BOSTON EDISON CO.
25 BRAINTREE HILL OFFICE PARK
BRAINTREE, MASSACHUSETTS 02184

TECHNICAL REPORT TR-6052-1, REV. 2

PILGRIM NUCLEAR POWER STATION
REACTOR PRESSURE VESSEL
PRESSURE TEMPERATURE LIMITS

JULY 19, 1984

TELEDYNE ENGINEERING SERVICES

130 SECOND AVENUE
WALTHAM, MASSACHUSETTS 02254
617-890-3350

TELEDYNE ENGINEERING SERVICES

Technical Report
TR-6052-1, Rev. 1

TABLE OF CONTENTS

	PAGE
1.0 INTRODUCTION	1
2.0 REACTOR VESSEL FRACTURE TOUGHNESS PROPERTIES	1
2.1 Reference Temperature, RT_{NDT}	2
2.1.1 Beltline	2
2.1.2 Closure Region and Shroud Support Region	4
2.1.3 Feedwater Nozzle	5
2.2 Upper Shelf Energy	5
2.2.1 Beltline	6
2.2.2 Closure Region, Shroud Region, F-W Nozzle	6
3.0 OPERATIONAL LIMITS	7
3.1 Closure Region	7
3.2 Shroud Support Region	9
3.3 Beltline	9
3.3.1 End-Of-Life	9
3.3.2 Intermediate Operational Periods	10
3.4 Feedwater Nozzle	11
4.0 PRESSURE-TEMPERATURE LIMIT CURVES	11
5.0 REFERENCES	12
APPENDIX A - EXAMPLE CALCULATIONS	
APPENDIX B - P-T PLOTS	

1.0 INTRODUCTION

Boston Edison Co. (BECO) has requested Teledyne Engineering Services (TES) to provide an assessment of the compliance of the Pilgrim NPS Reactor Pressure Vessel (RPV) with the recently amended requirements of 10CFR50, Appendix G (Reference 1).

This report addresses the requirements of Paragraph IV of Appendix G relative to the pressure-temperature (P-T) limits for the RPV. The current Technical Specification limits were developed for the Pilgrim RPV in 1976 (Reference 2). Reported herein is an assessment of the impact on the current P-T limits of the Paragraph IV requirements as they appear in the current amendment to Appendix G.

2.0 REACTOR VESSEL FRACTURE TOUGHNESS PROPERTIES

Appendix G imposes the fracture toughness testing requirements of Section III, Winter 1981 (Reference 3) and therefore, requires compliance with NB-2322 with regard to Charpy V-notch specimen orientation and location. For plate and forging product forms, NB-2322 requires C_V specimens to be oriented in a direction normal to the principal rolling direction, that is, the weaker direction.

For older plants in which current specimen orientation requirements may not have been imposed, USNRC Branch Technical Position MTEB 5-2 (Reference 4) provides procedures for estimating transverse impact properties from longitudinally-oriented specimens. These are stated as follows:

The temperature at which 50 ft-lbs and 35 mils would have been obtained on transverse specimens may be estimated by one of the following criteria:

(a) Test results from longitudinally oriented specimens reduced to 65% of their value

(b) Temperatures at which 50 ft-lbs and 35 mils were obtained on longitudinally oriented specimens increased by 20F

No adjustment for drop weight tests are required, although the Charpy adjustment may affect RT_{NDT}.

TES has reviewed the available impact test data for the Pilgrim RPV and applied the MTEB 5-2 adjustments where required. The resulting RT_{NDT} and upper-shelf energy levels are then determined for use in establishing P-T limits.

2.1 Reference Temperature, RT_{NDT}

2.1.1 Beltline

The Combustion Engineering (CE) Material Certification Reports (Reference 5) state that specimens were taken parallel to the major rolling direction of the plate at the 1/4 thickness level. Therefore, an adjustment to the Charpy impact data is required.

Applying this criteria to the CE base metal test results for the unirradiated beltline specimens result in the following (Note: Tabulation represents test temperature at 50 ft-lbs/35 mils):

CE		T_{NDT} + 60F Adjustment Criteria		Max.
DWT_{NDT}	C-V	(a)	(b)	T_{NDT}
-30	10/-6	48/50	30/14	-10*
-40	22/16	56/50	42/36	- 4
-20	13/-1	57/52	33/19	- 3

*See Appendix A for Example Calculation.

The dropweight T_{NDT} indicated by the Material Certification Reports are also tabulated above. For transverse specimens the above Charpy levels would have to be attained for a test temperature no greater than DWT_{NDT} + 60F. Since this is not the case, RT_{NDT} is taken as -3F (57-60) for the base metal.

Drop weight data for the weld and HAZ are not available. MTEB 5-2 provides for estimating T_{NDT} from full Charpy V-notch curves. For SA-533 Grade B, Class 1 plate and weld metal, T_{NDT} may be assumed to be the temperature at 30 ft-lbs or 0F, whichever is higher.

Southwest Research Institute (SwR) provides weld metal and HAZ Charpy impact data (Reference 6) for unirradiated beltline material. Applying the 30 ft-lbs criteria to the SwR data gives T_{NDT} as the greater of the following or 0F:

Weld Metal: -120F*
HAZ : - 70F

SwR (Reference 6) also provides the predicted adjustment to RT_{NDT} over 32 effective full power years (EFPY) due to irradiation. Accounting for the base metal adjustment for specimen orientation the following values apply to the beltline at the 1/4 thickness location:

	RT_{NDT}		
	ΔRT_{NDT}	Initial	32 EFPY
Base Metal	62F	0	62F
Weld Metal	136	0	136
HAZ	62	0	62

No adjustment has been made to the HAZ Charpy data since neither MTEB 5-2 nor ASTM E185 specifically requires such an adjustment.

In addition, the tabulation reflects a RT_{NDT} shift equal to that of the base material, even though Reference 6 reports this shift to be negligible for the HAZ.

2.1.2 Closure Region and Shroud Support Region

The Combustion Engineering Material Certification Reports for the head torus plates, the upper shell plates and the lower shell plates indicate that impact specimens were taken parallel to the major rolling direction. Applying the MTEB 5-2 adjustment for orientation gives the following:

	T_{NDT} + 60F			T_{NDT}	
		Adjusment Criteria			
	CE	(a)	(b)	(a)	(b)
Head	-11/-17	14/12	9/3	-46	-51
	22/12	47/43	42/32	-13	-18
Upper Shell	- 3/-15	56/55	17/5	- 4	-43
	35/11	75/68	55/31	15	- 5
	18/0	59/40	38/20	- 1	-22
Lower Shell	20/5	62/48	40/25	2	-20
	32/20	72/60	52/40	12	- 8
	34/15	77/55	54/35	17	- 6

The CE drop weight test data for the head, upper shell and lower shell material indicates no break at -10F. Since TR-2318 uses an RT_{NDT} of -10F for the head, the pressure temperature limits determined therein are appropriate for trar[illegible] impact properties of the head. For the upper shell, the 50 ft-l[illegible] mil) requirement for one specimen is met at a T_{NDT} of -5F (Adjustment Criteria (b)). Therefore, the TR-2318 results are

adjusted to an RT_{NDT} of -5F. For the lower shell, TR-2318 conservatively uses an RT_{NDT} of +40F whereas the Charpy data above indicates the transverse RT_{NDT} to be -6F. The TR-2318 results are adjusted to account for this effect, also.

2.1.3 Feedwater Nozzle

The CE Material Certification Reports do not indicate impact specimen orientation. Assuming standard procedures of the period were consistent with SA-370, it is assumed that a longitudinal orientation was used since SA-370 specifies longitudinal orientation unless otherwise specified.

Applying the MTEB 5-2 procedures to the CE impact data gives the following:

T_{NDT} + 60F			
CE	Adjustment (a)	Criteria (b)	Maximum T_{NDT}
-28/-40	14/0	-8/-20	-46

The CE drop weight test data indicates no break at 10F. This is also the RT_{NDT} value used in TR-2318. Therefore, the results therein for the feedwater nozzle are considered appropriate for transverse impact properties.

2.2 Upper Shelf Energy

An adjustment to upper shelf energy to account for specimen orientation is provided by MTEB 5-2 as follows:

> Reduce upper shelf Charpy energy values from longitudinal specimens to 65% of their value to estimate transverse values.

2.2.1 Beltline

The fracture toughness requirements of Appendix G, 10CFR50 (IV.A.1) specify minimum Charpy upper shelf energy levels for the beltline region of the reactor vessel. Initial upper shelf energy based on Charpy impact tests must be no less than 75 ft-lbs and must be maintained at no less than 50 ft-lbs throughout the vessel life.

The initial upper shelf energy levels for the beltline material are reported by SwR in Reference 6. Also reported is the decrease in shelf energy due to irradiation based on capsule specimen impact tests. This data along with the orientation adjustment is summarized below.

	Shelf Energy (ft-lbs)			
	Initial Longit.	Initial Transv.	Shift	32 EFPY
Base Metal	130	85*	15%	72
Weld Metal	113	113	27	82
HAZ	110	110	14	95

2.2.2 Closure Region, Shroud Region, F-W Nozzle

Applying the MTEB 5-2 adjustment to the C-E upper shelf energy data gives:

	Shelf Energy (ft-lbs)	
	Longit.	Transv.
Head	124	81
	127	83

(Cont'd)

	Shelf Energy (ft-lbs) Longit.	Transv.
Lower Shell	123	80
	130	85
	115	75
F-W Nozzle	147	96
	148	96
	136	88
Upper Shell	130	85
	123	80
	135	88

3.0 OPERATIONAL LIMITS

The pressure-temperature relationships tabulated below are determined using the results of TR-2318 adjusted for the impact properties determined in Section 2.0 and for irradiation, where applicable.

3.1 Closure Region

	Condition	Pressure (psi)	K_I (KSI$\sqrt{in}$)	T-RT_{NDT} (F)	T (F)	Ref. 2 Para.
Head RT_{NDT} = -10F	S.U./S.D.	0 (Bolt Preload)	48.2	37	27	C.1.1
	S.U./S.D.	250	68.7	83	73	C.1.1
	S.U./S.D.	500	94.9	117	108	C.1.1
	S.U./S.D.	750	120.9	139	129	C.1.1
	S.U./S.D.	1000	149.2	157	147	C.1.1

TELEDYNE ENGINEERING SERVICES

(Cont'd)

	Condition	Pressure (psi)	K_I (KSI$\sqrt{in}$)	$T-RT_{NDT}$ (F)	T (F)	Ref. 2 Para.
		0	41.2	10	0	
	Pressure Tests	750	88.7	110	100	C.1.2
		1000	109.2	130	120	C.1.2
		1140	119.2	138	128	C.1.2
	S.U./S.D.	0 (Bolt Preload)	125.5	142	137	C.1.1
Upper Shell	S.U./S.D.	250	131.6	146	141	C.1.1
RT_{NDT} = -5F	S.U./S.D.	500	164.7	165	160	C.1.1
	S.U./S.D.	750	170.3	168	163	C.1.1
	S.U./S.D.	1000	187.4	176	171	C.1.1
		0	95	117	112	
	Pressure Tests	750	104	125	120	C.1.2
		1000	107.3	128	123	C.1.2
		1140	109.2	130	125	C.1.2

When pressure exceeds 20% of the preservice system hydrostatic test pressure, Appendix G of 10CFR50 (IV.A.2) requires that the temperature of the closure flange regions, which are highly stressed by the bolt preload, exceed the RT_{NDT} by: a) 120F for normal operation, and b) 90F for hydrostatic tests and leak tests. Twenty percent of preservice system hydrostatic pressure is 313 psi. Therefore:

			Minimum Closure Temperature (F)	
	RT_{NDT} (F)	Pressure (psi)	Normal Operation	Hydrotest
Head	-10	313	110	80
Upper Shell	- 5	313	115	85

These conditions are satisfied (see Figures 4-1(a), (b), (c).

3.2 Shroud Support Region

The beltline region is more limiting than the lower shell with regard to both stress intensity factors and RT_{NDT}. Therefore, the shroud support region need not be evaluated further.

3.3 Beltline

The operational limits for the beltline are determined herein for various operational periods.

3.3.1 End-Of-Life

At 32 EFPY the fluence and RT_{NDT} shift at the 1/4 T location (weld metal) are predicted by SwR (Reference 6) to be 1.4×10^{18} n/cm^2 and 136F, respectively.

Condition	Pressure (psi)	K_I (KSI $\sqrt{in}$)	$T-RT_{NDT}$ (F)	T (F)	Ref. 2 Page
S.U./S.D.	1250	118.8	137	273	
	1050	100.	122	258	B-2-5
	800	74.8	93	229	
	525	49.	40	176	B-2-5
	400	37.4	-12	125	
	315	29.5	-105	31	
	263	24.4	-240	-104	B-2-5
Pressure Tests	1250	89.3	110	246	
	1138	82.1	102	238	B-2-8
	776	55.2	56	192	B-2-8
	690	48.9	39	175	B-2-8
	500	35.5	-25	111	
	400	28.4	-141	-5	

3.3.2 Intermediate Operational Periods

The tabulations belows provide the predicted operational limits applicable to various operational periods between the current outage (6.68 EFPY) and about 1994 (14.3 EFPY). These are based on BECO projected fast neutron fluence on the Pilgrim RPV (Reference 7) and on the SwR (Reference 6) predicted fluence and RT_{NDT} shift at the 1/4 T location (weld metal) for the given operational period. (Note that the initial RT_{NDT} for the beltline weld metal is OF.)

EFPY	RPV Wall Fluence, 1/4 T	ΔRT_{NDT}	RT_{NDT}
6.68	2.8×10^{17} n/cm^2	61	61
8.0	3.4×10^{17} n/cm^2	68	68
10.0	4.4×10^{17} n/cm^2	76	76
12.0	5.1×10^{17} n/cm^2	82	82
14.3	6.1×10^{17} n/cm^2	90	90

Subcritical Heatup/Cooldown Pressurization Temperature

		T(F)				
Pressure	$T-RT_{NDT}$	14.3 EFPY	12 EFPY	10 EFPY	8 EFPY	6.68 EFPY
1250	137	227	219	213	205	198
1050	122	212	204	198	190	183
800	93	183	175	169	161	154
525	40	130	122	116	108	101
400	- 12	78	70	64	56	49
315	-105	- 15	- 23	- 29	- 37	- 44
263	-240	-150	-158	-169	-172	-179

Hydro and Leak Tests Pressurization Temperature

		T(F)				
Pressure	$T-RT_{NDT}$	14.3 EFPY	12 EFPY	10 EFPY	8 EFPY	6.68 EFPY
1250	110	200	192	186	178	171
1138	102	192	184	178	170	163
900	74	164	156	150	142	135
776	56	146	138	132	124	117
690	39	129	121	115	107	100
500	- 25	65	57	51	43	36
400	-141	- 51	- 59	- 65	- 73	- 80

A composite plot of the pressure-temperature relationship for the beltline region is shown in Appendix B, Figure B.1, for 8, 12 and 32 EFPY. In addition, Figure B.2 presents the results as a function of temperature above (or below) RT_{NDT}.

3.4 Feedwater Nozzle

The closure region is more limiting than the feedwater nozzle with regard to both stress intensity factors and RT_{NDT}. Therefore, the P-T limits of the closure region will be controlling. At upper shelf temperatures the stress intensity factor is 60.6 KSI$\sqrt{in}$.

4.0 PRESSURE-TEMPERATURE LIMIT CURVES

Pressure-temperature limit curves are shown in Figures 4-1(a) through 4-1(c). Figure 4-1(a) reflects the predicted end-of-life (32 EFPY) beltline RT_{NDT} shift. Figures 4-1(b) and 4-1(c) represents the P-T limits for pressure tests and operating conditions, respectively. These curves represent the predicted conditions through about 1994 (14.3 EFPY). The following observations are noted:

(1) The closure shell is limiting primarily due to the preload stress condition.

(2) The indicated pressurizing temperature for the closure is always greater than the following:

Normal Operation: RT_{NDT} + 120F = 115F
Pressure Tests: RT_{NDT} + 90F = 85F

This complies with 10CFR50, Appendix G, Pargaraph IV.A.2.

(3) When the core is critical, the indicated pressurization temperature for the closure is greater than RT_{NDT} + 60F = 55F. This complies with Paragraph IV.A.3.

(4) For the pressure tests of IV.A.4 the indicated pressurization temperature, T, complies with 10CFR50:

EFPY	T(F)	RT_{NDT} + 60F
8	170	128
12	184	142
32	238	196

5.0 REFERENCES

(1) 10CFR50, Appendix G, Fracture Toughness Requirements, Effective July 26, 1983.

(2) Teledyne Engineering Services Technical Report TR-2318, Rev. 1, June 11, 1976 (Teledyne Materials Research).

(3) ASME BPVC, Section III, 1980 Edition and Addenda through Winter 1981.

(4) USNRC Standard Review Plan 5.3.2, "Pressure-Temperature Limits," Rev. 1, July 1981 and MTEB 5-2.

(5) Reactor Vessel Material Certification Test Results for Pilgrim 1, transmitted to BECO from C. E. Power Systems on May 11, 1976, Transmittal No. DRV-76-586.

(6) Southwest Research Institute, Project Report 02-5951, "PNPS Reactor Vessel Irradiation Surveillance Program," July 1981.

(7) Boston Edison Co. Memorandum dated May 16, 1984, "Projected Fast Neutron Fluence on Pilgrim Pressure Vessel," L. C. Hu to J. S. Roberts.

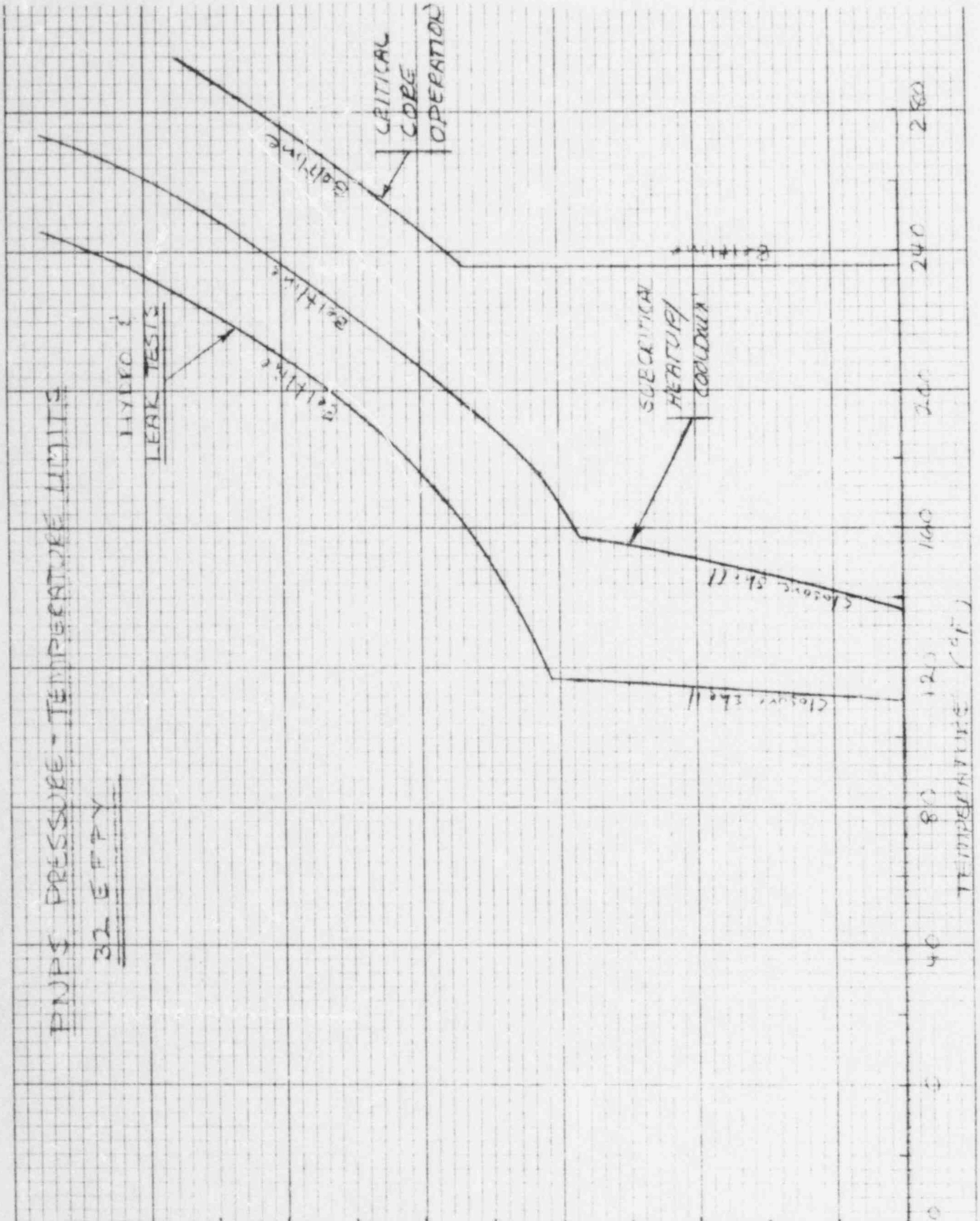
PNPS PRESSURE - TEMPERATURE LIMITS
32 EFPY
CRITICAL
CORE
OPERATION
HYDRO &
LEAK TESTS
SUBCRITICAL
HEATUP/
COOLDOWN
0
200
400
600
800
1000
-40
0
40
80
120
160
200
240
280

Figure 4-1 (a)

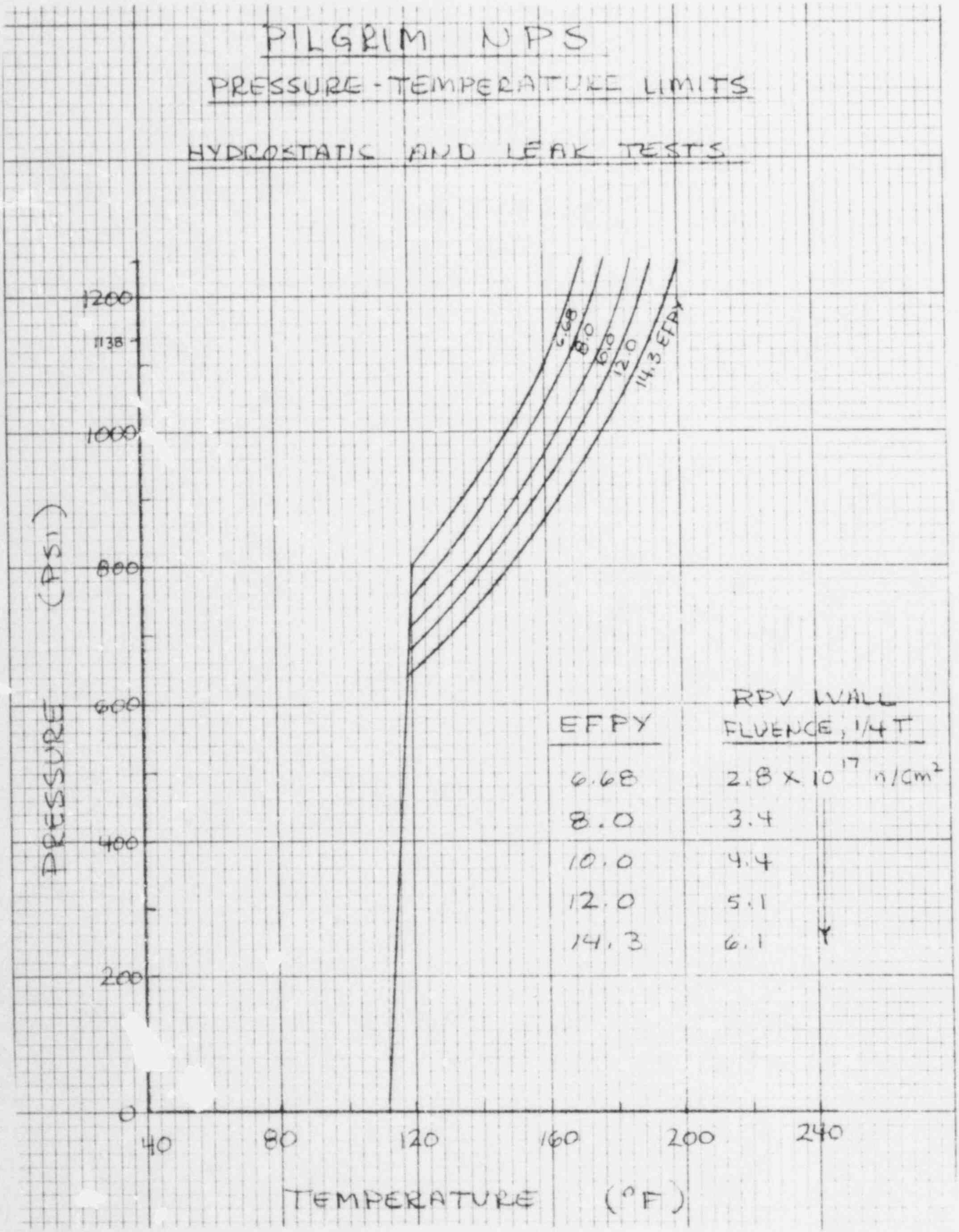
PILGRIM NPS
PRESSURE-TEMPERATURE LIMITS
HYDROSTATIC AND LEAK TESTS
1200
1138
1000
800
600
400
200
0
PRESSURE (PSI)
6.68
8.0
10.0
12.0
14.3 EFPY
EFPY
RPV WALL FLUENCE, 1/4 T
6.68 2.8 x 10^17 n/cm^2
8.0 3.4
10.0 4.4
12.0 5.1
14.3 6.1
40
80
120
160
200
240
TEMPERATURE (°F)

Figure 4-1 (b)

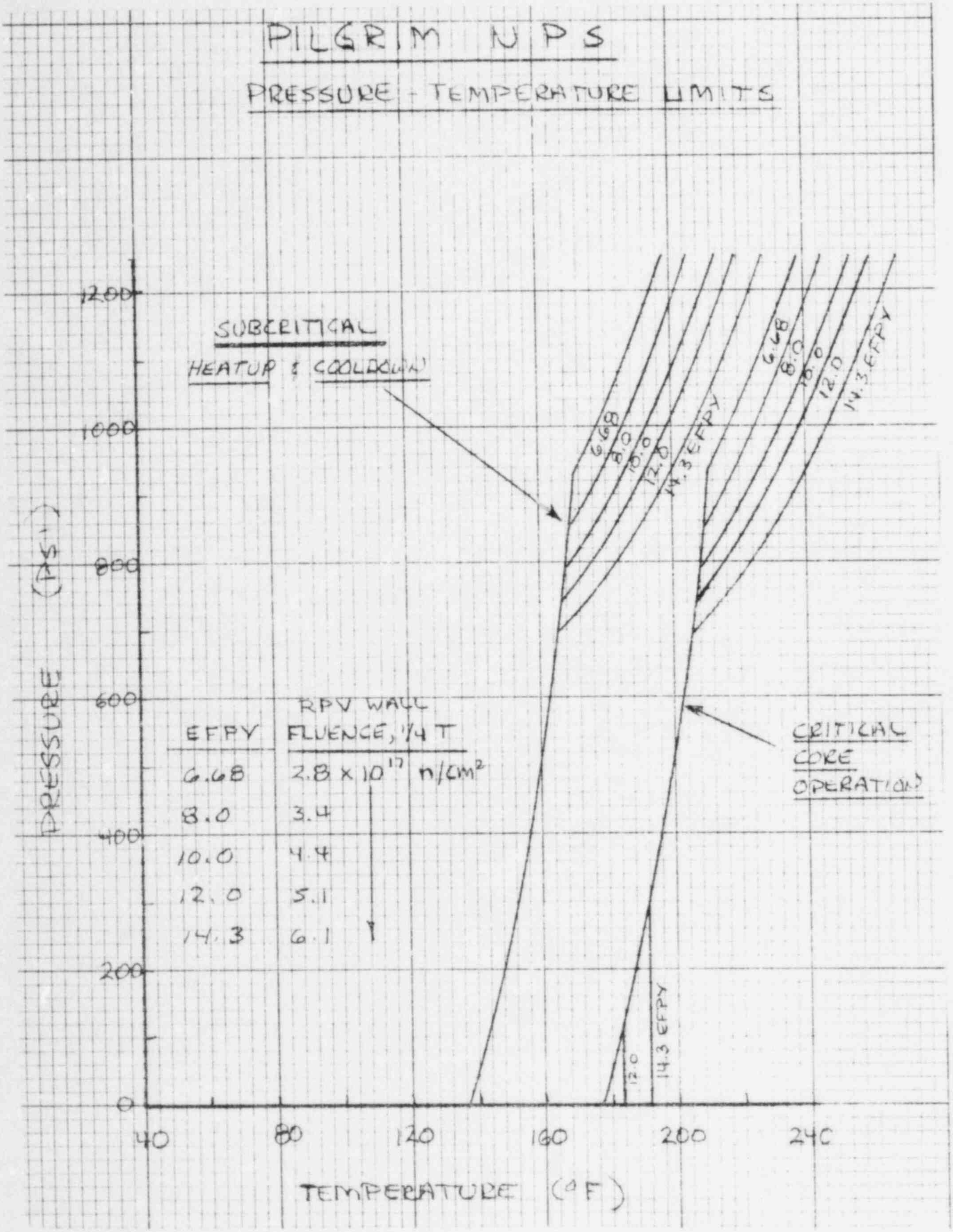
PILGRIM NPS
PRESSURE - TEMPERATURE LIMITS
SUBCRITICAL
HEATUP & COOLDOWN
CRITICAL CORE OPERATION
6.68
8.0
10.0
12.0
14.3 EFPY
14.3 EFPY
12.0
EFPY | RPV WALL FLUENCE, 1/4 T
6.68 | 2.8 x 10^17 n/cm^2
8.0 | 3.4
10.0 | 4.4
12.0 | 5.1
14.3 | 6.1
PRESSURE (PSI)
1200
1000
800
600
400
200
0
40
80
120
160
200
240
TEMPERATURE (°F)

Figure 4-1 (c)

APPENDIX A

APPENDIX A

Example Calculations

1) MTEB 5-2 Charpy V-Notch Adjustment for Specimen Orientation

> "If transverely-oriented Charpy V-notch specimens were not tested, the temperature at which 50 ft-lbs and 35 mils LE would have been obtained on tranverse specimens may be estimated by one of the following criteria.
>
> a. Test results from longitudinally-oriented specimens reduced to 65% of their value to provide conservative estimates of values expected from transversely oriented specimens.
>
> b. Temperatures at which 50 ft-lbs and 35 mils LE were obtained on longitudinally-oriented specimens increased 20F to provide a conservative estimate of the temperature that would have been required to obtain the same values on transversely-oriented specimens."

Figure A.1 shows the CE Charpy V-notch impact test results (Reference 5) for one longitudinal specimen of unirradiated beltline base material.

At 50 ft-lbs, the test temperature is 10F
At 35 mils, the test temperature is -6F

To apply the MTEB 5-2 (Reference 4) adjustment (a) for specimen orientation, enter the curves at:

$$\frac{50}{0.65} = 76.9 \text{ ft-lbs} \longrightarrow \text{Test Temperature} = 48F$$

$$\frac{35}{0.65} = 53.9 \text{ mils} \longrightarrow \text{Test Temperature} = 50F$$

For adjustment (b) add 20F to the 50 ft-lbs/35 mils temperature values:

$$10 + 20 = 30F$$
$$-6 + 20 = 14F$$

If these four temperature values are less than the dropweight T_{NDT} plus 60F, then T_{NDT} is the reference temperature, RT_{NDT}.

In this example:

$$DWT_{NDT} = -30F$$

$$DWT_{NDT} + 60 = +30F$$

Thus, the above requirement is not met and the RT_{NDT} is:

$$50F - 60 = -10F$$

2. MTEB 5-2 Estimation of T_{NDT} from Charpy V-Notch Data when Dropweight Tests are not Available.

> "If dropweight tests were not performed, but full Charpy V-notch curves were obtained, the NDTT for SA-533 Grade B, Class 1 plate and weld material may be assumed to be the temperature at which 30 ft-lbs was obtained in Charpy V-notch tests, or OF, whichever was higher."

Entering Figure 3 of Reference 6 at 30 ft-lbs gives a test temperature of -120F for unirradiated weld metal. Since 0F is greater than this value T_{NDT} = 0F.

3. MTEB 5-2 Estimation of Upper-Shelf Energy from Longitudinal Specimens

> "If tests were only made on longitudinal specimens, the values should be reduced to 65% of the longitudinal values to estimate the transverse properties."

From Figure 2 of Reference 6 the upper shelf energy is at least 130 ft-lbs. Therefore:

$$0.65 \times 130 = 85 \text{ ft-lbs}$$

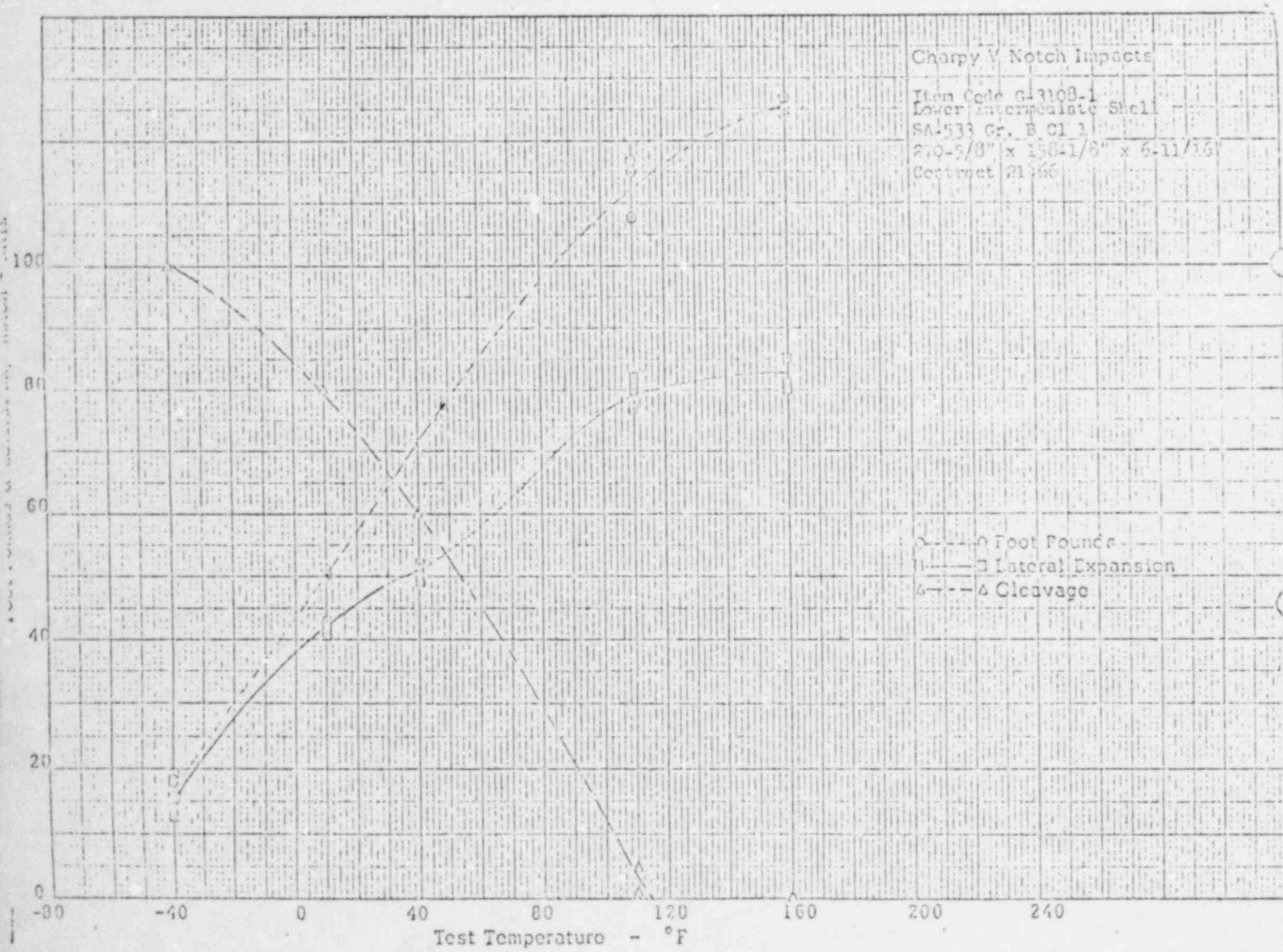
Charpy V Notch Impacts
Item Code G-3108-1
Lower Intermediate Shell
SA-533 Gr. B Cl 1
O----O Foot Pounds
□----□ Lateral Expansion
Δ----Δ Cleavage
100
80
60
40
20
0
-80
-40
0
40
80
120
160
200
240
Test Temperature - °F

Figure A.1

APPENDIX B

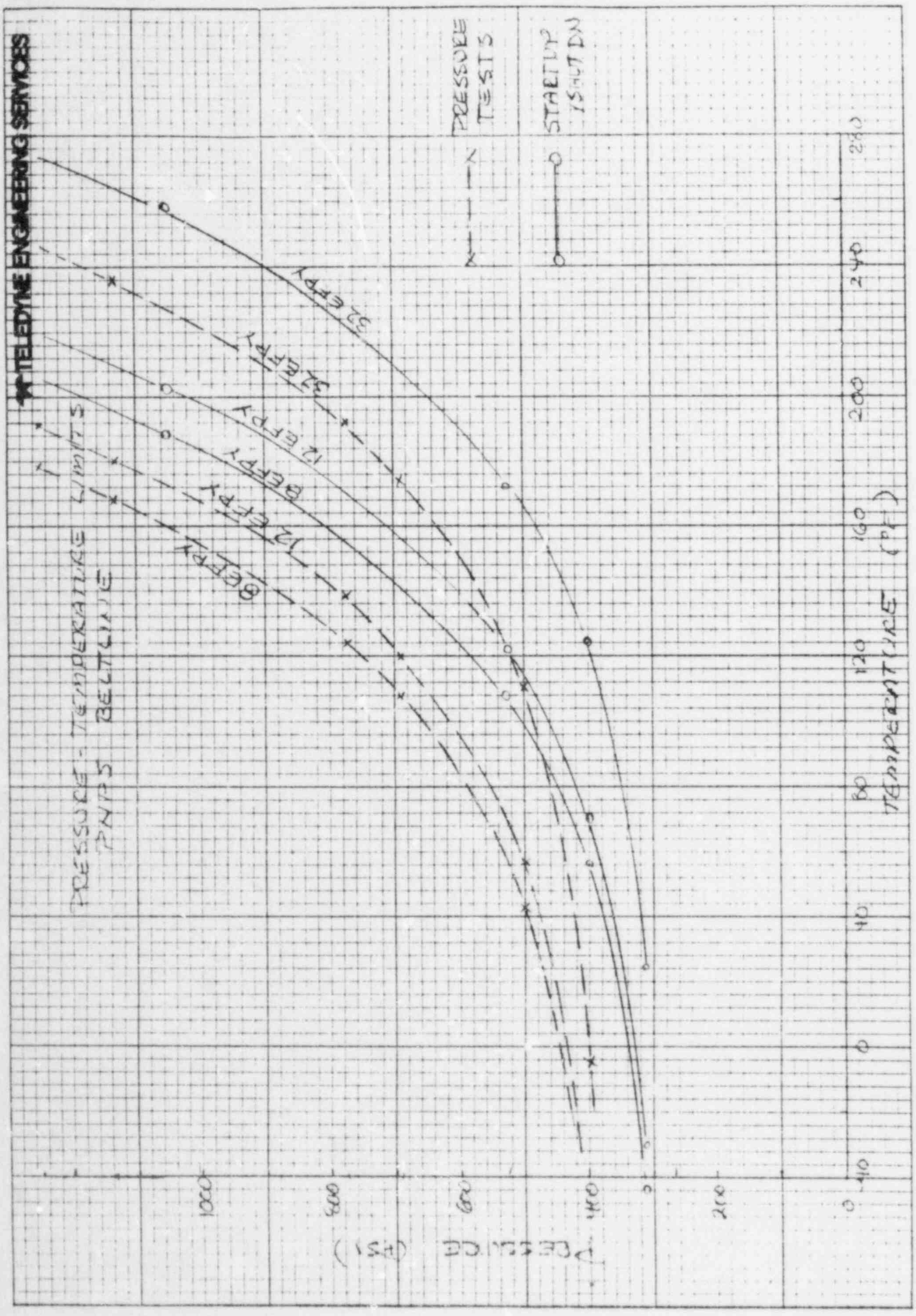
TELEDYNE ENGINEERING SERVICES
PRESSURE - TEMPERATURE LIMITS
PNPS BELTLINE
PRESSURE TESTS
STARTUP / SHUTDOWN
32 EFPY
32 EFPY
12 EFPY
12 EFPY
8 EFPY
8 EFPY
TEMPERATURE (°F)
40
80
120
160
200
240
280
1000
800
600
400
200
0

Figure B.1

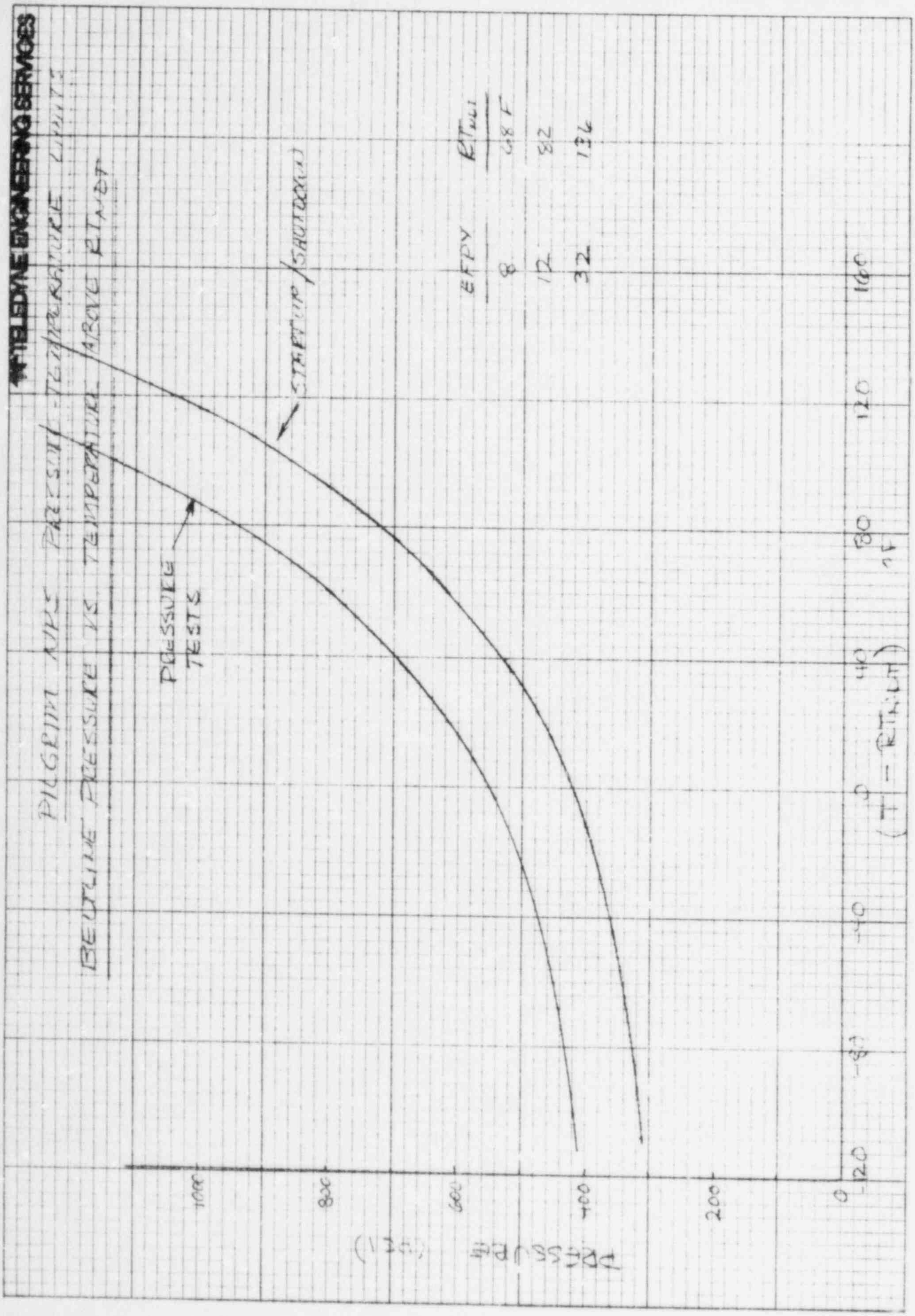
TELEDYNE ENGINEERING SERVICES
PILGRIM NPS PRESSURE-TEMPERATURE LIMITS
BELTLINE PRESSURE VS TEMPERATURE ABOVE RT_NDT
STARTUP/SHUTDOWN
PRESSURE TESTS
EFPY RT_NDT
8 68 F
12 82
32 136
1000
800
600
400
200
0
PRESSURE (PSIG)
-120
-80
-40
0
40
80
120
160
(T - RT_NDT) °F

Figure B.2