ASSESSMENT OF REGULATORY GUIDE 1.99, REVISION 2 UPON D. C. COOK UNITS 1 AND 2 ADJUSTED REFERENCE TEMPERATURES AND PRESSURE-TEMPERATURE CURVES

SwRI Project 17-2544

Prepared for

American Electric Power Service Corp.
1 Riverside Plaza
Columbus, Ohio 43216-6631

Prepared by

Nondestructive Evaluation Science and Technology Division

November 1988

Written by

Frank A. Iddings, Staff Scientist
Mark Williams (Consultant)

Approved by

B. T. Cross
Director
Department of Nondestructive Evaluation
Science and Research

[illegible]

TABLE OF CONTENTS

LIST OF FIGURES

1. SUMMARY OF RESULTS AND CONCLUSIONS

In response to the Nuclear Regulatory Commission Generic Letter 88-11 on the subject of radiation embrittlement of reactor vessel materials, dated July 12, 1988, American Electric Power Service Corp., on behalf of Indiana Michigan Power Company, requested that Southwest Research Institute evaluate the impact of methods described in Revision 2 of Regulatory Guide 1.99 for Donald C. Cook Nuclear Plants 1 and 2. This evaluation requires calculation of new reference temperatures, preparation of revised pressure-temperature curves, and comparison to previous results reported under Regulatory Guide 1.99, Revision 1. The following items summarize the comparison of this Revision 2 evaluation with Revision 1 results from previous reports (1,3,7).

(1) Unit 1 shows an increase from 285°F to 296°F for the Adjusted Reference Temperature (ART) at 1/4T into the vessel wall for 32 Effective Full Power Years (EFPY) for the Rev. 1 calculation in Reference 7 (1985) as compared to Rev. 2 calculations presented in this report. The controlling material in Unit 1 is the weld metal and the calculation uses Position 1 of Rev. 2 with average chemistry values of 0.31 percent copper and 0.74 percent nickel provided by Westinghouse in Reference 2.

(2) The D. C. Cook Unit 1 ART_{0T} of 325°F from Rev. 2 still is slightly more than 200°F below the operating temperature (550°F) which has been used as a screening criteria for older plants but is an increase greater than 300°F over the initial RT_{NDT} of 0°F for weld metal. An effort should be made to decrease the neutron embrittlement during the remaining life of the plant to obtain a lower ART at 32 EFPY, to retain operational flexibility.

(3) Table 2 shows an increase from 185°F to 267°F for weld metal (controlling material) at 12 EFPY for Unit 1, calculated by Rev. 1 and Rev. 2 respectively. This 80°F increase indicates the need to reduce the fast neutron flux on the pressure vessel wall according to the extremely conservative Rev. 2 procedures.

(4) The increase in the ART at 32 EFPY for Unit 2 is from 198°F for Rev. 1 in the last Surveillance Capsule Report to 211°F for Rev. 2 calculations in this report (3). The controlling material is plate material and the Rev. 2 value is less than a 200°F increase over the initial RT_{NDT} of 58°F for plate material. Unit 2 chemistry values are 0.14% Cu and 0.58% Ni.

(5) The Unit 2 ART at 1/4T from the Rev. 2 calculations is 195°F at 32 EFPY so the Unit 2 materials in the beltline region are projected to retain sufficient toughness to meet the current requirements of 10CFR50 Appendix G throughout the design life of the unit.

(6) The Pressure-Temperature Curves included in this report indicate the narrowing of the operating window for Unit 1 at 32 EFPY as fairly severe while the operating window for Unit 2 should not present unacceptable difficulties.

(7) Table 2 shows an increase of only about 20°F (159°F to 181°F) for the controlling material (plate) ART_{0T} at 12 EFPY for Unit 2. This small change indicates no near-term difficulties for Unit 2 just as the 32 EFPY calculations indicate no difficulties to end-of-life.

(8) Figure 9 is a plot of upper shelf energy decrease versus fluence for D. C. Cook Unit 1 using Reg. Guide 1.99, Rev. 2, Figure 2, page 1.99-9. The plot indicates adequate toughness for the surveillance capsule specimens of the controlling material, weld metal, through 32 EFPY (fluence of 2.3 x 10^{19} n/cm^2, Reference 3).

(9) Figure 10 is a plot for D. C. Cook Unit 2 indicating that the surveillance capsule specimens of the controlling material, plate, will retain adequate toughness through 32 EFPY (fluence of 2.1 x 10^{19} n/cm^2, Reference 3) to meet current upper shelf requirements of 10CFR50 Appendix G.

2. METHODOLOGY

Revision 2 of Regulatory Guide 1.99 provides for calculation of the ART using either of two positions: Position 1 (Surveillance Data Not Available) and Position 2 (Surveillance Data Available). Limitations of Position 1 given in 1.3 of Rev. 2 are satisfied by the data used from Units 1 and 2. The equations used in the two positions are noted below.

Position 1:

$$ART = \text{Initial } RT_{NDT} + \Delta RT_{NDT} + \text{Margin} \quad (1)$$

Initial RT_{NDT} is the unirradiated specimen data (from WCAP Report)

$$\Delta RT_{NDT} = (CF)\, f^{(0.28 - 0.10 \log f)} \quad (2)$$

CF is taken from Rev. 2: Table 1 for weld and Table 2 for plate

fluence factor is ff and

$$ff = f^{(0.28 - 0.10 \log f)}$$

where $f = \text{fluence}/10^{19}\ ^{n}/cm^2$ (E > 1MeV)

or

ff may be taken from Figure 1 of Rev. 2

$$f = f_{surface}\,(e^{-0.24x}) \quad (3)$$

for fluence at any depth in the vessel wall, x, as measured from the inner wall and as calculated from fluence at the inner surface (0T) of pressure vessel wall (Rev. 2, p. 1.99-3).

$$\text{Margin} = 2\sqrt{\sigma_I^2 + \sigma_\Delta^2} \quad (4)$$

σ_I the estimated precision for initial RT_{NDT} was taken to be 5°F or 10% of initial RT_{NDT}, whichever is larger [from inspection of Charpy curves and values in WCAP 8047 and WCAP 8512.(5,6)] Scatter in the Charpy test data is small, especially at 30 ft lb. region.

σ_Δ is 28°F for weld metal and 17°F for plate, p. 1.99-3 of Rev. 2 for Position 1.

Note: Margin for Position 1 for weld metal, in this report, is 57°F using above values. This compares well with the margin value of 59°F from NRC calculations of D. C. Cook Unit 1 PTS requirements (7).

Position 2:

Since the material content of the surveillance weld differs from that of the vessel weld for Unit 1, a ratio of the measured values of ΔRT_{NDT} were adjusted by a ratio of the chemistry in the vessel factor for the vessel weld to that of the surveillance weld. This ratio was 1.06 for the difference of 0.31% Cu (2) and 0.27% Cu in the capsule (1), respectively. [Chemistry Factors (CF) taken from Table 1 of Rev. 2].

For Unit 2 there was no difference in Cu values for vessel and capsule material so the ratio is 1.00. The CF for use in the RT_{NDT} Eq. (2) was calculated from surveillance capsule data (3 capsules) by taking the sum of the products for each adjusted ΔRT_{NDT} from capsule data multiplied by its corresponding fluence factor and dividing by the sum of the squares of the fluence factors. See Eq. (5) below.

$$CF = \frac{\Sigma_i (\Delta RT_{NDT} x\ ff)}{\Sigma_i (ff)^2} \qquad (5)$$

For margin calculations in Position 2, σ_Δ values were cut in half from those recommended for Position 1 values given in Reg. Guide 1.99, Rev. 2, p. 1.99-2; e.g., σ_Δ is:

14°F for weld metal and
8.5°F for plate (p. 1.99-4, Rev. 2)

General Discussion of Comments 1-5, Article B, Reg. Guide 1.99, Rev. 2

(1) Weld specimens in the capsules for D. C. Cook Unit 1 (the controlling material) do not exactly match the vessel weld metal so Position 1 calculation should be used for Unit 1. Position 2 calculations were done for comparison purposes. Also calculations were made for the plate material in Unit 1 for comparison purposes.

Plate material in the capsule specimens for D. C. Cook Unit 2 do match the plate material in the vessel and is the controlling material. Position 2 is the most appropriate calculation for Unit 2 since data from 3 capsules are available. Position 1 calculation matches Position 2 calculation of 212°F/211°F respectively for the chemistry values of 0.14% Cu and 0.58% Ni.(3)

(2) Scatter in the unirradiated materials for Units 1 and 2 is small and should be well represented by choosing either 5°F or 10 percent of the initial RT_{NDT} at 30 ft lb., whichever is larger. This gives values for the margin quite comparable to those accepted in recent PTS calculations (7). Typical standard deviation for a set of values at a test temperature is <5°F.

(3) Scatter in the surveillance capsule data for the wide range of fluence values represented is not large, as is shown by the fairly close agreement for Position 1 vs Position 2 values obtained for the plate and weld materials from the two units. Also see Figure 10 from Capsule Y Report, Unit 1 (1,3).

(4) All surveillance capsule thermal monitors were intact for the two units which indicates a good match to the temperatures experienced by the vessel inner wall.

(5) No severe excursions of the data from the correlation monitor in the surveillance capsules for Unit 1 has been noted. See Figures 8 and 10 from the Capsule Y Report for Unit 1. (Correlation monitor not reported in Capsule X Report of Unit 2.)

Examples of Calculations (for 32 EFPY):

Unit 1, Weld Metal (which is the controlling material in Unit 1), using Position 1 of Rev. 2:

ART = Initial RT_{NDT} + ΔRT_{NDT} + Margin (Eq. 1)

Initial RT_{NDT} = 0°F (WCAP-8047) Ref. 5

$\Delta RT_{NDT} = (CF)\, f^{(0.28 - 0.10 \log f)}$ Eq. (2)

CF = 219°F (Table 1, Rev. 2)

for: Cu = 0.31% Ni = 0.74% Ref. 2

f = 2.3 ($\times 10^{19}$ n/cm^2) Ref. 2

$= (219°F)\, 2.3^{(0.28 - 0.10 \log 2.3)}$

= (219°F) (1.22)

= 268°F

Margin $= 2\sqrt{\sigma_I^2 + \sigma_\Delta^2}$

σ_I = 5°F Ref. 5

5°F is greater than 10 percent of initial RT_{NDT} of 0°F

σ_Δ = 28°F (Position 1, Rev. 2, for welds)

= 56.9°F or 57°F

this is comparable to 59°F for generic value for margin in recent PTS calculations for D. C. Cook Unit 1 (7).

ART_{0T} = 0°F + 268°F + 57°F = 325°F

$f = f_{surface}\, (e^{-0.24x})$

for 1/4T (depth in vessel wall for 1/4T, x = 2.1 inch)

$f_{surface}$ = 2.3 Ref. 1

$f = 2.3\, [e^{-0.24\,(2.1)}]$ = 1.38

$ff = f^{(0.28 - 0.10 \log f)}$

$= 1.38^{(0.28 - 0.10 \log 1.38)}$ = 1.09

$ART_{1/4T} = 0°F + (219°F)(1.09) + 57°F = 296°F$

$f = 0.50$

for: 3/4T (depth in vessel wall, x = 6.4 inches)

$ff = 0.50^{(0.28 - 0.10 \log 0.50)} = 0.80$

$ART_{3/4T} = 0°F + (219°F)(0.80) + 57°F = 232°F$

Unit 1, Weld Metal, Position 2 of Rev. 2

(Shown as an example only; capsule weld metal may not be identical to vessel weld metal so Position 1 is appropriate for Unit 1 and Position 2 is not.)

(1) CF Ratio for $CF_{vessel}/CF_{capsule}$ = 219/206 (Table 1, Rev. 2)

219°F for 0.31% Cu, 0.74% Ni (Ref. 2)

206°F for 0.27% Cu, 0.74% Ni (Ref. 5)

= 1.06

(2) $$CF = \frac{\Sigma_i (\Delta RT_{NDT} x\ ff)}{\Sigma_i (ff)^2} \quad (5)$$

from Capsule Y Report, Figure 9 (Ref 1):

$f(10^{19}n/cm^2)$	ff	ΔRT_{NDT}
0.26	0.62	128°F
0.72	0.90	162°F
1.06	1.02	200°F

$$= 1.06 \frac{(0.62)(128) + (0.90)(162) + (1.02)(200)}{(0.62)^2 + (0.90)^2 + (1.02)^2}$$

$CF = 1.06 (193°F) = 205°F$

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

$f = 2.3$ (Ref. 1)

$= (205°F) (1.22) = 250°F$

$\text{Margin} = 2\sqrt{5^2 + [0.5 (28)]^2} = 30°F$

for weld: 5°F is larger than 10% of Initial RT_{NDT} of 0°F and Rev. 2 allows $\sigma_\Delta = 0.5 (28)$

$ART_{0T} = 0°F + 250°F + 30°F = 280°F$

$ART_{1/4T} = 0°F + (205°F)(1.09) + 30°F = 253°F$

$ART_{3/4T} = 0°F + (205°F)(0.80) + 30°F = 194°F$

Unit 2, Plate (which is the controlling material in Unit 2), Position 1 of Rev. 2

ART = Initial RT_{NDT} + ΔRT_{NDT} + Margin

Initial RT_{NDT} = 58°F (WCAP 8512) Ref. 3, 6

ΔRT_{NDT} = (CF) $f^{(0.28 - 0.10 \log f)}$

CF = 98.2°F (Table 2, Rev. 2)

for 0.14% Cu and 0.58% Ni
(Plate Analysis, Ref. 3, 6)

f = 2.1 ($\times 10^{19}$ n/cm^2) (Ref. 3)

= (98.2°F) $2.1^{(0.28 - 0.10 \log 2.1)}$

= (98.2°F)(1.20) = 118°F

Margin = $2\sqrt{\sigma_I^2 + \sigma_\Delta^2}$ = 36°F

σ_I = 5.8°F

(10% of initial RT_{NDT} of 58°F which is larger than 5°F)

σ_Δ = 17°F

Position 1, Rev. 2 for base metal
p. 1.99-4

ART_{0T} = 58°F + 118°F + 36°F = 212°F

f = 1.24 for 1/4T (x = 2.2 inch)

ff = 1.06

$ART_{1/4T}$ = 58°F + 98.2°F(1.06) + 36°F = 198°F

f = 0.44 for 3/4T (x = 6.5 inch)

ff = 0.78

$ART_{3/4T}$ = 58°F + 98.2°F(0.78) + 36°F = 170°F

Unit 2, Plate: Position 2 of Rev. 2:

(1) CF Ratio = 1.00 (Vessel and Surveillance Capsule Specimens have the same chemistry values)

(2) $$CF = \frac{\Sigma_i (\Delta RT_{NDT} \times ff)}{\Sigma_i (ff)^2} \quad (5)$$

from Capsule X Report (Ref. 3):

$f(10^{19}\ n/cm^2)$	ff	ΔRT_{NDT}
0.27	0.64	80°F
0.70	0.90	100°F
1.05	1.01	103°F

$$= \frac{(80)(0.64) + (100)(0.90) + (103)(1.01)}{(0.64)^2 + (0.90)^2 + (1.01)^2}$$

$= 110°F$

Margin $= 2\sqrt{(5.8)^2 + [0.5(17)]^2}$

$\sigma_I = 5.8°F$

(10% of 58°F for initial RT_{NDT})

$\sigma_\Delta = 0.5\ (17)$

for Position 2, plate material (Rev. 2)

$= 20.6°F\ (\sim 21°F)$

$\Delta RT_{NDT} = 110°F(1.20) = 132°F$

$ART_{0T} = 58°F + 132°F + 21°F = 211°F$

f = 1.24 for 1/4T (see Unit 2, Position 1)

ff = 1.06

$ART_{1/4T} = 58°F + 110°F(1.06) + 21°F = 195°F$

f = 0.44 for 3/4T (see Unit 2, Position 1)

ff = 0.78

$ART_{3/4T} = 58°F + (110°F)(0.78) + 21°F = 165°F$

3. RESULTS

Table 1

SUMMARY OF ART VALUES FOR 32 EFPY

		Rev. 1 (°F)		Rev. 2 (°F)		
Unit 1	Initial RT_{NDT} (°F)			Position 1	Position 2	Default[a]
Plate 0T	45[b]	220[b]		196	207	413
1/4T	45	185		184	192	377
3/4T	45	130		156	158	298
Weld 0T	0[b]	290[b]	478	325[c]	280	390
1/4T	0	283	373	297	253	354
3/4T	0	192	186	232	194	275
Unit 2						
Plate 0T	58[d]	198[d]		212	211[e]	419
1/4T	58	163		198	195	379
3/4T	58	130		170	164	303
Weld 0T	0[d]	108[d]		147	110	383
1/4T	0	80		136	100	343
3/4T	0	40		115	82	267

(a) Default values calculated from Reg. Guide 1.99, Rev. 2, Position 1 using chemistry values of 0.35% Cu and 1.00% Ni (p. 1.99-3). Use default "If no information available."

(b) Capsule Y Report on D. C. Cook Unit No. 1, 1984 (Ref. 1).

(c) Controlling material for Unit 1

(d) Capsule X Report on D. C. Cook Unit No.2, 1987 (8).

(e) Controlling material for Unit 2.

Table 2

SUMMARY OF ART VALUES FOR 12 EFPY

		Rev. 1 (°F)		Rev. 2 (°F)		
Unit 1	Initial RT_{NDT} (F°)			Position 1	Position 2	Default[a]
Plate 0T	45[b]	155[b]		171	177	341
1/4T	45	140		158	160	302
3/4T	45	105		124	129	228
Weld 0T	0[b]	185[b]	293	267[d]	215	318
1/4T	0	160	234[c]	236	187	279
3/4T	0	105	117	176	135	205
Unit 2						
Plate 0T	58[e]	159[e]		186	181[f]	347
1/4T	58	146		172	165	308
3/4T	58	102		146	136	236
Weld 0T	0[e]	66[e]		127	94	310
1/4T	0	47		116	84	271
3/4T	0	23		96	66	199

(a) Default values calculated from Reg. Guide 1.99, Rev. 2, Position 1 using chemistry values of 0.35% Cu and 1.00% Ni (p. 1.99-3). Use default "If no information available.".

(b) Capsule Y Report on D. C. Cook Unit No. 1, 1984 (Ref. 1).

(c) Southwest Research Institute letter to AEP (7).

(d) Controlling material for Unit 1

(e) Capsule X Report on D. C. Cook Unit No.2, 1987 (8).

(f) Controlling material for Unit 2.

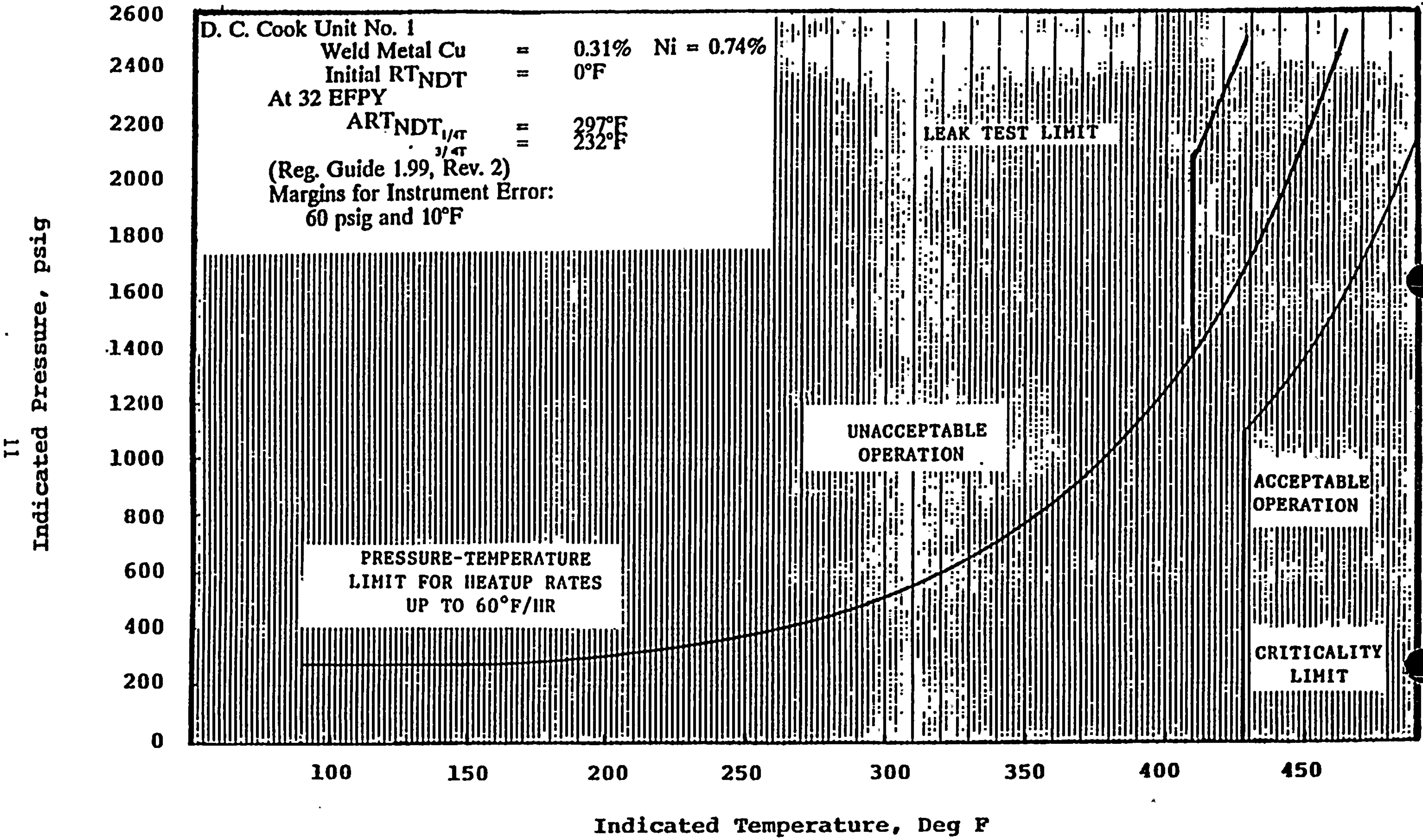

Figure 1. D. C. Cook Unit No. 1 reactor coolant heatup limitations applicable for up to 32 effective full power years

11

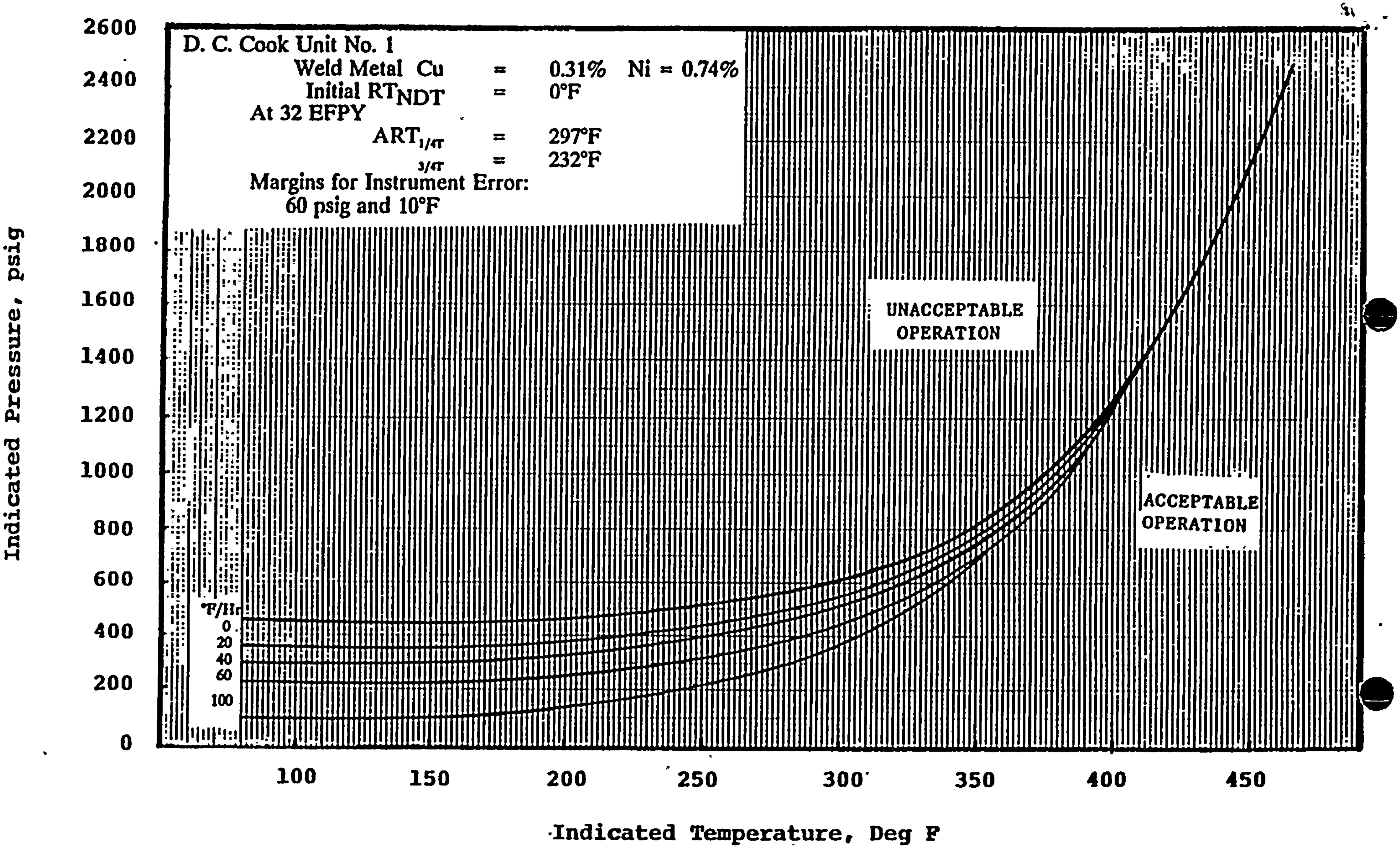

Figure 2. D. C. Cook Unit 1 reactor coolant system pressure-temperature limits vs cooldown rates for up to 32 effective full power years

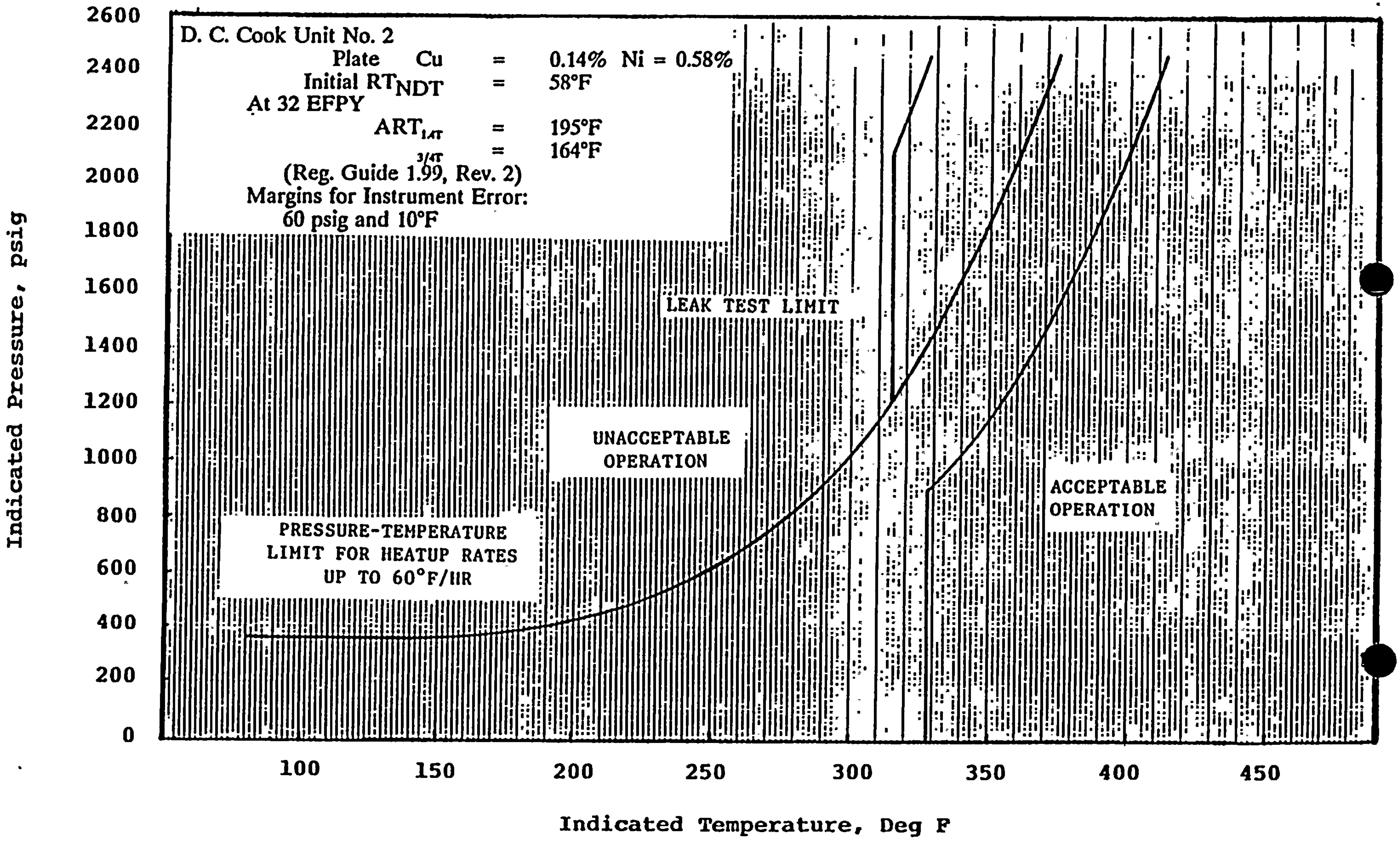

Figure 3. D. C. Cook Unit No. 2 reactor coolant heatup limitations applicable for up to 32 effective full power years

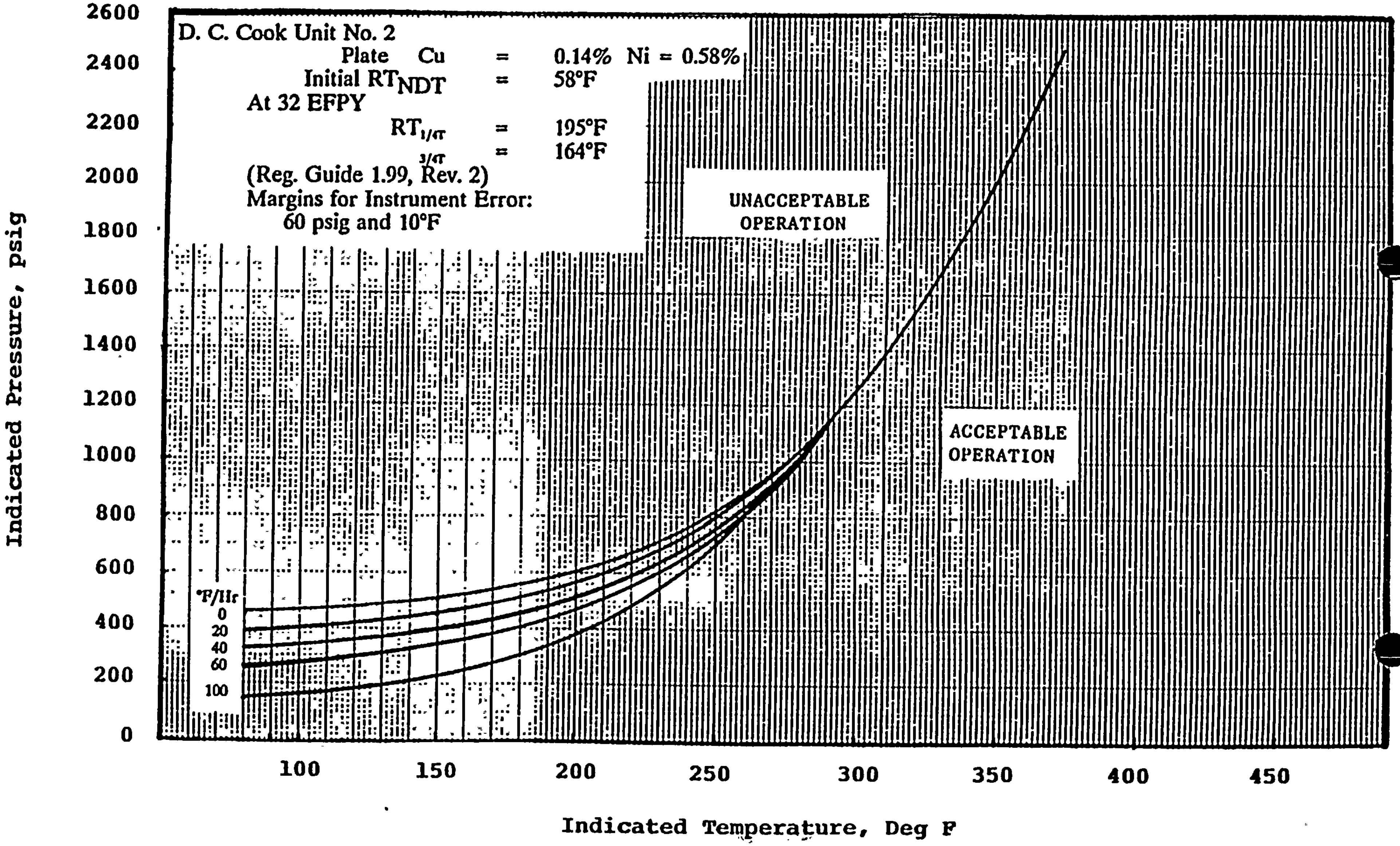

Figure 4. D. C. Cook Unit 2 reactor coolant system pressure-temperature limits vs cooldown rates for up to 32 effective full power years

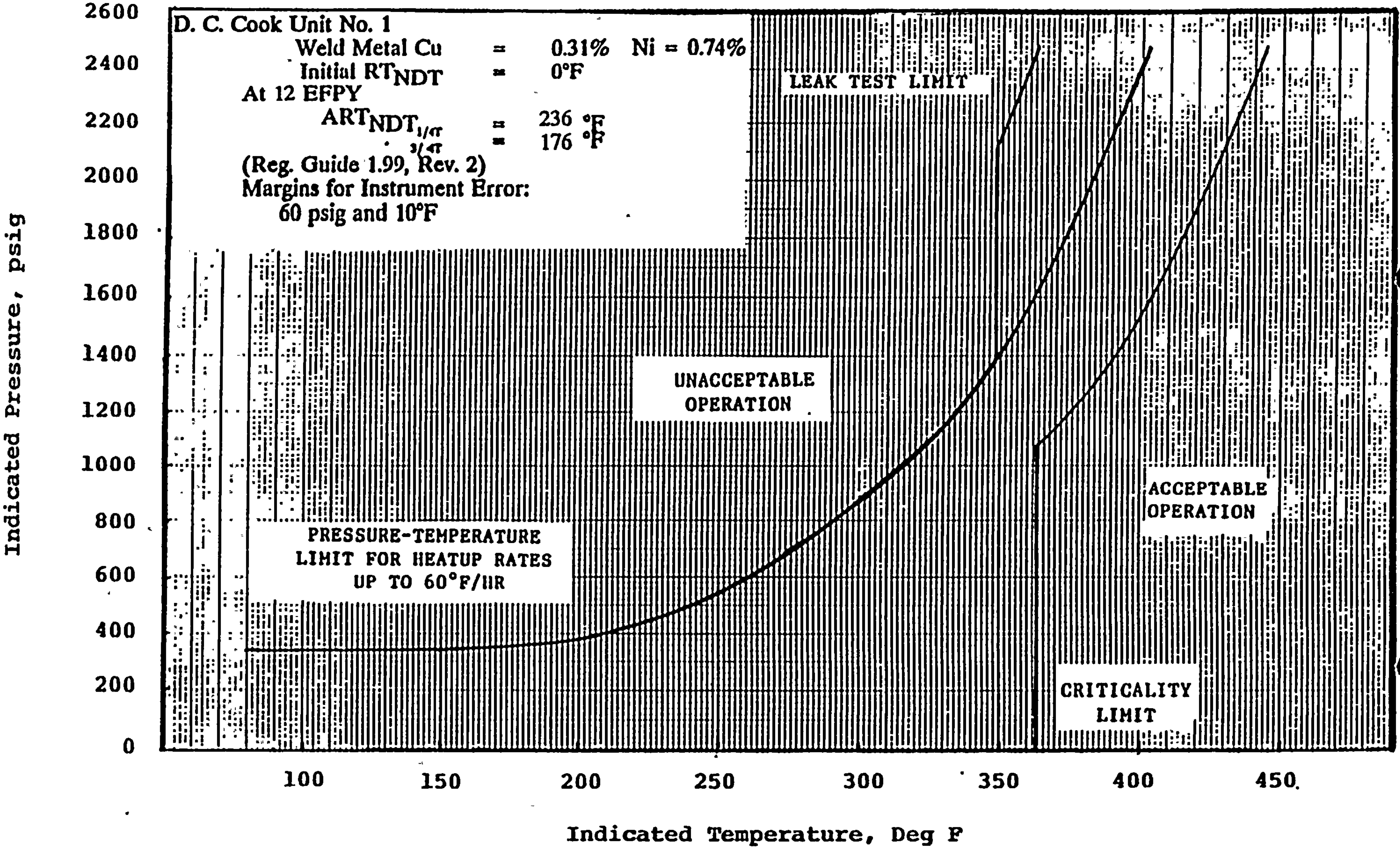

Figure 5. D. C. Cook Unit No. 1 reactor coolant heatup limitations applicable for up to 12 effective full power years

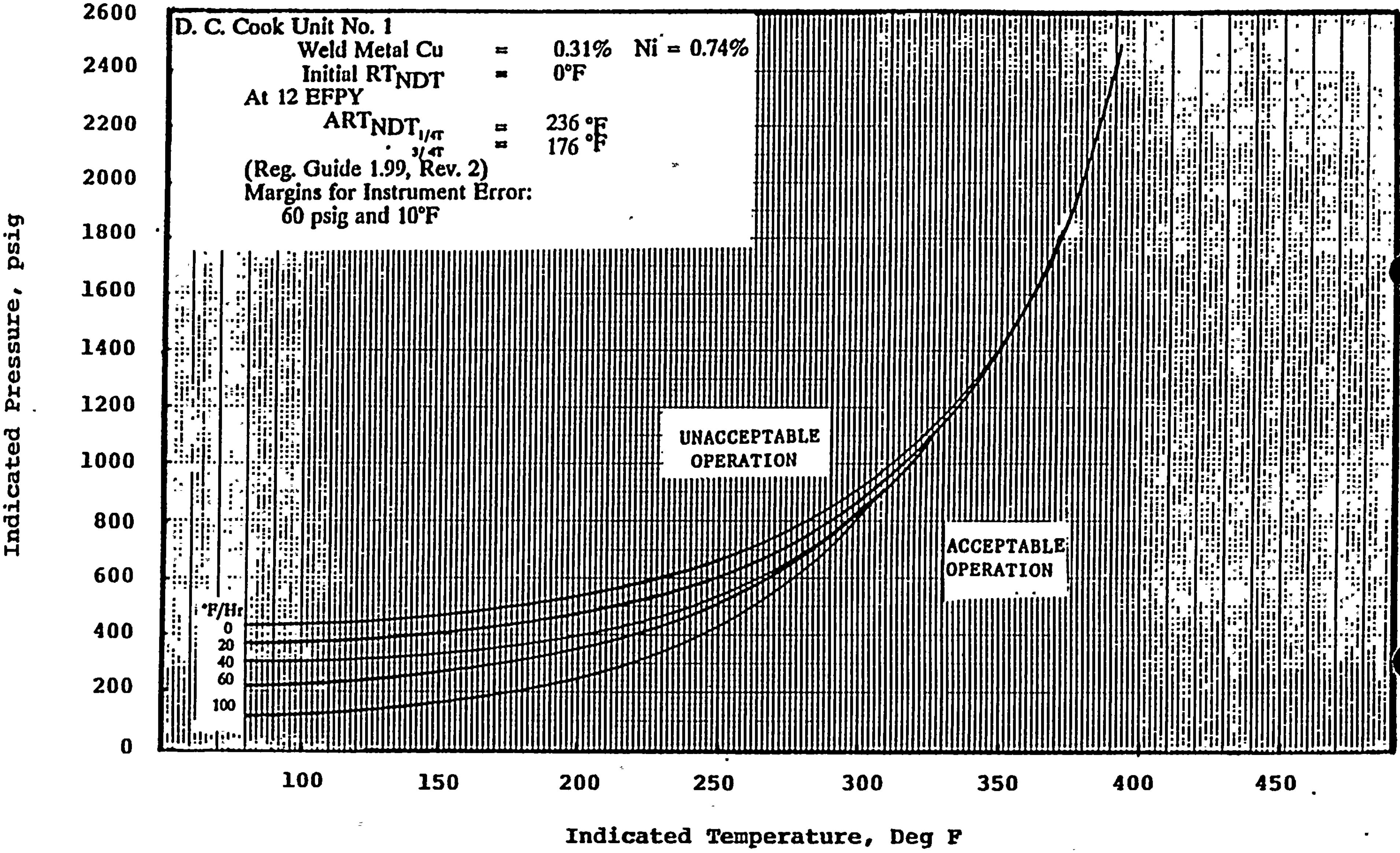

Figure 6. D. C. Cook Unit 1 reactor coolant system pressure-temperature limits vs cooldown rates for up to 12 effective full power years

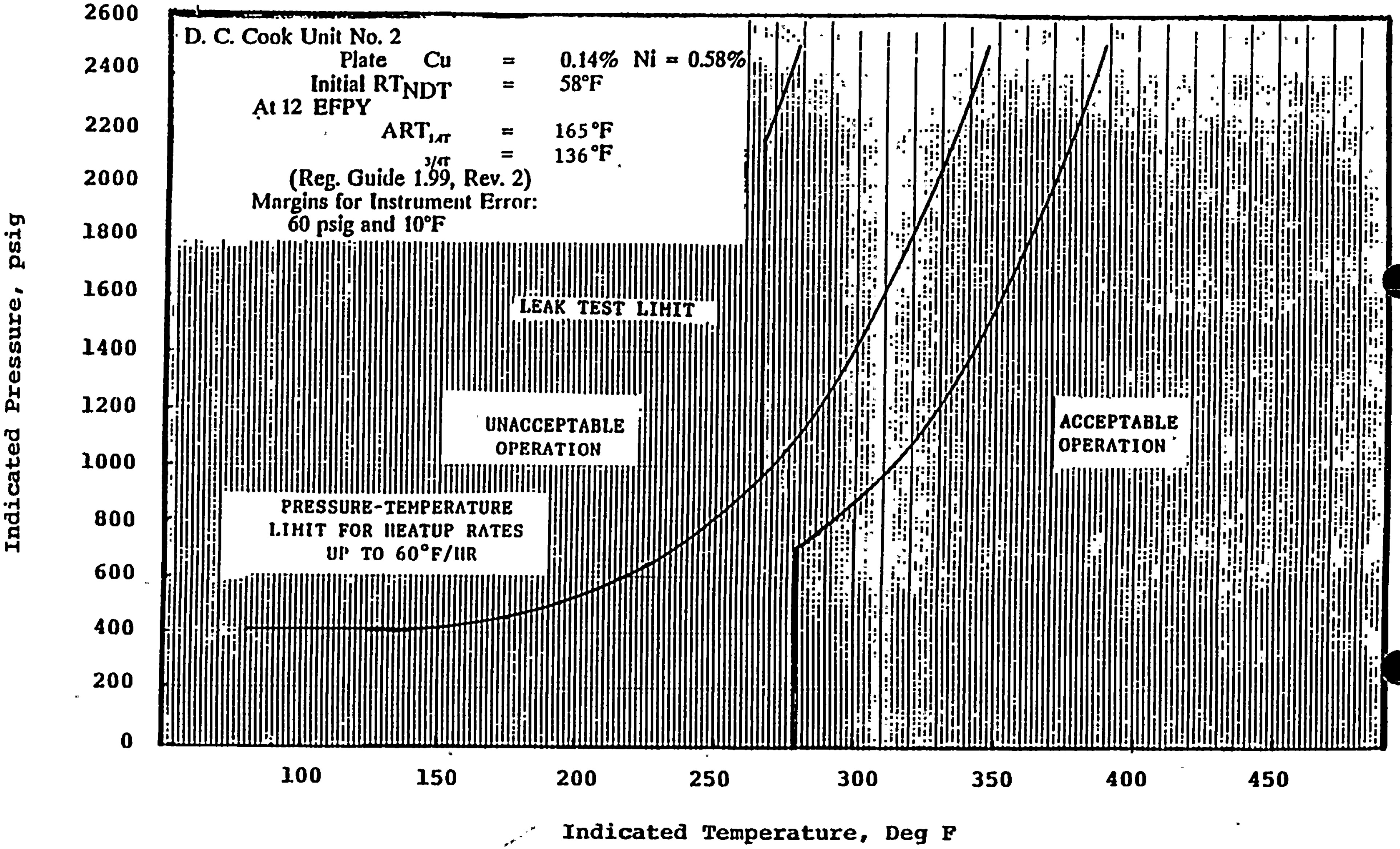

Figure 7. D. C. Cook Unit 2 reactor coolant heatup limitations applicable for up to 12 effective full power years

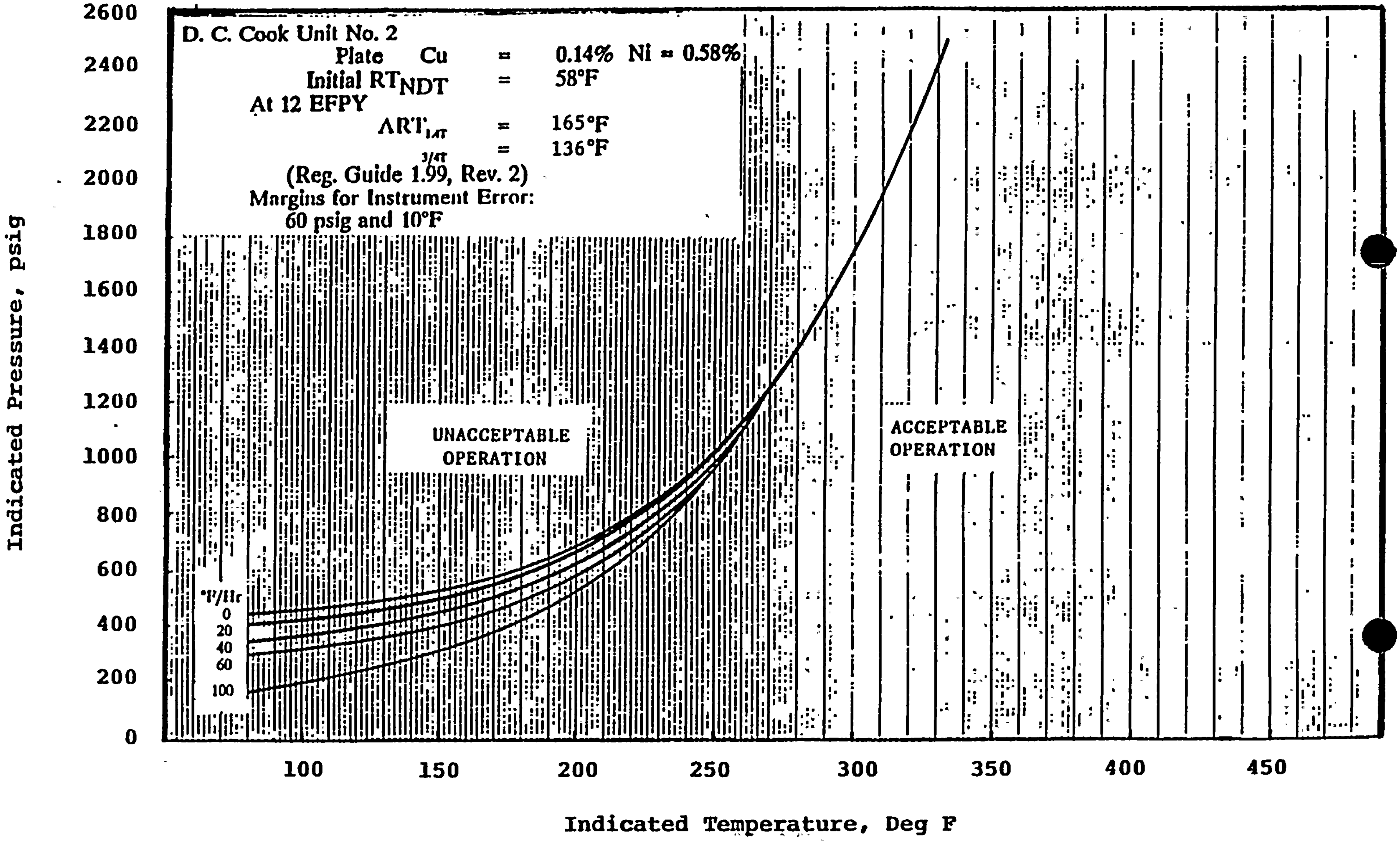

Figure 8. D. C. Cook Unit 2 reactor Coolant system pressure-temperature limits vs cooldown rates for up to 12 effective full power years

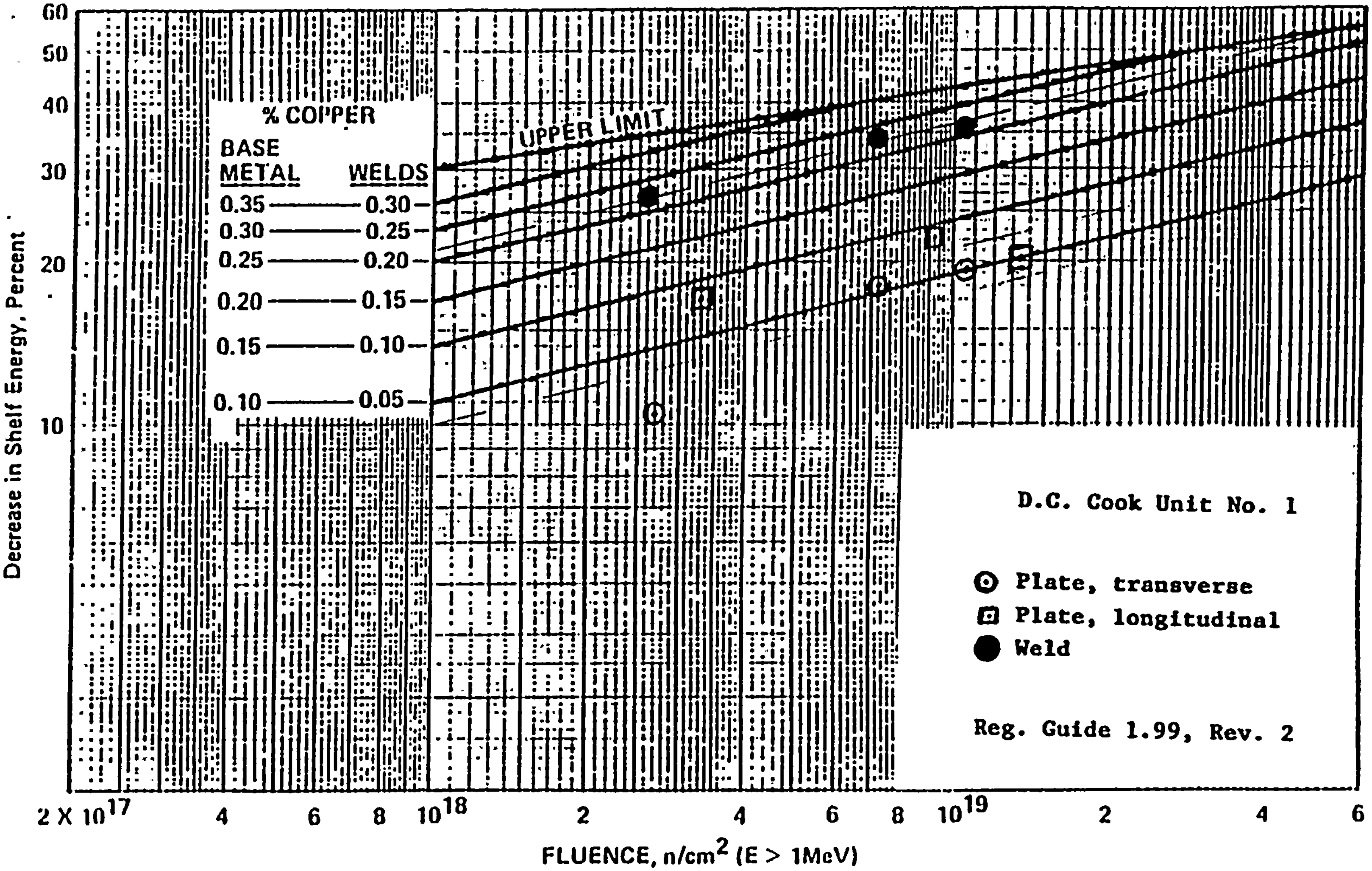

Figure 9. Predicted decrease in shelf energy as a function of copper content and fluence for D. C. Cook Unit 1

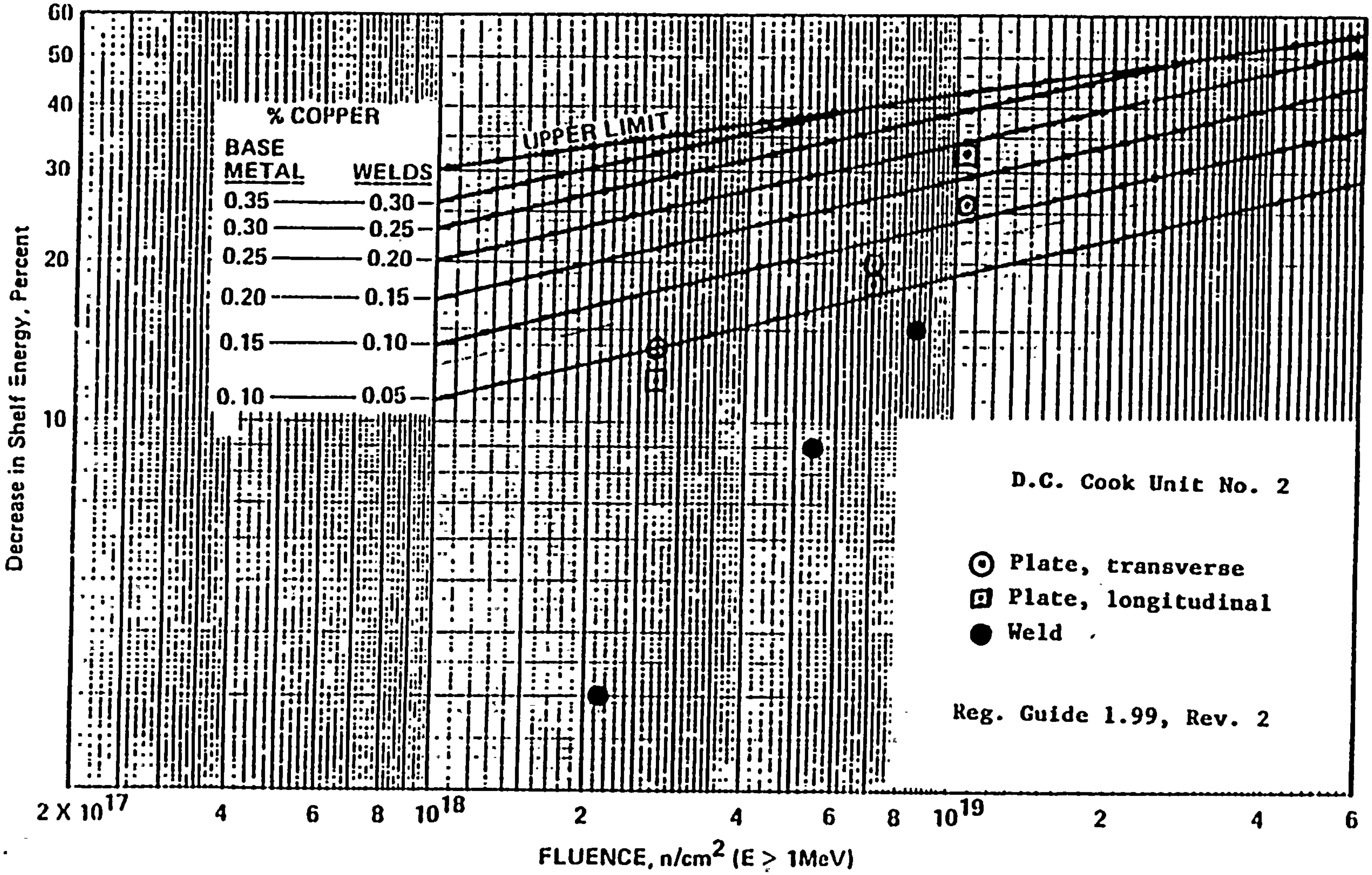

Figure 10. Predicted decrease in shelf energy as a function of copper content and fluence for D. C. Cook Unit 2

4. REFERENCES

1. Reactor Vessel Material Surveillance Program for Donald C. Cook Unit No. 1: "Analysis of Capsule Y," by E. B. Norris, Southwest Research Institute Report 06-7244, (January 1984).

2. Westinghouse Letter to M. P. Alexich of American Electric Power Service Corp., from A. P. Suda, Westinghouse Electric Corp., Water Reactor Division, Re: Reactor Vessel Beltline Region Weld Chemistry (June 14, 1985).

3. Reactor Vessel Material Surveillance Program for Donald C. Cook Unit No. 2: "Analysis of Capsule X," by P. K. Nair and M. L. Williams (Consultant), Southwest Research Institute Report 06-8888 (May 1987).

4. Regulatory Guide 1.99, Revision 2: Radiation Embrittlement of Reactor Vessel Materials (May 1988).

5. WCAP-8047, American Electric Power Service Corp., Donald C. Cook Unit No. 1: "Reactor Vessel Radiation Surveillance Program," Westinghouse Nuclear Energy Systems (March 1973).

6. WCAP-8512, American Electric Power Service Corp., Donald C. Cook Unit No. 2: "Rector Vessel Radiation Surveillance Program," Westinghouse Electric Corporation, Nuclear Energy Systems (November 1975).

7. Southwest Research Institute, letter from Dr. Prasad Nair (SwRI) to Mr. John Jensen, AEP Service Corp., Re: Heat Up and Cool Down Curves for D. C. Cook Unit No. 1 Reactor Vessel (July 1, 1985).

8. USNRC letter to John Dolan of Indiana and Michigan Electric Co., c/o American Electric Power Service Corp., from B. J. Youngblood, Director of PWR Project Directorate 14, Division of PWR Licensing, Docket Nos. 50-315 and 50-316 (March 27, 1987).