Title: Fatigue and Fracture Mechanics Evaluation of Pipe and Tube Up to 2" Nominal Size in Inert Gas or Air Systems Having a Maximum Design Pressure of 150 psig from -20°F to 120°F.

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Purpose

This calculation summarizes the methodology and results of the Fatigue and Fracture Mechanics analysis performed on pipe and tube up to 2" nominal size used in inert gas or air systems having a maximum design pressure of 150 psig and design temperature range of -20°F to 120°F.

Assumptions

1. All piping and tubing materials meet one of the following specifications:
   - ASTM A-269 TP304/TP316
   - ASTM A-312 TP304/TP316
   - ASTM A-632 TP304/TP316
   - ASTM A-53 Type S, E, F Grades A and B
   - ASTM A-120 Types S, E, F Grades A and B
   - ASTM A-179
   - ASTM A-789, UNS S32750
   - ASTM B-75
   - ASTM B-88 Types K, L, and M
   - ASTM B-210 Type 6061-T6
   - ASTM B-167, UNS N06600
   - ASTM B-338, Grade 2 Unalloyed Ti.
2. The piping and tubing operate in a temperature range of -20°F to 120°F.
3. The piping and tubing operate at or below a maximum internal pressure of 150 psig.
4. The piping and tubing wall thicknesses used in the analyses include tolerances that provide the most conservative results e.g: Actual analysis pipe and tube diameter is the specified diameter plus specified tolerance and actual analysis thickness used is the difference of nominal thickness minus thickness mill tolerance and thread depth (applicable only to piping materials) in accordance with each applicable material specification. See Ref. #19 for details.
5. The piping and tubing are subjected to non-corrosive service.
6. A semi elliptical longitudinal internal surface flaw initiates in the wall of the piping or tubing, and in a longitudinal weld if one exists.
7. Longitudinally welded piping or tubing is assumed to have the worst case weld type available for the respective specification as a conservative approach.
8. The tubing and piping does not contain any welds other than the welding performed during the fabrication of the tubing and piping.
9. The plain strain fracture toughness of the copper tubing is the point on the da/dN where the curve transitions from regime B to regime C. For more information see Ref. #17 Figure F.8.
10. The piping and tubing specified in Assumption #1 are subject to cyclic loading from internal pressures only. This calculation does not address rapid pressure fluctuation or sudden impact loadings due to rapid open-close cyclic valves or similar situations.
11. This calculation applies only to materials specified in Assumption #1 and of the sizes and thicknesess specified in Tables 1 to 19 of Ref. #19.

References

1. ASTM A-269-07a, Seamless and Welded Austenitic Stainless Steel Tubing for General Service.
2. ASTM A-312-02, Seamless and Welded Austenitic Stainless Steel Pipes.
3. ASTM A-632-04, Seamless and Welded Austenitic Stainless Steel Tubing (Small-Diameter) for General Service.
4. ASTM A-53-05, Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless.
5. ASTM A-120-84, Pipe, Steel, Black and Hot-Dipped Zinc-Coated (Galvanized) Welded and Seamless, For Ordinary Uses.
6. ASTM A-179-90a, Seamless Cold-Drawn Low Carbon Steel Heat-Exchanger and Condenser Tubes.
7. ASTM A-789-08a, Seamless and Welded Ferritic/Austenitic Stainless Steel Tubing for General Service.
8. ASTM B-75-02, Seamless Copper Tube.
9. ASTM B-88-03, Seamless Copper Water Tube.
10. ASTM B-210-04, Aluminum and Aluminum-Alloy Drawn Seamless Tubes.
11. ASTM B-167-08, Nickel-Chromium-Iron Alloys and Nickel-Chromium-Cobalt-Molybdenum Alloys Seamless Pipe and Tube.
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Discussion

This calculation determines the fatigue and fracture life in accordance with Ref. #14 and Ref. #17 for pipe and tube, up to 2 inches nominal size, in inert gas or air systems having a maximum design pressure of 150 psig from -20°F to 120°F. Fatigue and Fracture Mechanics analyses for each of the materials specified in Assumption #1 are accomplished using the ASMEHP and CLFLAW modules from Ref. #16 respectively. The Fracture Mechanics (CLFAW) analyses are accomplished by postulating a longitudinal internal surface flaw in all the materials specified in Assumption #1 and pipe sizes / wall thickness in Assumption #11. Based on the results of the surface flaw analyses another set of analyses (Through-Wall Flaw) are performed in accordance with Ref. #17 Part 9.5.2.4 on the materials that reached the critera for flaw recharacterization. The results of each of the analyses are presented below in tables and in attachments.

Fatigue Analysis

In order to perform a fatigue analysis on the piping and tubing it is necessary to identify the maximum membrane stresses induced in each piping or tubing. These stresses are calculated in the associated MAWP and Support Spacing calculation MTI-08-000831 (Ref. #19) and were used in the fatigue analysis. From the results of MTI-08-000831 calculation it is found that the developed membrane stress varies for each size, schedule, and manufacturing process: e.g. seamless or welded for each tube and pipe material and to provide conservative results only the maximum developed membrane stress amongst all sizes, schedules, and manufacturing process of each tube and/or pipe specification is used in each fatigue analysis. A summary of the membrane stress values used for each material analysis is shown in Table 1 below.

Table 1: Maximum Developed Membrane Stresses in Tube and Pipe Up to 2.0" Nominal Size

Material Specification	Max. Membrane Stress, psi	Material Specification	Max. Membrane Stress, psi
ASTM A-269 and ASTM A-632 Type 304/316	1,846	ASTM B-75	5,120
ASTM A-312 Type 304/316	4,926	ASTM B-88 Types K, L, and M	3,012
ASTM A-53 or ASTM A-120	9,657	ASTM B-210 Type 6061- T6	3,217
ASTM A-179	1,703	ASTM B-167, UNS N06600	3,941
ASTM A-789, UNS S32750	2,916	ASTM B-338, Grade 2 Unalloyed Titanium	2,912

Stress Intensity Factors:

The materials being analysed are considered cylindrical shells with no attachments and the stress intensity factors (SIF's) to be considered are due to tube bending and threads in pipe. Since a value of 2.3 SIF due to pipe threads (Ref. #13 Appendix D) is more conservative, it will be used in all the materials being analyzed for conservatism.

The calculated membrane stresses from Ref. #19 (shown in Table 1) and SIF of 2.3 are entered into the ASMEHP module of Ref. #16. This module performs a fatigue analysis based on the input parameters in accordance with Ref. #14, Appendices 4 and 5. In the case for aluminum tubing fatigue analysis, the referenced module performs the analysis using Battelle Joint Fatigue Curves. These curves were used since there are no ASME fatigue curves currently available for aluminum within Ref. #16. The Battelle Fatigue Curves were developed by researchers at Battelle Memorial Institute using actual test data, and have beein incorporated into the latest edition of ASME B&PV Code Section VIII Division 2. The results of the fatigue analyses are presented in detail in Attachments #1 through #10 and summarized in Table 2 below.

Table 2: Permissible Design Cycles Based On Fatigue Analysis

Material Specification	Max. Number of Cycles	Material Specification	Max. Number of Cycles
ASTM A-269 and ASTM A-632 Type 304/316	100,000,000,000	ASTM B-75	1,000,000
ASTM A-312 Type 304/316	100,000,000,000	ASTM B-88 Types K, L and M	1,000,000
ASTM A-53 or ASTM A-120	5,590,000	ASTM B-210 Type 6061- T6	8,250
ASTM A-179	100,000,000,000	ASTM B-167, UNS N06600	100,000,000,000
ASTM A-789, UNS S32750	100,000,000,000	ASTM B-338, Grade 2 Unalloyed Titanium	100,000,000,000

Based on the results of the analyses shown in Table 2 and Attachments #1 through #10, aluminum tubing (ASTM B-210 6061-T6) has a fatigue life of 8,250 cycles, copper tubing (ASTM B-75 and B-88 Types K, L, and M) has a fatigue life of 1,000,000 cycles, carbon steel pipe (ASTM A-53 and ASTM A-120) has a fatigue life of 5,590,000 cycles and the other pipe and tubing materials have a fatigue life of 1E11 cycles.

Fracture Mechanics Analysis

Fracture Mechanics Analyses are performed to determine the safe remaining life of the various materials and sizes of piping and tubing assuming a flaw developed in a longitudinal direction in the wall or longitudinal weld, if applicable. VCESage CLFLAW Analysis (Ref. #16) is used to evaluate the postulated longitudinal internal surface flaw for each material specification. For material specifications that apply to both seamless and longitudinally welded tubing and/or piping, the analysis is performed only for the welded tubing and/or piping to obtain conservative results.

The postulated flaw sizes for each material specification were determined in accordance with API 579 (Ref. #17). There are numerous inputs that need entered into the CLFLAW module of the VCESage software package for an accurate evaluation. Each critical value and the rationale behind the selection or modification are described below.

1. The depth of the crack (a) is postulated, in accordance with API 579, to be ¼ thru-wall thickness.
2. The a/c ratio is 0.33 and is taken from API 579, Part 9.1.2.2, which states that the crack length (2C) is equal to 6 times the depth (a).
3. The membrane stress values used in each of the analyses vary for each material type, size, schedule, and manufacturing process. For specifications that apply to seamless and welded pipe and/or tube materials, only the welded condition is analyzed for conservatism. The membrane stress values used in each analysis are shown in Tables 1 to 19 of Ref. #19 for each material specification. Stainless steel tube and pipe specifications ASTM A-269/632/312 TP 304/316, carbon steel tube specification ASTM A-179, ferritic/austenitic stainless steel tube ASTM A-789, and nickel-chromium-iron alloy pipe and tube ASTM B-167 analyses are all run using only the maximum membrane stress developed amongst all sizes, schedules and in the welded condition, if applicable, for conservatism. The remaining specifications are run using the actual membrane stress for the material, size, schedule, and welded (if applicable) condition being evaluated.

4. For the fatigue crack growth rate in the piping and tubing, the Paris Law was used. The fatigue crack growth material properties were determined from various sources and are shown in Table 3, below:

Table 3: Paris Law Constants

Material Specification	n	C	Source
ASTM A-269, ASTM A-312, and ASTM A-632 TP 304/316	3.00	8.61e-10	Ref. #17, Annex F.5.3.2a
ASTM A-53 or ASTM A-120	3.00	8.61e-10	Ref. #17, Annex F.5.3.2a
ASTM A-179	3.00	3.60e-10	Ref. #25, Pg. 634, Fig. 40
ASTM A-789, UNS S32750	3.25	8.00e-10	Ref. #25, Pg. 760, Fig. 8 (See Attach. #14)
ASTM B-75 and ASTM B-88 Types K, L, and M	3.20	5.00e-09	Ref. #21, Pg. 235, Fig. 3 (See Attach. #15)
ASTM B-210 Type 6061-T6	2.30	9.00e-08	Ref. #20 (Mat. Property ID: M6AB32WD1, 6061-T6 Extr; T-L; SW)
ASTM B-167, UNS N06600	4.36	1.00e-11	Ref. #23, Pg. 6, Fig. 1a (See Attach. #16)
ASTM B-338, Grade 2 Unalloyed Titanium	5.76	4.00e-08	Ref. #25, Pg. 846, Fig. 37 (See Attach. #17)

5. The lower bound fracture toughness, K_{IC}, used in each of the analyses was determined from various sources as indicated in Table 4, below:

Table 4: K_{IC} Values and Sources

Material Specification	K_{IC} ($ksi\sqrt{in}$)	Source
ASTM A-269, ASTM A-312, and ASTM A-632 TP 304/316	120.0	Ref. #17, Annex F.4.8
ASTM A-53 or ASTM A-120	57.3	Ref. #25, Pg. 621, Table 4
ASTM A-179	67.2	Ref. #25, Pg. 630, Fig. 28a @ 70°F and Ref. #17, Annex F.4.5.2a2. (See Attach. #18)
ASTM A-789, UNS S32750	107.8	Ref. #24, Pg. 3, Table 3 @ 20°C and Ref. #17, Annex F.4.5.2a2. (See Attach. #18)
ASTM B-75 and ASTM B-88 Types K, L, and M	13.5	Ref. #21, Pg. 235 and Assumption #9
ASTM B-210 Type 6061-T6	27.0	Ref. #20 (Mat. Property ID: M6AB32WD1, 6061-T6 Extr; T-L; SW)
ASTM B-167, UNS N06600	100	Ref. #20 (Mat. Property ID: Q3AB10AB1, Inconel 600 Sht Plt; Ann/SR; 75°F)
ASTM B-338, Grade 2 Unalloyed Titanium	60.1	Ref. #27

Residual Stresses

Welded piping and tubing is assumed to be welded with the worst case weld type available for the specification as a conservative approach (Assumption # 7). Therefore, the residual stresses for the postulated longitudinal flaws in welded piping and tubing are considered perpendicular to the flaw. These stress distributions were determined by the VCESage program in accordance with Ref. #17, Annex E. There are no residual stresses for any of the seamless piping or tubing.

Crack Growth Results

The crack growth results of the postulated longitudinal surface flaws are presented in Attachment #11, Part A and Part B for each material and pipe size. Part A summarizes the results in a table format for each material specification, and Part B shows the results in detail as determined using the CLFLAW module from Ref. #16. The postulated longitudinal surface flaws for materials listed below did not reach critical flaw size or reach the criteria for recharacterization to a thru-wall flaw over the course of 10,000,000 cycles for all the pipe/tube sizes and wall thicknesses evaluated.

- ASTM A-269 TP 304/316
- ASTM A-632 TP 304/316
- ASTM A-312 TP 304/316
- ASTM A-179
- ASTM A-789, UNS S32750
- ASTM B-88 Types K, L, and M
- ASTM B-167, UNS N06600
- ASTM B-338, Grade 2 Unalloyed Titanium

The postulated longitudinal surface flaws for materials of the specifications: ASTM A-53, ASTM A-120, ASTM B-75, and ASTM B-210 did not reach critical flaw size or reach the criteria for recharacterization to a thru-wall flaw over the course of 10,000,000 cycles, for the majority of the pipe/tube sizes and wall thicknesses evaluated. The pipe/tube sizes and wall thicknesses that did not reach 10,000,000 cycles are shown below in Table 5. The results pertinent to the Postulated Surface Flaw Analyses in Table 5 are shown in Column 4 (Cycles to Through Wall Transition) and Column 5 (C after transition). Column 4 shows the number of cycles it takes for the postulated longitudinal surface flaw to become a thru-wall flaw, and Column 5 shows the length of the flaw when it becomes thru wall.

Table 5 - Postulated Longitudinal Surface Flaw and Through-Wall Flaw Analyses

Material	Nominal Tube / Pipe Size	Nominal Wall Thickness (in)	Cycles to Through-Wall Transition	C after transition (in)	$2C_{LBB}$ (in)	Cycles to Critical Flaw Size After Through-Wall Transition	$2C_{crit}$ (in)
ASTM A-53 and ASTM A-120	1 (pipe)	0.114	4,620,000	0.0236	0.0851	506,500	0.4136
	1 ¼ (pipe)	0.117	3,100,000	0.0266	0.0961	357,600	0.4186
	1 ½ (pipe)	0.125	4,060,000	0.0348	0.1255	433,300	0.5304
	2 (pipe)	0.141	4,300,000	0.0463	0.1673	437,100	0.6464
	2 (pipe)	0.154	8,460,000	0.0605	0.2185	744,000	0.8072
ASTM B-75	1 ½ (tube)	0.032	7,930,000	0.0360	0.1300	525,200	0.4368
	2 (tube)	0.032	3,110,000	0.0360	0.1300	212,000	0.3096
ASTM B-210 Type 6061-T6	½	0.035	6,000,000	0.0405	0.1470	2,112,000	6.6*
	5/8	0.035	3,460,000	0.0405	0.1470	1,185,000	6.6*
	5/8	0.049	7,500,000	0.0564	0.2048	2,701,000	9.2*
	¾	0.035	2,238,000	0.0405	0.1470	763,800	6.6*
	¾	0.049	4,800,000	0.0564	0.2048	1,661,000	9.2*
	¾	0.065	9,240,000	0.0746	0.2712	3,445,000	12.2*
	7/8	0.049	3,310,000	0.0566	0.2052	1,125,000	9.2*
	7/8	0.065	6,320,000	0.0748	0.2716	2,248,000	12.2*
	1	0.035	1,129,000	0.0406	0.1472	395,700	6.6*
	1	0.049	2,400,000	0.0565	0.2050	814,200	9.2*
	1	0.058	3,460,000	0.0664	0.2408	1,179,000	10.8*
	1	0.065	4,560,000	0.0748	0.2716	1,582,000	12.2*
	1	0.083	8,330,000	0.0968	0.3516	3,071,000	15.8*
	1 ¼	0.065	2,650,000	0.0750	0.2720	900,000	12.2*
	1 ¼	0.083	4,790,000	0.0969	0.3518	1,670,000	15.8*
	1 ½	0.065	1,710,000	0.0750	0.2720	583,600	12.2*
	1 ½	0.125	7,940,000	0.1457	0.5294	2,935,000	23.8*
	1 ¾	0.125	5,430,000	0.1458	0.5296	1,921,000	23.8*
	2	0.049	462,100	0.0568	0.2056	146,900	3.98
	2	0.065	861,900	0.0751	0.2722	262,800	7.5
	2	0.125	3,910,000	0.1459	0.5298	1,351,000	23.8*

* The flaw did not reach critical flaw size during the evaluation, the analysis terminated since the flaw length reached the maximum flaw length limitation (100x wall thickness) within the analysis software (Ref. #16).

In the cases where the postulated longitudinal surface flaw analyses terminated prior to 10,000,000 cycles, the flaw propagated through 80% of wall thickness, where the flaws were recharacterized as a through-wall flaw in accordance with Ref. #17, Part 9.5.2.4, with a subsequent crack growth analysis (Leak Before Break) performed to determine the remaining life after transitioning to a through-wall flaw. The results of the through-wall flaw analyses are presented in detail in Attachment #12 and summarized in Table 5, Column 7 (Cycles to Critical Flaw Size After Through-Wall Transition) and Column 8 ($2C_{crit}$).

Leakage of postulated flaw after transition to through-wall flaw

Determine Crack Opening Area (Ref. #17)

For the through-wall flaw (leak before break) analyses to be valid, the leakage of the inert gas or air from the longitudinal through-wall flaw must be detectable as required by API 579, Part 9.5.2.2(a). Therefore, to determine if the through-wall flaw analyses are valid, the leak rate from the smallest flaw size that transitions to a through-wall flaw (1"Nominal Size x 0.114" wall, 2C = 0.0851 inches, for ASTM A-53/120) is determined and compared with various leak detection methods.

The crack opening area (COA) is determined in accordance with API 579, Annex K. The COA is determined assuming pneumatic leak testing is performed in accordance with ASME B31.3, para. 345.5 (Ref. #13) and the pressure system being considered operates at a minimum of 50 PSIG. Therefore the initial leak test pressure will be 25 PSIG at a minimum and will be used to determine the COA. The resulting COA for a through wall flaw in 1" Nominal Size x 0.114" wall pipe having a flaw length of 2C = 0.0851" was 3.25E-7 in^2 on the ID (A_1) and 3.34E-7 in^2 on the OD (A_2). The details of determining the COA can be found in Attachment #13.

Determine Crack Leak Rate (Ref. #29)

Reference #29 was used to determine a methodology for determining the crack flow rate (Q) based on transforming the COA's into rectangular cross sections. The inner and outer cross sectional areas (A_1 and A_2), the through-wall crack depth (D), and through-wall crack length (L) were used to determine the mean crack width (W) and crack divergence factor (d). See tables 6 and 7 for the values of each of the parameters required to determine flow rate (Q) through the COA.

Table 6 – Required Parameters for Determining Flow Rate Through COA

Description	Symbol	Value	Units	Equation	Equation # (Ref. #29)*
COA inlet	A_1	3.25E-07	in^2	-	-
COA outlet	A_2	3.34E-07	in^2	-	-
Through Crack Length	L	0.0851	in	-	-
Crack Width Inlet	w_1	3.82E-06	in	A_1/L	-
Crack Width Outlet	w_2	3.93E-06	in	A_2/L	-
Mean Crack Width Outlet	W	3.87E-06	in	$(w_1+w_2)/2$	*1b*
Crack Divergence Parameter	d	0.0143	unit less	$(w_2-w_1)/2W$	*1a*

*If applicable

The discharge coefficient (C_D) was then determined based on the friction number (F), which is dependent on the friction factor (f), the mean crack width (W) and the through-wall crack depth (D). The friction factor (f) is assumed to be 1.0, the upper bound on the friction factor which yields lower, more conservative, leak rate estimates as described in Part 6 of Ref. #29. Once the friction number (F) is determined, it is compared with the friction number limits (F_1 and F_2) to determine the analytical approximation (C_{DA}) to C_D.

Table 7 – Required Parameters for Determining Flow Rate Through COA (Continuation of Table 6)

Description	Symbol	Value	Units	Equation	Equation # (Ref. #29)*
Through Crack Depth	D	0.0189675	In	-	-
Friction factor	f	1	Unit less	-	-
Mean Crack Width Outlet	W	3.87E-06	in	-	-
Friction Number	F	2.04E-04	unit less	fW/D	3
Pressure inside tube or pipe	P_1	39.7	psia	-	-
Pressure outside tube or pipe	P_2	14.7	psia	-	-
Polytropic index	n	1	unitless	-	-
Friction Number Limits	F_1	1.18	unitless	$[n/(n+1)]*(1.5+2.5d)^2$	28a
	F_2	1.379	unitless	$[(1-d)(P_1/P_2^{(n+1)/2n})-n^{1/2}]^2/(n+1)$	28b
Discharge Coefficient	$C_D=C_{DA}$	0.394	unitless	$0.4(1-d)$	27a

Once the discharge coefficient was determined, the crack flow rate (Q) is determined using equation 2 of Ref. #29. The crack flow rate calculation is presented in tables 8 and 9 below:

Table 8 – Calculated Volumetric Flow Rate Through COA

Description	Symbol	Value	Units	Equation	Equation # (Ref. #29)*
Pressure inside tube	P_1	39.7	psia	-	-
Temperature	T	530	°R	-	-
Universal Gas Constant	R_{uni}	1545	ft-lbf/lbmole-°R	-	-
Molecular Weight	M	Varies, See Table 9	lbm/lbmole	-	-
Gas Constant	R	Varies, See Table 9	ft-lbf/lbm-°R	R_{uni}/M	-
Density	ρ_1	Varies, See Table 9	lbm/ft^3	P/RT	-
Density at STP	ρ_{STP}	Varies, See Table 9	lbm/ft^3	$14.7PSIA/(R^{\mp}*520°R)*144$	-
Crack flow rate	Q	Varies, See Table 9	lbm/sec	$C_DLW(P_1\rho_1)^{(1/2)}$	2
Volumetric Flow rate	V	0.044, See Table 9	sccs	$Q/\rho_{STP}*(28316cm^3/ft^3)$	-

∓ Units: ft-lbf/lbm-°R

Table 9 – Volumetric Flow Rate Through COA for Various Gases

	Nitrogen	Air	Argon	Helium	Neon	Xenon	Radon	Krypton
C_{DA}	0.394	0.394	0.394	0.394	0.394	0.394	0.394	0.394
L	0.0851	0.0851	0.0851	0.0851	0.0851	0.0851	0.0851	0.0851
W	3.87E-06	3.87E-06	3.87E-06	3.87E-06	3.87E-06	3.87E-06	3.87E-06	3.87E-06
M	28.013	28.975	39.95	4	20.18	131.29	222	83.8
R	55.15	53.32	38.67	386.25	76.56	11.77	6.96	18.44
ρ_1	0.196	0.202	0.279	0.028	0.141	0.917	1.550	0.585
Q	1.13E-07	1.17E-07	1.61E-07	1.61E-08	8.13E-08	5.29E-07	8.94E-07	3.38E-07
V	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044

Per Ref. #30, a leak rate of 0.044 sccs, as shown in Table 9 would be detectable with a pressure decay or bubble immersion test (leak test solution). Therefore, the conditions specified in API 579, Part 9.5.2.2(a), would be satisfied, provided pneumatic or bubble leak testing is performed on a regular interval.

Conclusions

Based on the above analyses, all of the listed materials specified in Assumption #1 with sizes up to 2" nominal size for piping and 2" outer diameter for tubing in inert gas or air systems with a maximum internal design pressure of 150 PSIG from -20°F to 120°F have a minimum fatigue life of: 8,250 operational cylces for ASTM B-210 6061-T6, 1,000,000 operational cycles for ASTM B-75 and B-88 Types K, L, and M, 5,590,000 operational cycles for ASTM A-53 and ASTM A-120 and 100,000,000,000 operational cycles for all other materials specified in Assumption #1. Furthermore, the safe remaining fracture life and leak before break criteria of the specified piping and tubing materials can be estimated for internal design pressures up to 150 PSIG from -20°F to 120°F using the results presented in Attachments #11 and #12, and provided the conditions specified in Ref. #17, Part 9.5.2.2, are met. Therefore, all the materials with sizes up to 2" nominal size for piping and 2" outer diameter for tubing specified in Assumption #1 are acceptable for use without further inspection for degregation due to fatigue or fracture under the cyclic limits of Assumption #10 and as presented in the results of this calculation if used in air or inert gas service up to 150 psig internal pressure over the temperature range -20°F to 120°F. Additional tube/pipe supporting criteria of Ref. #19 must also be met so cyclic loading is mostly pressure induced "hoop" stress as this calculation assumes.

ATTACHMENTS #1 to #10
MATERIAL FATIGUE LIFE ANALYSES

ATTACHMENT #1
ASTM A-269 and A-632 TP 304/316 Stainless Steel Tube Fatigue Analysis

```
$MTI-08-000832, Fatigue Analysis
 $ATT#1
 $A-269 Stainless Steel Tubing
 $
 ASMEHP
 $
 $  ASMEHP Analysis Module
 $
 $
 $  Option Keywords
 $
 CODE{ b31.3, , api579}
 $
 $  Design Condition Keywords
 $
 stemp=120.0, safact=1.0,
 SPEC{ a269, tp304, 2002, s30400, ---, ---}
 fcurve=asme, fimprove=none,
 scf=2.30, pm=1846.0,
 $
 Term

                    *** VCESage - ASMEHP Analysis Module ***
              *** Analysis Time & Date: 12:24:42, March 6, 2009 ***


          ------------------------------------------------------------

                      User Message - Program Unit: MATL_DB_RD

            MESSAGE - The VCESage Materials Database is being
            read from the following file:

            C:\PROGRA~2
              \VCESAG~1
              \material_database
              \vcesage_materials.txt

            ==> Database Created - DATE: October 27, 2006; TIME: 08:29:03;

            ==> Number of materials - 16968

          ------------------------------------------------------------

        -- Stress Classification per the ASME Code, Section VIII, Div. 2 --


                                  -- Design Code --
 Design Code. . . . . . . . . . . . . . Code(1) = B31.3
 Design Code Year. . . . . . . . . . . . Code(2) = 2002
 FFS Code. . . . . . . . . . . . . . . . Code(3) = API579

                              -- General Input Data --
 Design temperature. . . . . . . . . . . . STEMP =   120.0000  (F)
 Load factor. . . . . . . . . . . . . . . SAFACT =     1.0000
 Stress concentration factor. . . . . . . .  SCF =     2.3000

                               -- Material Data --
 Material specification. . . . . . . .   SPEC(1) =   A269
 Material grade. . . . . . . . . . . .   SPEC(2) =   TP304
 Year. . . . . . . . . . . . . . . . .   SPEC(3) =   2002
 UNS identification. . . . . . . . . .   SPEC(4) =   S30400
 Generic Material designation. . . . . .  GENMAT = HA:T304
 Minimum ultimate tensile strength. . .  UTS_MIN =  75000.000  (psi)
 Minimum yield strength. . . . . . . .  YS_MIN =  30000.000  (psi)
 Young's Modulus: ambient temperature. .  EY_AMB =  2.826E+07  (psi)
 Young's Modulus: design temperature. . . . . EY =  2.799E+07  (psi)
 Possion's ratio. . . . . . . . . . . . . . NU =     0.3000

                        -- Specified Stress Intensities --
 Primary Membrane. . . . . . . . . . . . . .  Pm =  1846.0000  (psi)
 Local membrane + primary bending. . . . . Pl+Pb =  1846.0000  (psi)
 Peak. . . . . . . . . . . . . . . . . . . . . F =  2399.7998  (psi)


                        -- Code Compliance Verification --
                  -- ASME B31.3 Piping Code - Extensions: API579 --

                Description                    Computed    Allowable     Notes
                                                 (psi)       (psi)
 ----------------------------------------  ----------  ----------  ----------
 Pm stress intensity                        1846.0000   20000.000      Ok
 Pl + Pb stress intensity                   1846.0000   30000.000      Ok
 Pl + Pb + Q stress intensity               1846.0000   60000.000      Ok
 ----------------------------------------  ----------  ----------  ----------

        -- Fatigue Analysis, ASME Code Section VIII, Div. 2, Appendix 5 --
           -- ASME Code Section VIII, Division 2 Design Fatigue Curve --
                          -- Figure 5-110.2.2, Curve B --
 Design fatigue curve identification. . . FCURVE = 110.2.2B
 Peak Stress Intensity = (Pl+Pb+Q+F). . . PlPbQF =  4245.7998  (psi)
 Ratio of Youngs Modulus. . . . . . . . . ERATIO =     1.0111
 Salt = 0.5*(Pl+Pb+Q+F)*ERATIO. . . . . . . Salt =  2146.5066  (psi)
 Permissible design cycles. . . . . . .  NCYCLES =  1.000E+11


                        *** ASMEHP Module Analysis Complete ***
                           *** CPU Time: 0.5312 Seconds ***

 $

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                  *** Shaker Heights, Ohio & Houston, Texas USA ***
```

ATTACHMENT #2
ASTM A-312 Stainless Steel Pipe Fatigue Analysis

```
$MTI-08-000832, Fatigue Analysis
 $ATT#2
 $A-312, Seamless Stainless Steel
 $
 ASMEHP
 $
 $  ASMEHP Analysis Module
 $
 $
 $  Option Keywords
 $
 CODE{ b31.3, , api579}
 $
 $  Design Condition Keywords
 $
 stemp=120.0,
 SPEC{ a312, tp304, 1993, s30400, ---, ---}
 fcurve=asme, fimprove=none,
 scf=2.30, pm=4926.0,
 $
 Term

                    *** VCESage - ASMEHP Analysis Module ***
              *** Analysis Time & Date: 12:26:56, March 6, 2009 ***


       -- Stress Classification per the ASME Code, Section VIII, Div. 2 --


                              -- Design Code --
 Design Code. . . . . . . . . . . . . . . Code(1) = B31.3
 Design Code Year. . . . . . . . . . . . Code(2) = 2002
 FFS Code. . . . . . . . . . . . . . . . Code(3) = API579

                           -- General Input Data --
 Design temperature. . . . . . . . . . . . STEMP =   120.0000  (F)
 Load factor. . . . . . . . . . . . . . . SAFACT =     1.0000
 Stress concentration factor. . . . . . . .  SCF =     2.3000

                             -- Material Data --
 Material specification. . . . . . . .   SPEC(1) =   A312
 Material grade. . . . . . . . . . . .   SPEC(2) =   TP304
 Year. . . . . . . . . . . . . . . . .   SPEC(3) =   1993
 UNS identification. . . . . . . . . .   SPEC(4) =   S30400
 Generic Material designation. . . . . .  GENMAT = HA:T304
 Minimum ultimate tensile strength. . .  UTS_MIN =  75000.000  (psi)
 Minimum yield strength. . . . . . . .  YS_MIN =  30000.000  (psi)
 Young's Modulus: ambient temperature. .  EY_AMB =  2.826E+07  (psi)
 Young's Modulus: design temperature. . . . . EY =  2.799E+07  (psi)
 Possion's ratio. . . . . . . . . . . . . . . NU =     0.3000

                       -- Specified Stress Intensities --
 Primary Membrane. . . . . . . . . . . . . .  Pm =  4926.0000  (psi)
 Local membrane + primary bending. . . . . Pl+Pb =  4926.0000  (psi)
 Peak. . . . . . . . . . . . . . . . . . . . . F =  6403.7998  (psi)


                       -- Code Compliance Verification --
                 -- ASME B31.3 Piping Code - Extensions: API579 --

                Description                   Computed    Allowable     Notes
                                                (psi)       (psi)
 ----------------------------------------  ----------  ----------  ----------
 Pm stress intensity                        4926.0000   20000.000      Ok
 Pl + Pb stress intensity                   4926.0000   30000.000      Ok
 Pl + Pb + Q stress intensity               4926.0000   60000.000      Ok
 ----------------------------------------  ----------  ----------  ----------

       -- Fatigue Analysis, ASME Code Section VIII, Div. 2, Appendix 5 --
          -- ASME Code Section VIII, Division 2 Design Fatigue Curve --
                          -- Figure 5-110.2.2, Curve B --
 Design fatigue curve identification. . . FCURVE = 110.2.2B
 Peak Stress Intensity = (Pl+Pb+Q+F). . . PlPbQF =  11329.800  (psi)
 Ratio of Youngs Modulus. . . . . . . . . ERATIO =     1.0111
 Salt = 0.5*(Pl+Pb+Q+F)*ERATIO. . . . . . . Salt =  5727.8936  (psi)
 Permissible design cycles. . . . . . .  NCYCLES =  1.000E+11


                      *** ASMEHP Module Analysis Complete ***
                         *** CPU Time: 0.0156 Seconds ***

 $

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```

ATTACHMENT #3
ASTM A-53 and ASTM A-120 Black or Galvanized Carbon Steel Pipe Fatigue Analysis

```
$MTI-08-000832, Fatigue Analysis
 $ATT#3
 $A-53 or A-120
 $
 ASMEHP
 $
 $  ASMEHP Analysis Module
 $
 $
 $  Option Keywords
 $
 CODE{ b31.3, , api579}
 $
 $  Design Condition Keywords
 $
 stemp=120.0,
 SPEC{ a53, b, 1996, ---, ---, ---}
 fcurve=asme, fimprove=none,
 scf=2.30, pm=9657.0,
 $
 Term

                    *** VCESage - ASMEHP Analysis Module ***
               *** Analysis Time & Date: 12:28:32, March 6, 2009 ***


       -- Stress Classification per the ASME Code, Section VIII, Div. 2 --


                                -- Design Code --
 Design Code. . . . . . . . . . . . . . . Code(1) = B31.3
 Design Code Year. . . . . . . . . . . . . Code(2) = 2002
 FFS Code. . . . . . . . . . . . . . . . . Code(3) = API579

                            -- General Input Data --
 Design temperature. . . . . . . . . . . . STEMP =   120.0000  (F)
 Load factor. . . . . . . . . . . . . . . . SAFACT =     1.0000
 Stress concentration factor. . . . . . . .  SCF =     2.3000

                               -- Material Data --
 Material specification. . . . . . . .   SPEC(1) =   A53
 Material grade. . . . . . . . . . . .   SPEC(2) =   B
 Year. . . . . . . . . . . . . . . . . .   SPEC(3) =   1996
 Generic Material designation. . . . . .  GENMAT = CS:C-SI
 Minimum ultimate tensile strength. . .  UTS_MIN =  60000.000  (psi)
 Minimum yield strength. . . . . . . . .  YS_MIN =  35000.000  (psi)
 Young's Modulus: ambient temperature. .  EY_AMB =  2.937E+07  (psi)
 Young's Modulus: design temperature. . . . . EY =  2.913E+07  (psi)
 Possion's ratio. . . . . . . . . . . . . . . NU =     0.3000

                        -- Specified Stress Intensities --
 Primary Membrane. . . . . . . . . . . . . .  Pm =  9657.0000  (psi)
 Local membrane + primary bending. . . . . Pl+Pb =  9657.0000  (psi)
 Peak. . . . . . . . . . . . . . . . . . . . . . F =  12554.100  (psi)


                        -- Code Compliance Verification --
                 -- ASME B31.3 Piping Code - Extensions: API579 --

                Description                   Computed    Allowable     Notes
                                                (psi)       (psi)
 ---------------------------------------  ----------  ----------  ----------
 Pm stress intensity                       9657.0000   20000.000      Ok
 Pl + Pb stress intensity                  9657.0000   30000.000      Ok
 Pl + Pb + Q stress intensity              9657.0000   60000.000      Ok
 ---------------------------------------  ----------  ----------  ----------

       -- Fatigue Analysis, ASME Code Section VIII, Div. 2, Appendix 5 --
          -- ASME Code Section VIII, Division 2 Design Fatigue Curve --
                        -- Figure 5-110.1, UTS <= 80 ksi --
 Design fatigue curve identification. . . FCURVE = 110.1A
 Peak Stress Intensity = (Pl+Pb+Q+F). . . PlPbQF =  22211.100  (psi)
 Ratio of Youngs Modulus. . . . . . . . . ERATIO =     1.0299
 Salt = 0.5*(Pl+Pb+Q+F)*ERATIO. . . . . . . Salt =  11438.068  (psi)
 Permissible design cycles. . . . . . .  NCYCLES =  5.590E+06


                     *** ASMEHP Module Analysis Complete ***
                        *** CPU Time: 0.0156 Seconds ***

 $

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```

ATTACHMENT #4
ASTM A-179 Carbon Steel Tube Fatigue Analysis

```
$MTI-08-000832, Fatigue Analysis
 $ATT#4
 $A-179  Seamless Carbon Steel Tubing
 $
 ASMEHP
 $
 $  ASMEHP Analysis Module
 $
 $
 $  Option Keywords
 $
 CODE{ b31.3, , api579}
 $
 $  Design Condition Keywords
 $
 stemp=120.0,
 SPEC{ a179, ---, 2002, k01200, ---, ---}
 fcurve=110.1a, fimprove=none,
 scf=2.30, pm=1703.0,
 $
 Term

                    *** VCESage - ASMEHP Analysis Module ***
               *** Analysis Time & Date: 12:29:42, March 6, 2009 ***


        -- Stress Classification per the ASME Code, Section VIII, Div. 2 --


                                -- Design Code --
 Design Code. . . . . . . . . . . . . . Code(1) = B31.3
 Design Code Year. . . . . . . . . . . . Code(2) = 2002
 FFS Code. . . . . . . . . . . . . . . . Code(3) = API579

                            -- General Input Data --
 Design temperature. . . . . . . . . . . . STEMP =   120.0000  (F)
 Load factor. . . . . . . . . . . . . . . SAFACT =     1.0000
 Stress concentration factor. . . . . . . .  SCF =     2.3000

                              -- Material Data --
 Material specification. . . . . . . .   SPEC(1) =   A179
 Year. . . . . . . . . . . . . . . . .   SPEC(3) =   2002
 UNS identification. . . . . . . . . .   SPEC(4) =   K01200
 Generic Material designation. . . . . .  GENMAT = CS:C-MN-SI
 Minimum ultimate tensile strength. . .  UTS_MIN =  47000.000  (psi)
 Minimum yield strength. . . . . . . . .  YS_MIN =  26000.000  (psi)
 Young's Modulus: ambient temperature. .  EY_AMB =  2.905E+07  (psi)
 Young's Modulus: design temperature. . . . . EY =  2.881E+07  (psi)
 Possion's ratio. . . . . . . . . . . . . . . NU =     0.3000

                        -- Specified Stress Intensities --
 Primary Membrane. . . . . . . . . . . . . .  Pm =  1703.0000  (psi)
 Local membrane + primary bending. . . . . Pl+Pb =  1703.0000  (psi)
 Peak. . . . . . . . . . . . . . . . . . . . . . F =  2213.8999  (psi)


                        -- Code Compliance Verification --
                  -- ASME B31.3 Piping Code - Extensions: API579 --

                Description                   Computed    Allowable     Notes
                                                (psi)       (psi)
 ----------------------------------------  ----------  ----------  ----------
 Pm stress intensity                        1703.0000   15560.000      Ok
 Pl + Pb stress intensity                   1703.0000   23340.000      Ok
 Pl + Pb + Q stress intensity               1703.0000   46890.000      Ok
 ----------------------------------------  ----------  ----------  ----------

        -- Fatigue Analysis, ASME Code Section VIII, Div. 2, Appendix 5 --
           -- ASME Code Section VIII, Division 2 Design Fatigue Curve --
                        -- Figure 5-110.1, UTS <= 80 ksi --
 Design fatigue curve identification. . . FCURVE = 110.1A
 Peak Stress Intensity = (Pl+Pb+Q+F). . . PlPbQF =  3916.8999  (psi)
 Ratio of Youngs Modulus. . . . . . . . . ERATIO =     1.0414
 Salt = 0.5*(Pl+Pb+Q+F)*ERATIO. . . . . . . Salt =  2039.5515  (psi)
 Permissible design cycles. . . . . . .  NCYCLES =  1.000E+11


                       *** ASMEHP Module Analysis Complete ***
                          *** CPU Time: 0.0000 Seconds ***

 $

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                 *** Shaker Heights, Ohio & Houston, Texas USA ***
```

ATTACHMENT #5
ASTM A-789 Super Duplex Tube, UNS S32750 Fatigue Analysis

```
$MTI-08-000832, Fatigue Analysis
 $ATT#5
 $A-789, Seamless Super Duplex Tubing (S-32750)
 $
 ASMEHP
 $
 $  ASMEHP Analysis Module
 $
 $
 $  Option Keywords
 $
 CODE{ b31.3, , api579}
 $
 $  Design Condition Keywords
 $
 stemp=100.0,
 SPEC{ a789, ---, 2002, s32750, ---, ---}
 fcurve=110.1a, fimprove=none,
 scf=2.30, pm=2916.0,
 $
 Term
                    *** VCESage - ASMEHP Analysis Module ***
               *** Analysis Time & Date: 09:11:15, April 1, 2009 ***


          ------------------------------------------------------------

                      User Message - Program Unit: MATL_DB_RD

            MESSAGE - The VCESage Materials Database is being
            read from the following file:

            C:\PROGRA~2
              \VCESAG~1
              \material_database
              \vcesage_materials.txt

            ==> Database Created - DATE: October 27, 2006; TIME: 08:29:03;

            ==> Number of materials - 16968

          ------------------------------------------------------------

        -- Stress Classification per the ASME Code, Section VIII, Div. 2 --


                                  -- Design Code --
 Design Code. . . . . . . . . . . . . . . Code(1) = B31.3
 Design Code Year. . . . . . . . . . . . . Code(2) = 2002
 FFS Code. . . . . . . . . . . . . . . . . Code(3) = API579

                             -- General Input Data --
 Design temperature. . . . . . . . . . . . STEMP =   100.0000  (F)
 Load factor. . . . . . . . . . . . . . . . SAFACT =     1.0000
 Stress concentration factor. . . . . . . .  SCF =     2.3000

                               -- Material Data --
 Material specification. . . . . . . .   SPEC(1) =   A789
 Year. . . . . . . . . . . . . . . . .   SPEC(3) =   2002
 UNS identification. . . . . . . . . .   SPEC(4) =   S32900
 Generic Material designation. . . . . .  GENMAT = DP:DUPLEX-329
 Minimum ultimate tensile strength. . .  UTS_MIN =  90000.000  (psi)
 Minimum yield strength. . . . . . . .  YS_MIN =  70000.000  (psi)
 Young's Modulus: ambient temperature. .  EY_AMB =  2.901E+07  (psi)
 Young's Modulus: design temperature. . . . . EY =  2.881E+07  (psi)
 Possion's ratio. . . . . . . . . . . . . . . NU =     0.3000

                        -- Specified Stress Intensities --
 Primary Membrane. . . . . . . . . . . . . .  Pm =  2916.0000  (psi)
 Local membrane + primary bending. . . . . Pl+Pb =  2916.0000  (psi)
 Peak. . . . . . . . . . . . . . . . . . . . . . F =  3790.7998  (psi)


                        -- Code Compliance Verification --
                  -- ASME B31.3 Piping Code - Extensions: API579 --

                Description                   Computed    Allowable     Notes
                                                (psi)       (psi)
----------------------------------------  ----------  ----------  ----------
Pm stress intensity                         2916.0000   30000.000      Ok
Pl + Pb stress intensity                    2916.0000   45000.000      Ok
Pl + Pb + Q stress intensity                2916.0000   90000.000      Ok
----------------------------------------  ----------  ----------  ----------

        -- Fatigue Analysis, ASME Code Section VIII, Div. 2, Appendix 5 --
           -- ASME Code Section VIII, Division 2 Design Fatigue Curve --
                        -- Figure 5-110.1, UTS <= 80 ksi --
 Design fatigue curve identification. . . FCURVE = 110.1A
 Peak Stress Intensity = (Pl+Pb+Q+F). . . PlPbQF =  6706.7998  (psi)
 Ratio of Youngs Modulus. . . . . . . . . ERATIO =     1.0414
 Salt = 0.5*(Pl+Pb+Q+F)*ERATIO. . . . . . . Salt =  3492.1108  (psi)
 Permissible design cycles. . . . . . .  NCYCLES =  1.000E+11


                      *** ASMEHP Module Analysis Complete ***
                         *** CPU Time: 0.5625 Seconds ***
 $

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```

ATTACHMENT #6
ASTM B-75 Copper Tube Fatigue Analysis

```
$MTI-08-000832, Fatigue Analysis
 $ATT#6
 $B-75 Soft Annealed Seamless Copper Tubing
 $
 ASMEHP
 $
 $  ASMEHP Analysis Module
 $
 $
 $  Option Keywords
 $
 CODE{ b31.3, 2002, api579}
 $
 $  Design Condition Keywords
 $
 stemp=120.0, safact=1.0,
 SPEC{ B75CU, ---, 2002, C12000, 050, ---}
 fcurve=110.3a, fimprove=none,
 scf=2.30, pm=5120.0,
 $
 Term

                    *** VCESage - ASMEHP Analysis Module ***
             *** Analysis Time & Date: 11:53:19, March 17, 2009 ***


       -- Stress Classification per the ASME Code, Section VIII, Div. 2 --


                                -- Design Code --
 Design Code. . . . . . . . . . . . . . . Code(1) = B31.3
 Design Code Year. . . . . . . . . . . . . Code(2) = 2002
 FFS Code. . . . . . . . . . . . . . . . . Code(3) = API579

                            -- General Input Data --
 Design temperature. . . . . . . . . . . . STEMP =   120.0000  (F)
 Load factor. . . . . . . . . . . . . . . SAFACT =     1.0000
 Stress concentration factor. . . . . . . .  SCF =     2.3000

                              -- Material Data --
 Material specification. . . . . . . .   SPEC(1) =   B75CU
 Year. . . . . . . . . . . . . . . . .   SPEC(3) =   2002
 UNS identification. . . . . . . . . .   SPEC(4) =   C12000
 Class/Condition/Temper. . . . . . . .   SPEC(5) =   050
 Generic Material designation. . . . . .  GENMAT = CU:CU_DLP
 Minimum ultimate tensile strength. . .  UTS_MIN =  30000.000  (psi)
 Minimum yield strength. . . . . . . . .  YS_MIN =  9000.0000  (psi)
 Young's Modulus: ambient temperature. .  EY_AMB =  1.700E+07  (psi)
 Young's Modulus: design temperature. . . . . EY =  1.685E+07  (psi)
 Possion's ratio. . . . . . . . . . . . . . . NU =     0.3300

                        -- Specified Stress Intensities --
 Primary Membrane. . . . . . . . . . . . . .  Pm =  5120.0000  (psi)
 Local membrane + primary bending. . . . . Pl+Pb =  5120.0000  (psi)
 Peak. . . . . . . . . . . . . . . . . . . . . . F =  6656.0000  (psi)


                        -- Code Compliance Verification --
                  -- ASME B31.3 Piping Code - Extensions: API579 --

                Description                   Computed    Allowable     Notes
                                                (psi)       (psi)
----------------------------------------  ----------  ----------  ----------
Pm stress intensity                         5120.0000   5640.0000      Ok
Pl + Pb stress intensity                    5120.0000   8460.0000      Ok
Pl + Pb + Q stress intensity                5120.0000   17460.000      Ok
----------------------------------------  ----------  ----------  ----------

       -- Fatigue Analysis, ASME Code Section VIII, Div. 2, Appendix 5 --
          -- ASME Code Section VIII, Division 2 Design Fatigue Curve --
                        -- Figure 5-110.3, Sy = 18 ksi --
 Design fatigue curve identification. . . FCURVE = 110.3A
 Peak Stress Intensity = (Pl+Pb+Q+F). . . PlPbQF =  11776.000  (psi)
 Ratio of Youngs Modulus. . . . . . . . . ERATIO =     1.1867
 Salt = 0.5*(Pl+Pb+Q+F)*ERATIO. . . . . . . Salt =  6987.4976  (psi)
 Permissible design cycles. . . . . . .  NCYCLES =    1000000


                      *** ASMEHP Module Analysis Complete ***
                         *** CPU Time: 0.0156 Seconds ***

 $

           *** Leaving VCESage - Version 8.00.0010 - WIN/NT Edition ***
              *** A Product Of The Equity Engineering Group, Inc. ***
                 *** Shaker Heights, Ohio & Houston, Texas USA ***
```

ATTACHMENT #7
ASTM B-88 Type K, L, and M Copper Tube Fatigue Analysis

```
$MTI-08-000832, Fatigue Analysis
 $ATT#7
 $B-88 Soft Annealed Seamless Copper Tubing
 $
 ASMEHP
 $
 $  ASMEHP Analysis Module
 $
 $
 $  Option Keywords
 $
 CODE{ b31.3, 2002, api579}
 $
 $  Design Condition Keywords
 $
 stemp=120.0, safact=1.0,
 SPEC{ b88cu, ---, 2002, c12200, 050, ---}
 fcurve=110.3a, fimprove=none,
 scf=2.30, pm=3012.0,
 $
 Term

                    *** VCESage - ASMEHP Analysis Module ***
              *** Analysis Time & Date: 12:01:52, March 17, 2009 ***


          ------------------------------------------------------------

                    User Message - Program Unit: MPN_DB_EYMD

            MESSAGE - The specified temperature is above
            the upper temperature limit, the elastic
            modulus is evaluated at the upper temperature
            limit.
                Specified temperature =    120.0000  (F)
              Upper temperature limit =     76.0000  (F)

          ------------------------------------------------------------

       -- Stress Classification per the ASME Code, Section VIII, Div. 2 --


                                 -- Design Code --
 Design Code. . . . . . . . . . . . . . . Code(1) = B31.3
 Design Code Year. . . . . . . . . . . . Code(2) = 2002
 FFS Code. . . . . . . . . . . . . . . . Code(3) = API579

                             -- General Input Data --
 Design temperature. . . . . . . . . . . . STEMP =   120.0000  (F)
 Load factor. . . . . . . . . . . . . . . SAFACT =     1.0000
 Stress concentration factor. . . . . . . .  SCF =     2.3000

                                -- Material Data --
 Material specification. . . . . . . .   SPEC(1) =   B88CU
 Year. . . . . . . . . . . . . . . . .   SPEC(3) =   2002
 UNS identification. . . . . . . . . .   SPEC(4) =   C12200
 Class/Condition/Temper. . . . . . . .   SPEC(5) =   050
 Generic Material designation. . . . . .  GENMAT = CU:CU_DHP
 Minimum ultimate tensile strength. . .  UTS_MIN =  30000.000  (psi)
 Minimum yield strength. . . . . . . .  YS_MIN =  9000.0000  (psi)
 Young's Modulus: ambient temperature. .  EY_AMB =  1.514E+07  (psi)
 Young's Modulus: design temperature. . . . . EY =  1.509E+07  (psi)
 Possion's ratio. . . . . . . . . . . . . . NU =     0.3300

                         -- Specified Stress Intensities --
 Primary Membrane. . . . . . . . . . . . . .  Pm =  3012.0000  (psi)
 Local membrane + primary bending. . . . . Pl+Pb =  3012.0000  (psi)
 Peak. . . . . . . . . . . . . . . . . . . . . . F =  3915.5999  (psi)


                         -- Code Compliance Verification --
                  -- ASME B31.3 Piping Code - Extensions: API579 --

                Description                   Computed    Allowable     Notes
                                                (psi)       (psi)
 ----------------------------------------  ----------  ----------  ----------
 Pm stress intensity                        3012.0000   5640.0000      Ok
 Pl + Pb stress intensity                   3012.0000   8460.0000      Ok
 Pl + Pb + Q stress intensity               3012.0000   17460.000      Ok
 ----------------------------------------  ----------  ----------  ----------

       -- Fatigue Analysis, ASME Code Section VIII, Div. 2, Appendix 5 --
          -- ASME Code Section VIII, Division 2 Design Fatigue Curve --
                          -- Figure 5-110.3, Sy = 18 ksi --
 Design fatigue curve identification. . . FCURVE = 110.3A
 Peak Stress Intensity = (Pl+Pb+Q+F). . . PlPbQF =  6927.5996  (psi)
 Ratio of Youngs Modulus. . . . . . . . . ERATIO =     1.3256
 Salt = 0.5*(Pl+Pb+Q+F)*ERATIO. . . . . . . Salt =  4591.4551  (psi)
 Permissible design cycles. . . . . . .  NCYCLES =    1000000


                      *** ASMEHP Module Analysis Complete ***
                         *** CPU Time: 0.0156 Seconds ***

 $


           *** Leaving VCESage - Version 8.00.0010 - WIN/NT Edition ***
              *** A Product Of The Equity Engineering Group, Inc. ***
                 *** Shaker Heights, Ohio & Houston, Texas USA ***
```

ATTACHMENT #8
ASTM B-210 Type 6061-T6 Aluminum Tube Fatigue Analysis

```
*** Welcome To VCESage - Version 8.4.7 - WIN/NT Edition ***
*** A Product Of The Equity Engineering Group, Inc. ***
*** Shaker Heights, Ohio & Houston, Texas USA ***

$
$  ASTM B-210 Seamless Drawn Al.Tube T6061-T6
$
$  NOMINAL: 0.035 in thickness
$  ACTUAL:  0.033
$
$  -3 sigma curve
$
ASMEHP
$
$  ASMEHP Analysis Module
$
$
$  Option Keywords
$
metr=no,
CODE{ b31.3}
$
$  Design Condition Keywords
$
stemp=120.0,
SPEC{ B210, 6061, 2002, A96061, T6, ---}
st=0.033, fcurve=bm3siglc,
scf=2.3, pm=3217.0,
$
Term
*** VCESage - ASMEHP Analysis Module ***
*** Analysis Time & Date: 11:40:02, March 17, 2009 ***


-----------------------------------------------------------

User Message - Program Unit: MATL_CYCLIC_SSCURVE

MESSAGE - Seeger's Unifrom Material Model is used
to approximate the cyclic stress-strain curve that
is used in the Neuber Correction.

-----------------------------------------------------------


-- Stress Classification per the ASME Code, Section VIII, Div. 2 --


-- Design Code --
Design Code. . . . . .  Code(1) = B31.3
Design Code Year. . . . . . . . . . . Code(2) = 2002

-- General Input Data --
Design temperature. . . . . . . . . . . STEMP =   120.0000  (F)
Load factor. . . . . . . . . . . . . . . SAFACT =     1.0000
Stress concentration factor. . . . . . . .  SCF =     2.3000

-- Material Data --
Material specification. . . . . . . .   SPEC(1) =   B210
Material grade. . . . . . . . . . . .   SPEC(2) =   6061
Year. . . . . . . . . . . . . . . . .   SPEC(3) =   2002
UNS identification. . . . . . . . . .   SPEC(4) =   A96061
Class/Condition/Temper. . . . . . . .   SPEC(5) =   T6
Generic Material designation. . . . . .  GENMAT = AL:AL_6061
Minimum ultimate tensile strength. . .  UTS_MIN =  42000.000  (psi)
Minimum yield strength. . . . . . . . .  YS_MIN =  35000.000  (psi)
Young's Modulus: ambient temperature. .  EY_AMB =  1.046E+07  (psi)
Young's Modulus: design temperature. . . . . EY =  1.037E+07  (psi)
Possion's ratio. . . . . . . . . . . . . . NU =     0.3300
UTS at design temperature. . . . . . . .  UTS =  40984.204  (psi)
Plastic cyclic ss curve exponent. . . . .  NCSS =     0.1100
Plastic cyclic ss curve coefficient. . . . KCSS =  65984.569  (psi)

-- Specified Stress Intensities --
Primary Membrane. . . . . . . . . . . . .  Pm =  3217.0000  (psi)
Local membrane + primary bending. . . . . Pl+Pb =  3217.0000  (psi)
Peak. . . . . . . . . . . . . . . . . . . . . F =  4182.1000  (psi)


-- Code Compliance Verification --
-- ASME B31.3 Piping Code --

Description                          Computed    Allowable     Notes
                                       (psi)       (psi)
---------------------------------------  ----------  ----------  ----------
Pm stress intensity                      3217.0000   14000.000      Ok
Pl + Pb stress intensity                 3217.0000   21000.000      Ok
Pl + Pb + Q stress intensity             3217.0000   42000.000      Ok
---------------------------------------  ----------  ----------  ----------


-- Battelle Fatigue Analysis ---
-- Battelle Joint Fatigue Curve: Battelle-M3Sig-LC-Aluminum --
Design fatigue curve identification. . . FCURVE = BM3SIGLC
Fatigue curve exponent. . . . . . . . . .  HH =     0.2771
```

```
Fatigue curve constant. . . . . .  CC =   133.2900
Material/Temperature correction factor. . . FMT =     0.3570
Environment correction factor. . . . . . . FC =     4.0000
Fatigue improvement method. . . . . .  FIMPROVE = NONE
Fatigue improvement factor. . . . . . .  FIMP =     1.0000
Wall thickness. . . . . . . . . . . . . . . ST =     0.0330  (in)
Depth of flaw at weld toe. . . . . . . . AIWT =     0.0000  (in)
Normal stress: membrane. . . . . . . . . . SIGM =  3217.0000  (psi)
Normal stress: bending. . . . . . . . . .  SIGB =     0.0000  (psi)
Normal stress range. . . . . . . . . . . . SIGR =  3217.0000  (psi)
IR Factor. . . . . . . . . . . . . . . . . . IR =     1.2214
Neuber correction. . . . . . . . . . .  NEUBERC = Yes
Normal stress range - corrected. .  SIGR_NEUBER =  3610.1448  (psi)
Normal stress R-ratio. . . . . . . . .  SIGRRAT =     0.0000
Shear stress: membrane. . . . . . . . . .  TAUM =     0.0000  (psi)
Shear stress: bending. . . . . . . . . . . TAUB =     0.0000  (psi)
Shear stress range. . . . . . . . . . . .  TAUR =     0.0000  (psi)
Normal-shear stress phase angle. . . . .  DELTA =     0.0000  (degrees)
Multi-axial correction factor. . . . . . FDELTA =     1.0000
Equivalent structural stress range. . . SIGEQSS =  2662.4961  (psi)
Permissible design cycles. . . . . .  NCYCLES =       8250


                    *** ASMEHP Module Analysis Complete ***
                       *** CPU Time: 0.7812 Seconds ***
$
$  0.033 in thickness, -2 sigma curve
$
fcurve=bm2siglc,
Term
                  *** VCESage - ASMEHP Analysis Module ***
            *** Analysis Time & Date: 11:40:03, March 17, 2009 ***


         ------------------------------------------------------------

                User Message - Program Unit: MATL_CYCLIC_SSCURVE

           MESSAGE - Seeger's Unifrom Material Model is used
           to approximate the cyclic stress-strain curve that
           is used in the Neuber Correction.

         ------------------------------------------------------------


       -- Stress Classification per the ASME Code, Section VIII, Div. 2 --


                              -- Design Code --
Design Code. . . . . . . . . . . . . .  Code(1) = B31.3
Design Code Year. . . . . . . . . . . . Code(2) = 2002

                           -- General Input Data --
Design temperature. . . . . . . . . . . . STEMP =   120.0000  (F)
Load factor. . . . . . . . . . . . . . . SAFACT =     1.0000
Stress concentration factor. . . . . . .  SCF =     2.3000

                             -- Material Data --
Material specification. . . . . . . .   SPEC(1) =   B210
Material grade. . . . . . . . . . . .   SPEC(2) =   6061
Year. . . . . . . . . . . . . . . . .   SPEC(3) =   2002
UNS identification. . . . . . . . . .   SPEC(4) =   A96061
Class/Condition/Temper. . . . . . . .   SPEC(5) =   T6
Generic Material designation. . . . . .  GENMAT = AL:AL_6061
Minimum ultimate tensile strength. . .  UTS_MIN =  42000.000  (psi)
Minimum yield strength. . . . . . . .  YS_MIN =  35000.000  (psi)
Young's Modulus: ambient temperature. .  EY_AMB =  1.046E+07  (psi)
Young's Modulus: design temperature. . . . . EY =  1.037E+07  (psi)
Possion's ratio. . . . . . . . . . . . . . NU =     0.3300
UTS at design temperature. . . . . . . .  UTS =  40984.204  (psi)
Plastic cyclic ss curve exponent. . . . .  NCSS =     0.1100
Plastic cyclic ss curve coefficient. . . . KCSS =  65984.569  (psi)

                       -- Specified Stress Intensities --
Primary Membrane. . . . . . . . . . . . . . . Pm =  3217.0000  (psi)
Local membrane + primary bending. . . . . Pl+Pb =  3217.0000  (psi)
Peak. . . . . . . . . . . . . . . . . . . . . . F =  4182.1000  (psi)


                       -- Code Compliance Verification --
                          -- ASME B31.3 Piping Code --

               Description                   Computed    Allowable     Notes
                                               (psi)       (psi)
----------------------------------------  ----------  ----------  ----------
Pm stress intensity                        3217.0000   14000.000      Ok
Pl + Pb stress intensity                   3217.0000   21000.000      Ok
Pl + Pb + Q stress intensity               3217.0000   42000.000      Ok
----------------------------------------  ----------  ----------  ----------


                       -- Battelle Fatigue Analysis ---
         -- Battelle Joint Fatigue Curve: Battelle-M2Sig-LC-Aluminum --
Design fatigue curve identification. . . FCURVE = BM2SIGLC
Fatigue curve exponent. . . . . . . . . .  HH =     0.2771
Fatigue curve constant. . . . . . . . . .  CC =   163.7300
Material/Temperature correction factor. . . FMT =     0.3570
```

```
Environment correction factor. . . . . FC =     4.0000
Fatigue improvement method. . . . . FIMPROVE = NONE
Fatigue improvement factor. . . . . FIMP =     1.0000
Wall thickness. . . . . ST =     0.0330  (in)
Depth of flaw at weld toe. . . . . AIWT =     0.0000  (in)
Normal stress: membrane. . . . . SIGM =  3217.0000  (psi)
Normal stress: bending. . . . . SIGB =     0.0000  (psi)
Normal stress range. . . . . SIGR =  3217.0000  (psi)
IR Factor. . . . . IR =     1.2214
Neuber correction. . . . . NEUBERC = Yes
Normal stress range - corrected. . SIGR_NEUBER =  3610.1448  (psi)
Normal stress R-ratio. . . . . SIGRRAT =     0.0000
Shear stress: membrane. . . . . TAUM =     0.0000  (psi)
Shear stress: bending. . . . . TAUB =     0.0000  (psi)
Shear stress range. . . . . TAUR =     0.0000  (psi)
Normal-shear stress phase angle. . . . . DELTA =     0.0000  (degrees)
Multi-axial correction factor. . . . . FDELTA =     1.0000
Equivalent structural stress range. . . SIGEQSS =  2662.4961  (psi)
Permissible design cycles. . . . . NCYCLES =      17332


                    *** ASMEHP Module Analysis Complete ***
                       *** CPU Time: 0.4375 Seconds ***
$
$
$  0.033 in thickness, -1 sigma curve
$
fcurve=bm1siglc,
Term
                    *** VCESage - ASMEHP Analysis Module ***
             *** Analysis Time & Date: 11:40:03, March 17, 2009 ***


         ------------------------------------------------------------

                User Message - Program Unit: MATL_CYCLIC_SSCURVE

           MESSAGE - Seeger's Unifrom Material Model is used
           to approximate the cyclic stress-strain curve that
           is used in the Neuber Correction.

         ------------------------------------------------------------



       -- Stress Classification per the ASME Code, Section VIII, Div. 2 --


                                -- Design Code --
Design Code. . . . . Code(1) = B31.3
Design Code Year. . . . . Code(2) = 2002

                            -- General Input Data --
Design temperature. . . . . STEMP =   120.0000  (F)
Load factor. . . . . SAFACT =     1.0000
Stress concentration factor. . . . . SCF =     2.3000

                               -- Material Data --
Material specification. . . . . SPEC(1) =   B210
Material grade. . . . . SPEC(2) =   6061
Year. . . . . SPEC(3) =   2002
UNS identification. . . . . SPEC(4) =   A96061
Class/Condition/Temper. . . . . SPEC(5) =   T6
Generic Material designation. . . . . GENMAT = AL:AL_6061
Minimum ultimate tensile strength. . . UTS_MIN =  42000.000  (psi)
Minimum yield strength. . . . . YS_MIN =  35000.000  (psi)
Young's Modulus: ambient temperature. . EY_AMB =  1.046E+07  (psi)
Young's Modulus: design temperature. . . . . EY =  1.037E+07  (psi)
Possion's ratio. . . . . NU =     0.3300
UTS at design temperature. . . . . UTS =  40984.204  (psi)
Plastic cyclic ss curve exponent. . . . . NCSS =     0.1100
Plastic cyclic ss curve coefficient. . . . KCSS =  65984.569  (psi)

                        -- Specified Stress Intensities --
Primary Membrane. . . . . Pm =  3217.0000  (psi)
Local membrane + primary bending. . . . . Pl+Pb =  3217.0000  (psi)
Peak. . . . . F =  4182.1000  (psi)


                        -- Code Compliance Verification --
                           -- ASME B31.3 Piping Code --

              Description                    Computed     Allowable      Notes
                                               (psi)        (psi)
----------------------------------------  ----------  ----------  ----------
Pm stress intensity                        3217.0000   14000.000      Ok
Pl + Pb stress intensity                   3217.0000   21000.000      Ok
Pl + Pb + Q stress intensity               3217.0000   42000.000      Ok
----------------------------------------  ----------  ----------  ----------


                        -- Battelle Fatigue Analysis ---
          -- Battelle Joint Fatigue Curve: Battelle-M1Sig-LC-Aluminum --
Design fatigue curve identification. . . FCURVE = BM1SIGLC
Fatigue curve exponent. . . . . HH =     0.2771
Fatigue curve constant. . . . . CC =   201.1200
Material/Temperature correction factor. . . FMT =     0.3570
Environment correction factor. . . . . FC =     4.0000
```

```
Fatigue improvement method. . . . . .  FIMPROVE = NONE
Fatigue improvement factor. . . . . . . .  FIMP =     1.0000
Wall thickness. . . . . . . . . . . . . . . . ST =     0.0330  (in)
Depth of flaw at weld toe. . . . . . . . . AIWT =     0.0000  (in)
Normal stress: membrane. . . . . . . . . . SIGM =  3217.0000  (psi)
Normal stress: bending. . . . . . . . . . . SIGB =     0.0000  (psi)
Normal stress range. . . . . . . . . . . . SIGR =  3217.0000  (psi)
IR Factor. . . . . . . . . . . . . . . . . . . IR =     1.2214
Neuber correction. . . . . . . . . . . . NEUBERC = Yes
Normal stress range - corrected. .  SIGR_NEUBER =  3610.1448  (psi)
Normal stress R-ratio. . . . . . . . . . SIGRRAT =     0.0000
Shear stress: membrane. . . . . . . . . . . TAUM =     0.0000  (psi)
Shear stress: bending. . . . . . . . . . . TAUB =     0.0000  (psi)
Shear stress range. . . . . . . . . . . . . TAUR =     0.0000  (psi)
Normal-shear stress phase angle. . . . .  DELTA =     0.0000  (degrees)
Multi-axial correction factor. . . . . . FDELTA =     1.0000
Equivalent structural stress range. . . SIGEQSS =  2662.4961  (psi)
Permissible design cycles. . . . . . .  NCYCLES =      36407


                    *** ASMEHP Module Analysis Complete ***
                       *** CPU Time: 0.4375 Seconds ***
$
$  0.033 in thickness, mean curve
$
fcurve=bmeanlc,
Term
                    *** VCESage - ASMEHP Analysis Module ***
             *** Analysis Time & Date: 11:40:03, March 17, 2009 ***


         ------------------------------------------------------------

               User Message - Program Unit: MATL_CYCLIC_SSCURVE

            MESSAGE - Seeger's Unifrom Material Model is used
            to approximate the cyclic stress-strain curve that
            is used in the Neuber Correction.

         ------------------------------------------------------------



       -- Stress Classification per the ASME Code, Section VIII, Div. 2 --


                                -- Design Code --
Design Code. . . . . . . . . . . . . . .  Code(1) = B31.3
Design Code Year. . . . . . . . . . . . . Code(2) = 2002

                            -- General Input Data --
Design temperature. . . . . . . . . . . . STEMP =   120.0000  (F)
Load factor. . . . . . . . . . . . . . . . SAFACT =     1.0000
Stress concentration factor. . . . . . . .  SCF =     2.3000

                              -- Material Data --
Material specification. . . . . . . .   SPEC(1) =   B210
Material grade. . . . . . . . . . . .   SPEC(2) =   6061
Year. . . . . . . . . . . . . . . . .   SPEC(3) =   2002
UNS identification. . . . . . . . . .   SPEC(4) =   A96061
Class/Condition/Temper. . . . . . . .   SPEC(5) =   T6
Generic Material designation. . . . . .  GENMAT = AL:AL_6061
Minimum ultimate tensile strength. . .  UTS_MIN =  42000.000  (psi)
Minimum yield strength. . . . . . . .  YS_MIN =  35000.000  (psi)
Young's Modulus: ambient temperature. .  EY_AMB =  1.046E+07  (psi)
Young's Modulus: design temperature. . . . . EY =  1.037E+07  (psi)
Possion's ratio. . . . . . . . . . . . . . . NU =     0.3300
UTS at design temperature. . . . . . . . .  UTS =  40984.204  (psi)
Plastic cyclic ss curve exponent. . . . .  NCSS =     0.1100
Plastic cyclic ss curve coefficient. . . . KCSS =  65984.569  (psi)

                        -- Specified Stress Intensities --
Primary Membrane. . . . . . . . . . . . . . . Pm =  3217.0000  (psi)
Local membrane + primary bending. . . . . Pl+Pb =  3217.0000  (psi)
Peak. . . . . . . . . . . . . . . . . . . . . . . F =  4182.1000  (psi)


                       -- Code Compliance Verification --
                          -- ASME B31.3 Piping Code --

              Description                    Computed    Allowable     Notes
                                               (psi)       (psi)
----------------------------------------  ----------  ----------  ----------
Pm stress intensity                        3217.0000   14000.000      Ok
Pl + Pb stress intensity                   3217.0000   21000.000      Ok
Pl + Pb + Q stress intensity               3217.0000   42000.000      Ok
----------------------------------------  ----------  ----------  ----------


                        -- Battelle Fatigue Analysis ---
          -- Battelle Joint Fatigue Curve: Battelle-Mean-LC-Aluminum --
Design fatigue curve identification. . . FCURVE = BMEANLC
Fatigue curve exponent. . . . . . . . . .  HH =     0.2771
Fatigue curve constant. . . . . . . . . .  CC =   247.0400
Material/Temperature correction factor. . . FMT =     0.3570
Environment correction factor. . . . . . . . FC =     4.0000
Fatigue improvement method. . . . . .  FIMPROVE = NONE
Fatigue improvement factor. . . . . . . .  FIMP =     1.0000
```

```
Wall thickness. . . . . .  ST =     0.0330  (in)
Depth of flaw at weld toe. . . . . . . . . AIWT =     0.0000  (in)
Normal stress: membrane. . . . . . . . . . SIGM =  3217.0000  (psi)
Normal stress: bending. . . . . . . . . . SIGB =     0.0000  (psi)
Normal stress range. . . . . . . . . . . . SIGR =  3217.0000  (psi)
IR Factor. . . . . . . . . . . . . . . . . IR =     1.2214
Neuber correction. . . . . . . . . . . NEUBERC = Yes
Normal stress range - corrected. .  SIGR_NEUBER =  3610.1448  (psi)
Normal stress R-ratio. . . . . . . . . SIGRRAT =     0.0000
Shear stress: membrane. . . . . . . . . . TAUM =     0.0000  (psi)
Shear stress: bending. . . . . . . . . . TAUB =     0.0000  (psi)
Shear stress range. . . . . . . . . . . . TAUR =     0.0000  (psi)
Normal-shear stress phase angle. . . . . DELTA =     0.0000  (degrees)
Multi-axial correction factor. . . . . . FDELTA =     1.0000
Equivalent structural stress range. . . SIGEQSS =  2662.4961  (psi)
Permissible design cycles. . . . . . . NCYCLES =      76468


                    *** ASMEHP Module Analysis Complete ***
                       *** CPU Time: 0.4219 Seconds ***
$
$  NOMINAL:  0.125" thickness
$  ACTUAL:   0.119" thickness
$
$  0.119 in thickness, -3 sigma curve
$
st=0.119, fcurve=bm3siglc,
Term
                    *** VCESage - ASMEHP Analysis Module ***
             *** Analysis Time & Date: 11:40:04, March 17, 2009 ***


         ------------------------------------------------------------

                User Message - Program Unit: MATL_CYCLIC_SSCURVE

           MESSAGE - Seeger's Unifrom Material Model is used
           to approximate the cyclic stress-strain curve that
           is used in the Neuber Correction.

         ------------------------------------------------------------



       -- Stress Classification per the ASME Code, Section VIII, Div. 2 --


                                -- Design Code --
Design Code. . . . . . . . . . . . . . Code(1) = B31.3
Design Code Year. . . . . . . . . . . . Code(2) = 2002

                             -- General Input Data --
Design temperature. . . . . . . . . . . . STEMP =   120.0000  (F)
Load factor. . . . . . . . . . . . . . . SAFACT =     1.0000
Stress concentration factor. . . . . . . .  SCF =     2.3000

                              -- Material Data --
Material specification. . . . . . . .   SPEC(1) =   B210
Material grade. . . . . . . . . . . .   SPEC(2) =   6061
Year. . . . . . . . . . . . . . . . .   SPEC(3) =   2002
UNS identification. . . . . . . . . .   SPEC(4) =   A96061
Class/Condition/Temper. . . . . . . .   SPEC(5) =   T6
Generic Material designation. . . . . .  GENMAT = AL:AL_6061
Minimum ultimate tensile strength. . .  UTS_MIN =  42000.000  (psi)
Minimum yield strength. . . . . . . .  YS_MIN =  35000.000  (psi)
Young's Modulus: ambient temperature. .  EY_AMB =  1.046E+07  (psi)
Young's Modulus: design temperature. . . . . EY =  1.037E+07  (psi)
Possion's ratio. . . . . . . . . . . . . . NU =     0.3300
UTS at design temperature. . . . . . . .  UTS =  40984.204  (psi)
Plastic cyclic ss curve exponent. . . . .  NCSS =     0.1100
Plastic cyclic ss curve coefficient. . . . KCSS =  65984.569  (psi)

                        -- Specified Stress Intensities --
Primary Membrane. . . . . . . . . . . . . .  Pm =  3217.0000  (psi)
Local membrane + primary bending. . . . . Pl+Pb =  3217.0000  (psi)
Peak. . . . . . . . . . . . . . . . . . . . . F =  4182.1000  (psi)


                        -- Code Compliance Verification --
                           -- ASME B31.3 Piping Code --

              Description                   Computed    Allowable     Notes
                                              (psi)       (psi)
----------------------------------------  ----------  ----------  ----------
Pm stress intensity                        3217.0000   14000.000      Ok
Pl + Pb stress intensity                   3217.0000   21000.000      Ok
Pl + Pb + Q stress intensity               3217.0000   42000.000      Ok
----------------------------------------  ----------  ----------  ----------


                        -- Battelle Fatigue Analysis ---
         -- Battelle Joint Fatigue Curve: Battelle-M3Sig-LC-Aluminum --
Design fatigue curve identification. . . FCURVE = BM3SIGLC
Fatigue curve exponent. . . . . . . . . .  HH =     0.2771
Fatigue curve constant. . . . . . . . . .  CC =   133.2900
Material/Temperature correction factor. . . FMT =     0.3570
Environment correction factor. . . . . . . FC =     4.0000
Fatigue improvement method. . . . . .  FIMPROVE = NONE
```

```
Fatigue improvement factor. . . . . .  FIMP =     1.0000
Wall thickness. . . . . . . . . . . . . . . ST =     0.1190  (in)
Depth of flaw at weld toe. . . . . . . . . AIWT =     0.0000  (in)
Normal stress: membrane. . . . . . . . . . SIGM =  3217.0000  (psi)
Normal stress: bending. . . . . . . . . . . SIGB =     0.0000  (psi)
Normal stress range. . . . . . . . . . . . SIGR =  3217.0000  (psi)
IR Factor. . . . . . . . . . . . . . . . . . IR =     1.2214
Neuber correction. . . . . . . . . . . . NEUBERC = Yes
Normal stress range - corrected. .  SIGR_NEUBER =  3610.1448  (psi)
Normal stress R-ratio. . . . . . . . . . SIGRRAT =     0.0000
Shear stress: membrane. . . . . . . . . . . TAUM =     0.0000  (psi)
Shear stress: bending. . . . . . . . . . . TAUB =     0.0000  (psi)
Shear stress range. . . . . . . . . . . . . TAUR =     0.0000  (psi)
Normal-shear stress phase angle. . . . . . DELTA =     0.0000  (degrees)
Multi-axial correction factor. . . . . . FDELTA =     1.0000
Equivalent structural stress range. . . SIGEQSS =  2662.4961  (psi)
Permissible design cycles. . . . . . . NCYCLES =       8250


                    *** ASMEHP Module Analysis Complete ***
                       *** CPU Time: 0.4375 Seconds ***
$
$  0.119 in thickness, -2 sigma curve
$
fcurve=bm2siglc,
Term
                    *** VCESage - ASMEHP Analysis Module ***
             *** Analysis Time & Date: 11:40:04, March 17, 2009 ***


         ------------------------------------------------------------

                User Message - Program Unit: MATL_CYCLIC_SSCURVE

           MESSAGE - Seeger's Unifrom Material Model is used
           to approximate the cyclic stress-strain curve that
           is used in the Neuber Correction.

         ------------------------------------------------------------



       -- Stress Classification per the ASME Code, Section VIII, Div. 2 --


                                 -- Design Code --
Design Code. . . . . . . . . . . . . . . Code(1) = B31.3
Design Code Year. . . . . . . . . . . . . Code(2) = 2002

                             -- General Input Data --
Design temperature. . . . . . . . . . . . STEMP =   120.0000  (F)
Load factor. . . . . . . . . . . . . . . . SAFACT =     1.0000
Stress concentration factor. . . . . . . .  SCF =     2.3000

                               -- Material Data --
Material specification. . . . . . . .   SPEC(1) =   B210
Material grade. . . . . . . . . . . .   SPEC(2) =   6061
Year. . . . . . . . . . . . . . . . .   SPEC(3) =   2002
UNS identification. . . . . . . . . .   SPEC(4) =   A96061
Class/Condition/Temper. . . . . . . .   SPEC(5) =   T6
Generic Material designation. . . . . .  GENMAT = AL:AL_6061
Minimum ultimate tensile strength. . .  UTS_MIN =  42000.000  (psi)
Minimum yield strength. . . . . . . . .  YS_MIN =  35000.000  (psi)
Young's Modulus: ambient temperature. .  EY_AMB =  1.046E+07  (psi)
Young's Modulus: design temperature. . . . . EY =  1.037E+07  (psi)
Possion's ratio. . . . . . . . . . . . . . . NU =     0.3300
UTS at design temperature. . . . . . . . .  UTS =  40984.204  (psi)
Plastic cyclic ss curve exponent. . . . .  NCSS =     0.1100
Plastic cyclic ss curve coefficient. . . . KCSS =  65984.569  (psi)

                        -- Specified Stress Intensities --
Primary Membrane. . . . . . . . . . . . . . . Pm =  3217.0000  (psi)
Local membrane + primary bending. . . . . Pl+Pb =  3217.0000  (psi)
Peak. . . . . . . . . . . . . . . . . . . . . . . F =  4182.1000  (psi)


                        -- Code Compliance Verification --
                           -- ASME B31.3 Piping Code --

              Description                    Computed    Allowable     Notes
                                               (psi)       (psi)
----------------------------------------  ----------  ----------  ----------
Pm stress intensity                        3217.0000   14000.000      Ok
Pl + Pb stress intensity                   3217.0000   21000.000      Ok
Pl + Pb + Q stress intensity               3217.0000   42000.000      Ok
----------------------------------------  ----------  ----------  ----------


                        -- Battelle Fatigue Analysis ---
         -- Battelle Joint Fatigue Curve: Battelle-M2Sig-LC-Aluminum --
Design fatigue curve identification. . . FCURVE = BM2SIGLC
Fatigue curve exponent. . . . . . . . . . .  HH =     0.2771
Fatigue curve constant. . . . . . . . . . .  CC =   163.7300
Material/Temperature correction factor. . . FMT =     0.3570
Environment correction factor. . . . . . . . FC =     4.0000
Fatigue improvement method. . . . . .  FIMPROVE = NONE
Fatigue improvement factor. . . . . . .  FIMP =     1.0000
Wall thickness. . . . . . . . . . . . . . . ST =     0.1190  (in)
```

```
Depth of flaw at weld toe. . . . . AIWT =     0.0000  (in)
Normal stress: membrane. . . . . . . . . . SIGM =  3217.0000  (psi)
Normal stress: bending. . . . . . . . . . . SIGB =     0.0000  (psi)
Normal stress range. . . . . . . . . . . . SIGR =  3217.0000  (psi)
IR Factor. . . . . . . . . . . . . . . . . IR =     1.2214
Neuber correction. . . . . . . . . . . . NEUBERC = Yes
Normal stress range - corrected. .  SIGR_NEUBER =  3610.1448  (psi)
Normal stress R-ratio. . . . . . . . . . SIGRRAT =     0.0000
Shear stress: membrane. . . . . . . . . . TAUM =     0.0000  (psi)
Shear stress: bending. . . . . . . . . . . TAUB =     0.0000  (psi)
Shear stress range. . . . . . . . . . . . TAUR =     0.0000  (psi)
Normal-shear stress phase angle. . . . . DELTA =     0.0000  (degrees)
Multi-axial correction factor. . . . . . FDELTA =     1.0000
Equivalent structural stress range. . . SIGEQSS =  2662.4961  (psi)
Permissible design cycles. . . . . . . NCYCLES =      17332


                    *** ASMEHP Module Analysis Complete ***
                       *** CPU Time: 0.4531 Seconds ***
$
$  0.119 in thickness, -1 sigma curve
$
fcurve=bm1siglc,
Term
                    *** VCESage - ASMEHP Analysis Module ***
             *** Analysis Time & Date: 11:40:05, March 17, 2009 ***


         ----------------------------------------------------------

               User Message - Program Unit: MATL_CYCLIC_SSCURVE

           MESSAGE - Seeger's Unifrom Material Model is used
           to approximate the cyclic stress-strain curve that
           is used in the Neuber Correction.

         ----------------------------------------------------------



       -- Stress Classification per the ASME Code, Section VIII, Div. 2 --


                                -- Design Code --
Design Code. . . . . . . . . . . . . . . Code(1) = B31.3
Design Code Year. . . . . . . . . . . . . Code(2) = 2002

                            -- General Input Data --
Design temperature. . . . . . . . . . . . STEMP =   120.0000  (F)
Load factor. . . . . . . . . . . . . . . SAFACT =     1.0000
Stress concentration factor. . . . . . . .  SCF =     2.3000

                               -- Material Data --
Material specification. . . . . . . .   SPEC(1) =   B210
Material grade. . . . . . . . . . . .   SPEC(2) =   6061
Year. . . . . . . . . . . . . . . . .   SPEC(3) =   2002
UNS identification. . . . . . . . . .   SPEC(4) =   A96061
Class/Condition/Temper. . . . . . . .   SPEC(5) =   T6
Generic Material designation. . . . . .  GENMAT = AL:AL_6061
Minimum ultimate tensile strength. . .  UTS_MIN =  42000.000  (psi)
Minimum yield strength. . . . . . . . .  YS_MIN =  35000.000  (psi)
Young's Modulus: ambient temperature. .  EY_AMB =  1.046E+07  (psi)
Young's Modulus: design temperature. . . . . EY =  1.037E+07  (psi)
Possion's ratio. . . . . . . . . . . . . . NU =     0.3300
UTS at design temperature. . . . . . . . .  UTS =  40984.204  (psi)
Plastic cyclic ss curve exponent. . . . .  NCSS =     0.1100
Plastic cyclic ss curve coefficient. . . . KCSS =  65984.569  (psi)

                        -- Specified Stress Intensities --
Primary Membrane. . . . . . . . . . . . . . Pm =  3217.0000  (psi)
Local membrane + primary bending. . . . . Pl+Pb =  3217.0000  (psi)
Peak. . . . . . . . . . . . . . . . . . . . F =  4182.1000  (psi)


                        -- Code Compliance Verification --
                           -- ASME B31.3 Piping Code --

               Description                    Computed    Allowable     Notes
                                                (psi)       (psi)
----------------------------------------  ----------  ----------  ----------
Pm stress intensity                        3217.0000   14000.000      Ok
Pl + Pb stress intensity                   3217.0000   21000.000      Ok
Pl + Pb + Q stress intensity               3217.0000   42000.000      Ok
----------------------------------------  ----------  ----------  ----------


                        -- Battelle Fatigue Analysis ---
         -- Battelle Joint Fatigue Curve: Battelle-M1Sig-LC-Aluminum --
Design fatigue curve identification. . . FCURVE = BM1SIGLC
Fatigue curve exponent. . . . . . . . . .  HH =     0.2771
Fatigue curve constant. . . . . . . . . .  CC =   201.1200
Material/Temperature correction factor. . . FMT =     0.3570
Environment correction factor. . . . . . . FC =     4.0000
Fatigue improvement method. . . . . .  FIMPROVE = NONE
Fatigue improvement factor. . . . . . .  FIMP =     1.0000
Wall thickness. . . . . . . . . . . . . .  ST =     0.1190  (in)
Depth of flaw at weld toe. . . . . . . . AIWT =     0.0000  (in)
Normal stress: membrane. . . . . . . . . SIGM =  3217.0000  (psi)
```

```
Normal stress: bending. . . . . .  SIGB =     0.0000  (psi)
Normal stress range. . . . . . . . . . . SIGR =  3217.0000  (psi)
IR Factor. . . . . . . . . . . . . . . . . IR =     1.2214
Neuber correction. . . . . . . . . . .  NEUBERC = Yes
Normal stress range - corrected. .  SIGR_NEUBER =  3610.1448  (psi)
Normal stress R-ratio. . . . . . . . .  SIGRRAT =     0.0000
Shear stress: membrane. . . . . . . . .  TAUM =     0.0000  (psi)
Shear stress: bending. . . . . . . . . . TAUB =     0.0000  (psi)
Shear stress range. . . . . . . . . . .  TAUR =     0.0000  (psi)
Normal-shear stress phase angle. . . . .  DELTA =     0.0000  (degrees)
Multi-axial correction factor. . . . . . FDELTA =     1.0000
Equivalent structural stress range. . . SIGEQSS =  2662.4961  (psi)
Permissible design cycles. . . . . .  NCYCLES =      36407


                    *** ASMEHP Module Analysis Complete ***
                       *** CPU Time: 0.4531 Seconds ***
$
$  0.119 in thickness, mean curve
$
fcurve=bmeanlc,
Term
                  *** VCESage - ASMEHP Analysis Module ***
             *** Analysis Time & Date: 11:40:05, March 17, 2009 ***


         ------------------------------------------------------------

                User Message - Program Unit: MATL_CYCLIC_SSCURVE

           MESSAGE - Seeger's Unifrom Material Model is used
           to approximate the cyclic stress-strain curve that
           is used in the Neuber Correction.

         ------------------------------------------------------------


       -- Stress Classification per the ASME Code, Section VIII, Div. 2 --


                                -- Design Code --
Design Code. . . . . . . . . . . . .  Code(1) = B31.3
Design Code Year. . . . . . . . . . . Code(2) = 2002

                             -- General Input Data --
Design temperature. . . . . . . . . . . . STEMP =   120.0000  (F)
Load factor. . . . . . . . . . . . . . . SAFACT =     1.0000
Stress concentration factor. . . . . . .  SCF =     2.3000

                              -- Material Data --
Material specification. . . . . . . .   SPEC(1) =   B210
Material grade. . . . . . . . . . . .   SPEC(2) =   6061
Year. . . . . . . . . . . . . . . . .   SPEC(3) =   2002
UNS identification. . . . . . . . . .   SPEC(4) =   A96061
Class/Condition/Temper. . . . . . . .   SPEC(5) =   T6
Generic Material designation. . . . . .  GENMAT = AL:AL_6061
Minimum ultimate tensile strength. . .  UTS_MIN =  42000.000  (psi)
Minimum yield strength. . . . . . . .  YS_MIN =  35000.000  (psi)
Young's Modulus: ambient temperature. .  EY_AMB =  1.046E+07  (psi)
Young's Modulus: design temperature. . . . . EY =  1.037E+07  (psi)
Possion's ratio. . . . . . . . . . . . . . NU =     0.3300
UTS at design temperature. . . . . . . .  UTS =  40984.204  (psi)
Plastic cyclic ss curve exponent. . . . .  NCSS =     0.1100
Plastic cyclic ss curve coefficient. . . . KCSS =  65984.569  (psi)

                        -- Specified Stress Intensities --
Primary Membrane. . . . . . . . . . . . . .  Pm =  3217.0000  (psi)
Local membrane + primary bending. . . . . Pl+Pb =  3217.0000  (psi)
Peak. . . . . . . . . . . . . . . . . . . . . F =  4182.1000  (psi)


                       -- Code Compliance Verification --
                          -- ASME B31.3 Piping Code --

              Description                   Computed    Allowable     Notes
                                              (psi)       (psi)
----------------------------------------  ----------  ----------  ----------
Pm stress intensity                        3217.0000   14000.000      Ok
Pl + Pb stress intensity                   3217.0000   21000.000      Ok
Pl + Pb + Q stress intensity               3217.0000   42000.000      Ok
----------------------------------------  ----------  ----------  ----------


                        -- Battelle Fatigue Analysis ---
          -- Battelle Joint Fatigue Curve: Battelle-Mean-LC-Aluminum --
Design fatigue curve identification. . . FCURVE = BMEANLC
Fatigue curve exponent. . . . . . . . . .  HH =     0.2771
Fatigue curve constant. . . . . . . . . .  CC =   247.0400
Material/Temperature correction factor. . . FMT =     0.3570
Environment correction factor. . . . . . . FC =     4.0000
Fatigue improvement method. . . . . .  FIMPROVE = NONE
Fatigue improvement factor. . . . . . . . FIMP =     1.0000
Wall thickness. . . . . . . . . . . . . .  ST =     0.1190  (in)
Depth of flaw at weld toe. . . . . . . . AIWT =     0.0000  (in)
Normal stress: membrane. . . . . . . . . SIGM =  3217.0000  (psi)
Normal stress: bending. . . . . . . . .  SIGB =     0.0000  (psi)
Normal stress range. . . . . . . . . . . SIGR =  3217.0000  (psi)
```

```
IR Factor. . . . . IR =      1.2214
Neuber correction. . . . . NEUBERC = Yes
Normal stress range - corrected. . SIGR_NEUBER =  3610.1448  (psi)
Normal stress R-ratio. . . . . SIGRRAT =      0.0000
Shear stress: membrane. . . . . TAUM =      0.0000  (psi)
Shear stress: bending. . . . . TAUB =      0.0000  (psi)
Shear stress range. . . . . TAUR =      0.0000  (psi)
Normal-shear stress phase angle. . . . . DELTA =      0.0000  (degrees)
Multi-axial correction factor. . . . . FDELTA =      1.0000
Equivalent structural stress range. . . SIGEQSS =  2662.4961  (psi)
Permissible design cycles. . . . . NCYCLES =      76468

                    *** ASMEHP Module Analysis Complete ***
                       *** CPU Time: 0.4531 Seconds ***

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                 *** Shaker Heights, Ohio & Houston, Texas USA ***
```

ATTACHMENT #9
ASTM B-167 Nickel-Chromium-Iron Alloy Tube, UNS N06600
Fatigue Analysis

```
$MTI-08-000832, Fatigue Analysis
 $ATT#8
 $B-167, Seamless Nickel,Chromium-Iron Alloy (Alloy 600)
 $
 ASMEHP
 $
 $  ASMEHP Analysis Module
 $
 $
 $  Option Keywords
 $
 CODE{ b31.3, , api579}
 $
 $  Design Condition Keywords
 $
 stemp=120.0,
 SPEC{ b167, ---, 2002, n06600, cdann, gt5}
 fcurve=110.2.2a, fimprove=none,
 scf=2.30, pm=3941.0,
 $
 Term

                    *** VCESage - ASMEHP Analysis Module ***
             *** Analysis Time & Date: 12:02:29, March 17, 2009 ***


       -- Stress Classification per the ASME Code, Section VIII, Div. 2 --


                              -- Design Code --
 Design Code. . . . . . . . . . . . . . . . Code(1) = B31.3
 Design Code Year. . . . . . . . . . . . . Code(2) = 2002
 FFS Code. . . . . . . . . . . . . . . . . Code(3) = API579

                           -- General Input Data --
 Design temperature. . . . . . . . . . . . STEMP =   120.0000  (F)
 Load factor. . . . . . . . . . . . . . . SAFACT =     1.0000
 Stress concentration factor. . . . . . . .  SCF =     2.3000

                             -- Material Data --
 Material specification. . . . . . . .   SPEC(1) =   B167
 Year. . . . . . . . . . . . . . . . .   SPEC(3) =   2002
 UNS identification. . . . . . . . . .   SPEC(4) =   N06600
 Class/Condition/Temper. . . . . . . .   SPEC(5) =   CDANN
 Size/Thickness. . . . . . . . . . . .   SPEC(6) =   GT5
 Generic Material designation. . . . . .  GENMAT = NF:INCONEL_600
 Minimum ultimate tensile strength. . .  UTS_MIN =  80000.000  (psi)
 Minimum yield strength. . . . . . . .  YS_MIN =  30000.000  (psi)
 Young's Modulus: ambient temperature. .  EY_AMB =  3.119E+07  (psi)
 Young's Modulus: design temperature. . . . . EY =  3.099E+07  (psi)
 Possion's ratio. . . . . . . . . . . . . . . NU =     0.2900

                        -- Specified Stress Intensities --
 Primary Membrane. . . . . . . . . . . . . .  Pm =  3941.0000  (psi)
 Local membrane + primary bending. . . . . Pl+Pb =  3941.0000  (psi)
 Peak. . . . . . . . . . . . . . . . . . . . . . F =  5123.2998  (psi)


                       -- Code Compliance Verification --
                 -- ASME B31.3 Piping Code - Extensions: API579 --

                Description                   Computed    Allowable     Notes
                                                (psi)       (psi)
 ----------------------------------------  ----------  ----------  ----------
 Pm stress intensity                        3941.0000   20000.000      Ok
 Pl + Pb stress intensity                   3941.0000   30000.000      Ok
 Pl + Pb + Q stress intensity               3941.0000   60000.000      Ok
 ----------------------------------------  ----------  ----------  ----------

       -- Fatigue Analysis, ASME Code Section VIII, Div. 2, Appendix 5 --
          -- ASME Code Section VIII, Division 2 Design Fatigue Curve --
                          -- Figure 5-110.2.2, Curve A --
 Design fatigue curve identification. . . FCURVE = 110.2.2A
 Peak Stress Intensity = (Pl+Pb+Q+F). . . PlPbQF =  9064.2998  (psi)
 Ratio of Youngs Modulus. . . . . . . . . ERATIO =     0.9133
 Salt = 0.5*(Pl+Pb+Q+F)*ERATIO. . . . . . . Salt =  4139.1631  (psi)
 Permissible design cycles. . . . . . .  NCYCLES =  1.000E+11


                      *** ASMEHP Module Analysis Complete ***
                         *** CPU Time: 0.0156 Seconds ***

 $

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                 *** Shaker Heights, Ohio & Houston, Texas USA ***
```

ATTACHMENT #10
ASTM B-338 Grade 2 Unalloyed Titanium Tube Fatigue Analysis

```
$MTI-08-000832, Fatigue Analysis
 $ATT#9
 $B-338 Seamless Grade 2 Titanium
 $
 ASMEHP
 $
 $  ASMEHP Analysis Module
 $
 $
 $  Option Keywords
 $
 CODE{ b31.3, , api579}
 $
 $  Design Condition Keywords
 $
 stemp=120.0,
 SPEC{ b337, 2, 2002, r50400, ---, ---}
 fcurve=110.1a, fimprove=none,
 scf=2.30, pm=2912.0,
 $
 Term

                    *** VCESage - ASMEHP Analysis Module ***
              *** Analysis Time & Date: 12:03:06, March 17, 2009 ***


       -- Stress Classification per the ASME Code, Section VIII, Div. 2 --


                              -- Design Code --
 Design Code. . . . . . . . . . . . . . . Code(1) = B31.3
 Design Code Year. . . . . . . . . . . . . Code(2) = 2002
 FFS Code. . . . . . . . . . . . . . . . . Code(3) = API579

                           -- General Input Data --
 Design temperature. . . . . . . . . . . . STEMP =   120.0000  (F)
 Load factor. . . . . . . . . . . . . . . . SAFACT =     1.0000
 Stress concentration factor. . . . . . . .  SCF =     2.3000

                              -- Material Data --
 Material specification. . . . . . . .   SPEC(1) =   B337
 Material grade. . . . . . . . . . . .   SPEC(2) =   2
 Year. . . . . . . . . . . . . . . . .   SPEC(3) =   2002
 UNS identification. . . . . . . . . .   SPEC(4) =   R50400
 Generic Material designation. . . . . .  GENMAT = TI:GRADE_2
 Minimum ultimate tensile strength. . .  UTS_MIN =  50000.000  (psi)
 Minimum yield strength. . . . . . . .  YS_MIN =  40000.000  (psi)
 Young's Modulus: ambient temperature. .  EY_AMB =  1.533E+07  (psi)
 Young's Modulus: design temperature. . . . . EY =  1.518E+07  (psi)
 Possion's ratio. . . . . . . . . . . . . . . NU =     0.3200

                        -- Specified Stress Intensities --
 Primary Membrane. . . . . . . . . . . . . .  Pm =  2912.0000  (psi)
 Local membrane + primary bending. . . . . Pl+Pb =  2912.0000  (psi)
 Peak. . . . . . . . . . . . . . . . . . . . . . F =  3785.5999  (psi)


                        -- Code Compliance Verification --
                  -- ASME B31.3 Piping Code - Extensions: API579 --

                Description                   Computed    Allowable     Notes
                                                (psi)       (psi)
 ----------------------------------------  ----------  ----------  ----------
 Pm stress intensity                        2912.0000   16700.000      Ok
 Pl + Pb stress intensity                   2912.0000   25050.000      Ok
 Pl + Pb + Q stress intensity               2912.0000   50100.000      Ok
 ----------------------------------------  ----------  ----------  ----------

       -- Fatigue Analysis, ASME Code Section VIII, Div. 2, Appendix 5 --
          -- ASME Code Section VIII, Division 2 Design Fatigue Curve --
                        -- Figure 5-110.1, UTS <= 80 ksi --
 Design fatigue curve identification. . . FCURVE = 110.1A
 Peak Stress Intensity = (Pl+Pb+Q+F). . . PlPbQF =  6697.5996  (psi)
 Ratio of Youngs Modulus. . . . . . . . . ERATIO =     1.9765
 Salt = 0.5*(Pl+Pb+Q+F)*ERATIO. . . . . . . Salt =  6618.7583  (psi)
 Permissible design cycles. . . . . . .  NCYCLES =  1.000E+11


                      *** ASMEHP Module Analysis Complete ***
                         *** CPU Time: 0.0156 Seconds ***

 $

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```

ATTACHMENT # 11
LONGITUDINAL SURFACE FLAW ANALYSES

PART A

MTI-08-00832 Attachment # 11 Part A
Longitudinal Surface Flaw Analyses

Table 1 - Welded Stainless Steel Tubing. ASTM A-269/632 TP 304/316
Table 2 - Welded Black or Galvanized Carbon Steel Piping. ASTM A-53 and ASTM A-120
Table 3 - Soft Annealed Seamless Copper Tubing. ASTM B-75
Table 4 - Soft Annealed Seamless Copper Tubing. ASTM B-88 Types K, L, and M
Table 5 - Seamless Aluminum Tubing. ASTM B-210 Type 6061-T6
Table 6 - Welded Stainless Steel Piping. ASTM A-312 TP 304/316
Table 7 - Seamless Carbon Steel Tubing. ASTM A-179
Table 8 - Welded Super Duplex Tubing. ASTM A-789, UNS S32750
Table 9 - Seamless Nickel-Chromium-Iron Alloy (Alloy 600) Piping and Tubing. ASTM B-167, UNS N06600
Table 10 - Welded Grade 2 Titanium Tubing. ASTM B-338, Unalloyed Titanium

Notes: 1) For the definitions of all variables used in Tables 1 to 10 see Ref. #19 Piping and Tubing Data Section, unless otherwise specified.
2) The term N/A is used in Tables 1 to 10 to denote that a postulated longitudinal surface flaw did not reach the criteria for a through-wall flaw analysis. For Table 4, the term N/A also denotes the specified material is not commercially available.

Design Pressure, P =	150	PSIG from -20 to 120°F
Coefficient, Y =	0.4	Varies, See Paragraph 304.1.1 of ASME B31.3 (Ref. #13)
Weld Joint Strength Reduction Factor, W =	1.0	Ref. #13, Paragraph 302.3.5(e)

Material Specification	Maximum Allowable Stress, S, psi	Weld Quality Factor, E
Welded ASTM A-269/632 TP 304/316	20,000	0.80
Welded ASTM A-53 or A-120	16,000	0.60
Seamless ASTM B-75	5,640	1.00
Seamless ASTM B-88 Types K, L, and M	5,640	1.00
Seamless ASTM B-210 Type 6061-T6	14,000	1.00
Welded ASTM A-312 TP 304/316	16,700	0.80
Seamless ASTM A-179	15,560	1.00
Welded ASTM A-789, UNS S32750	37,960	0.80
Seamless ASTM B-167	20,000	1.00
Welded ASTM B-338, Unalloyed Titanium	16,700	1.00

Table 1 - Welded Stainless Steel Tubing
(Material Specifications ASTM A-269 TP304, TP316 and ASTM A-632 TP304, TP316)

Size	D in.	c_D in.	t_m in.	c in.	α	c_t in.	Y	Membrane Stress, psi	Analysis Membrane Stress, psi	$D + c_D$ in.	$t_c = t_m - c_t - c$ in.	Outer Radius R_o, in.	Inner Radius R_i, in.	Postulated Crack Depth a, in.	Postulated Crack Length, 2C, in.	Cycles to Through-Wall Transition	Depth "a" after transition, in.	Length "C" after transition, in.
1/16	0.0625	0.005	0.010	0.0000	15.0%	0.0015	0.400	669	1,846	0.0675	0.00850	0.03375	0.02525	0.0021	0.0128	10,000,000	N/A	N/A
1/16	0.0625	0.005	0.012	0.0000	15.0%	0.0018	0.400	545	1,846	0.0675	0.01020	0.03375	0.02355	0.0026	0.0153	10,000,000	N/A	N/A
1/16	0.0625	0.005	0.014	0.0000	15.0%	0.0021	0.393	458	1,846	0.0675	0.01190	0.03375	0.02185	0.0030	0.0179	10,000,000	N/A	N/A
1/16	0.0625	0.005	0.016	0.0000	15.0%	0.0024	0.374	395	1,846	0.0675	0.01360	0.03375	0.02015	0.0034	0.0204	10,000,000	N/A	N/A
1/16	0.0625	0.005	0.020	0.0000	15.0%	0.0030	0.332	310	1,846	0.0675	0.01700	0.03375	0.01675	0.0043	0.0255	10,000,000	N/A	N/A
1/8	0.125	0.005	0.028	0.0000	15.0%	0.0042	0.388	439	1,846	0.1300	0.02380	0.06500	0.04120	0.0060	0.0357	10,000,000	N/A	N/A
1/8	0.125	0.005	0.035	0.0000	15.0%	0.0053	0.352	344	1,846	0.1300	0.02975	0.06500	0.03525	0.0074	0.0446	10,000,000	N/A	N/A
3/16	0.1875	0.005	0.028	0.0000	15.0%	0.0042	0.400	683	1,846	0.1925	0.02380	0.09625	0.07245	0.0060	0.0357	10,000,000	N/A	N/A
3/16	0.1875	0.005	0.035	0.0000	15.0%	0.0053	0.400	532	1,846	0.1925	0.02975	0.09625	0.06650	0.0074	0.0446	10,000,000	N/A	N/A
3/16	0.1875	0.005	0.049	0.0000	15.0%	0.0074	0.362	365	1,846	0.1925	0.04165	0.09625	0.05460	0.0104	0.0625	10,000,000	N/A	N/A
1/4	0.250	0.005	0.028	0.0000	15.0%	0.0042	0.400	929	1,846	0.2550	0.02380	0.12750	0.10370	0.0060	0.0357	10,000,000	N/A	N/A
1/4	0.250	0.005	0.035	0.0000	15.0%	0.0053	0.400	729	1,846	0.2550	0.02975	0.12750	0.09775	0.0074	0.0446	10,000,000	N/A	N/A
1/4	0.250	0.005	0.049	0.0000	15.0%	0.0074	0.400	499	1,846	0.2550	0.04165	0.12750	0.08585	0.0104	0.0625	10,000,000	N/A	N/A
1/4	0.250	0.005	0.065	0.0000	15.0%	0.0098	0.362	365	1,846	0.2550	0.05525	0.12750	0.07225	0.0138	0.0829	10,000,000	N/A	N/A
5/16	0.3125	0.005	0.035	0.0000	15.0%	0.0053	0.400	926	1,846	0.3175	0.02975	0.15875	0.12900	0.0074	0.0446	10,000,000	N/A	N/A
5/16	0.3125	0.005	0.049	0.0000	15.0%	0.0074	0.400	640	1,846	0.3175	0.04165	0.15875	0.11710	0.0104	0.0625	10,000,000	N/A	N/A
5/16	0.3125	0.005	0.065	0.0000	15.0%	0.0098	0.395	465	1,846	0.3175	0.05525	0.15875	0.10350	0.0138	0.0829	10,000,000	N/A	N/A
3/8	0.375	0.005	0.035	0.0000	15.0%	0.0053	0.400	1,122	1,846	0.3800	0.02975	0.19000	0.16025	0.0074	0.0446	10,000,000	N/A	N/A
3/8	0.375	0.005	0.049	0.0000	15.0%	0.0074	0.400	780	1,846	0.3800	0.04165	0.19000	0.14835	0.0104	0.0625	10,000,000	N/A	N/A
3/8	0.375	0.005	0.065	0.0000	15.0%	0.0098	0.400	570	1,846	0.3800	0.05525	0.19000	0.13475	0.0138	0.0829	10,000,000	N/A	N/A
3/8	0.375	0.005	0.083	0.0000	15.0%	0.0125	0.386	433	1,846	0.3800	0.07055	0.19000	0.11945	0.0176	0.1058	10,000,000	N/A	N/A
1/2	0.500	0.005	0.035	0.0000	10.0%	0.0035	0.400	1,428	1,846	0.5050	0.03150	0.25250	0.22100	0.0079	0.0473	10,000,000	N/A	N/A
1/2	0.500	0.005	0.049	0.0000	10.0%	0.0049	0.400	999	1,846	0.5050	0.04410	0.25250	0.20840	0.0110	0.0662	10,000,000	N/A	N/A
1/2	0.500	0.005	0.065	0.0000	10.0%	0.0065	0.400	734	1,846	0.5050	0.05850	0.25250	0.19400	0.0146	0.0878	10,000,000	N/A	N/A
1/2	0.500	0.005	0.083	0.0000	10.0%	0.0083	0.400	559	1,846	0.5050	0.07470	0.25250	0.17780	0.0187	0.1121	10,000,000	N/A	N/A
5/8	0.625	0.005	0.049	0.0000	10.0%	0.0049	0.400	1,264	1,846	0.6300	0.04410	0.31500	0.27090	0.0110	0.0662	10,000,000	N/A	N/A
5/8	0.625	0.005	0.065	0.0000	10.0%	0.0065	0.400	935	1,846	0.6300	0.05850	0.31500	0.25650	0.0146	0.0878	10,000,000	N/A	N/A
5/8	0.625	0.005	0.083	0.0000	10.0%	0.0083	0.400	716	1,846	0.6300	0.07470	0.31500	0.24030	0.0187	0.1121	10,000,000	N/A	N/A
5/8	0.625	0.005	0.095	0.0000	10.0%	0.0095	0.400	616	1,846	0.6300	0.08550	0.31500	0.22950	0.0214	0.1283	10,000,000	N/A	N/A
3/4	0.750	0.005	0.049	0.0000	10.0%	0.0049	0.400	1,530	1,846	0.7550	0.04410	0.37750	0.33340	0.0110	0.0662	10,000,000	N/A	N/A
3/4	0.750	0.005	0.065	0.0000	10.0%	0.0065	0.400	1,135	1,846	0.7550	0.05850	0.37750	0.31900	0.0146	0.0878	10,000,000	N/A	N/A
3/4	0.750	0.005	0.083	0.0000	10.0%	0.0083	0.400	873	1,846	0.7550	0.07470	0.37750	0.30280	0.0187	0.1121	10,000,000	N/A	N/A
3/4	0.750	0.005	0.095	0.0000	10.0%	0.0095	0.400	753	1,846	0.7550	0.08550	0.37750	0.29200	0.0214	0.1283	10,000,000	N/A	N/A
3/4	0.750	0.005	0.109	0.0000	10.0%	0.0109	0.400	647	1,846	0.7550	0.09810	0.37750	0.27940	0.0245	0.1472	10,000,000	N/A	N/A
7/8	0.875	0.005	0.049	0.0000	10.0%	0.0049	0.400	1,796	1,846	0.8800	0.04410	0.44000	0.39590	0.0110	0.0662	10,000,000	N/A	N/A
7/8	0.875	0.005	0.065	0.0000	10.0%	0.0065	0.400	1,335	1,846	0.8800	0.05850	0.44000	0.38150	0.0146	0.0878	10,000,000	N/A	N/A
7/8	0.875	0.005	0.083	0.0000	10.0%	0.0083	0.400	1,029	1,846	0.8800	0.07470	0.44000	0.36530	0.0187	0.1121	10,000,000	N/A	N/A
7/8	0.875	0.005	0.095	0.0000	10.0%	0.0095	0.400	890	1,846	0.8800	0.08550	0.44000	0.35450	0.0214	0.1283	10,000,000	N/A	N/A
7/8	0.875	0.005	0.109	0.0000	10.0%	0.0109	0.400	766	1,846	0.8800	0.09810	0.44000	0.34190	0.0245	0.1472	10,000,000	N/A	N/A
1	1.000	0.005	0.065	0.0000	10.0%	0.0065	0.400	1,536	1,846	1.0050	0.05850	0.50250	0.44400	0.0146	0.0878	10,000,000	N/A	N/A
1	1.000	0.005	0.083	0.0000	10.0%	0.0083	0.400	1,186	1,846	1.0050	0.07470	0.50250	0.42780	0.0187	0.1121	10,000,000	N/A	N/A
1	1.000	0.005	0.095	0.0000	10.0%	0.0095	0.400	1,027	1,846	1.0050	0.08550	0.50250	0.41700	0.0214	0.1283	10,000,000	N/A	N/A
1	1.000	0.005	0.109	0.0000	10.0%	0.0109	0.400	885	1,846	1.0050	0.09810	0.50250	0.40440	0.0245	0.1472	10,000,000	N/A	N/A
1	1.000	0.005	0.120	0.0000	10.0%	0.0120	0.400	797	1,846	1.0050	0.10800	0.50250	0.39450	0.0270	0.1620	10,000,000	N/A	N/A
1 1/4	1.250	0.005	0.083	0.0000	10.0%	0.0083	0.400	1,500	1,846	1.2550	0.07470	0.62750	0.55280	0.0187	0.1121	10,000,000	N/A	N/A
1 1/4	1.250	0.005	0.095	0.0000	10.0%	0.0095	0.400	1,301	1,846	1.2550	0.08550	0.62750	0.54200	0.0214	0.1283	10,000,000	N/A	N/A
1 1/4	1.250	0.005	0.109	0.0000	10.0%	0.0109	0.400	1,124	1,846	1.2550	0.09810	0.62750	0.52940	0.0245	0.1472	10,000,000	N/A	N/A
1 1/4	1.250	0.005	0.120	0.0000	10.0%	0.0120	0.400	1,014	1,846	1.2550	0.10800	0.62750	0.51950	0.0270	0.1620	10,000,000	N/A	N/A
1 1/4	1.250	0.005	0.134	0.0000	10.0%	0.0134	0.400	901	1,846	1.2550	0.12060	0.62750	0.50690	0.0302	0.1809	10,000,000	N/A	N/A
1 1/4	1.250	0.005	0.156	0.0000	10.0%	0.0156	0.400	763	1,846	1.2550	0.14040	0.62750	0.48710	0.0351	0.2106	10,000,000	N/A	N/A
1 1/2	1.500	0.010	0.095	0.0000	10.0%	0.0095	0.400	1,581	1,846	1.5100	0.08550	0.75500	0.66950	0.0214	0.1283	10,000,000	N/A	N/A
1 1/2	1.500	0.010	0.109	0.0000	10.0%	0.0109	0.400	1,368	1,846	1.5100	0.09810	0.75500	0.65690	0.0245	0.1472	10,000,000	N/A	N/A
1 1/2	1.500	0.010	0.120	0.0000	10.0%	0.0120	0.400	1,236	1,846	1.5100	0.10800	0.75500	0.64700	0.0270	0.1620	10,000,000	N/A	N/A
1 1/2	1.500	0.010	0.134	0.0000	10.0%	0.0134	0.400	1,099	1,846	1.5100	0.12060	0.75500	0.63440	0.0302	0.1809	10,000,000	N/A	N/A
1 1/2	1.500	0.010	0.156	0.0000	10.0%	0.0156	0.400	933	1,846	1.5100	0.14040	0.75500	0.61460	0.0351	0.2106	10,000,000	N/A	N/A
1 1/2	1.500	0.010	0.188	0.0000	10.0%	0.0188	0.400	762	1,846	1.5100	0.16920	0.75500	0.58580	0.0423	0.2538	10,000,000	N/A	N/A
2	2.000	0.010	0.109	0.0000	10.0%	0.0109	0.400	1,846	1,846	2.0100	0.09810	1.00500	0.90690	0.0245	0.1472	10,000,000	N/A	N/A
2	2.000	0.010	0.120	0.0000	10.0%	0.0120	0.400	1,670	1,846	2.0100	0.10800	1.00500	0.89700	0.0270	0.1620	10,000,000	N/A	N/A
2	2.000	0.010	0.134	0.0000	10.0%	0.0134	0.400	1,488	1,846	2.0100	0.12060	1.00500	0.88440	0.0302	0.1809	10,000,000	N/A	N/A
2	2.000	0.010	0.156	0.0000	10.0%	0.0156	0.400	1,267	1,846	2.0100	0.14040	1.00500	0.86460	0.0351	0.2106	10,000,000	N/A	N/A
2	2.000	0.010	0.188	0.0000	10.0%	0.0188	0.400	1,039	1,846	2.0100	0.16920	1.00500	0.83580	0.0423	0.2538	10,000,000	N/A	N/A

Maximum Developed Membrane Stress: 1,846

Table 2 - Welded Black or Galvanized Carbon Steel Piping
(Material Specifications ASTM A-53 or ASTM A-120)

Size	D in.	c_D in.	t_m in.	c in.	α	c_t in.	Y	Membrane Stress, psi	Analysis Membrane Stress, psi	$D + c_D$ in.	$t_c = t_m - c_t - c$ in.	Outer Radius R_o, in.	Inner Radius R_i, in.	Postulated Crack Depth a, in.	Postulated Crack Length, 2C, in.	Cycles to Through-Wall Transition	Depth "a" after transition, in.	Length "C" after transition, in.
1/8	0.405	0.015625	0.068	0.0383	12.5%	0.00850	0.400	2,383	2,383	0.420625	0.0211725	0.2103125	0.1891400	0.0053	0.0318	10,000,000	N/A	N/A
1/8	0.405	0.015625	0.095	0.0383	12.5%	0.01188	0.400	1,074	1,074	0.420625	0.0447975	0.2103125	0.1655150	0.0112	0.0672	10,000,000	N/A	N/A
1/4	0.540	0.015625	0.088	0.0542	12.5%	0.01100	0.400	2,949	2,949	0.555625	0.0227825	0.2778125	0.2550300	0.0057	0.0342	10,000,000	N/A	N/A
1/4	0.540	0.015625	0.119	0.0542	12.5%	0.01488	0.400	1,292	1,292	0.555625	0.0499075	0.2778125	0.2279050	0.0125	0.0749	10,000,000	N/A	N/A
3/8	0.675	0.015625	0.091	0.0540	12.5%	0.01138	0.400	3,273	3,273	0.690625	0.0255975	0.3453125	0.3197150	0.0064	0.0384	10,000,000	N/A	N/A
3/8	0.675	0.015625	0.126	0.0540	12.5%	0.01575	0.400	1,435	1,435	0.690625	0.0562225	0.3453125	0.2890900	0.0141	0.0843	10,000,000	N/A	N/A
1/2	0.840	0.015625	0.065	0.0000	12.5%	0.00813	0.400	1,780	1,780	0.855625	0.0568750	0.4278125	0.3709375	0.0142	0.0853	10,000,000	N/A	N/A
1/2	0.840	0.015625	0.083	0.0000	12.5%	0.01038	0.400	1,373	1,373	0.855625	0.0726250	0.4278125	0.3551875	0.0182	0.1089	10,000,000	N/A	N/A
1/2	0.840	0.015625	0.095	0.0000	12.5%	0.01188	0.400	1,187	1,187	0.855625	0.0831250	0.4278125	0.3446875	0.0208	0.1247	10,000,000	N/A	N/A
1/2	0.840	0.015625	0.109	0.0672	12.5%	0.01363	0.400	3,692	3,692	0.855625	0.0282075	0.4278125	0.3996050	0.0071	0.0423	10,000,000	N/A	N/A
1/2	0.840	0.015625	0.147	0.0672	12.5%	0.01838	0.400	1,640	1,640	0.855625	0.0614575	0.4278125	0.3663550	0.0154	0.0922	10,000,000	N/A	N/A
1/2	0.840	0.015625	0.188	0.0672	12.5%	0.02350	0.400	999	999	0.855625	0.0973325	0.4278125	0.3304800	0.0243	0.1460	10,000,000	N/A	N/A
1/2	0.840	0.015625	0.294	0.0672	12.5%	0.03675	0.357	473	473	0.855625	0.1900825	0.4278125	0.2377300	0.0475	0.2851	10,000,000	N/A	N/A
3/4	1.050	0.015625	0.065	0.0000	12.5%	0.00813	0.400	2,242	2,242	1.065625	0.0568750	0.5328125	0.4759375	0.0142	0.0853	10,000,000	N/A	N/A
3/4	1.050	0.015625	0.083	0.0000	12.5%	0.01038	0.400	1,734	1,734	1.065625	0.0726250	0.5328125	0.4601875	0.0182	0.1089	10,000,000	N/A	N/A
3/4	1.050	0.015625	0.095	0.0000	12.5%	0.01188	0.400	1,502	1,502	1.065625	0.0831250	0.5328125	0.4496875	0.0208	0.1247	10,000,000	N/A	N/A
3/4	1.050	0.015625	0.113	0.0669	12.5%	0.01413	0.400	4,072	4,072	1.065625	0.0319275	0.5328125	0.5008850	0.0080	0.0479	10,000,000	N/A	N/A
3/4	1.050	0.015625	0.154	0.0669	12.5%	0.01925	0.400	1,865	1,865	1.065625	0.0678025	0.5328125	0.4650100	0.0170	0.1017	10,000,000	N/A	N/A
3/4	1.050	0.015625	0.219	0.0669	12.5%	0.02738	0.400	968	968	1.065625	0.1246775	0.5328125	0.4081350	0.0312	0.1870	10,000,000	N/A	N/A
3/4	1.050	0.015625	0.308	0.0669	12.5%	0.03850	0.383	562	562	1.065625	0.2025525	0.5328125	0.3302600	0.0506	0.3038	10,000,000	N/A	N/A
1	1.315	0.015625	0.065	0.0000	12.5%	0.00813	0.400	2,824	2,824	1.330625	0.0568750	0.6653125	0.6084375	0.0142	0.0853	10,000,000	N/A	N/A
1	1.315	0.015625	0.109	0.0000	12.5%	0.01363	0.400	1,644	1,644	1.330625	0.0953750	0.6653125	0.5699375	0.0238	0.1431	10,000,000	N/A	N/A
1	1.315	0.015625	0.114	0.0808	12.5%	0.01425	0.400	8,669	8,669	1.330625	0.0189675	0.6653125	0.6463450	0.0047	0.0285	4,620,000	0.0151	0.0236
1	1.315	0.015625	0.133	0.0808	12.5%	0.01663	0.400	4,573	4,573	1.330625	0.0355925	0.6653125	0.6297200	0.0089	0.0534	10,000,000	N/A	N/A
1	1.315	0.015625	0.179	0.0808	12.5%	0.02238	0.400	2,093	2,093	1.330625	0.0758425	0.6653125	0.5894700	0.0190	0.1138	10,000,000	N/A	N/A
1	1.315	0.015625	0.250	0.0808	12.5%	0.03125	0.400	1,106	1,106	1.330625	0.1379675	0.6653125	0.5273450	0.0345	0.2070	10,000,000	N/A	N/A
1	1.315	0.015625	0.358	0.0808	12.5%	0.04475	0.394	617	617	1.330625	0.2324675	0.6653125	0.4328450	0.0581	0.3487	10,000,000	N/A	N/A
1 1/4	1.660	0.015625	0.065	0.0000	12.5%	0.00813	0.400	3,583	3,583	1.675625	0.0568750	0.8378125	0.7809375	0.0142	0.0853	10,000,000	N/A	N/A
1 1/4	1.660	0.015625	0.109	0.0000	12.5%	0.01363	0.400	2,096	2,096	1.675625	0.0953750	0.8378125	0.7424375	0.0238	0.1431	10,000,000	N/A	N/A
1 1/4	1.660	0.015625	0.117	0.0809	12.5%	0.01463	0.400	9,657	9,657	1.675625	0.0214675	0.8378125	0.8163450	0.0054	0.0322	3,100,000	0.0171	0.0266
1 1/4	1.660	0.015625	0.140	0.0809	12.5%	0.01750	0.400	4,936	4,936	1.675625	0.0415925	0.8378125	0.7962200	0.0104	0.0624	10,000,000	N/A	N/A
1 1/4	1.660	0.015625	0.191	0.0809	12.5%	0.02388	0.400	2,329	2,329	1.675625	0.0862175	0.8378125	0.7515950	0.0216	0.1293	10,000,000	N/A	N/A
1 1/4	1.660	0.015625	0.250	0.0809	12.5%	0.03125	0.400	1,420	1,420	1.675625	0.1378425	0.8378125	0.6999700	0.0345	0.2068	10,000,000	N/A	N/A
1 1/4	1.660	0.015625	0.382	0.0809	12.5%	0.04775	0.400	727	727	1.675625	0.2533425	0.8378125	0.5844700	0.0633	0.3800	10,000,000	N/A	N/A
1 1/2	1.900	0.015625	0.065	0.0000	12.5%	0.00813	0.400	4,110	4,110	1.915625	0.0568750	0.9578125	0.9009375	0.0142	0.0853	10,000,000	N/A	N/A
1 1/2	1.900	0.015625	0.109	0.0000	12.5%	0.01363	0.400	2,411	2,411	1.915625	0.0953750	0.9578125	0.8624375	0.0238	0.1431	10,000,000	N/A	N/A
1 1/2	1.900	0.015625	0.125	0.0814	12.5%	0.01563	0.400	8,468	8,468	1.915625	0.0279475	0.9578125	0.9298650	0.0070	0.0419	4,060,000	0.0223	0.0348
1 1/2	1.900	0.015625	0.145	0.0814	12.5%	0.01813	0.400	5,169	5,169	1.915625	0.0454475	0.9578125	0.9123650	0.0114	0.0682	10,000,000	N/A	N/A
1 1/2	1.900	0.015625	0.200	0.0814	12.5%	0.02500	0.400	2,459	2,459	1.915625	0.0935725	0.9578125	0.8642400	0.0234	0.1404	10,000,000	N/A	N/A
1 1/2	1.900	0.015625	0.281	0.0814	12.5%	0.03513	0.400	1,356	1,356	1.915625	0.1644475	0.9578125	0.7933650	0.0411	0.2467	10,000,000	N/A	N/A
1 1/2	1.900	0.015625	0.400	0.0814	12.5%	0.05000	0.400	792	792	1.915625	0.2685725	0.9578125	0.6892400	0.0671	0.4029	10,000,000	N/A	N/A
2	2.375	0.02375	0.065	0.0000	12.5%	0.00813	0.400	5,172	5,172	2.398750	0.0568750	1.1993750	1.1425000	0.0142	0.0853	10,000,000	N/A	N/A
2	2.375	0.02375	0.083	0.0000	12.5%	0.01038	0.400	4,029	4,029	2.398750	0.0726250	1.1993750	1.1267500	0.0182	0.1089	10,000,000	N/A	N/A
2	2.375	0.02375	0.109	0.0000	12.5%	0.01363	0.400	3,044	3,044	2.398750	0.0953750	1.1993750	1.1040000	0.0238	0.1431	10,000,000	N/A	N/A
2	2.375	0.02375	0.141	0.0860	12.5%	0.01763	0.400	7,928	7,928	2.398750	0.0373500	1.1993750	1.1620250	0.0093	0.0560	4,300,000	0.0298	0.0463
2	2.375	0.02375	0.154	0.0860	12.5%	0.01925	0.400	6,054	6,054	2.398750	0.0487250	1.1993750	1.1506500	0.0122	0.0731	8,460,000	0.0390	0.0605
2	2.375	0.02375	0.172	0.0860	12.5%	0.02150	0.400	4,551	4,551	2.398750	0.0644750	1.1993750	1.1349000	0.0161	0.0967	10,000,000	N/A	N/A
2	2.375	0.02375	0.188	0.0860	12.5%	0.02350	0.400	3,721	3,721	2.398750	0.0784750	1.1993750	1.1209000	0.0196	0.1177	10,000,000	N/A	N/A
2	2.375	0.02375	0.218	0.0860	12.5%	0.02725	0.400	2,763	2,763	2.398750	0.1047250	1.1993750	1.0946500	0.0262	0.1571	10,000,000	N/A	N/A
2	2.375	0.02375	0.250	0.0860	12.5%	0.03125	0.400	2,159	2,159	2.398750	0.1327250	1.1993750	1.0666500	0.0332	0.1991	10,000,000	N/A	N/A
2	2.375	0.02375	0.281	0.0860	12.5%	0.03513	0.400	1,776	1,776	2.398750	0.1598500	1.1993750	1.0395250	0.0400	0.2398	10,000,000	N/A	N/A
2	2.375	0.02375	0.344	0.0860	12.5%	0.04300	0.400	1,295	1,295	2.398750	0.2149750	1.1993750	0.9844000	0.0537	0.3225	10,000,000	N/A	N/A
2	2.375	0.02375	0.436	0.0860	12.5%	0.05450	0.400	915	915	2.398750	0.2954750	1.1993750	0.9039000	0.0739	0.4432	10,000,000	N/A	N/A

Maximum Developed Membrane Stress: 9,657

Table 3 - Soft Annealed Seamless Copper Tubing
(Material Specification ASTM B-75)

Size	D in.	c_D in.	t_m in.	c in.	α	c_t in.	Y	Membrane Stress, psi	Analysis Membrane Stress, psi	$D + c_D$ in.	$t_c = t_m - c_t - c$ in.	Outer Radius R_o, in.	Inner Radius R_i, in.	Postulated Crack Depth a, in.	Postulated Crack Length, 2C, in.	Cycles to Through-Wall Transition	Depth "a" after transition, in.	Length "C" after transition, in.
1/8	0.125	0.002	0.028	0.0000	N/A	0.0030	0.377	324	324	0.12700	0.02500	0.06350	0.03850	0.0063	0.0375	10,000,000	N/A	N/A
1/8	0.125	0.002	0.035	0.0000	N/A	0.0030	0.332	248	248	0.12700	0.03200	0.06350	0.03150	0.0080	0.0480	10,000,000	N/A	N/A
3/16	0.1875	0.002	0.028	0.0000	N/A	0.0025	0.400	497	497	0.18950	0.02550	0.09475	0.06925	0.0064	0.0383	10,000,000	N/A	N/A
3/16	0.1875	0.002	0.035	0.0000	N/A	0.0030	0.398	384	384	0.18950	0.03200	0.09475	0.06275	0.0080	0.0480	10,000,000	N/A	N/A
3/16	0.1875	0.002	0.049	0.0000	N/A	0.0030	0.340	258	258	0.18950	0.04600	0.09475	0.04875	0.0115	0.0690	10,000,000	N/A	N/A
1/4	0.250	0.002	0.028	0.0000	N/A	0.0025	0.400	681	681	0.25200	0.02550	0.12600	0.10050	0.0064	0.0383	10,000,000	N/A	N/A
1/4	0.250	0.002	0.035	0.0000	N/A	0.0030	0.400	531	531	0.25200	0.03200	0.12600	0.09400	0.0080	0.0480	10,000,000	N/A	N/A
1/4	0.250	0.002	0.049	0.0000	N/A	0.0030	0.388	353	353	0.25200	0.04600	0.12600	0.08000	0.0115	0.0690	10,000,000	N/A	N/A
1/4	0.250	0.002	0.065	0.0000	N/A	0.0035	0.339	257	257	0.25200	0.06150	0.12600	0.06450	0.0154	0.0923	10,000,000	N/A	N/A
5/16	0.3125	0.002	0.035	0.0000	N/A	0.0030	0.400	677	677	0.31450	0.03200	0.15725	0.12525	0.0080	0.0480	10,000,000	N/A	N/A
5/16	0.3125	0.002	0.049	0.0000	N/A	0.0030	0.400	453	453	0.31450	0.04600	0.15725	0.11125	0.0115	0.0690	10,000,000	N/A	N/A
5/16	0.3125	0.002	0.065	0.0000	N/A	0.0035	0.378	327	327	0.31450	0.06150	0.15725	0.09575	0.0154	0.0923	10,000,000	N/A	N/A
3/8	0.375	0.002	0.035	0.0000	N/A	0.0030	0.400	824	824	0.37700	0.03200	0.18850	0.15650	0.0080	0.0480	10,000,000	N/A	N/A
3/8	0.375	0.002	0.049	0.0000	N/A	0.0030	0.400	555	555	0.37700	0.04600	0.18850	0.14250	0.0115	0.0690	10,000,000	N/A	N/A
3/8	0.375	0.002	0.065	0.0000	N/A	0.0035	0.400	400	400	0.37700	0.06150	0.18850	0.12700	0.0154	0.0923	10,000,000	N/A	N/A
1/2	0.500	0.002	0.035	0.0000	N/A	0.0030	0.400	1,117	1,117	0.50200	0.03200	0.25100	0.21900	0.0080	0.0480	10,000,000	N/A	N/A
1/2	0.500	0.002	0.049	0.0000	N/A	0.0030	0.400	758	758	0.50200	0.04600	0.25100	0.20500	0.0115	0.0690	10,000,000	N/A	N/A
1/2	0.500	0.002	0.065	0.0000	N/A	0.0035	0.400	552	552	0.50200	0.06150	0.25100	0.18950	0.0154	0.0923	10,000,000	N/A	N/A
1/2	0.500	0.002	0.083	0.0000	N/A	0.0040	0.400	417	417	0.50200	0.07900	0.25100	0.17200	0.0198	0.1185	10,000,000	N/A	N/A
5/8	0.625	0.002	0.049	0.0000	N/A	0.0030	0.400	962	962	0.62700	0.04600	0.31350	0.26750	0.0115	0.0690	10,000,000	N/A	N/A
5/8	0.625	0.002	0.065	0.0000	N/A	0.0035	0.400	705	705	0.62700	0.06150	0.31350	0.25200	0.0154	0.0923	10,000,000	N/A	N/A
5/8	0.625	0.002	0.083	0.0000	N/A	0.0040	0.400	535	535	0.62700	0.07900	0.31350	0.23450	0.0198	0.1185	10,000,000	N/A	N/A
5/8	0.625	0.002	0.095	0.0000	N/A	0.0040	0.400	457	457	0.62700	0.09100	0.31350	0.22250	0.0228	0.1365	10,000,000	N/A	N/A
3/4	0.750	0.0025	0.049	0.0000	N/A	0.0035	0.400	1,180	1,180	0.75250	0.04550	0.37625	0.33075	0.0114	0.0683	10,000,000	N/A	N/A
3/4	0.750	0.0025	0.065	0.0000	N/A	0.0040	0.400	865	865	0.75250	0.06100	0.37625	0.31525	0.0153	0.0915	10,000,000	N/A	N/A
3/4	0.750	0.0025	0.083	0.0000	N/A	0.0050	0.400	664	664	0.75250	0.07800	0.37625	0.29825	0.0195	0.1170	10,000,000	N/A	N/A
3/4	0.750	0.0025	0.095	0.0000	N/A	0.0050	0.400	567	567	0.75250	0.09000	0.37625	0.28625	0.0225	0.1350	10,000,000	N/A	N/A
3/4	0.750	0.0025	0.109	0.0000	N/A	0.0050	0.400	483	483	0.75250	0.10400	0.37625	0.27225	0.0260	0.1560	10,000,000	N/A	N/A
7/8	0.875	0.0025	0.049	0.0000	N/A	0.0035	0.400	1,386	1,386	0.87750	0.04550	0.43875	0.39325	0.0114	0.0683	10,000,000	N/A	N/A
7/8	0.875	0.0025	0.065	0.0000	N/A	0.0040	0.400	1,019	1,019	0.87750	0.06100	0.43875	0.37775	0.0153	0.0915	10,000,000	N/A	N/A
7/8	0.875	0.0025	0.083	0.0000	N/A	0.0050	0.400	784	784	0.87750	0.07800	0.43875	0.36075	0.0195	0.1170	10,000,000	N/A	N/A
7/8	0.875	0.0025	0.095	0.0000	N/A	0.0050	0.400	671	671	0.87750	0.09000	0.43875	0.34875	0.0225	0.1350	10,000,000	N/A	N/A
7/8	0.875	0.0025	0.109	0.0000	N/A	0.0050	0.400	573	573	0.87750	0.10400	0.43875	0.33475	0.0260	0.1560	10,000,000	N/A	N/A
1	1.000	0.0025	0.049	0.0000	N/A	0.0035	0.400	1,592	1,592	1.00250	0.04550	0.50125	0.45575	0.0114	0.0683	10,000,000	N/A	N/A
1	1.000	0.0025	0.065	0.0000	N/A	0.0040	0.400	1,173	1,173	1.00250	0.06100	0.50125	0.44025	0.0153	0.0915	10,000,000	N/A	N/A
1	1.000	0.0025	0.083	0.0000	N/A	0.0050	0.400	904	904	1.00250	0.07800	0.50125	0.42325	0.0195	0.1170	10,000,000	N/A	N/A
1	1.000	0.0025	0.095	0.0000	N/A	0.0050	0.400	775	775	1.00250	0.09000	0.50125	0.41125	0.0225	0.1350	10,000,000	N/A	N/A
1	1.000	0.0025	0.109	0.0000	N/A	0.0050	0.400	663	663	1.00250	0.10400	0.50125	0.39725	0.0260	0.1560	10,000,000	N/A	N/A
1	1.000	0.0025	0.120	0.0000	N/A	0.0060	0.400	600	600	1.00250	0.11400	0.50125	0.38725	0.0285	0.1710	10,000,000	N/A	N/A
1 1/8	1.125	0.003	0.065	0.0000	N/A	0.0040	0.400	1,327	1,327	1.12800	0.06100	0.56400	0.50300	0.0153	0.0915	10,000,000	N/A	N/A
1 1/8	1.125	0.003	0.083	0.0000	N/A	0.0050	0.400	1,025	1,025	1.12800	0.07800	0.56400	0.48600	0.0195	0.1170	10,000,000	N/A	N/A
1 1/8	1.125	0.003	0.095	0.0000	N/A	0.0050	0.400	880	880	1.12800	0.09000	0.56400	0.47400	0.0225	0.1350	10,000,000	N/A	N/A
1 1/8	1.125	0.003	0.109	0.0000	N/A	0.0050	0.400	753	753	1.12800	0.10400	0.56400	0.46000	0.0260	0.1560	10,000,000	N/A	N/A
1 1/8	1.125	0.003	0.120	0.0000	N/A	0.0060	0.400	682	682	1.12800	0.11400	0.56400	0.45000	0.0285	0.1710	10,000,000	N/A	N/A
1 1/8	1.125	0.003	0.134	0.0000	N/A	0.0060	0.400	601	601	1.12800	0.12800	0.56400	0.43600	0.0320	0.1920	10,000,000	N/A	N/A
1 1/4	1.250	0.003	0.032	0.0000	N/A	0.0030	0.400	3,181	3,181	1.25300	0.02900	0.62650	0.59750	0.0073	0.0435	10,000,000	N/A	N/A
1 1/4	1.250	0.003	0.065	0.0000	N/A	0.0040	0.400	1,481	1,481	1.25300	0.06100	0.62650	0.56550	0.0153	0.0915	10,000,000	N/A	N/A
1 1/2	1.500	0.003	0.032	0.0000	N/A	0.0030	0.400	3,827	3,827	1.50300	0.02900	0.75150	0.72250	0.0073	0.0435	7,930,000	0.0232	0.0360
1 1/2	1.500	0.003	0.065	0.0000	N/A	0.0040	0.400	1,788	1,788	1.50300	0.06100	0.75150	0.69050	0.0153	0.0915	10,000,000	N/A	N/A
2	2.000	0.003	0.032	0.0000	N/A	0.0030	0.400	5,120	5,120	2.00300	0.02900	1.00150	0.97250	0.0073	0.0435	3,110,000	0.0231	0.0360
2	2.000	0.003	0.065	0.0000	N/A	0.0040	0.400	2,403	2,403	2.00300	0.06100	1.00150	0.94050	0.0153	0.0915	10,000,000	N/A	N/A
2	2.000	0.003	0.070	0.0000	N/A	0.0040	0.400	2,216	2,216	2.00300	0.06600	1.00150	0.93550	0.0165	0.0990	10,000,000	N/A	N/A
2	2.000	0.003	0.083	0.0000	N/A	0.0050	0.400	1,866	1,866	2.00300	0.07800	1.00150	0.92350	0.0195	0.1170	10,000,000	N/A	N/A

Maximum Developed Membrane Stress: 5,120

Table 4 - Soft Annealed Seamless Copper Tubing
(Material Specification ASTM B-88 Types K, L, and M)

Size	D in.	c_D in.	t_m in.	c in.	α	c_t in.	Y	Membrane Stress, psi	Analysis Membrane Stress, psi	$D + c_D$ in.	$t_c = t_m - c_t - c$ in.	Outer Radius R_o, in.	Inner Radius R_i, in.	Postulated Crack Depth a, in.	Postulated Crack Length, 2C, in.	Cycles to Through-Wall Transition	Depth "a" after transition, in.	Length "C" after transition, in.
Type K																		
1/4	0.375	0.0020	0.035	0.0000	N/A	0.0035	0.400	838	838	0.3770	0.0315	0.1885	0.1570	0.007875	0.04725	10,000,000	N/A	N/A
3/8	0.500	0.0025	0.049	0.0000	N/A	0.0050	0.400	797	797	0.5025	0.0440	0.2513	0.2073	0.011000	0.06600	10,000,000	N/A	N/A
1/2	0.625	0.0025	0.049	0.0000	N/A	0.0050	0.400	1,010	1,010	0.6275	0.0440	0.3138	0.2698	0.011000	0.06600	10,000,000	N/A	N/A
5/8	0.750	0.0025	0.049	0.0000	N/A	0.0050	0.400	1,223	1,223	0.7525	0.0440	0.3763	0.3323	0.011000	0.06600	10,000,000	N/A	N/A
3/4	0.875	0.0030	0.065	0.0000	N/A	0.0060	0.400	1,056	1,056	0.8780	0.0590	0.4390	0.3800	0.014750	0.08850	10,000,000	N/A	N/A
1	1.125	0.0035	0.065	0.0000	N/A	0.0060	0.400	1,375	1,375	1.1285	0.0590	0.5643	0.5053	0.014750	0.08850	10,000,000	N/A	N/A
1 1/4	1.375	0.0040	0.065	0.0000	N/A	0.0060	0.400	1,693	1,693	1.3790	0.0590	0.6895	0.6305	0.014750	0.08850	10,000,000	N/A	N/A
1 1/2	1.625	0.0045	0.072	0.0000	N/A	0.0070	0.400	1,820	1,820	1.6295	0.0650	0.8148	0.7498	0.016250	0.09750	10,000,000	N/A	N/A
2	2.125	0.0050	0.083	0.0000	N/A	0.0080	0.400	2,070	2,070	2.1300	0.0750	1.0650	0.9900	0.018750	0.11250	10,000,000	N/A	N/A
Type L																		
1/4	0.375	0.0020	0.030	0.0000	N/A	0.0030	0.400	987	987	0.3770	0.0270	0.1885	0.1615	0.006750	0.04050	10,000,000	N/A	N/A
3/8	0.500	0.0025	0.035	0.0000	N/A	0.0040	0.400	1,156	1,156	0.5025	0.0310	0.2513	0.2203	0.007750	0.04650	10,000,000	N/A	N/A
1/2	0.625	0.0025	0.040	0.0000	N/A	0.0040	0.400	1,247	1,247	0.6275	0.0360	0.3138	0.2778	0.009000	0.05400	10,000,000	N/A	N/A
5/8	0.750	0.0025	0.042	0.0000	N/A	0.0040	0.400	1,425	1,425	0.7525	0.0380	0.3763	0.3383	0.009500	0.05700	10,000,000	N/A	N/A
3/4	0.875	0.0030	0.045	0.0000	N/A	0.0040	0.400	1,546	1,546	0.8780	0.0410	0.4390	0.3980	0.010250	0.06150	10,000,000	N/A	N/A
1	1.125	0.0035	0.050	0.0000	N/A	0.0050	0.400	1,821	1,821	1.1285	0.0450	0.5643	0.5193	0.011250	0.06750	10,000,000	N/A	N/A
1 1/4	1.375	0.0040	0.055	0.0000	N/A	0.0060	0.400	2,051	2,051	1.3790	0.0490	0.6895	0.6405	0.012250	0.07350	10,000,000	N/A	N/A
1 1/2	1.625	0.0045	0.060	0.0000	N/A	0.0060	0.400	2,203	2,203	1.6295	0.0540	0.8148	0.7608	0.013500	0.08100	10,000,000	N/A	N/A
2	2.125	0.0050	0.070	0.0000	N/A	0.0070	0.400	2,476	2,476	2.1300	0.0630	1.0650	1.0020	0.015750	0.09450	10,000,000	N/A	N/A
Type M																		
1/4	0.375	0.0020	N/A	0.0000	N/A	0.0000	0.000	N/A	N/A	0.3770	N/A	0.1885	N/A	N/A	N/A	N/A	N/A	N/A
3/8	0.500	0.0025	0.025	0.0000	N/A	0.0020	0.400	1,579	1,579	0.5025	0.0230	0.2513	0.2283	0.005750	0.03450	10,000,000	N/A	N/A
1/2	0.625	0.0025	0.028	0.0000	N/A	0.0030	0.400	1,823	1,823	0.6275	0.0250	0.3138	0.2888	0.006250	0.03750	10,000,000	N/A	N/A
5/8	0.750	0.0025	N/A	0.0000	N/A	0.0000	0.000	N/A	N/A	0.7525	N/A	0.3763	N/A	N/A	N/A	N/A	N/A	N/A
3/4	0.875	0.0030	0.032	0.0000	N/A	0.0030	0.400	2,211	2,211	0.8780	0.0290	0.4390	0.4100	0.007250	0.04350	10,000,000	N/A	N/A
1	1.125	0.0035	0.035	0.0000	N/A	0.0040	0.400	2,670	2,670	1.1285	0.0310	0.5643	0.5333	0.007750	0.04650	10,000,000	N/A	N/A
1 1/4	1.375	0.0040	0.042	0.0000	N/A	0.0040	0.400	2,662	2,662	1.3790	0.0380	0.6895	0.6515	0.009500	0.05700	10,000,000	N/A	N/A
1 1/2	1.625	0.0045	0.049	0.0000	N/A	0.0050	0.400	2,718	2,718	1.6295	0.0440	0.8148	0.7708	0.011000	0.06600	10,000,000	N/A	N/A
2	2.125	0.0050	0.058	0.0000	N/A	0.0060	0.400	3,012	3,012	2.1300	0.0520	1.0650	1.0130	0.013000	0.07800	10,000,000	N/A	N/A

Maximum Developed Membrane Stress: 3,012

Table 5 - Seamless Aluminum Tubing
(Material Specification ASTM B-210 Type 6061-T6)

Size	D in.	c_D in.	t_m in.	c in.	α	c_t in.	Y	Membrane Stress, psi	Analysis Membrane Stress, psi	D + c_D in.	$t_c = t_m - c_t - c$ in.	Outer Radius R_o, in.	Inner Radius R_i, in.	Postulated Crack Depth a, in.	Postulated Crack Length, 2C, in.	Cycles to Through-Wall Transition	Depth "a" after transition, in.	Length "C" after transition, in.
1/8	0.125	0.006	0.035	0.000	N/A	0.002	0.332	248	248	0.1310	0.0330	0.0655	0.0325	0.0083	0.0495	10,000,000	N/A	N/A
3/16	0.1875	0.006	0.035	0.000	N/A	0.002	0.397	380	380	0.1935	0.0330	0.0968	0.0638	0.0083	0.0495	10,000,000	N/A	N/A
3/16	0.1875	0.006	0.049	0.000	N/A	0.003	0.344	264	264	0.1935	0.0460	0.0968	0.0508	0.0115	0.0690	10,000,000	N/A	N/A
1/4	0.250	0.006	0.035	0.000	N/A	0.002	0.400	522	522	0.2560	0.0330	0.1280	0.0950	0.0083	0.0495	10,000,000	N/A	N/A
1/4	0.250	0.006	0.049	0.000	N/A	0.003	0.390	359	359	0.2560	0.0460	0.1280	0.0820	0.0115	0.0690	10,000,000	N/A	N/A
5/16	0.3125	0.006	0.035	0.000	N/A	0.002	0.400	664	664	0.3185	0.0330	0.1593	0.1263	0.0083	0.0495	10,000,000	N/A	N/A
5/16	0.3125	0.006	0.049	0.000	N/A	0.003	0.400	459	459	0.3185	0.0460	0.1593	0.1133	0.0115	0.0690	10,000,000	N/A	N/A
3/8	0.375	0.006	0.035	0.000	N/A	0.002	0.400	806	806	0.3810	0.0330	0.1905	0.1575	0.0083	0.0495	10,000,000	N/A	N/A
3/8	0.375	0.006	0.049	0.000	N/A	0.003	0.400	561	561	0.3810	0.0460	0.1905	0.1445	0.0115	0.0690	10,000,000	N/A	N/A
3/8	0.375	0.006	0.065	0.000	N/A	0.004	0.400	408	408	0.3810	0.0610	0.1905	0.1295	0.0153	0.0915	10,000,000	N/A	N/A
1/2	0.500	0.006	0.035	0.000	N/A	0.002	0.400	1,090	1,090	0.5060	0.0330	0.2530	0.2200	0.0083	0.0495	6,000,000	0.0264	0.0405
1/2	0.500	0.006	0.049	0.000	N/A	0.003	0.400	765	765	0.5060	0.0460	0.2530	0.2070	0.0115	0.0690	10,000,000	N/A	N/A
1/2	0.500	0.006	0.065	0.000	N/A	0.004	0.400	562	562	0.5060	0.0610	0.2530	0.1920	0.0153	0.0915	10,000,000	N/A	N/A
1/2	0.500	0.006	0.120	0.000	N/A	0.005	0.353	277	277	0.5060	0.1150	0.2530	0.1380	0.0288	0.1725	10,000,000	N/A	N/A
5/8	0.625	0.008	0.035	0.000	N/A	0.002	0.400	1,379	1,379	0.6330	0.0330	0.3165	0.2835	0.0083	0.0495	3,460,000	0.0263	0.0405
5/8	0.625	0.008	0.049	0.000	N/A	0.003	0.400	972	972	0.6330	0.0460	0.3165	0.2705	0.0115	0.0690	7,500,000	0.0368	0.0564
5/8	0.625	0.008	0.058	0.000	N/A	0.004	0.400	819	819	0.6330	0.0540	0.3165	0.2625	0.0135	0.0810	10,000,000	N/A	N/A
5/8	0.625	0.008	0.065	0.000	N/A	0.004	0.400	718	718	0.6330	0.0610	0.3165	0.2555	0.0153	0.0915	10,000,000	N/A	N/A
5/8	0.625	0.008	0.125	0.000	N/A	0.006	0.384	341	341	0.6330	0.1190	0.3165	0.1975	0.0298	0.1785	10,000,000	N/A	N/A
3/4	0.750	0.008	0.035	0.000	N/A	0.002	0.400	1,663	1,663	0.7580	0.0330	0.3790	0.3460	0.0083	0.0495	2,238,000	0.0263	0.0405
3/4	0.750	0.008	0.049	0.000	N/A	0.003	0.400	1,176	1,176	0.7580	0.0460	0.3790	0.3330	0.0115	0.0690	4,800,000	0.0367	0.0564
3/4	0.750	0.008	0.065	0.000	N/A	0.004	0.400	872	872	0.7580	0.0610	0.3790	0.3180	0.0153	0.0915	9,240,000	0.0487	0.0746
3/4	0.750	0.008	0.083	0.000	N/A	0.004	0.400	660	660	0.7580	0.0790	0.3790	0.3000	0.0198	0.1185	10,000,000	N/A	N/A
3/4	0.750	0.008	0.125	0.000	N/A	0.006	0.400	418	418	0.7580	0.1190	0.3790	0.2600	0.0298	0.1785	10,000,000	N/A	N/A
7/8	0.875	0.008	0.049	0.000	N/A	0.003	0.400	1,380	1,380	0.8830	0.0460	0.4415	0.3955	0.0115	0.0690	3,310,000	0.0368	0.0566
7/8	0.875	0.008	0.065	0.000	N/A	0.004	0.400	1,026	1,026	0.8830	0.0610	0.4415	0.3805	0.0153	0.0915	6,320,000	0.0488	0.0748
7/8	0.875	0.008	0.125	0.000	N/A	0.006	0.400	497	497	0.8830	0.1190	0.4415	0.3225	0.0298	0.1785	10,000,000	N/A	N/A
1	1.000	0.008	0.035	0.000	N/A	0.002	0.400	2,231	2,231	1.0080	0.0330	0.5040	0.4710	0.0083	0.0495	1,129,000	0.0263	0.0406
1	1.000	0.008	0.049	0.000	N/A	0.003	0.400	1,583	1,583	1.0080	0.0460	0.5040	0.4580	0.0115	0.0690	2,400,000	0.0367	0.0565
1	1.000	0.008	0.058	0.000	N/A	0.004	0.400	1,340	1,340	1.0080	0.0540	0.5040	0.4500	0.0135	0.0810	3,460,000	0.0432	0.0664
1	1.000	0.008	0.065	0.000	N/A	0.004	0.400	1,179	1,179	1.0080	0.0610	0.5040	0.4430	0.0153	0.0915	4,560,000	0.0487	0.0748
1	1.000	0.008	0.083	0.000	N/A	0.004	0.400	897	897	1.0080	0.0790	0.5040	0.4250	0.0198	0.1185	8,330,000	0.0632	0.0968
1	1.000	0.008	0.095	0.000	N/A	0.005	0.400	780	780	1.0080	0.0900	0.5040	0.4140	0.0225	0.1350	10,000,000	N/A	N/A
1	1.000	0.008	0.125	0.000	N/A	0.006	0.400	575	575	1.0080	0.1190	0.5040	0.3850	0.0298	0.1785	10,000,000	N/A	N/A
1 1/4	1.250	0.010	0.065	0.000	N/A	0.004	0.400	1,489	1,489	1.2600	0.0610	0.6300	0.5690	0.0153	0.0915	2,650,000	0.0488	0.0750
1 1/4	1.250	0.010	0.083	0.000	N/A	0.004	0.400	1,136	1,136	1.2600	0.0790	0.6300	0.5510	0.0198	0.1185	4,790,000	0.0631	0.0969
1 1/4	1.250	0.010	0.125	0.000	N/A	0.006	0.400	734	734	1.2600	0.1190	0.6300	0.5110	0.0298	0.1785	10,000,000	N/A	N/A
1 1/2	1.500	0.010	0.065	0.000	N/A	0.004	0.400	1,797	1,797	1.5100	0.0610	0.7550	0.6940	0.0153	0.0915	1,710,000	0.0487	0.0750
1 1/2	1.500	0.010	0.125	0.000	N/A	0.006	0.400	892	892	1.5100	0.1190	0.7550	0.6360	0.0298	0.1785	7,940,000	0.0951	0.1457
1 3/4	1.750	0.010	0.125	0.000	N/A	0.006	0.400	1,049	1,049	1.7600	0.1190	0.8800	0.7610	0.0298	0.1785	5,430,000	0.0950	0.1458
1 3/4	1.750	0.010	0.250	0.000	N/A	0.008	0.400	485	485	1.7600	0.2420	0.8800	0.6380	0.0605	0.3630	10,000,000	N/A	N/A
2	2.000	0.010	0.049	0.000	N/A	0.003	0.400	3,217	3,217	2.0100	0.0460	1.0050	0.9590	0.0115	0.0690	462,100	0.0367	0.0568
2	2.000	0.010	0.065	0.000	N/A	0.004	0.400	2,411	2,411	2.0100	0.0610	1.0050	0.9440	0.0153	0.0915	861,900	0.0486	0.0751
2	2.000	0.010	0.125	0.000	N/A	0.006	0.400	1,207	1,207	2.0100	0.1190	1.0050	0.8860	0.0298	0.1785	3,910,000	0.0949	0.1459

Maximum Developed Membrane Stress: 3,217

Table 6 - Welded Stainless Steel Piping
(Material Specification ASTM A-312 TP 304/316)

Size	D in.	c_D in.	t_m in.	c in.	α	c_t in.	Y	Membrane Stress, psi	Analysis Membrane Stress, psi	D + c_D in.	$t_c = t_m - c_t - c$ in.	Outer Radius R_o, in.	Inner Radius R_i, in.	Postulated Crack Depth a, in.	Postulated Crack Length, 2C, in.	Cycles to Through-Wall Transition	Depth "a" after transition, in.	Length "C" after transition, in.
1/8 (Pipe)	0.405	0.0156	0.068	0.0383	12.5%	0.009	0.400	1,786	4,926	0.4206	0.0212	0.2103	0.1891	0.0053	0.0318	10,000,000	N/A	N/A
1/8 (Pipe)	0.405	0.0156	0.095	0.0383	12.5%	0.012	0.400	805	4,926	0.4206	0.0448	0.2103	0.1655	0.0112	0.0672	10,000,000	N/A	N/A
1/4 (Pipe)	0.540	0.0156	0.088	0.0542	12.5%	0.011	0.400	2,210	4,926	0.5556	0.0228	0.2778	0.2550	0.0057	0.0342	10,000,000	N/A	N/A
1/4 (Pipe)	0.540	0.0156	0.119	0.0542	12.5%	0.015	0.400	968	4,926	0.5556	0.0499	0.2778	0.2279	0.0125	0.0749	10,000,000	N/A	N/A
3/8 (Pipe)	0.675	0.0156	0.091	0.0540	12.5%	0.011	0.400	2,453	4,926	0.6906	0.0256	0.3453	0.3197	0.0064	0.0384	10,000,000	N/A	N/A
3/8 (Pipe)	0.675	0.0156	0.126	0.0540	12.5%	0.016	0.400	1,076	4,926	0.6906	0.0562	0.3453	0.2891	0.0141	0.0844	10,000,000	N/A	N/A
1/2 (Pipe)	0.840	0.0156	0.065	0.0000	12.5%	0.008	0.400	1,335	4,926	0.8556	0.0569	0.4278	0.3709	0.0142	0.0853	10,000,000	N/A	N/A
1/2 (Pipe)	0.840	0.0156	0.083	0.0000	12.5%	0.010	0.400	1,029	4,926	0.8556	0.0726	0.4278	0.3552	0.0182	0.1089	10,000,000	N/A	N/A
1/2 (Pipe)	0.840	0.0156	0.109	0.0672	12.5%	0.014	0.400	2,767	4,926	0.8556	0.0282	0.4278	0.3996	0.0071	0.0423	10,000,000	N/A	N/A
1/2 (Pipe)	0.840	0.0156	0.147	0.0672	12.5%	0.018	0.400	1,230	4,926	0.8556	0.0615	0.4278	0.3663	0.0154	0.0922	10,000,000	N/A	N/A
3/4 (Pipe)	1.050	0.0156	0.065	0.0000	12.5%	0.008	0.400	1,681	4,926	1.0656	0.0569	0.5328	0.4759	0.0142	0.0853	10,000,000	N/A	N/A
3/4 (Pipe)	1.050	0.0156	0.083	0.0000	12.5%	0.010	0.400	1,301	4,926	1.0656	0.0726	0.5328	0.4602	0.0182	0.1089	10,000,000	N/A	N/A
3/4 (Pipe)	1.050	0.0156	0.113	0.0669	12.5%	0.014	0.400	3,053	4,926	1.0656	0.0319	0.5328	0.5009	0.0080	0.0479	10,000,000	N/A	N/A
3/4 (Pipe)	1.050	0.0156	0.154	0.0669	12.5%	0.019	0.400	1,398	4,926	1.0656	0.0678	0.5328	0.4650	0.0170	0.1017	10,000,000	N/A	N/A
1 (Pipe)	1.315	0.0156	0.065	0.0000	12.5%	0.008	0.400	2,118	4,926	1.3306	0.0569	0.6653	0.6084	0.0142	0.0853	10,000,000	N/A	N/A
1 (Pipe)	1.315	0.0156	0.109	0.0000	12.5%	0.014	0.400	1,233	4,926	1.3306	0.0954	0.6653	0.5699	0.0238	0.1431	10,000,000	N/A	N/A
1 (Pipe)	1.315	0.0156	0.133	0.0808	12.5%	0.017	0.400	3,429	4,926	1.3306	0.0356	0.6653	0.6297	0.0089	0.0534	10,000,000	N/A	N/A
1 (Pipe)	1.315	0.0156	0.179	0.0808	12.5%	0.022	0.400	1,570	4,926	1.3306	0.0759	0.6653	0.5894	0.0190	0.1138	10,000,000	N/A	N/A
1 1/4 (Pipe)	1.660	0.0156	0.065	0.0000	12.5%	0.008	0.400	2,687	4,926	1.6756	0.0569	0.8378	0.7809	0.0142	0.0853	10,000,000	N/A	N/A
1 1/4 (Pipe)	1.660	0.0156	0.109	0.0000	12.5%	0.014	0.400	1,572	4,926	1.6756	0.0954	0.8378	0.7424	0.0238	0.1431	10,000,000	N/A	N/A
1 1/4 (Pipe)	1.660	0.0156	0.140	0.0809	12.5%	0.018	0.400	3,701	4,926	1.6756	0.0416	0.8378	0.7962	0.0104	0.0624	10,000,000	N/A	N/A
1 1/4 (Pipe)	1.660	0.0156	0.191	0.0809	12.5%	0.024	0.400	1,747	4,926	1.6756	0.0862	0.8378	0.7516	0.0216	0.1293	10,000,000	N/A	N/A
1 1/2 (Pipe)	1.900	0.0156	0.065	0.0000	12.5%	0.008	0.400	3,083	4,926	1.9156	0.0569	0.9578	0.9009	0.0142	0.0853	10,000,000	N/A	N/A
1 1/2 (Pipe)	1.900	0.0156	0.109	0.0000	12.5%	0.014	0.400	1,808	4,926	1.9156	0.0954	0.9578	0.8624	0.0238	0.1431	10,000,000	N/A	N/A
1 1/2 (Pipe)	1.900	0.0156	0.145	0.0814	12.5%	0.018	0.400	3,875	4,926	1.9156	0.0455	0.9578	0.9123	0.0114	0.0682	10,000,000	N/A	N/A
1 1/2 (Pipe)	1.900	0.0156	0.200	0.0814	12.5%	0.025	0.400	1,844	4,926	1.9156	0.0936	0.9578	0.8642	0.0234	0.1404	10,000,000	N/A	N/A
2 (Pipe)	2.375	0.031	0.065	0.0000	12.5%	0.008	0.400	3,891	4,926	2.4060	0.0569	1.2030	1.1461	0.0142	0.0853	10,000,000	N/A	N/A
2 (Pipe)	2.375	0.031	0.109	0.0000	12.5%	0.014	0.400	2,290	4,926	2.4060	0.0954	1.2030	1.1076	0.0238	0.1431	10,000,000	N/A	N/A
2 (Pipe)	2.375	0.031	0.154	0.0897	12.5%	0.019	0.400	4,926	4,926	2.4060	0.0451	1.2030	1.1579	0.0113	0.0676	10,000,000	N/A	N/A
2 (Pipe)	2.375	0.031	0.218	0.0897	12.5%	0.027	0.400	2,156	4,926	2.4060	0.1011	1.2030	1.1019	0.0253	0.1517	10,000,000	N/A	N/A

Maximum Developed Membrane Stress: 4,926

Table 7 - Seamless Carbon Steel Tubing
(Material Specification ASTM A-179)

Size	D in.	c_D in.	t_m in.	c in.	α	c_t in.	Y	Membrane Stress, psi	Analysis Membrane Stress, psi	$D + c_D$ in.	$t_c = t_m - c_t - c$ in.	Outer Radius R_o, in.	Inner Radius R_i, in.	Postulated Crack Depth a, in.	Postulated Crack Length, 2C, in.	Cycles to Through-Wall Transition	Depth "a" after transition, in.	Length "C" after transition, in.
1/8	0.125	0.004	0.028	0.000	10%	0.003	0.379	327	1,703	0.1290	0.0252	0.0645	0.0393	0.0063	0.0378	10,000,000	N/A	N/A
1/8	0.125	0.004	0.035	0.000	10%	0.004	0.338	256	1,703	0.1290	0.0315	0.0645	0.0330	0.0079	0.0473	10,000,000	N/A	N/A
3/16	0.1875	0.004	0.028	0.000	10%	0.003	0.400	510	1,703	0.1915	0.0252	0.0958	0.0706	0.0063	0.0378	10,000,000	N/A	N/A
3/16	0.1875	0.004	0.035	0.000	10%	0.004	0.400	396	1,703	0.1915	0.0315	0.0958	0.0643	0.0079	0.0473	10,000,000	N/A	N/A
3/16	0.1875	0.004	0.049	0.000	10%	0.005	0.350	273	1,703	0.1915	0.0441	0.0958	0.0517	0.0110	0.0662	10,000,000	N/A	N/A
1/4	0.250	0.004	0.028	0.000	10%	0.003	0.400	696	1,703	0.2540	0.0252	0.1270	0.1018	0.0063	0.0378	10,000,000	N/A	N/A
1/4	0.250	0.004	0.035	0.000	10%	0.004	0.400	545	1,703	0.2540	0.0315	0.1270	0.0955	0.0079	0.0473	10,000,000	N/A	N/A
1/4	0.250	0.004	0.049	0.000	10%	0.005	0.395	373	1,703	0.2540	0.0441	0.1270	0.0829	0.0110	0.0662	10,000,000	N/A	N/A
1/4	0.250	0.004	0.065	0.000	10%	0.007	0.350	273	1,703	0.2540	0.0585	0.1270	0.0685	0.0146	0.0878	10,000,000	N/A	N/A
5/16	0.3125	0.004	0.035	0.000	10%	0.004	0.400	694	1,703	0.3165	0.0315	0.1583	0.1268	0.0079	0.0473	10,000,000	N/A	N/A
5/16	0.3125	0.004	0.049	0.000	10%	0.005	0.400	478	1,703	0.3165	0.0441	0.1583	0.1142	0.0110	0.0662	10,000,000	N/A	N/A
5/16	0.3125	0.004	0.065	0.000	10%	0.007	0.387	348	1,703	0.3165	0.0585	0.1583	0.0998	0.0146	0.0878	10,000,000	N/A	N/A
3/8	0.375	0.004	0.035	0.000	10%	0.004	0.400	842	1,703	0.3790	0.0315	0.1895	0.1580	0.0079	0.0473	10,000,000	N/A	N/A
3/8	0.375	0.004	0.049	0.000	10%	0.005	0.400	585	1,703	0.3790	0.0441	0.1895	0.1454	0.0110	0.0662	10,000,000	N/A	N/A
3/8	0.375	0.004	0.065	0.000	10%	0.007	0.400	426	1,703	0.3790	0.0585	0.1895	0.1310	0.0146	0.0878	10,000,000	N/A	N/A
1/2	0.500	0.004	0.035	0.000	10%	0.004	0.400	1,140	1,703	0.5040	0.0315	0.2520	0.2205	0.0079	0.0473	10,000,000	N/A	N/A
1/2	0.500	0.004	0.049	0.000	10%	0.005	0.400	797	1,703	0.5040	0.0441	0.2520	0.2079	0.0110	0.0662	10,000,000	N/A	N/A
1/2	0.500	0.004	0.065	0.000	10%	0.007	0.400	586	1,703	0.5040	0.0585	0.2520	0.1935	0.0146	0.0878	10,000,000	N/A	N/A
1/2	0.500	0.004	0.083	0.000	10%	0.008	0.400	446	1,703	0.5040	0.0747	0.2520	0.1773	0.0187	0.1121	10,000,000	N/A	N/A
5/8	0.625	0.004	0.035	0.000	10%	0.004	0.400	1,438	1,703	0.6290	0.0315	0.3145	0.2830	0.0079	0.0473	10,000,000	N/A	N/A
5/8	0.625	0.004	0.049	0.000	10%	0.005	0.400	1,010	1,703	0.6290	0.0441	0.3145	0.2704	0.0110	0.0662	10,000,000	N/A	N/A
5/8	0.625	0.004	0.065	0.000	10%	0.007	0.400	746	1,703	0.6290	0.0585	0.3145	0.2560	0.0146	0.0878	10,000,000	N/A	N/A
5/8	0.625	0.004	0.083	0.000	10%	0.008	0.400	572	1,703	0.6290	0.0747	0.3145	0.2398	0.0187	0.1121	10,000,000	N/A	N/A
5/8	0.625	0.004	0.095	0.000	10%	0.010	0.400	492	1,703	0.6290	0.0855	0.3145	0.2290	0.0214	0.1283	10,000,000	N/A	N/A
3/4	0.750	0.004	0.049	0.000	10%	0.005	0.400	1,222	1,703	0.7540	0.0441	0.3770	0.3329	0.0110	0.0662	10,000,000	N/A	N/A
3/4	0.750	0.004	0.065	0.000	10%	0.007	0.400	907	1,703	0.7540	0.0585	0.3770	0.3185	0.0146	0.0878	10,000,000	N/A	N/A
3/4	0.750	0.004	0.083	0.000	10%	0.008	0.400	697	1,703	0.7540	0.0747	0.3770	0.3023	0.0187	0.1121	10,000,000	N/A	N/A
3/4	0.750	0.004	0.095	0.000	10%	0.010	0.400	601	1,703	0.7540	0.0855	0.3770	0.2915	0.0214	0.1283	10,000,000	N/A	N/A
3/4	0.750	0.004	0.109	0.000	10%	0.011	0.400	516	1,703	0.7540	0.0981	0.3770	0.2789	0.0245	0.1472	10,000,000	N/A	N/A
7/8	0.875	0.004	0.049	0.000	10%	0.005	0.400	1,435	1,703	0.8790	0.0441	0.4395	0.3954	0.0110	0.0662	10,000,000	N/A	N/A
7/8	0.875	0.004	0.065	0.000	10%	0.007	0.400	1,067	1,703	0.8790	0.0585	0.4395	0.3810	0.0146	0.0878	10,000,000	N/A	N/A
7/8	0.875	0.004	0.083	0.000	10%	0.008	0.400	823	1,703	0.8790	0.0747	0.4395	0.3648	0.0187	0.1121	10,000,000	N/A	N/A
7/8	0.875	0.004	0.095	0.000	10%	0.010	0.400	711	1,703	0.8790	0.0855	0.4395	0.3540	0.0214	0.1283	10,000,000	N/A	N/A
7/8	0.875	0.004	0.109	0.000	10%	0.011	0.400	612	1,703	0.8790	0.0981	0.4395	0.3414	0.0245	0.1472	10,000,000	N/A	N/A
1	1.000	0.006	0.049	0.000	10%	0.005	0.400	1,651	1,703	1.0060	0.0441	0.5030	0.4589	0.0110	0.0662	10,000,000	N/A	N/A
1	1.000	0.006	0.065	0.000	10%	0.007	0.400	1,230	1,703	1.0060	0.0585	0.5030	0.4445	0.0146	0.0878	10,000,000	N/A	N/A
1	1.000	0.006	0.083	0.000	10%	0.008	0.400	950	1,703	1.0060	0.0747	0.5030	0.4283	0.0187	0.1121	10,000,000	N/A	N/A
1	1.000	0.006	0.095	0.000	10%	0.010	0.400	822	1,703	1.0060	0.0855	0.5030	0.4175	0.0214	0.1283	10,000,000	N/A	N/A
1	1.000	0.006	0.109	0.000	10%	0.011	0.400	709	1,703	1.0060	0.0981	0.5030	0.4049	0.0245	0.1472	10,000,000	N/A	N/A
1	1.000	0.006	0.120	0.000	10%	0.012	0.400	639	1,703	1.0060	0.1080	0.5030	0.3950	0.0270	0.1620	10,000,000	N/A	N/A
1 1/8	1.125	0.006	0.065	0.000	10%	0.007	0.400	1,390	1,703	1.1310	0.0585	0.5655	0.5070	0.0146	0.0878	10,000,000	N/A	N/A
1 1/8	1.125	0.006	0.083	0.000	10%	0.008	0.400	1,076	1,703	1.1310	0.0747	0.5655	0.4908	0.0187	0.1121	10,000,000	N/A	N/A
1 1/8	1.125	0.006	0.095	0.000	10%	0.010	0.400	932	1,703	1.1310	0.0855	0.5655	0.4800	0.0214	0.1283	10,000,000	N/A	N/A
1 1/8	1.125	0.006	0.109	0.000	10%	0.011	0.400	805	1,703	1.1310	0.0981	0.5655	0.4674	0.0245	0.1472	10,000,000	N/A	N/A
1 1/8	1.125	0.006	0.120	0.000	10%	0.012	0.400	725	1,703	1.1310	0.1080	0.5655	0.4575	0.0270	0.1620	10,000,000	N/A	N/A
1 1/8	1.125	0.006	0.134	0.000	10%	0.013	0.400	643	1,703	1.1310	0.1206	0.5655	0.4449	0.0302	0.1809	10,000,000	N/A	N/A
1 1/4	1.250	0.006	0.065	0.000	10%	0.007	0.400	1,550	1,703	1.2560	0.0585	0.6280	0.5695	0.0146	0.0878	10,000,000	N/A	N/A
1 1/4	1.250	0.006	0.083	0.000	10%	0.008	0.400	1,201	1,703	1.2560	0.0747	0.6280	0.5533	0.0187	0.1121	10,000,000	N/A	N/A
1 1/4	1.250	0.006	0.095	0.000	10%	0.010	0.400	1,042	1,703	1.2560	0.0855	0.6280	0.5425	0.0214	0.1283	10,000,000	N/A	N/A
1 1/4	1.250	0.006	0.109	0.000	10%	0.011	0.400	900	1,703	1.2560	0.0981	0.6280	0.5299	0.0245	0.1472	10,000,000	N/A	N/A
1 1/4	1.250	0.006	0.120	0.000	10%	0.012	0.400	812	1,703	1.2560	0.1080	0.6280	0.5200	0.0270	0.1620	10,000,000	N/A	N/A
1 1/4	1.250	0.006	0.134	0.000	10%	0.013	0.400	721	1,703	1.2560	0.1206	0.6280	0.5074	0.0302	0.1809	10,000,000	N/A	N/A
1 1/4	1.250	0.006	0.148	0.000	10%	0.015	0.400	647	1,703	1.2560	0.1332	0.6280	0.4948	0.0333	0.1998	10,000,000	N/A	N/A
1 1/4	1.250	0.006	0.165	0.000	10%	0.017	0.400	574	1,703	1.2560	0.1485	0.6280	0.4795	0.0371	0.2228	10,000,000	N/A	N/A
1 1/4	1.250	0.006	0.180	0.000	10%	0.018	0.400	521	1,703	1.2560	0.1620	0.6280	0.4660	0.0405	0.2430	10,000,000	N/A	N/A
1 1/2	1.500	0.006	0.083	0.000	10%	0.008	0.400	1,452	1,703	1.5060	0.0747	0.7530	0.6783	0.0187	0.1121	10,000,000	N/A	N/A
1 1/2	1.500	0.006	0.095	0.000	10%	0.010	0.400	1,261	1,703	1.5060	0.0855	0.7530	0.6675	0.0214	0.1283	10,000,000	N/A	N/A
1 1/2	1.500	0.006	0.109	0.000	10%	0.011	0.400	1,091	1,703	1.5060	0.0981	0.7530	0.6549	0.0245	0.1472	10,000,000	N/A	N/A
1 1/2	1.500	0.006	0.120	0.000	10%	0.012	0.400	986	1,703	1.5060	0.1080	0.7530	0.6450	0.0270	0.1620	10,000,000	N/A	N/A
1 1/2	1.500	0.006	0.134	0.000	10%	0.013	0.400	877	1,703	1.5060	0.1206	0.7530	0.6324	0.0302	0.1809	10,000,000	N/A	N/A
1 1/2	1.500	0.006	0.148	0.000	10%	0.015	0.400	788	1,703	1.5060	0.1332	0.7530	0.6198	0.0333	0.1998	10,000,000	N/A	N/A
1 1/2	1.500	0.006	0.165	0.000	10%	0.017	0.400	701	1,703	1.5060	0.1485	0.7530	0.6045	0.0371	0.2228	10,000,000	N/A	N/A
1 1/2	1.500	0.006	0.180	0.000	10%	0.018	0.400	637	1,703	1.5060	0.1620	0.7530	0.5910	0.0405	0.2430	10,000,000	N/A	N/A
1 1/2	1.500	0.006	0.220	0.000	10%	0.022	0.400	510	1,703	1.5060	0.1980	0.7530	0.5550	0.0495	0.2970	10,000,000	N/A	N/A

Table 7 - Continued, Seamless Carbon Steel Tubing (Material Specification ASTM A-179)

Size	D in.	c_D in.	t_m in.	c in.	α	c_t in.	Y	Membrane Stress, psi	Analysis Membrane Stress, psi	$D + c_D$ in.	$t_c = t_m - c_t - c$ in.	Outer Radius R_o, in.	Inner Radius R_i, in.	Postulated Crack Depth a, in.	Postulated Crack Length, 2C, in.	Cycles to Through-Wall Transition	Depth "a" after transition, in.	Length "C" after transition, in.
2	2.000	0.010	0.095	0.000	10%	0.010	0.400	1,703	1,703	2.0100	0.0855	1.0050	0.9195	0.0214	0.1283	10,000,000	N/A	N/A
2	2.000	0.010	0.109	0.000	10%	0.011	0.400	1,477	1,703	2.0100	0.0981	1.0050	0.9069	0.0245	0.1472	10,000,000	N/A	N/A
2	2.000	0.010	0.120	0.000	10%	0.012	0.400	1,336	1,703	2.0100	0.1080	1.0050	0.8970	0.0270	0.1620	10,000,000	N/A	N/A
2	2.000	0.010	0.134	0.000	10%	0.013	0.400	1,190	1,703	2.0100	0.1206	1.0050	0.8844	0.0302	0.1809	10,000,000	N/A	N/A
2	2.000	0.010	0.148	0.000	10%	0.015	0.400	1,072	1,703	2.0100	0.1332	1.0050	0.8718	0.0333	0.1998	10,000,000	N/A	N/A
2	2.000	0.010	0.165	0.000	10%	0.017	0.400	955	1,703	2.0100	0.1485	1.0050	0.8565	0.0371	0.2228	10,000,000	N/A	N/A
2	2.000	0.010	0.180	0.000	10%	0.018	0.400	871	1,703	2.0100	0.1620	1.0050	0.8430	0.0405	0.2430	10,000,000	N/A	N/A
2	2.000	0.010	0.220	0.000	10%	0.022	0.400	701	1,703	2.0100	0.1980	1.0050	0.8070	0.0495	0.2970	10,000,000	N/A	N/A
						Maximum Developed Membrane Stress:		1,703										

Table 8 - Welded Super Duplex Tubing
(Material Specification ASTM A-789, UNS S32750)

Size	D in.	c_D in.	t_m in.	c in.	α	c_t in.	Y	Membrane Stress, psi	Analysis Membrane Stress, psi	D + c_D in.	$t_c = t_m - c_t - c$ in.	Outer Radius R_o, in.	Inner Radius R_i, in.	Postulated Crack Depth a, in.	Postulated Crack Length, 2C, in.	Cycles to Through-Wall Transition	Depth "a" after transition, in.	Length "C" after transition, in.
1/8	0.125	0.005	0.028	0.000	15%	0.004	0.388	439	2,916	0.1300	0.0238	0.0650	0.0412	0.0060	0.0357	10,000,000	N/A	N/A
1/8	0.125	0.005	0.035	0.000	15%	0.005	0.352	344	2,916	0.1300	0.0298	0.0650	0.0353	0.0074	0.0446	10,000,000	N/A	N/A
3/16	0.1875	0.005	0.028	0.000	15%	0.004	0.400	683	2,916	0.1925	0.0238	0.0963	0.0725	0.0060	0.0357	10,000,000	N/A	N/A
3/16	0.1875	0.005	0.035	0.000	15%	0.005	0.400	532	2,916	0.1925	0.0298	0.0963	0.0665	0.0074	0.0446	10,000,000	N/A	N/A
3/16	0.1875	0.005	0.049	0.000	15%	0.007	0.362	365	2,916	0.1925	0.0417	0.0963	0.0546	0.0104	0.0625	10,000,000	N/A	N/A
1/4	0.250	0.005	0.028	0.000	15%	0.004	0.400	929	2,916	0.2550	0.0238	0.1275	0.1037	0.0060	0.0357	10,000,000	N/A	N/A
1/4	0.250	0.005	0.035	0.000	15%	0.005	0.400	729	2,916	0.2550	0.0298	0.1275	0.0978	0.0074	0.0446	10,000,000	N/A	N/A
1/4	0.250	0.005	0.049	0.000	15%	0.007	0.400	499	2,916	0.2550	0.0417	0.1275	0.0859	0.0104	0.0625	10,000,000	N/A	N/A
1/4	0.250	0.005	0.065	0.000	15%	0.010	0.362	365	2,916	0.2550	0.0553	0.1275	0.0723	0.0138	0.0829	10,000,000	N/A	N/A
5/16	0.3125	0.005	0.035	0.000	15%	0.005	0.400	926	2,916	0.3175	0.0298	0.1588	0.1290	0.0074	0.0446	10,000,000	N/A	N/A
5/16	0.3125	0.005	0.049	0.000	15%	0.007	0.400	640	2,916	0.3175	0.0417	0.1588	0.1171	0.0104	0.0625	10,000,000	N/A	N/A
5/16	0.3125	0.005	0.065	0.000	15%	0.010	0.395	465	2,916	0.3175	0.0553	0.1588	0.1035	0.0138	0.0829	10,000,000	N/A	N/A
3/8	0.375	0.005	0.035	0.000	15%	0.005	0.400	1,122	2,916	0.3800	0.0298	0.1900	0.1603	0.0074	0.0446	10,000,000	N/A	N/A
3/8	0.375	0.005	0.049	0.000	15%	0.007	0.400	780	2,916	0.3800	0.0417	0.1900	0.1484	0.0104	0.0625	10,000,000	N/A	N/A
3/8	0.375	0.005	0.065	0.000	15%	0.010	0.400	570	2,916	0.3800	0.0553	0.1900	0.1348	0.0138	0.0829	10,000,000	N/A	N/A
1/2	0.500	0.005	0.035	0.000	10%	0.004	0.400	1,428	2,916	0.5050	0.0315	0.2525	0.2210	0.0079	0.0473	10,000,000	N/A	N/A
1/2	0.500	0.005	0.049	0.000	10%	0.005	0.400	999	2,916	0.5050	0.0441	0.2525	0.2084	0.0110	0.0662	10,000,000	N/A	N/A
1/2	0.500	0.005	0.065	0.000	10%	0.007	0.400	734	2,916	0.5050	0.0585	0.2525	0.1940	0.0146	0.0878	10,000,000	N/A	N/A
1/2	0.500	0.005	0.083	0.000	10%	0.008	0.400	559	2,916	0.5050	0.0747	0.2525	0.1778	0.0187	0.1121	10,000,000	N/A	N/A
5/8	0.625	0.005	0.049	0.000	10%	0.005	0.400	1,264	2,916	0.6300	0.0441	0.3150	0.2709	0.0110	0.0662	10,000,000	N/A	N/A
5/8	0.625	0.005	0.065	0.000	10%	0.007	0.400	935	2,916	0.6300	0.0585	0.3150	0.2565	0.0146	0.0878	10,000,000	N/A	N/A
5/8	0.625	0.005	0.083	0.000	10%	0.008	0.400	716	2,916	0.6300	0.0747	0.3150	0.2403	0.0187	0.1121	10,000,000	N/A	N/A
5/8	0.625	0.005	0.095	0.000	10%	0.010	0.400	616	2,916	0.6300	0.0855	0.3150	0.2295	0.0214	0.1283	10,000,000	N/A	N/A
3/4	0.750	0.005	0.049	0.000	10%	0.005	0.400	1,530	2,916	0.7550	0.0441	0.3775	0.3334	0.0110	0.0662	10,000,000	N/A	N/A
3/4	0.750	0.005	0.065	0.000	10%	0.007	0.400	1,135	2,916	0.7550	0.0585	0.3775	0.3190	0.0146	0.0878	10,000,000	N/A	N/A
3/4	0.750	0.005	0.083	0.000	10%	0.008	0.400	873	2,916	0.7550	0.0747	0.3775	0.3028	0.0187	0.1121	10,000,000	N/A	N/A
3/4	0.750	0.005	0.095	0.000	10%	0.010	0.400	753	2,916	0.7550	0.0855	0.3775	0.2920	0.0214	0.1283	10,000,000	N/A	N/A
3/4	0.750	0.005	0.109	0.000	10%	0.011	0.400	647	2,916	0.7550	0.0981	0.3775	0.2794	0.0245	0.1472	10,000,000	N/A	N/A
7/8	0.875	0.005	0.049	0.000	10%	0.005	0.400	1,796	2,916	0.8800	0.0441	0.4400	0.3959	0.0110	0.0662	10,000,000	N/A	N/A
7/8	0.875	0.005	0.065	0.000	10%	0.007	0.400	1,335	2,916	0.8800	0.0585	0.4400	0.3815	0.0146	0.0878	10,000,000	N/A	N/A
7/8	0.875	0.005	0.083	0.000	10%	0.008	0.400	1,029	2,916	0.8800	0.0747	0.4400	0.3653	0.0187	0.1121	10,000,000	N/A	N/A
7/8	0.875	0.005	0.095	0.000	10%	0.010	0.400	890	2,916	0.8800	0.0855	0.4400	0.3545	0.0214	0.1283	10,000,000	N/A	N/A
7/8	0.875	0.005	0.109	0.000	10%	0.011	0.400	766	2,916	0.8800	0.0981	0.4400	0.3419	0.0245	0.1472	10,000,000	N/A	N/A
1	1.000	0.005	0.049	0.000	10%	0.005	0.400	2,061	2,916	1.0050	0.0441	0.5025	0.4584	0.0110	0.0662	10,000,000	N/A	N/A
1	1.000	0.005	0.065	0.000	10%	0.007	0.400	1,536	2,916	1.0050	0.0585	0.5025	0.4440	0.0146	0.0878	10,000,000	N/A	N/A
1	1.000	0.005	0.083	0.000	10%	0.008	0.400	1,186	2,916	1.0050	0.0747	0.5025	0.4278	0.0187	0.1121	10,000,000	N/A	N/A
1	1.000	0.005	0.095	0.000	10%	0.010	0.400	1,027	2,916	1.0050	0.0855	0.5025	0.4170	0.0214	0.1283	10,000,000	N/A	N/A
1	1.000	0.005	0.109	0.000	10%	0.011	0.400	885	2,916	1.0050	0.0981	0.5025	0.4044	0.0245	0.1472	10,000,000	N/A	N/A
1	1.000	0.005	0.120	0.000	10%	0.012	0.400	797	2,916	1.0050	0.1080	0.5025	0.3945	0.0270	0.1620	10,000,000	N/A	N/A
1 1/8	1.125	0.005	0.065	0.000	10%	0.007	0.400	1,736	2,916	1.1300	0.0585	0.5650	0.5065	0.0146	0.0878	10,000,000	N/A	N/A
1 1/8	1.125	0.005	0.083	0.000	10%	0.008	0.400	1,343	2,916	1.1300	0.0747	0.5650	0.4903	0.0187	0.1121	10,000,000	N/A	N/A
1 1/8	1.125	0.005	0.095	0.000	10%	0.010	0.400	1,164	2,916	1.1300	0.0855	0.5650	0.4795	0.0214	0.1283	10,000,000	N/A	N/A
1 1/8	1.125	0.005	0.109	0.000	10%	0.011	0.400	1,005	2,916	1.1300	0.0981	0.5650	0.4669	0.0245	0.1472	10,000,000	N/A	N/A
1 1/8	1.125	0.005	0.120	0.000	10%	0.012	0.400	906	2,916	1.1300	0.1080	0.5650	0.4570	0.0270	0.1620	10,000,000	N/A	N/A
1 1/8	1.125	0.005	0.134	0.000	10%	0.013	0.400	803	2,916	1.1300	0.1206	0.5650	0.4444	0.0302	0.1809	10,000,000	N/A	N/A
1 1/4	1.250	0.005	0.055	0.000	10%	0.006	0.400	2,302	2,916	1.2550	0.0495	0.6275	0.5780	0.0124	0.0743	10,000,000	N/A	N/A
1 1/4	1.250	0.005	0.065	0.000	10%	0.007	0.400	1,936	2,916	1.2550	0.0585	0.6275	0.5690	0.0146	0.0878	10,000,000	N/A	N/A
1 1/2	1.500	0.010	0.060	0.000	10%	0.006	0.400	2,547	2,916	1.5100	0.0540	0.7550	0.7010	0.0135	0.0810	10,000,000	N/A	N/A
1 1/2	1.500	0.010	0.072	0.000	10%	0.007	0.400	2,110	2,916	1.5100	0.0648	0.7550	0.6902	0.0162	0.0972	10,000,000	N/A	N/A
2	2.000	0.010	0.070	0.000	10%	0.007	0.400	2,916	2,916	2.0100	0.0630	1.0050	0.9420	0.0158	0.0945	10,000,000	N/A	N/A
2	2.000	0.010	0.083	0.000	10%	0.008	0.400	2,448	2,916	2.0100	0.0747	1.0050	0.9303	0.0187	0.1121	10,000,000	N/A	N/A

Maximum Developed Membrane Stress: 2,916

Table 9 - Seamless Nickel-Chromium-Iron Alloy (Alloy 600) Piping and Tubing
(Material Specification ASTM B-167, UNS N06600)

Size	D in.	c_D in.	t_m in.	c in.	α	c_f in.	Y	Membrane Stress, psi	Analysis Membrane Stress, psi	D + c_D in.	$t_c = t_m - c_f - c$ in.	Outer Radius R_o, in.	Inner Radius R_i, in.	Postulated Crack Depth a, in.	Postulated Crack Length, 2C, in.	Cycles to Through-Wall Transition	Depth "a" after transition, in.	Length "C" after transition, in.
1/4 (Pipe)	0.540	0.005	0.088	0.0489	15%	0.0132	0.400	1,518	3,941	0.5450	0.0259	0.2725	0.2466	0.0065	0.0388	10,000,000	N/A	N/A
1/4 (Tube)	0.250	0.005	0.028	0.0000	15%	0.0042	0.400	744	3,941	0.2550	0.0238	0.1275	0.1037	0.0060	0.0357	10,000,000	N/A	N/A
1/4 (Tube)	0.250	0.005	0.035	0.0000	15%	0.0053	0.400	583	3,941	0.2550	0.0298	0.1275	0.0978	0.0074	0.0446	10,000,000	N/A	N/A
1/4 (Tube)	0.250	0.005	0.049	0.0000	15%	0.0074	0.400	399	3,941	0.2550	0.0417	0.1275	0.0859	0.0104	0.0625	10,000,000	N/A	N/A
1/4 (Tube)	0.250	0.005	0.065	0.0000	15%	0.0098	0.362	292	3,941	0.2550	0.0553	0.1275	0.0723	0.0138	0.0829	10,000,000	N/A	N/A
3/8 (Pipe)	0.675	0.0075	0.091	0.0500	10%	0.0091	0.400	1,543	3,941	0.6825	0.0319	0.3413	0.3093	0.0080	0.0479	10,000,000	N/A	N/A
3/8 (Pipe)	0.675	0.0075	0.126	0.0500	10%	0.0126	0.400	747	3,941	0.6825	0.0634	0.3413	0.2778	0.0159	0.0952	10,000,000	N/A	N/A
3/8 (Tube)	0.375	0.005	0.035	0.0000	15%	0.0053	0.400	898	3,941	0.3800	0.0298	0.1900	0.1603	0.0074	0.0446	10,000,000	N/A	N/A
3/8 (Tube)	0.375	0.005	0.049	0.0000	15%	0.0074	0.400	624	3,941	0.3800	0.0417	0.1900	0.1484	0.0104	0.0625	10,000,000	N/A	N/A
3/8 (Tube)	0.375	0.005	0.065	0.0000	15%	0.0098	0.400	456	3,941	0.3800	0.0553	0.1900	0.1348	0.0138	0.0829	10,000,000	N/A	N/A
1/2 (Pipe)	0.840	0.0075	0.083	0.0000	10%	0.0083	0.400	791	3,941	0.8475	0.0747	0.4238	0.3491	0.0187	0.1121	10,000,000	N/A	N/A
1/2 (Pipe)	0.840	0.0075	0.109	0.0631	10%	0.0109	0.400	1,756	3,941	0.8475	0.0350	0.4238	0.3888	0.0087	0.0525	10,000,000	N/A	N/A
1/2 (Pipe)	0.840	0.0075	0.147	0.0631	10%	0.0147	0.400	859	3,941	0.8475	0.0692	0.4238	0.3546	0.0173	0.1038	10,000,000	N/A	N/A
1/2 (Tube)	0.500	0.005	0.035	0.0000	15%	0.0053	0.400	1,213	3,941	0.5050	0.0298	0.2525	0.2228	0.0074	0.0446	10,000,000	N/A	N/A
1/2 (Tube)	0.500	0.005	0.049	0.0000	15%	0.0074	0.400	849	3,941	0.5050	0.0417	0.2525	0.2109	0.0104	0.0625	10,000,000	N/A	N/A
1/2 (Tube)	0.500	0.005	0.065	0.0000	15%	0.0098	0.400	626	3,941	0.5050	0.0553	0.2525	0.1973	0.0138	0.0829	10,000,000	N/A	N/A
3/4 (Pipe)	1.050	0.015	0.083	0.0000	12.5%	0.0104	0.400	1,040	3,941	1.0650	0.0726	0.5325	0.4599	0.0182	0.1089	10,000,000	N/A	N/A
3/4 (Pipe)	1.050	0.015	0.113	0.0666	12.5%	0.0141	0.400	2,418	3,941	1.0650	0.0322	0.5325	0.5003	0.0081	0.0484	10,000,000	N/A	N/A
3/4 (Pipe)	1.050	0.015	0.154	0.0666	12.5%	0.0193	0.400	1,113	3,941	1.0650	0.0681	0.5325	0.4644	0.0170	0.1022	10,000,000	N/A	N/A
1 (Pipe)	1.315	0.015	0.109	0.0000	12.5%	0.0136	0.400	986	3,941	1.3300	0.0954	0.6650	0.5696	0.0238	0.1431	10,000,000	N/A	N/A
1 (Pipe)	1.315	0.015	0.133	0.0805	12.5%	0.0166	0.400	2,718	3,941	1.3300	0.0359	0.6650	0.6291	0.0090	0.0539	10,000,000	N/A	N/A
1 (Pipe)	1.315	0.015	0.179	0.0805	12.5%	0.0224	0.400	1,250	3,941	1.3300	0.0762	0.6650	0.5888	0.0190	0.1142	10,000,000	N/A	N/A
1 1/4 (Pipe)	1.660	0.015	0.109	0.0000	12.5%	0.0136	0.400	1,257	3,941	1.6750	0.0954	0.8375	0.7421	0.0238	0.1431	10,000,000	N/A	N/A
1 1/4 (Pipe)	1.660	0.015	0.140	0.0806	12.5%	0.0175	0.400	2,938	3,941	1.6750	0.0419	0.8375	0.7956	0.0105	0.0629	10,000,000	N/A	N/A
1 1/4 (Pipe)	1.660	0.015	0.191	0.0806	12.5%	0.0239	0.400	1,392	3,941	1.6750	0.0865	0.8375	0.7510	0.0216	0.1298	10,000,000	N/A	N/A
1 1/2 (Pipe)	1.900	0.015	0.109	0.0000	12.5%	0.0136	0.400	1,446	3,941	1.9150	0.0954	0.9575	0.8621	0.0238	0.1431	10,000,000	N/A	N/A
1 1/2 (Pipe)	1.900	0.015	0.145	0.0811	12.5%	0.0181	0.400	3,079	3,941	1.9150	0.0458	0.9575	0.9117	0.0114	0.0686	10,000,000	N/A	N/A
1 1/2 (Pipe)	1.900	0.015	0.200	0.0811	12.5%	0.0250	0.400	1,470	3,941	1.9150	0.0939	0.9575	0.8636	0.0235	0.1408	10,000,000	N/A	N/A
2 (Pipe)	2.375	0.031	0.109	0.0000	12.5%	0.0136	0.400	1,832	3,941	2.4060	0.0954	1.2030	1.1076	0.0238	0.1431	10,000,000	N/A	N/A
2 (Pipe)	2.375	0.031	0.154	0.0897	12.5%	0.0193	0.400	3,941	3,941	2.4060	0.0451	1.2030	1.1579	0.0113	0.0676	10,000,000	N/A	N/A
2 (Pipe)	2.375	0.031	0.218	0.0897	12.5%	0.0273	0.400	1,725	3,941	2.4060	0.1011	1.2030	1.1019	0.0253	0.1517	10,000,000	N/A	N/A
Maximum Developed Membrane Stress: 3,941																		

Table 10 - Welded Grade 2 Titanium Tubing
(Material Specification ASTM B-338, Unalloyed Titanium)

Size	D in.	c_D in.	t_m in.	c in.	α	c_t in.	Y	Membrane Stress, psi	Analysis Membrane Stress, psi	D + c_D in.	$t_c = t_m - c_t - c$ in.	Outer Radius R_o, in.	Inner Radius R_i, in.	Postulated Crack Depth a, in.	Postulated Crack Length, 2C, in.	Cycles to Through-Wall Transition	Depth "a" after transition, in.	Length "C" after transition, in.
1/8	0.125	0.004	0.028	0.000	10%	0.003	0.379	327	327	0.1290	0.0252	0.0645	0.0393	0.0063	0.0378	10,000,000	N/A	N/A
1/8	0.125	0.004	0.035	0.000	10%	0.004	0.338	256	256	0.1290	0.0315	0.0645	0.0330	0.0079	0.0473	10,000,000	N/A	N/A
3/16	0.1875	0.004	0.028	0.000	10%	0.003	0.400	510	510	0.1915	0.0252	0.0958	0.0706	0.0063	0.0378	10,000,000	N/A	N/A
3/16	0.1875	0.004	0.035	0.000	10%	0.004	0.400	396	396	0.1915	0.0315	0.0958	0.0643	0.0079	0.0473	10,000,000	N/A	N/A
3/16	0.1875	0.004	0.049	0.000	10%	0.005	0.350	273	273	0.1915	0.0441	0.0958	0.0517	0.0110	0.0662	10,000,000	N/A	N/A
1/4	0.250	0.004	0.028	0.000	10%	0.003	0.400	696	696	0.2540	0.0252	0.1270	0.1018	0.0063	0.0378	10,000,000	N/A	N/A
1/4	0.250	0.004	0.035	0.000	10%	0.004	0.400	545	545	0.2540	0.0315	0.1270	0.0955	0.0079	0.0473	10,000,000	N/A	N/A
1/4	0.250	0.004	0.049	0.000	10%	0.005	0.395	373	373	0.2540	0.0441	0.1270	0.0829	0.0110	0.0662	10,000,000	N/A	N/A
1/4	0.250	0.004	0.065	0.000	10%	0.007	0.350	273	273	0.2540	0.0585	0.1270	0.0685	0.0146	0.0878	10,000,000	N/A	N/A
5/16	0.3125	0.004	0.035	0.000	10%	0.004	0.400	694	694	0.3165	0.0315	0.1583	0.1268	0.0079	0.0473	10,000,000	N/A	N/A
5/16	0.3125	0.004	0.049	0.000	10%	0.005	0.400	478	478	0.3165	0.0441	0.1583	0.1142	0.0110	0.0662	10,000,000	N/A	N/A
5/16	0.3125	0.004	0.065	0.000	10%	0.007	0.387	348	348	0.3165	0.0585	0.1583	0.0998	0.0146	0.0878	10,000,000	N/A	N/A
3/8	0.375	0.004	0.035	0.000	10%	0.004	0.400	842	842	0.3790	0.0315	0.1895	0.1580	0.0079	0.0473	10,000,000	N/A	N/A
3/8	0.375	0.004	0.049	0.000	10%	0.005	0.400	585	585	0.3790	0.0441	0.1895	0.1454	0.0110	0.0662	10,000,000	N/A	N/A
3/8	0.375	0.004	0.065	0.000	10%	0.007	0.400	426	426	0.3790	0.0585	0.1895	0.1310	0.0146	0.0878	10,000,000	N/A	N/A
1/2	0.500	0.004	0.035	0.000	10%	0.004	0.400	1,140	1,140	0.5040	0.0315	0.2520	0.2205	0.0079	0.0473	10,000,000	N/A	N/A
1/2	0.500	0.004	0.049	0.000	10%	0.005	0.400	797	797	0.5040	0.0441	0.2520	0.2079	0.0110	0.0662	10,000,000	N/A	N/A
1/2	0.500	0.004	0.065	0.000	10%	0.007	0.400	586	586	0.5040	0.0585	0.2520	0.1935	0.0146	0.0878	10,000,000	N/A	N/A
1/2	0.500	0.004	0.083	0.000	10%	0.008	0.400	446	446	0.5040	0.0747	0.2520	0.1773	0.0187	0.1121	10,000,000	N/A	N/A
5/8	0.625	0.004	0.049	0.000	10%	0.005	0.400	1,010	1,010	0.6290	0.0441	0.3145	0.2704	0.0110	0.0662	10,000,000	N/A	N/A
5/8	0.625	0.004	0.065	0.000	10%	0.007	0.400	746	746	0.6290	0.0585	0.3145	0.2560	0.0146	0.0878	10,000,000	N/A	N/A
5/8	0.625	0.004	0.083	0.000	10%	0.008	0.400	572	572	0.6290	0.0747	0.3145	0.2398	0.0187	0.1121	10,000,000	N/A	N/A
5/8	0.625	0.004	0.095	0.000	10%	0.010	0.400	492	492	0.6290	0.0855	0.3145	0.2290	0.0214	0.1283	10,000,000	N/A	N/A
3/4	0.750	0.004	0.049	0.000	10%	0.005	0.400	1,222	1,222	0.7540	0.0441	0.3770	0.3329	0.0110	0.0662	10,000,000	N/A	N/A
3/4	0.750	0.004	0.065	0.000	10%	0.007	0.400	907	907	0.7540	0.0585	0.3770	0.3185	0.0146	0.0878	10,000,000	N/A	N/A
3/4	0.750	0.004	0.083	0.000	10%	0.008	0.400	697	697	0.7540	0.0747	0.3770	0.3023	0.0187	0.1121	10,000,000	N/A	N/A
3/4	0.750	0.004	0.095	0.000	10%	0.010	0.400	601	601	0.7540	0.0855	0.3770	0.2915	0.0214	0.1283	10,000,000	N/A	N/A
3/4	0.750	0.004	0.109	0.000	10%	0.011	0.400	516	516	0.7540	0.0981	0.3770	0.2789	0.0245	0.1472	10,000,000	N/A	N/A
7/8	0.875	0.004	0.049	0.000	10%	0.005	0.400	1,435	1,435	0.8790	0.0441	0.4395	0.3954	0.0110	0.0662	10,000,000	N/A	N/A
7/8	0.875	0.004	0.065	0.000	10%	0.007	0.400	1,067	1,067	0.8790	0.0585	0.4395	0.3810	0.0146	0.0878	10,000,000	N/A	N/A
7/8	0.875	0.004	0.083	0.000	10%	0.008	0.400	823	823	0.8790	0.0747	0.4395	0.3648	0.0187	0.1121	10,000,000	N/A	N/A
7/8	0.875	0.004	0.095	0.000	10%	0.010	0.400	711	711	0.8790	0.0855	0.4395	0.3540	0.0214	0.1283	10,000,000	N/A	N/A
7/8	0.875	0.004	0.109	0.000	10%	0.011	0.400	612	612	0.8790	0.0981	0.4395	0.3414	0.0245	0.1472	10,000,000	N/A	N/A
1	1.000	0.005	0.049	0.000	10%	0.005	0.400	1,649	1,649	1.0050	0.0441	0.5025	0.4584	0.0110	0.0662	10,000,000	N/A	N/A
1	1.000	0.005	0.065	0.000	10%	0.007	0.400	1,228	1,228	1.0050	0.0585	0.5025	0.4440	0.0146	0.0878	10,000,000	N/A	N/A
1	1.000	0.005	0.083	0.000	10%	0.008	0.400	949	949	1.0050	0.0747	0.5025	0.4278	0.0187	0.1121	10,000,000	N/A	N/A
1	1.000	0.005	0.095	0.000	10%	0.010	0.400	822	822	1.0050	0.0855	0.5025	0.4170	0.0214	0.1283	10,000,000	N/A	N/A
1	1.000	0.005	0.109	0.000	10%	0.011	0.400	708	708	1.0050	0.0981	0.5025	0.4044	0.0245	0.1472	10,000,000	N/A	N/A
1	1.000	0.005	0.120	0.000	10%	0.012	0.400	638	638	1.0050	0.1080	0.5025	0.3945	0.0270	0.1620	10,000,000	N/A	N/A
1 1/8	1.125	0.005	0.065	0.000	10%	0.007	0.400	1,389	1,389	1.1300	0.0585	0.5650	0.5065	0.0146	0.0878	10,000,000	N/A	N/A
1 1/8	1.125	0.005	0.083	0.000	10%	0.008	0.400	1,075	1,075	1.1300	0.0747	0.5650	0.4903	0.0187	0.1121	10,000,000	N/A	N/A
1 1/8	1.125	0.005	0.095	0.000	10%	0.010	0.400	931	931	1.1300	0.0855	0.5650	0.4795	0.0214	0.1283	10,000,000	N/A	N/A
1 1/8	1.125	0.005	0.109	0.000	10%	0.011	0.400	804	804	1.1300	0.0981	0.5650	0.4669	0.0245	0.1472	10,000,000	N/A	N/A
1 1/8	1.125	0.005	0.120	0.000	10%	0.012	0.400	725	725	1.1300	0.1080	0.5650	0.4570	0.0270	0.1620	10,000,000	N/A	N/A
1 1/8	1.125	0.005	0.134	0.000	10%	0.013	0.400	643	643	1.1300	0.1206	0.5650	0.4444	0.0302	0.1809	10,000,000	N/A	N/A
1 1/4	1.250	0.005	0.055	0.000	10%	0.006	0.400	1,842	1,842	1.2550	0.0495	0.6275	0.5780	0.0124	0.0743	10,000,000	N/A	N/A
1 1/4	1.250	0.005	0.065	0.000	10%	0.007	0.400	1,549	1,549	1.2550	0.0585	0.6275	0.5690	0.0146	0.0878	10,000,000	N/A	N/A
1 1/2	1.500	0.006	0.060	0.000	10%	0.006	0.400	2,032	2,032	1.5060	0.0540	0.7530	0.6990	0.0135	0.0810	10,000,000	N/A	N/A
1 1/2	1.500	0.006	0.072	0.000	10%	0.007	0.400	1,683	1,683	1.5060	0.0648	0.7530	0.6882	0.0162	0.0972	10,000,000	N/A	N/A
2	2.000	0.007	0.070	0.000	10%	0.007	0.400	2,329	2,329	2.0070	0.0630	1.0035	0.9405	0.0158	0.0945	10,000,000	N/A	N/A
2	2.000	0.007	0.083	0.000	10%	0.008	0.400	1,955	1,955	2.0070	0.0747	1.0035	0.9288	0.0187	0.1121	10,000,000	N/A	N/A

Maximum Developed Membrane Stress: 2,329

ATTACHMENT # 11
LONGITUDINAL SURFACE FLAW ANALYSES

PART B

Attachment #11 Part B
Longitudinal Surface Flaw Analyses

Section 1 – Welded Stainless Steel Tubing, ASTM A-269/632 TP 304/316 2

Section 2 – Welded Black and Galvinized Carbon Steel Piping, ASTM A-53 and ASTM A-120 918

Section 3 – Soft Annealed Seamless Copper Tubing, ASTM B-75 1702

Section 4 – Soft Annealed Seamless Copper Tubing, ASTM B-88 Types K, L, and M 2435

Section 5 – Seamless Aluminum Tubing, ASTM B-210 Type 6061-T6 2811

Section 6 – Welded Stainless Steel Piping, ASTM A-312 TP 304/316 3316

Section 7 – Seamless Carbon Steel Tubing, ASTM A-179 3767

Section 8 – Welded Super Duplex Tubing, ASTM A-789, UNS S32750 4777

Section 9 – Seamless Nickel-Chromium-Iron Alloy (Alloy 600) Piping /Tubing, ASTM B-167, UNS N06600 5543

Section 10 – Welded Grade 2 Titanium Tubing, ASTM B-338, Unalloyed Titanium 5979

ATTACHMENT # 12
THROUGH WALL FLAW ANALYSES

Attachment #12
Through Wall Flaw Analyses

Section 1 – ASTM A-53, ASTM A-120 Through Wall Flaw Analyses 2

Section 2 – ASTM B-75 Through Wall Flaw Analyses 34

Section 3 - ASTM B-210 Type 6061-T6 Through Wall Flaw Analyses 45

ATTACHMENT #13
DETERMINATION OF CRACK OPENING AREA (COA)

MTI-08-000832 Attachment #13
Crack Opening Area Annex K of API-579 FFS-1 2007

	Parameter Variable	Material Specification ASTM A-53 and A-120	Units	Reference Equation
Modulus of Elasticity	E	2.94E+07	psi	
Internal Pressure	p	25	psig	
Outside Diameter of Cylindrical Shell	OD	1.330625	in	
Wall Thickness	t	0.0189675	in	
Crack Length Parameter	c	0.04255	in	
Outside Radius of Cylindrical Shell	Ro	[redacted]	in	
Inside Radius of Cylindrical Shell	Ri	[redacted]	in	
Through-wall crack shell parameter	λ	[redacted]	unitless	Table K-1 / Table K-2
	Ri/t	[redacted]	unitless	Table K-1 / Table K-2

	A0	A1	A2	A3	A4	A5	A6	A7	Ref.
Inside	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	Table K-1
Outside	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	Table K-2

Pressure loading crack parameter for determining the COA

	Inside	Outside	Inside limit	Outside limit
Hp	[redacted]	[redacted]	[redacted]	[redacted]
Ref. Eq	Table K-1	Table K-1	K.2	K.3

Crack opening area

	Inside	Outside
COA (in^2)	[redacted]	[redacted]
Ref. Eq	K.1	K.1

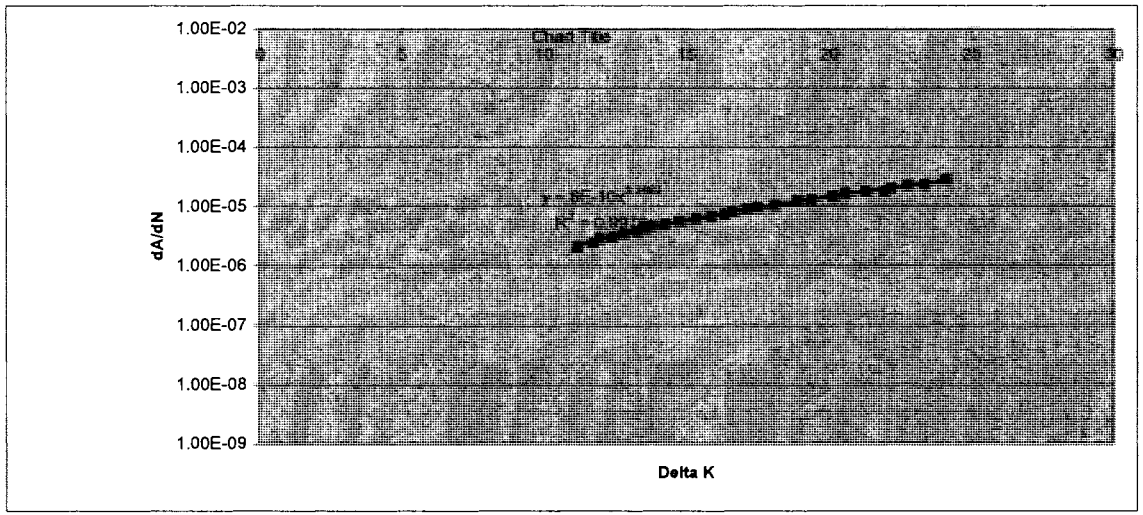
ATTACHMENT # 14
ASTM A-789, UNS S32750
DETERMINATION OF FATIGUE CRACK GROWTH RATE

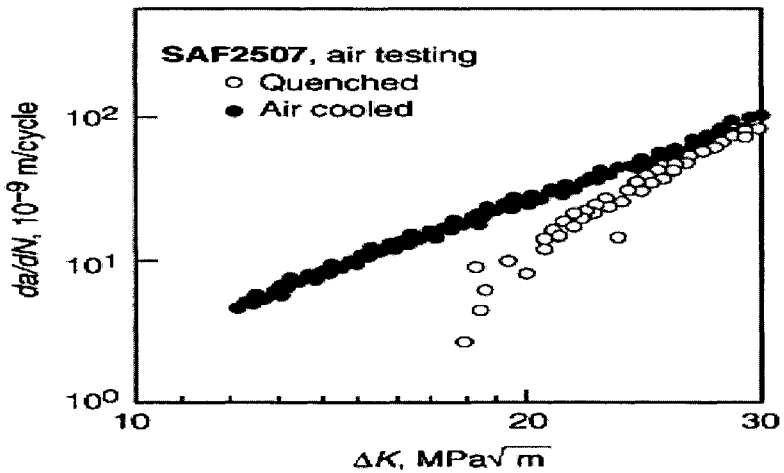
MTI-08-000832 Attachment #14

ASTM A-789, UNS S32750 Ferritc/Austenitic Stainless Steel Fatigue Crack Growth (Super Duplex Stainless Steel, SAF 2507)

Fine Grain

ΔK MN*m^(-3/2)	dA/dN m/cycle	ksi(in^1/2)	in/cycle
1.23E+01	5.13E-08	11.18487	2.02E-06
1.29E+01	6.12E-08	11.72225	2.41E-06
1.32E+01	7.22E-08	11.97728	2.84E-06
1.36E+01	7.60E-08	12.42358	2.99E-06
1.41E+01	8.63E-08	12.79702	3.40E-06
1.46E+01	9.55E-08	13.27976	3.76E-06
1.49E+01	1.06E-07	13.58943	4.16E-06
1.51E+01	1.16E-07	13.78981	4.55E-06
1.57E+01	1.23E-07	14.26344	4.85E-06
1.62E+01	1.40E-07	14.75528	5.50E-06
1.68E+01	1.55E-07	15.3291	6.09E-06
1.74E+01	1.67E-07	15.85738	6.57E-06
1.80E+01	1.85E-07	16.34922	7.28E-06
1.83E+01	2.05E-07	16.64068	8.05E-06
1.88E+01	2.26E-07	17.11431	8.91E-06
1.92E+01	2.41E-07	17.48774	9.50E-06
1.99E+01	2.60E-07	18.08889	1.02E-05
2.07E+01	3.11E-07	18.8813	1.22E-05
2.13E+01	3.19E-07	19.38225	1.26E-05
2.21E+01	3.62E-07	20.13823	1.43E-05
2.26E+01	4.11E-07	20.58453	1.62E-05
2.34E+01	4.49E-07	21.3223	1.77E-05
2.41E+01	4.50E-07	21.95987	1.77E-05
2.44E+01	5.04E-07	22.18758	1.98E-05
2.50E+01	5.65E-07	22.77961	2.22E-05
2.56E+01	5.79E-07	23.35342	2.28E-05
2.65E+01	7.10E-07	24.11851	2.79E-05





ATTACHMENT #15
ASTM B-75 AND B-88 Types K, L, and M
DETERMINATION OF FATIGUE CRACK GROWTH RATE

MTI-08-000832 Attachment #15

ASTM B-75 and B-88 Seamless Copper Tube Fatigue Crack Growth Rate

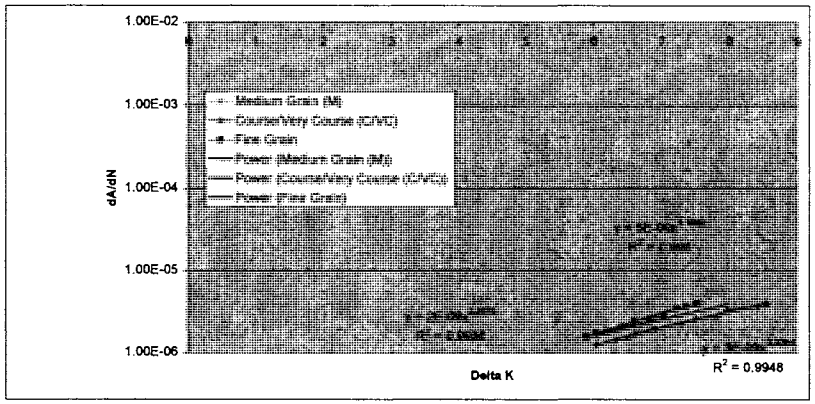
Fine Grain			
ΔK	dA/dN		
MN*m^(-3/2)	mm/cycle	ksi(in^1/2)	in/cycle
6.4563	3.91E-05	5.880527	1.55E-06
6.6148	4.28E-05	6.024892	1.69E-06
7.05E+00	5.18E-05	6.422556	2.05E-06
7.25E+00	6.06E-05	6.602261	2.40E-06
7.49E+00	6.48E-05	6.819765	2.57E-06
7.73E+00	7.42E-05	7.036267	2.94E-06
7.92E+00	8.69E-05	7.21588	3.44E-06
8.08E+00	9.19E-05	7.360792	3.64E-06
8.24E+00	9.83E-05	7.50543	3.89E-06
8.28E+00	1.02E-04	7.541316	4.03E-06

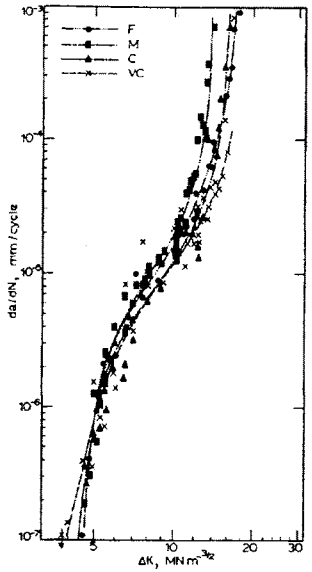
Medium Grain			
ΔK	dA/dN		
MN*m^(-3/2)	mm/cycle	ksi(in^1/2)	in/cycle
6.6159	4.00E-05	6.025894	1.58E-06
7.0128	4.78E-05	6.387398	1.89E-06
7.2509	5.35E-05	6.604265	2.12E-06
7.5287	6.06E-05	6.857291	2.40E-06
7.8077	6.41E-05	7.111409	2.54E-06
7.9262	7.01E-05	7.219341	2.78E-06
8.1646	7.67E-05	7.436481	3.04E-06
8.3232	8.30E-05	7.580937	3.29E-06
8.4427	8.58E-05	7.68978	3.40E-06
8.5619	8.97E-05	7.79835	3.55E-06
8.6807	9.60E-05	7.906555	3.80E-06
8.7601	9.93E-05	7.978874	3.93E-06

Course / Very Course Grain			
ΔK	dA/dN		
MN*m^(-3/2)	mm/cycle	ksi(in^1/2)	in/cycle
6.6202	3.12E-05	6.029811	1.23E-06
6.9379	3.57E-05	6.319178	1.41E-06
7.1367	3.82E-05	6.500249	1.51E-06
7.2548	4.27E-05	6.607817	1.69E-06
7.5724	4.89E-05	6.897093	1.94E-06
8.0099	5.66E-05	7.295577	2.24E-06
8.2474	6.55E-05	7.511897	2.59E-06
8.566	7.08E-05	7.802084	2.80E-06
8.7631	8.38E-05	7.981607	3.32E-06
9.2417	9.06E-05	8.417525	3.59E-06
9.3603	9.81E-05	8.525548	3.88E-06
9.4003	9.81E-05	8.561981	3.88E-06

Effects of grain size and stacking fault energy on fatigue-crack-propagation thresholds in Cu–Al aluminium alloys

Y. Higo, A. C. Pickard, and J. F. Knott





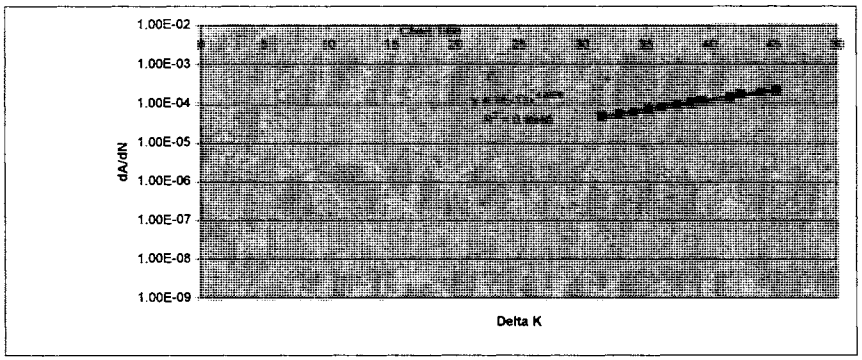
3 Log (da/dN) v. log ΔK: pure copper

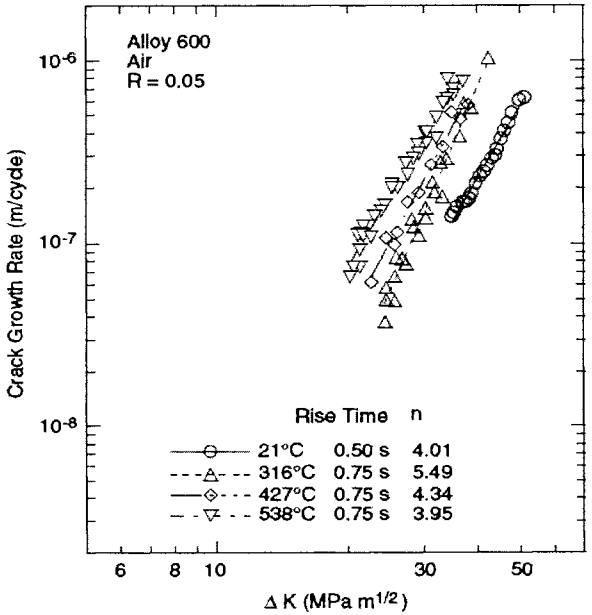
ATTACHMENT # 16
ASTM B-167, UNS N06600
DETERMINATION OF FATIGUE CRACK GROWTH RATE

MTI-08-000832 Attachment #16

ASTM B-167 Nickel-Chromium Iron Alloys and Nickel-Chromium-Cobalt-Molybdenum Alloys Fatigue Crack Growth Rate

Fine Grain			
ΔK	dA/dN		
MN*m^(-3/2)	m/cycle	ksi(in^1/2)	in/cycle
3.46E+01	1.16E-06	31.53259	4.57E-05
3.61E+01	1.34E-06	32.87149	5.26E-05
3.74E+01	1.46E-06	34.02824	5.74E-05
3.87E+01	1.67E-06	35.23052	6.59E-05
3.98E+01	1.99E-06	36.22331	7.84E-05
4.12E+01	2.25E-06	37.49846	8.85E-05
4.23E+01	2.54E-06	38.55501	9.99E-05
4.32E+01	2.92E-06	39.36564	1.15E-04
4.57E+01	3.53E-06	41.61537	1.39E-04
4.67E+01	4.20E-06	42.48975	1.65E-04
4.83E+01	4.74E-06	43.99261	1.87E-04
4.97E+01	5.26E-06	45.22221	2.07E-04



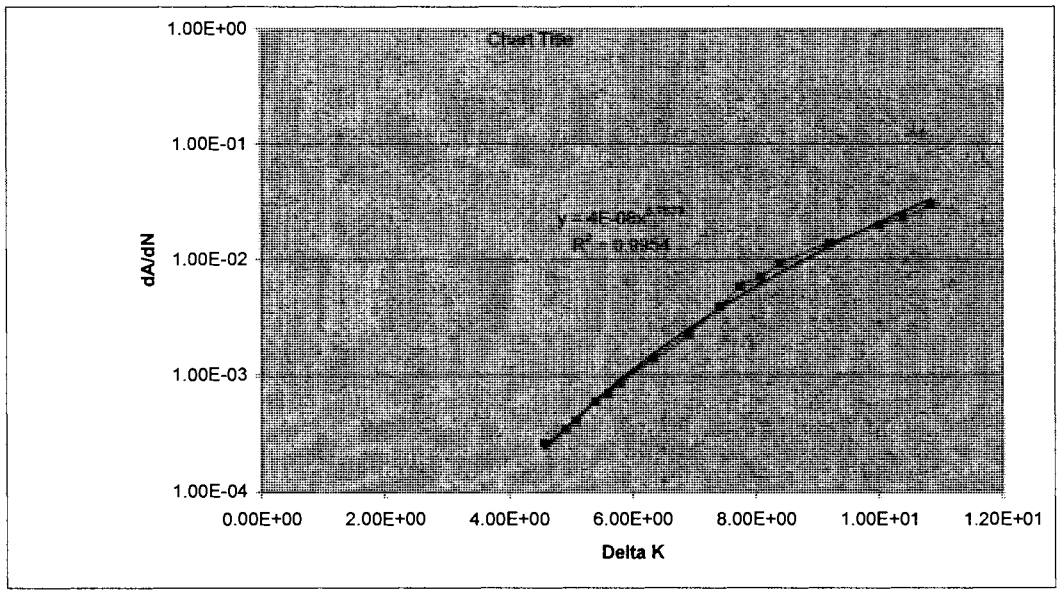


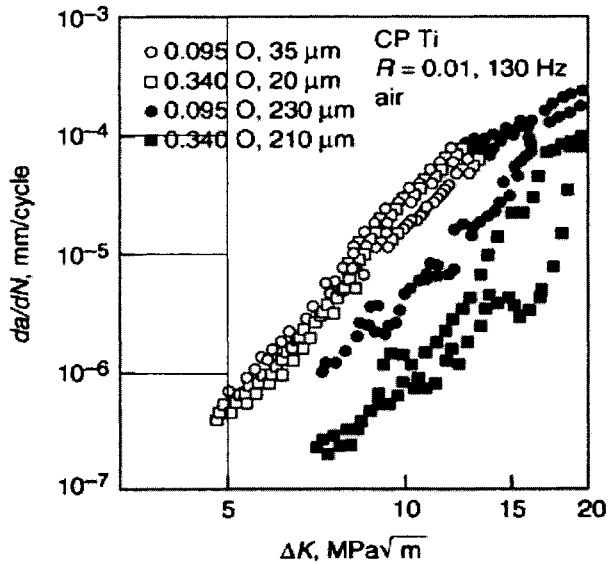
ATTACHMENT #17
ASTM B-338, Grade 2 Unalloyed Titanium
DETERMINATION OF FATIGUE CRACK GROWTH RATE

MTI-08-000832 Attachment #17

ASTM B-338, Grade 2, Commercially Pure (CP) Titanium Fatigue Crack Growth Rate

Fine Grain			
ΔK	dA/dN		
MN*m^(-3/2)	m/cycle	ksi(in^1/2)	in/cycle
5.02E+00	6.54E-06	4.57E+00	2.58E-04
5.39E+00	8.60E-06	4.91E+00	3.38E-04
5.57E+00	1.01E-05	5.07E+00	3.97E-04
5.93E+00	1.48E-05	5.40E+00	5.84E-04
6.16E+00	1.74E-05	5.61E+00	6.85E-04
6.36E+00	2.13E-05	5.79E+00	8.40E-04
6.96E+00	3.44E-05	6.34E+00	1.35E-03
7.58E+00	5.66E-05	6.91E+00	2.23E-03
8.14E+00	9.76E-05	7.41E+00	3.84E-03
8.50E+00	1.47E-04	7.74E+00	5.78E-03
8.87E+00	1.76E-04	8.08E+00	6.94E-03
9.21E+00	2.31E-04	8.39E+00	9.11E-03
1.01E+01	3.48E-04	9.18E+00	1.37E-02
1.10E+01	5.01E-04	1.00E+01	1.97E-02
1.14E+01	5.74E-04	1.04E+01	2.26E-02
1.19E+01	7.54E-04	1.08E+01	2.97E-02





ATTACHMENT #18
ASTM A-179 and ASTM A-789, UNS S32750
LOWER BOUND PLANE STRAIN FRACTURE TOUGHNESS CALCULATION

MTI-08-000832 Attachment #18

Calculation of Lower Bound Plane Strain Fracture Toughness (K_{IC}) from Charpy V-Notch Testing (CVN) in Accordance with Ref. #17 Annex F.4.5.2a2

K_{IC} = Plane strain fracture toughness, ksi $\sqrt{in}$
CVN = Charpy V-Notch Impact Value, ft-lb
σ_{ys} = Material yield strength, ksi

$$\left(\frac{K_{IC}}{\sigma_{ys}}\right)^2 = 4\left(\frac{CVN}{\sigma_{ys}} - 0.1\right) \quad , \quad \left(ksi\sqrt{in},\ ksi,\ ft-lb\right)$$

Material Specification	σ_{ys} (Ref. # 13)	CVN	K_{IC}
ASTM A-179	26	46.0	67.2
ASTM A-789, UNS S32750	80	44.3	107.8