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FLORIDA POWER AND LIGHT
UNITS 3 & 4

REACTOR VESSEL HEATUP AND COOLDOWN LIMIT CURVES FOR NORMAL OPERATION

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HEATUP AND COOLDOWN LIMIT CURVES FOR NORMAL OPERATION

1.0 INTRODUCTION

Heatup and cooldown limit curves are calculated using the most limiting value of RT_{NDT} (reference nil-ductility temperature) for the reactor vessel. The most limiting RT_{NDT} of the material in the core region of the reactor vessel is determined by using the preservice reactor vessel material fracture toughness properties and estimating the radiation-induced ΔRT_{NDT}. RT_{NDT} is designated as the higher of either the drop weight nil-ductility transition temperature (NDTT) or the temperature at which the material exhibits at least 50 ft-lb of impact energy and 35-mil lateral expansion (normal to the major working direction) minus 60°F.

RT_{NDT} increases as the material is exposed to fast-neutron radiation. Therefore, to find the most limiting RT_{NDT} at any time period in the reactor's life, ΔRT_{NDT} due to the radiation exposure associated with that time period must be added to the original unirradiated RT_{NDT}. The extent of the shift in RT_{NDT} is enhanced by certain chemical elements (such as copper and nickel) present in reactor vessel steels. Westinghouse, other NSSS vendors, the U.S. Nuclear Regulatory Commission and others have developed methods for predicting adjustment of RT_{NDT} as a function of fluence and the copper and nickel content. The Nuclear Regulatory Commission (NRC) published these methods in Regulatory Guide 1.99 Rev. 2 (Radiation Embrittlement of Reactor Vessel Materials)[1]. The value, "f", given in figure 1 is the calculated value of the neutron fluence at the location of interest (inner surface, 1/4T, or 3/4T) in the vessel at the location of the postulated defect, n/cm^2 ($E > 1$ MeV) divided by 10^{19}. The fluence factor is determined from figure 1.

2.0 FRACTURE TOUGHNESS PROPERTIES

The fracture-toughness properties of the ferritic material in the reactor coolant pressure boundary are determined in accordance with the NRC Regulatory Standard Review Plan[2]. The postirradiation fracture-toughness properties of the reactor vessel beltline material were obtained directly from the Turkey Point Units 3 & 4 Vessel Material Surveillance Program.

3.0 CRITERIA FOR ALLOWABLE PRESSURE-TEMPERATURE RELATIONSHIPS

The ASME approach for calculating the allowable limit curves for various heatup and cooldown rates specifies that the total stress intensity factor, K_I, for the combined thermal and pressure stresses at any time during heatup or cooldown cannot be greater than the reference stress intensity factor, K_{IR}, for the metal temperature at that time. K_{IR} is obtained from the reference fracture toughness curve, defined in Appendix G to the ASME Code[3]. The K_{IR} curve is given by the following equation:

$$K_{IR} = 26.78 + 1.223 \exp [0.0145 (T - RT_{NDT} + 160)] \qquad (1)$$

where

K_{IR} = reference stress intensity factor as a function of the metal temperature T and the metal reference nil-ductility temperature RT_{NDT}

Therefore, the governing equation for the heatup-cooldown analysis is defined in appendix G of the ASME Code[3] as follows:

$$C\, K_{IM} + K_{IT} \leq K_{IR} \qquad (2)$$

where

K_{IM} = stress intensity factor caused by membrane (pressure) stress

K_{IT} = stress intensity factor caused by the thermal gradients

K_{IR} = function of temperature relative to the RT_{NDT} of the material

C = 2.0 for Level A and Level B service limits

C = 1.5 for hydrostatic and leak test conditions during which the reactor core is not critical

At any time during the heatup or cooldown transient, K_{IR} is determined by the metal temperature at the tip of the postulated flaw, the appropriate value for RT_{NDT}, and the reference fracture toughness curve. The thermal stresses resulting from the temperature gradients through the vessel wall are calculated and then the corresponding (thermal) stress intensity factors, K_{IT}, for the reference flaw are computed. From equation 2, the pressure stress intensity factors are obtained and, from these, the allowable pressures are calculated.

For the calculation of the allowable pressure versus coolant temperature during cooldown, the reference flaw of appendix G to the ASME Code is assumed to exist at the inside of the vessel wall. During cooldown, the controlling location of the flaw is always at the inside of the wall because the thermal gradients produce tensile stresses at the inside, which increase with increasing cooldown rates. Allowable pressure-temperature relations are generated for both steady-state and finite cooldown rate situations. From these relations, composite limit curves are constructed for each cooldown rate of interest.

The use of the composite curve in the cooldown analysis is necessary because control of the cooldown procedure is based on the measurement of reactor coolant temperature, whereas the limiting pressure is actually dependent on the material temperature at the tip of the assumed flaw.

During cooldown, the 1/4 T vessel location is at a higher temperature than the fluid adjacent to the vessel ID. This condition, of course, is not true for the steady-state situation. It follows that, at any given reactor coolant temperature, the ΔT developed during cooldown results in a higher value of K_{IR} at the 1/4 T location for finite cooldown rates than for steady-state operation. Furthermore, if conditions exist so that the increase in K_{IR} exceeds K_{IT}, the calculated allowable pressure during cooldown will be greater than the steady-state value.

The above procedures are needed because there is no direct control on temperature at the 1/4 T location and, therefore, allowable pressures may unknowingly be violated if the rate of cooling is decreased at various intervals along a cooldown ramp. The use of the composite curve eliminates this problem and ensures conservative operation of the system for the entire cooldown period.

Three separate calculations are required to determine the limit curves for finite heatup rates. As is done in the cooldown analysis, allowable pressure-temperature relationships are developed for steady-state conditions as well as finite heatup rate conditions assuming the presence of a 1/4 T defect at the inside of the wall that alleviate the tensile stresses produced by internal pressure. The metal temperature at the crack tip lags the coolant temperature; therefore, the K_{IR} for the 1/4 T crack during heatup is lower than the K_{IR} for the 1/4 T crack during steady-state conditions at the same time coolant temperature. During heatup, especially at the end of the transient, conditions may exist so that the effects of compressive thermal stresses and lower K_{IR}'s do not offset each other, and the pressure-temperature curve based on steady-state conditions no longer represents a lower bound of all similar curves for finite heatup rates when the 1/4 T flaw is considered. Therefore, both cases have to be analyzed in order to ensure that at any coolant temperature the lower value of the allowable pressure calculated for steady-state and finite heatup rates is obtained.

The second portion of the heatup analysis concerns the calculation of the pressure-temperature limitations for the case in which a 1/4 T deep outside surface flaw is assumed. Unlike the situation at the vessel inside surface, the thermal gradients established at the outside surface during heatup produce stresses which are tensile in nature and therefore tend to reinforce any pressure stresses present. These thermal stresses are dependent on both the rate of heatup and the time (or coolant temperature) along the heatup ramp. Since the thermal stresses at the outside are tensile and increase with increasing heatup rates, each heatup rate must be analyzed on an individual basis.

Following the generation of pressure-temperature curves for both the steady-state and finite heatup rate situations, the final limit curves are produced by constructing a composite curve based on a point-by-point comparison of the steady-state and finite heatup rate data. At any given temperature, the allowable pressure is taken to be the lesser of the three values taken from the curves under consideration. The use of the composite curve is necessary to set conservative heatup limitations because it is possible for conditions to exist wherein, over the course of the heatup ramp, the controlling condition switches from the inside to the outside, and the pressure limit must at all times be based on analysis of the most critical criterion.

Finally, the 1983 Amendment to 10CFR50[4] has a rule which addresses the metal temperature of the closure head flange and vessel flange regions. This rule states that the metal temperature of the closure flange regions must exceed the material RT_{NDT} by at least 120°F for normal operation when the pressure exceeds 20 percent of the preservice hydrostatic test pressure.

Table 1 indicates that the limiting RT_{NDT} of 44°F occurs in the vessel flange of Turkey Point Unit 3, so the minimum allowable temperature of this region is 164°F. These limits are less restrictive than the curves shown on figures 2, 3, and 4.

4.0 HEATUP AND COOLDOWN LIMIT CURVES

Limit curves for normal heatup and cooldown of the primary Reactor Coolant System have been calculated using the methods discussed in section 3, and the procedure is presented in reference 5.

Transition temperature shifts occurring in the pressure vessel materials due to radiation exposure have been obtained directly from the reactor pressure vessel surveillance program.

Allowable combinations of temperature and pressure for specific temperature change rates are below and to the right of the limit lines shown in figures 2, 3, and 4. This is in addition to other criteria which must be met before the reactor is made critical.

The leak limit curve shown in figures 2 and 3 represents minimum temperature requirements at the leak test pressure specified by applicable codes[2,3]. The leak test limit curve was determined by methods of references 2 and 4.

Figures 2, 3 and 4 define limits for ensuring prevention of nonductile failure for the Turkey Point Units 3 and 4 Primary Reactor Coolant System.

5.0 ADJUSTED REFERENCE TEMPERATURE

From Regulatory Guide 1.99 Rev. 2 the adjusted reference temperature (ART) for each material in the beltline is given by the following expression:

$$ART = \text{Initial } RT_{NDT} + \Delta RT_{NDT} + \text{Margin} \qquad (3)$$

Initial RT_{NDT} is the reference temperature for the unirradiated material as defined in paragraph NB-2331 of Section III of the ASME Boiler and Pressure Vessel Code. If measured values of initial RT_{NDT} for the material in question are not available, generic mean values for that class of material may be used if there are sufficient test results to establish a mean and standard deviation for the class.

ΔRT_{NDT} is the mean value of the adjustment in reference temperature caused by irradiation and should be calculated as follows:

$$\Delta RT_{NDT} = [CF] f^{(0.28-0.10 \log f)} \quad (4)$$

To calculate ΔRT_{NDT} at any depth (e.g., at 1/4T or 3/4T), the following formula must first be used to attenuate the fluence at the specific depth.

$$f_{(depth\ X)} = f_{surface}{}^{(e^{-.24x})} \quad (5)$$

where x (in inches) is the depth into the vessel wall measured from the vessel inner (wetted) surface. The resultant fluence is then put into equation (4) to calculate ΔRT_{NDT} at the specific depth.

CF (°F) is the chemistry factor, obtained by multiplying each measured ΔRT_{NDT} by its corresponding fluence factor, summing the products, and dividing by the sum of the squares of the fluence factors. Capsule data from reference 6 was used.

At the vessel inside radius, the calculated neutron fluence for 20 effective full power years (EFPY) is 2.022×10^{19} n/cm^2 at the critical weld.

For the limiting circumferential weld, the chemistry factor is 200.5, based on ref. 1. From equation (4), the ΔRT_{NDT} at the inner surface is equal to 239°F (200.5 x 1.192). Regulatory Guide 1.99 revision 2 provides a formula and rules for establishing margin:

$$\text{Margin} = 2\sqrt{\sigma_I^2 + \sigma_\Delta^2} \quad (6)$$

σ_I = 0°F for measured value of initial R_{TNDT}

σ_A = 28°F for welds (critical material) - This value is cut in half to take credit for credible surveillance data used to calculate CF.

$$\text{Margin} = 2\sqrt{0 + (14)^2} = 28°F$$

ART = 10 + 239 + 28 = 277°F

Using the vessel thickness of 7.75 inches at the beltline, Equations (3), (4), and 5 are used to calculate the ART at the 1/4 and 3/4 thickness locations. These are 252.5°F and 200.4°F respectively.

The above analysis was used to develop the Turkey Point Units 3 and 4 heatup and cooldown curves shown in figures 2, 3 and 4 respectively.

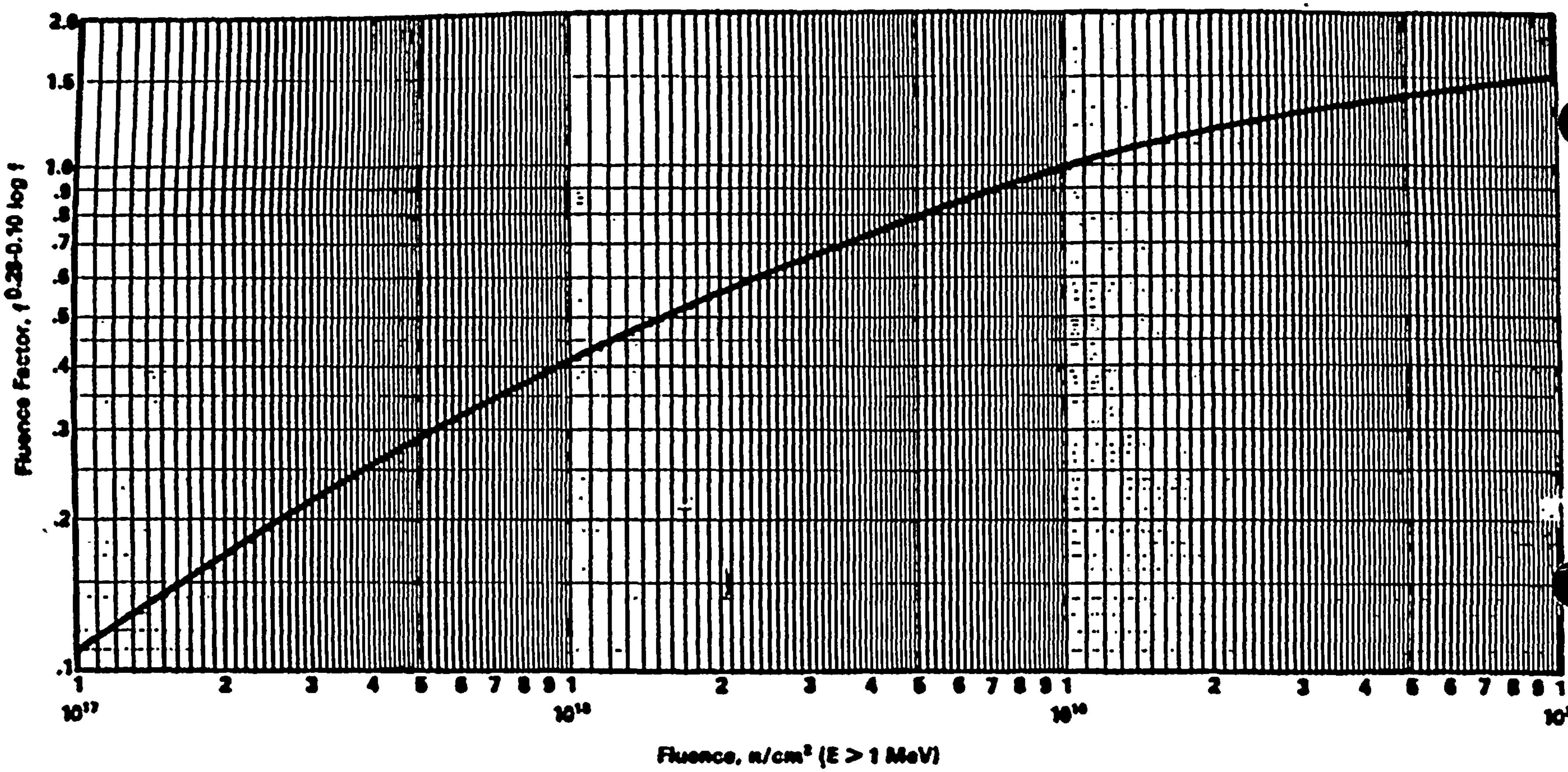

Figure 1. Fluence Factor for Use in the Expression for ΔRT_{NDT}

MATERIAL PROPERTY BASIS

CONTROLLING MATERIAL: CIRCUMFERENTIAL WELD[1]
INITIAL RT_{NDT}: 10°F[1]

RT_{NDT} AFTER 20 EFPY: 1/4T, 252.5°F
3/4T, 200.4°F

CURVES APPLICABLE FOR HEATUP RATES UP TO 60°F/HR FOR THE SERVICE PERIOD UP TO 20 EFPY. NO MARGINS ARE GIVEN FOR POSSIBLE INSTRUMENT ERRORS.

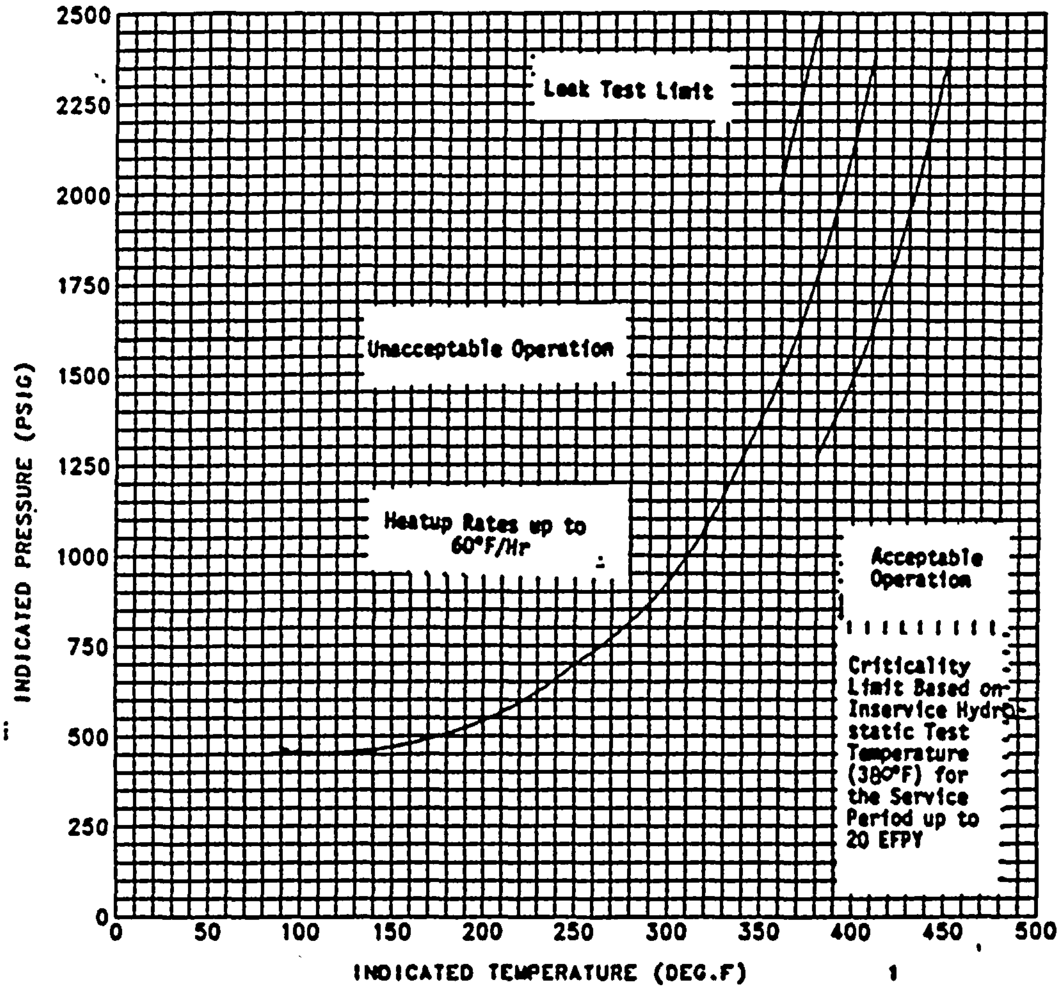

Figure 2. Turkey Point Units 3 & 4 Reactor Coolant System Heatup Limitations Applicable for the First 20 EFPY

[1] See reference 6.

MATERIAL PROPERTY BASIS

CONTROLLING MATERIAL: CIRCUMFERENTIAL WELD[1]
INITIAL RT_{NDT}: 10°F[1]

RT_{NDT} AFTER 20 EFPY: 1/4T, 252.5°F
3/4T, 200.4°F

CURVES APPLICABLE FOR HEATUP RATES UP TO 100°F/HR FOR THE SERVICE PERIOD UP TO 20 EFPY. NO MARGINS ARE GIVEN FOR POSSIBLE INSTRUMENT ERRORS.

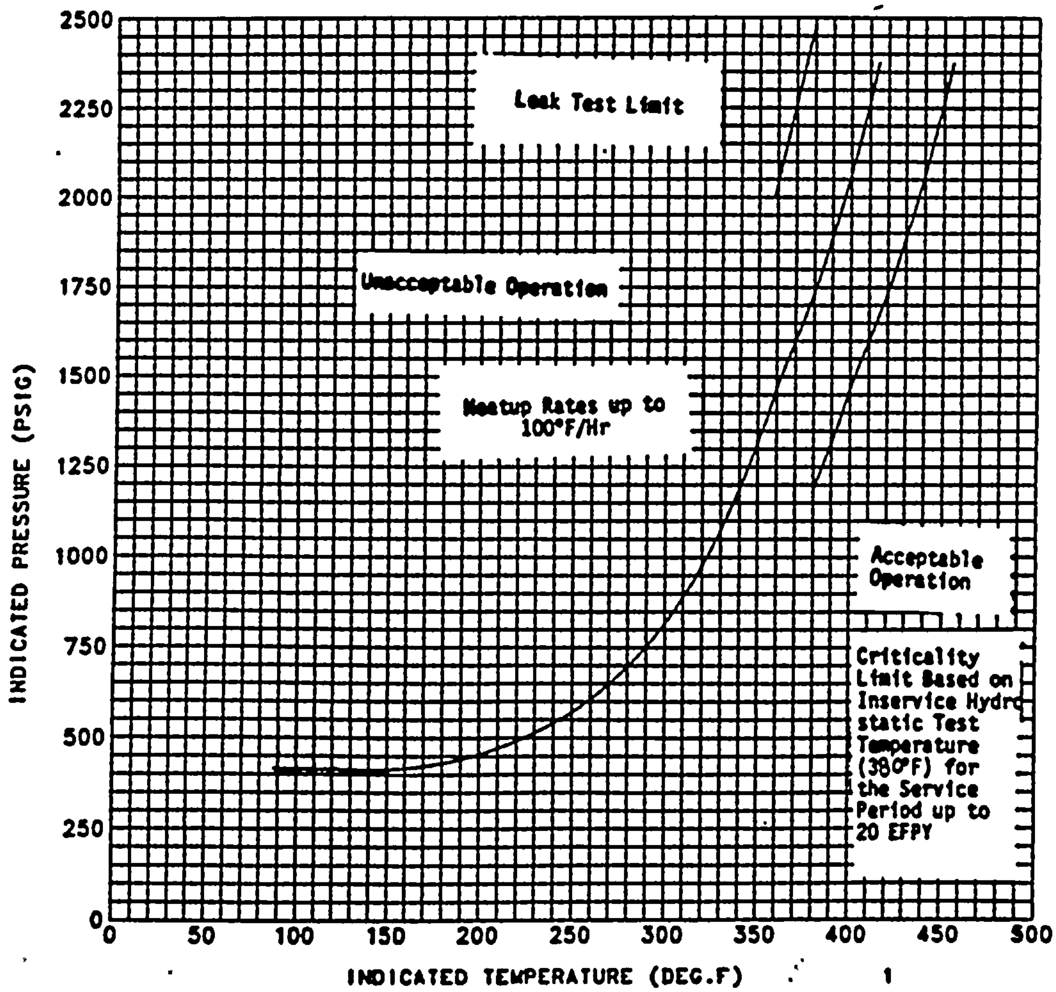

Figure 3. Turkey Point Units 3 & 4 Reactor Coolant System Heatup Limitations Applicable for the First 20 EFPY

[1] See reference 6.

MATERIAL PROPERTY BASIS

CONTROLLING MATERIAL: CIRCUMFERENTIAL WELD[1]
INITIAL RT_{NDT}: 10°F

RT_{NDT} AFTER 20 EFPY: 1/4T, 252.5°F
3/4T, 200.4°F

CURVES APPLICABLE FOR COOLDOWN RATES UP TO 100°F/HR FOR THE SERVICE PERIOD UP TO 20 EFPY. NO MARGINS ARE GIVEN FOR POSSIBLE INSTRUMENT ERRORS.

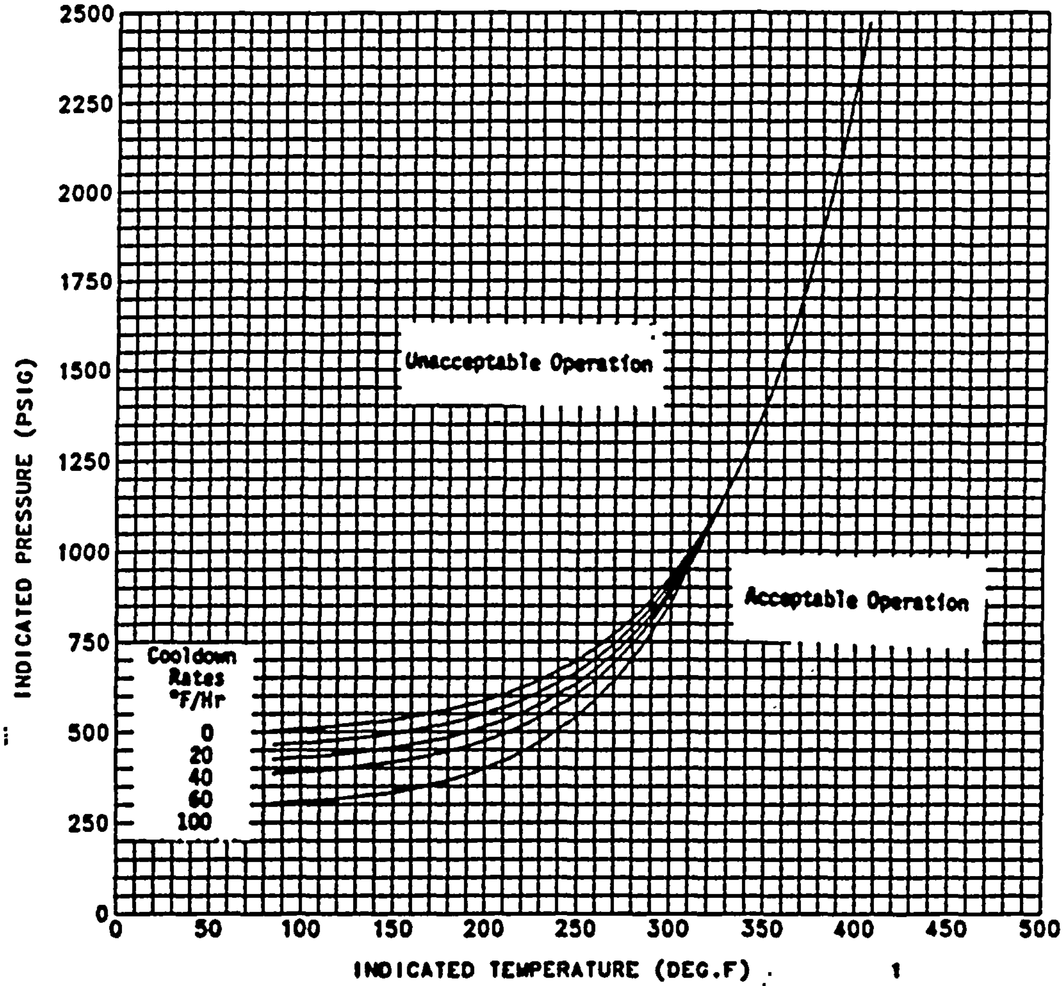

Figure 4. Turkey Point Units 3 & 4 Reactor Coolant System Cooldown limitations Applicable for the First 20 EFPY

[1] See reference 6.

TABLE 1
TURKEY POINT UNIT 3 REACTOR VESSEL
TOUGHNESS DATA (UNIRRADIATED)

Component	Material Type	Cu (%)	Ni(d) (%)	P (%)	NDTT (°F)	RT_{NDT}(a) (°F)
Cl. Hd. dome	A302 Gr B	--	--	0.010	0	0
Cl. Hd. flange	A508 Cl 2	--	0.72	0.010	44(a)	44
Ves. Sh. flange	A508 Cl 2	--	0.65	0.010	-23(a)	-23
Inlet nozzle	A508 Cl 2	--	0.76	0.019	60(a)	60
Inlet nozzle	A508 Cl 2	--	0.74	0.019	60(a)	60
Inlet nozzle	A508 Cl 2	--	0.80	0.019	60(a)	60
Outlet nozzle	A508 Cl 2	--	0.79	0.010	27(a)	27
Outlet nozzle	A508 Cl 2	--	0.72	0.010	7(a)	7
Outlet nozzle	A508 Cl 2	--	0.72	0.010	42(a)	42
Upper shell	A508 Cl 2	--	0.68	0.010	50	50
Inter. shell	A508 Cl 2	0.058	0.70	0.010	40	40
Lower shell	A508 Cl 2	0.079	0.67	0.010	30	30
Trans. ring	A508 Cl 2	--	0.69	0.013	60(a)	60
Bot. hd. dome	A302 Gr B	--	--	0.010	-10	30
Weld (inter to lower shell girth weld)	SAW(c)	0.26	0.60	0.011	0	10(b)

TABLE 1 (Cont'd.)
TURKEY POINT UNIT 4 REACTOR VESSEL
TOUGHNESS DATA (UNIRRADIATED)

Component	Material Type	Cu (%)	Ni(d) (%)	P (%)	NDTT (°F)	RT_{NDT}(a) (°F)
Closure head dome	A302 Gr B	--	--	.008	-20	30
Closure head flange	A508 Cl 2	--	.72	.010	-4(a)	-4
Vessel flange	A508 Cl 2	--	.68	.010	-1(a)	-1
Inlet nozzle	A508 Cl 2	.08	.71	.009	60(a)	60
Inlet nozzle	A508 Cl 2	--	.84	.019	60(a)	60
Inlet nozzle	A508 Cl 2	--	.75	.008	16(a)	16
Outlet nozzle	A508 Cl 2	--	.78	.010	7(a)	7
Outlet nozzle	A508 Cl 2	--	.68	.010	38(a)	38
Outlet nozzle	A508 Cl 2	--	.70	.010	60(a)	60
Upper shell	A508 Cl 2	--	.70	.010	40	40
Inter. shell	A508 Cl 2	.054	.69	.010	50	50
Lower shell	A508 Cl 2	.056	.74	.010	40	40
Trans. ring	A508 Cl 2	--	.69	.011	60(a)	60
Bottom head dome	A302 Gr B	--	--	.010	10	10
Weld inter. shell to lower shell girth weld		.26	.60	.011	0	10(b)

(a) Estimated values based on procedures listed in U.S.NRC Standard Review Plan, NUREG-0800, Rev. 1, July 1981.

(b) Actual value

(c) Wire heat No. 71249, Linde 80 flux Lot 8445.

(d) From material certified test report

6.0 REFERENCES

1. Regulatory Guide 1.99, Revision 2, "Radiation Embrittlement of Reactor Vessel Materials," U.S. Nuclear Regulatory Commission, May, 1988.

2. "Fracture Toughness Requirements," Branch Technical Position MTEB 5-2, Chapter 5.3.2 in Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, LWR Edition, NUREG-0800, 1981.

3. ASME Boiler and Pressure Vessel Code, Section III, Division 1 - Appendixes, "Rules for Construction of Nuclear Vessels, Appendix G, Protection Against Nonductile Failure," pp. 559-564, 1983 Edition, American Society of Mechanical Engineers, New York, 1983.

4. Code of Federal Regulations, 10CFR50, Appendix G, "Fracture Toughness Requirements," U.S. Nuclear Regulatory Commission, Washington, D.C., Amended May 17, 1983 (48 Federal Register 24010).

5. "Procedure for Developing Heatup and Cooldown Curves," J. C. Schmertz, GTSD-A-1.12.

6. Surveillance data for Florida Power & Light Company. Letter and attachment (JNS-MCI-88-084, May 4, 1988) from R. S. Boggs to J. C. Schmertz

APPENDIX A

HEATUP COOLDOWN
DATA POINTS

THE FOLLOWING DATA WERE CALCULATEDFOR THE INSERVICE HYDROSTATIC LEAK TEST.

MINIMUM INSERVICE LEAK TEST TEMPERATURE (20.000 EFPY)

PRESSURE (PSI)	TEMPERATURE (DEG.F)
2000	358
2485	380

PRESSURE (PSI)	PRESSURE STRESS (PSI)	1.5 K1M (PSI SQ.RT.IN.)
2000	21112	84324
2485	26232	105679

FPL 60F/HR HEATUP CURVE FOR FPL, NRC 1.99 REV. 2 WELD 08/10/88

COMPOSITE CURVE PLOTTED FOR HEATUP PROFILE 2 HEATUP RATE(S) (DEG.F/HR) = 60.0

IRRADIATION PERIOD = 20.000 EFP YEARS

	INDICATED TEMPERATURE (DEG.F)	INDICATED PRESSURE (PSI)		INDICATED TEMPERATURE (DEG.F)	INDICATED PRESSURE (PSI)		INDICATED TEMPERATURE (DEG.F)	INDICATED PRESSURE (PSI)
1	85.000	477.25	23	195.000	532.84	45	305.000	961.21
2	90.000	468.24	24	200.000	543.02	46	310.000	996.90
3	95.000	461.90	25	205.000	553.92	47	315.000	1035.22
4	100.000	457.42	26	210.000	565.75	48	320.000	1076.61
5	105.000	454.68	27	215.000	578.52	49	325.000	1120.88
6	110.000	453.13	28	220.000	592.24	50	330.000	1168.46
7	115.000	452.78	29	225.000	606.92	51	335.000	1219.52
8	120.000	453.24	30	230.000	622.83	52	340.000	1274.21
9	125.000	454.58	31	235.000	639.94	53	345.000	1323.17
10	130.000	456.52	32	240.000	658.21	54	350.000	1375.50
11	135.000	459.15	33	245.000	678.02	55	355.000	1431.54
12	140.000	462.29	34	250.000	699.06	56	360.000	1491.56
13	145.000	466.02	35	255.000	715.32	57	365.000	1555.62
14	150.000	470.22	36	260.000	732.77	58	370.000	1624.77
15	155.000	474.98	37	265.000	751.38	59	375.000	1698.28
16	160.000	480.21	38	270.000	771.57	60	380.000	1777.59
17	165.000	486.00	39	275.000	793.05	61	385.000	1862.13
18	170.000	492.30	40	280.000	816.39	62	390.000	1952.64
19	175.000	499.18	41	285.000	841.23	63	395.000	2049.30
20	180.000	506.55	42	290.000	868.17	64	400.000	2152.71
21	185.000	514.64	43	295.000	896.90	65	405.000	2263.24
22	190.000	523.38	44	300.000	927.97	66	410.000	2381.19

FPL100F/HR HEATUP CURVE FOR FPL, NRC 1.99 REV. 2 WELD 08/10/88

COMPOSITE CURVE PLOTTED FOR HEATUP PROFILE 2 HEATUP RATE(S) (DEG.F/HR) = 100.0

IRRADIATION PERIOD = 20.000 EFP YEARS

	INDICATED TEMPERATURE (DEG.F)	INDICATED PRESSURE (PSI)		INDICATED TEMPERATURE (DEG.F)	INDICATED PRESSURE (PSI)		INDICATED TEMPERATURE (DEG.F)	INDICATED PRESSURE (PSI)
1	85.000	475.54	24	200.000	455.60	46	310.000	890.67
2	80.000	462.00	25	205.000	463.36	47	315.000	931.88
3	95.000	450.76	26	210.000	471.84	48	320.000	976.16
4	100.000	441.29	27	215.000	481.09	49	325.000	1023.58
5	105.000	433.54	28	220.000	491.13	50	330.000	1074.45
6	110.000	427.13	29	225.000	501.95	51	335.000	1128.85
7	115.000	422.08	30	230.000	513.75	52	340.000	1187.47
8	120.000	418.09	31	235.000	526.53	53	345.000	1250.26
9	125.000	415.18	32	240.000	540.33	54	350.000	1317.24
10	130.000	413.13	33	245.000	555.12	55	355.000	1389.46
11	135.000	412.02	34	250.000	571.19	56	360.000	1466.46
12	140.000	411.58	35	255.000	588.51	57	365.000	1535.99
13	145.000	411.88	36	260.000	607.04	58	370.000	1596.96
14	150.000	412.76	37	265.000	627.14	59	375.000	1662.18
15	155.000	414.36	38	270.000	648.62	60	380.000	1732.01
16	160.000	416.54	39	275.000	671.89	61	385.000	1806.82
17	165.000	419.35	40	280.000	696.75	62	390.000	1886.78
18	170.000	422.72	41	285.000	723.66	63	395.000	1972.12
19	175.000	426.70	42	290.000	752.40	64	400.000	2063.56
20	180.000	431.26	43	295.000	783.47	65	405.000	2161.11
21	185.000	436.42	44	300.000	816.71	66	410.000	2265.38
22	190.000	442.19	45	305.000	852.37	67	415.000	2376.73
23	195.000	448.54						

FPL COOLDOWN CURVES FOR , NRC 1.99 REV. 2 WELD 08/10/88

THE FOLLOWING DATA WERE PLOTTED FOR COOLDOWN PROFILE 1 (STEADY-STATE COOLDOWN)

IRRADIATION PERIOD = 20.000 EFP YEARS

	INDICATED TEMPERATURE (DEG.F)	INDICATED PRESSURE (PSI)
1	85.000	503.06
2	80.000	504.55
3	95.000	506.15
4	100.000	507.87
5	105.000	509.72
6	110.000	511.70
7	115.000	513.84
8	120.000	516.14
9	125.000	518.61
10	130.000	521.27
11	135.000	524.13
12	140.000	527.20
13	145.000	530.50
14	150.000	534.06
15	155.000	537.87
16	160.000	541.98
17	165.000	546.29
18	170.000	551.03
19	175.000	556.13
20	180.000	561.62
21	185.000	567.51
22	190.000	573.85
23	195.000	580.67
24	200.000	588.00
25	205.000	595.75
26	210.000	604.22
27	215.000	613.33
28	220.000	623.12
29	225.000	633.64
30	230.000	644.81
31	235.000	656.98
32	240.000	670.06
33	245.000	684.10
34	250.000	699.06
35	255.000	715.32
36	260.000	732.77
37	265.000	751.38
38	270.000	771.87
39	275.000	793.05
40	280.000	816.39
41	285.000	841.23
42	290.000	868.17
43	295.000	896.90
44	300.000	927.97
45	305.000	961.21
46	310.000	896.90
47	315.000	1035.22
48	320.000	1076.61
49	325.000	1120.88
50	330.000	1168.46
51	335.000	1219.52
52	340.000	1274.21
53	345.000	1333.21
54	350.000	1396.39
55	355.000	1463.95
56	360.000	1536.81
57	365.000	1614.70
58	370.000	1697.98
59	375.000	1787.80
60	380.000	1883.56
61	385.000	1985.97
62	390.000	2095.91
63	395.000	2213.23
64	400.000	2338.69
65	405.000	2472.58

FPL COOLDOWN CURVES FOR , NRC 1.99 REV. 2 WELD 08/10/88

THE FOLLOWING DATA WERE PLOTTED FOR COOLDOWN PROFILE 2 (20 DEG-F / HR COOLDOWN)

IRRADIATION PERIOD = 20.000 EFP YEARS

	INDICATED TEMPERATURE (DEG.F)	INDICATED PRESSURE (PSI)		INDICATED TEMPERATURE (DEG.F)	INDICATED PRESSURE (PSI)		INDICATED TEMPERATURE (DEG.F)	INDICATED PRESSURE (PSI)
1	85.000	464.97	18	170.000	512.99	35	255.000	685.16
2	90.000	466.37	19	175.000	518.25	36	260.000	703.47
3	95.000	467.91	20	180.000	523.90	37	265.000	723.35
4	100.000	469.55	21	185.000	530.01	38	270.000	744.54
5	105.000	471.35	22	190.000	536.57	39	275.000	767.55
6	110.000	473.28	23	195.000	543.66	40	280.000	792.08
7	115.000	475.38	24	200.000	551.17	41	285.000	818.71
8	120.000	477.64	25	205.000	559.39	42	290.000	847.11
9	125.000	480.10	26	210.000	568.23	43	295.000	877.84
10	130.000	482.74	27	215.000	577.76	44	300.000	910.78
11	135.000	485.61	28	220.000	588.01	45	305.000	946.11
12	140.000	488.69	29	225.000	598.93	46	310.000	984.11
13	145.000	492.03	30	230.000	610.81	47	315.000	1025.18
14	150.000	495.62	31	235.000	623.61	48	320.000	1069.14
15	155.000	499.52	32	240.000	637.36	49	325.000	1116.37
16	160.000	503.60	33	245.000	652.06	50	330.000	1167.13
17	165.000	508.13	34	250.000	668.00			

FPL COOLDOWN CURVES FOR , NRC 1.99 REV. 2 WELD 08/10/88

THE FOLLOWING DATA WERE PLOTTED FOR COOLDOWN PROFILE 3 (40 DEG-F / HR COOLDOWN)

IRRADIATION PERIOD = 20.000 EFP YEARS

	INDICATED TEMPERATURE (DEG.F)	INDICATED PRESSURE (PSI)		INDICATED TEMPERATURE (DEG.F)	INDICATED PRESSURE (PSI)		INDICATED TEMPERATURE (DEG.F)	INDICATED PRESSURE (PSI)
1	85.000	426.07	18	170.000	474.29	34	250.000	636.99
2	90.000	427.39	19	175.000	479.72	35	255.000	655.05
3	95.000	428.85	20	180.000	485.57	36	260.000	674.60
4	100.000	430.43	21	185.000	491.91	37	265.000	695.52
5	105.000	432.18	22	190.000	498.72	38	270.000	718.19
6	110.000	434.05	23	195.000	506.02	39	275.000	742.45
7	115.000	436.13	24	200.000	513.96	40	280.000	768.74
8	120.000	438.36	25	205.000	522.56	41	285.000	796.86
9	125.000	440.80	26	210.000	531.81	42	290.000	827.27
10	130.000	443.44	27	215.000	541.81	43	295.000	859.90
11	135.000	446.25	28	220.000	552.46	44	300.000	894.91
12	140.000	449.35	29	225.000	564.09	45	305.000	932.81
13	145.000	452.74	30	230.000	576.58	46	310.000	973.38
14	150.000	456.39	31	235.000	590.09	47	315.000	1017.05
15	155.000	460.36	32	240.000	604.48	48	320.000	1063.97
16	160.000	464.64	33	245.000	620.15	49	325.000	1114.49
17	165.000	469.29						

FPL COOLDOWN CURVES FOR , NRC 1.99 REV. 2 WELD 08/10/88

THE FOLLOWING DATA WERE PLOTTED FOR COOLDOWN PROFILE 4 . (60 DEG-F / HR COOLDOWN)

IRRADIATION PERIOD = 20.000 EFP YEARS.

	INDICATED TEMPERATURE (DEG.F)	INDICATED PRESSURE (PSI)		INDICATED TEMPERATURE (DEG.F)	INDICATED PRESSURE (PSI)		INDICATED TEMPERATURE (DEG.F)	INDICATED PRESSURE (PSI)
1	85.000	386.31	18	170.000	434.89	34	250.000	605.99
2	90.000	387.55	19	175.000	440.52	35	255.000	625.29
3	95.000	388.94	20	180.000	446.51	36	260.000	645.89
4	100.000	390.46	21	185.000	453.10	37	265.000	668.30
5	105.000	392.15	22	190.000	460.21	38	270.000	692.24
6	110.000	393.89	23	195.000	467.93	39	275.000	718.26
7	115.000	396.03	24	200.000	476.24	40	280.000	746.05
8	120.000	398.24	25	205.000	485.25	41	285.000	776.22
9	125.000	400.68	26	210.000	494.96	42	290.000	808.49
10	130.000	403.32	27	215.000	505.39	43	295.000	843.27
11	135.000	406.23	28	220.000	516.71	44	300.000	880.85
12	140.000	409.37	29	225.000	528.96	45	305.000	921.19
13	145.000	412.75	30	230.000	542.15	46	310.000	964.57
14	150.000	416.47	31	235.000	556.31	47	315.000	1011.27
15	155.000	420.54	32	240.000	571.67	48	320.000	1061.44
16	160.000	424.93	33	245.000	588.26	49	325.000	1115.44
17	165.000	429.72						

FPL COOLDOWN CURVES FOR , NRC 1.99 REV. 2 WELD 08/10/88

THE FOLLOWING DATA WERE PLOTTED FOR COOLDOWN PROFILE 5 (100 DEG-F/HR COOLDOWN)

IRRADIATION PERIOD = 20.000 EFP YEARS

	INDICATED TEMPERATURE (DEG.F)	INDICATED PRESSURE (PSI)		INDICATED TEMPERATURE (DEG.F)	INDICATED PRESSURE (PSI)		INDICATED TEMPERATURE (DEG.F)	INDICATED PRESSURE (PSI)
1	85.000	303.97	17	165.000	348.28	33	245.000	524.81
2	90.000	305.05	18	170.000	353.85	34	250.000	545.01
3	95.000	306.32	19	175.000	359.95	35	255.000	566.76
4	100.000	307.72	20	180.000	366.55	36	260.000	590.32
5	105.000	309.33	21	185.000	373.72	37	265.000	615.66
6	110.000	311.09	22	190.000	381.82	38	270.000	643.07
7	115.000	313.09	23	195.000	390.03	39	275.000	672.59
8	120.000	315.28	24	200.000	399.21	40	280.000	704.34
9	125.000	317.74	25	205.000	409.21	41	285.000	738.75
10	130.000	320.42	26	210.000	419.94	42	290.000	775.71
11	135.000	323.41	27	215.000	431.67	43	295.000	815.56
12	140.000	326.66	28	220.000	444.32	44	300.000	858.43
13	145.000	330.22	29	225.000	457.98	45	305.000	904.65
14	150.000	334.14	30	230.000	472.79	46	310.000	954.39
15	155.000	338.45	31	235.000	488.84	47	315.000	1007.97
16	160.000	343.13	32	240.000	506.06	48	320.000	1065.55