 0.413 \cdot in$

$r_2 := AA_{1,0} \cdot in$ $\qquad r_2 = 0.307 \cdot in$

$\varepsilon_{p1} := AA_{2,0}$ $\qquad \varepsilon_{p1} = 1.147 \cdot \%$

$\varepsilon_{p2} := AA_{3,0}$ $\qquad \varepsilon_{p2} = 0.143 \cdot \%$

$vol_1 := AA_{4,0} \cdot ft^3$ $\qquad vol_1 = 0.074 \cdot ft^3$

$vol_2 := AA_{5,0} \cdot ft^3$ $\qquad vol_2 = 0.926 \cdot ft^3$

$v := AA_{6,0} \cdot ft^3 \cdot lb^{-1}$ $\qquad v = 0.016197 \cdot ft^3 \cdot lb^{-1}$

$P := AA_{7,0} \cdot psi$ $\qquad P = 1.7081 \cdot 10^4 \cdot psi$

$\sigma_{h1} := AA_{8,0} \cdot psi$ $\qquad \sigma_{h1} = 28.206 \cdot ksi$

$\sigma_{h2} := AA_{9,0} \cdot psi$ $\qquad \sigma_{h2} = 23.939 \cdot ksi$

$m_{w1} := AA_{10,0} \cdot lb$ $\qquad m_{w1} = 4.599 \cdot lb$

$m_{w2} := AA_{11,0} \cdot lb$ $\qquad m_{w2} = 57.191 \cdot lb$

AA =

	0
0	0.413
1	0.307
2	0.011
3	$1.43 \cdot 10^{-3}$
4	0.074
5	0.926
6	0.016
7	$1.708 \cdot 10^4$
8	$2.821 \cdot 10^4$
9	$2.394 \cdot 10^4$
10	4.599
11	57.191

The principal stresses for the first pipe are calculated

$$S_{11} := \frac{P \cdot r_1}{t_1 \cdot in} \qquad S_{11} = 28.206 \cdot ksi$$

$$S_{2p1} := \frac{P \cdot r_1}{2 \cdot t_1 \cdot in} + S_{m1} \qquad S_{2p1} = 34.103 \cdot ksi$$

$$S_{2m1} := \frac{P \cdot r_1}{2 \cdot t_1 \cdot in} - S_{m1} \qquad S_{2m1} = -5.897 \cdot ksi$$

$$S_{31} := \frac{-P}{2} \qquad S_{31} = -8.54 \cdot ksi$$

$$BB_1 := \begin{bmatrix} \left| S_{11} - S_{2p1} \right| \\ \left| S_{11} - S_{2m1} \right| \\ \left| S_{2p1} - S_{31} \right| \\ \left| S_{2m1} - S_{31} \right| \\ \left| S_{31} - S_{11} \right| \end{bmatrix} \qquad BB_1 = \begin{bmatrix} 5.897 \\ 34.103 \\ 42.643 \\ 2.643 \\ 36.747 \end{bmatrix} \cdot ksi$$

The stress intensity

$$SI := \max(BB_1) \qquad SI = 42.643 \cdot ksi$$

The allowable stress is

$$S_{allowable} := 0.7 \cdot S_{u1} \qquad S_{allowable} = 47.95 \cdot ksi$$

The stress index is

$$Index := \frac{SI}{S_{allowable}} \qquad Index = 0.889$$

The principal stresses for the second pipe are calculated

$S_{12} := \dfrac{P \cdot r_2}{t_2 \cdot in}$ $\qquad S_{12} = 23.939 \cdot ksi$

$S_{2p2} := \dfrac{P \cdot r_2}{2 \cdot t_2 \cdot in} + S_{m2}$ $\qquad S_{2p2} = 31.969 \cdot ksi$

$S_{2m2} := \dfrac{P \cdot r_2}{2 \cdot t_2 \cdot in} - S_{m2}$ $\qquad S_{2m2} = -8.031 \cdot ksi$

$S_{32} := \dfrac{-P}{2}$ $\qquad S_{32} = -8.54 \cdot ksi$

$$BB_2 := \begin{bmatrix} \left| S_{12} - S_{2p2} \right| \\ \left| S_{12} - S_{2m2} \right| \\ \left| S_{2p2} - S_{32} \right| \\ \left| S_{2m2} - S_{32} \right| \\ \left| S_{32} - S_{12} \right| \end{bmatrix} \qquad BB_2 = \begin{bmatrix} 8.031 \\ 31.969 \\ 40.51 \\ 0.51 \\ 32.479 \end{bmatrix} \cdot ksi$$

The stress intensity

$SI := \max(BB_2)$ $\qquad SI = 40.51 \cdot ksi$

The allowable stress is

$S_{allowable} := 0.7 \cdot S_{u2}$ $\qquad S_{allowable} = 47.95 \cdot ksi$

The stress index is

$Index := \dfrac{SI}{S_{allowable}}$ $\qquad Index = 0.845$

APPENDIX C

PURPOSE:

The purpose of this calculation is to perform an evaluation of isolated piping segments that penetrate the containment to determine the effect of thermal over-pressurization during a design basis accident by the thermal expansion of the contained water. The results of this calculation represent penetration CPN-37 at D.C. Cook, Unit 2.

CALCULATION:

The expected temperature of the water during a LOCA and the ambient temperature are

$T_{LOCA} := 250$ $\quad$ $T_{amb} := 70$

The conversion for psi to ksi is

$ksi := 1000\ psi$

For penetration CPN-37, there are two different types of pipes in the system. Using References 5, 12 and 13, the pipe material properties and geometry were determined, respectively.

The first pipe is 4" Sch 10, pipe specification B-14

$ID_{4B14} := 4.260\ in$ $\quad$ $S_{m4B14} := 20\ ksi$ $\quad$ $E_{4B14} := 27.3 \cdot 10^{6}\ psi$

$t_{4B14} := 0.120\ in$ $\quad$ $S_{y4B14} := 23.7\ ksi$ $\quad$ $E_{p4B14} := 0.425 \cdot 10^{6}\ psi$

$OD_{4B14} := ID_{4B14} + 2 \cdot t_{4B14}$ $\quad$ $S_{u4B14} := 68.5\ ksi$ $\quad$ SA-312 Gr TP304

$OD_{4B14} = 4.5 \cdot in$

The second pipe is 1" Sch 40, pipe specification B-14

$ID_{1B14} := 1.049\ in$ $\quad$ $S_{m1B14} := 20\ ksi$ $\quad$ $E_{1B14} := 27.3 \cdot 10^{6}\ psi$

$t_{1B14} := 0.133\ in$ $\quad$ $S_{y1B14} := 23.7\ ksi$ $\quad$ $E_{p1B14} := 0.425 \cdot 10^{6}\ psi$

$OD_{1B14} := ID_{1B14} + 2 \cdot t_{1B14}$ $\quad$ $S_{u1B14} := 68.5\ ksi$ $\quad$ SA-312 Gr TP304

$OD_{1B14} = 1.315 \cdot in$

The lengths of the two different pipes are determined from the drawings in Reference 5. The 4" pipe has a total length of approximately 34 ft. while the 1" pipe has a total length of approximately 3 ft.

$L_{1} := (34\ ft) \cdot in^{-1}$ $\quad$ $L_{2} := (3\ ft) \cdot in^{-1}$

$L_{1} = 408$ inches $\quad$ $L_{2} = 36$ inches

For the first pipe (4" Sch 40, B-14), the specific material parameters used in the calculation are

$t_1 := t_{4B14}\cdot in^{-1}$ $t_1 = 0.12$ inches

$r_{01} := \left(\frac{OD_{4B14}\cdot in^{-1}}{2}\right) - t_1$ $r_{01} = 2.13$ inches

$S_{y1} := S_{y4B14}\cdot psi^{-1}$ $S_{y1} = 2.37\cdot 10^{4}$ psi

$E_1 := E_{4B14}\cdot psi^{-1}$ $E_1 = 2.73\cdot 10^{7}$ psi

$E_{p1} := E_{p4B14}\cdot psi^{-1}$ $E_{p1} = 4.25\cdot 10^{5}$ psi

$\varepsilon_{y1} := \frac{S_{y1}}{E_1}$ $\varepsilon_{y1} = 8.681\cdot 10^{-4}$ in/in

$S_{m1} := S_{m4B14}$ $S_{m1} = 2\cdot 10^{4}\,psi$

$S_{u1} := S_{u4B14}$ $S_{u1} = 6.85\cdot 10^{4}\,psi$

For the second pipe (1" Sch 10, B-14), the specific material parameters for the calculation are

$t_2 := t_{1B14}\cdot in^{-1}$ $t_2 = 0.133$ inches

$r_{02} := \left(\frac{OD_{1B14}\cdot in^{-1}}{2}\right) - t_2$ $r_{02} = 0.524$ inches

$S_{y2} := S_{y1B14}\cdot psi^{-1}$ $S_{y2} = 2.37\cdot 10^{4}$ psi

$E_2 := E_{1B14}\cdot psi^{-1}$ $E_2 = 2.73\cdot 10^{7}$ psi

$E_{p2} := E_{p1B14}\cdot psi^{-1}$ $E_{p2} = 4.25\cdot 10^{5}$ psi

$\varepsilon_{y2} := \frac{S_{y2}}{E_2}$ $\varepsilon_{y2} = 8.681\cdot 10^{-4}$ in/in

$S_{m2} := S_{m1B14}$ $S_{m2} = 2\cdot 10^{4}\,psi$

$S_{u2} := S_{u1B14}$ $S_{u2} = 6.85\cdot 10^{4}\,psi$

At the ambient condition of 70 F, the water has a specific volume

$v_{initial} := 0.01605\ ft^{3}\cdot lb^{-1}$

Therefore, the mass of water in a unit length (1 inch) of pipe is

$m_{w1i} := \frac{\pi \cdot r_{01}{}^{2} \cdot 1}{\left(v_{initial} \cdot lb \cdot in^{-3}\right)}$ $m_{w1i} = 0.514$ lb per unit length (4" Sch 40)

$m_{w2i} := \frac{\pi \cdot r_{02}{}^{2} \cdot 1}{\left(v_{initial} \cdot lb \cdot in^{-3}\right)}$ $m_{w2i} = 0.031$ lb per unit length (1" Sch 10)

The mean coefficient of thermal expansion for SA-312 Gr TP304 at 250 F (Reference 12) is

$\alpha_T := 8.90 \cdot 10^{-6}$

And the strain due to thermal expansion is

$\varepsilon_{th} := \alpha_T \cdot \left(T_{LOCA} - T_{amb}\right)$ $\varepsilon_{th} = 1.602 \cdot 10^{-3}$ in/in

The total mass of the water in the piping, assuming that the pipe is filled, is

$m_{tot} := m_{w1i} \cdot L_1 + m_{w2i} \cdot L_2$ $m_{tot} = 210.799$ lb

To solve the equations for the system with both pipe sizes, we must guess inital values for the variables.

$P := 3000$ $\varepsilon_{p1} := 0.01$ $vol_1 := 1$

$v := 0.016$ $\varepsilon_{p2} := 0.01$ $vol_2 := 1$

$\sigma_{h1} := 100$ $r_1 := 1$ $m_{w1} := 1$

$\sigma_{h2} := 100$ $r_2 := 1$ $m_{w2} := 1$

Assign a function to represent the change from elastic strain to plastic strain as follows:

$$f_1\left(\sigma_{h1}, S_{y1}, E_1, E_{p1}, \varepsilon_{y1}\right) := if\left(\sigma_{h1} > S_{y1}, \frac{\sigma_{h1} - S_{y1}}{E_{p1}} + \varepsilon_{y1}, \frac{\sigma_{h1}}{E_1}\right)$$

$$f_2\left(\sigma_{h2}, S_{y2}, E_2, E_{p2}, \varepsilon_{y2}\right) := if\left(\sigma_{h2} > S_{y2}, \frac{\sigma_{h2} - S_{y2}}{E_{p2}} + \varepsilon_{y2}, \frac{\sigma_{h2}}{E_2}\right)$$

Given

$r_1=(1+\varepsilon_{p1})\cdot r_{01}\cdot(1+\varepsilon_{th})$ $\qquad$ $r_2=(1+\varepsilon_{p2})\cdot r_{02}\cdot(1+\varepsilon_{th})$

$vol_1=\dfrac{\pi\cdot r_1^{2}\cdot(1+\varepsilon_{th})\cdot L_1}{(12^3)}$ $\qquad$ $vol_2=\dfrac{\pi\cdot r_2^{2}\cdot(1+\varepsilon_{th})\cdot L_2}{(12^3)}$

$v=\dfrac{vol_1}{m_{w1}}$ $\qquad$ $v=\dfrac{vol_2}{m_{w2}}$

$P=(4.507\cdot10^{9})\cdot v^{2}-(1.690\cdot10^{8})\cdot v+1.572\cdot10^{6}$ $\qquad$ $m_{tot}=m_{w1}+m_{w2}$

$\sigma_{h1}=P\cdot\dfrac{r_1}{t_1}$ $\qquad$ $\sigma_{h2}=P\cdot\dfrac{r_2}{t_2}$

$\varepsilon_{p1}=f_1(\sigma_{h1},S_{y1},E_1,E_{p1},\varepsilon_{y1})$ $\qquad$ $\varepsilon_{p2}=f_2(\sigma_{h2},S_{y2},E_2,E_{p2},\varepsilon_{y2})$

Solving the equations.

$AA:=\mathrm{Find}(r_1,r_2,\varepsilon_{p1},\varepsilon_{p2},vol_1,vol_2,v,P,\sigma_{h1},\sigma_{h2},m_{w1},m_{w2})$

$r_1:=AA_{0,0}\cdot in$ $\qquad$ $r_1=2.189\,in$

$r_2:=AA_{1,0}\cdot in$ $\qquad$ $r_2=0.525\,in$

$\varepsilon_{p1}:=AA_{2,0}$ $\qquad$ $\varepsilon_{p1}=2.614\,\%$

$\varepsilon_{p2}:=AA_{3,0}$ $\qquad$ $\varepsilon_{p2}=0.027\,\%$

$vol_1:=AA_{4,0}\cdot ft^3$ $\qquad$ $vol_1=3.561\,ft^3$

$vol_2:=AA_{5,0}\cdot ft^3$ $\qquad$ $vol_2=0.018\,ft^3$

$v:=AA_{6,0}\cdot ft^3\cdot lb^{-1}$ $\qquad$ $v=0.016977\,ft^3\cdot lb^{-1}$

$P:=AA_{7,0}\cdot psi$ $\qquad$ $P=1.888\cdot10^{3}\,psi$

$\sigma_{h1}:=AA_{8,0}\cdot psi$ $\qquad$ $\sigma_{h1}=34.442\,ksi$

$\sigma_{h2}:=AA_{9,0}\cdot psi$ $\qquad$ $\sigma_{h2}=7.459\,ksi$

$m_{w1}:=AA_{10,0}\cdot lb$ $\qquad$ $m_{w1}=209.732\,lb$

$m_{w2}:=AA_{11,0}\cdot lb$ $\qquad$ $m_{w2}=1.066\,lb$

AA =

	0
0	2.189
1	0.525
2	0.026
3	$2.732\cdot10^{-4}$
4	3.561
5	0.018
6	0.017
7	$1.888\cdot10^{3}$
8	$3.444\cdot10^{4}$
9	$7.459\cdot10^{3}$
10	209.732
11	1.066

The principal stresses for the first pipe are calculated

$$S_{11} := \frac{P \cdot r_1}{t_1 \cdot in} \qquad S_{11} = 34.442 \cdot ksi$$

$$S_{2p1} := \frac{P \cdot r_1}{2 \cdot t_1 \cdot in} + S_{m1} \qquad S_{2p1} = 37.221 \cdot ksi$$

$$S_{2m1} := \frac{P \cdot r_1}{2 \cdot t_1 \cdot in} - S_{m1} \qquad S_{2m1} = -2.779 \cdot ksi$$

$$S_{31} := \frac{-P}{2} \qquad S_{31} = -0.944 \cdot ksi$$

$$BB_1 := \begin{bmatrix} \left| S_{11} - S_{2p1} \right| \\ \left| S_{11} - S_{2m1} \right| \\ \left| S_{2p1} - S_{31} \right| \\ \left| S_{2m1} - S_{31} \right| \\ \left| S_{31} - S_{11} \right| \end{bmatrix} \qquad BB_1 = \begin{bmatrix} 2.779 \\ 37.221 \\ 38.165 \\ 1.835 \\ 35.386 \end{bmatrix} \cdot ksi$$

The stress intensity

$$SI := \max\left(BB_1\right) \qquad SI = 38.165 \cdot ksi$$

The allowable stress is

$$S_{allowable} := 0.7 \cdot S_{u1} \qquad S_{allowable} = 47.95 \cdot ksi$$

The stress index is

$$Index := \frac{SI}{S_{allowable}} \qquad Index = 0.796$$

The principal stresses for the second pipe are calculated

$$S_{12} := \frac{P \cdot r_2}{t_2 \cdot in} \qquad S_{12} = 7.459 \cdot ksi$$

$$S_{2p2} := \frac{P \cdot r_2}{2 \cdot t_2 \cdot in} + S_{m2} \qquad S_{2p2} = 23.73 \cdot ksi$$

$$S_{2m2} := \frac{P \cdot r_2}{2 \cdot t_2 \cdot in} - S_{m2} \qquad S_{2m2} = -16.27 \cdot ksi$$

$$S_{32} := \frac{-P}{2} \qquad S_{32} = -0.944 \cdot ksi$$

$$BB_2 := \begin{bmatrix} \left| S_{12} - S_{2p2} \right| \\ \left| S_{12} - S_{2m2} \right| \\ \left| S_{2p2} - S_{32} \right| \\ \left| S_{2m2} - S_{32} \right| \\ \left| S_{32} - S_{12} \right| \end{bmatrix} \qquad BB_2 = \begin{bmatrix} 16.27 \\ 23.73 \\ 24.674 \\ 15.326 \\ 8.403 \end{bmatrix} \cdot ksi$$

The stress intensity

$$SI := \max(BB_2) \qquad SI = 24.674 \cdot ksi$$

The allowable stress is

$$S_{allowable} := 0.7 \cdot S_{u2} \qquad S_{allowable} = 47.95 \cdot ksi$$

The stress index is

$$Index := \frac{SI}{S_{allowable}} \qquad Index = 0.515$$

APPENDIX D

PURPOSE:

The purpose of this calculation is to perform an evaluation of isolated piping segments that penetrate the containment to determine the effect of thermal over-pressurization during a design basis accident by the thermal expansion of the contained water. The results of this calculation represent penetration CPN-32 at D.C. Cook, Unit 2.

CALCULATION:

The expected temperature of the water during a LOCA and the ambient temperature are

$T_{LOCA} := 240$ $T_{amb} := 70$

The conversion for psi to ksi is

$\mathrm{ksi} := 1000\ \mathrm{psi}$

For penetration CPN-32, there are two different types of pipes in the system. Using References 6, 12 and 13, the pipe material properties and geometry were determined, respectively.

The first pipe is 1" Sch 160, pipe specification M-14

$ID_{1M14} := 0.815\ \mathrm{in}$ $S_{m1M14} := 20\ \mathrm{ksi}$ $E_{1M14} := 27.3 \cdot 10^{6}\ \mathrm{psi}$

$t_{1M14} := 0.250\ \mathrm{in}$ $S_{y1M14} := 23.7\ \mathrm{ksi}$ $E_{p1M14} := 0.425 \cdot 10^{6}\ \mathrm{psi}$

$OD_{1M14} := ID_{1M14} + 2 \cdot t_{1M14}$ $S_{u1M14} := 68.5\ \mathrm{ksi}$ SA-376 Gr TP304

$OD_{1M14} = 1.315 \circ \mathrm{in}$

The second pipe is 3/4" Sch 160, pipe specification M-14

$ID_{34M14} := 0.612\ \mathrm{in}$ $S_{m34M14} := 20\ \mathrm{ksi}$ $E_{34M14} := 27.3 \cdot 10^{6}\ \mathrm{psi}$

$t_{34M14} := 0.219\ \mathrm{in}$ $S_{y34M14} := 23.7\ \mathrm{ksi}$ $E_{p34M14} := 0.425 \cdot 10^{6}\ \mathrm{psi}$

$OD_{34M14} := ID_{34M14} + 2 \cdot t_{34M14}$ $S_{u34M14} := 68.5\ \mathrm{ksi}$ SA-376 Gr TP304

$OD_{34M14} = 1.05 \circ \mathrm{in}$

The lengths of the two different pipes are determined from the drawings in Reference 6. The 1" pipe has a total length of approximately 270 ft. while the 3/4" pipe has a total length of approximately 138 ft.

$L_{1} := (270\ \mathrm{ft}) \cdot \mathrm{in}^{-1}$ $L_{2} := (138\ \mathrm{ft}) \cdot \mathrm{in}^{-1}$

$L_{1} = 3.24 \cdot 10^{3}$ inches $L_{2} = 1.656 \cdot 10^{3}$ inches

For the first pipe (1" Sch 160, M-14), the specific material parameters used in the calculation are

$t_1 := t_{1M14} \cdot in^{-1}$	$t_1 = 0.25$	inches
$r_{01} := \left(\frac{OD_{1M14} \cdot in^{-1}}{2}\right) - t_1$	$r_{01} = 0.408$	inches
$S_{y1} := S_{y1M14} \cdot psi^{-1}$	$S_{y1} = 2.37 \cdot 10^{4}$	psi
$E_1 := E_{1M14} \cdot psi^{-1}$	$E_1 = 2.73 \cdot 10^{7}$	psi
$E_{p1} := E_{p1M14} \cdot psi^{-1}$	$E_{p1} = 4.25 \cdot 10^{5}$	psi
$\varepsilon_{y1} := \frac{S_{y1}}{E_1}$	$\varepsilon_{y1} = 8.681 \cdot 10^{-4}$	in/in
$S_{m1} := S_{m1M14}$	$S_{m1} = 2 \cdot 10^{4} \circ psi$	
$S_{u1} := S_{u1M14}$	$S_{u1} = 6.85 \cdot 10^{4} \circ psi$	

For the second pipe (3/4" Sch 160, M-14), the specific material parameters for the calculation are

$t_2 := t_{34M14} \cdot in^{-1}$	$t_2 = 0.219$	inches
$r_{02} := \left(\frac{OD_{34M14} \cdot in^{-1}}{2}\right) - t_2$	$r_{02} = 0.306$	inches
$S_{y2} := S_{y34M14} \cdot psi^{-1}$	$S_{y2} = 2.37 \cdot 10^{4}$	psi
$E_2 := E_{34M14} \cdot psi^{-1}$	$E_2 = 2.73 \cdot 10^{7}$	psi
$E_{p2} := E_{p34M14} \cdot psi^{-1}$	$E_{p2} = 4.25 \cdot 10^{5}$	psi
$\varepsilon_{y2} := \frac{S_{y2}}{E_2}$	$\varepsilon_{y2} = 8.681 \cdot 10^{-4}$	in/in
$S_{m2} := S_{m34M14}$	$S_{m2} = 2 \cdot 10^{4} \circ psi$	
$S_{u2} := S_{u34M14}$	$S_{u2} = 6.85 \cdot 10^{4} \circ psi$	

At the design conditions of 1800 psia and 70 F, the water has a specific volume

$$v_{initial} := 0.015961\ ft^{3} \cdot lb^{-1}$$

Therefore, the mass of water in a unit length (1 inch) of pipe is

$m_{w1i} := \frac{\pi \cdot r_{01}^{2} \cdot 1}{\left(v_{initial} \cdot lb \cdot in^{-3}\right)}$ $m_{w1i} = 0.019$ lb per unit length (1" Sch 160)

$m_{w2i} := \frac{\pi \cdot r_{02}^{2} \cdot 1}{\left(v_{initial} \cdot lb \cdot in^{-3}\right)}$ $m_{w2i} = 0.011$ lb per unit length (3/4" Sch 160)

The mean coefficient of thermal expansion for SA-376 Gr TP304 at 250 F (Reference 12) is

$\alpha_{T} := 8.90 \cdot 10^{-6}$

And the strain due to thermal expansion is

$\varepsilon_{th} := \alpha_{T} \cdot \left(T_{LOCA} - T_{amb}\right)$ $\varepsilon_{th} = 1.513 \cdot 10^{-3}$ in/in

The total mass of the water in the piping, assuming that the pipe is filled, is

$m_{tot} := m_{w1i} \cdot L_{1} + m_{w2i} \cdot L_{2}$ $m_{tot} = 78.946$ lb

To solve the equations for the system with both pipe sizes, we must guess inital values for the variables.

$P := 3000$

$v := 0.016$

$\sigma_{h1} := 100$

$\sigma_{h2} := 100$

$\varepsilon_{p1} := 0.01$

$\varepsilon_{p2} := 0.01$

$r_{1} := 1$

$r_{2} := 1$

$vol_{1} := 1$

$vol_{2} := 1$

$m_{w1} := 1$

$m_{w2} := 1$

Assign a function to represent the change from elastic strain to plastic strain as follows:

$$f_{1}\left(\sigma_{h1}, S_{y1}, E_{1}, E_{p1}, \varepsilon_{y1}\right) := \mathrm{if}\left(\sigma_{h1} > S_{y1}, \frac{\sigma_{h1} - S_{y1}}{E_{p1}} + \varepsilon_{y1}, \frac{\sigma_{h1}}{E_{1}}\right)$$

$$f_{2}\left(\sigma_{h2}, S_{y2}, E_{2}, E_{p2}, \varepsilon_{y2}\right) := \mathrm{if}\left(\sigma_{h2} > S_{y2}, \frac{\sigma_{h2} - S_{y2}}{E_{p2}} + \varepsilon_{y2}, \frac{\sigma_{h2}}{E_{2}}\right)$$

Given

$$r_1 = (1 + \varepsilon_{p1}) \cdot r_{01} \cdot (1 + \varepsilon_{th}) \qquad r_2 = (1 + \varepsilon_{p2}) \cdot r_{02} \cdot (1 + \varepsilon_{th})$$

$$vol_1 = \frac{\pi \cdot r_1^2 \cdot (1 + \varepsilon_{th}) \cdot L_1}{(12^3)} \qquad vol_2 = \frac{\pi \cdot r_2^2 \cdot (1 + \varepsilon_{th}) \cdot L_2}{(12^3)}$$

$$v = \frac{vol_1}{m_{w1}} \qquad v = \frac{vol_2}{m_{w2}}$$

$$P = (4.8551 \cdot 10^9) \cdot v^2 - (1.8015 \cdot 10^8) \cdot v + 1.6583 \cdot 10^6 \qquad m_{tot} = m_{w1} + m_{w2}$$

$$\sigma_{h1} = P \cdot \frac{r_1}{t_1} \qquad \sigma_{h2} = P \cdot \frac{r_2}{t_2}$$

$$\varepsilon_{p1} = f_1(\sigma_{h1}, S_{y1}, E_1, E_{p1}, \varepsilon_{y1}) \qquad \varepsilon_{p2} = f_2(\sigma_{h2}, S_{y2}, E_2, E_{p2}, \varepsilon_{y2})$$

Solving the equations.

$$AA := \text{Find}(r_1, r_2, \varepsilon_{p1}, \varepsilon_{p2}, vol_1, vol_2, v, P, \sigma_{h1}, \sigma_{h2}, m_{w1}, m_{w2})$$

$r_1 := AA_{0,0} \cdot \text{in}$ $\quad r_1 = 0.41 \circ \text{in}$

$r_2 := AA_{1,0} \cdot \text{in}$ $\quad r_2 = 0.307 \circ \text{in}$

$\varepsilon_{p1} := AA_{2,0}$ $\quad \varepsilon_{p1} = 0.422 \circ \%$

$\varepsilon_{p2} := AA_{3,0}$ $\quad \varepsilon_{p2} = 0.079 \circ \%$

$vol_1 := AA_{4,0} \cdot \text{ft}^3$ $\quad vol_1 = 0.991 \circ \text{ft}^3$

$vol_2 := AA_{5,0} \cdot \text{ft}^3$ $\quad vol_2 = 0.284 \circ \text{ft}^3$

$v := AA_{6,0} \cdot \text{ft}^3 \cdot \text{lb}^{-1}$ $\quad v = 0.016144 \circ \text{ft}^3 \cdot \text{lb}^{-1}$

$P := AA_{7,0} \cdot \text{psi}$ $\quad P = 1.5326 \cdot 10^4 \circ \text{psi}$

$\sigma_{h1} := AA_{8,0} \cdot \text{psi}$ $\quad \sigma_{h1} = 25.125 \circ \text{ksi}$

$\sigma_{h2} := AA_{9,0} \cdot \text{psi}$ $\quad \sigma_{h2} = 21.464 \circ \text{ksi}$

$m_{w1} := AA_{10,0} \cdot \text{lb}$ $\quad m_{w1} = 61.378 \circ \text{lb}$

$m_{w2} := AA_{11,0} \cdot \text{lb}$ $\quad m_{w2} = 17.569 \circ \text{lb}$

AA =

	0
0	0.41
1	0.307
2	$4.22 \cdot 10^{-3}$
3	$7.862 \cdot 10^{-4}$
4	0.991
5	0.284
6	0.016
7	$1.533 \cdot 10^4$
8	$2.512 \cdot 10^4$
9	$2.146 \cdot 10^4$
10	61.378
11	17.569

The principal stresses for the first pipe are calculated

$S_{11} := \frac{P \cdot r_1}{t_1 \cdot in}$ $\qquad$ $S_{11} = 25.125 \circ ksi$

$S_{2p1} := \frac{P \cdot r_1}{2 \cdot t_1 \cdot in} + S_{m1}$ $\qquad$ $S_{2p1} = 32.562 \circ ksi$

$S_{2m1} := \frac{P \cdot r_1}{2 \cdot t_1 \cdot in} - S_{m1}$ $\qquad$ $S_{2m1} = -7.438 \circ ksi$

$S_{31} := \frac{-P}{2}$ $\qquad$ $S_{31} = -7.663 \circ ksi$

$$BB_1 := \begin{bmatrix} \left| S_{11} - S_{2p1} \right| \\ \left| S_{11} - S_{2m1} \right| \\ \left| S_{2p1} - S_{31} \right| \\ \left| S_{2m1} - S_{31} \right| \\ \left| S_{31} - S_{11} \right| \end{bmatrix} \qquad BB_1 = \begin{bmatrix} 7.438 \\ 32.562 \\ 40.225 \\ 0.225 \\ 32.788 \end{bmatrix} \circ ksi$$

The stress intensity

$SI := \max(BB_1)$ $\qquad$ $SI = 40.225 \circ ksi$

The allowable stress is

$S_{allowable} := 0.7 \cdot S_{u1}$ $\qquad$ $S_{allowable} = 47.95 \circ ksi$

The stress index is

$Index := \frac{SI}{S_{allowable}}$ $\qquad$ $Index = 0.839$

The principal stresses for the second pipe are calculated

$$S_{12} := \frac{P \cdot r_2}{t_2 \cdot in} \qquad S_{12} = 21.464 \cdot ksi$$

$$S_{2p2} := \frac{P \cdot r_2}{2 \cdot t_2 \cdot in} + S_{m2} \qquad S_{2p2} = 30.732 \cdot ksi$$

$$S_{2m2} := \frac{P \cdot r_2}{2 \cdot t_2 \cdot in} - S_{m2} \qquad S_{2m2} = -9.268 \cdot ksi$$

$$S_{32} := \frac{-P}{2} \qquad S_{32} = -7.663 \cdot ksi$$

$$BB_2 := \begin{bmatrix} \left| S_{12} - S_{2p2} \right| \\ \left| S_{12} - S_{2m2} \right| \\ \left| S_{2p2} - S_{32} \right| \\ \left| S_{2m2} - S_{32} \right| \\ \left| S_{32} - S_{12} \right| \end{bmatrix} \qquad BB_2 = \begin{bmatrix} 9.268 \\ 30.732 \\ 38.395 \\ 1.605 \\ 29.127 \end{bmatrix} \cdot ksi$$

The stress intensity

$$SI := \max(BB_2) \qquad SI = 38.395 \cdot ksi$$

The allowable stress is

$$S_{allowable} := 0.7 \cdot S_{u2} \qquad S_{allowable} = 47.95 \cdot ksi$$

The stress index is

$$Index := \frac{SI}{S_{allowable}} \qquad Index = 0.801$$

APPENDIX E

SENSITIVITY ANALYSIS: EFFECT OF PIPE WALL VARIATION ON CALCULATED PIPING PRESSURE AND STRESS

PURPOSE

The purpose of this appendix is to perform a sensitivity analysis on the isolated piping segments referenced in MPR Calculation 025-057-01 for D.C. Cook, Unit 2 and to determine the effect of variations in pipe wall thickness on the calculated stress intensities of the piping. The results included herein for CPN-32 are representative of all four penetration segments.

RESULTS

The following pages repeat the analysis method used in Appendix D of this calculation for wall thicknesses that vary by ±12.5% from nominal wall thickness for the CPN-32 piping segment. Results (pressure, strain, and stress intensity) are summarized in Table 1. For comparison, Table 1 also presents comparable results from Appendix D for the nominal wall thickness case.

Table 1 illustrates that there is less than a one percent difference in stress intensities when using either the maximum or minimum wall thickness in comparison to nominal wall thickness. Also, the pipe strain is well below the five percent allowable for all cases. Accordingly, the effect of using either the minimum or maximum wall thickness is negligible for pipe stress and strain evaluations.

Table E-1
Effect of Variation in Pipe Wall Thickness
on Piping Pressure, Strain and Stress Intensity

Segment		Pressure (psia)			Strain (inch/inch)			Stress Intensity, psi			Δ
		t_{min}	t_{nom}	T_{max}	T_{min}	t_{nom}	t_{max}	t_{min}	t_{nom}	t_{max}	
CPN-32	1"	13,925	15,326	16,634	0.0066	0.0042	0.0020	40,038	40,225	40,410	0.5%
	3/4"				0.0008	0.0008	0.0008	38,106	38,395	38,671	0.7%

where t_{min} = 87.5% of t_{nom}, t_{max} = 112.5% of t_{nom} and "Δ" is the maximum percent difference between stress intensity calculated for t_{nom} versus t_{min} or t_{max}.

CALCULATION:

The expected temperature of the water during a LOCA and the ambient temperature are

$T_{LOCA} := 240$ $\quad$ $T_{amb} := 70$ $\quad$ $ksi := 1000\ psi$

The min/max wall thickness is +/- 12.5% the nominal wall thickness.

$f_{min} := 0.875$ (-12.5%) $\quad$ $f_{max} := 1.125$ (+12.5%)

For penetration CPN-32, there are two different types of pipes in the system. Using References 6, 12 and 13, the pipe material properties and geometry were determined, respectively.

Minimum Wall Thickness Evaluation:

The first pipe is 1" Sch 160, pipe specification M-14

$ID_{1M14} := 0.815\ in$ $\quad$ $S_{m1M14} := 20\ ksi$ $\quad$ $E_{1M14} := 27.3 \cdot 10^6\ psi$

$t_{1M14} := (0.250 \cdot f_{min})\ in$ $\quad$ $S_{y1M14} := 23.7\ ksi$ $\quad$ $E_{p1M14} := 0.425 \cdot 10^6\ psi$

$OD_{1M14} := ID_{1M14} + 2 \cdot t_{1M14}$ $\quad$ $S_{u1M14} := 68.5\ ksi$ $\quad$ SA-376 Gr TP304

$OD_{1M14} = 1.252 \circ in$

The second pipe is 3/4" Sch 160, pipe specification M-14

$ID_{34M14} := 0.612\ in$ $\quad$ $S_{m34M14} := 20\ ksi$ $\quad$ $E_{34M14} := 27.3 \cdot 10^6\ psi$

$t_{34M14} := (0.219 \cdot f_{min})\ in$ $\quad$ $S_{y34M14} := 23.7\ ksi$ $\quad$ $E_{p34M14} := 0.425 \cdot 10^6\ psi$

$OD_{34M14} := ID_{34M14} + 2 \cdot t_{34M14}$ $\quad$ $S_{u34M14} := 68.5\ ksi$ $\quad$ SA-376 Gr TP304

$OD_{34M14} = 0.995 \circ in$

The lengths of the two different pipes are determined from the drawings in Reference 6. The 1" pipe has a total length of approximately 270 ft. while the 3/4" pipe has a total length of approximately 138 ft.

$L_1 := (270\ ft) \cdot in^{-1}$ $\quad$ $L_2 := (138\ ft) \cdot in^{-1}$

$L_1 = 3.24 \cdot 10^3$ inches $\quad$ $L_2 = 1.656 \cdot 10^3$ inches

For the first pipe (1" Sch 160, M-14), the specific material parameters used in the calculation are

$t_1 := t_{1M14} \cdot in^{-1}$ $\quad$ $t_1 = 0.219$ inches

$r_{01} := \left(\dfrac{OD_{1M14} \cdot in^{-1}}{2} \right) - t_1$ $\quad$ $r_{01} = 0.407$ inches

$S_{y1} := S_{y1M14} \cdot psi^{-1}$ $\qquad$ $S_{y1} = 2.37 \cdot 10^{4}$ psi

$E_{1} := E_{1M14} \cdot psi^{-1}$ $\qquad$ $E_{1} = 2.73 \cdot 10^{7}$ psi

$E_{p1} := E_{p1M14} \cdot psi^{-1}$ $\qquad$ $E_{p1} = 4.25 \cdot 10^{5}$ psi

$\varepsilon_{y1} := \frac{S_{y1}}{E_{1}}$ $\qquad$ $\varepsilon_{y1} = 8.681 \cdot 10^{-4}$ in/in

$S_{m1} := S_{m1M14}$ $\qquad$ $S_{m1} = 2 \cdot 10^{4} \cdot psi$

$S_{u1} := S_{u1M14}$ $\qquad$ $S_{u1} = 6.85 \cdot 10^{4} \cdot psi$

For the second pipe (3/4" Sch 160, M-14), the specific material parameters for the calculation are

$t_{2} := t_{34M14} \cdot in^{-1}$ $\qquad$ $t_{2} = 0.192$ inches

$r_{02} := \left(\frac{OD_{34M14} \cdot in^{-1}}{2}\right) - t_{2}$ $\qquad$ $r_{02} = 0.306$ inches

$S_{y2} := S_{y34M14} \cdot psi^{-1}$ $\qquad$ $S_{y2} = 2.37 \cdot 10^{4}$ psi

$E_{2} := E_{34M14} \cdot psi^{-1}$ $\qquad$ $E_{2} = 2.73 \cdot 10^{7}$ psi

$E_{p2} := E_{p34M14} \cdot psi^{-1}$ $\qquad$ $E_{p2} = 4.25 \cdot 10^{5}$ psi

$\varepsilon_{y2} := \frac{S_{y2}}{E_{2}}$ $\qquad$ $\varepsilon_{y2} = 8.681 \cdot 10^{-4}$ in/in

$S_{m2} := S_{m34M14}$ $\qquad$ $S_{m2} = 2 \cdot 10^{4} \cdot psi$

$S_{u2} := S_{u34M14}$ $\qquad$ $S_{u2} = 6.85 \cdot 10^{4} \cdot psi$

At the initial conditions of 1800 psia and 70 F, the water has a specific volume

$v_{initial} := 0.015961\ ft^{3} \cdot lb^{-1}$

Therefore, the mass of water in a unit length (1 inch) of pipe is

$m_{w1i} := \frac{\pi \cdot r_{01}^{2} \cdot 1}{\left(v_{initial} \cdot lb \cdot in^{-3}\right)}$ $\qquad$ $m_{w1i} = 0.019$ lb per unit length (1" Sch 160)

$m_{w2i} := \frac{\pi \cdot r_{02}^{2} \cdot 1}{\left(v_{initial} \cdot lb \cdot in^{-3}\right)}$ $\qquad$ $m_{w2i} = 0.011$ lb per unit length (3/4" Sch 160)

The mean coefficient of thermal expansion for SA-376 Gr TP304 at 250 F (Reference 12) is

$$\alpha_T := 8.90 \cdot 10^{-6}$$

And the strain due to thermal expansion is

$$\varepsilon_{th} := \alpha_T \cdot \left(T_{LOCA} - T_{amb}\right) \qquad \varepsilon_{th} = 1.513 \cdot 10^{-3} \quad \text{in/in}$$

The total mass of the water in the piping, assuming that the pipe is filled, is

$$m_{tot} := m_{w1i} \cdot L_1 + m_{w2i} \cdot L_2 \qquad m_{tot} = 78.946 \quad \text{lb}$$

To solve the equations for the system with both pipe sizes, we must guess inital values for the variables.

$P := 3000$ $\quad \varepsilon_{p1} := 0.01$ $\quad vol_1 := 1$

$v := 0.016$ $\quad \varepsilon_{p2} := 0.01$ $\quad vol_2 := 1$

$\sigma_{h1} := 100$ $\quad r_1 := 1$ $\quad m_{w1} := 1$

$\sigma_{h2} := 100$ $\quad r_2 := 1$ $\quad m_{w2} := 1$

Assign a function to represent the change from elastic strain to plastic strain as follows:

$$f_1\left(\sigma_{h1}, S_{y1}, E_1, E_{p1}, \varepsilon_{y1}\right) := \mathrm{if}\left(\sigma_{h1} > S_{y1}, \frac{\sigma_{h1} - S_{y1}}{E_{p1}} + \varepsilon_{y1}, \frac{\sigma_{h1}}{E_1}\right)$$

$$f_2\left(\sigma_{h2}, S_{y2}, E_2, E_{p2}, \varepsilon_{y2}\right) := \mathrm{if}\left(\sigma_{h2} > S_{y2}, \frac{\sigma_{h2} - S_{y2}}{E_{p2}} + \varepsilon_{y2}, \frac{\sigma_{h2}}{E_2}\right)$$

Given

$$r_1 = \left(1 + \varepsilon_{p1}\right) \cdot r_{01} \cdot \left(1 + \varepsilon_{th}\right) \qquad r_2 = \left(1 + \varepsilon_{p2}\right) \cdot r_{02} \cdot \left(1 + \varepsilon_{th}\right)$$

$$vol_1 = \frac{\pi \cdot r_1^{2} \cdot \left(1 + \varepsilon_{th}\right) \cdot L_1}{\left(12^3\right)} \qquad vol_2 = \frac{\pi \cdot r_2^{2} \cdot \left(1 + \varepsilon_{th}\right) \cdot L_2}{\left(12^3\right)}$$

$$v = \frac{vol_1}{m_{w1}} \qquad v = \frac{vol_2}{m_{w2}}$$

$$P = \left(4.8551 \cdot 10^9\right) \cdot v^2 - \left(1.8015 \cdot 10^8\right) \cdot v + 1.6583 \cdot 10^6 \qquad m_{tot} = m_{w1} + m_{w2}$$

$$\sigma_{h1} = P \cdot \frac{r_1}{t_1} \qquad \sigma_{h2} = P \cdot \frac{r_2}{t_2}$$

$$\varepsilon_{p1} = f_1\left(\sigma_{h1}, S_{y1}, E_1, E_{p1}, \varepsilon_{y1}\right) \qquad \varepsilon_{p2} = f_2\left(\sigma_{h2}, S_{y2}, E_2, E_{p2}, \varepsilon_{y2}\right)$$

Solving the equations.

$$AA := \mathrm{Find}(r_1, r_2, \varepsilon_{p1}, \varepsilon_{p2}, vol_1, vol_2, v, P, \sigma_{h1}, \sigma_{h2}, m_{w1}, m_{w2})$$

$r_1 := AA_{0,0} \cdot in$ $\quad r_1 = 0.411 \cdot in$

$r_2 := AA_{1,0} \cdot in$ $\quad r_2 = 0.307 \cdot in$

$\varepsilon_{p1} := AA_{2,0}$ $\quad \varepsilon_{p1} = 0.664 \cdot \%$

$\varepsilon_{p2} := AA_{3,0}$ $\quad \varepsilon_{p2} = 0.082 \cdot \%$

$vol_1 := AA_{4,0} \cdot ft^3$ $\quad vol_1 = 0.996 \cdot ft^3$

$vol_2 := AA_{5,0} \cdot ft^3$ $\quad vol_2 = 0.284 \cdot ft^3$

$v := AA_{6,0} \cdot ft^3 \cdot lb^{-1}$ $\quad v = 0.016205 \cdot ft^3 \cdot lb^{-1}$

$P := AA_{7,0} \cdot psi$ $\quad P = 1.3925 \cdot 10^4 \cdot psi$

$\sigma_{h1} := AA_{8,0} \cdot psi$ $\quad \sigma_{h1} = 26.151 \cdot ksi$

$\sigma_{h2} := AA_{9,0} \cdot psi$ $\quad \sigma_{h2} = 22.288 \cdot ksi$

$m_{w1} := AA_{10,0} \cdot lb$ $\quad m_{w1} = 61.442 \cdot lb$

$m_{w2} := AA_{11,0} \cdot lb$ $\quad m_{w2} = 17.504 \cdot lb$

AA =

	0
0	0.411
1	0.307
2	$6.636 \cdot 10^{-3}$
3	$8.164 \cdot 10^{-4}$
4	0.996
5	0.284
6	0.016
7	$1.392 \cdot 10^4$
8	$2.615 \cdot 10^4$
9	$2.229 \cdot 10^4$
10	61.442
11	17.504

The principal stresses for the first pipe are calculated

$$S_{11} := \frac{P \cdot r_1}{t_1 \cdot in} \qquad S_{11} = 26.151 \cdot ksi$$

$$S_{2p1} := \frac{P \cdot r_1}{2 \cdot t_1 \cdot in} + S_{m1} \qquad S_{2p1} = 33.076 \cdot ksi$$

$$S_{2m1} := \frac{P \cdot r_1}{2 \cdot t_1 \cdot in} - S_{m1} \qquad S_{2m1} = -6.924 \cdot ksi$$

$$S_{31} := \frac{-P}{2} \qquad S_{31} = -6.962 \cdot ksi$$

$$BB_1 := \begin{bmatrix} \left| S_{11} - S_{2p1} \right| \\ \left| S_{11} - S_{2m1} \right| \\ \left| S_{2p1} - S_{31} \right| \\ \left| S_{2m1} - S_{31} \right| \\ \left| S_{31} - S_{11} \right| \end{bmatrix} \qquad BB_1 = \begin{bmatrix} 6.924 \\ 33.076 \\ 40.038 \\ 0.038 \\ 33.114 \end{bmatrix} \cdot ksi$$

The stress intensity

$SI := \max(BB_1)$ $\qquad SI = 40.038 \cdot ksi$

The allowable stress is

$S_{allowable} := 0.7 \cdot S_{u1}$ $\qquad S_{allowable} = 47.95 \cdot ksi$

The stress index is

$Index := \dfrac{SI}{S_{allowable}}$ $\qquad Index = 0.835$

The principal stresses for the second pipe are calculated

$S_{12} := \dfrac{P \cdot r_2}{t_2 \cdot in}$ $\qquad S_{12} = 22.288 \cdot ksi$

$S_{2p2} := \dfrac{P \cdot r_2}{2 \cdot t_2 \cdot in} + S_{m2}$ $\qquad S_{2p2} = 31.144 \cdot ksi$

$S_{2m2} := \dfrac{P \cdot r_2}{2 \cdot t_2 \cdot in} - S_{m2}$ $\qquad S_{2m2} = -8.856 \cdot ksi$

$S_{32} := \dfrac{-P}{2}$ $\qquad S_{32} = -6.962 \cdot ksi$

$$BB_2 := \begin{bmatrix} |S_{12} - S_{2p2}| \\ |S_{12} - S_{2m2}| \\ |S_{2p2} - S_{32}| \\ |S_{2m2} - S_{32}| \\ |S_{32} - S_{12}| \end{bmatrix} \qquad BB_2 = \begin{bmatrix} 8.856 \\ 31.144 \\ 38.106 \\ 1.894 \\ 29.25 \end{bmatrix} \cdot ksi$$

The stress intensity

$SI := \max(BB_2)$ $\qquad SI = 38.106 \cdot ksi$

The allowable stress is

$S_{allowable} := 0.7 \cdot S_{u2}$ $\qquad S_{allowable} = 47.95 \cdot ksi$

The stress index is

$Index := \dfrac{SI}{S_{allowable}}$ $\qquad Index = 0.795$

Maximum Wall Thickness Evaluation:

The first pipe is 1" Sch 160, pipe specification M-14

$ID_{1M14} := 0.815\ in$ $\quad S_{m1M14} := 20\ ksi$ $\quad E_{1M14} := 27.3\cdot 10^{6}\ psi$

$t_{1M14} := (0.250\cdot f_{max})\ in$ $\quad S_{y1M14} := 23.7\ ksi$ $\quad E_{p1M14} := 0.425\cdot 10^{6}\ psi$

$OD_{1M14} := ID_{1M14} + 2\cdot t_{1M14}$ $\quad S_{u1M14} := 68.5\ ksi$ $\quad$ SA-376 Gr TP304

$OD_{1M14} = 1.377\circ in$

The second pipe is 3/4" Sch 160, pipe specification M-14

$ID_{34M14} := 0.612\ in$ $\quad S_{m34M14} := 20\ ksi$ $\quad E_{34M14} := 27.3\cdot 10^{6}\ psi$

$t_{34M14} := (0.219\cdot f_{max})\ in$ $\quad S_{y34M14} := 23.7\ ksi$ $\quad E_{p34M14} := 0.425\cdot 10^{6}\ psi$

$OD_{34M14} := ID_{34M14} + 2\cdot t_{34M14}$ $\quad S_{u34M14} := 68.5\ ksi$ $\quad$ SA-376 Gr TP304

$OD_{34M14} = 1.105\circ in$

The lengths of the two different pipes are determined from the drawings in Reference 6. The 1" pipe has a total length of approximately 270 ft. while the 3/4" pipe has a total length of approximately 138 ft.

$L_1 := (270\ ft)\cdot in^{-1}$ $\quad L_2 := (138\ ft)\cdot in^{-1}$

$L_1 = 3.24\cdot 10^{3}$ inches $\quad L_2 = 1.656\cdot 10^{3}$ inches

For the first pipe (1" Sch 160, M-14), the specific material parameters used in the calculation are

$t_1 := t_{1M14}\cdot in^{-1}$ $\quad t_1 = 0.281$ inches

$r_{01} := \left(\dfrac{OD_{1M14}\cdot in^{-1}}{2}\right) - t_1$ $\quad r_{01} = 0.408$ inches

$S_{y1} := S_{y1M14}\cdot psi^{-1}$ $\quad S_{y1} = 2.37\cdot 10^{4}$ psi

$E_1 := E_{1M14}\cdot psi^{-1}$ $\quad E_1 = 2.73\cdot 10^{7}$ psi

$E_{p1} := E_{p1M14}\cdot psi^{-1}$ $\quad E_{p1} = 4.25\cdot 10^{5}$ psi

$\varepsilon_{y1} := \dfrac{S_{y1}}{E_1}$ $\quad \varepsilon_{y1} = 8.681\cdot 10^{-4}$ in/in

$S_{m1} := S_{m1M14}$ $\quad S_{m1} = 2\cdot 10^{4}\circ psi$

$S_{u1} := S_{u1M14}$ $\quad S_{u1} = 6.85\cdot 10^{4}\circ psi$

For the second pipe (3/4" Sch 160, M-14), the specific material parameters for the calculation are

$t_2 := t_{34M14} \cdot in^{-1}$ $\quad t_2 = 0.246$ inches

$r_{02} := \left(\frac{OD_{34M14} \cdot in^{-1}}{2} \right) - t_2$ $\quad r_{02} = 0.306$ inches

$S_{y2} := S_{y34M14} \cdot psi^{-1}$ $\quad S_{y2} = 2.37 \cdot 10^4$ psi

$E_2 := E_{34M14} \cdot psi^{-1}$ $\quad E_2 = 2.73 \cdot 10^7$ psi

$E_{p2} := E_{p34M14} \cdot psi^{-1}$ $\quad E_{p2} = 4.25 \cdot 10^5$ psi

$\varepsilon_{y2} := \frac{S_{y2}}{E_2}$ $\quad \varepsilon_{y2} = 8.681 \cdot 10^{-4}$ in/in

$S_{m2} := S_{m34M14}$ $\quad S_{m2} = 2 \cdot 10^4 \, psi$

$S_{u2} := S_{u34M14}$ $\quad S_{u2} = 6.85 \cdot 10^4 \, psi$

At the ambient condition of 70 F, the water has a specific volume

$v_{initial} := 0.015961 \, ft^3 \cdot lb^{-1}$

Therefore, the mass of water in a unit length (1 inch) of pipe is

$m_{w1i} := \frac{\pi \cdot r_{01}{}^2 \cdot 1}{\left(v_{initial} \cdot lb \cdot in^{-3} \right)}$ $\quad m_{w1i} = 0.019$ lb per unit length (1" Sch 160)

$m_{w2i} := \frac{\pi \cdot r_{02}{}^2 \cdot 1}{\left(v_{initial} \cdot lb \cdot in^{-3} \right)}$ $\quad m_{w2i} = 0.011$ lb per unit length (3/4" Sch 160)

The mean coefficient of thermal expansion for SA-376 Gr TP304 at 250 F (Reference 12) is

$\alpha_T := 8.90 \cdot 10^{-6}$

And the strain due to thermal expansion is

$\varepsilon_{th} := \alpha_T \cdot \left(T_{LOCA} - T_{amb} \right)$ $\quad \varepsilon_{th} = 1.513 \cdot 10^{-3}$ in/in

The total mass of the water in the piping, assuming that the pipe is filled, is

$m_{tot} := m_{w1i} \cdot L_1 + m_{w2i} \cdot L_2$ $\quad m_{tot} = 78.946$ lb

To solve the equations for the system with both pipe sizes, we must guess inital values for the variables.

$P := 3000$	$\varepsilon_{p1} := 0.01$	$vol_1 := 1$
$v := 0.016$	$\varepsilon_{p2} := 0.01$	$vol_2 := 1$
$\sigma_{h1} := 100$	$r_1 := 1$	$m_{w1} := 1$
$\sigma_{h2} := 100$	$r_2 := 1$	$m_{w2} := 1$

Assign a function to represent the change from elastic strain to plastic strain as follows:

$$f_1(\sigma_{h1}, S_{y1}, E_1, E_{p1}, \varepsilon_{y1}) := \mathrm{if}\left(\sigma_{h1} > S_{y1}, \frac{\sigma_{h1} - S_{y1}}{E_{p1}} + \varepsilon_{y1}, \frac{\sigma_{h1}}{E_1}\right)$$

$$f_2(\sigma_{h2}, S_{y2}, E_2, E_{p2}, \varepsilon_{y2}) := \mathrm{if}\left(\sigma_{h2} > S_{y2}, \frac{\sigma_{h2} - S_{y2}}{E_{p2}} + \varepsilon_{y2}, \frac{\sigma_{h2}}{E_2}\right)$$

Given

$$r_1 = (1 + \varepsilon_{p1}) \cdot r_{01} \cdot (1 + \varepsilon_{th}) \qquad r_2 = (1 + \varepsilon_{p2}) \cdot r_{02} \cdot (1 + \varepsilon_{th})$$

$$vol_1 = \frac{\pi \cdot {r_1}^2 \cdot (1 + \varepsilon_{th}) \cdot L_1}{(12^3)} \qquad vol_2 = \frac{\pi \cdot {r_2}^2 \cdot (1 + \varepsilon_{th}) \cdot L_2}{(12^3)}$$

$$v = \frac{vol_1}{m_{w1}} \qquad v = \frac{vol_2}{m_{w2}}$$

$$P = (4.8551 \cdot 10^9) \cdot v^2 - (1.8015 \cdot 10^8) \cdot v + 1.6583 \cdot 10^6 \qquad m_{tot} = m_{w1} + m_{w2}$$

$$\sigma_{h1} = P \cdot \frac{r_1}{t_1} \qquad \sigma_{h2} = P \cdot \frac{r_2}{t_2}$$

$$\varepsilon_{p1} = f_1(\sigma_{h1}, S_{y1}, E_1, E_{p1}, \varepsilon_{y1}) \qquad \varepsilon_{p2} = f_2(\sigma_{h2}, S_{y2}, E_2, E_{p2}, \varepsilon_{y2})$$

Solving the equations.

$$AA := Find\left(r_1, r_2, \varepsilon_{p1}, \varepsilon_{p2}, vol_1, vol_2, v, P, \sigma_{h1}, \sigma_{h2}, m_{w1}, m_{w2}\right)$$

$r_1 := AA_{0,0} \cdot in$ $\quad r_1 = 0.409 \circ in$

$r_2 := AA_{1,0} \cdot in$ $\quad r_2 = 0.307 \circ in$

$\varepsilon_{p1} := AA_{2,0}$ $\quad \varepsilon_{p1} = 0.201 \circ \%$

$\varepsilon_{p2} := AA_{3,0}$ $\quad \varepsilon_{p2} = 0.076 \circ \%$

$vol_1 := AA_{4,0} \cdot ft^3$ $\quad vol_1 = 0.987 \circ ft^3$

$vol_2 := AA_{5,0} \cdot ft^3$ $\quad vol_2 = 0.284 \circ ft^3$

$v := AA_{6,0} \cdot ft^3 \cdot lb^{-1}$ $\quad v = 0.016089 \circ ft^3 \cdot lb^{-1}$

$P := AA_{7,0} \cdot psi$ $\quad P = 1.6634 \cdot 10^4 \circ psi$

$\sigma_{h1} := AA_{8,0} \cdot psi$ $\quad \sigma_{h1} = 24.186 \circ ksi$

$\sigma_{h2} := AA_{9,0} \cdot psi$ $\quad \sigma_{h2} = 20.707 \circ ksi$

$m_{w1} := AA_{10,0} \cdot lb$ $\quad m_{w1} = 61.318 \circ lb$

$m_{w2} := AA_{11,0} \cdot lb$ $\quad m_{w2} = 17.628 \circ lb$

AA =

	0
0	0.409
1	0.307
2	$2.013 \cdot 10^{-3}$
3	$7.585 \cdot 10^{-4}$
4	0.987
5	0.284
6	0.016
7	$1.663 \cdot 10^4$
8	$2.419 \cdot 10^4$
9	$2.071 \cdot 10^4$
10	61.318
11	17.628

The principal stresses for the first pipe are calculated

$S_{11} := \dfrac{P \cdot r_1}{t_1 \cdot in}$ $\quad S_{11} = 24.186 \circ ksi$

$S_{2p1} := \dfrac{P \cdot r_1}{2 \cdot t_1 \cdot in} + S_{m1}$ $\quad S_{2p1} = 32.093 \circ ksi$

$S_{2m1} := \dfrac{P \cdot r_1}{2 \cdot t_1 \cdot in} - S_{m1}$ $\quad S_{2m1} = -7.907 \circ ksi$

$S_{31} := \dfrac{-P}{2}$ $\quad S_{31} = -8.317 \circ ksi$

$$BB_1 := \begin{bmatrix} \left| S_{11} - S_{2p1} \right| \\ \left| S_{11} - S_{2m1} \right| \\ \left| S_{2p1} - S_{31} \right| \\ \left| S_{2m1} - S_{31} \right| \\ \left| S_{31} - S_{11} \right| \end{bmatrix} \qquad BB_1 = \begin{bmatrix} 7.907 \\ 32.093 \\ 40.41 \\ 0.41 \\ 32.504 \end{bmatrix} \circ ksi$$

The stress intensity

$SI := \max(BB_1)$ $\qquad SI = 40.41 \cdot ksi$

The allowable stress is

$S_{allowable} := 0.7 \cdot S_{u1}$ $\qquad S_{allowable} = 47.95 \cdot ksi$

The stress index is

$Index := \frac{SI}{S_{allowable}}$ $\qquad Index = 0.843$

The principal stresses for the second pipe are calculated

$S_{12} := \frac{P \cdot r_2}{t_2 \cdot in}$ $\qquad S_{12} = 20.707 \cdot ksi$

$S_{2p2} := \frac{P \cdot r_2}{2 \cdot t_2 \cdot in} + S_{m2}$ $\qquad S_{2p2} = 30.354 \cdot ksi$

$S_{2m2} := \frac{P \cdot r_2}{2 \cdot t_2 \cdot in} - S_{m2}$ $\qquad S_{2m2} = -9.646 \cdot ksi$

$S_{32} := \frac{-P}{2}$ $\qquad S_{32} = -8.317 \cdot ksi$

$$BB_2 := \begin{bmatrix} |S_{12} - S_{2p2}| \\ |S_{12} - S_{2m2}| \\ |S_{2p2} - S_{32}| \\ |S_{2m2} - S_{32}| \\ |S_{32} - S_{12}| \end{bmatrix} \qquad BB_2 = \begin{bmatrix} 9.646 \\ 30.354 \\ 38.671 \\ 1.329 \\ 29.024 \end{bmatrix} \cdot ksi$$

The stress intensity

$SI := \max(BB_2)$ $\qquad SI = 38.671 \cdot ksi$

The allowable stress is

$S_{allowable} := 0.7 \cdot S_{u2}$ $\qquad S_{allowable} = 47.95 \cdot ksi$

The stress index is

$Index := \frac{SI}{S_{allowable}}$ $\qquad Index = 0.806$

THE FOLLOWING IS A LISTING OF OVERSIZED DRAWINGS CONTAINED WITHIN THIS DOCUMENT.

TO VIEW A DRAWING, REFERENCE THE DRAWING NUMBER SPECIFIC TO THE DESIRED DRAWING (NOTED ON THE LIST) AND LOCATE IT WITHIN THIS PACKAGE

OR,

PERFORM A SEARCH USING THE DRAWING NUMBER

NOTE: Because of these page's large file size, it may be more convenient to copy the file to a local drive and use the Imaging (Wang) viewer, which can be accessed from the Programs/Accessories menu.

The following drawings provide an overview of the non-essential-service water (NESW) system and the details of the NESW piping for components located inside the containment that were modeled in the waterhammer analysis.

Unit 1 Drawings

Inside Containment

OP-1-5114-82	Flow Diagram Non-Essential Service Water Unit 1
OP-1-5114A-25	Flow Diagram Non-Essential Service Water
1-NSW-65	Upper Containment Ventilation Unit 4 Supply Line
1-NSW-66	Upper Containment Ventilation Unit 3 Supply Line
1-NSW-67	Upper Containment Ventilation Unit 2 Supply Line
1-NSW-68	Upper Containment Ventilation Unit 1 Supply Line
1-NSW-69	Upper Containment Ventilation Unit 4 Return Line
1-NSW-70	Upper Containment Ventilation Unit 3 Return Line
1-NSW-71	Upper Containment Ventilation Unit 2 Return Line
1-NSW-72	Upper Containment Ventilation Unit 1 Return Line
1-NSW-174	Instrument Room Ventilation Unit 3 Supply Line
1-NSW-175	Instrument Room Ventilation Unit 4 Supply Line
1-NSW-176	Instrument Room Ventilation Unit 3 Return Line
1-NSW-177	Instrument Room Ventilation Unit 4 Return Line
1-NSW-178	Lower Containment Ventilation Unit 1 Supply Line
1-NSW-179	Lower Containment Ventilation Unit 2 Supply Line
1-NSW-180	Lower Containment Ventilation Unit 3 Supply Line
1-NSW-181	Lower Containment Ventilation Unit 4 Supply Line
1-NSW-182	Lower Containment Ventilation Unit 1 Return Line
1-NSW-183	Lower Containment Ventilation Unit 2 Return Line
1-NSW-184	Lower Containment Ventilation Unit 3 Return Line
1-NSW-185	Lower Containment Ventilation Unit 4 Return Line

Outside Containment

1-NSW-37	Lower Containment Ventilation Unit 2 Supply Line
1-NSW-38	Lower Containment Ventilation Unit 3 Supply Line
1-NSW-39	Upper Containment Ventilation Unit 2 Supply Line
1-NSW-42	Upper Containment Ventilation Unit 3 Supply Line
1-NSW-44	Upper Containment Ventilation Unit 2 Return Line
1-NSW-45	Lower Containment Ventilation Unit 2 Return Line
1-NSW-46	Lower Containment Ventilation Unit 3 Return Line
1-NSW-47	Upper Containment Ventilation Unit 3 Return Line
1-NSW-49	Instrument Room Ventilation Unit 3 Supply Line
1-NSW-50	Instrument Room Ventilation Unit 4 Return Line

1-NSW-51	Instrument Room Ventilation Unit 3 Return Line
1-NSW-52	Instrument Room Ventilation Unit 4 Supply Line
1-NSW-54	Upper Containment Ventilation Unit 1 Supply Line
1-NSW-55	Lower Containment Ventilation Unit 1 Supply Line
1-NSW-57	Upper Containment Ventilation Unit 4 Supply Line
1-NSW-58	Lower Containment Ventilation Unit 4 Supply Line
1-NSW-59	Lower Containment Ventilation Unit 1 Return Line
1-NSW-60	Upper Containment Ventilation Unit 1 Return Line
1-NSW-62	Lower Containment Ventilation Unit 4 Return Line
1-NSW-63	Upper Containment Ventilation Unit 4 Return Line

Unit 2 Drawings

Inside Containment

OP-2-5114-50	Flow Diagram Non-Essential Service Water Unit No. 2
OP-2-5114A-29	Flow Diagram Non-Essential Service Water
2-NSW-130	Upper Containment Ventilation Unit 1 Supply Line
2-NSW-131	Upper Containment Ventilation Unit 2 Supply Line
2-NSW-132	Upper Containment Ventilation Unit 3 Supply Line
2-NSW-133	Upper Containment Ventilation Unit 4 Supply Line
2-NSW-138	Upper Containment Ventilation Unit 1 Return Line
2-NSW-139	Upper Containment Ventilation Unit 2 Return Line
2-NSW-140	Upper Containment Ventilation Unit 3 Return Line
2-NSW-141	Upper Containment Ventilation Unit 4 Return Line
2-NSW-186	Instrument Room Ventilation Unit 3 Supply Line
2-NSW-187	Instrument Room Ventilation Unit 4 Supply Line
2-NSW-188	Instrument Room Ventilation Unit 3 Return Line
2-NSW-189	Instrument Room Ventilation Unit 4 Return Line
2-NSW-192	Lower Containment Ventilation Unit 1 Supply Line
2-NSW-193	Lower Containment Ventilation Unit 2 Supply Line
2-NSW-194	Lower Containment Ventilation Unit 3 Supply Line
2-NSW-195	Lower Containment Ventilation Unit 4 Supply Line
2-NSW-196	Lower Containment Ventilation Unit 1 Return Line
2-NSW-197	Lower Containment Ventilation Unit 2 Return Line
2-NSW-198	Lower Containment Ventilation Unit 3 Return Line
2-NSW-199	Lower Containment Ventilation Unit 4 Return Line

Outside Containment

2-NSW-100	Lower Containment Ventilation Unit 2 Supply Line
2-NSW-101	Lower Containment Ventilation Unit 3 Supply Line
2-NSW-102	Upper Containment Ventilation Unit 2 Supply Line

2-NSW-105	Upper Containment Ventilation Unit 3 Supply Line
2-NSW-106	Instrument Room Ventilation Unit 3 Supply Line
2-NSW-107	Instrument Room Ventilation Unit 4 Supply Line
2-NSW-108	Upper Containment Ventilation Unit 4 Supply Line
2-NSW-111	Upper Containment Ventilation Unit 1 Supply Line
2-NSW-112	Lower Containment Ventilation Unit 1 Supply Line
2-NSW-114	Upper Containment Ventilation Unit 2 Return Line
2-NSW-115	Lower Containment Ventilation Unit 3 Return Line
2-NSW-116	Lower Containment Ventilation Unit 1 Return Line
2-NSW-117	Upper Containment Ventilation Unit 3 Return Line
2-NSW-119	Instrument Room Ventilation Unit 3 Return Line
2-NSW-120	Instrument Room Ventilation Unit 4 Return Line
2-NSW-122	Upper Containment Ventilation Unit 4 Return Line
2-NSW-123	Lower Containment Ventilation Unit 2 Return Line
2-NSW-124	Lower Containment Ventilation Unit 4 Return Line
2-NSW-125	Upper Containment Ventilation Unit 1 Return Line
2-NSW-146	Lower Containment Ventilation Unit 4 Supply Line

In accordance with the restrictions stated on drawings OP-1-5114-82, OP-1-5114A-25, OP-25114-50 and OP-2-5114A-29, Indiana Michigan Power Company (I&M) hereby releases these documents to the Nuclear Regulatory Commission (NRC) for its information and use in connection with the review of I&M's submittal. I&M also permits the NRC to reproduce the drawings as necessary to facilitate the review and distribution of the submittal to meet NRC requirements.