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		Date May 26, 1995			
Project Title/Work Order Sodium Loop Framework Structural Analysis		EDT No. 608489			
		ECN No. NA			
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P. M. Nguyen	G2-02	X			
Central Files	L8-04	X			
File (WHC-SD-TP-ANAL-003)	G2-02	X			
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JUN 06 1995 (21) ENGINEERING DATA TRANSMITTAL

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1. EDT 608489

2. To: (Receiving Organization) Packaging Engineering	3. From: (Originating Organization) Packaging Engineering	4. Related EDT No.: NA
5. Proj./Prog./Dept./Div.: 84100	6. Cog. Engr.: P. M. Nguyen B6012	7. Purchase Order No.: NA
8. Originator Remarks: For Approval and Release.		9. Equip./Component No.: NA
		10. System/Bldg./Facility: NA
11. Receiver Remarks:		12. Major Assm. Dwg. No.: NA
		13. Permit/Permit Application No.: NA
		14. Required Response Date: May 26, 1995

15. DATA TRANSMITTED					(F)	(G)	(H)	(I)
(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev. No.	(E) Title or Description of Data Transmitted	Approval Designator	Reason for Transmittal	Originator Disposition	Receiver Disposition
1	WHC-SD-TP-ANAL-003		0	Sodium Loop Framework Structural Analysis	NA KN	1;2	1;2	1;2

16. KEY									
Approval Designator (F)		Reason for Transmittal (G)				Disposition (H) & (I)			
E, S, Q, D or N/A (see WHC-CM-3-5, Sec.12.7)		1. Approval 2. Release 3. Information		4. Review 5. Post-Review 6. Dist. (Receipt Acknow. Required)		1. Approved 2. Approved w/comment 3. Disapproved w/comment		4. Reviewed no/comment 5. Reviewed w/comment 6. Receipt acknowledged	
(G)	(H)	17. SIGNATURE/DISTRIBUTION (See Approval Designator for required signatures)						(G)	(H)
Reason	Disp.	(J) Name	(K) Signature	(L) Date	(M) MSIN	(J) Name	(K) Signature	(L) Date	(M) MSIN
1;2	1;2	Cog.Eng.: PM Nguyen	<i>PM Nguyen</i>	05/23/95	G2-02				
1;2	1;2	Cog. Mgr.: JG Field	<i>JG Field</i>	5/23/95	G2-02				
		QA							
		Safety							
		Env.							
1;2	1;2	SS Shiraga	<i>SS Shiraga</i>	5/23/95	G2-02				
18.		19.				20.		21. DOE APPROVAL (if required) Ctrl. No.	
PM Nguyen <i>PM Nguyen</i> Signature of EDT Originator		Authorized Representative Date				JG Field <i>JG Field</i> Cognizant Manager		☐ Approved ☐ Approved w/comments ☐ Disapproved w/comments	

RELEASE AUTHORIZATION

Document Number: WHC-SD-TP-ANAL-003, Rev. 0

Document Title: Sodium Loop Framework Structural Analysis

Release Date: June 6, 1995

This document was reviewed following the
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APPROVED FOR PUBLIC RELEASE

WHC Information Release Administration Specialist:

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June 6, 1995

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A-6001-400.2 (09/94) WEF256

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SUPPORTING DOCUMENT1. Total Pages **42**

2. Title

Sodium Loop Framework Structural Analysis

3. Number

WHC-SD-TP-ANAL-003

4. Rev No.

0

5. Key Words

Sodium loop, sodium metal

6. Author

Name: **P. M. Nguyen***PMNguyen 05/23/95*

Signature

Organization/Charge Code **84100/B6012**

7. Abstract

This document provides the structural analysis of the Sodium Loop framework in a drop condition. The drop is similar to the U.S. Department of Transportation non-bulk, performance-oriented packaging (Packaging Group I) drop test. The drop height evaluated for the Sodium Loop framework is 5.9 ft.

8.

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SODIUM LOOP FRAMEWORK STRUCTURAL ANALYSIS

1.0 INTRODUCTION

The Sodium Loop framework is scheduled to be transported from the Hanford Site near Richland, Washington, to LM Manufacturing, Ltd., in Marysville, Washington. The framework is required to be transported in accordance with the U.S. Department of Transportation requirements. However, testing is not economically feasible; therefore, an analysis has been performed to determine the structural integrity of the framework in a drop analysis similar to the one required for Packaging Group I packaging.

2.0 SUMMARY OF RESULTS

The drop test required for Packaging Group I is defined to be a drop of 5.9 ft onto a rigid, nonresilient, flat and horizontal surface. The engineering calculation results show that the Sodium Loop framework can survive the 5.9-ft drop, as described above, using a wooden box made out of white fir acting as an overpack (see Appendix, "Calculations"). The evaluation is based on the conservative classical linear elastic methods, which addresses the dynamic loadings resulting from the drop as static equivalent loads. It is assumed that the time of the loading is relatively long, as compared to the natural period of the package. In addition, the evaluation assumed that all packaging metal materials are ductile, isotropic, homogenous, and follow Hooke's law.

The analysis was performed for the package only in the flat bottom drop situation. This position is determined to be the most unfavorable orientation for the package in accordance with the *Shock Vibration Handbook* (Harris 1988). The study analyzed the critical structural components. The components are evaluated with the deceleration loadings from the drop. The stresses are evaluated against the dynamic yield values for the materials. Acceptability of the structure is established from a positive margin of safety relative to the stress value.

Based upon the design configuration and orientation of the drop, a portion of drop loading energy is absorbed by the wood being crushed; i.e., the energy is absorbed by the crushing action of the wooden box. The crushing load is obtained by relating the wood deformation to the crushed volume and the drop energy. The load is transmitted to the framework legs. The legs are evaluated by modeling them as Euler columns. This determination is based on the ratio of the length of the column with respect to the radius of gyration of the leg. The margin of safety of the legs shows that the leg design is sufficient to withstand the drop loading.

The evaluation is performed for the pipe in which the sodium is contained. Based on the restraining method employed to minimize the movement of the pipes within the framework, it is assumed that there is banding at each

of the pipe bends. The loading for the pipe is the reaction loading produced from the drop. The pipe is modeled as a circular ring loaded by an internal static fluid weight. The margin of safety for the pipe shows that the pipe design is adequate for the loading situation.

The analysis is also performed for the Sodium Loop without the wooden box overpack. The evaluation method is similar to the one performed for the framework with the wood box overpack. The drop deceleration value is obtained in accordance with the *Shock Vibration Handbook* (Harris 1988). The evaluation result for the Sodium Loop without the wooden box overpack shows that the framework legs will buckle under the load, and the pipes containing sodium will yield with the loading from the drop. Clearly, the result demonstrates that the wooden box absorbs the majority of the drop energy, and as such, the framework and consequently the sodium pipes will not be damaged due to the loading from a drop height described above.

The framework is scheduled to be shipped one-way only; hence, the expected cyclic loading on the containment pipings is less than the cyclic loading for material with 10^3 cycles. The fatigue data for material starts at 10^3 cycles; therefore, for component with loading cycle of less than 10^3 , a fatigue analysis is not required.

The sodium pipes are expected to experience conditions well within the design pressure; therefore, pressurization analysis is not required.

It is recommended that the wooden box overpack be utilized for the Sodium Loop transport campaign.

3.0 REFERENCES

- Committee of Stainless Steel Producers - American Iron and Steel Institute, 1977, *Designers' Handbook on Stainless Steel*, Washington, D. C.
- Harris, C. M., 1988, *Shock Vibration Handbook*, Third Edition, New York, New York.
- U. S. Forest Products Laboratory, 1974, *Wood Engineering Handbook*, Englewood Cliffs, New Jersey.
- WHC, 1971a, Drawing No. H-3-35473, *HTL #1 Transient B-Pass Loop Arrangement*, Rev. 5, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1971b, Drawing No. H-3-35477, *HTL #1 Transient By-Pass Loop Enclosure Frame*, Rev. 5, Westinghouse Hanford Company, Richland, Washington.
- Young, W. C., 1989, *Roark's Formulas for Stress & Strain*, 6th edition, New York, New York.

APPENDIX
CALCULATIONS

ENGINEERING ANALYSIS

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Building Rev. 0 Job No.
Subject Weight and Center of Gravity of Sodium Heat Transfer Loop
Originator T. M. Kaufman *Teresa M. Kaufman* Date 5/03/95
Checker P. M. Nguyen *CA Nguyen* Date 5/05/95

I. Objectives:

The objective of this analysis is to determine the weight and center of gravity of the Sodium Heat Transfer Loop, Section III.

II. References:

1. ASM International, *Metals Handbook*, Volume 1, Tenth Edition, 1990.
2. Beer, Ferdinand P.; Johnston, Jr., E. Russell, *Mechanics of Materials*, McGraw-Hill, Inc., 1981.
3. WHC Drawing No. H-3-35473, "HTL #1 Transient By-Pass Loop Arrangement," H-3-35476, "HTL #1 Transient By-Pass Loop Enclosure," H-3-35477, "HTL #1 Transient By-Pass Loop Enclosure Frame," and SK-3-16218, "HTL #1 Transient By-Pass Loop Piping Details."
4. Gailey, K. D., Whitten, K. W., *General Chemistry with Qualitative Analysis*, 2nd Edition, CBS Publishing, 1984.

III. Results and Conclusions:

The weight and center of gravity calculated are estimates and are the basis for other engineering evaluations applicable to the Sodium Heat Transfer Loop. Center of gravity values are all relative to Figure 1. For conservatism, all the piping is assumed to be filled with sodium.

Total weight of the section (includes the frame, panels, piping, sodium and other miscellaneous items):

4,600 lb (2,087kg)

Center of gravity (x, y, z coordinates):

$cg_x = 4.76$ ft (1.45 m)

$cg_y = 7.93$ ft (2.42 m)

$cg_z = 3.26$ ft (approx. 1 m)

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 Checker P. M. Nguyen PMN Date 5/05/95

IV. Engineering Evaluation:

Figure 1: Schematic of Sodium Loop for Center of Gravity Calculation

Weight of Enclosure Frame:
 (Refer to Reference 3)

Elevation (front):

$$w_{pf_{L3}} = 9.4 \frac{\text{lb}}{\text{ft}}$$

L3x3x1/2 (3 each):

$$L = 168 \text{ in} \quad L = 14 \text{ ft}$$

$$w_{f1} = 3w_{pf_{L3}}L \quad w_{f1} = 394.8 \text{ lb}$$

L1 1/2x1 1/2x1/4 (3 each):

$$w_{pf_{L1.5}} = 2.34 \frac{\text{lb}}{\text{ft}} \quad L = 82 \text{ in}$$

$$w_{f2} = 3w_{pf_{L1.5}}L \quad w_{f2} = 47.97 \text{ lb}$$

$$\text{C4x5.4 (3 each): } w_{pf_{C4}} = 5.4 \frac{\text{lb}}{\text{ft}} \quad L = 114 \text{ in}$$

$$w_{f3} = 3w_{pf_{C4}}L \quad w_{f3} = 153.9 \text{ lb}$$

$$\text{C4x5.4 (1 each): } L = 86 \text{ in} \quad w_{f4} = w_{pf_{C4}}L \quad w_{f4} = 38.7 \text{ lb}$$

$$\text{C4x5.4 (1 each): } L = 12 \text{ in} \quad w_{f5} = w_{pf_{C4}}L \quad w_{f5} = 5.4 \text{ lb}$$

$$\text{C4x5.4 (1 each): } L = 16 \text{ in} \quad w_{f6} = w_{pf_{C4}}L \quad w_{f6} = 7.2 \text{ lb}$$

$$\text{Total front weight: } W_f = w_{f1} + w_{f2} + w_{f3} + w_{f4} + w_{f5} + w_{f6} \quad W_f = 647.97 \text{ lb}$$

Elevation E-E (left side):

$$\text{C4x5.4 (3 each): } L = 6 \text{ ft} \quad w_{11} = 3w_{pf_{C4}}L \quad w_{11} = 97.2 \text{ lb}$$

$$\text{L1 1/2x1 1/2x1/4 (2 each): } L = 82 \text{ in} \quad w_{12} = 2w_{pf_{L1.5}}L \quad w_{12} = 31.98 \text{ lb}$$

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 Checker P. M. Nauyen 0111 Date 5/05/95

C4x5.4 (1 each): $L = 82 \text{ in}$ $w_{13} = w_{pf_{C4}} L$ $w_{13} = 36.9 \text{ lb}$

Total weight of left side: $W_1 = w_{11} + w_{12} + w_{13}$ $W_1 = 166.08 \text{ lb}$

Elevation F-F (right side):

C4x5.4 (3 each): $L = 6 \text{ ft}$ $w_{r1} = 3w_{pf_{C4}} L$ $w_{r1} = 97.2 \text{ lb}$

L1 1/2x1 1/2x1/4 (1 each): $L = 6 \text{ ft}$ $w_{r2} = w_{pf_{L1.5}} L$ $w_{r2} = 14.04 \text{ lb}$

L1 1/2x1 1/2x1/4 (2 each): $L = 52 \text{ in}$ $w_{r3} = 2w_{pf_{L1.5}} L$ $w_{r3} = 20.28 \text{ lb}$

C4x5.4 (2 each): $L = 8 \text{ in}$ $w_{r4} = 2w_{pf_{C4}} L$ $w_{r4} = 7.2 \text{ lb}$

C4x5.4 (1 each): $L = 16 \text{ in}$ $w_{r5} = w_{pf_{C4}} L$ $w_{r5} = 7.2 \text{ lb}$

C4x5.4 (1 each): $L = 82 \text{ in}$ $w_{r6} = w_{pf_{C4}} L$ $w_{r6} = 36.9 \text{ lb}$

Total weight of right side: $W_r = w_{r1} + w_{r2} + w_{r3} + w_{r4} + w_{r5} + w_{r6}$ $W_r = 182.82 \text{ lb}$

Elevation G-G (back):

C4x5.4 (3 each): $L = 114 \text{ in}$ $w_{b1} = 3w_{pf_{C4}} L$ $w_{b1} = 153.9 \text{ lb}$

L1 1/2x1 1/2x1/4 (2 each): $L = 72 \text{ in}$ $w_{b2} = 2w_{pf_{L1.5}} L$ $w_{b2} = 28.08 \text{ lb}$

L1 1/2x1 1/2x1/4 (3 each): $L = 82 \text{ in}$ $w_{b3} = 3w_{pf_{L1.5}} L$ $w_{b3} = 47.97 \text{ lb}$

L3x3x1/2 (1 each): $L = 82 \text{ in}$ $w_{b4} = w_{pf_{L3}} L$ $w_{b4} = 64.23 \text{ lb}$

L3x3x1/2 (1 each): $L = 86 \text{ in}$ $w_{b5} = w_{pf_{L3}} L$ $w_{b5} = 67.37 \text{ lb}$

C4x5.4 (1 each): $L = 16 \text{ in}$ $w_{b6} = w_{pf_{C4}} L$ $w_{b6} = 7.2 \text{ lb}$

C4x5.4 (1 each): $L = 6 \text{ in}$ $w_{b7} = w_{pf_{C4}} L$ $w_{b7} = 2.7 \text{ lb}$

L3x3x1/2 (2 each): $L = 14 \text{ ft}$ $w_{b8} = 2w_{pf_{L3}} L$ $w_{b8} = 263.2 \text{ lb}$

Total weight of back side:

$$W_b = w_{b1} + w_{b2} + w_{b3} + w_{b4} + w_{b5} + w_{b6} + w_{b7} + w_{b8} \quad W_b = 634.65 \text{ lb}$$

Plan C-C (top):

C4x5.4 (4 each): $L = 6 \text{ ft}$ $w_{t1} = 4w_{pf_{C4}} L$ $w_{t1} = 129.6 \text{ lb}$

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$$\text{C4x5.4 (1 each):} \quad L = 3 \text{ ft} \quad w_{t2} = w_{pf_{C4}} L \quad w_{t2} = 16.2 \text{ lb}$$

$$\text{C4x5.4 (1 each):} \quad L = 57 \text{ in} \quad w_{t3} = w_{pf_{C4}} L \quad w_{t3} = 25.65 \text{ lb}$$

$$\text{C4x5.4 (1 each):} \quad L = 18 \text{ in} \quad w_{t4} = w_{pf_{C4}} L \quad w_{t4} = 8.1 \text{ lb}$$

$$\text{C4x5.4 (2 each):} \quad L = 21 \text{ in} \quad w_{t5} = w_{pf_{C4}} L \quad w_{t5} = 9.45 \text{ lb}$$

$$\text{Total weight of top side:} \quad W_t = w_{t1} + w_{t2} + w_{t3} + w_{t4} + w_{t5} \quad W_t = 189.1 \text{ lb}$$

Plan A-A (bottom):

$$\text{C4x5.4 (1 each):} \quad L = 6 \text{ ft} \quad w_{bot} = w_{pf_{C4}} L \quad w_{bot} = 32.4 \text{ lb}$$

$$\text{Plan B-B (horizontal middle):} \quad w_{pf_{L2}} = 3.19 \frac{\text{lb}}{\text{ft}}$$

$$\text{L2x2x1/4 (1 each):} \quad L = 6 \text{ ft} \quad w_{h1} = w_{pf_{L2}} L \quad w_{h1} = 19.14 \text{ lb}$$

$$\text{C4x5.4 (2 each):} \quad L = 6 \text{ ft} \quad w_{h2} = 2w_{pf_{C4}} L \quad w_{h2} = 64.8 \text{ lb}$$

$$\text{Total weight of horizontal middle section:} \quad W_h = w_{h1} + w_{h2} \quad W_h = 83.94 \text{ lb}$$

Plan D-D (vertical middle):

$$\text{L3x3x1/2 (1 each):} \quad L = 14 \text{ ft} \quad w_{v1} = w_{pf_{L3}} L \quad w_{v1} = 131.6 \text{ lb}$$

$$\text{L2x2x1/4 (3 each):} \quad L = 8 \text{ ft} \quad w_{v2} = 3w_{pf_{L2}} L \quad w_{v2} = 76.56 \text{ lb}$$

$$\text{L2x2x1/4 (2 each):} \quad L = 6 \text{ ft} \quad w_{v3} = 2w_{pf_{L2}} L \quad w_{v3} = 38.28 \text{ lb}$$

$$\text{C4x5.4 (2 each):} \quad L = 6 \text{ ft} \quad w_{v4} = 2w_{pf_{C4}} L \quad w_{v4} = 64.8 \text{ lb}$$

$$\text{L2x2x1/4 (1 each):} \quad L = 6 \text{ ft} \quad w_{v5} = w_{pf_{L2}} L \quad w_{v5} = 19.14 \text{ lb}$$

Total weight of vertical middle section:

$$W_v = w_{v1} + w_{v2} + w_{v3} + w_{v4} + w_{v5} \quad W_v = 330.38 \text{ lb}$$

Total Weight of Enclosure Frame:

$$W_{frame} = W_f + W_l + W_r + W_b + W_t + W_{bot} + W_h + W_v \quad W_{frame} = 2,267.24 \text{ lb}$$

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Enclosure Panels:
 (Refer to Reference 3 for this section)

Thickness of panels: $t = \frac{1}{16}$ in

Density of carbon steel (Reference 2): $\rho = 0.284 \frac{\text{lb}}{\text{in}^3}$

West Elevation:

W-1:	L = 42 in	h = 86 in	$w_1 = \rho L h t$	$w_1 = 64.11 \text{ lb}$
W-2:	L = 34 in	h = 86 in	$w_2 = \rho L h t$	$w_2 = 51.9 \text{ lb}$
W-3:	L = 38 in	h = 86 in	$w_3 = \rho L h t$	$w_3 = 58.01 \text{ lb}$
W-4:	L = 42 in	h = 82 in	$w_4 = \rho L h t$	$w_4 = 55.31 \text{ lb}$
W-5:	L = 4 ft	h = 82 in	$w_5 = \rho L h t$	$w_5 = 69.86 \text{ lb}$
W-6:	L = 2 ft	h = 82 in	$w_6 = \rho L h t$	$w_6 = 34.93 \text{ lb}$

Observation window:

Glass: L = 17.5 in h = 13.5 in $\rho_{\text{glass}} = 0.079 \frac{\text{lb}}{\text{in}^3}$

$$w_{\text{glass}} = \rho_{\text{glass}} L h t \quad w_{\text{glass}} = 1.17 \text{ lb}$$

Carbon steel: $w_{\text{st}} = \rho L h t$ $w_{\text{st}} = 4.19 \text{ lb}$

Total window weight: $w_{\text{win}} = w_{\text{glass}} + w_{\text{st}}$ $w_{\text{win}} = 5.36 \text{ lb}$

Bar handle: d = 0.5 in L = 6 in $w_{\text{bh}} = \frac{\pi d^2}{4} L \rho$ $w_{\text{bh}} = 0.33 \text{ lb}$

Total weight of west elevation:

$$W_w = w_1 + w_2 + w_3 + w_4 + w_5 + w_6 + w_{\text{win}} + w_{\text{bh}} \quad W_w = 339.82 \text{ lb}$$

South Elevation:

S-1:	L = 6 ft	h = 52 in	$s_1 = \rho L h t$	$s_1 = 66.46 \text{ lb}$
S-2:	L = 34 in	h = 6 ft	$s_2 = \rho L h t$	$s_2 = 43.45 \text{ lb}$
S-3:	L = 38 in	h = 62 in	$s_3 = \rho L h t$	$s_3 = 41.82 \text{ lb}$

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$$S-4: \quad L = 34 \text{ in} \quad h = 62 \text{ in} \quad s_4 = \rho L h t \quad s_4 = 37.42 \text{ lb}$$

Observation window:

$$L = 18 \text{ in} \quad h = 10 \text{ in} \quad s_{\text{glass}} = L h r \rho_{\text{glass}} \quad s_{\text{glass}} = 0.89 \text{ lb}$$

$$s_s = L h t \rho \quad s_{\text{win}} = s_{\text{glass}} + s_s \quad s_{\text{win}} = 4.08 \text{ lb}$$

Total weight of south elevation:

$$W_s = s_1 + s_2 + s_3 + s_4 + s_{\text{win}} \quad W_s = 193.23 \text{ lb}$$

East Elevation:

$$\begin{aligned} E-1: \quad L &= 42.5 \text{ in} \quad h = 86 \text{ in} \quad e_1 = \rho L h t \quad e_1 = 64.88 \text{ lb} \\ E-2: \quad L &= 6 \text{ ft} \quad h = 28 \text{ in} \quad e_2 = \rho L h t \quad e_2 = 35.78 \text{ lb} \\ E-3: \quad L &= 6 \text{ ft} \quad h = 2 \text{ ft} \quad e_3 = \rho L h t \quad e_3 = 30.67 \text{ lb} \\ E-4: \quad L &= 6 \text{ ft} \quad h = 34 \text{ in} \quad e_4 = \rho L h t \quad e_4 = 43.45 \text{ lb} \\ E-5: \quad L &= 4 \text{ ft} \quad h = 82 \text{ in} \quad e_5 = \rho L h t \quad e_5 = 69.86 \text{ lb} \\ E-6: \quad L &= 45 \text{ in} \quad h = 82 \text{ in} \quad e_6 = \rho L h t \quad e_6 = 65.5 \text{ lb} \\ E-7: \quad L &= 21 \text{ in} \quad h = 82 \text{ in} \quad e_7 = \rho L h t \quad e_7 = 30.57 \text{ lb} \end{aligned}$$

Total weight of east elevation:

$$W_e = e_1 + e_2 + e_3 + e_4 + e_5 + e_6 + e_7 \quad W_e = 340.71 \text{ lb}$$

Plan C-C:

$$\begin{aligned} T-1: \quad L &= 36 \text{ in} \quad h = 6 \text{ ft} \quad t_1 = \rho L h t \quad t_1 = 46.01 \text{ lb} \\ T-2: \quad L &= 36 \text{ in} \quad h = 3 \text{ ft} \quad t_2 = \rho L h t \quad t_2 = 23 \text{ lb} \\ T-3: \quad L &= 36 \text{ in} \quad h = 3 \text{ ft} \quad t_3 = t_2 \quad t_3 = 23 \text{ lb} \\ T-4: \quad L &= 21 \text{ in} \quad h = 3 \text{ ft} \quad t_4 = \rho L h t \quad t_4 = 13.42 \text{ lb} \\ T-5: \quad L &= 21 \text{ in} \quad h = 3 \text{ ft} \quad t_5 = t_4 \quad t_5 = 13.42 \text{ lb} \\ T-6: \quad L &= 21 \text{ in} \quad h = 6 \text{ ft} \quad t_6 = \rho L h t \quad t_6 = 26.84 \text{ lb} \end{aligned}$$

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Total weight of plan C-C:

$$W_{cc} = t_1 + t_2 + t_3 + t_4 + t_5 + t_6 \quad W_{cc} = 145.69 \text{ lb}$$

North Elevation:

N-1:	L = 34 in	h = 86 in	$n_1 = \rho L h t$	$n_1 = 51.9 \text{ lb}$
N-2:	L = 38 in	h = 86 in	$n_2 = \rho L h t$	$n_2 = 51.9 \text{ lb}$
N-3:	L = 2 ft	h = 82 in	$n_3 = \rho L h t$	$n_3 = 34.93 \text{ lb}$
N-4:	L = 2 ft	h = 82 in	$n_4 = n_3$	$n_4 = 34.93 \text{ lb}$
N-5:	L = 2 ft	h = 82 in	$n_5 = n_4$	$n_5 = 34.93 \text{ lb}$

Observation window:

$$L = 17.5 \text{ in} \quad h = 13.5 \text{ in} \quad n_{win} = w_{win} \quad n_{win} = 5.36 \text{ lb}$$

Total weight of north elevation:

$$W_n = n_1 + n_2 + n_3 + n_4 + n_5 + n_{win} \quad W_n = 220.06 \text{ lb}$$

Section D-D:

DD-1:	L = 2 ft	h = 8 ft	$dd_1 = \rho L h t$	$dd_1 = 40.9 \text{ lb}$
DD-2:	L = 14.5 in	h = 8 ft	$dd_2 = \rho L h t$	$dd_2 = 24.71 \text{ lb}$
DD-3:	L = 33.5 in	h = 8 ft	$dd_3 = \rho L h t$	$dd_3 = 57.08 \text{ lb}$
DD-4:	L = 4 ft	h = 6 ft	$dd_4 = \rho L h t$	$dd_4 = 61.34 \text{ lb}$
DD-5:	L = 2 ft	h = 6 ft	$dd_5 = \rho L h t$	$dd_5 = 30.67 \text{ lb}$

Total weight for section D-D:

$$W_{dd} = dd_1 + dd_2 + dd_3 + dd_4 + dd_5 \quad W_{dd} = 214.7 \text{ lb}$$

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Total Weight of Enclosure Panels:

$$W_{\text{panels}} = W_w + W_s + W_e + W_{cc} + W_n + W_{dd} \quad W_{\text{panels}} = 1,454.22 \text{ lb}$$

TOTAL WEIGHT OF FRAME AND PANELS:

$$W_{fp} = W_{\text{frame}} + W_{\text{panels}} \quad W_{fp} = 3,721.46 \text{ lb} \quad \text{Therefore,} \quad W_{fp} = 4,000 \text{ lb}$$

Weight of Piping:

(Refer to Reference 3 for this section)

Density of stainless steel type 304 (Reference 1): $\rho_{\text{steel}} = 0.285 \frac{\text{lb}}{\text{in}^3}$

Density of sodium (Reference 4, p. 920): $\rho_{\text{na}} = 0.035 \frac{\text{lb}}{\text{in}^3}$

Total length of item 12 pipe:

L12:

$$L_{12a} = \left(\frac{14}{16} + \frac{8}{16} + \frac{22}{16} + \frac{8}{16} + 2 + 2.5 + \frac{8}{16} + \frac{9}{16} + \frac{20}{16} + \frac{8}{16} + \frac{21}{16} + \frac{17}{16} + 1 + \frac{17}{16} + \frac{21}{16} + \frac{10}{16} + \frac{21}{16} + \frac{8}{16} \right) \text{ in}$$

$$L_{12b} = \left(\frac{36}{16} + \frac{18}{16} + \frac{19}{16} + \frac{12}{16} + \frac{37}{16} + 1 + \frac{14}{16} + \frac{4}{16} + \frac{11}{16} + \frac{29}{16} + \frac{4}{16} + \frac{4}{16} + \frac{12}{16} + \frac{14}{16} + \frac{7}{16} + \frac{22}{16} + \frac{38}{16} + \frac{4}{16} \right) \text{ in}$$

$$L_{12c} = \left(\frac{3}{16} + 1.5 + \frac{6}{16} + \frac{11}{16} + \frac{14}{16} + \frac{8}{16} + \frac{26}{16} + \frac{11}{16} + 2 + \frac{15}{16} + \frac{20}{16} + \frac{10}{16} + \frac{20}{16} + 3 + \frac{28}{16} + \frac{4}{16} + \frac{12}{16} + \frac{8}{16} \right) \text{ in}$$

$$L_{12d} = \left(1.5 + \frac{18}{16} + \frac{34}{16} + \frac{66}{16} + \frac{34}{16} + \frac{17}{16} + \frac{43}{16} + \frac{5}{16} + \frac{5}{16} \right) \text{ in}$$

$$L_{12\text{scale}} = L_{12a} + L_{12b} + L_{12c} + L_{12d} \quad L_{12\text{scale}} = 71.69 \text{ in}$$

$$L_{12} = \frac{31.1448 L_{12\text{scale}}}{1.066} \quad L_{12} = 174.54 \text{ ft}$$

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Outside diameter: $od_{12} = 1.315$ in Thickness: $t_{12} = 0.133$ in

Inside diameter: $id_{12} = od_{12} - 2t_{12}$

Volume of item 12 pipe: $V_{12} = \pi \frac{id_{12}^2}{4} L_{12}$ $V_{12} = 1,810.14$ in³

Weight of sodium: $w_{12na} = V_{12} \rho_{na}$ $w_{12na} = 63.35$ lb

Weight of item 12 pipe:

$$w_{12pipe} = \pi \frac{od_{12}^2 - id_{12}^2}{4} L_{12} \rho_{steel} + w_{12na} \quad w_{12pipe} = 358.16 \text{ lb}$$

Length of item 14 pipe:

L14:

$$L_{14scale} = \left(1 + \frac{19}{16} + \frac{28}{16} + 1 + \frac{33}{16} + \frac{9}{16}\right) \text{ in} \quad L_{14scale} = 7.56 \text{ in}$$

$$L_{14} = \frac{31.1448 L_{14scale}}{1.066} \quad L_{14} = 18.41 \text{ ft}$$

Outside diameter: $od_{14} = 0.84$ in Thickness: $t_{14} = 0.109$ in

Inside diameter: $id_{14} = od_{14} - 2t_{14}$

Volume of item 14 pipe: $V_{14} = \pi \frac{id_{14}^2}{4} L_{14}$ $V_{14} = 67.14$ in³

Weight of sodium: $w_{14na} = V_{14} \rho_{na}$ $w_{14na} = 2.35$ lb

Weight of item 14 pipe: $w_{14pipe} = \pi \frac{od_{14}^2 - id_{14}^2}{4} L_{14} \rho_{steel} + w_{14na}$ $w_{14pipe} = 18.11$ lb

Length of item 13 pipe: $L_{13scale} = \frac{42}{16}$ in

$$L13: \quad L_{13} = \frac{31.1448 L_{13scale}}{1.066}$$

Outside diameter: $od_{13} = 1.05$ in Thickness: $t_{13} = 0.113$ in

Inside diameter: $id_{13} = od_{13} - 2t_{13}$

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Volume of item 13 pipe: $V_{13} = \pi \frac{id_{13}^2}{4} L_{13}$ $V_{13} = 40.9 \text{ in}^3$

Weight of sodium: $w_{13na} = V_{13} \rho_{na}$ $w_{13na} = 1.43 \text{ lb}$

Weight of item 13 pipe: $w_{13pipe} = \pi \frac{od_{13}^2 - id_{13}^2}{4} L_{13} \rho_{steel} + w_{13na}$ $w_{13pipe} = 8.7 \text{ lb}$

Length of item 16 pipe: $L_{16} = \frac{31.1448 \frac{59}{16}}{1.066} \text{ in}$ Outside diameter: $od_{16} = \frac{3}{8} \text{ in}$

Thickness: $t_{16} = 0.065 \text{ in}$

Inside diameter: $id_{16} = od_{16} - 2t_{16}$

Volume of item 16 pipe: $V_{16} = \pi \frac{id_{16}^2}{4} L_{16}$ $V_{16} = 5.08 \text{ in}^3$

Weight of sodium: $w_{16na} = V_{16} \rho_{na}$ $w_{16na} = 0.18 \text{ lb}$

Weight of 16 pipes:

$w_{16pipe} = \pi \frac{od_{16}^2 - id_{16}^2}{4} L_{16} \rho_{steel} + w_{16na}$ $w_{16pipe} = 2.12 \text{ lb}$

Length of item 29 pipe: $L_{29} = (3)(2.3) \text{ in}$

Outside diameter: $od_{29} = 0.84 \text{ in}$

Thickness: $t_{29} = 0.147 \text{ in}$

Inside diameter: $id_{29} = od_{29} - 2t_{29}$

Volume of item 29 pipe: $V_{29} = \pi \frac{id_{29}^2}{4} L_{29}$ $V_{29} = 1.62 \text{ in}^3$

Weight of sodium: $w_{29na} = V_{29} \rho_{na}$ $w_{29na} = 0.06 \text{ lb}$

Weight of 29 pipe:

$w_{29pipe} = \pi \frac{od_{29}^2 - id_{29}^2}{4} L_{29} \rho_{steel} + w_{29na}$ $w_{29pipe} = 0.69 \text{ lb}$

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Total weight of piping: $W_{\text{piping}} = W_{12\text{pipe}} + W_{14\text{pipe}} + W_{13\text{pipe}} + W_{29\text{pipe}} + W_{16\text{pipe}}$

$$W_{\text{piping}} = 387.78 \text{ lb}$$

Weight of miscellaneous parts: (Refer to Reference 3 of this section)

Part #2: Heater

Outside diameter: $od_2 = 10 \text{ in}$ Thickness: $t_2 = 0.25 \text{ in}$

Length: $L_2 = 62.5 \text{ in}$

Inside diameter: $id_2 = od_2 - 2t_2$ $W_2 = \pi \frac{od_2^2 - id_2^2}{4} L_2 \rho_{\text{steel}}$

Weight of heater: $W_2 = 136.40 \text{ lb}$

Part #3: Flow meter:

Outside diameter: $od_3 = 1.315 \text{ in}$

Thickness: $t_3 = 0.133 \text{ in}$ Length: $L_3 = 1 \text{ ft}$

Inside diameter: $id_3 = od_3 - 2t_3$

$$W_3 = \pi \frac{od_3^2 - id_3^2}{4} L_3 \rho_{\text{steel}} \quad W_3 = 1.69 \text{ lb}$$

Box:

Length: $l_{b3} = 13.6 \text{ in}$ Width: $w_{b3} = 17.5 \text{ in}$

Height: $h_{b3} = 13.6 \text{ in}$ Thickness: $t_{b3} = 0.125 \text{ in}$

$$W_{3\text{box}} = [(l_{b3} + t_{b3})(w_{b3} + t_{b3})(h_{b3} + t_{b3}) - (l_{b3} w_{b3} h_{b3})] \rho_{\text{steel}} \quad W_{3\text{box}} = 23.75 \text{ lb}$$

Total weight: $W_3 = W_3 + W_{3\text{box}} \quad W_3 = 25.44 \text{ lb}$

Part #4: Flowmeter

Outside diameter: $od_4 = 1.05 \text{ in}$ Thickness: $t_4 = 0.113 \text{ in}$

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Length: $L_4 = 12$ in Inside diameter: $id_4 = od_4 - 2t_4$

$$W_4 = \pi \frac{od_4^2 - id_4^2}{4} L_4 \rho_{steel} \quad W_4 = 1.14 \text{ lb}$$

Box:

Length: $L_{b4} = 11.8$ in Width: $w_{b4} = 15.6$ in

Height: $h_{b4} = 17.5$ in Thickness: $t_{b4} = 0.125$ in

$$w_{b4} = [(L_{b4} + t_{b4})(w_{b4} + t_{b4})(h_{b4} + t_{b4}) - (L_{b4} w_{b4} h_{b4})] \rho_{steel} \quad w_{b4} = 23.84 \text{ lb}$$

Total weight: $W_4 = w_4 + w_{b4} \quad W_4 = 24.98 \text{ lb}$

Part #5: Flowmeter

Outside diameter: $od_5 = 0.84$ in Thickness: $t_5 = 0.109$ in

Length: $L_5 = 1$ ft

Inside diameter: $id_5 = od_5 - 2t_5$

$$W_5 = \pi \frac{od_5^2 - id_5^2}{4} L_5 \rho_{steel} \quad W_5 = 0.86 \text{ lb}$$

Box:

Length: $L_{b5} = 11.8$ in Width: $w_{b5} = L_{b5}$ Height: $h_{b5} = L_{b5}$

Thickness: $t_{b5} = 0.125$ in

$$w_{b5} = [(L_{b5} + t_{b5})^3 - L_{b5}^3] \rho_{steel} \quad w_{b5} = 15.04 \text{ lb}$$

Total weight: $W_5 = w_5 + w_{b5} \quad W_5 = 15.90 \text{ lb}$

Part #6: Flowmeter

Outside diameter: $od_6 = 0.54$ in Thickness: $t_6 = 0.088$ in

Length: $L_6 = 1$ ft

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Inside diameter: $id_6 = od_6 - 2t_6$

$$W_6 = \pi \frac{od_6^2 - id_6^2}{4} L_6 \rho_{steel} \quad W_6 = 0.43 \text{ lb}$$

Box: $w_{b6} = w_{b5}$ $w_{b6} = 15.04 \text{ lb}$

Total weight: $W_6 = w_6 + w_{b6}$ $W_6 = 15.47 \text{ lb}$

Part #7: Flowmeter

Box: $w_7 = w_6$ $w_{b7} = w_{b6}$ $W_7 = W_6$ $W_7 = 15.47 \text{ lb}$

Part #8: Angle Valve: (Cylinder Operated) (8 each)

$$W_8 = (8) (1.5) \text{ lb} \quad W_8 = 12 \text{ lb}$$

Part #9: Angle Valve: (Diaphragm Operated) (3 each)

$$W_9 = (3) (1.5) \text{ lb} \quad W_9 = 4.5 \text{ lb}$$

Part #10: Thermocouple: (7 each) $W_{10} = (7) (1.5) \text{ lb}$ $W_{10} = 10.5 \text{ lb}$

Part #11: Thermocouple Connector: (7 each) $W_{11} = (7) (1.5) \text{ lb}$ $W_{11} = 10.5 \text{ lb}$

Part #17: Eccentric Reducer: (2 each) $W_{17} = 2 \text{ lb}$ $W_{17} = 2 \text{ lb}$

Part #18: Eccentric Reducer: $W_{18} = 1 \text{ lb}$

Part #19: Eccentric Reducer: (2 each) $W_{19} = 2 \text{ lb}$

Part #20: Eccentric Reducer: (3 each) $W_{20} = 3 \text{ lb}$

Part #21: Elbow: (8 each)

Outside diameter: $od_{21} = 1.315 \text{ in}$ Thickness: $t_{21} = 0.133 \text{ in}$

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Inside diameter: $id_{21} = od_{21} - 2t_{21}$ Length: $L_{21} = (2) (1.84) \text{ in}$

Weight of elbow: $W_{21} = \pi \frac{od_{21}^2 - id_{21}^2}{4} L_{21} \rho_{\text{steel}} 8$ $W_{21} = 4.14 \text{ lb}$

Part #22: Elbow:

Outside diameter: $od_{22} = 1.05 \text{ in}$ Thickness: $t_{22} = 0.113 \text{ in}$

Inside diameter: $id_{22} = od_{22} - 2t_{22}$ Length: $L_{22} = (2) (1.84) \text{ in}$

Weight of elbow: $W_{22} = \pi \frac{od_{22}^2 - id_{22}^2}{4} L_{22} \rho_{\text{steel}} 8$ $W_{22} = 0.35 \text{ lb}$

Part #23: Tee BW: (8 each):

Outside diameter: $od_{23} = 1.315 \text{ in}$ Thickness: $t_{23} = 0.133 \text{ in}$

Inside diameter: $id_{23} = od_{23} - 2t_{23}$ Length:

$$L_{23} = (3.58 + 1.23) \text{ in}$$

Weight of elbow: $W_{23} = \pi \frac{od_{23}^2 - id_{23}^2}{4} L_{23} \rho_{\text{steel}} 8$ $W_{23} = 5.42 \text{ lb}$

Part #24: Tee BW:

Outside diameter: $od_{24} = 0.84 \text{ in}$ Thickness: $t_{24} = 0.109 \text{ in}$

Inside diameter: $id_{24} = od_{24} - 2t_{24}$ Length:

$$L_{24} = (2.76 + 0.9) \text{ in}$$

Weight of elbow: $W_{24} = \pi \frac{od_{24}^2 - id_{24}^2}{4} L_{24} \rho_{\text{steel}} 8$ $W_{24} = 0.68 \text{ lb}$

Part #25: Tee Reducing BW: $W_{25} = 0.5 \text{ lb}$

Part #26: Tee Reducing BW: $W_{26} = (4) (0.5) \text{ lb}$ $W_{26} = 2 \text{ lb}$

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Part #27: Cross Red:

$W_{27} = 0.5 \text{ lb}$

Part #28: Vapor Trap:

Outside diameter: $od_{28} = 4.5 \text{ in}$ Thickness: $t_{28} = 0.237 \text{ in}$

Inside diameter: $id_{28} = od_{28} - 2t_{28}$ Length: $L_{28} = 12 \text{ in}$

Weight of vapor trap: $W_{28} = \pi \frac{od_{28}^2 - id_{28}^2}{4} L_{28} \rho_{\text{steel}}$ $W_{28} = 10.86 \text{ lb}$

Part #30: Pressure Relief:

$W_{30} = 0.5 \text{ lb}$

Part #31: 180 Return BW:

Outside diameter: $od_{31} = 1.315 \text{ in}$ Thickness: $t_{31} = 0.133 \text{ in}$

Inside diameter: $id_{31} = od_{31} - 2t_{31}$ Length: $L_{31} = 2 \text{ in}$

Weight of return: $W_{31} = \pi \frac{od_{31}^2 - id_{31}^2}{4} L_{31} \rho_{\text{steel}}$ $W_{31} = 0.28 \text{ lb}$

Part #33: Bulkhead Union:

Outside diameter: $od_{33} = \frac{3}{8} \text{ in}$ Inside diameter: $id_{33} = 0.28 \text{ in}$

Length: $L_{33} = 2.45 \text{ in}$

Weight of bulkhead union: $W_{33} = \pi \frac{od_{33}^2 - id_{33}^2}{4} L_{33} \rho_{\text{steel}}$ $W_{33} = 0.03 \text{ lb}$

Part #34: 180 Return: (2 each)

Outside diameter: $od_{34} = 0.54 \text{ in}$ Thickness: $t_{34} = 0.088 \text{ in}$

Inside diameter: $id_{34} = od_{34} - 2t_{34}$ Length: $L_{34} = 2 \text{ in}$

Weight of return: $W_{34} = \pi \frac{od_{34}^2 - id_{34}^2}{4} L_{34} \rho_{\text{steel}} 2$ $W_{34} = 0.14 \text{ lb}$

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Part #35: Elbow:

Outside diameter: $od_{35} = 0.54 \text{ in}$ Thickness: $t_{35} = 0.088 \text{ in}$
 Inside diameter: $id_{35} = od_{35} - 2t_{35}$ Length: $L_{35} = 1.07 \text{ in}$
 Weight of elbow: $W_{35} = \pi \frac{od_{35}^2 - id_{35}^2}{4} L_{35} \rho_{steel} 2$ $W_{35} = 0.08 \text{ lb}$

Part #37: Surge/Mixing Tank:

Outside diameter: $od_{37} = 21.41 \text{ in}$ Thickness: $t_{37} = 0.25 \text{ in}$
 Inside diameter: $id_{37} = od_{37} - 2t_{37}$ Length: $L_{37} = 35.04 \text{ in}$
 Weight of tank: $W_{37} = \pi \frac{od_{37}^2 - id_{37}^2}{4} L_{37} \rho_{steel}$ $W_{37} = 165.96 \text{ lb}$

Part #38: Weld Conn: (2 each)

Outside diameter: $od_{38} = 0.54 \text{ in}$ Thickness: $t_{38} = 0.088 \text{ in}$
 Inside diameter: $id_{38} = od_{38} - 2t_{38}$ Length:
 $L_{38} = (1.07 + 0.78) \text{ in}$

Weight of weld conn.: $W_{38} = \pi \frac{od_{38}^2 - id_{38}^2}{4} L_{38} \rho_{steel} 2$ $W_{38} = 0.13 \text{ lb}$

Part #39: Pipe Cap: (4 each)

$W_{39} = (4) (0.5) \text{ lb}$ $W_{39} = 2 \text{ lb}$

Part #40: Pipe Cap: (2 each)

$W_{40} = (2) (0.3) \text{ lb}$ $W_{40} = 0.6 \text{ lb}$

Part #41: Pipe Cap:

$W_{41} = 0.1 \text{ lb}$

Part #42: Ball Valve:

$W_{42} = 5 \text{ lb}$

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 Originator T. M. Kaufman TMK Date 5/03/95
 Checker P. M. Nauven PMN Date 5/05/95

Part #43: Union Tee:

Outside diameter: $od_{43} = \frac{3}{8}$ in

Inside diameter: $id_{43} = 0.28$ in Length: $L_{43} = (2.4 + 0.66)$ in

Weight of union tee: $W_{43} = \pi \frac{od_{43}^2 - id_{43}^2}{4} L_{43} \rho_{steel} 2$ $W_{43} = 0.09$ lb

Part #44: Bellow Valve: (2 each) $W_{44} = (2) (0.5)$ lb $W_{44} = 1$ lb

Part #45: Valve Stem Extension:

Outside diameter: $od_{45} = \frac{3}{8}$ in

Inside diameter: $id_{45} = 0.312$ in Length: $L_{45} = 20.5$ in

Weight of union tee: $W_{45} = \pi \frac{od_{45}^2 - id_{45}^2}{4} L_{45} \rho$ $W_{45} = 0.2$ lb

Part #46: Strainer: $W_{46} = 5$ lb

Part #47: Butt Welding Hub: (4 each) $W_{47} = (4) (0.5)$ lb $W_{47} = 2$ lb

Part #48: Seal Ring: (4 each) $W_{48} = (4) (0.3)$ lb $W_{48} = 1.2$ lb

Part #49: Blind Hub: (4 each) $W_{49} = (4) (0.3)$ lb $W_{49} = 1.2$ lb

Part #50: Clamp w/ Studs: (4 each) $W_{50} = (4) (0.3)$ lb $W_{50} = 1.2$ lb

Total Weight of Miscellaneous Items:

$$W_a = W_2 + W_3 + W_4 + W_5 + W_6 + W_7 + W_8 + W_9 + W_{10} + W_{11} + W_{17} + W_{18} + W_{19} + W_{20}$$

$$W_b = W_{21} + W_{22} + W_{23} + W_{24} + W_{25} + W_{26} + W_{27} + W_{28} + W_{30} + W_{31} + W_{33} + W_{34} + W_{35}$$

$$W_c = W_{37} + W_{38} + W_{39} + W_{40} + W_{41} + W_{42} + W_{43} + W_{44} + W_{45} + W_{46} + W_{47} + W_{48} + W_{49}$$

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$$W = W_a + W_b + W_c + W_{so} \quad W = 490.3 \text{ lb}$$

Total Weight of Piping and Miscellaneous Items:

$$W_{inside} = W_{piping} + W \quad W_{inside} = 878.08 \text{ lb}$$

TOTAL WEIGHT OF NA LOOP SECTION:

$$W_{total} = W_{frame} + W_{panels} + W_{inside} \quad W_{total} = 4,599.54 \text{ lb}$$

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Center of Gravity Calculation:

Elevation (front & right side) Enclosure Frame:

$$i = 1..22$$

x_i	y_i	z_i	w_i	x_i	y_i	z_i	w_i
57	0	0	51.3	102	87	0	7.2
57	86	0	51.3	114	168	36	32.4
57	168	0	51.3	114	86	36	32.4
0	84	0	131.6	114	86	36	32.4
42	84	0	131.6	114	52	36	14.04
114	84	0	131.6	114	26	24	10.14
21	127	0	15.99	114	26	48	10.14
66	127	0	15.99	114	87	4	3.6
90	127	0	15.99	114	87	30	3.6
76	43	0	38.7	114	87	54	7.2
78	87	0	5.4	114	127	34	36.9

$$xw_i = \sum_{i=1}^{22} x_i w_i \quad xw_i = 57,070.41$$

$$yw_i = \sum_{i=1}^{22} y_i w_i \quad yw_i = 73,258.35$$

$$zw_i = \sum_{i=1}^{22} z_i w_i \quad zw_i = 6,500.52$$

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Elevation (back & top sides) Enclosure Frame:

$$j = 1..23$$

x_j	y_j	z_j	w_j	x_j	y_j	z_j	w_j
57	0	72	51.3	0	84	72	131.6
57	86	72	51.3	114	84	72	131.6
57	168	72	51.3	21	168	36	32.4
36	28	72	14.04	42	168	36	32.4
36	52	72	14.04	78	168	36	32.4
24	127	72	15.99	96	168	36	32.4
48	127	72	15.99	60	168	18	16.2
93	127	72	15.99	28.5	168	36	25.65
72	127	72	64.233	51	168	7.25	8.1
72	172	72	67.367	31.5	168	22.75	4.725
8	87	72	7.2	31.5	168	22.75	4.725
27	87	72	2.7				

$$xw_j = \sum_{j=1}^{23} x_j w_j \quad xw_j = 47,122.23$$

$$yw_j = \sum_{j=1}^{23} y_j w_j \quad yw_j = 94,712.41$$

$$zw_j = \sum_{j=1}^{23} z_j w_j \quad zw_j = 51,849.11$$

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Elevation (left, bottom, horizontal middle, & vertical middle) Enclosure Frame:

$$k = 1..19$$

x_k	y_k	z_k	w_k	x_k	y_k	z_k	w_k
0	168	36	32.4	42	84	72	131.6
0	86	36	32.4	42	48	24	25.52
0	0	36	32.4	42	48	38.5	25.52
0	127	24	15.99	42	48	54.5	25.52
0	127	48	15.99	42	132	24	19.14
0	43	34	36.9	42	132	48	19.14
42	0	36	32.4	42	168	36	32.4
42	86	36	19.14	42	0	36	32.4
78	86	36	32.4	42	96	36	19.14
96	86	36	32.4				

$$xw_k = \sum_{k=1}^{19} x_k w_k \quad xw_k = 21,678.24$$

$$yw_k = \sum_{k=1}^{19} y_k w_k \quad yw_k = 48,159.48$$

$$zw_k = \sum_{k=1}^{19} z_k w_k \quad zw_k = 26,954.28$$

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West, South, & East Elevations (front, right, & back) Enclosure Panels:

$$m = 1..22$$

x_m	y_m	z_m	w_m	x_m	y_m	z_m	w_m
21	43	0	64.113	114	117	55	41.819
59	43	0	51.901	114	117	18	37.417
95	43	0	58.007	114	106	18	0.889
21	84	0	55.309	114	106	18	4.084
66	84	0	69.864	92.75	43	72	64.876
102	84	0	34.932	36	14	72	35.784
66	71.66	0	1.166	36	40	72	30.672
66	71.66	0	5.36	36	69	72	43.452
115	60.33	0	0.335	24	127	72	69.864
114	26	36	66.456	72	127	72	65.498
114	69	36	43.452	103.5	127	72	30.565

$$xw_m = \sum_{m=1}^{22} x_m w_m \quad xw_m = 61,383.36$$

$$yw_m = \sum_{m=1}^{22} y_m w_m \quad yw_m = 64,531.82$$

$$zw_m = \sum_{m=1}^{22} z_m w_m \quad zw_m = 31,550.95$$

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Top, left, & half section Enclosure Panels and Inside Piping & Miscellaneous Items:

$$n = 1..19$$

x_n	y_n	z_n	w_n	x_n	y_n	z_n	w_n
96	168	36	46.008	0	127	12	34.932
60	168	18	23.004	0	64.08	6.75	1.166
60	168	54	23.004	0	64.08	6.75	4.193
31.5	168	54	13.419	42	48	12	40.896
31.5	168	18	13.419	42	48	31.25	24.708
10.5	168	36	26.838	42	48	55.25	57.084
0	43	55	51.901	42	132	24	61.344
0	3	19	58.007	42	132	60	30.672
0	127	60	34.932	66	112	48	878.08
0	127	36	34.932				

$$xw_n = \sum_{n=1}^{19} x_n w_n \quad xw_n = 75,275.29$$

$$yw_n = \sum_{n=1}^{19} y_n w_n \quad yw_n = 157,000$$

$$zw_n = \sum_{n=1}^{19} z_n w_n \quad zw_n = 62,887.61$$

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 Checker P. M. Nauyen 05/05/95 Date 5/05/95

CENTER OF GRAVITY:

$$CG_x = \frac{(xw_1 + xw_j + xw_k + xw_n) \text{ in-lb}}{W_{\text{total}}} \quad CG_x = 4.76 \text{ ft}$$

$$CG_y = \frac{(yw_1 + yw_j + yw_k + yw_m + yw_n) \text{ in-lb}}{W_{\text{total}}} \quad CG_y = 7.93 \text{ ft}$$

$$CG_z = \frac{(zw_1 + zw_j + zw_k + zw_m + zw_n) \text{ in-lb}}{W_{\text{total}}} \quad CG_z = 3.26 \text{ ft}$$

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 Subject Drop for Sodium Heat Transfer Loop
 Originator P. M. Nguyen PMA/nyng Date 4/28/95
 Checker S. S. Shiraga Date 5/05/95

I. Objectives:

The objective of this engineering calculation is to determine if a Sodium Loop framework package has sufficient structural integrity to withstand a drop similar to the drop test required for Packaging Group I. The drop test for Packaging Group I is defined as 5.9-ft drop onto a rigid, non-resilient, flat and horizontal surface.

II. References:

1. Harris, *Shock Vibration Handbook*, Third Edition.
2. WHC, Drawing No. H-3-35473, "HTL #1 Transient By-Pass Loop Arrangement".
3. WHC, Drawing No. H-3-35477, "HTL #1 Transient By-Pass Loop Enclosure Frame".
4. Young, *Roark's Formulas for Stress & Strain*, 6th edition.
5. Committee of Stainless Steel Producers - American Iron and Steel Institute, *Designers' Handbook on Stainless Steel*.
6. Young, *Roark's Formulas for Stress & Strain*, 4th edition.
7. U. S. Forest Products Laboratory, *Wood Engineering Handbook*.

III. Results and Conclusions:

The drop test required for Packing Group I is defined to be a drop of 5.9 ft onto a rigid, non-resilient, flat and horizontal surface. The engineering calculation results show that the Sodium Loop framework can survive the 5.9-ft drop, as described above using a wooden box made out of White fir acting as an overpack. The evaluation is based on the conservative classical linear elastic methods, which addresses the dynamic loadings resulting from the drop as static equivalent loads. It is assumed that the time of the loading is relatively long as compared to the natural period of the package. In addition, the evaluation assumed that all metal packaging materials are ductile, isotropic, homogenous, and follow Hooke's law.

The analysis was performed for the package only in the flat bottom drop situation. This position is determined to be the most unfavorable orientation for the package in accordance with, *Shock Vibration Handbook*, (Harris 1988). The study analyzed the critical structural components. The components are evaluated with the deceleration loadings from the drop. The stresses are evaluated against the dynamic yield values for the materials. Acceptability of the structure is established from a positive margin of safety relative to the stress value.

Based upon the design configuration and orientation of the drop, a portion of drop loading energy is absorbed by the wood being crushed, ie, the energy is absorbed by

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the crushing action of the wooden box. The crushing load is obtained by relating the wood deformation to the crushed volume, and the drop energy. The load is transmitted to the framework legs. The legs are evaluated by modeling them as Euler columns, this determination is based on the ratio of the length of the column with respect to the radius of gyration of the leg. The margin of safety of the legs shows that the leg design is sufficient to withstand the drop loading.

The evaluation is performed for the pipe in which the sodium is contained. Based on the restraining method employed to minimize the movement of the pipes within the framework, it is assumed that there is banding at each of the pipe bends. The loading for the pipe is the reaction loading produced from the drop. The pipe is modeled as a circular ring loaded by an internal static fluid weight. The margin of safety for the pipe shows that the pipe design is adequate for the loading situation.

The analysis is also performed for the Sodium Loop without the wooden box overpack. The evaluation method is similar to the one performed for the framework with the wood box overpack. The drop deceleration value is obtained in accordance with, *Shock Vibration Handbook*, (Harris 1988). The evaluation result for the Na Loop without the wooden box overpack, shows that the framework legs will buckle under the load, and the pipes containing Sodium will yield with the loading from the drop. Clearly, the result demonstrates that the wooden box absorbs the majority of the drop energy, and as such the framework and consequently the Sodium pipes will not be damaged due to the loading from a drop height described above.

The framework is scheduled to be shipped one-way only, hence the expected cyclic loading on the containment pipings is less than the cyclic loading for material with 10^5 cycles. The fatigue data for material starts at 10^5 cycles, therefore for component with loading cycle of less than 10^5 , a fatigue analysis is not required.

The sodium pipes are expected to experience conditions well within the design pressure during transportation, therefore pressurization analysis is not required.

It is recommended that the wooden box overpack be utilized for the Sodium Loop transport campaign.

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IV. Engineering Evaluation:

Drop calculation for the Na Loop, the calculation accounts for the wooden box outside of the Na Loop.

Package weight (Reference Weight and CG calculation): $w_{pack} = 4,600 \text{ lb}$

Largest framework (Reference H-3-35477): $14' \times 9'6" \times 6'$

Length of framework: $l_{lbox} = 14 \text{ ft}$

Width of framework: $w_{lbox} = 9 \text{ ft} + 6 \text{ in}$

Height of framework: $h_{lbox} = 6 \text{ ft}$

Area of loading: $A_{lbox} = l_{lbox} w_{lbox}$

Static loading: $\sigma_{lbox} = \frac{w_{pack}}{A_{lbox}} \quad \sigma_{lbox} = 0.24 \text{ psi}$

Drop energy at 5.9 ft drop height: $h_{drop} = 5.9 \text{ ft}$

$$Ener_{drp} = (h_{drop})w_{pack} \quad Ener_{drp} = 27,140 \text{ ft-lb}$$

Wooden box: Assume bottom drop, and wood box is made out of 2x4s and plywood:

Number of supports: $n_{wood} = 3$ Support length: $l_{wood} = 9.5 \text{ ft}$

Support width: $w_{wood} = 2 \text{ in}$ Support height: $h_{wood} = 4 \text{ in}$

Modulus of rupture (compression parallel to grain) for White fir (Reference Wood Engineering Handbook, p. 4-12):

$$E_{wrup} = 280 \text{ psi}$$

Available wood volume: $V_{wood} = n_{wood} w_{wood} h_{wood} l_{wood}$

Wood energy absorption: $Ener_{wood} = E_{wrup} V_{wood} \quad Ener_{wood} = 63,840 \text{ ft-lb}$

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Stress: Assume bottom drop. This position is determined to be the worst orientation in accordance with Shock & Vibration Handbook, Crede and Harris.

Crush volume from the package weight:

$$V_{\text{crush}} = \frac{E_{\text{ener_drop}}}{E_{\text{crush}}} \quad V_{\text{crush}} = 1,264.29 \text{ in}^3$$

Crush volume for each support: $V_{\text{crush}} = \frac{V_{\text{crush}}}{n_{\text{wood}}} \quad V_{\text{crush}} = 421.43 \text{ in}^3$

Wood deformation: $\delta_{\text{crush}} = \frac{V_{\text{crush}}}{3.4 \text{ in} \times 9.6 \text{ ft}} \quad \delta_{\text{crush}} = 0.91 \text{ in}$

Loading on the framework leg: $P_c = \frac{E_{\text{ener_drop}}}{\delta_{\text{crush}}} \quad P_c = 387,072 \text{ lb}$

Frame leg data:

Number of legs: $n_{\text{leg}} = 9$ Length of support between members: $l_{\text{leg}} = (7 \text{ ft} + 2 \text{ in})$

Cross-section area (Reference AISC): $A_{\text{leg}} = 2.75 \text{ in}^2$

Moment of inertia (Reference AISC): $I_{yy} = 2.22 \text{ in}^4 \quad I_{xx} = 2.22 \text{ in}^4$

Radius of gyration (Reference AISC): $r_{gyr} = 0.584 \text{ in}$

Modulus of elasticity: $E_{\text{leg}} = 30,000,000 \text{ psi}$

Load in each leg: $P_{\text{leg}} = \frac{P_c}{n_{\text{leg}}} \quad P_{\text{leg}} = 43,008 \text{ lb}$

Ratio of length to radius of gyration: $\text{ratio} = \frac{l_{\text{leg}}}{r_{gyr}} \quad \text{ratio} = 147.26$

Ratio >130 therefore use Euler Column equation.

Use Case 7, Roark's 6th edition, p. 679: $P_{\text{column}} = \frac{\pi^2 E_{\text{leg}} I_{xx}}{l_{\text{leg}}^2} \quad P_{\text{column}} = 88,874.48 \text{ lb}$

Margin of safety for frame leg: $MS_{\text{leg}} = \frac{P_{\text{column}}}{P_{\text{leg}}} - 1 \quad MS_{\text{leg}} = 1.07 \quad \text{OK}$

Deceleration of package: $g_{\text{pack}} = \frac{2h_{\text{drop}}}{\delta_{\text{crush}}} \quad g_{\text{pack}} = 168.29$

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Drawing scale: $\text{scale} = \frac{14}{11} \frac{\text{ft}}{\text{in}}$ $\text{scale} = 1.27 \frac{\text{ft}}{\text{in}}$

Length of pipe from scaling off the drawing:

$$l_{\text{pipe1}} = \text{scale} \left(\frac{14}{16} + \frac{8}{16} + 1 + \frac{6}{16} + \frac{8}{16} + 2 + 2 + \frac{1}{2} + \frac{9}{16} + 1 + \frac{5}{16} \right) \text{ in}$$

$$l_{\text{pipe1}} = 12.25 \text{ ft}$$

Pipe data (Reference H-3-35473):

Pipe diameter: $d_{\text{pipe1}} = 0.54 \text{ in}$ Pipe wall thickness: $t_{\text{wall1}} = 0.088 \text{ in}$

Pipe unit weight: $w_{\text{pipe1}} = 0.42 \frac{\text{lb}}{\text{ft}}$

Pipe cross sectional area: $A_{\text{pipe1}} = \frac{\pi}{4} [d_{\text{pipe1}}^2 - (d_{\text{pipe1}} - 2t_{\text{wall1}})^2]$

Pipe moment of inertia: $I_{\text{pipe1}} = \frac{\pi}{64} [d_{\text{pipe1}}^4 - (d_{\text{pipe1}} - 2t_{\text{wall1}})^4]$

Pipe weight: $w_{\text{pipe1}} = w_{\text{pipe1}} l_{\text{pipe1}}$ $w_{\text{pipe1}} = 5.14 \text{ lb}$

Loading on pipe from drop of package: $F_{\text{pipe1}} = g_{\text{pack}} w_{\text{pipe1}}$ $F_{\text{pipe1}} = 865.86 \text{ lb}$

304SS material data:

Ultimate strength: $\sigma_{\text{ult304}} = 84,000 \text{ psi}$ Yield strength: $\sigma_{\text{y304}} = 42,000 \text{ psi}$

Constant where yielding can be tolerated (Reference Shock and Vibration Handbook, Crede and Harris):

$$C = 0.5$$

Dynamic yield strength: $\sigma_{\text{dy304}} = \sigma_{\text{y304}} + C(\sigma_{\text{ult304}} - \sigma_{\text{y304}})$ $\sigma_{\text{dy304}} = 63,000 \text{ psi}$

Pipe stresses assuming banding is done at the curve of the pipe. Assume the pipe drops on its curve.

Length of pipe section between banding supports:

$$l_{\text{pidrop}} = \text{scale} 2.5 \text{ in} \quad l_{\text{pidrop}} = 3.18 \text{ ft}$$

Ratio of length to height: $\text{ratio}_{\text{lh}} = \frac{l_{\text{pidrop}}}{d_{\text{pipe1}}}$ $\text{ratio}_{\text{lh}} = 70.71$

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Ratio of length to height is more than 4, therefore maximum shear theory can be neglected.

Linear unit weight of pipe: $w_{\text{pipe1}} = g_{\text{pack}} w_{\text{pipe1}}$ $w_{\text{pipe1}} = 70.68 \frac{\text{lb}}{\text{ft}}$

Poisson's ratio for stainless steel: $\nu = 0.3$

Loading due to weight (Roark's 4th edition, Case 20):

Radius of pipe: $r_{\text{pipe1}} = \frac{d_{\text{pipe1}}}{2}$

$x = 0 \text{ deg}$

$\theta = 0 \text{ deg}$

$u = \cos(x)$

$z = \sin(x)$

Load density: $\rho_r = \frac{F_{\text{pipe1}}}{\pi r_{\text{pipe1}}^2 l_{\text{pidrop}}}$ $\rho_r = 99.02 \frac{\text{lb}}{\text{in}^3}$

Moment due to weight: $M_r = \rho_r r_{\text{pipe1}}^3 \left(\frac{1}{2} + \frac{1}{4}u - \frac{1}{2}\pi z + \frac{1}{2}xz \right)$ $M_r = 1.46 \text{ lb} \frac{\text{in}}{\text{in}}$

Tangential load due to weight:

$T_r = \rho_r r_{\text{pipe1}}^2 \left(1 + \frac{1}{4}u - \frac{1}{2}\pi z + \frac{1}{2}xz \right)$ $T_r = 9.02 \frac{\text{lb}}{\text{in}}$

Radial shear load due to weight:

$V_r = \rho_r r_{\text{pipe1}}^2 \left(1 + \frac{1}{4}u - \frac{1}{2}\pi z + \frac{1}{2}xz \right)$ $V_r = 9.02 \frac{\text{lb}}{\text{in}}$

Total moments and loads on pipe: $M_{\text{tot}} = M_r l_{\text{pidrop}}$ $M_{\text{tot}} = 4.65 \text{ lb-ft}$

$V_{\text{tot}} = V_r l_{\text{pidrop}}$ $V_{\text{tot}} = 344.52 \text{ lb}$

$T_{\text{tot}} = T_r l_{\text{pidrop}}$ $T_{\text{tot}} = 344.52 \text{ lb}$

Stresses in the pipe:

Bending stress: $\sigma_{\text{bbend}} = \frac{M_{\text{tot}} r_{\text{pipe1}}}{I_{\text{pipe1}}}$ $\sigma_{\text{bbend}} = 4,549.6 \text{ psi}$

Tangential stress: $\sigma_{\text{tbend}} = \frac{T_{\text{tot}}}{A_{\text{pipe1}}}$ $\sigma_{\text{tbend}} = 2,757.01 \text{ psi}$

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Shear stress: $\tau_{tbend} = \frac{V_{tot}}{A_{pipe1}}$ $\tau_{tbend} = 2,757.01 \text{ psi}$

Total stress: $\sigma_{tot1} = \sigma_{bbend} + \sigma_{tbend} + \tau_{tbend}$ $\sigma_{tot1} = 10,063.62 \text{ psi}$

Margin of safety: $MS_{pipe1} = \frac{\sigma_{dy104}}{\sigma_{tot1}} - 1$ $MS_{pipe1} = 5.26$ OK

Load on pipe due to the Sodium weight: Due to the Sodium relative lack of strength, conservatively model Sodium as a fluid in a pipe.

Pipe outside diameter: $op_{Na} = 0.54 \text{ in}$

Pipe wall thickness (Ref. Stainless Steel Schedule 40): $t_{sk} = 0.088 \text{ in}$

Pipe inside diameter: $ip_{Na} = op_{Na} - 2t_{sk}$

Pipe cross section area: $A_{Na} = \frac{\pi}{4}(op_{Na}^2 - ip_{Na}^2)$

Na weight over the area: $A_{smx} = \frac{\pi}{4} op_{Na}^2$

Length between supports: $L_{Na} = \text{scale } 2.5 \text{ in}$ $L_{Na} = 3.18 \text{ ft}$

Sodium density (MathCAD Standard Handbook):

$$\rho_{Na} = (0.97)(62.4) \frac{\text{lb}}{\text{ft}^3} \quad \rho_{Na} = 0.04 \frac{\text{lb}}{\text{in}^3}$$

Weight of sodium between supports: $w_{sNa} = A_{smx} L_{Na} \rho_{Na}$ $w_{sNa} = 0.306 \text{ lb}$

Weight density over the area: $\rho_{smx} = 0.04 \frac{\text{lb}}{\text{in}^3}$

Stresses due to Na, (Membrane theory, pipe filled between supports):

Location where stress is determined: $z_{Na} = \frac{L_{Na}}{2}$

Angle of evaluation: $\theta_{Na} = 180 \text{ deg}$

Tangential stress: $\sigma_t = \frac{g_{pack} \rho_{smx} z_{Na}^2}{t_{sk}} (1 - \cos(\theta_{Na}))$ $\sigma_t = 48,829 \text{ psi}$

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Longitudinal stress: $\sigma_1 = \frac{-\sigma_{\text{pack}} \rho_{\text{smr}}}{t_{\text{sk}}} \left(\frac{Z_{\text{Na}}^2}{2} \right) \cos(\theta_{\text{Na}}) + v \sigma_t$ $\sigma_1 = 2,441 \text{ psi}$

Shear stress: $\sigma_{\text{shr}} = \frac{-\sigma_{\text{pack}} \rho_{\text{smr}}}{t_{\text{sk}}} \left(\frac{Z_{\text{Na}}^2}{2} \right) \sin(\theta_{\text{Na}})$ $\sigma_{\text{shr}} = (9.35) 10^{-12} \text{ psi}$

Total stress at maximum deflection: $\sigma_{\text{tot}} = \sigma_t + \sigma_1 + \sigma_{\text{shr}}$ $\sigma_{\text{tot}} = 51,270 \text{ psi}$

Margin of safety: $MS_{\text{Naslump}} = \frac{\sigma_{\text{dy304}}}{\sigma_{\text{tot}}} - 1$ $MS_{\text{Naslump}} = 0.23$ OK

No yielding in pipe under this loading.

Drop calculation for Na Loop without wooden box:

Package weight (Reference 1): $w_{\text{pack}} = 5,000 \text{ lb}$

Largest framework (Reference H-3-35477): $14' \times 9'6" \times 6'$

Length of framework: $l_{\text{box}} = 14 \text{ ft}$

Width of framework: $w_{\text{box}} = 9 \text{ ft} + 6 \text{ in}$

Height of framework: $h_{\text{box}} = 6 \text{ ft}$

Area of loading: $A_{\text{box}} = l_{\text{box}} w_{\text{box}}$

Static loading: $\sigma_{\text{box}} = \frac{w_{\text{pack}}}{A_{\text{box}}}$ $\sigma_{\text{box}} = 0.24 \text{ psi}$

Drop loading at 5.9 ft drop height:

G-value for unyielding surface drop:

Rise time for metal container drop onto hard unyielding surface (Reference 1):

$t_z = 0.002 \text{ sec}$

Drop height: $h_1 = 5.9 \text{ ft}$ Constant: $c = 0.0128 \frac{\text{sec}^2}{\text{in}}$

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Acceleration: $g_{uny} = \sqrt{\frac{ch_1}{t_z^2}}$ $g_{uny} = 475.98$

$F_{leg} = g_{uny} W_{pack}$ $F_{leg} = 2,189,508 \text{ lb}$

Stress: Assume bottom drop.

Framework leg data:

Number of legs: $n_{leg} = 9$

Length of support between members: $l_{leg} = (7 \text{ ft} + 2 \text{ in})$

Cross section Area (Reference AISC): $A_{leg} = 2.75 \text{ in}^2$

Moment of inertia (Reference AISC): $I_{yy} = 2.22 \text{ in}^4$ $I_{xx} = 2.22 \text{ in}^4$

Radius of gyration: $r_{gyr} = 0.584 \text{ in}$

Modulus of elasticity: $E_{leg} = 30,000,000 \text{ psi}$

Load in each leg: $P_{leg} = \frac{F_{leg}}{n_{leg}}$ $P_{leg} = 264,433.33 \text{ lb}$

Ratio of length to radius of gyration: $\text{ratio} = \frac{l_{leg}}{r_{gyr}}$ $\text{ratio} = 147.26$

Ratio > 130, therefore use Euler Column equation.

Use Case 7, Roark's 6th edition, p. 679:

Leg (column) critical load: $P_{column} = \frac{\pi^2 E_{leg} I_{xx}}{l_{leg}^2}$ $P_{column} = 88,874.48 \text{ lb}$

Margin of safety for box leg: $MS_{leg} = \frac{P_{column}}{P_{leg}} - 1$ $MS_{leg} = -0.66$ NO GOOD!!

The Margin of safety shows that the legs will buckle.

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Pipe data: $\text{scale} = \frac{14}{11} \frac{\text{ft}}{\text{in}}$ $\text{scale} = 1.27 \frac{\text{ft}}{\text{in}}$ $d_{\text{pipe1}} = 0.54 \text{ in}$

$t_{\text{wall1}} = 0.088 \text{ in}$ $w_{\text{pipe1}} = 0.42 \frac{\text{lb}}{\text{ft}}$

Pipe cross sectional area: $A_{\text{pipe1}} = \frac{\pi}{4} [d_{\text{pipe1}}^2 - (d_{\text{pipe1}} - 2t_{\text{wall1}})^2]$

Pipe moment of inertia: $I_{\text{pipe1}} = \frac{\pi}{64} [d_{\text{pipe1}}^4 - (d_{\text{pipe1}} - 2t_{\text{wall1}})^4]$

$l_{\text{pipe1}} = \text{scale} \left(\frac{14}{16} + \frac{8}{16} + 1 + \frac{6}{16} + \frac{8}{16} + 2 + 2 + \frac{1}{2} + \frac{9}{16} + 1 + \frac{5}{16} \right) \text{ in}$

$l_{\text{pipe1}} = 12.25 \text{ ft}$

$v_{\text{pipe1}} = \frac{\pi}{4} [d_{\text{pipe1}}^2 - (d_{\text{pipe1}} - 2t_{\text{wall1}})^2] l_{\text{pipe1}}$ $v_{\text{pipe1}} = 18.37 \text{ in}^3$

$w_{\text{pipe1}} = w_{\text{pipe1}} l_{\text{pipe1}}$ $w_{\text{pipe1}} = 5.14 \text{ lb}$

Loading on pipe from deceleration: $F_{\text{pipe1}} = g_{\text{uncy}} w_{\text{pipe1}}$ $F_{\text{pipe1}} = 2,448.92 \text{ lb}$

304S ss material data (Reference Designers' Handbook on SSt):

Ultimate strength: $\sigma_{\text{ult304}} = 84,000 \text{ psi}$ Yield strength: $\sigma_{y304} = 42,000 \text{ psi}$

Constant where yielding can be tolerated (Reference Shock and Vibration Handbook, Crede and Harris): $C = 0.5$

Dynamic yield strength: $\sigma_{dy304} = \sigma_{y304} + C(\sigma_{\text{ult304}} - \sigma_{y304})$ $\sigma_{dy304} = 63,000 \text{ psi}$

Pipe stresses assuming that banding is done at the curve of the pipe. Assume the pipe drops on its curve.

Length of pipe section between banding supports:

$l_{\text{pdrop}} = \text{scale} (2.5 \text{ in})$ $l_{\text{pdrop}} = 3.18 \text{ ft}$

Ratio of length to height: $\text{ratio}_{\text{lh}} = \frac{l_{\text{pdrop}}}{d_{\text{pipe1}}}$ $\text{ratio}_{\text{lh}} = 70.71$

Ratio of length to height is more than 4, therefore maximum shear theory is negligible.

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Assuming banding is at the curve of the pipe:

$$W_{\text{pipe1}} = \gamma_{\text{w}} W_{\text{upipe1}} \quad W_{\text{pipe1}} = 199.91 \frac{\text{lb}}{\text{ft}}$$

Poisson's ratio of stainless steel: $\nu = 0.3$

Loading due to weight (Roark's 4th edition, Case 20):

Radius of pipe: $r_{\text{pipe1}} = \frac{d_{\text{pipe1}}}{2}$

$$x = 0 \text{ deg} \quad \theta = 0 \text{ deg} \quad u = \cos(x) \quad z = \sin(x)$$

Load density: $\rho_z = \frac{F_{\text{pipe1}}}{\pi r_{\text{pipe1}}^2 l_{\text{pidrop}}} \quad \rho_z = 280.05 \frac{\text{lb}}{\text{in}^3}$

Moment due to weight: $M_z = \rho_z r_{\text{pipe1}}^3 \left(\frac{1}{2} + \frac{1}{4}u - \frac{1}{2}\pi z + \frac{1}{2}xz \right) \quad M_z = 4.13 \text{ lb} \frac{\text{in}}{\text{in}}$

Tangential load due to weight:

$$T_z = \rho_z r_{\text{pipe1}}^2 \left(1 + \frac{1}{4}u - \frac{1}{2}\pi z + \frac{1}{2}xz \right) \quad T_z = 25.52 \frac{\text{lb}}{\text{in}}$$

Radial shear load due to weight:

$$V_z = \rho_z r_{\text{pipe1}}^2 \left(1 + \frac{1}{4}u - \frac{1}{2}\pi z + \frac{1}{2}xz \right) \quad V_z = 25.52 \frac{\text{lb}}{\text{in}}$$

Total moments and loads on pipe: $M_{\text{tot}} = M_z l_{\text{pidrop}} \quad M_{\text{tot}} = 13.15 \text{ lb-ft}$

$$V_{\text{tot}} = V_z l_{\text{pidrop}} \quad V_{\text{tot}} = 974.39 \text{ lb}$$

$$T_{\text{tot}} = T_z l_{\text{pidrop}} \quad T_{\text{tot}} = 974.39 \text{ lb}$$

Stresses in the pipe:

Bending stress: $\sigma_{\text{bbend}} = \frac{M_{\text{tot}} r_{\text{pipe1}}}{I_{\text{pipe1}}} \quad \sigma_{\text{bbend}} = 12,867.61 \text{ psi}$

Tangential stress: $\sigma_{\text{tbend}} = \frac{T_{\text{tot}}}{A_{\text{pipe1}}} \quad \sigma_{\text{tbend}} = 7,797.64 \text{ psi}$

Shear stress: $\tau_{\text{tbend}} = \frac{V_{\text{tot}}}{A_{\text{pipe1}}} \quad \tau_{\text{tbend}} = 7,797.64 \text{ psi}$

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Total stress: $\sigma_{tot1} = \sigma_{hbend} + \sigma_{tbend} + \tau_{tbend}$ $\sigma_{tot1} = 28,462.89 \text{ psi}$

Margin of safety: $MS_{pipe1} = \frac{\sigma_{dy104}}{\sigma_{tot1}} - 1$ $MS_{pipe1} = 1.21$ OK

Load on pipe due to the Sodium weight: Due to the Sodium relative lack of strength, conservatively model Sodium as a fluid in a pipe.

Pipe outside diameter: $op_{Na} = 0.54 \text{ in}$

Pipe wall thickness (Ref. Stainless Steel Schedule 40): $t_{sk} = 0.088 \text{ in}$

Pipe inside diameter: $ip_{Na} = op_{Na} - 2t_{sk}$

Pipe cross section area: $A_{Na} = \frac{\pi}{4}(op_{Na}^2 - ip_{Na}^2)$

Na weight over the area: $A_{smr} = \frac{\pi}{4} op_{Na}^2$

Length between supports: $L_{Na} = \text{scale } 2.5 \text{ in}$ $L_{Na} = 3.18 \text{ ft}$

Sodium density (MathCAD Standard Handbook):

$$\rho_{Na} = (0.97)(62.4) \frac{\text{lb}}{\text{ft}^3} \quad \rho_{Na} = 0.04 \frac{\text{lb}}{\text{in}^3}$$

Weight of sodium between supports: $w_{sNa} = A_{smr} L_{Na} \rho_{Na}$ $w_{sNa} = 0.306 \text{ lb}$

Weight density over the area: $\rho_{smr} = 0.04 \frac{\text{lb}}{\text{in}^3}$

Stresses due to Na, (Membrane theory, pipe filled between supports)

Tangential stress: $\sigma_t = \frac{g_{unv} \rho_{smr} z_{Na}^2}{t_{sk}} (1 - \cos(\theta_{Na}))$ $\sigma_t = 138,103 \text{ psi}$

Longitudinal stress: $\sigma_1 = \frac{g_{unv} \rho_{smr}}{t_{sk}} \left(\frac{z_{Na}^2}{2} \right) \cos(\theta_{Na}) + v_{\sigma_t}$ $\sigma_1 = 6,905 \text{ psi}$

Shear stress: $\sigma_{shr} = \frac{-g_{unv} \rho_{smr}}{t_{sk}} \left(\frac{z_{Na}^2}{2} \right) \sin(\theta_{Na})$ $\sigma_{shr} = (2.64) 10^{-11} \text{ psi}$

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Total stress at maximum deflection: $\sigma_{tot} = \sigma_t + \sigma_l + \sigma_{shr}$ $\sigma_{tot} = 145,008 \text{ psi}$

Margin of safety: $MS_{Naslump} = \frac{\sigma_{dy304}}{\sigma_{tot}} - 1$ $MS_{Naslump} = -0.57$ NO GOOD!!

The Margin of safety shows that the pipes will yield under this loading!