LOFT TECHNICAL REPORT LTR 114-90
JUNE 6, 1978

TECHNICAL SPECIFICATION FIGURE 3-1,
PCS TEMPERATURE VS. PRESSURE

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IDAHO OPERATIONS OFFICE UNDER CONTRACT EY-76-C-07-1570

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**LOFT TECHNICAL REPORT
LOFT PROGRAM**FORM EG&G-229
(Rev. 12-76)

TITLE TECHNICAL SPECIFICATION FIGURE 3-1, PCS		REPORT NO. LTR 114-90
Temperature vs. Pressure		
AUTHOR E. S. Brown <i>ESB</i> 11-11-77	GWA NO.	
PERFORMING ORGANIZATION	DATE	
LOFT APPROVAL 4-26-78 <i>[Signature]</i> PSE	5/8/78 <i>[Signature]</i> PSE	6-6-78 <i>[Signature]</i>
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ABSTRACT

The bases and procedure for plotting LOFT Technical Specification Figure 3-1, PCS Temperature vs. Pressure is presented herein. The curves define fracture toughness limits for the carbon steel vessels (Reactor vessel, pressurizer and steam generator) in the primary coolant system (PCS). An allowance is included for the lag between measured fluid temperature and metal temperature of the carbon steel components for the heat up situation. As a result the curves are conservative for the cooldown situation. However, no allowances for expected pressure and temperature instrument errors is included in the curves. The reactor vessel curves in Figure 3-1 labeled "After Start of Power to End of Core I" and "Reactor Critical (other than low power physics test)" include an expected ΔT_{NDT} at end of Core I equal to 45°F.

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1.0 INTRODUCTION

The safe operating region of Technical Specification Figure 3-1 (page 7 of this report) is defined for three times: The time prior to initial power operation, the time during Low Power Physics Testing and the time after start of power operation to end of Core I.

The left curved boundary defined by the reactor vessel fracture toughness limit line shifts to the right 45°F (ΔRT_{NDT}) after the start of Low Power Physics Testing to account for neutron irradiation damage. An additional 40°F shift to the right is required by 10CFR50 when power operation is initiated.

2.0 BASES

The reactor vessel fracture toughness limit line is presented in LTR-114-58⁽¹⁾ as a curve with coordinates of pressure and $RT_{\text{NDT}} + T$. Left boundary curves (for the reactor vessel) utilized a value of $RT_{\text{NDT}} = -15^{\circ}$ prior to power operation⁽²⁾ and a value of $RT_{\text{NDT}} = 30^{\circ}$ after start of power operation to end of Core I. Thus, $\Delta RT_{\text{NDT}} = 45^{\circ}$ is the end-of-Core I value and is applicable during the low power physics testing phase of startup defined by 10CFR50 appendix G, IV.A. 2.a and c. Whenever the reactor is critical except for initial low power physics tests, 10CFR50 requires an additional 40° shift to the right of the curve defined by the ASME code Appendix G and calculated by LTR 114-58⁽¹⁾. $\Delta RT = 45^{\circ}\text{F}$ is taken from the most conservative curve (Tech. Spec. Figure 3-2) (weld material 0.20% Cu.) at a neutron fluence $> 1 \text{ MeV}$ of $10^{18} \text{ (n/cm}^2\text{)}$ see page 8 of this report. This compares with an expected fluence for the reactor vessel of $4.75 \times 10^{17} \text{ (n/cm}^2\text{)} > .821 \text{ MeV}$ ⁽³⁾ at the end of Core I. Core I represents about 2.38% of $2 \times 10^{19} \text{ (n/cm}^2\text{)} > 1 \text{ MeV}$, the expected fluence life of the vessel⁽⁴⁾.

The RT_{NDT} for the ferritic material of the LOFT reactor pressure vessel has been verified by test⁽²⁾ to be -15°F before irradiation. The ΔRT_{NDT} curve for the reactor vessel steel is a conservative composite of the information contained in Figure 13 of NRL 6349⁽⁵⁾, BAW 10055⁽⁶⁾, RESAR⁽⁷⁾ and the copper content⁽⁴⁾ of the material used to fabricate the LOFT reactor vessel.

As discussed above, RT_{NDT} prior to power operation is -15°F and at the end of Core I is conservatively estimated at 30°F . ΔRT_{NDT} at the end of subsequent cores will be determined using Tech. Spec. Figure 3-3, Fluence vs. Effective

Full Power Hours, and Figure 3-2, RT_{NDT} vs. Neutron Fluence, see pages 8 and 9 of this report. Values of RT_{NDT} determined in this manner will be used until the results of the material surveillance samples removed at 30%, 50% and 80% of lifetime neutron fluence⁽³⁾ and evaluated according to ASTM E185 indicate they are inappropriate.

In the time regime prior to power operation the pressurizer and steam generator rather than the reactor vessel can be limiting. The pressurizer heaters can be utilized to keep the pressurizer temperature to the right of the pressurizer fracture toughness limit line.

3.0 PLOTTING PROCEDURE

Coordinates of points on the fracture toughness curves (Figure 3-1, page 7) for each of the carbon steel vessels in the LOFT primary coolant system (reactor vessel, pressurizer and steam generator) are tabulated on the following pages. The report number, title, release date and page number used as the source for tabulating the coordinates is indicated by footnote.

4.0 REFERENCES

- (1) LTR 114-58, "LOFT Pressurizer, Steam Generator and Reactor Vessel Hydrotest and Operating Condition Pressure vs. RT_{NDT} ", G. W. Gilkey, May 2, 1975
- (2) Aerojet Nuclear Company Technical Report 667, July 11, 1975, "Nil Ductility Transformation Temperatures for LOFT Systems Components," H. L. Brown.
- (3) LTR 111-44, "LOFT Reactor Vessel Material Surveillance", W. H. Penny, November 8, 1972
- (4) LOFT FSAR, Supplement 1, Comments 4.2 and 4.3
- (5) NRL 6349, "Radiation Damage Surveillance of Power Reactor Pressure Vessels", C. S. Serpan, et. al., Figure 13, March 26, 1966
- (6) R. A. Turner, "Fuel Densification Report", Babcock and Wilcox, BAW-10055, Figure 6, February 1973, Page 48
- (7) RESAR-3, Westinghouse Electric Company, Section 16.3, Figure 16.3-3, June 1972, Page 16-3-65

TABLE I

PRESSURIZER NORMAL OPERATING CONDITION FRACTURE TOUGHNESS LINE

(1)	(2)	(3)	(4)	(5)	Coordinates of Fracture Toughness Curve Fig 3-1	
RT _{NDT}	T	RT _{NDT} + T	Pressure (Psig)	Correct RT _{NDT} + T to allow for 20°F lag between fluid and metal	Max Allowable Hot Leg Pressure	Cold Leg Temperature
90°F	-60	30	1270	50	1270	50
90°F	-40	50	1355	70	1355	70
90°F	-20	70°F	1446	90	1446	90
90°F	0	90°F	1610	110	1610	110
90°F	+20	110°F	1805	130	1805	130
90°F	+40	130°F	2010	150	2010	150
90°F	+60	150°F	2309	170	2309	170
90°F	+71	161°F	2500	181	2500	181

(1) See page 7 of reference 2.

(2) See first column of tabulation "RT_{NDT} + °F" on page 12 of reference 1.

(3) Computed by adding column (1) value to column (2) value.

(4) See third column of tabulation "p allowable (psi)" on page 12 of reference 1; p allowable corresponding to T= 60 and -40 were calculated from the equation $p = \frac{K_{IR}(T)}{24.90}$ derived on page 11 of JJC-20-73 (LTR 114-42, Rev. A)

(5) Computed by adding 20°F to each temperature in column (3)

STEAM GENERATOR NORMAL OPERATING CONDITION FRACTURE TOUGHNESS LINE-PRIMARY SIDE

(1)	(2)	(3)	(4)	(5)	Coordinates of Fracture Toughness Curve Fig 3-1	
RT_{NDT}	T	$RT_{NDT} + T$	Pressure (Psig)	Correct $RT_{NDT} + T$ to allow for 20°F lag log between fluid and metal	Max Allowable Hot Leg Pressure	Cold Leg Temperature
25°F	-20	5	1338	25	1338	25
25°F	0	25	1487	45	1487	45
25°F	20	45	1635	65	1635	65
25°F	40	65	1858	85	1858	85
25°F	60	85	2118	105	2118	105
25°F	80	105	2490	125	2490	125

- (1) See page 7 of reference 2.
- (2) See first column of tabulation " $RT_{NDT} + °F$ " on page 6 of reference 1.
- (3) Computed by adding column (1) value to column (2) value.
- (4) See third column of tabulation "p allowable (psi)" on page 6 of reference 1.
- (5) Computed by adding 20°F to each temperature in column (3).

REACTOR VESSEL NORMAL OPERATING CONDITION FRACTURE TOUGHNESS LINES

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
RT_{NDT}	T	$RT_{NDT} + T$	Max Allowable Hot Leg Press. (Psig)	Correct (3) for 20 F Metal Fluid Lag, Cold Leg Temp.▲	▲ RT_{NDT} End of Core I	Cold Leg Temp▼	+40 F 10CFR50	Cold Leg Temp.◆
-15°F	-20	-35	1026	-15	+45	30	+40	70
-15°F	0	-15	1140	5	+45	50	+40	90
-15°F	20	5	1284	25	+45	70	+40	110
-15°F	40	25	1426	45	+45	90	+40	130
-15°F	60	45	1640	65	+45	110	+40	150
-15°F	80	65	1927	85	+45	130	+40	170
-15°F	100	85	2310	105	+45	150	+40	190
-15°F	110	95	2500	115	+45	160	+40	200

(1) See page 7 of reference 2.

(2) See first column of tabulation " $RT_{NDT} + T$ " on page 10 of reference 1.

(3) Computed by adding column (1) value to column (2) value.

(4) See third column of tabulation "p allowable (psi) on page 10 of reference 1. This column and column (5), (7) or (9) forms the coordinates for the three reactor vessel fracture toughness curves plotted on Fig 3-1 of the Tech. Spec's. (▲ - reactor vessel prior to power operating, ▼Reactor Vessel after star of power to end of Core I, and ◆ Reactor critical other than low power physics tests).

(5) Column (3) + 20°F for ▲ coordinates.

(6) Enter Figure 3-3, page 9, at 2000 EFP (end of Core I) and read 4.75×10^{17} n/cm². Enter Figure 3.2, page 8 at 10^{18} n/cm² (approx 4.75×10^{17}) and read $\Delta RT_{NDT} = 45^\circ\text{F}$ from weld material curve.

(7) Column (5) + Column (6).

(8) Ref. 10CFR50 Appendix G, par. IV. A.2.c.

(9) Column (7) + Column (8).

Figure 3-1 PCS Temperature vs. Pressure

INEL-A-2141

Figure 3-2 Effects of Neutron Fluence and Copper Content on Shift of RT_{NDT}

ANC-A-4462

LTR 11430

ANC - A - 4459

Figure 3-3 Neutron Fluence as a Function of Operating Time