APPENDIX A

Discussion of Dimensional Uncertainties and Determination of K_I Allowable Ratio vs Flaw Size

PURPOSE:

The purpose of Appendix A to this calculation is to address NRC Staff concerns regarding uncertainty in the UT sizing of the RV Outside Indication of the McGuire Unit 2 Reactor Vessel. The indication was qualified in Revision 1 of this calculation to satisfy all ASME Section XI requirements. Appendix A does not serve as part of the actual qualification of the indication but rather serves to resolve the staff's uncertainty concerns.

METHOD:

Appendix A includes two parts. Part I presents a discussion establishing a conservative bound on the uncertainty. In Part II, the Revision 1 Fracture Mechanics analysis is extended to determine the allowable flaw size by computing the flaw size that corresponds to the envelope of:

$$(KI) / (K_{Ia}\sqrt{10}) = 1.0 \text{ for Normal \& Upset Conditions}$$

and

$$(KI) / (K_{Ic}\sqrt{2}) = 1.0 \text{ for Emergency and Faulted Conditions}$$

Part I: CONSERVATIVE BOUND ON CUMULATIVE UNCERTAINTY

The cumulative uncertainty is comprised of two parts: (1) maximum possible error in sizing the flaw and (2) possible variation in the cladding thickness.

B&W maintains, and Duke concurs, that the maximum error in sizing the flaw = .05". Our position is substantiated by "EPRI Report NP-6273, Final Report, Accuracy of Ultrasonic Flaw Sizing Technique for Reactor Pressure Vessels, March 1989." The EPRI report concludes that the accuracy using a technique equivalent to that used by B&W to size the subject flaw (Reference Attachment 12-4 of this calculation) is 1 mm (equals 0.039"). Using the less accurate but more conservative "a" of 0.59" from Attachment 12-4 and the maximum upper bound sizing error of 0.05", the resulting upper bound on flaw size "a" = 0.59 + 0.05 = 0.64" Similarly an upper bound "l" equals 2.40" plus sizing uncertainty of 0.05", or 2.45".

Tolerances are also applied to the cladding. The cladding thickness is used in Attachment 12-4 to determine the vessel thickness t. Results of the fracture mechanics analyses are a function of the a/t ratio and the aspect ratio a/l. Sensitivites to the uncertainty in these variations are discussed in the following paragraphs.

Westinghouse drawing number 30738-1512 gives a minimum cladding thickness of 0.126" and a nominal cladding thickness of 0.157". No maximum thickness is provided on the drawing but we will conservatively assume a maximum clad thickness = 2 x (nominal - minimum) + nominal.

Maximum t_{clad} = (0.157-0.126) 2 + 0.157 = 0.219"

Conservatively, calculate the minimum vessel wall thickness equal to the measured wall thickness minus UT measurement uncertainty minus maximum clad thickness. Minimum vessel thickness = 5.85 - 0.05 - 0.219" = 5.58" as compared to a vessel thickness used in the Rev. 1 analysis and the Appendix A analyses of 5.690".

By examination of ASME Section XI, Figures A-3300-3 and A-3300-5 there is no significant difference in the Membrane Stress Correction Factor, Mm , or in the Bending Stress Correction Factor, Mb, in the regions of interest

Part II: DETERMINATION OF K_I ALLOWABLE RATIO vs FLAW SIZE

This fracture mechanics analysis investigates the ratio of calculated KI to Code allowable KI for larger crack sizes assuming constant a/l ratio. Some load conditions are revised from the parent Revision 1 analysis; this is discussed below.

Results are shown in Figure A-1. This analysis predicts Code allowable would not be exceeded unless the crack was approximately 0.77 inches deep, or 1.54 times actual size. The upper line in this Figure represents the comparison of calculated KI to KIa/√10, the allowable for normal and upset conditions. The lower line in this Figure represents the comparison of calculated KI to KIc/√2, the allowable for emergency and faulted conditions.

Figure A-2 is included to aid in visualizing the sizes depicted in Figure A-1. The minimum thickness [t min] line (4.312 inches) is shown for visual reference.

Table A-1 shows the sizes and load values evaluated to produce Figure A-1. Each size evaluated (0.5, 1.0, 1.5 inches deep) was evaluated for the load conditions shown in Figure A-3. The ratio plotted for each size is the worst case of the three load conditions.

Figure A-3 shows the possible pressure/temperature values during a heatup. It differs from the previous Enclosure 13.4-2 in that it recognizes that actual plant practice is based on Low Temperature Over Pressure Protection (LTOP) considerations. LTOP is more restrictive in limiting pressures allowed for temperatures below the enable temperature of 300°F.

References for the LTOP curve of Figure A-3 are:

[A-1] For temperatures 85 to 300°F (LTOP region), the maximum pressure is calculated to be 483.2 psi + 58.8 psi = 542 psi (by MCC-1223.03-00-0033, Rev. 0, dated 2/16/93). This is the limiting LTOP pressurization transient.

[A-2] The LTOP enable temperature is defined by Technical Specification 3.4.9.3 to be 300 °F.

[A-3] (An administrative limit to achieve 320 °F prior to removing LTOP [step 3.2.38 of OP/2/A/6100/01] would actually move the vertical line at 300 °F to the right, a factor conservatively ignored in this evaluation.)

The three pressure/temperature points chosen for analysis are depicted on the figure.

In order that this analysis continue to be bounding on the previous efforts, stress effects of welding and temperature transients were also included. The 85 °F/ 483 psi point is analyzed in combination with residual stress of 10 ksi and stress effects of 60 °F/hr, since this pressure/temperature point is valid only for heatup. The 300 °F/ 2500 psi point is analyzed in combination with residual stress of 10 ksi and stress effects of 60 °F/hr, since this pressure/temperature point is also valid only for heatup. Since the 212 °F/ 2500 psi point is included to bound previous analyses in Sections 13.5 and 13.6, it is analyzed in combination with stress effects of 44°F/8 sec as well as residual stress of 10 ksi.

CONCLUSION:

Entering Figure A-1 with "a" equal to 0.64 (equaling actual flaw size plus upper bound cumulative uncertainty) the ratio to Code Allowable remains below one for all loading conditions. Thus, even considering the upper bound cumulative uncertainty the flaw size continues to satisfy ASME Section XI Code requirements; i.e. maximum allowable flaw size is greater than the actual flaw size plus uncertainty.

Table A1

1980 ASME Section XI Appendix A Analysis of Flaw Indications

Additional Flaw Indications Analyzed for K_I/K_Iallowable
(Envelope of All Transients)

Units inch, kip, °F

Reactor	Note									
Temp	(1)	85.000	300.000	212.000	85.000	300.000	212.000	85.000	300.000	212.000
Press	(1)	542.000	2500.000	2500.000	542.000	2500.000	2500.000	542.000	2500.000	2500.000
a	(2)	0.500	0.500	0.500	1.000	1.000	1.000	1.500	1.500	1.500
l	(2)	2.400	2.400	2.400	4.800	4.800	4.800	7.200	7.200	7.200
t	(2)	5.690	5.690	5.690	5.690	5.690	5.690	5.690	5.690	5.690
a/t		0.088	0.088	0.088	0.176	0.176	0.176	0.264	0.264	0.264
a/l		0.208	0.208	0.208	0.208	0.208	0.208	0.208	0.208	0.208
RT_{NDT}	(3)	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000
$T-RT_{NDT}$		75.000	290.000	202.000	75.000	290.000	202.000	75.000	290.000	202.000
KI_a	(4)	64.024	200.000	200.000	64.024	200.000	200.000	64.024	200.000	200.000
KI_c	(4)	126.122	200.000	200.000	126.122	200.000	200.000	126.122	200.000	200.000
σ_m pres	(5)	4.209	19.415	19.415	4.209	19.415	19.415	4.209	19.415	19.415
ΔT memb	(6)	5.170	5.170	13.450	5.170	5.170	13.450	5.170	5.170	13.450
σ_m ΔT	(6)	1.572	1.572	4.090	1.572	1.572	4.090	1.572	1.572	4.090
σ_m resid	(7)	0	0	0	0	0	0	0	0	0
σ_m	(8)	5.781	20.987	23.505	5.781	20.987	23.505	5.781	20.987	23.505
σ_b pres	(5)	0	0	0	0	0	0	0	0	0
ΔT bend	(6)	0	0	0	0	0	0	0	0	0
σ_b ΔT	(6)	0	0	0	0	0	0	0	0	0
σ_b resid	(7)	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000
σ_b	(8)	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000
M_m	(9)	1.100	1.100	1.100	1.120	1.120	1.120	1.140	1.140	1.140
M_b	(9)	0.920	0.920	0.920	0.850	0.850	0.850	0.750	0.750	0.750
σ_{ys}	(10)	50.000	45.200	46.872	50.000	45.200	46.872	50.000	45.200	46.872
Q	(11)	1.324	1.246	1.237	1.324	1.246	1.237	1.324	1.246	1.237
K_I	(12)	16.947	36.257	39.505	23.067	50.830	55.503	26.583	61.125	66.942
$\sqrt{2}K_I/K_{Ic}$	(13)	0.190	0.256	0.279	0.259	0.359	0.392	0.29[illegible]	0.432	0.473
$\sqrt{10}K_I/K_{Ia}$	(13)	0.837	0.573	0.625	1.139	0.804	0.878	1.313	0.966	1.058

Notes:

(1) Enveloped Pressure & Temperature Transients Reference [A-1 & A-2] & Figure A3.
(2) Crack depth, length & vessel wall thickness for hypothetical & actual flaws.
(3) Determination of Reference Transition/Nil Ductility Temperature, reference section 13.1
(4) Available fracture toughness based on crack arrest & fracture initiation, respectively, for the corresponding crack tip temperature (ksi√in) as defined in ASME Section XI, Appendix A, Figure A-4200-1 (reference section 4.0).
(5) Membrane pressure stress = PD/4t (thin wall theory hoop stress in a spherical shell) where D = 176.75". Bending component of pressure stress = 0.
(6) Maximum of average minus outside temperature from TRANS2A analysis (microfiche attachment M1 & Figures 13.4-6 & 13.5-2), used to calculate σm (EαΔT/(1-μ) where E = 29.9E3, α = 7.12E-6 in/in/°F, μ = 0.3). Conservatively define all transient stress to be membrane (M_m is larger than M_b in K_I computation, reference ASME Section XI Appendix A, article A-3300).
(7) Residual stress is conservatively assumed to be 10 ksi bending per the 1986 edition of the ASME Section XI Appendix E, Table E-2.
(8) Total membrane/bending stress to be used in K_I determination. Sum of pressure, transient & residual stresses.
(9) Correction factors for membrane & bending stress as defined in ASME Section XI, Appendix A, article A-3300. See Figures A-3300-3 & A-3300-5
(10) Yield stress of material @ temperature. Reference Figure 13.4-7 & ASME Section III, Appendix I, 1977.
(11) Shape factor for flaw as defined in Figure A-3300-1 of ASME Section XI Appendix A
(12) Stress intensity factor as defined in ASME Section XI Appendix A, article A-3300.
$K_I = \sigma_m M_m \sqrt{\pi}\sqrt{(a/Q)} + \sigma_b M_b \sqrt{\pi}\sqrt{(a/Q)}$
(13) Ratio to allowables; $K_I < K_{Ia}/\sqrt{10}$ for normal conditions and $K_I < K_{Ic}/\sqrt{2}$ for emergency & faulted conditions, are required by ASME Section XI article IWB-3612.

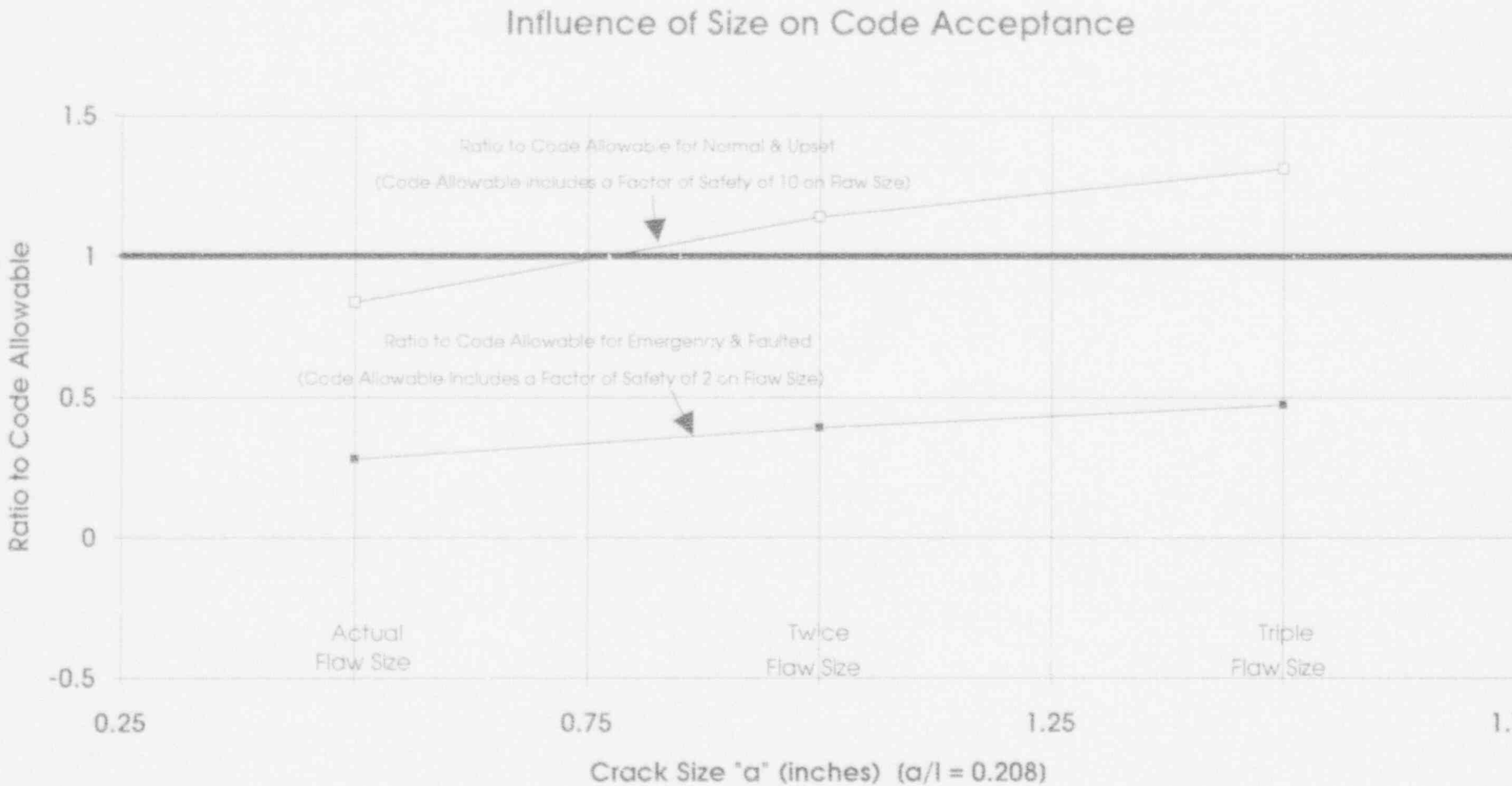
Influence of Size on Code Acceptance
Ratio to Code Allowable for Normal & Upset
(Code Allowable includes a Factor of Safety of 10 on Flaw Size)
Ratio to Code Allowable for Emergency & Faulted
(Code Allowable includes a Factor of Safety of 2 on Flaw Size)
Ratio to Code Allowable
1.5
1
0.5
0
-0.5
Actual Flaw Size
Twice Flaw Size
Triple Flaw Size
0.25
0.75
1.25
1.75
Crack Size "a" (inches) (a/l = 0.208)

Figure A-1

Representation of Larger Flaw Sizes as Analyzed for KI / KI allowables

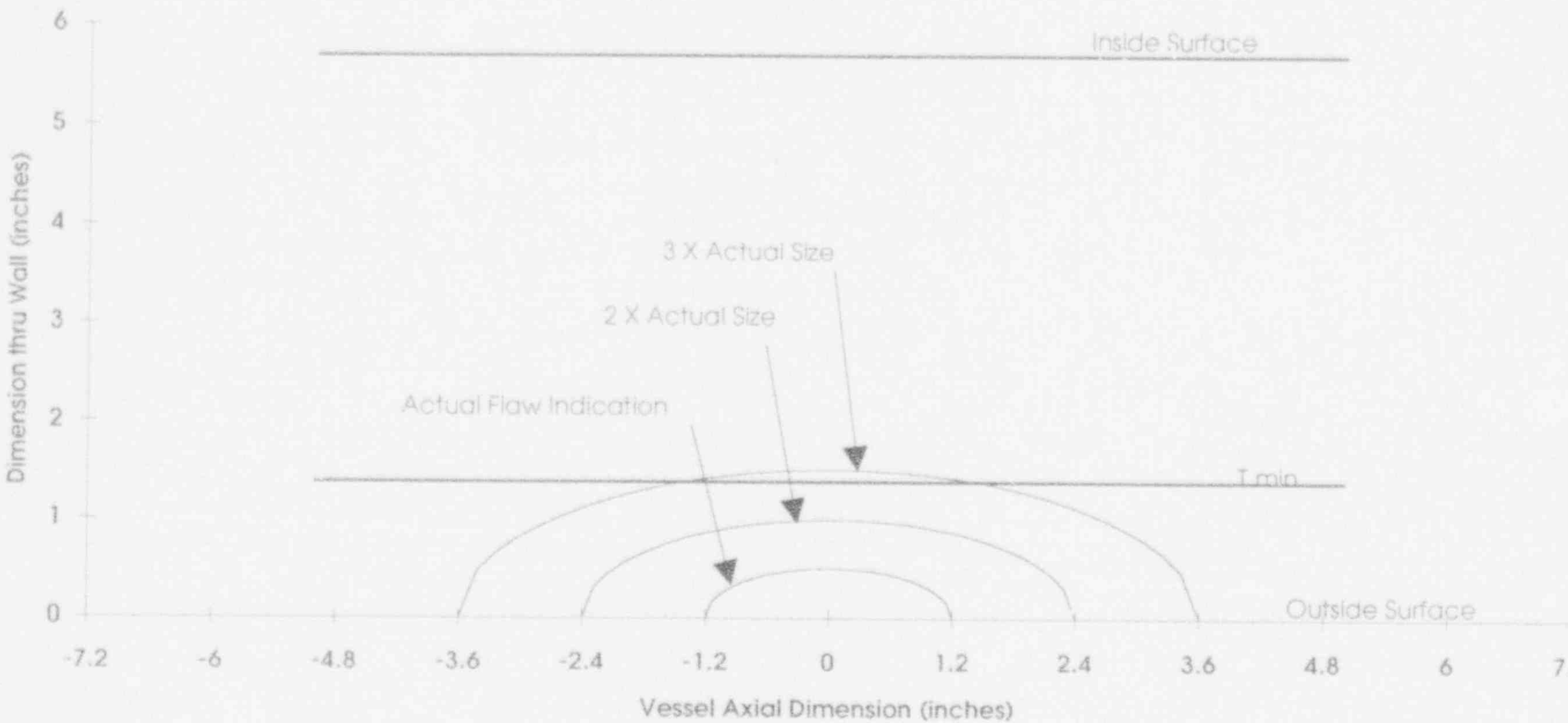

Figure A-2

PT.XLC

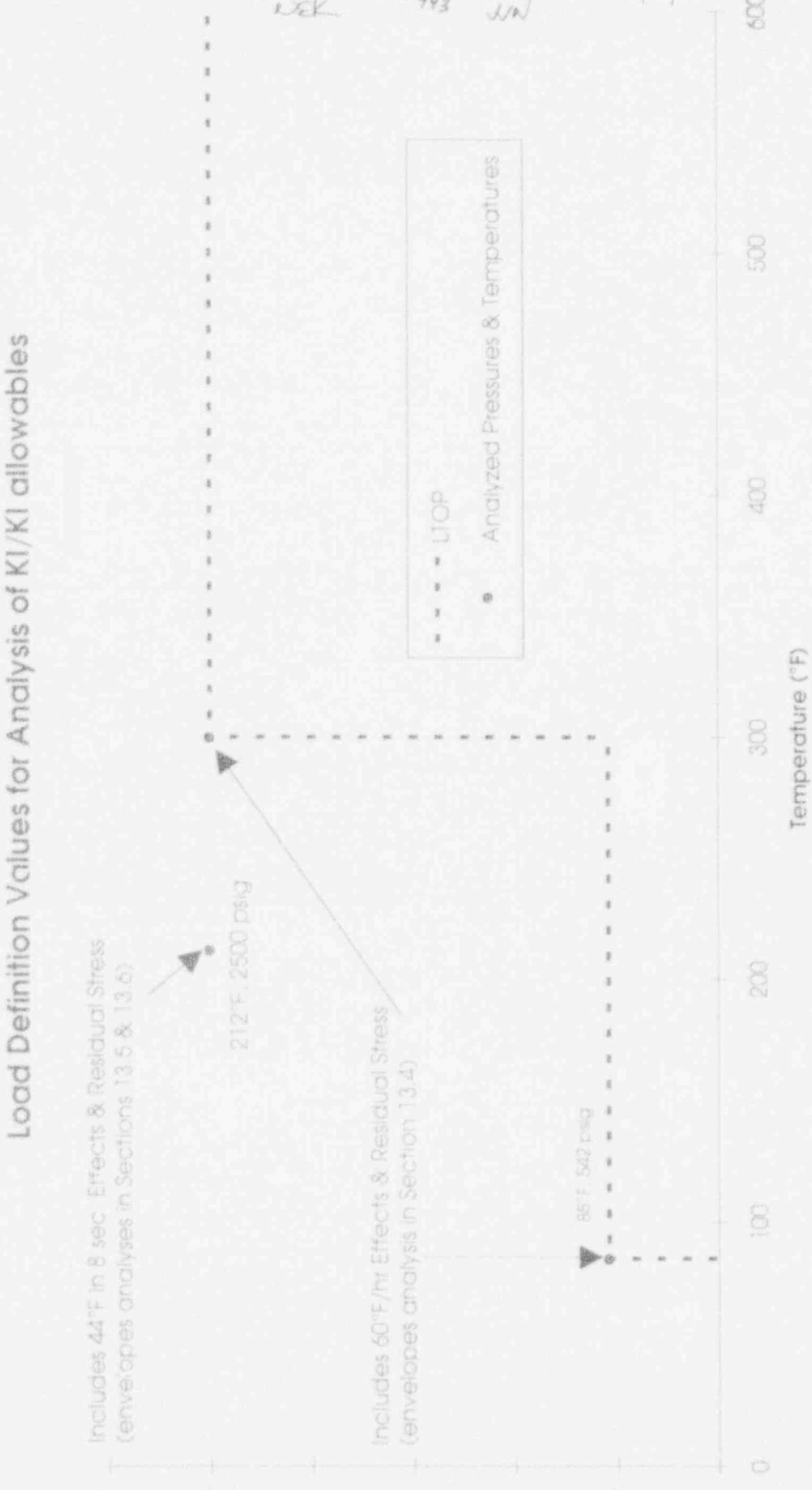

Figure A-3