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IMPLEMENTATION OF REGULATORY GUIDE 1.99, REVISION 2 FOR THE MONTICELLO NUCLEAR GENERATING PLANT

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1.0 INTRODUCTION

In 1984, GE provided Northern States Power (NSP) with pressure-temperature (P-T) curves updated to the 1983 requirements of 10CFR50, Appendix G. The report [6-1] showed the weld material to be the limiting material in the beltline region, because of the high initial reference temperature of nil-ductility transition (RT_{NDT}) assumed. The high initial RT_{NDT}, 40°F, was reported in a 1979 GE report on the Monticello surveillance program [6-2]. The value of 40°F was established from the Monticello vessel purchase specification requirements because there were no Charpy data available for the weld material heats used in the Monticello beltline welds.

In 1987, NSP obtained data from Alloy Rods to use as a basis for reducing the value of the assumed initial RT_{NDT} of the beltline welds. GE revised the estimate of weld initial RT_{NDT}, based on the data provided by NSP, and revised the pressure-temperature curves for Monticello, still using Regulatory Guide 1.99, Revision 1 to predict RT_{NDT} shift due to irradiation [6-3].

In May 1988, Revision 2 to Regulatory Guide 1.99 (Rev 2) was issued by the NRC. Rev 2 presents different methods for predicting RT_{NDT} shift, typically increasing shifts for BWRs. NSP has requested that the P-T curves and RT_{NDT} shift relationships reported in [6-3] be revised to reflect the methods of Rev 2. In further discussions between GE and NSP, it was agreed that reductions in heating prior to pressure testing might be possible by monitoring the bottom head temperatures against a separate P-T curve from that used for the beltline and the rest of the vessel, and that GE would address the bottom head monitoring option in this analysis. Therefore, the objectives of this report are as follows:

1. Determine the limiting beltline material and calculate the irradiation shift as a function of fluence using Rev 2 as a basis.

2. Revise the pressure-temperature curves, if necessary, to reflect the initial RT_{NDT} value of the limiting beltline material.

3. Include the necessary discussion and technical bases to explain and justify monitoring bottom head temperatures separately from beltline temperatures during pressure testing.

4. Modify the updated final safety analysis report (UFSAR) and Technical Specification inputs from [6-3] to reflect the changes due to this evaluation.

2.0 SUMMARY

The pressure-temperature curves governing vessel operating limits for Monticello are revised to reflect implementation of Regulatory Guide 1.99, Revision 2. Initial RT_{NDT} values are documented, as well as their uncertainty, if appropriate. The approach in Revision 2 to determining quarter thickness fluence, ΔRT_{NDT} and Margin are presented. Predictions for adjusted reference temperature (ART) for 32 effective full power years of operation are made, showing that conditions for ART specified in 10CFR50 Appendix G are met.

The plate material (plate 1-15) is shown to still be the limiting beltline material. The relationship of irradiation shift versus fluence was revised. The new curve is calculated according to Regulatory Guide 1.99, Revision 2, with the chemical composition of the limiting plate.

The pressure-temperature curves consist of the curves for the region remote from the beltline, which are not affected by the change in the regulatory guide, and the beltline curves. The beltline, including the irradiation shift per Revision 2, is more limiting than the non-beltline for conditions of interest such as the pressure test.

The pressure test curve for the region remote from the beltline may be used for allowable bottom head temperatures, rather than using the more restrictive limits of the beltline curve. This may allow NSP to lower pressure tests temperatures 20°F to 30°F, offsetting some of the impact of the increase due to Rev 2.

Suggested revisions to the UFSAR and Technical Specification from are modified to reflect the changes of this analysis. The modified versions are in Appendices A and B. Changes from the text previously provided to NSP are indicated with a bar in the margin.

3.0 INITIAL RT_{NDT} OF BELTLINE MATERIALS

The methods used to determine initial RT_{NDT} values of the beltline plate materials, and the resulting RT_{NDT}s were presented in [6-1], and are reviewed briefly below. The most recent determination of beltline weld initial RT_{NDT} in [6-3] is reviewed here as well. Rev 2 includes a new requirement to determine the uncertainty of initial RT_{NDT} values, σ_I, which is addressed in this section.

3.1 PLATE INITIAL RT_{NDT}

Charpy testing of plates during fabrication demonstrated 30 ft-lb impact energy in longitudinal specimens. A GE procedure shown in [6-1] was used on these data to calculate equivalent RT_{NDT} values to those that would be determined with post-1972 (current) ASME Code test methods. The GE procedure basically requires a 2°/ft-lb adjustment on test temperature to raise Charpy energy data to the 50 ft-lb level, and then requires a 30°F addition to RT_{NDT} to account for the difference between longitudinal and transverse Charpy specimen orientation.

The GE procedure was derived as a conservative bound of data for 24 plates of SA-533 low alloy steel tested as part of the work reported in Welding Research Council (WRC) Bulletin 217 [6-4] and 22 plant-specific plate data sets retrieved from GE Quality Assurance records.

3.2 WELD INITIAL RT_{NDT}

The vessel beltline seam welds were made using a shielded metal arc welding (SMAW) process. As shown in [6-2], the welding rods used for the seam welds were provided by Alloy Rods Company. Since the records provided with the welding rods did not include Charpy test data, it is not possible to determine specific RT_{NDT} values for the Monticello beltline weld heats.

During fabrication, there was some material certification tests, referred to as "Category B" tests, which included dropweight and Charpy testing of E8018NM weld material used in the Monticello vessel. The dropweight and Charpy data, shown in [6-3], support a RT_{NDT} value of -50°F.

The first capsule of the Monticello surveillance program was removed and tested in 1984 [6-5]. The test results included Charpy data for irradiated weld metal which indicated a RT_{NDT} of -75°F in the irradiated condition. Therefore, the weld metal heat, or heats, used to make the surveillance weld had an initial RT_{NDT} of -75°F or lower.

While this information provides justification for a lower weld RT_{NDT}, it cannot be used as a valid basis for estimating the initial weld RT_{NDT}, because many different weld metal heats could have been used in the beltline welds. Therefore, NSP contacted Alloy Rods Corporation to obtain a data base of E8018NM RT_{NDT} values for statistical use. There are 45 RT_{NDT} values, shown in [6-3], ranging from -30°F to -90°F. Assuming a normal distribution,

$$\text{Mean } RT_{NDT} = -65.6°F,$$

$$\sigma_I = 12.7°F,$$

where σ_I is the standard deviation.

3.3 INITIAL RT_{NDT} UNCERTAINTY

The methods of Rev 2 include a Margin term to be added to the calculated value ΔRT_{NDT}. The Margin term includes a component for uncertainty in initial RT_{NDT}, σ_I. Rev 2 discusses determination of σ_I for two categories of initial RT_{NDT}, measured values and generic mean values. For generic mean values, σ_I is simply the standard deviation calculated for the data set used to compute the mean. For measured values, requirements for determination of σ_I are somewhat vague.

Rev 2 states, "If a measured value of initial RT_{NDT} for the material in question is available, σ_I is to be estimated from the precision of the test method."[a] GE's position for RT_{NDT} values derived from measured data is that σ_I is zero, as explained below.

The Charpy curves fit to surveillance data, which ultimately provided the ΔRT_{NDT} data for development of Rev 2, were best-estimate fits. An idealized example is provided as curve #1 in Figure 3-1. However, the ASME Code approach to determining RT_{NDT} is based on the lowest value of three specimens exceeding the required limits of impact energy and lateral expansion. A visualization of a Charpy curve drawn on the basis of the Code RT_{NDT} approach is shown as curve #2 in Figure 3-1. In comparing curves #1 and #2, it is clear that curve #2, which is based on the lowest value rather than the mean value, provides a conservative estimate of initial RT_{NDT}. Therefore, the ASME Code method of determining RT_{NDT} from measured data is conservative, and $\sigma_I = 0°F$ is appropriate.

As discussed in Section 3.1, a procedure was used to modify the measured data for plates to make the data equivalent to current methods. As already mentioned, that procedure yields conservative RT_{NDT} estimates. Furthermore, the procedure operates on the lowest Charpy energy, not the mean or average energy for a given test temperature. Therefore, for the case of equivalent RT_{NDT} values based on measured Charpy data, $\sigma_I = 0°F$ is appropriate.

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[a] In the Rev 2 draft which was circulated <u>after</u> editing to incorporate public comments, the text stated, "σ_I, the standard deviation for the initial RT_{NDT}, may be taken as zero if a measured value of initial RT_{NDT} for the material in question is available."

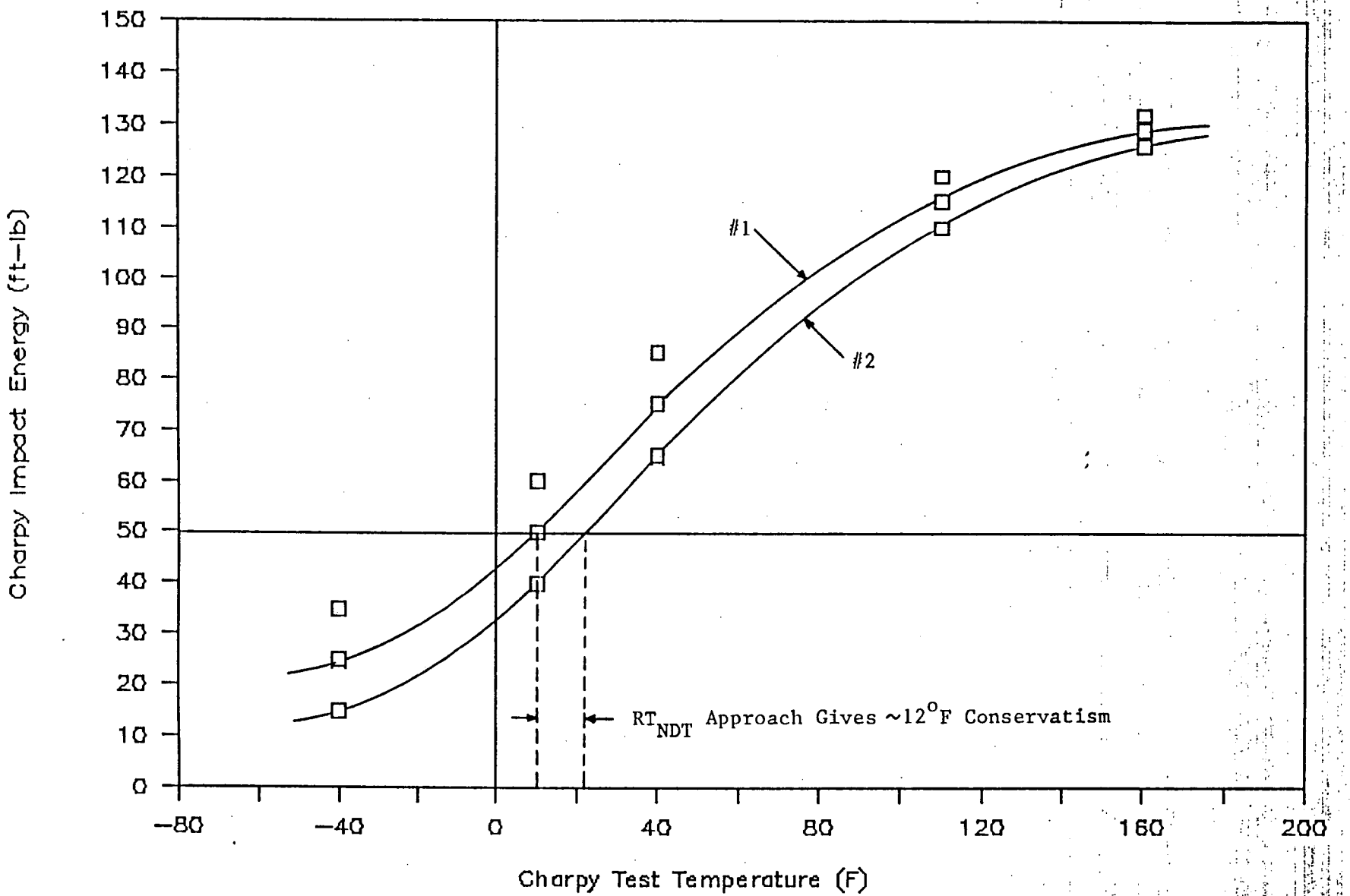


Figure 3-1. Comparison of Surveillance Data Fit and RT_{NDT} Approach

4.0 IRRADIATION SHIFT

4.1 REV 2 METHODS

Rev 2 provides methods to predict RT_{NDT} shift due to irradiation, as did Regulatory Guide 1.99, Revision 1. In addition, Rev 2 has methods for determining uncertainty margin to be included as part of the shift, and has methods for determining fluence attenuation. The shift correlation in Rev 2 consists of two terms:

$$SHIFT = \Delta RT_{NDT} + Margin \tag{4-1}$$

$$\Delta RT_{NDT} = [CF]*f^{(0.28 - 0.10 \log f)} \tag{4-2}$$

$$Margin = 2(\sigma_I^2 + \sigma_\Delta^2)^{0.5} \tag{4-3}$$

where f = fluence (n/cm^2) / 10^{19}, and
CF = chemistry factor,
provided in Rev 2 tables.

In previous shift calculations with Rev 1, the 1/4 T fluence was used as one of the inputs to regulatory guide calculation. However, Rev 2 now requires that the vessel inside surface fluence, f_{surf}, be used as one of the inputs to the regulatory guide calculation. The surface fluence is then attenuated to the vessel 1/4 thickness depth (1/4 T) as part of the regulatory guide calculation by the expression

$$f_x = f_{surf} \, (e^{-0.24x}) \tag{4-4}$$

where x = distance (inches) into the vessel
from the inside surface.

The minimum thickness assumed for the vessel in the beltline region is 5.06 inches, neglecting cladding.

A ratio of surface fluence to 1/4 T fluence of 1.30 is reported in [6-5]. The 1/4 T fluence previously assumed for 32 EFPY [6-3] was 3.9×10^{18} n/cm^2, so based on the ratio from [6-5], the surface fluence, f_{surf}, is 5.1×10^{18} n/cm^2.

Once ΔRT_{NDT} has been calculated, Margin is determined based on σ_I and σ_Δ. Rev 2 has set values of σ_Δ of 17°F for plate and 28°F for weld. However, σ_Δ need not be greater than $0.5*\Delta RT_{NDT}$.

The adjusted reference temperature (ART) is the initial RT_{NDT} plus the Rev 2 shift in Equation 4-1:

$$ART = \text{Initial } RT_{NDT} + \Delta RT_{NDT} + \text{Margin} \qquad (4\text{-}5)$$

4.2 LIMITING BELTLINE MATERIAL

The limiting beltline material, from the perspective of brittle fracture, is the material with the highest ART at a given time. The information on plate and weld chemical compositions from [6-2], initial RT_{NDT} values and 32 EFPY shifts are summarized in Table 4-1. As shown, the plate material (plate 1-15) is the limiting beltline material.

4.3 IRRADIATION SHIFT VERSUS FLUENCE

The Rev 2 shift correlation, Equation 4-1, for the chemical composition of plate 1-15 is plotted versus 1/4 T fluence in Figure 4-1. The fluence shown is the value attenuated from the inside surface fluence, per Equation 4-4. For example, the attenuated 1/4 T fluence for 32 EFPY is:

$$f_{1/4\ T} = 5.1\text{x}10^{18}\ e^{-0.24(5.06/4)}$$

$$f_{1/4\ T} = 3.8\text{x}10^{18}\ \text{n/cm}^2 \text{ at 32 EFPY.}$$

Table 4-1

DETERMINATION OF LIMITING BELTLINE MATERIAL

Material Identification	%Cu	%Ni	Chemistry Factor	Initial RT_{NDT}	σ_I	ΔRT_{NDT} [a]	Margin	ART
Plates:								
1-14	0.17	0.58	125.3	0°F	0°F	92.1°F	34°F	126.1°F
1-15	0.17	0.58	125.3	14°F	0°F	92.1°F	34°F	140.1°F
1-16	0.14	0.56	98.2	0°F	0°F	72.2°F	34°F	106.2°F
1-17	0.17	0.50	118.5	6°F	0°F	87.1°F	34°F	127.1°F
Welds:								
Limiting Case	0.10 [b]	0.99	134.9	-65.6°F	12.7°F	99.1°F	61.5°F	95.0°F

a ΔRT_{NDT} values computed for a 32 EFPY fluence at the vessel inside surface of 5.1×10^{18} n/cm² (3.8×10^{18} n/cm² at 1/4 T).

b Cu limit accepted by NRC in correspondence following surveillance weld chemical analysis.

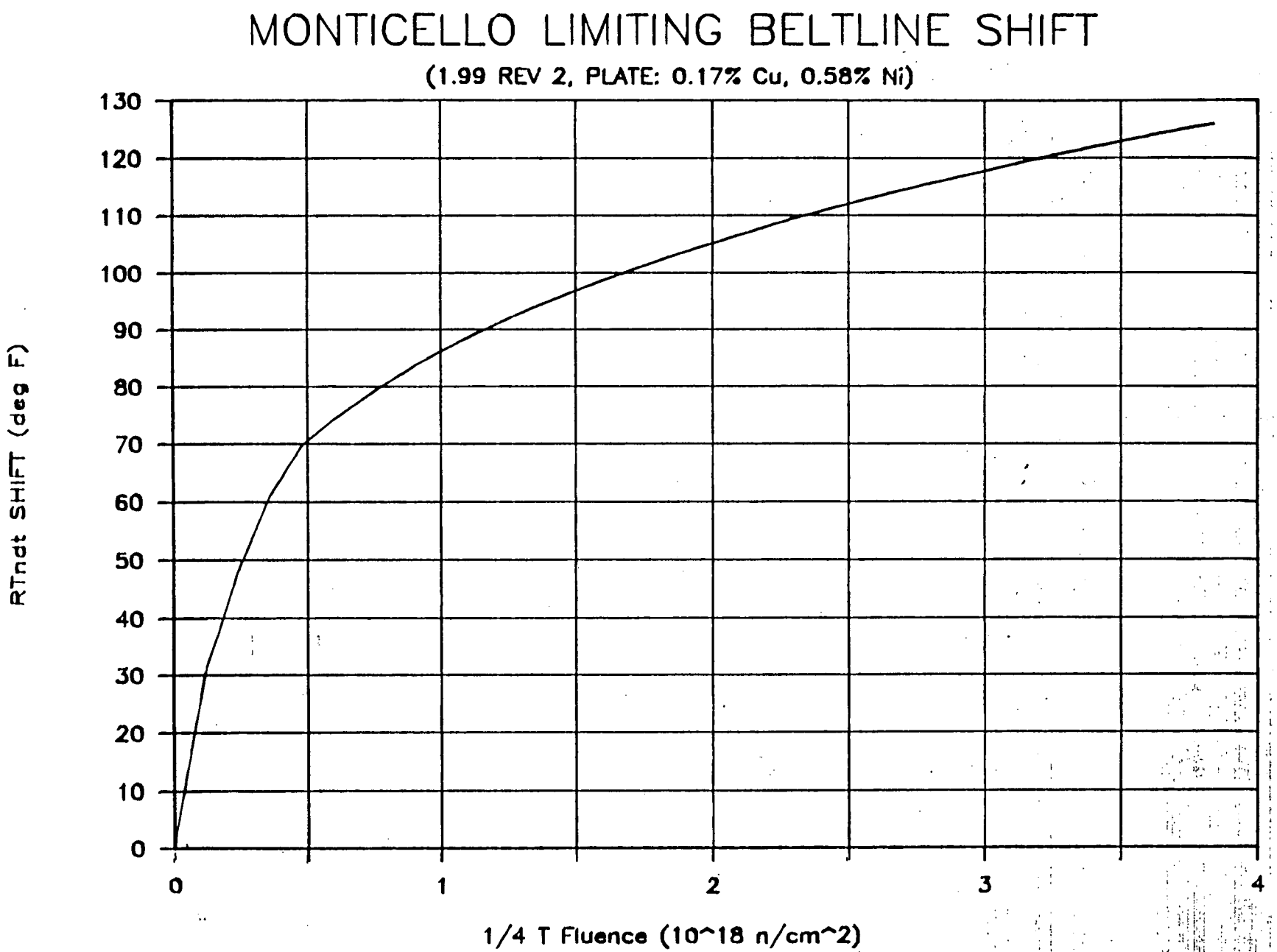


Figure 4-1. Irradiation Shift Adjustment for Core Beltline

5.0 PRESSURE-TEMPERATURE CURVES

The pressure-temperature curves used in the Monticello Technical Specification consist of two separate curves: a curve remote from the beltline and a curve for the beltline. The curves remote from the beltline are based on the feedwater nozzle limits with a RT_{NDT} of 40°F. These curves apply to all vessel regions except the beltline region, and are not affected by the changes to RT_{NDT} shift associated with Rev 2. The beltline curves apply to the plates and welds discussed in Section 4, and must be calculated taking into account the Rev 2 RT_{NDT} shifts. The P-T curve plots for Monticello are shown in Figures 5-1 through 5-3.

5.1 APPLICATION OF THE P-T CURVES

Figure 5-1 is the pressure-temperature curve for pressure tests, referred to as Curve A. Figure 5-2 is the curve for non-nuclear heatup and cooldown, called Curve B. Core critical operation is governed by the pressure-temperature limits in Figure 5-3, called Curve C. The beltline region curves are calculated according to Appendix G of ASME Code Section III, assuming a 1/4 T flaw. The beltline values correspond to the initial, or zero EFPY, plate properties (RT_{NDT} = 14°F). The actual beltline limits for a given period of operation are determined by adding the appropriate shift from Figure 4-1, based on Rev 2, to the beltline P-T curves.

The vessel operating limits are determined as the combination of beltline and non-beltline limits that result in the highest temperature for a given pressure. For a leak test at 1000 psig, the non-beltline temperature of 162°F is no longer governing compared to the shifted beltline curve. Assuming that Monticello has accumulated about 12 EFPY of operation, the leak test temperature, based on the beltline curve, is 95°F + 96°F Shift = 191°F.

5.2 BOTTOM HEAD MONITORING DURING PRESSURE TESTS

While the beltline curves are limiting for pressure test conditions, the non-beltline limits can still be applied to the bottom head region. It is likely that, during leak and hydrostatic pressure testing, the bottom head temperature may be significantly cooler than the higher elevations of the vessel. This condition can occur when the recirculation pumps are operating at low speed, or are off, and injection through the control rod drives is used to pressurize the vessel.

Monitoring the bottom head separately from the beltline region may reduce the required pressure test temperature by as much as 20°F to 30°F. Some hypothetical temperatures demonstrating the potential benefit of separate bottom head monitoring are shown in Figure 5-4. The Technical Specifications currently require that <u>all</u> vessel temperatures be above the limiting conditions on the P-T curve. That would mean the bottom head would have to be heated above 191°F at 12 EFPY, as shown in case (a) of Figure 5-4. The bottom head temperature reading would likely be the limiting reading on the vessel during the test. If the required temperature for the bottom head were only 162°F, the limiting reading would probably be near the beltline, as shown in case (b), and the actual vessel temperatures could be lowered compared to case (a).

One condition on monitoring the bottom head separately is that it must be demonstrated that the vessel beltline temperature can be monitored during pressure testing. An experiment has been conducted at a BWR/4 which showed that thermocouples on the vessel near the feedwater nozzles, or temperature measurements of recirculation pump inlet water provide good estimates of the beltline temperature during pressure testing. NSP may need to confirm this before implementing separate monitoring of the bottom head.

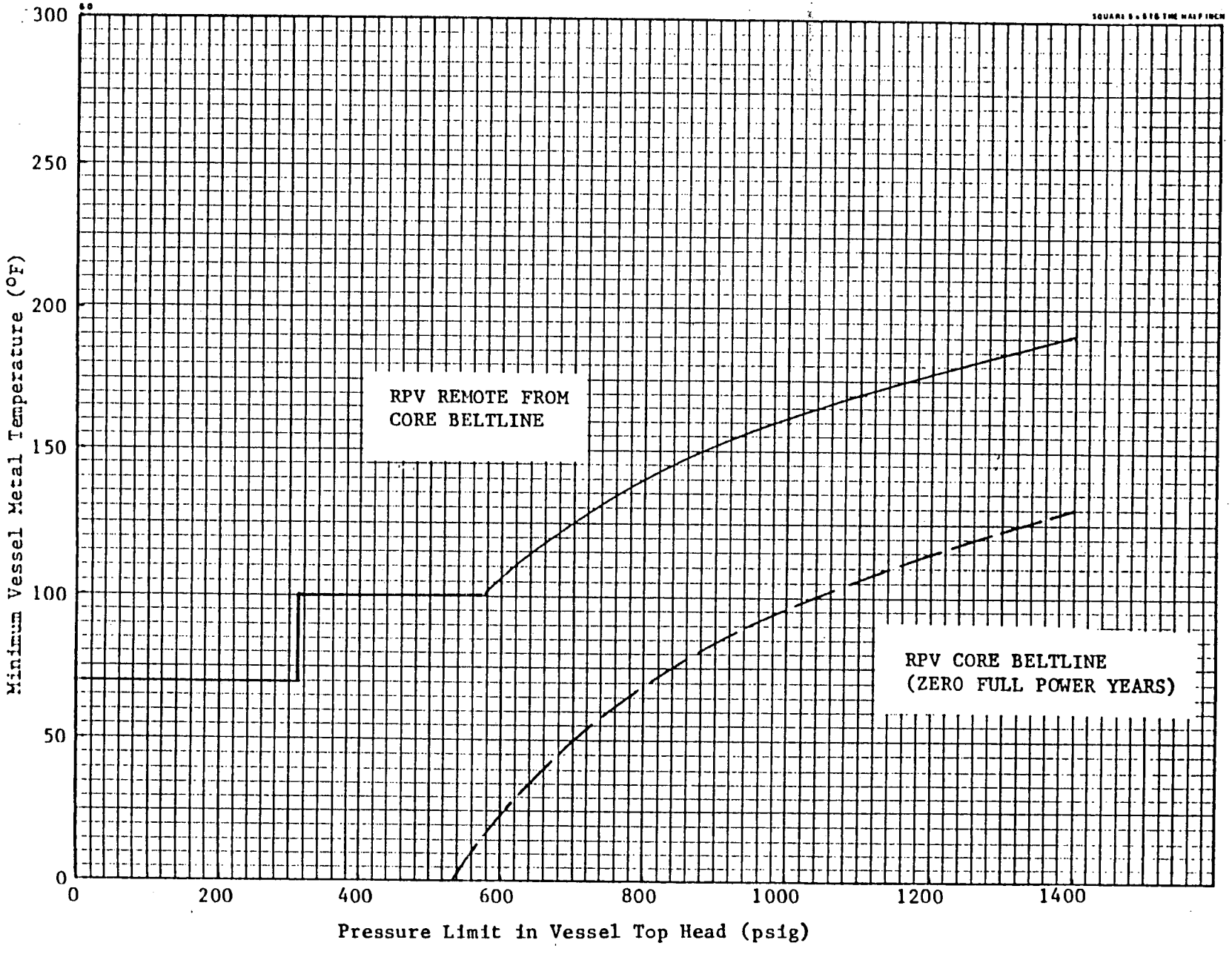


Figure 5-1. Minimum Temperature versus Pressure for Pressure Tests

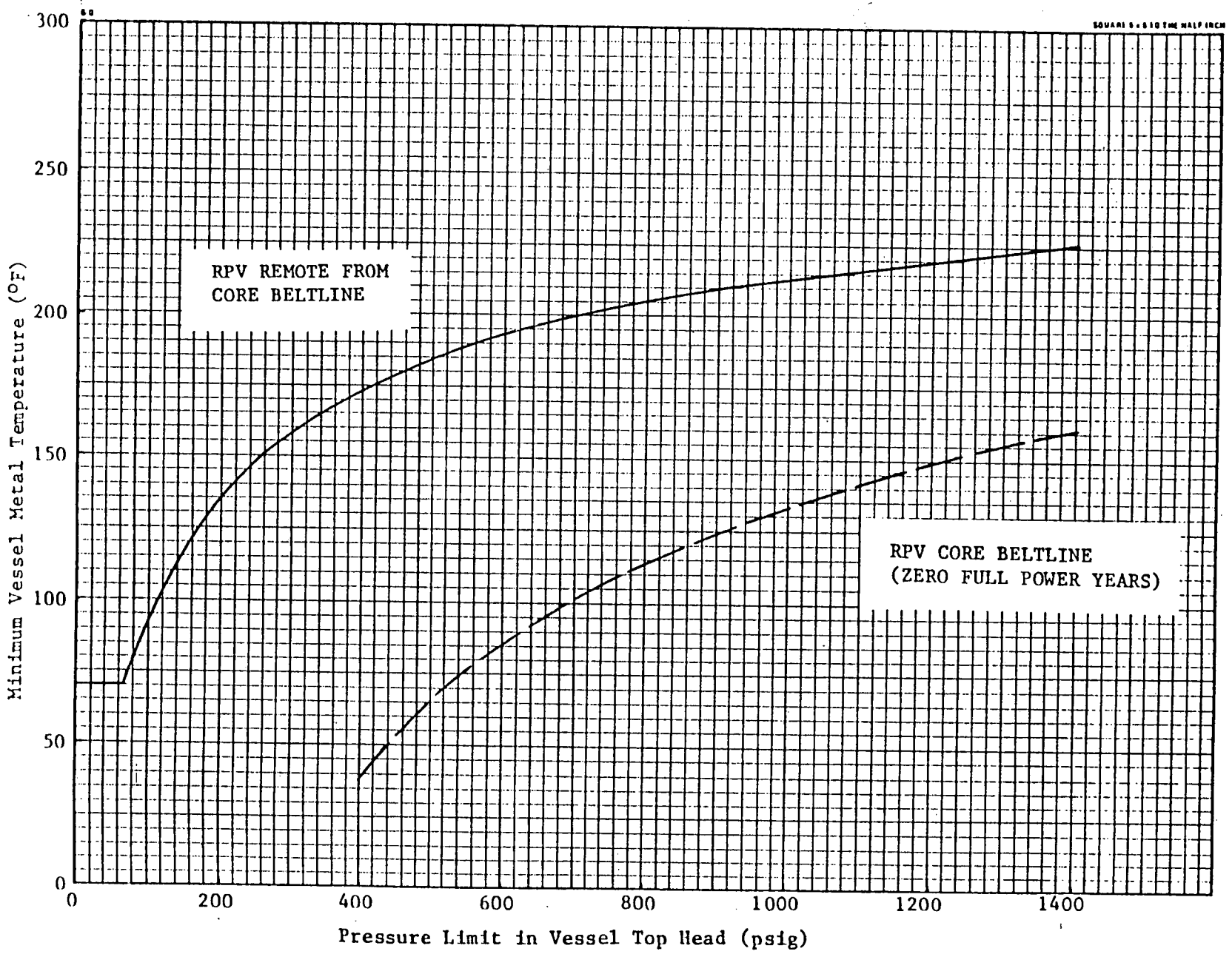


Figure 5-2. Minimum Temperature versus Pressure for Non-Nuclear Heatup or Cooldown

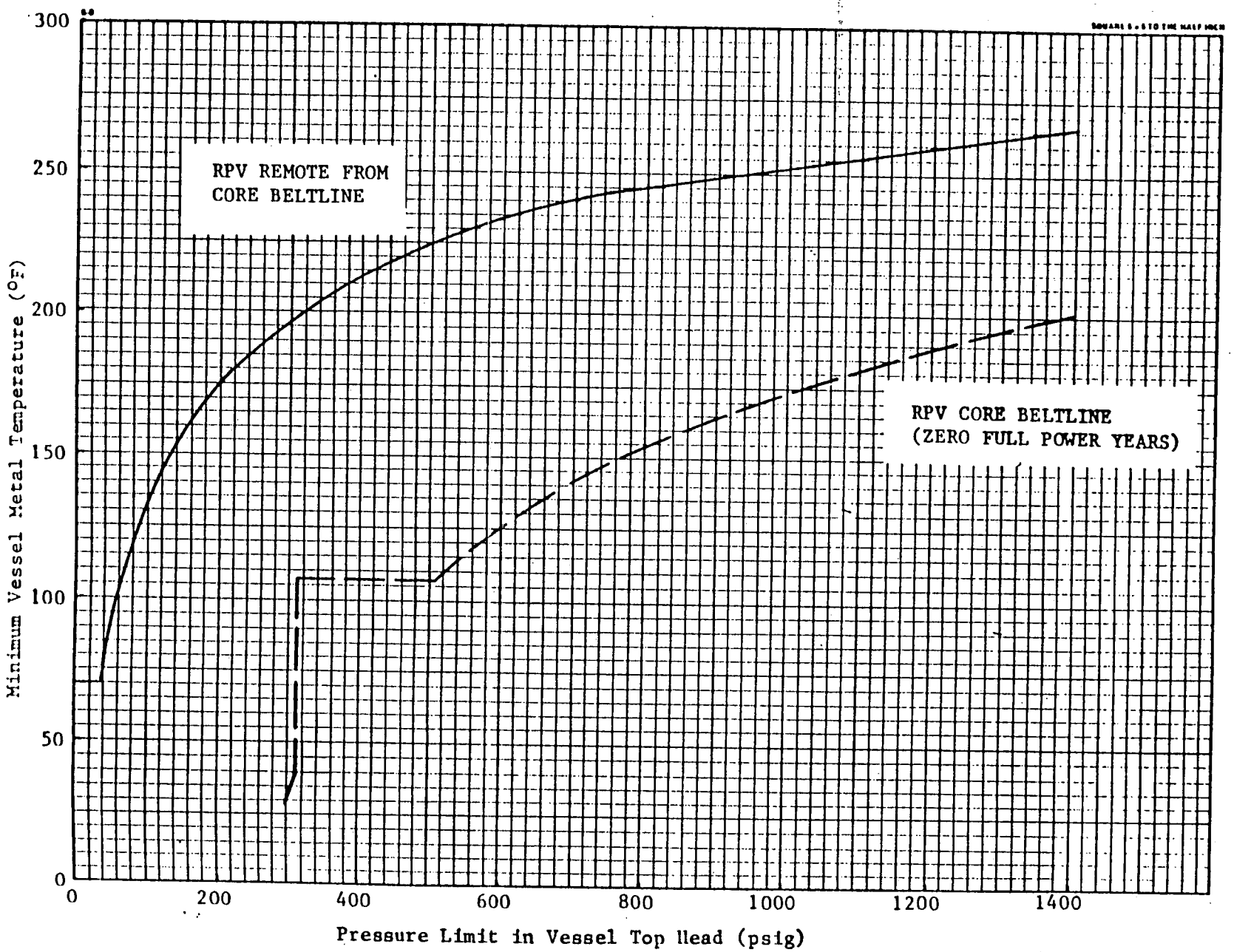
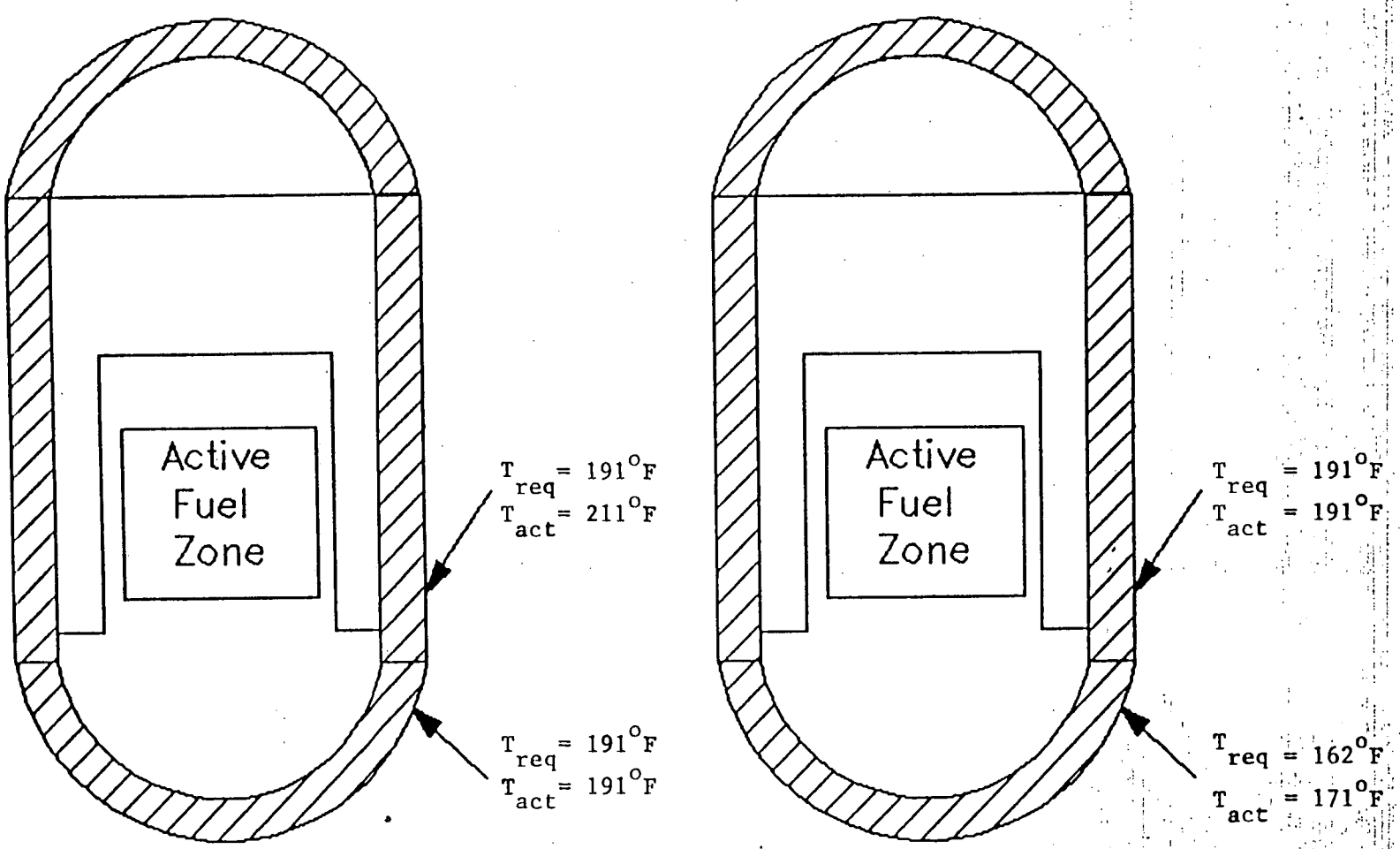


Figure 5-3. Minimum Temperature versus Pressure for Core Critical Operation



a) Bottom Head Monitored by Beltline Limits

b) Bottom Head Monitored Separately from Beltline

Figure 5-4. Schematic of Hypothetical Case Showing Reduction of Pressure Test Temperature as a Result of Separate Bottom Head Monitoring

6.0 REFERENCES

6-1 "Monticello Nuclear Generating Plant Final Safety Analysis and Technical Specifications Revised to 10CFR50 Appendix G, 1983," General Electric Company, September 1984.

6-2 "Monticello Nuclear Generating Plant Information on Reactor Vessel Material Surveillance Program," GE Report NEDO-24197, Revision 1, October 1979.

6-3 "Revision of Pressure-Temperature Curves to Reflect Improved Beltline Weld Toughness Estimate for the Monticello Nuclear Generating Plant," GE Report SASR 87-61, Revision 1, December 1987.

6-4 Hodge, J.M., "Properties of Heavy Section Nuclear Reactor Steels," Welding Research Council Bulletin 217, July 1976.

6-5 "Examination, Testing and Evaluation of Irradiated Pressure Vessel Surveillance Specimens from the Monticello Nuclear Generating Plant," Battelle Columbus Laboratories Report BCL-585-84-2, Revision 1, November 1984.

APPENDIX A

SUGGESTED REVISION TO THE UPDATED FINAL SAFETY ANALYSIS REPORT

Subsection 4.2.3.2 of the Monticello Updated Final Safety Analysis Report (UFSAR) should be replaced with the text in this Appendix. Revisions of this text from the version in [6-3] are indicated with revision bars in the margin. Pagination of the UFSAR should be changed to accommodate this revision.

4.2.3.2 Fracture Toughness of Reactor Pressure Vessel

4.2.3.2.1 Compliance with 10CFR50 Appendix G, May 1983

A major condition necessary for full compliance to Appendix G is satisfaction of the requirements for the Summer 1972 Addenda to Section III of the ASME Code. This is not possible with components which were purchased to earlier Code requirements. (The Monticello reactor pressure vessel (RPV) was manufactured to the 1965 Edition of the ASME Code, to and including the Summer 1966 Addenda.)

Ferritic materials complying with 10CFR50 Appendix G must have both drop weight tests and Charpy V-Notch (CVN) tests with the CVN specimens oriented transverse to the principal material working direction to establish the reference temperature RT_{NDT}. The CVN tests must be evaluated against both an absorbed energy and a lateral expansion criteria. The maximum acceptable RT_{NDT} must be determined in accordance with the analytical procedures of the ASME Code Section III, Appendix G. Appendix G of 10CFR50 requires a minimum of 75 ft-lbs upper shelf CVN energy for unirradiated beltline materials, and at least 50 ft-lbs upper-shelf CVN energy at the end-of-life. It also requires at least 45 ft-lbs CVN energy and 25 mils lateral expansion for bolting material at the lower of the preload or lowest service temperature.

By comparison, materials for the Monticello RPV were qualified by drop weight tests and/or longitudinally oriented CVN tests (both not required), generally at only one temperature, confirming that the material nil-ductility transition temperature (NDT) is at least 60°F below the lowest service temperature. There was no upper-shelf CVN energy requirement on the Monticello beltline materials. The bolting material was qualified to a 30 ft-lb CVN energy requirement at 60°F below the minimum preload temperature.

From the above comparison it can be seen that the fracture toughness testing performed on the Monticello RPV material cannot be shown to comply directly with 10CFR50 Appendix G. However, to determine operating limits in accordance with 10CFR50 Appendix G, estimates of the beltline materials RT_{NDT} values and the highest RT_{NDT} values of all other materials were made, as explained in Paragraph 4.2.3.2.1.1. The method for developing these operating limits is described in Paragraph 4.2.3.2.1.2. On the basis of the last paragraph on page 19013 of the July 17, 1973 Federal Register, the following is considered an appropriate method of compliance.

4.2.3.2.1.1 Method of Compliance

The intent of the proposed special method of compliance with Appendix G of the ASME Code is to provide operating limitations on pressure and temperature based on fracture toughness. These operating limits assure that a margin of safety against a non-ductile failure of this vessel is essentially the same as a vessel built to the Summer 1972 Addenda.

The specific temperature limits for operation are based on 10CFR50, Appendix G, May 1983.

4.2.3.2.1.2 Methods of Obtaining Limits Based on Fracture Toughness

Operating limits which define minimum metal temperatures versus reactor pressure during normal heatup and cooldown, and during inservice hydrostatic testing, were established using the methods of Appendix G of Section III of the ASME Boiler and Pressure Vessel Code, up to and including the Summer 1976 Addenda.

The vessel and discontinuities such as the RPV flanges, nozzles and bottom head penetrations were evaluated and the operating limit curves are based on the limiting location. The boltup limits for the flange and adjacent shell regions are based on a minimum metal temperature of RT_{NDT} + 60°F. The maximum through-wall temperature gradient from

continuous heating and cooling at 100°F per hour was considered. The safety factors were as specified in the ASME Code Appendix G.

For the purpose of setting these operating limits the reference temperature, RT_{NDT}, was determined from the toughness test data taken in accordance with requirements of the Code and the General Electric RPV purchase specification to which the Monticello RPV was designed and manufactured. These toughness test data, Charpy V-Notch (CVN) and/or dropweight nil ductility transition temperature (NDT) were analyzed to establish compliance with the intent of 10CFR50 Appendix G. Because all toughness testing needed for strict compliance with Appendix G was not required at the time of RPV procurement, some toughness results are not available. For example, longitudinal CVNs, instead of transverse, were tested, usually at a single test temperature of +10°F or +40°F, and only against an absorbed energy criteria. Also, at the time, either CVN or drop-weight testing was permitted; therefore, in some cases both tests were not performed as is currently required. To substitute for this absence of certain data, toughness property correlations were derived for the vessel materials in order to operate upon the available data to give a conservative estimate of RT_{NDT}, compliant with the intent of 10CFR50 Appendix G criteria.

These toughness correlations vary, depending upon the specific material analyzed, and were derived from the results of WRC Bulletin 217, "Properties of Heavy Section Nuclear Reactor Steels", and from toughness data for other BWR reactors. In the case of vessel plate material (SA-533 Grade B, Class 1), the predicted limiting toughness property is either NDT or transverse CVN 50 ft-lb temperature minus 60°F, whichever is greater.

As a matter of practice where NDT results are missing, NDT is estimated as the longitudinal CVN 35 ft-lb transition temperature. However, for the Monticello vessel plates, "no break" dropweight information was available at GE specified temperatures, so the nil ductility transformation temperature was conservatively taken as 10 degrees below the "no break" test temperature. The transverse CVN

50 ft-lb transition temperature was estimated from longitudinal CVN data in the following manner. The lowest longitudinal CVN ft-lb values was adjusted to derive a longitudinal CVN 50 ft-lb transition temperature by adding 2°F per ft-lb to the test temperature. If the actual data equalled or exceeded 50 ft-lb, the test temperature was used. Once the longitudinal 50 ft-lb temperature was derived, an additional 30°F was added to account for the orientation change from longitudinal 50 ft-lb to transverse 50 ft-lb. For forgings (SA-508 Class 2), the predicted limiting property is the same as for vessel plates, and the RT_{NDT} was estimated in the same way.

For the vessel weld metal the predicted limiting property is the CVN 50 ft-lb transition temperature minus 60°F, as GE experience indicates the dropweight NDT values are typically -50°F, or lower for these materials. The CVN 50 ft-lb temperature would be derived in the same way as for the vessel plate material, except the 30°F addition for orientation effects was omitted since there is no principal working direction in weld metal. If NDT values were available, they would also be considered and the RT_{NDT} would be taken as the higher of NDT or the 50 ft-lb transition temperature minus 60°F. However, no data, either Charpy or dropweight, were available on the fracture toughness of the specific weld materials used in the Monticello RPV. The weld rod supplier, Alloy Rods Corporation, provided RT_{NDT} data for E8018NM weld metal, which was used to determine a statistically conservative estimate of the beltline weld RT_{NDT}. The data showed a mean RT_{NDT} of -65.6°F, with a standard deviation of 12.7°F.

For vessel weld heat affected zone (HAZ) material the RT_{NDT} was assumed the same as for the base material as ASME Code weld procedure qualification test requirements and post weld heat treatment indicate this assumption is valid.

Original closure bolting material (SA-540 Grade B24) toughness test requirements were for 30 ft-lb at 60°F below the boltup temperature. Current 10CFR50 Appendix G requirements are for 45 ft-lb and 25 mil lateral expansion (MLE) at the preload or lowest service temperature, including boltup. All closure stud materials meet 45 ft-lb absorbed

energy at +10°F but mils lateral expansion results were not reported. Since total compliance with current requirements could not be shown, the original requirements were used to establish the boltup temperature. The purchase agreement for Monticello closure stud material was for 30 ft-lb at +10°F, and no deviations were reported.

4.2.3.2.1.3 Calculated Values of Initial RT_{NDT}

The methods of Subsection 4.2.3.2.1.2 were used to calculate initial RT_{NDT} values for the core beltline plates and welds, closure flange region, nozzles and other discontinuities, and closure bolting material. The calculation methods conservatively estimate RT_{NDT}, in order to meet the intent of 10CFR50 Appendix G criteria.

The core beltline plate and weld RT_{NDT} values are presented in Table 4.2.3.2-1. Regulatory Guide 1.99, Revision 2 requires that the standard deviation σ_I be estimated for each beltline material. For the beltline welds, σ_I is estimated from the data set evaluation performed. For the beltline plates, actual measured values from each plate in question were obtained, and a conservative method of determining RT_{NDT} from that data was used. Therefore, σ_I for the beltline plates is estimated to be 0°F.

Adjusted CVN data for the closure flanges and adjacent plates gave an RT_{NDT} of +10°F. Based on the NDT requirement in the purchase agreement, the RT_{NDT} of the welds at the closure flanges was +10°F also. Calculations for the nozzles and discontinuities gave an RT_{NDT} of +40°F based on purchase agreement NDT requirements. The closure bolting material RT_{NDT} used was +10°F, based on the purchase agreement NDT requirement.

4.2.3.2.1.4 Effect of Nozzles and Discontinuities on Operating Limits

The minimum temperature for boltup and pressurization was established by adding 60°F to the RT_{NDT} for the closure flange region, the critical location during boltup.

The 60°F temperature added for boltup, a requirement of the ASME Code applicable to the original Monticello design work, provides 60°F margin not required by 10CFR50 Appendix G for boltup and pressurization up to 20% of the system hydrostatic test pressure. Above 20% test pressure, 10CFR50 Appendix G, Paragraph IV.A.2 requires the closure flange region to be 90°F above RT_{NDT} for hydrostatic pressure tests and leak tests, 120°F above RT_{NDT} for normal operation, and 160°F above RT_{NDT} when the core is critical. The 90°F requirement is met by adding 30°F at 20% test pressure to the 60°F boltup margin. The temperatures required at 10% test pressure for non-nuclear heatup and cooldown and core critical operation exceed the respective 120°F and 160°F margins required by 10CFR50 Appendix G.

The effect of the nozzle and bottom head discontinuities was considered by adjusting the results of BWR/6 reactor discontinuity analyses to the Monticello reactor. The adjustment was made by increasing the minimum temperatures required by the difference between the Monticello and BWR/6 RT_{NDT} values. The nozzle and bottom head adjustments were based on an RT_{NDT} of +40°F.

4.2.3.2.2 Pressure Temperature Limits

4.2.3.2.2.1 Limit Curves

The basis for setting operational limits on pressure and temperature for normal, upset and test conditions for the RPV is described in Section 4.2.3.2.1.2.

The fracture toughness analysis was done for the normal heatup or cooldown rate of 100°F/hour and it also included the effects of cold water injections into the nozzles and other operation transients. The temperature gradients and thermal stress effects are included. The results of the analyses are a set of operating limits on Figure 4.2.3.2-1, including pressure testing (curves labeled A), non-nuclear heatup or cooldown (curves labeled B) and core critical operation (curves labeled C).

4.2.3.2.2.2 Temperature Limits for Boltup

A minimum temperature of 70°F is required for the closure studs. A sufficient number of studs may be tensioned at 70°F to seal the closure flange O-rings for the purpose of raising reactor water level about the closure flanges in order to assist in warming them. The flanges and adjacent shell are required to be warmed to minimum temperatures of 70°F before they are stressed by the full intended bolt preload. The fully preloaded boltup limits are shown in Figure 4.2.3.2-1.

4.2.3.2.3 Irradiation Effects

Estimated maximum changes in RT_{NDT} for 32 effective full power years (EFPY) of fluence at the one-quarter thickness (1/4 T) depth of the vessel beltline materials are shown in Table 4.2.3.2-1. The updated predicted peak 32 EFPY fluence at the 1/4 T depth of the RPV beltline, based on the methods in Regulatory Guide 1.99, Revision 2, is 3.8×10^{18} n/cm^2. Irradiation shifts, including Margin, were calculated in accordance with the rules of Regulatory Guide 1.99, Revision 2. Results show that beltline plate 1-15 is limiting through 32 EFPY. Since predicted adjusted reference temperatures (ART) are less than 200°F, provisions to permit thermal annealing of the RPV in accordance with Paragraph IV.B of 10CFR50 Appendix G is not required.

The predicted 32 EFPY shift in RT_{NDT} for plate 1-15, shown in Figure 4.2.3.2-2 (based on the neutron fluence at 1/4 of the vessel wall thickness) was added to the core beltline limits to arrive at the curves A′, B′ and C′ in Figure 4.2.3.2-1. The predicted shift in the core beltline RT_{NDT} shown in Figure 4.2.3.2-2 is based on the results of flux wire measurements of fluence versus full power years of operation together with the relationships between fluence and Cu and Ni given in Regulatory Guide 1.99, Revision 2.

4.2.3.2:4 Operating Procedures

By comparison of the pressure versus temperature limits in Paragraph 4.2.3.2.2 above, with intended normal operating procedures for the most severe upset transient, it is shown that the limits will not be exceeded during any foreseeable upset condition. Reactor operating procedures have been established such that actual transients will not be more severe than those for which the vessel design adequacy has been demonstrated. Of the design transients, the upset condition producing the most adverse temperature and pressure condition anywhere in the vessel head and/or shell areas yields a minimum fluid temperature of 250°F and a maximum pressure peak of 1180 psig. Scram automatically occurs with initiation of this event, prior to the reduction in the fluid temperature, so the applicable operating limits are given by Figure 4.2.3.2-1 Curves A. For a temperature of 250°F, the maximum allowable pressure exceeds 1300 psig for the intended margin against non-ductile failure. The maximum transient pressure of 1180 psig is therefore within the specified allowable limits.

Table 4.2.3.2-1

DETERMINATION OF LIMITING BELTLINE MATERIAL

Material Identification	%Cu	%Ni	Chemistry Factor	Initial RT_{NDT}	σ_I	ΔRT_{NDT} [a]	Margin	ART
Plates:								
1-14	0.17	0.58	125.3	0°F	0°F	92.1°F	34°F	126.1°F
1-15	0.17	0.58	125.3	14°F	0°F	92.1°F	34°F	140.1°F
1-16	0.14	0.56	98.2	0°F	0°F	72.2°F	34°F	106.2°F
1-17	0.17	0.50	118.5	6°F	0°F	87.1°F	34°F	127.1°F
Welds:								
Limiting Case	0.10 [b]	0.99	134.9	-65.6°F	12.7°F	99.1°F	61.5°F	95.0°F

[a] ΔRT_{NDT} values computed for a 32 EFPY fluence at the vessel inside surface of 5.1×10^{18} n/cm² (3.8×10^{18} n/cm² at 1/4 T).

[b] Cu limit accepted by NRC in correspondence following surveillance weld chemical analysis.

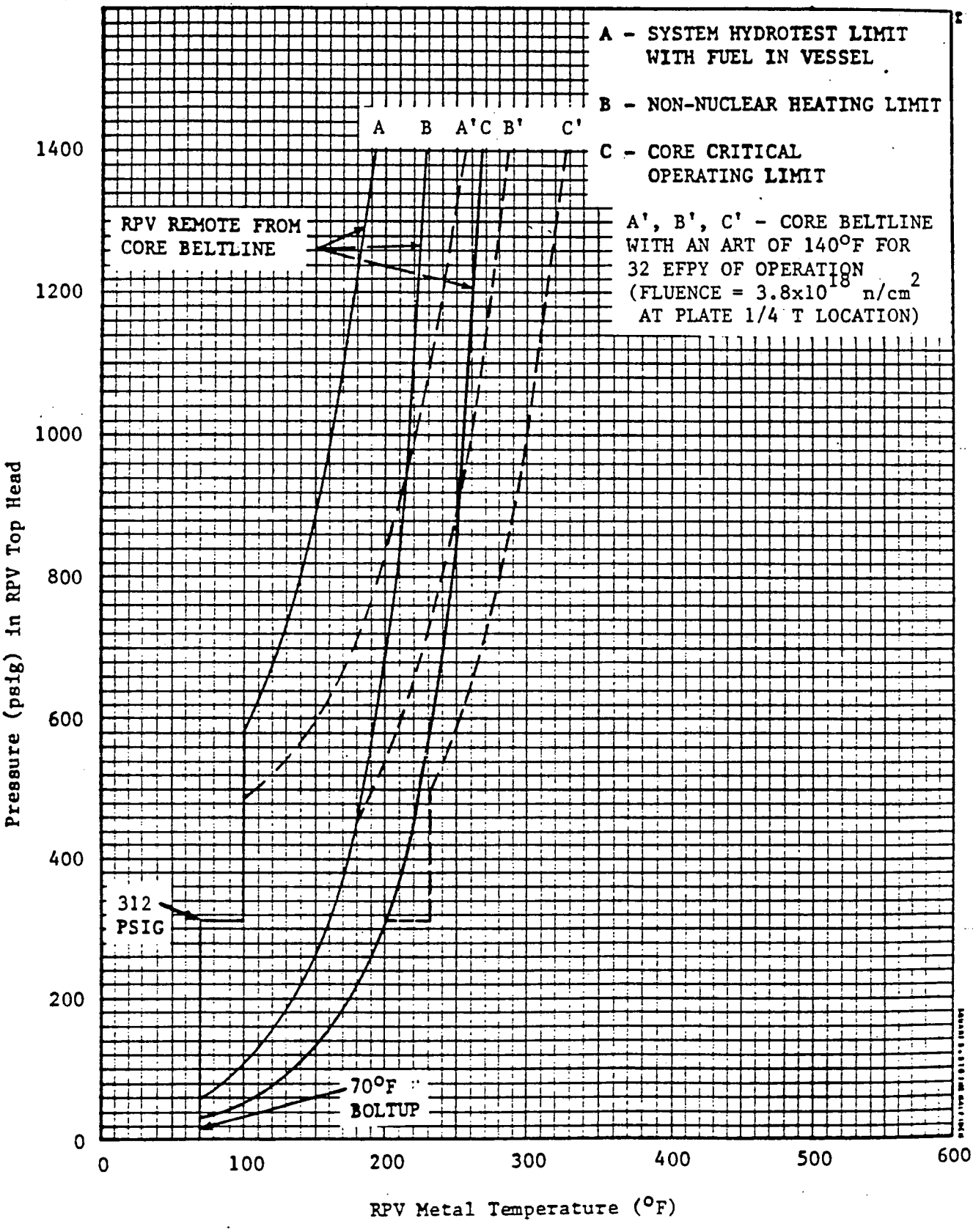


Figure 4.2.3.2-1 Reactor Pressure versus Minimum Required Temperature

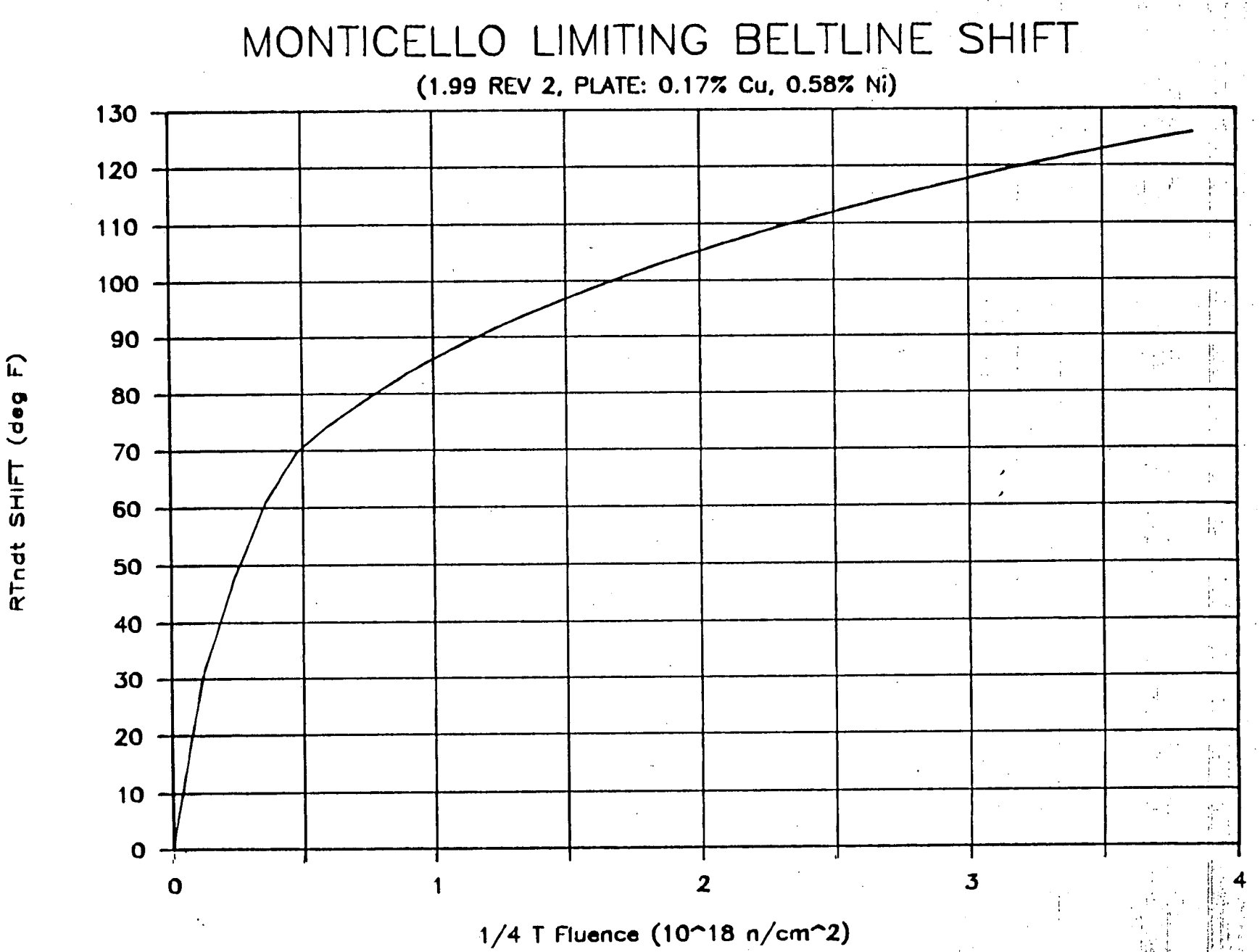


Figure 4.2.3.2-2 Core Beltline Operating Limits Curve Adjustment vs. Fluence

APPENDIX B

SUGGESTED REVISION TO THE TECHNICAL SPECIFICATION

The following listed technical specification changes are recommended for Monticello.

Tech Spec Page(s)	Replacement Text
122	B-2
133 through 136	B-3 through B-6

Revisions to the text are indicated by margin bars. Figure 3.6.1 has been revised to reflect the shift relationship presented in this report. Figures 3.6.2 through 3.6.4 are unchanged from the curves presented in [6-3], but are included in this appendix for information. The current technical specification pagination and figure designation should be revised, if necessary.

3.6 LIMITING CONDITIONS FOR OPERATION

B. Reactor Vessel Temperature and Pressure

1. During in-service hydrostatic or leak testing, the reactor vessel shell temperatures specified in 4.6.B.1, except for the reactor vessel bottom head, shall be at or above the higher of the temperatures shown on the two curves of Figure 3.6.2 where the dashed curve, "RPV Beltline Region", is increased by the core beltline temperature adjustment from Figure 3.6.1. The reactor vessel bottom head temperature shall be at or above the temperatures shown on the solid curve of Figure 3.6.2, "RPV Remote from Core Beltline", with no adjustment from Figure 3.6.1.

2. During heatup by non-nuclear means (except with the reactor vessel vented), cooldown following nuclear shutdown, or low level physics tests the reactor vessel shell and fluid temperatures specified in 4.6.A shall be at or above the higher of the temperatures of Figure 3.6.3 where the dashed curve, "RPV Beltline Region", is increased by the core beltline temperature adjustment from Figure 3.6.1.

4.6 SURVEILLANCE REQUIREMENTS

B. Reactor Vessel Temperature and Pressure

1. During in-service hydrostatic or leak testing when the vessel pressure is above 312 psig, the following temperatures shall be recorded at least every 15 minutes:

   a. Reactor vessel shell adjacent to shell flange.

   b. Reactor vessel bottom head.

   c. Reactor vessel shell or coolant temperature representative of the minimum temperature of the beltline region.

2. Test specimens representing the reactor vessel, base weld, and weld heat affected zone metal shall be installed in the reactor vessel adjacent to the vessel wall at the core midplane level. The material sample program shall conform to ASTM E185-66. Samples shall be withdrawn at one fourth and three fourths service life. Analysis of the first sample shall include a quantitative determination of the material chemistries. (Note: Analysis of the first sample has been completed. The Figure 3.6.1 core beltline temperature adjustment curve reflects the chemistry data obtained).

3.6 LIMITING CONDITIONS FOR OPERATION
B. Reactor Vessel Temperature and Pressure

3. During all operation with a critical reactor, other than for low level physics tests or at times when the reactor vessel is vented, the reactor vessel shell and fluid temperatures specified in 4.6.A shall be at or above the higher of the temperatures of Figure 3.6.4 where the dashed curve, "RPV Beltline Region", is increased by the core beltline temperature adjustment from Figure 3.6.1.

4.6 SURVEILLANCE REQUIREMENTS
B. Reactor Vessel Temperature and Pressure

3. Neutron flux wires shall be installed in the reactor vessel adjacent to the reactor vessel wall at the core midplane level. The wires shall be removed and tested during the first refueling outage to experimentally verify the calculated value of neutron fluence at one fourth of the beltline shell thickness that is used to determine the core beltline temperature adjustment from Figure 3.6.1. (Note: this surveillance requirement has been completed and the core beltline temperature adjustment shown in Figure 3.6.1 now reflects the flux wire experimental results).

Bases 3.6 and 4.6:

A. Reactor Coolant Heatup and Cooldown

The vessel has been analyzed for stresses caused by thermal and pressure transients. Heating and cooling transients throughout plant life at uniform rates of 100°F per hour were considered in the temperature range of 100 to 546°F and were shown to be within the requirements for stress intensity and fatigue limits of Section III of the ASME Boiler and Pressure Vessel Code.

During reactor operation, the temperature of the coolant in an idle recirculation loop is expected to remain at reactor coolant temperature unless it is valved out of service. Requiring the coolant temperature in an idle loop to be within 50°F of the reactor coolant temperature before the pump is started assures that the change in coolant temperature at the reactor vessel nozzles and bottom head region are within the conditions analyzed for the reactor vessel thermal and pressure transients.

During hydrostatic pressure testing, a coolant heatup or cooldown of 20°F in any one hour period has a negligible effect on the reactor operating limits of Figure 3.6.2.

B. Reactor Vessel Temperature and Pressure

Operating limits on the reactor vessel pressure and temperature during normal heatup and cooldown and during in-service hydrostatic testing were established using 10CFR50 Appendix G, May 1983 and Appendix G of the Summer 1976 or later Addenda to Section III of the ASME Boiler and Pressure Vessel Code. These operating limits assure that a large postulated surface flaw, having a depth of 0.24 inches at the flange-to-vessel junction and one-quarter of the material thickness at all other reactor vessel locations and discontinuity regions can be safely accommodated. For the purpose of setting these operating limits the reference temperature, RT_{NDT}, of the vessel material was estimated from impact test data taken in accordance with requirements of the Code to which this vessel was designated and manufactured (1965 Edition including Summer 1966 Addenda).

Bases 3.6 and 4.6 - Continued

A General Electric Company procedure, designed to evaluate fracture toughness requirements for older plants where information may be incomplete, was used to estimate RT_{NDT} values on an equivalent basis to the new requirements for plants which have construction permits after August 15, 1973.

The fracture toughness of all ferritic steels gradually and uniformly decreases with exposure to fast neutrons above a threshold value, and it is prudent and conservative to account for this in the operation of the reactor pressure vessel. Two types of information are needed in this analysis: 1) A relationship between the changes in fracture toughness of the reactor pressure vessel steel and the neutron fluence (integrated neutron flux), and 2) A measure of the neutron fluence at the point of interest in the reactor pressure vessel wall.

The relationship of predicted adjustment of reference temperature versus fluence and the copper and nickel content of the core beltline materials given in Regulatory Guide 1.99, Revision 2, was used to define the core beltline temperature adjustment versus fluence shown on Figure 3.6.1.

A relationship between full power years of operation and neutron fluence has been experimentally determined for the reactor vessel. The vessel pressurization temperatures at any time period can be determined from the thermal energy output of the plant and Figure 3.6.1 used in conjunction with Figure 3.6.2 (pressure tests), Figures 3.6.3 (mechanical heatup or cooldown following nuclear shutdown), or Figure 3.6.4 (operation with a critical core). During the first fuel cycle, only calculated neutron fluence values were used. At the first refueling, neutron dosimeter wires which were installed adjacent to the vessel wall were removed to experimentally determine the neutron fluence versus full power years of operation. This experimental result was updated by testing additional dosimetry removed with the first surveillance capsule.

Bases 3.6 and 4.6 - Continued)

Reactor vessel material samples are provided, however, to verify the relationship expressed by Figure 3.6.1. Three sets of mechanical test specimens representing the base metal, weld metal, and weld heat affected zone (HAZ) metal have been placed in the vessel and can be removed and tested as required. An analysis and report will be submitted to the Commission on all such surveillance specimens removed from the reactor vessel in accordance with 10CFR50, Appendix H, including information obtained on the level of integrated fast neutron irradiation received by the specimens and actual vessel material.

The requirements for cold bolt-up of the reactor vessel closure are based on the RT_{NDT} temperature plus 60°F which is derived from the requirements of the ASME Boiler and Pressure Vessel Code to which the vessel was built. The RT_{NDT} temperature of the closure flanges, adjacent head and shell material, and stud material is a maximum of 10°F. The minimum temperature for bolt-up is therefore 10° + 60° = 70°F. The neutron radiation fluence at the closure flanges is well below 10^{17} n/cm^2 (E>1 MEV) and therefore radiation effects will be minor and will not influence this temperature.

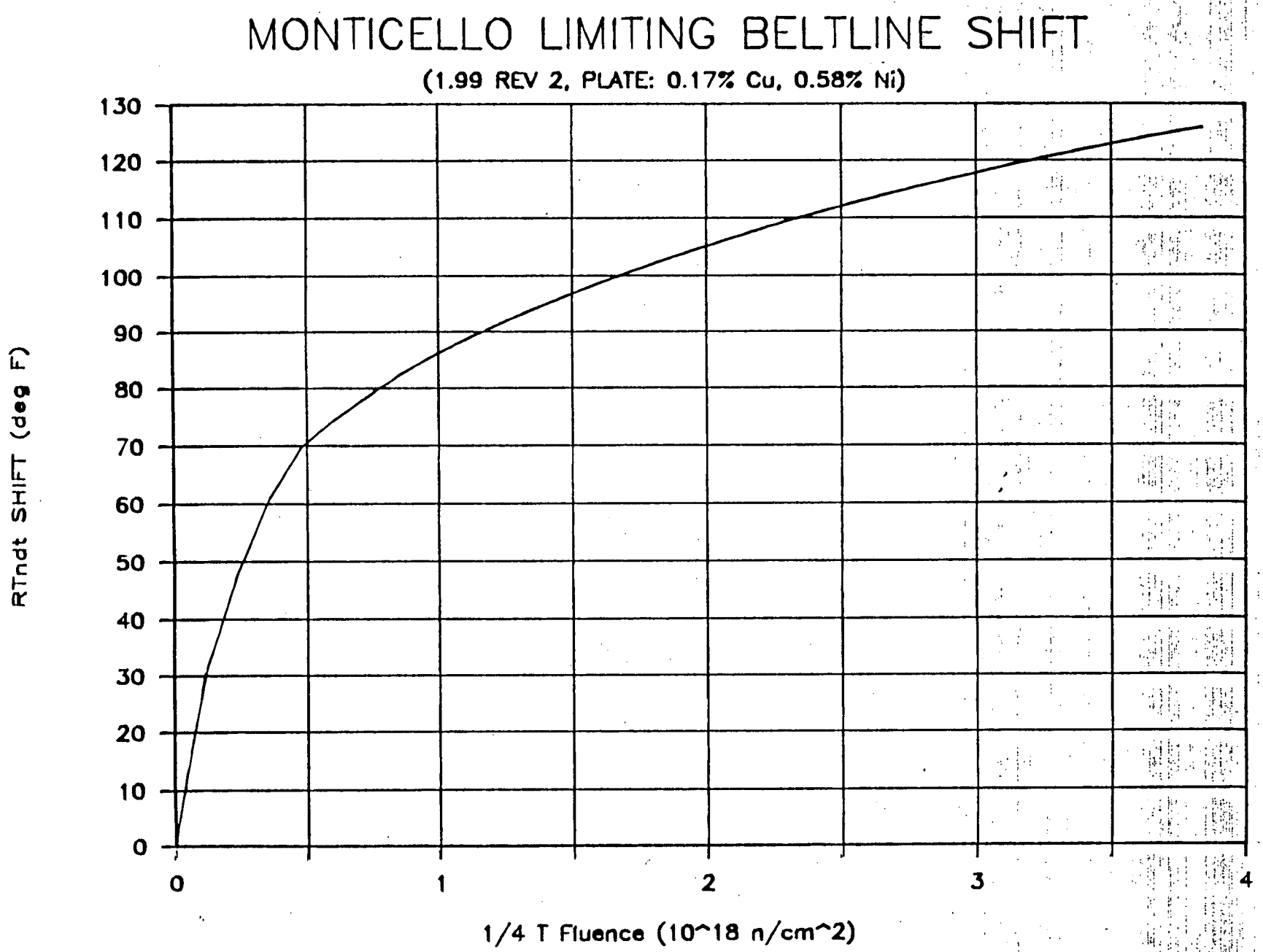


Figure 3.6.1 Core Beltline Operating Limits Curve Adjustment vs. Fluence

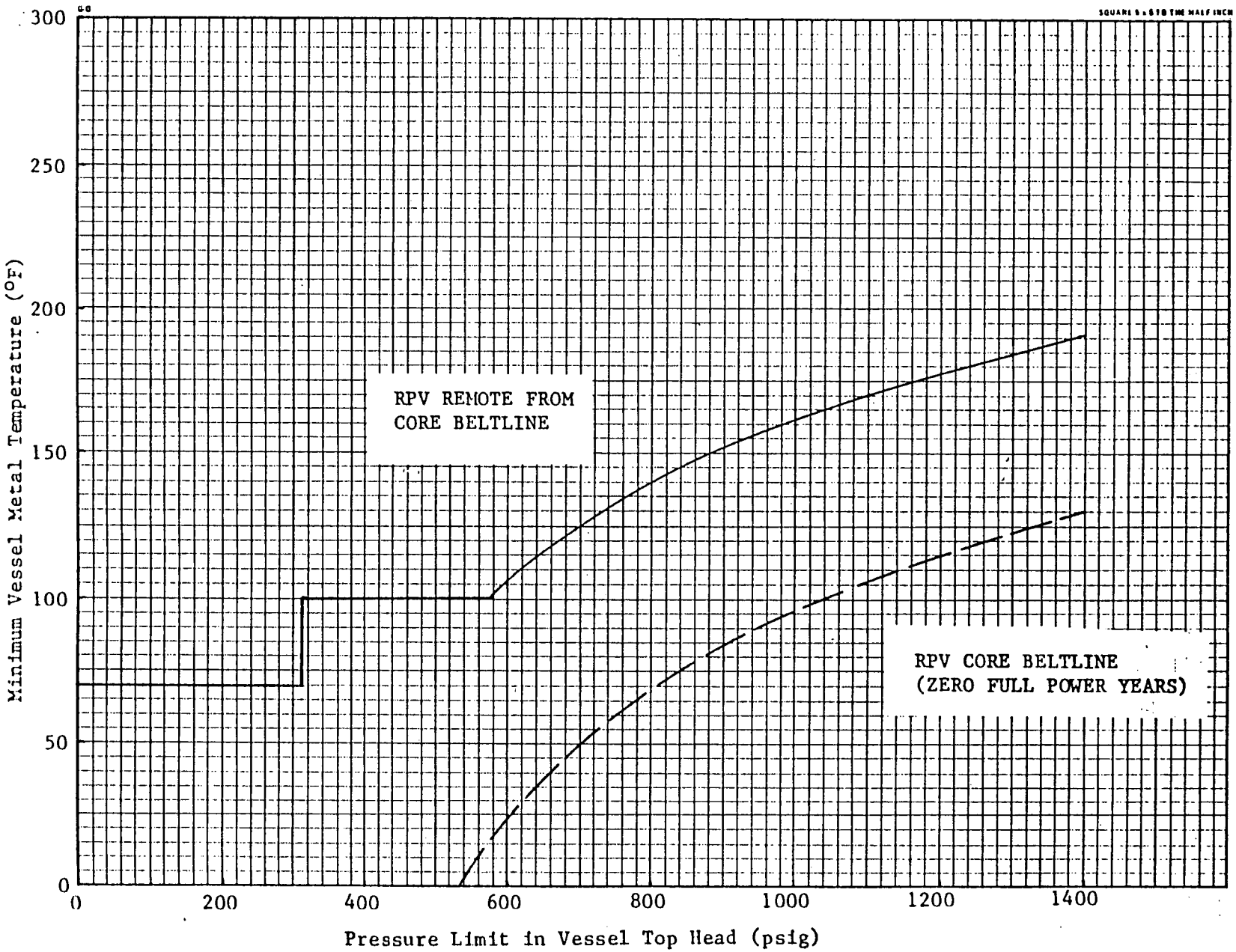


Figure 3.6.2 Minimum Temperature vs. Pressure for Pressure Tests

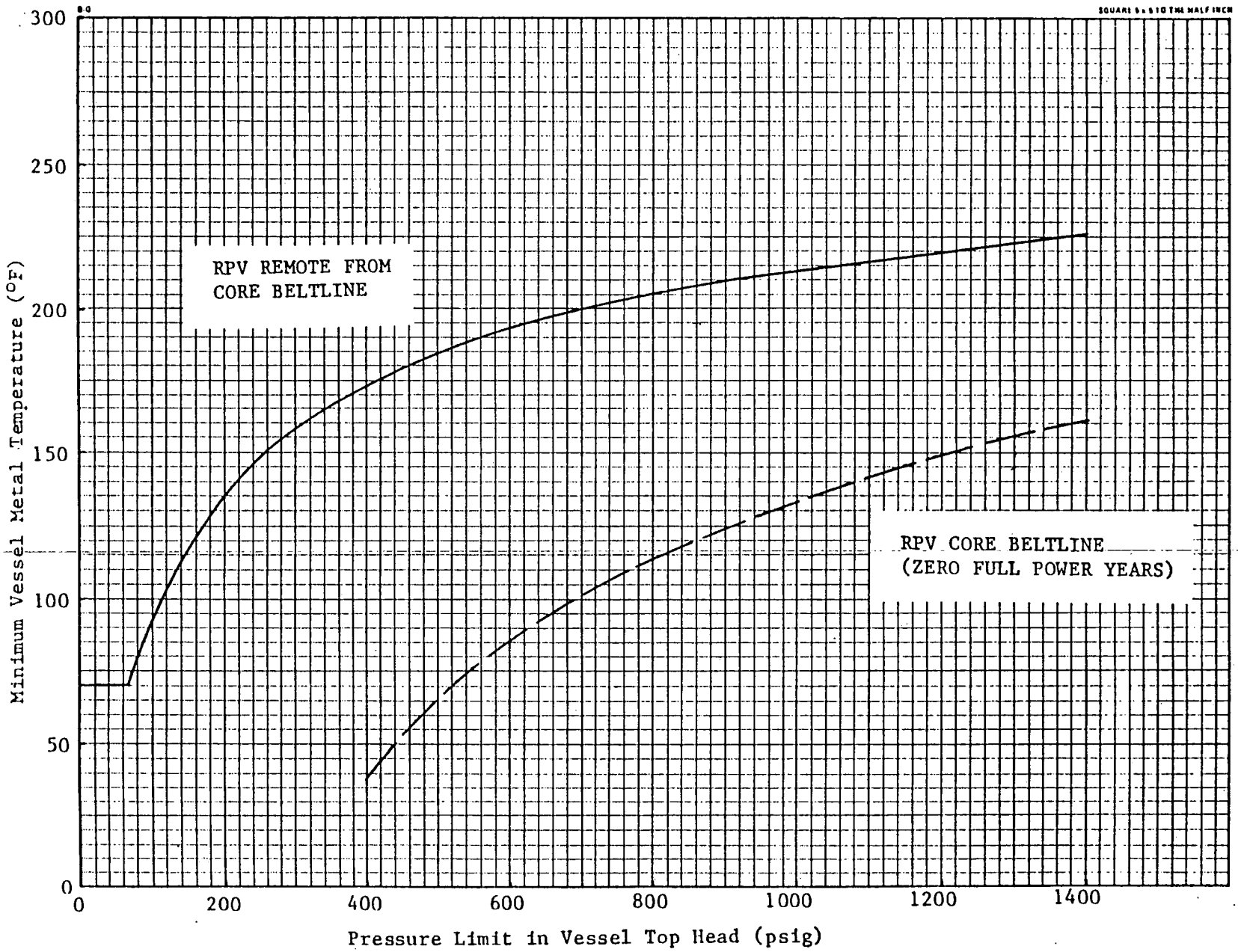


Figure 3.6.3 Minimum Temperature vs. Pressure for Mechanical Heatup of Cooldown without the Core Critical

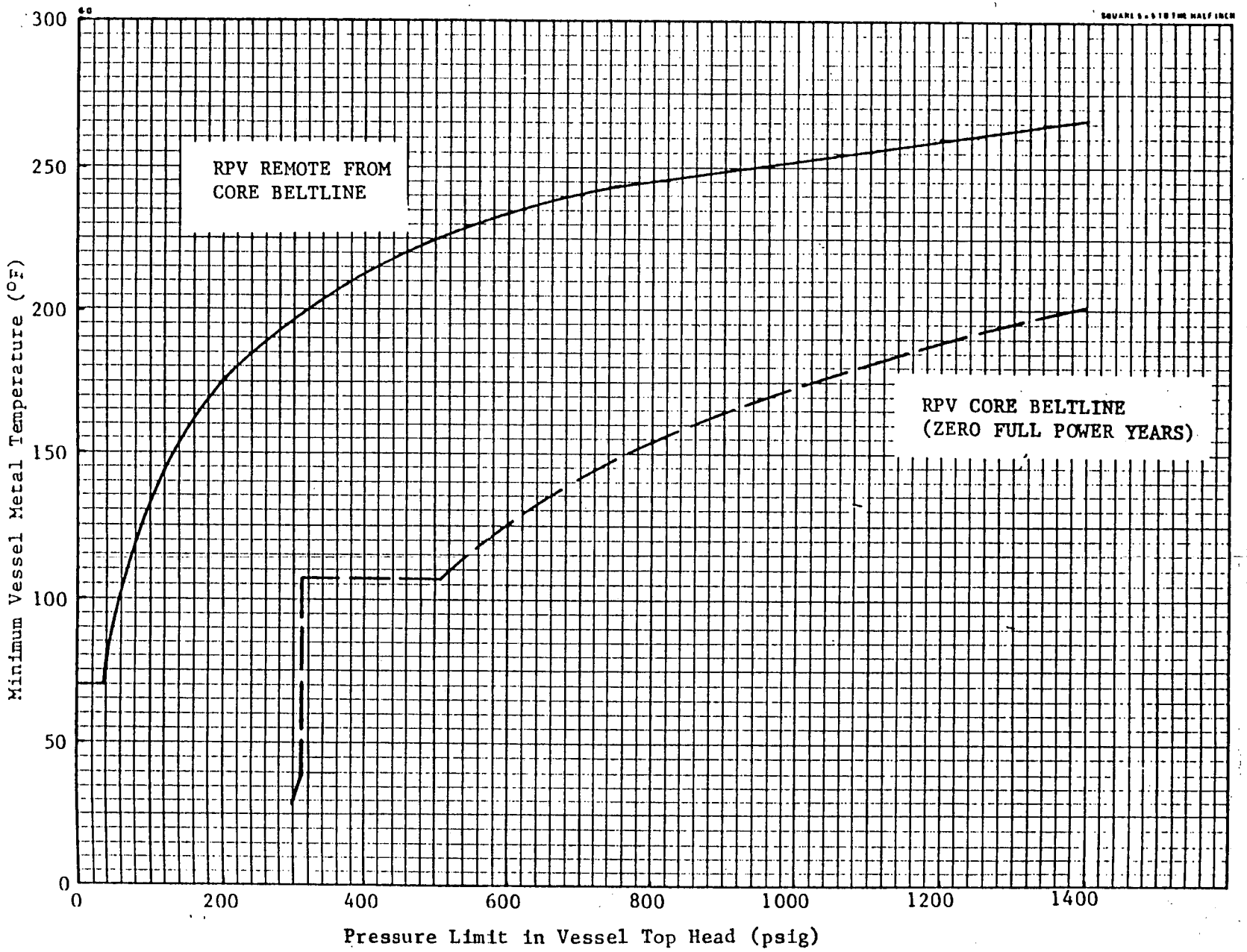


Figure 3.6.4 Minimum Temperature vs. Pressure for Core Operation

MONTICELLO