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NLS2004005
January 29, 2004

U.S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, D.C. 20555-0001

Subject: License Amendment Request to Revise Technical Specification 3.4.9 Pressure Temperature (P/T) Curves figures 3.4.9-1, 3.4.9-2, and 3.4.9-3.
Cooper Nuclear Station, Docket 50-298, DPR-46

The purpose of this letter is for the Nebraska Public Power District (NPPD) to request an amendment to Facility Operating License DPR-46 in accordance with the provisions of 10 CFR 50.4 and 10 CFR 50.90 to revise the Cooper Nuclear Station (CNS) Technical Specifications (TS). The proposed amendment would revise TS section 3.4.9 Pressure Temperature curves 3.4.9-1, 3.4.9-2 and 3.4.9-3 for Heatup/Cooldown-Core not Critical, Pressure Test and Heatup/Cooldown-Core Critical conditions. The curves are being revised to accommodate Reactor Operation to 32 Effective Full Power Years. The curves were developed in accordance with the 1995 Edition, 1996 Addenda, American Society of Mechanical Engineers (ASME) Boiler Pressure Vessel Code Section XI Appendix G, 10 CFR 50 Appendix G, and ASME Section XI Code Case N-640. Regulatory Guide 1.147, Revision 13, identifies Code Case N-640 as an NRC acceptable Section XI code case.

NPPD requests NRC approval of the proposed TS change and issue of the requested license amendment by September 30, 2004. Once approved, the amendment will be implemented within 60 days.

Attachment 1 provides a description of the TS change, the basis for the amendment, the no significant hazards consideration evaluation pursuant to 10 CFR 50.91(a)(1), and the environmental impact evaluation pursuant to 10 CFR 51.22. Attachment 2 provides the proposed changes to the current CNS TS and Bases (provided for information) on marked up pages. Attachment 3 provides the revised TS and Bases (provided for information) pages in final typed format. Enclosure 1 provides the calculations and methodology used by Structural Integrity Associates, Inc. to create the revised CNS Pressure Temperature curves.

This proposed TS change has been reviewed by the necessary safety review committees (Station Operations Review Committee and Safety Review and Audit Board). Amendments to the CNS Facility Operating License through Amendment 202 issued December 5, 2003, have been

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incorporated into this request. NPPD has concluded that the proposed change does not involve a significant hazards consideration and that it satisfies the categorical exclusion criterion of 10 CFR 51.22(c)(9). This request is submitted under oath pursuant to 10 CFR 50.30(b).

By copy of this letter and its attachments, the appropriate State of Nebraska official is notified in accordance with 10 CFR 50.91(b)(1). Copies to the NRC Region IV office and the CNS Resident Inspector are also being provided in accordance with 10 CFR 50.4(b)(1).

Should you have any questions concerning this matter, please contact Mr. Paul Fleming at (402) 825-2774.

Sincerely,

Randall K. Edington
Vice President - Nuclear and
Chief Nuclear Officer

/rar

Attachments and Enclosure

cc: Regional Administrator w/ attachments and enclosure
USNRC - Region IV

Senior Project Manager w/ attachments and enclosure
USNRC - NRR Project Directorate IV-1

Senior Resident Inspector w/ attachments and enclosure
USNRC

Nebraska Health and Human Services w/ attachments and enclosure
Department of Regulation and Licensure

NPG Distribution w/o attachments and enclosure

Records w/ attachments and enclosure

**Affidavit**

STATE OF NEBRASKA )
)
NEMAHA COUNTY )

Randall K. Edington, being first duly sworn, deposes and says that he is an authorized representative of the Nebraska Public Power District, a public corporation and political subdivision of the State of Nebraska; that he is duly authorized to submit this correspondence on behalf of Nebraska Public Power District; and that the statements contained herein are true to the best of his knowledge and belief.

Randall K. Edington

Randall K. Edington

Subscribed in my presence and sworn to before me this 29 day of Jan., 2004.

Wilma M Werner

NOTARY PUBLIC

GENERAL NOTARY - State of Nebraska
WILMA M. WERNER
My Comm. Exp. Oct. 26, 2006

## NPPD's Evaluation

**LICENSE AMENDMENT REQUEST TO REVISE TECHNICAL SPECIFICATION 3.4.9 PRESSURE TEMPERATURE (P/T) CURVES FIGURES 3.4.9-1, 3.4.9-2, AND 3.4.9-3.**

**Cooper Nuclear Station, NRC Docket 50-298, DPR-46**

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## 1.0 Introduction

This letter is a request to amend Operating License DPR-46 for Cooper Nuclear Station (CNS).

The current Technical Specification (TS) 3.4.9 Pressure Temperature (P/T) Curves in figures 3.4.9-1, 3.4.9-2, and 3.4.9-3 provide for plant operation through 21 Effective Full Power Years (EFPY). The proposed change will revise the P/T curves for plant operation through 32 EFPY. Section 3.4.9 of the TS define, through Figures 3.4.9-1, 3.4.9-2, and 3.4.9-3, the pressure temperature boundaries within which the plant must operate to ensure adequate margin against brittle fracture of the Reactor Coolant System. The curves were developed in accordance with the 1995 Edition, 1996 Addenda of the American Society of Mechanical Engineers (ASME) Section X1 Appendix G, 10 CFR 50 Appendix G, and ASME Section XI Code Case N-640. The primary effect of the proposed revision is continued plant operation from 21 EFPY (expected by December of 2004) to 32 EFPY, and to allow required reactor vessel hydrostatic and leak tests to be performed at a significantly lower temperature.

## 2.0 Description of Proposed Amendment

This proposed change will revise TS 3.4.9 P/T curves, figures 3.4.9-1, 3.4.9-2, and 3.4.9-3, to allow plant operation from 21 EFPY through 32 EFPY. The proposed amendment includes a full set of updated P/T curves for pressure test, core not critical and core critical conditions. The three regions of the reactor pressure vessel that are evaluated are the beltline region, the bottom head region, and the feedwater nozzle/upper vessel region. These regions bound all other regions with respect to brittle fracture. The P/T curve limits are developed according to Appendix G of ASME Boiler and Pressure Vessel Code, Section XI. ASME Section XI Code Case N-640 was used in the development of the P/T curves. There are two lower bound fracture toughness curves available in Section

XI: Kia, which is a lower bound on all static, dynamic and arrest fracture toughness, and Kic, which is a lower bound on static fracture toughness only. ASME Section XI Code Case N-640 changes the fracture toughness curve used for development of P/T limit curves from Kia to Kic. The P/T curves based on the Kic fracture toughness limits enhance industrial safety by expanding the P/T window low-temperature operating region. Potential benefits from this proposed TS change include reduced challenges to personnel safety as personnel can perform their duties at lower ambient temperatures, reduced dose to inspectors due to increased inspection effectiveness at the lower ambient temperatures and reduced critical path time associated with hydrostatic and leak testing during refueling outages.

The TS Bases for TS 3.4.9 will be revised as appropriate to provide supporting and clarifying information for revision of the P/T curves.

## 3.0 Background

The current P/T curves were developed based on the results from the first and second vessel material surveillance. The Adjusted Reference Temperature (ART) values were developed for the reactor pressure vessel materials in accordance with Regulatory Guide (RG) 1.99 Revision 2. The most limiting beltline material is the Lower Longitudinal Weld with an ART value of 127.6 degrees Fahrenheit (°F).

The P/T curves for the CNS beltline, bottom head, and upper vessel regions have been updated. Heatup/Cooldown curves were developed for 32 EFPY. The curves revised were developed in accordance with the requirements of 10 CFR 50 Appendix G. The methods in the 1995 Edition, 1996 Addenda of ASME Code, Section XI, Appendix G were used with ASME Section XI Code Case N-640, "Alternative Reference Fracture Toughness for Development of P-T Limit Curves." Regulatory Guide (RG) 1.147, Revision 13, identifies ASME Section XI Code Case N-640 as a Nuclear Regulatory Commission (NRC) acceptable ASME Section XI code case. ASME Section XI Code Case N-640 was also used in the development of the P/T curves approved by the NRC staff for Susquehanna Units 1 and 2. The new P/T curves for CNS and Susquehanna were developed by Structural Integrity Associates.

## 4.0 Technical Analysis

### CURVE A (DEVELOPMENT OF UPDATED PRESSURE TEST P/T CURVES)

Updated Safety Analysis Report, Section IV-2.6.2, "Brittle Fracture Consideration" provides the reference temperature of nil-ductility temperature (RTNDT) estimates for the CNS reactor pressure vessel (RPV) materials in accordance with RG 1.99, Revision 2.

Three regions were evaluated: (1) the beltline region, (2) the bottom head region, and (3) the feedwater nozzle/upper vessel region. The approach used for calculating the pressure test P/T curves for each of these regions is summarized in the following subsections.

Beltline Region

The temperature at the assumed flaw tip, T1/4t (i.e., 1/4 thickness into the vessel wall), is equal to the fluid temperature, as the pressure test condition neglects any thermal effects. The assumed temperature that is read on the plant's gauge has an uncertainty of +/- 5°F. A temperature 5°F less than that assumed is used for calculating the allowable pressure. This method produces a lower allowable pressure, making it conservative.

Bottom Head Region

The bottom head region calculations are the same as for the beltline region, except that the equation for pressure stress in a spherical shell is substituted for the cylindrical pressure stress equation and a stress concentration factor is used to account for the Control Rod Drive (CRD) penetrations.

Feedwater Nozzle/Upper Vessel Region

The feedwater nozzle is selected to represent non-beltline/upper vessel components for fracture toughness analyses because the stress conditions at this location are the most severe experienced in the vessel. In addition to the more severe pressure and piping load stresses resulting from the nozzle discontinuity, the feedwater nozzle region experiences relatively cold feedwater flow into hotter vessel coolant.

The methodology used for the feedwater nozzle is contained in Welding Research Council Bulletin 175, "PVRC [Pressure Vessel Research Committee] Recommendations on Toughness Requirements for Ferritic Materials."

Two additional requirements were used to define the lower portion of the upper vessel P/T curve. These limits are established by the discontinuity regions of the vessel (i.e., flanges), and are specified in Table 1 of 10 CFR 50, Appendix G. The requirements are:

> If the calculated pressure, P, is greater than 20% of the pre-service hydro test pressure, the temperature must be greater than RTNDT of the limiting flange material + 90°F. The pre-service hydro test pressure was 1,563 psig, and the limiting flange material has an RTNDT of 20°F.
>
> If the calculated pressure, P, is less than or equal to 20% of the pre-service hydro test pressure, the minimum temperature is typically greater than or equal to the RTNDT of the limiting flange material.

General Electric recommends the application of an additional 60°F margin to the RTNDT value as a standard for the Boiling Water Reactor (BWR) industry for non-ductile failure protection. For the CNS flange material, this minimum would be 80°F (i.e., 20 + 60°F). The gauge's uncertainty of +/- 5°F is not applied here since the included margin encompasses instrument uncertainty. Use of the minimum temperature of 80 degrees is consistent with previous NRC approved P/T curve TS amendments 120 and 155 as well as section 2.6.3.5 of the Updated Safety Analysis Report.

**CURVE B (HEATUP/COOLDOWN, CORE NOT CRITICAL)**

There are three regions that were evaluated: (1) the beltline region, (2) the bottom head region, and (3) the feedwater nozzle/upper vessel region. The methodology used to calculate the heatup/cooldown P/T curves for each of these regions is summarized in the following subsections:

Beltline Region

The temperature at the assumed flaw tip, T1/4t (i.e., 1/4t into the vessel wall), was conservatively assumed to be zero and the metal temperature was assumed equivalent to the fluid temperature. The CNS temperature gauge has an uncertainty of +/- 5°F. A temperature 5°F less than the initially assumed fluid temperature was used to calculate the allowable pressure, producing a lower allowable pressure, and therefore making the calculation conservative.

Bottom Head Region

The bottom head region calculations are the same as for the beltline region, except that the equation for pressure stress in a spherical shell is substituted for the cylindrical pressure stress equation and a stress intensity factor is used to account for the CRD penetrations.

Feedwater Nozzle/Upper Vessel Region

The feedwater nozzle was selected to represent non-beltline/upper vessel components for fracture toughness analyses because the stress conditions at this location are the most severe that the vessel experiences. In addition to the more severe pressure and piping load stresses resulting from the nozzle discontinuity, the feedwater nozzle region experiences thermal cycling due to relatively cold feedwater flow into hotter vessel coolant.

Two additional requirements were used to define the lower portion of the upper vessel P/T curve. These limits are established by the discontinuity regions of the vessel (i.e., flanges), and are specified in Table 1 of 10 CFR 50, Appendix G. The requirements are:

If the calculated pressure, P, is greater than 20% of the pre-service hydro test pressure, the temperature must be greater than RTNDT of the limiting flange material + 120°F. The pre-service hydro test pressure was 1,563 psig, and the limiting flange material has an RTNDT of 20°F.

If the calculated pressure, P, is less than or equal to 20% of the pre-service hydro test pressure, the same requirements apply as were applicable for Curve A.

**CURVE C (HEATUP/COOLDOWN, CORE CRITICAL)**

Curve C, the core critical operation curve, is generated from the requirements of 10 CFR 50 Appendix G. Table 1 of Appendix G requires that core critical P/T limits be 40°F above any Curve A (Updated Pressure Test) or B (Heatup/Cooldown, Core not Critical) limits when pressure exceeds 20% of the pre-service system hydrostatic test pressure. Curve B is more limiting than Curve A, so limiting Curve C values are equal to Curve B plus 40°F for pressures above 312 psig.

Table 1 of Appendix G also dictates that, for a BWR with water level within normal range for power operation, the allowed temperature for initial criticality at the closure flange region is (RTNDT + 60°F) at pressures below 312 psig (20% of pre-service hydrostatic pressure test). This requirement makes the minimum criticality temperature 80°F for CNS, based on an ART value of 20°F for the flange region. In addition, above 312 psig, the Curve C temperature must be at least the greater of ART of the closure flange region + 160°F, or the temperature required for the hydrostatic pressure test (Curve A at 1,100 psig). Therefore, this requirement causes a temperature shift in Curve C at 312 psig.

## 4.1 Precedent

A similar TS change for P/T curves was approved by the NRC staff for Susquehanna Units 1 and 2 (Amendment No. 200/Amendment No. 174, dated February 7, 2002). The P/T curves for Susquehanna were also developed by Structural Integrity Associates using the requirements of 10 CFR 50 Appendix G, ASME Section XI, Appendix G, and ASME Section XI Code Case N-640. During NRC review of the Susquehanna amendment request, supplemental information was provided by Susquehanna to facilitate the performance of independent fluence calculations.

Amendment 201 to the CNS Operating License, issued October 31, 2003, implemented the Boiling Water Reactor Vessel and Internals Reactor Pressure Vessel Integrated Surveillance Program (ISP). As part of the ISP, CNS vessel surveillance capsules are evaluated using fluence calculations that conform with Regulatory Guide (RG) 1.190, Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence. Additionally, CNS committed in Amendment 201 to a recalculation of fluences for previously pulled surveillance capsules in conformance with RG 1.190.

## 5.0 Regulatory Analysis

### 5.1 No Significant Hazards Consideration

10 CFR 50.91(a)(1) requires that licensee requests for operating license amendments be accompanied by an evaluation of significant hazard posed by issuance of an amendment. Nebraska Public Power District (NPPD) has evaluated this proposed amendment with respect to the criteria given in 10 CFR 50.92 (c).

This proposed change will revise Technical Specification (TS) 3.4.9 Pressure Temperature (P/T) curves, figures 3.4.9-1, 3.4.9-2, and 3.4.9-3, to allow plant operation from 21 Effective Full Power Years (EFPY) through 32 EFPY. The proposed change includes a full set of updated P/T curves for pressure test, core not critical and core critical conditions. The three regions of the reactor pressure vessel that are evaluated are the beltline region, the bottom head region, and the feedwater nozzle/upper vessel region. These regions bound all other regions with respect to brittle fracture.

The following evaluation supports a finding of "no significant hazards consideration" associated with this proposed change.

#### 5.1.1 Do the proposed changes involve a significant increase in the probability or consequences of an accident previously evaluated?

The proposed revisions to the Cooper Nuclear Station (CNS) P/T curves are based on the recommendations in Regulatory Guide (RG) 1.99, Revision 2, and are therefore in accordance with the latest Nuclear Regulatory Commission (NRC) guidance. The evaluation for the P/T curves for 32 EFPY was performed using the approved methodologies of 10 CFR 50, Appendix G. The curves generated from these methods provide guidance to ensure that the P/T limits will not be exceeded during any phase of reactor operation. Accordingly, the proposed revision to the CNS P/T curves is based on an NRC accepted means of ensuring protection against brittle reactor vessel fracture, and compliance with 10 CFR 50 Appendix G. Therefore, this proposed change does not involve a significant increase in the probability or consequences of an accident previously evaluated.

Based on the above, NPPD concludes that the proposed TS change to TS 3.4.9 P/T curves, figures 3.4.9-1, 3.4.9-2, and 3.4.9-3 does not significantly increase the probability or consequences of an accident previously evaluated.

**5.1.2 Do the proposed changes create the possibility of a new or different kind of accident from any accident previously evaluated?**

The proposed change updates existing P/T operating limits to correspond to the current NRC guidance. The proposed TS change provides more operating flexibility in the P/T curves for in-service leakage and hydrostatic pressure testing, non-nuclear heatup and cooldown, and criticality, with the benefits primarily in the area of pressure test being performed at a lower temperature. The proposed change does not involve a physical change to the plant, add any new equipment or any new mode of operation. These changes demonstrate compliance with the brittle fracture requirements of 10 CFR 50 Appendix G, and therefore do not create the possibility for a new or different kind of accident from any accident previously evaluated.

Based on the above, NPPD concludes that the proposed TS change to TS 3.4.9 P/T curves, figures 3.4.9-1, 3.4.9-2, and 3.4.9-3 does not create the possibility of a new or different kind of accident from any accident previously evaluated.

**5.1.3 Do the proposed changes involve a significant reduction in the margin of safety?**

The proposed change to the CNS P/T curves does not create a significant reduction in the margin of safety. The proposed change revises the existing CNS P/T curves to be consistent with recommendations of RG 1.99, Revision 2, the current NRC guidance given to ensure compliance with 10 CFR 50 Appendix G.

For P/T curve development ASME Section XI Code Case N-640 uses the Kic fracture toughness curve as the lower bound for fracture toughness. P/T curves based on the Kic fracture toughness limits enhance industrial safety by expanding the P/T window in the low-temperature operating region. The potential benefits are a reduction in the duration of the pressure test and, associated increase in personnel safety, while conducting inspections in primary containment. Therefore, operational flexibility is gained while maintaining an adequate margin of safety to Reactor Pressure Vessel brittle fracture. As stated above the development of the P/T curves to 32 EFPY was performed per the guidelines of 10 CFR 50 Appendix G, and thus, the margin of safety is not significantly reduced as the result of the proposed TS change.

Based on the above, NPPD concludes that the proposed TS change to TS 3.4.9 P/T curves, figures 3.4.9-1, 3.4.9-2, and 3.4.9-3 does not involve a significant reduction in the margin of safety.

In conclusion, NPPD has determined that the proposed amendment involves no significant hazards consideration under the standards set forth in 10 CFR 50.92(c), and, accordingly, a finding of "no significant hazards consideration" is justified.

## 5.2 Regulatory Requirements and Guidance

10 CFR 50.60, "Acceptance Criteria for Fracture Prevention of Lightwater Nuclear Power Reactors for Normal Operation," provides the requirements that the pressure and temperature limits as well as the associated vessel surveillance program are consistent with 10 CFR 50 Appendix G, "Fracture Toughness Requirements," and 10 CFR 50 Appendix H, "Reactor Vessel Material Surveillance Program Requirements."

10 CFR 50 Appendix G and Appendix H also describe specific requirements for fracture toughness and reactor vessel material surveillance that must be considered in establishing P/T curves. 10 CFR 50 Appendix G specifies the fracture toughness and testing requirements for reactor vessel material in accordance with Section XI of the ASME Boiler and Pressure Vessel Code, Appendix G. 10 CFR 50, Appendix G also requires the prediction of the effects of neutron irradiation on the vessel embrittlement by calculating the ART and Charpy upper shelf energy. Generic Letter 88-11, "NRC Position on Radiation Embrittlement of Reactor Vessel Materials and Its Impact on Plant Operations," requires that the methods in Regulatory Guide 1.99, Revision 2, be used to predict the effect of neutron irradiation on the reactor vessel material. Appendix H of 10 CFR 50 requires the establishment of a surveillance program to periodically withdraw surveillance capsules from the reactor vessel.

The heatup and cooldown process for CNS is controlled by TS 3.4.9 P/T curves, which are developed based on fracture mechanics analysis. These limits are developed according to Appendix G of ASME Boiler and Pressure Vessel Code, Section XI, 10 CFR 50, Appendix G and ASME Section XI Code Case N-640. There are two lower bound fracture toughness curves available in Section XI: Kia, which is a lower bound on all static, dynamic and arrest fracture toughness, and Kic, which is a lower bound on static fracture toughness only. ASME Section XI Code Case N-640 changes the fracture toughness curve used for development of P/T limit curves from Kia to Kic. RG 1.147, Revision 13, identifies ASME Section XI Code Case N-640 as an NRC acceptable ASME Section XI code case.

In conclusion, based on the considerations discussed above, (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, (2) such activities will be conducted in compliance with the Commission's regulations, and (3) the issuance of the amendment will not be inimical to the common defense and security or to the health and safety of the public.

## 6.0 Environmental Consideration

10 CFR 51.22(b) allows that an environmental assessment (EA) or an environmental impact statement (EIS) is not required for any action included in the list of categorical exclusions in 10 CFR 51.22(c). 10 CFR 51.22(c)(9) identifies an amendment to an operating license which changes a requirement with respect to installation or use of a facility component located within the restricted area, or which changes an inspection or a surveillance requirement, as a categorical exclusion if operation of the facility in accordance with the proposed amendment would not: (1) involve a significant hazards consideration, (2) result in a significant change in the types or significant increase in the amount of any effluents that may be released off-site, or (3) result in an increase in individual or cumulative occupational radiation exposure.

NPPD has reviewed the proposed license amendment and concludes that it meets the eligibility criteria for categorical exclusion set forth in 10 CFR 51.22(c)(9). Pursuant to 10 CFR 51.22(c), no environmental impact statement or environmental assessment needs to be prepared in connection with issuance of the proposed license changes. The basis for this determination is as follows:

1. The proposed license amendment does not involve significant hazards as described previously in the No Significant Hazards Consideration Evaluation.

2. This proposed change does not result in a significant change in the types or significant increase in the amounts of any effluents that may be released off-site. The proposed license amendment does not introduce any new equipment, nor does it require any existing equipment or systems to perform a different type of function than they are presently designed to perform. NPPD has concluded that there will not be a significant increase in the types or amounts of any effluents that may be released off-site and these changes do not involve irreversible environmental consequences beyond those already associated with normal operation.

3. This change does not adversely affect plant systems or operation and therefore, does not significantly increase individual or cumulative occupational radiation exposure beyond that already associated with normal operation.

## 7.0 References

1. Structural Integrity Associates Calculation No. COOP-05Q-301, Development of Updated Pressure Test (Curve A) P-T Curves.

2. Structural Integrity Associates Calculation No. COOP-05Q-302, Development of Updated Heatup/Cooldown (Curves B &C) P-T Curves.

3. ASME Boiler and Pressure Vessel Code, Code Case N-640, "Alternate Reference Fracture Toughness for Development of P-T Limit Curves, "Section XI, Division 1, Approved February 26, 1999

4. USAR, Section IV-2.6.2, Brittle Fracture Consideration

5. Letter NSD930270, from G. R. Horn, NPPD, to USNRC, Submittal of Reactor Vessel Surveillance Test results, February 25,1993.

6. 1995 Edition, 1996 Addenda, ASME Boiler and Pressure Vessel Code Section XI, Appendix G, "Fracture Toughness Criteria for Protection Against Failure"

# ATTACHMENT 2

## PROPOSED TECHNICAL SPECIFICATIONS AND ASSOCIATED BASES REVISIONS MARKUP FORMAT

## COOPER NUCLEAR STATION NRC DOCKET 50-298, LICENSE DPR-46

Listing of Revised Pages

<u>TS Pages</u>
3.4-23
3.4-24
3.4-25

<u>TS Bases Pages</u>
B 3.4-44
B 3.4-46
B 3.4-49
B 3.4-52

Note: Bases are provided for information. Following approval of the proposed TS change, Bases changes will be implemented in accordance with TS 5.5.10, Technical Specification (TS) Bases Control Program.

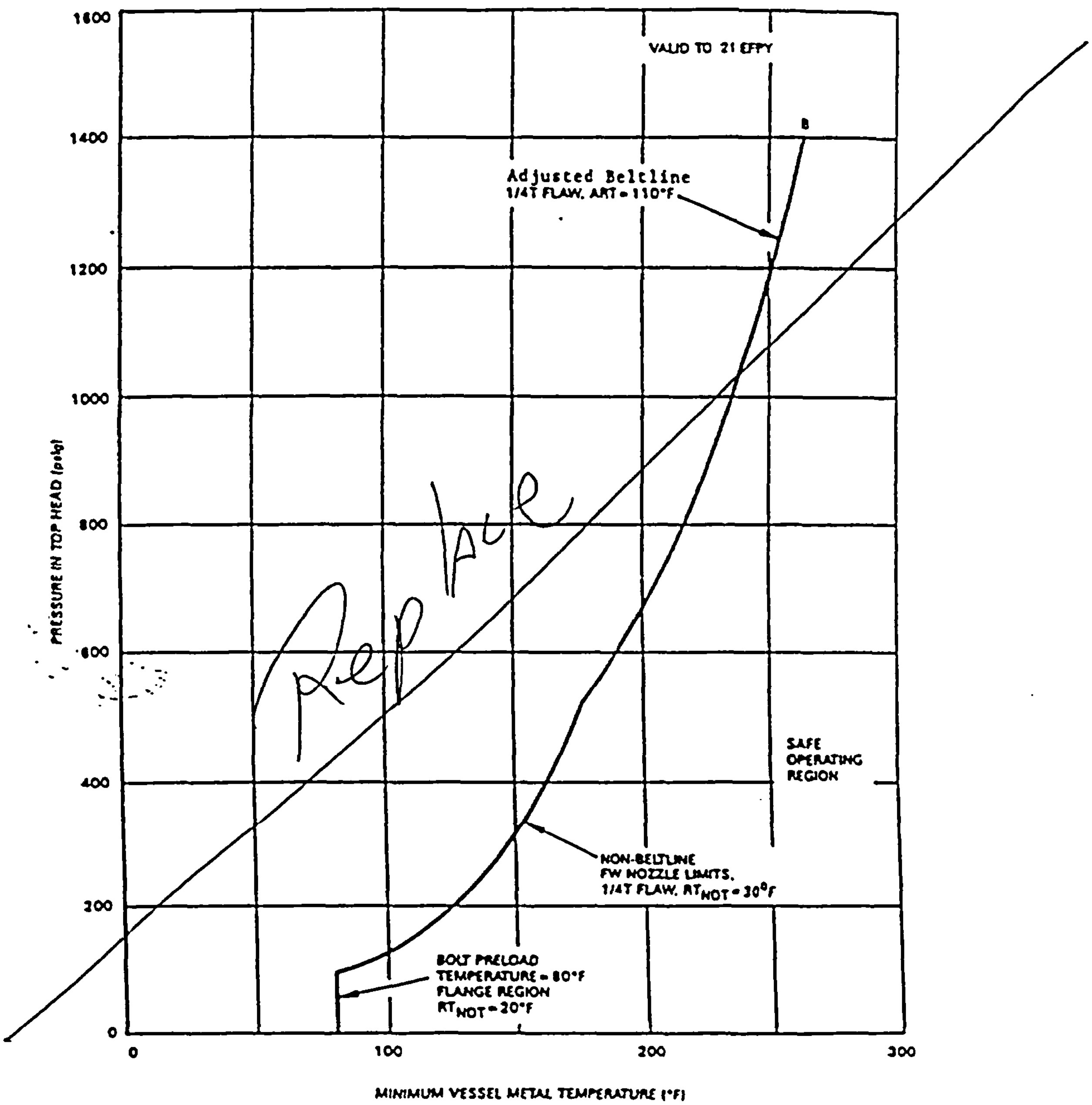


Figure 3.4.9-1 (page 1 of 1)
Temperature/Pressure Limits for
Non-Nuclear Heatup or Cooldown Following Nuclear Shutdown

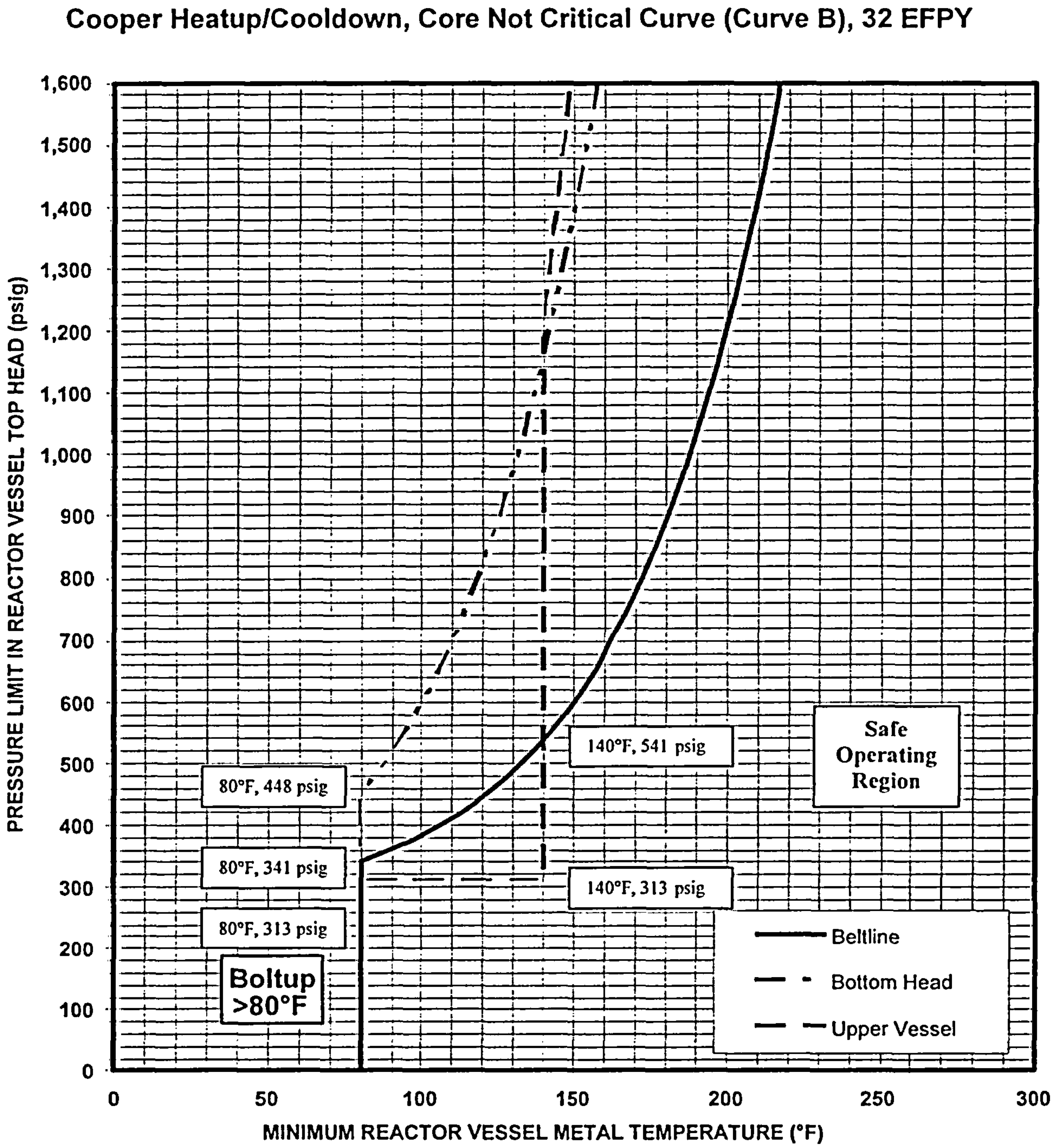


**Figure 3.4.9-1 (page 1 of 1)**
**Pressure/Temperature Limits for**
**Non-Nuclear Heatup or Cooldown Following Nuclear Shutdown**

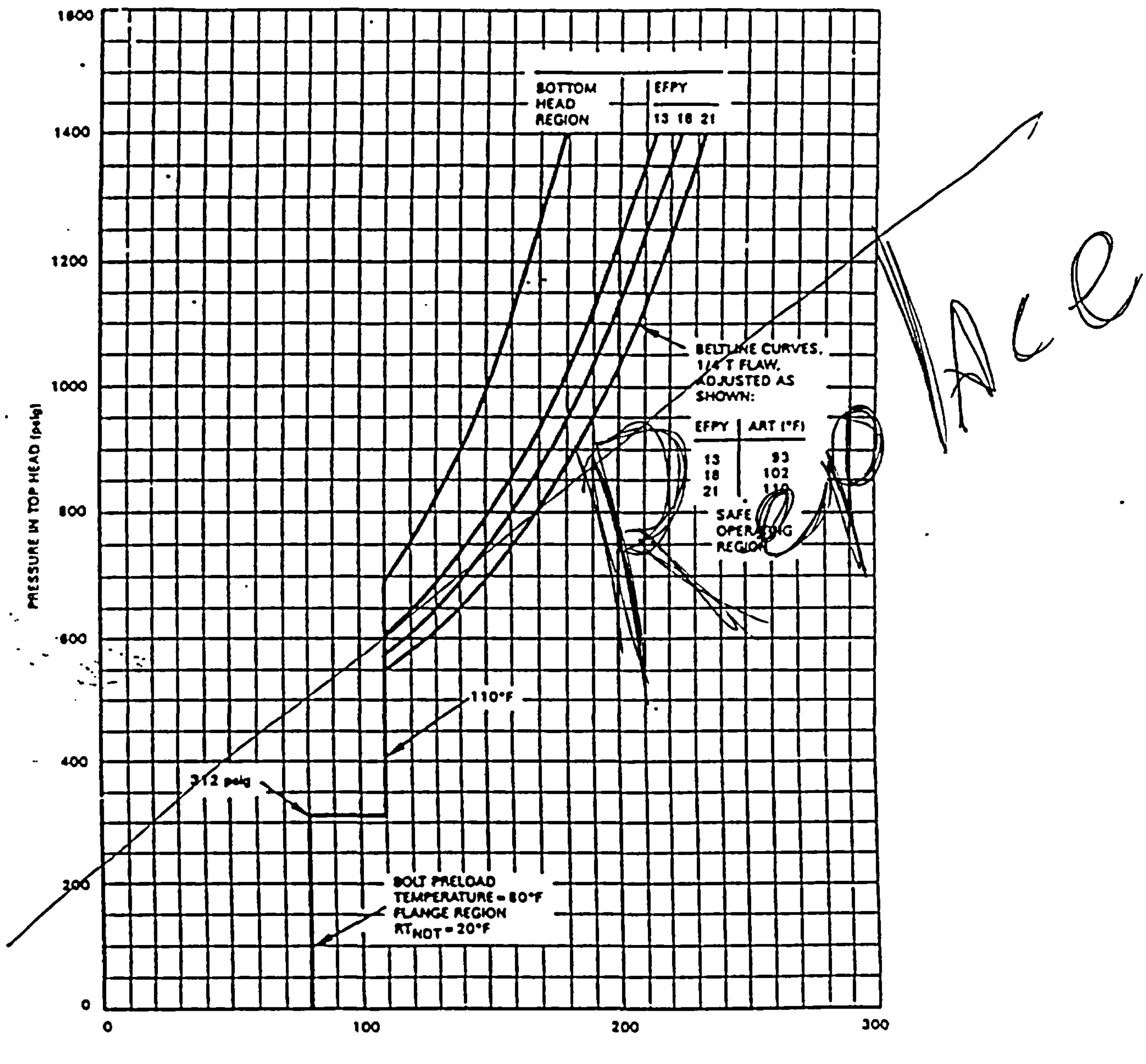


Figure 3.4.9-2 (page 1 of 1)
Temperature/Pressure Limits for
Inservice Hydrostatic and Inservice Leakage Tests

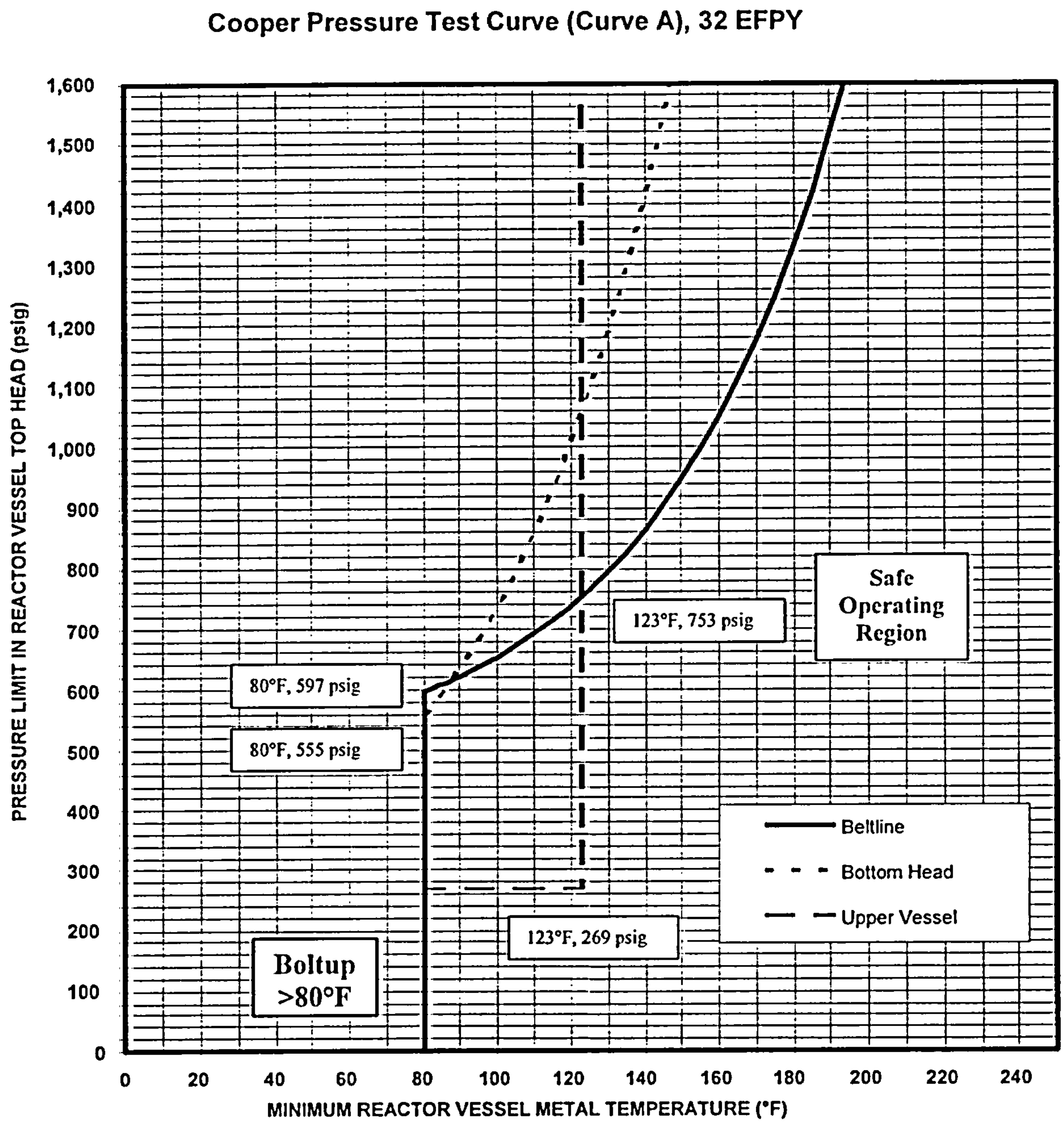


**Figure 3.4.9-2 (page 1 of 1)**
**Pressure/Temperature Limits for**
**Inservice Hydrostatic and Inservice Leakage Tests**

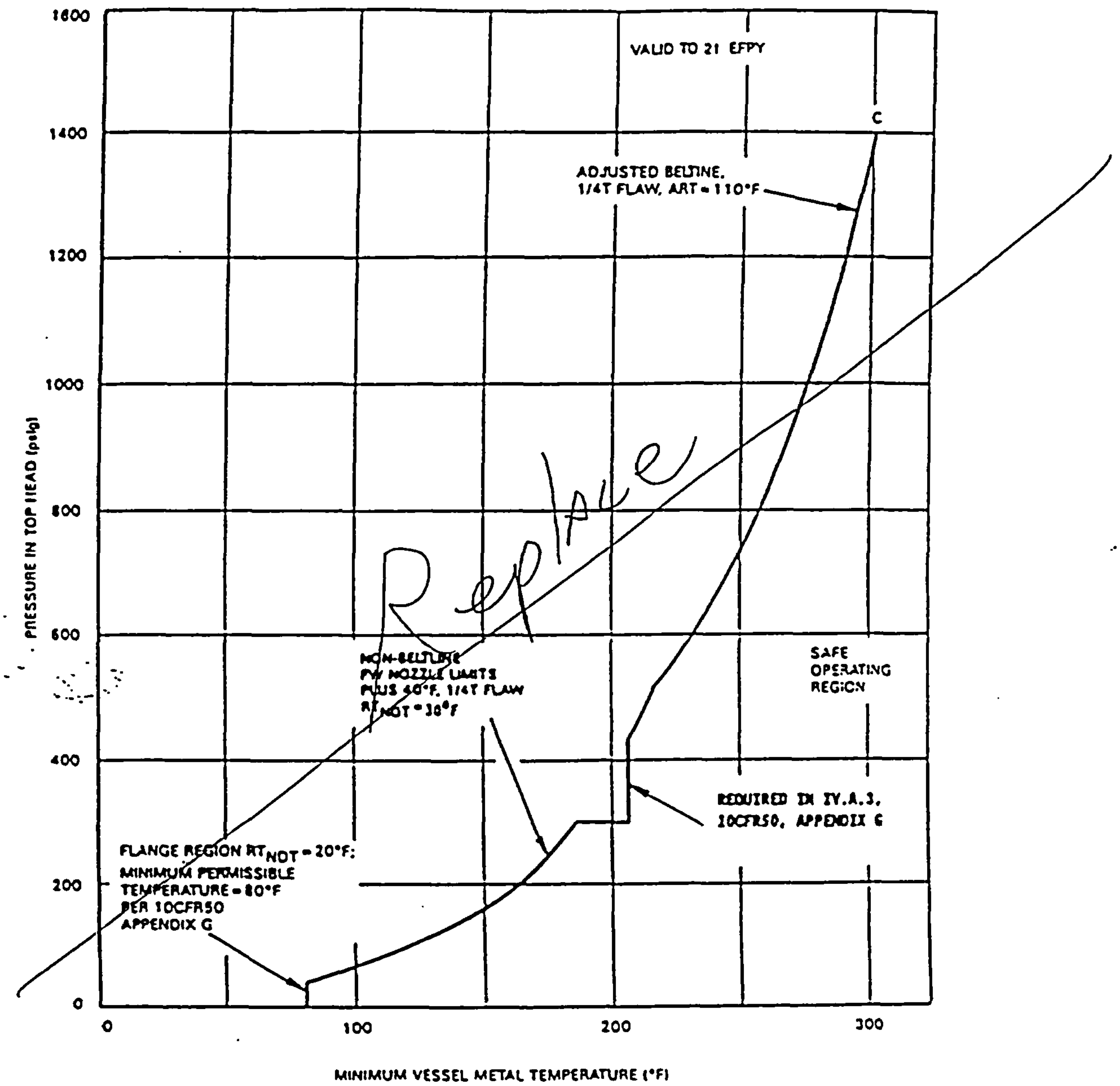


Figure 3.4.9-3 (page 1 of 1)
Temperature/Pressure Limits for Criticality

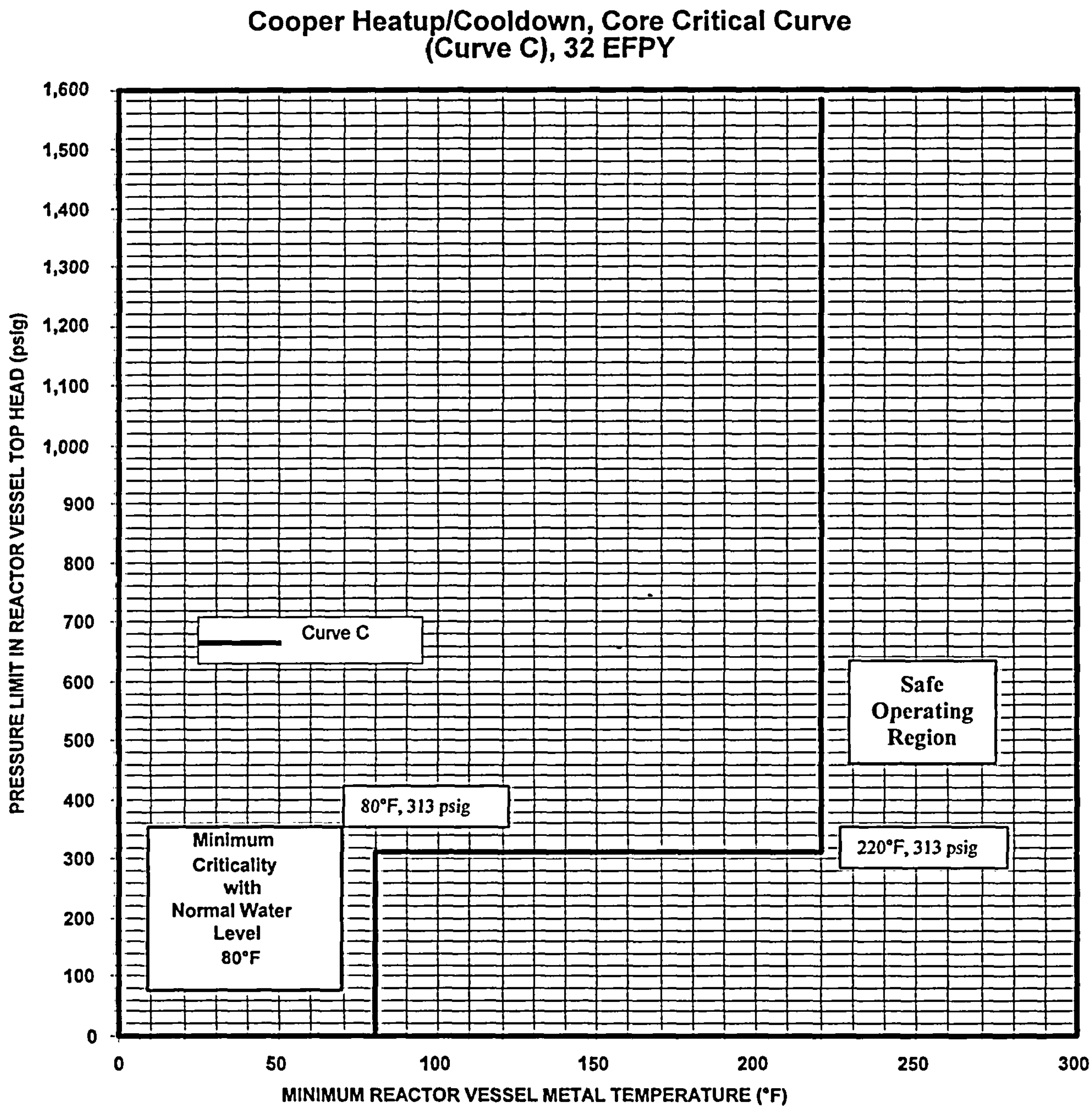


**Figure 3.4.9-3 (page 1 of 1)**
**Pressure/Temperature Limits for Criticality**

B 3.4 REACTOR COOLANT SYSTEM (RCS)

B 3.4.9 RCS Pressure and Temperature (P/T) Limits

BASES

BACKGROUND

All components of the RCS are designed to withstand effects of cyclic loads due to system pressure and temperature changes. These loads are introduced by startup (heatup) and shutdown (cooldown) operations, power transients, and reactor trips. This LCO limits the pressure and temperature changes during RCS heatup and cooldown, within the design assumptions and the stress limits for cyclic operation.

This Specification contains P/T limit curves for heatup, cooldown, and inservice leakage and hydrostatic testing, criticality, and data for the maximum rate of change of reactor coolant temperature.

Each P/T limit curve defines an acceptable region for normal operation. The usual use of the curves is operational guidance during heatup or cooldown maneuvering, when pressure and temperature indications are monitored and compared to the applicable curve to determine that operation is within the allowable region.

The LCO establishes operating limits that provide a margin to brittle failure of the reactor vessel and piping of the reactor coolant pressure boundary (RCPB). The vessel is the component most subject to brittle failure. Therefore, the LCO limits apply mainly to the vessel.

10 CFR 50, Appendix G (Ref. 1), requires the establishment of P/T limits for material fracture toughness requirements of the RCPB materials. Reference 1 requires an adequate margin to brittle failure during normal operation, abnormal operational transients, and system hydrostatic tests. It mandates the use of the ASME Code, Section III, Appendix G (Ref. 2). The NRC has also approved the use of alternate fracture toughness curves for establishing these limits (Ref. 10).

The actual shift in the $RT_{NDT}$ of the vessel material will be established periodically by removing and evaluating the irradiated reactor vessel material specimens, in accordance with BWRVIP-86-A (Ref. 3) and Appendix H of 10 CFR 50 (Ref. 4). The operating P/T limit curves will be adjusted,

(continued)

BASES

APPLICABLE SAFETY ANALYSES (continued)

P/T limits are not derived from any DBA, there are no acceptance limits related to the P/T limits. Rather, the P/T limits are acceptance limits themselves since they preclude operation in an unanalyzed condition.

RCS P/T limits satisfy Criterion 2 of 10 CFR 50.36(c)(2)(ii) (Ref. 8).

LCO

The elements of this LCO are:

a. RCS pressure and temperature (Beltline, Bottom Head, and Upper Vessel) are within the applicable limits of Figure 3.4.9-1 and Figure 3.4.9-2, and heatup or cooldown rates are ≤ 100°F when averaged over a one hour period during RCS heatup, cooldown, and inservice leak and hydrostatic testing (The Adjusted Reference Temperature (ART) beltline region must be determined from ~~the appropriate beltline curve (13, 18, or 21 Effective Full Power Years (EFPY) of~~ Figure 3.4.9-2 ~~depending on the current accumulated number of EFPY)~~;

b. The temperature difference between the reactor vessel bottom head coolant and the reactor pressure vessel (RPV) coolant is ≤ 145°F *during recirculation pump startup;*

c. The temperature difference between the reactor coolant in the respective recirculation loop and in the reactor vessel is ≤ 50°F during recirculation pump startup;

d. RCS pressure and temperature are within the criticality limits specified in Figure 3.4.9-3, prior to achieving criticality; and

e. The reactor vessel flange and the head flange temperatures are > 80°F when tensioning the reactor vessel head bolting studs.

These limits define allowable operating regions and permit a large number of operating cycles while also providing a wide margin to nonductile failure.

(continued)

BASES

ACTIONS

B.1 and B.2 (continued)

36 hours. The allowed Completion Times are reasonable, based on operating experience, to reach the required plant conditions from full power conditions in an orderly manner and without challenging plant systems.

C.1 and C.2

Operation outside the P/T limits in other than MODES 1, 2, and 3 (including defueled conditions) must be corrected so that the RCPB is returned to a condition that has been verified by stress analyses. The Required Action must be initiated without delay and continued until the limits are restored.

Besides restoring the P/T limit parameters to within limits, an evaluation is required to determine if RCS operation is allowed. This evaluation must verify that the RCPB integrity is acceptable and must be completed before approaching criticality or heating up to > 212°F. Several methods may be used, including comparison with pre-analyzed transients, new analyses, or inspection of the components. ASME Code, Section XI, Appendix E (Ref. 7), may be used to support the evaluation; however, its use is restricted to evaluation of the beltline.

Condition C is modified by a Note requiring Required Action C.2 be completed whenever the Condition is entered. The Note emphasizes the need to perform the evaluation of the effects of the excursion outside the allowable limits. Restoration alone per Required Action C.1 is insufficient because higher than analyzed stresses may have occurred and may have affected the reactor pressure vessel integrity.

SURVEILLANCE REQUIREMENTS

SR 3.4.9.1

Verification that operation is within RCS pressure, RCS temperature, and RCS heatup and cooldown rate limits by monitoring the bottom head drain, recirculation loop temperatures, and RPV metal temperatures (Beltline, Bottom Head, and Upper Vessel) is required every 30 minutes when RCS pressure and temperature conditions are undergoing planned changes. This Frequency is considered

(continued)

BASES

SURVEILLANCE REQUIREMENTS

SR 3.4.9.5, SR 3.4.9.6, and SR 3.4.9.7 (continued)

The 30 minute Frequency reflects the urgency of maintaining the temperatures within limits, and also limits the time that the temperature limits could be exceeded. The 12 hour Frequency is reasonable based on the rate of temperature change possible at these temperatures.

SR 3.4.9.5 is modified by a Note that requires the Surveillance to be performed only when tensioning the reactor vessel head bolting studs. SR 3.4.9.6 is modified by a Note that requires the Surveillance to be initiated 30 minutes after RCS temperature ≤ 90°F in MODE 4. SR 3.4.9.7 is modified by a Note that requires the Surveillance to be initiated 12 hours after RCS temperature ≤ 100°F in MODE 4. The Notes contained in these SRs are necessary to specify when the reactor vessel flange and head flange temperatures are required to be within the specified limits.

REFERENCES

1. 10 CFR 50, Appendix G.
2. ASME, Boiler and Pressure Vessel Code, Section III, Appendix G.
3. BWRVIP-86-A, October 2002.
4. 10 CFR 50, Appendix H.
5. Regulatory Guide 1.99, Revision 2, May 1988.
6. USAR, Section IV-2.6.
7. ASME, Boiler and Pressure Vessel Code, Section XI, Appendix E.
8. 10 CFR 50.36(c)(2)(ii).
9. USAR, Appendix G.
10. ASME XI Code Case N-640

# ATTACHMENT 3

## PROPOSED TECHNICAL SPECIFICATIONS AND ASSOCIATED BASES REVISIONS FINAL TYPED FORMAT

## COOPER NUCLEAR STATION NRC DOCKET 50-298, LICENSE DPR-46

Listing of Revised Pages

<u>TS Pages</u>
3.4-23
3.4-24
3.4-25

<u>TS Bases Pages</u>
B 3.4-44
B 3.4-46
B 3.4-49
B 3.4-52

Note: Bases are provided for information. Following approval of the proposed TS change, Bases changes will be implemented in accordance with TS 5.5.10, Technical Specification (TS) Bases Control Program.

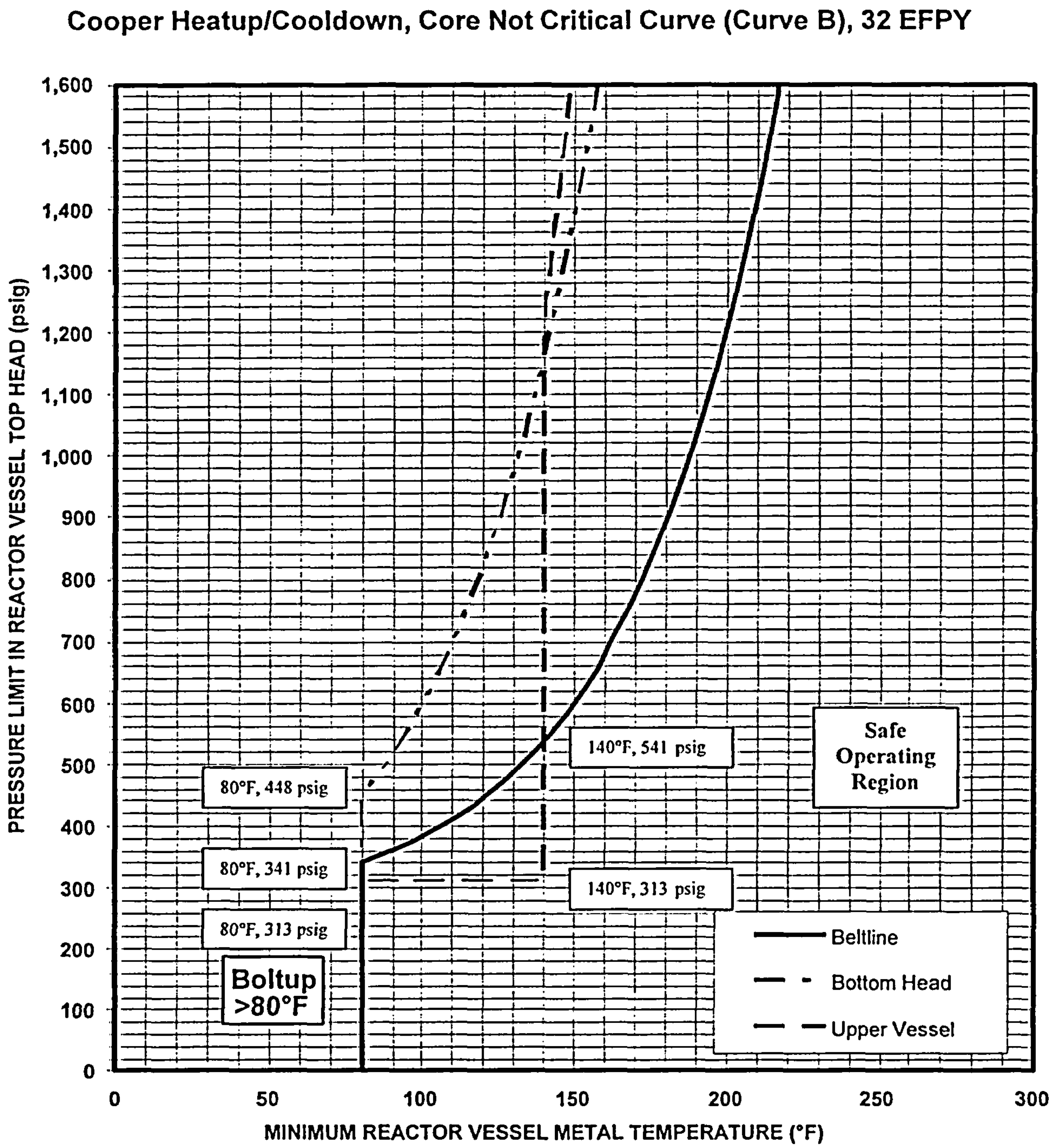


**Figure 3.4.9-1 (page 1 of 1)**
**Pressure/Temperature Limits for**
**Non-Nuclear Heatup or Cooldown Following Nuclear Shutdown**

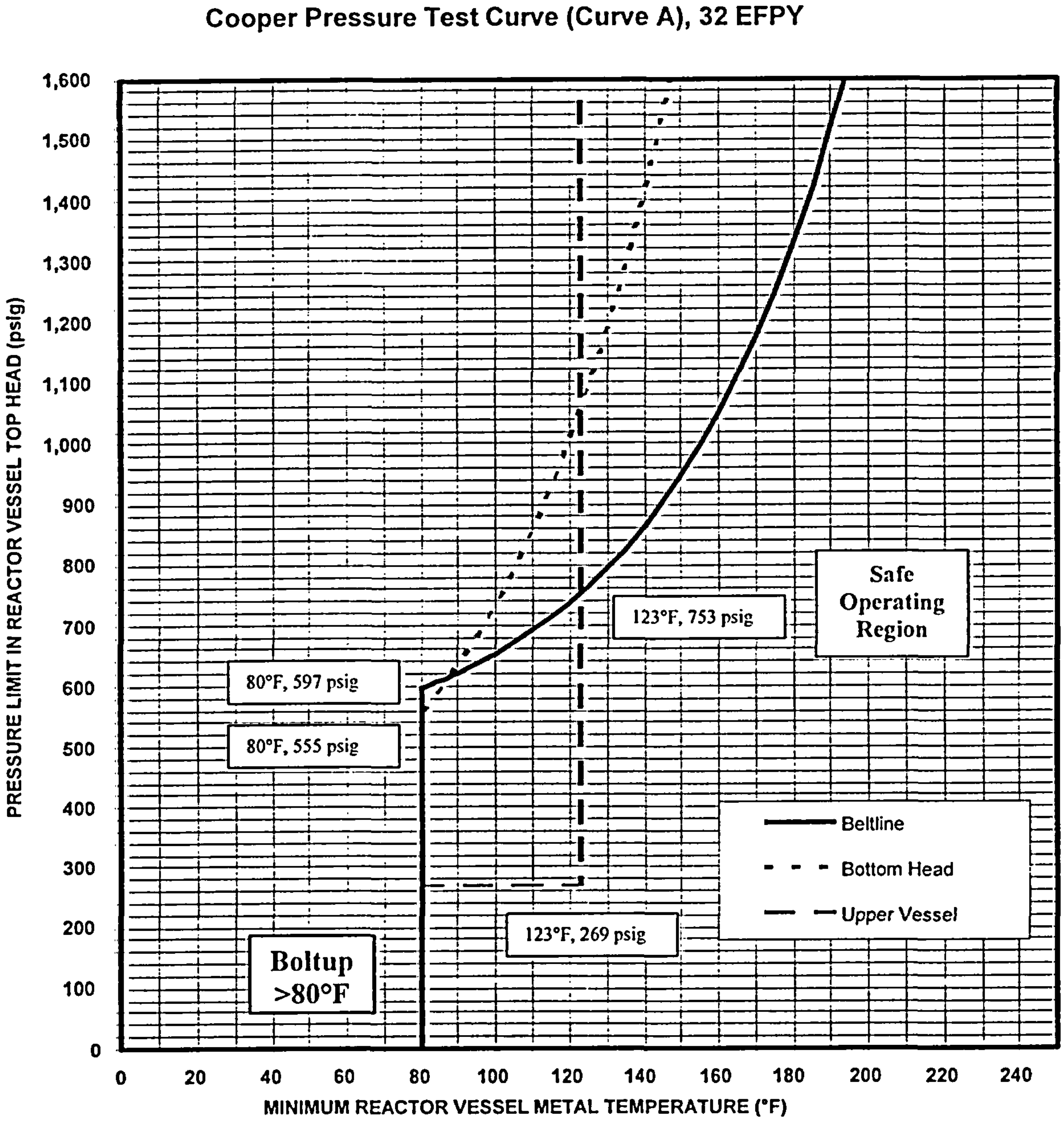


**Figure 3.4.9-2 (page 1 of 1)**
**Pressure/Temperature Limits for**
**Inservice Hydrostatic and Inservice Leakage Tests**

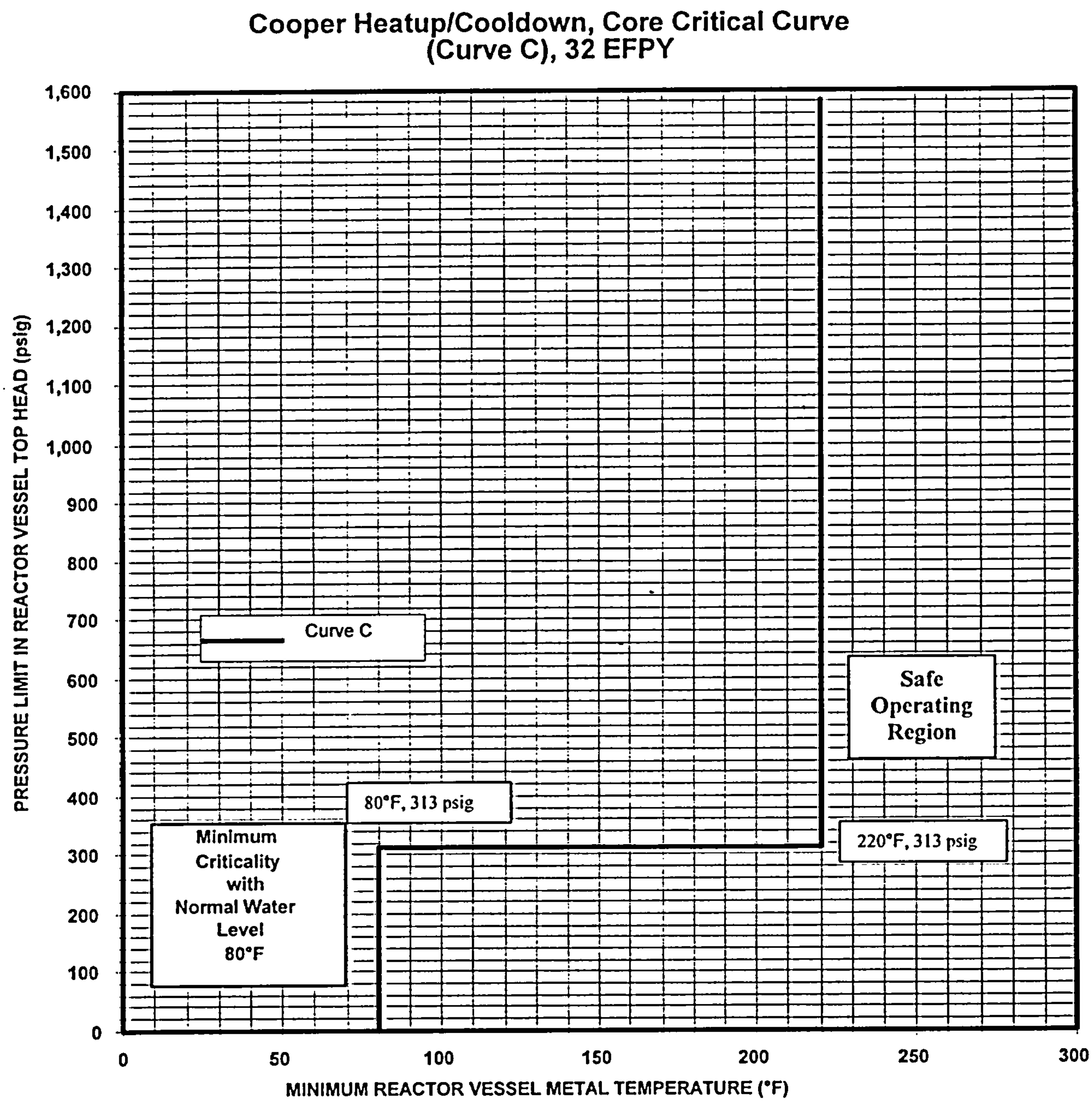


**Figure 3.4.9-3 (page 1 of 1)**
**Pressure/Temperature Limits for Criticality**

B 3.4 REACTOR COOLANT SYSTEM (RCS)

B 3.4.9 RCS Pressure and Temperature (P/T) Limits

BASES

BACKGROUND

All components of the RCS are designed to withstand effects of cyclic loads due to system pressure and temperature changes. These loads are introduced by startup (heatup) and shutdown (cooldown) operations, power transients, and reactor trips. This LCO limits the pressure and temperature changes during RCS heatup and cooldown, within the design assumptions and the stress limits for cyclic operation.

This Specification contains P/T limit curves for heatup, cooldown, and inservice leakage and hydrostatic testing, criticality, and data for the maximum rate of change of reactor coolant temperature.

Each P/T limit curve defines an acceptable region for normal operation. The usual use of the curves is operational guidance during heatup or cooldown maneuvering, when pressure and temperature indications are monitored and compared to the applicable curve to determine that operation is within the allowable region.

The LCO establishes operating limits that provide a margin to brittle failure of the reactor vessel and piping of the reactor coolant pressure boundary (RCPB). The vessel is the component most subject to brittle failure. Therefore, the LCO limits apply mainly to the vessel.

10 CFR 50, Appendix G (Ref. 1), requires the establishment of P/T limits for material fracture toughness requirements of the RCPB materials. Reference 1 requires an adequate margin to brittle failure during normal operation, abnormal operational transients, and system hydrostatic tests. It mandates the use of the ASME Code, Section III, Appendix G (Ref. 2). The NRC has also approved the use of alternate fracture toughness curves for establishing these limits (Ref. 10).

The actual shift in the $RT_{NDT}$ of the vessel material will be established periodically by removing and evaluating the irradiated reactor vessel material specimens, in accordance with BWRVIP-86-A (Ref. 3) and Appendix H of 10 CFR 50 (Ref. 4). The operating P/T limit curves will be adjusted,

(continued)

BASES

APPLICABLE SAFETY ANALYSES (continued)

P/T limits are not derived from any DBA, there are no acceptance limits related to the P/T limits. Rather, the P/T limits are acceptance limits themselves since they preclude operation in an unanalyzed condition.

RCS P/T limits satisfy Criterion 2 of 10 CFR 50.36(c)(2)(ii) (Ref. 8).

LCO

The elements of this LCO are:

a. RCS pressure and temperature (Beltline, Bottom Head, and Upper Vessel) are within the applicable limits of Figure 3.4.9-1 and Figure 3.4.9-2, and heatup or cooldown rates are ≤ 100°F when averaged over a one hour period during RCS heatup, cooldown, and inservice leak and hydrostatic testing (The Adjusted Reference Temperature (ART) beltline region must be determined from Figure 3.4.9-2;

b. The temperature difference between the reactor vessel bottom head coolant and the reactor pressure vessel (RPV) coolant is ≤ 145°F during recirculation pump startup;

c. The temperature difference between the reactor coolant in the respective recirculation loop and in the reactor vessel is ≤ 50°F during recirculation pump startup;

d. RCS pressure and temperature are within the criticality limits specified in Figure 3.4.9-3, prior to achieving criticality; and

e. The reactor vessel flange and the head flange temperatures are > 80°F when tensioning the reactor vessel head bolting studs.

These limits define allowable operating regions and permit a large number of operating cycles while also providing a wide margin to nonductile failure.

(continued)

BASES

ACTIONS

B.1 and B.2 (continued)

36 hours. The allowed Completion Times are reasonable, based on operating experience, to reach the required plant conditions from full power conditions in an orderly manner and without challenging plant systems.

C.1 and C.2

Operation outside the P/T limits in other than MODES 1, 2, and 3 (including defueled conditions) must be corrected so that the RCPB is returned to a condition that has been verified by stress analyses. The Required Action must be initiated without delay and continued until the limits are restored.

Besides restoring the P/T limit parameters to within limits, an evaluation is required to determine if RCS operation is allowed. This evaluation must verify that the RCPB integrity is acceptable and must be completed before approaching criticality or heating up to > 212°F. Several methods may be used, including comparison with pre-analyzed transients, new analyses, or inspection of the components. ASME Code, Section XI, Appendix E (Ref. 7), may be used to support the evaluation; however, its use is restricted to evaluation of the beltline.

Condition C is modified by a Note requiring Required Action C.2 be completed whenever the Condition is entered. The Note emphasizes the need to perform the evaluation of the effects of the excursion outside the allowable limits. Restoration alone per Required Action C.1 is insufficient because higher than analyzed stresses may have occurred and may have affected the reactor pressure vessel integrity.

SURVEILLANCE REQUIREMENTS

SR 3.4.9.1

Verification that operation is within RCS pressure, RCS temperature, and RCS heatup and cooldown rate limits by monitoring the bottom head drain, recirculation loop temperatures, and RPV metal temperatures (Beltline, Bottom Head, and Upper Vessel) is required every 30 minutes when RCS pressure and temperature conditions are undergoing planned changes. This Frequency is considered

(continued)

BASES

SURVEILLANCE REQUIREMENTS

SR 3.4.9.5, SR 3.4.9.6, and SR 3.4.9.7 (continued)

The 30 minute Frequency reflects the urgency of maintaining the temperatures within limits, and also limits the time that the temperature limits could be exceeded. The 12 hour Frequency is reasonable based on the rate of temperature change possible at these temperatures.

SR 3.4.9.5 is modified by a Note that requires the Surveillance to be performed only when tensioning the reactor vessel head bolting studs. SR 3.4.9.6 is modified by a Note that requires the Surveillance to be initiated 30 minutes after RCS temperature ≤ 90°F in MODE 4. SR 3.4.9.7 is modified by a Note that requires the Surveillance to be initiated 12 hours after RCS temperature ≤ 100°F in MODE 4. The Notes contained in these SRs are necessary to specify when the reactor vessel flange and head flange temperatures are required to be within the specified limits.

REFERENCES

1. 10 CFR 50, Appendix G.
2. ASME, Boiler and Pressure Vessel Code, Section III, Appendix G.
3. BWRVIP-86-A, October 2002.
4. 10 CFR 50, Appendix H.
5. Regulatory Guide 1.99, Revision 2, May 1988.
6. USAR, Section IV-2.6.
7. ASME, Boiler and Pressure Vessel Code, Section XI, Appendix E.
8. 10 CFR 50.36(c)(2)(ii).
9. USAR, Appendix G.
10. ASME XI Code Case N-640

# ENCLOSURE 1

# REVISED PRESSURE TEMPERATURE CURVES METHODOLOGY AND SUPPORTING CALCULATIONS PROVIDED FOR COOPER NUCLEAR STATION BY STRUCTURAL INTEGRITY ASSOCIATES, INC.

## COOPER NUCLEAR STATION
## NRC DOCKET 50-298, LICENSE DPR-46

**Structural Integrity Associates, Inc.**

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October 15, 2003
CRL-03-004
SIR-03-074, Rev. 1

Mr. Ken Thomas
Nebraska Public Power District
Cooper Nuclear Station
P. O. Box 98
Brownville, NE 68321

Subject: Updated Pressure-Temperature Curves for Cooper

Reference: Cooper Purchase Order No. 4500000438 dated 03/06/2003.

Dear Ken:

The attachment to this letter documents the updated set of pressure-temperature (P-T) curves developed for the Cooper Nuclear Station, in accordance with SI's Quality Assurance Program. This work was performed in accordance with the referenced contract, and includes a full set of updated P-T curves (i.e., pressure test, core not critical, and core critical conditions) for 32 effective full power years (EFPY). The curves were developed in accordance with 1995 Edition, 1996 Addenda ASME Code Section XI Appendix G, U.S. 10CFR 50 Appendix G, and ASME Code Case N-640.

The inputs, methodology, and results for this effort are summarized in the attachment. The calculations for this work (COOP-05Q-301 and -302) are also attached.

Please don't hesitate to call me if you have any questions.

Prepared By: Carl R. Limpus, Engineer

Reviewed By: Bryan P. Templeton, Engineer

Approved By: Gary L. Stevens, P. E., Senior Associate

crl
Attachments
cc: COOP-05Q-401

# ATTACHMENT

## Updated P-T Curves for Cooper

### 1.0 Introduction

This attachment documents the updated set of pressure-temperature (P-T) curves developed for the Cooper Nuclear Station (CNS). This work includes a full set of updated P-T curves (i.e., pressure test, core not critical, and core critical conditions) for 32 effective full power years (EFPY). The curves were developed using the methodology specified in ASME Code Case N-640 [4], as well as the 1995 Edition, 1996 Addenda ASME Code Section XI Appendix G [3], 10CFR50 Appendix G [1], and WRC-175 [7]. The improvement realized from the Code Case methodology is as much as 60°F, and is primarily obtained from using the critical fracture toughness, $K_{IC}$, in accordance with Code Case N-640.

### 2.0 $RT_{NDT}$ Values

Adjusted reference temperature (ART) values were obtained from Reference [5] for the Cooper reactor pressure vessel (RPV) materials in accordance with NRC Regulatory Guide 1.99, Revision 2 [9]. Table 1 shows the results of the calculations for 32 EFPY. The most limiting beltline material is the Lower Intermediate Longitudinal Weld.

## *Table 1: Cooper RPV Material ART 32 EFPY Calculations*

| Component | Part No. | Heat No. | Initial $RT_{NDT}$ (°F) | Chemistry | | Chemistry Factor (°F) | Adjustments For 1/4t | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Cu (wt %) | Ni (wt %) | | $\Delta RT_{NDT}$ (°F) | Margin Terms | | ART (°F) |
| | | | | | | | | $\sigma_\Delta$ (°F) | $\sigma_I$ (°F) | |
| **Beltline Plates**[1] | | | | | | | | | | |
| Lower Shell Plates | G2803-1 | C2274-1 | 14.0 | 0.20 | 0.68 | 153.00 | 87.5 | 17.0 | 0.0 | 118.5 |
| | G2803-2 | C2307-1 | 0.0 | 0.21 | 0.73 | 162.80 | 93.1 | 17.0 | 0.0 | 110.1 |
| | G2803-3 | C2274-2 | -8.0 | 0.20 | 0.68 | 153.00 | 87.5 | 17.0 | 0.0 | 96.5 |
| Lower-Intermediate Shell Plates | G2801-7 | C2407-1 | -10.0 | 0.13 | 0.65 | 92.25 | 64.6 | 17.0 | 0.0 | 71.6 |
| | G2802-1 | C2331-2 | 10.0 | 0.17 | 0.58 | 125.30 | 87.7 | 17.0 | 0.0 | 114.7 |
| | G2802-2 | C2307-2 | -20.0 | 0.21 | 0.73 | 162.80 | 113.9 | 17.0 | 0.0 | 110.9 |
| **Beltline Welds**[1] | | | | | | | | | | |
| Lower Longitudinal | 2-233 | 12420 | -50.0 | 0.22 | 1.02 | 234.50 | 133.0 | 28.0 | 0.0 | 111.0 |
| Lower-Intermediate Longitudinal | 1-233 | 27204 | -50.0 | 0.19 | 0.97 | 215.65 | 149.6 | 28.0 | 0.0 | 127.6 |
| Lower to Lower-Intermediate Girth | 1-240 | 21935 | -50.0 | 0.20 | 0.69 | 175.30 | 121.6 | 28.0 | 0.0 | 99.6 |
| **Non-Beltline Regions**[2] | | | | | | | | | | |
| Closure Flange Region | — | — | 20.0 | — | — | — | — | — | — | 20.0 |
| Bottom Head Region | — | — | 28.0 | — | — | — | — | — | — | 28.0 |

| Fluence Location | Wall Thickness (in.) | | Peak Fluence at ID for 32 EFPY EOL | Attenuation @ 1/4t = $e^{-0.24x}$ | Peak Fluence @ 1/4t for 32 EFPY = f (n/cm2) | Fluence Factor, FF $f^{(0.28 - 0.10 \log f)}$ |
|---|---|---|---|---|---|---|
| | Full | 1/4t | | | | |
| Lower-Int. Shell | 5.375 | 1.344 | 1.57E+18 | 0.724 | 1.14E+18 | 0.443 |
| Lower Shell | 6.375 | 1.594 | 1.10E+18 | 0.682 | 7.52E+17 | 0.362 |

| Surveillance Adjustment | |
|---|---|
| Plates | Welds |
| 1.58 | 1.57 |

Note 1: Beltline material input per Table 7-2 of Reference [5]
Note 2: Non-beltline material input per Reference [5].

## 3.0 P-T Curve Methodology

The P-T curve methodology is based on the requirements of References [1] through [4] and [7]. The supporting calculations for the curves are contained in References [10] and [11]. There are three regions of the reactor pressure vessel (RPV) that are evaluated: (1) the beltline region, (2) the bottom head region, and (3) the feedwater nozzle/upper vessel region. These regions bound all other regions with respect to brittle fracture.

The approach used for the beltline and bottom head (all curves), and upper vessel (Curve A only) includes the following steps:

a. Assume a fluid temperature, T. The temperature of the metal at the assumed flaw tip, $T_{1/4t}$ (i.e., 1/4t into the vessel wall) is conservatively assumed equal to the fluid temperature. The assumed temperature must also account for an instrument uncertainty of 5°F [15].

b. Calculate the allowable stress intensity factor, $K_{IC}$, based on $T_{1/4t}$ using the relationship from Code Case N-640 [4], as follows:

$$K_{IC} = 20.734\, e^{[0.02(T_{1/4t} - ART_{NDT})]} + 33.2 \qquad \text{(eqn. from Ref. [2])}$$

where:
- $T_{1/4t}$ = metal temperature at assumed flaw tip (°F)
- $ART_{NDT}$ = adjusted reference temperature for location under consideration and desired EFPY (°F)
- $K_{IC}$ = allowable stress intensity factor (ksi√inch)

c. Calculate the thermal stress intensity factor, $K_{IT}$ for the beltline and bottom head regions, or from finite element results for the feedwater nozzle/upper vessel region.

d. Calculate the allowable pressure stress intensity factor, $K_{IP}$, using the following relationship:

$$K_{IP} = (K_{IC} - K_{IT})/SF$$

where:
- $K_{IP}$ = allowable pressure stress intensity factor (ksi√inch)
- SF = safety factor
  - = 1.5 for pressure test conditions (Curve A)
  - = 2.0 for heatup/cooldown conditions (Curves B and C)

e. Compute the allowable pressure, P, from the allowable pressure stress intensity factor, $K_{IP}$.

f. Subtract any applicable adjustments for pressure from P. The beltline and bottom head include a pressure adjustment of 19.9 psig to account for the static pressure head of a full vessel. An instrument error of 24.0 psig (2% of 1,200 psig) was applied [15].

g. Repeat steps (a) through (f) for other temperatures to generate a series of P-T points.

The approach used for the upper vessel (Curves B & C) includes the following steps:

a. Assume a fluid pressure, P. The pressure includes an instrument uncertainty of 24.0 psig [15].

b. Calculate the thermal stress intensity factor, $K_{IT}$, based on finite element stresses. The feedwater nozzle stresses were obtained from the finite element analysis results contained in Reference [8]. The highest linearized (membrane and membrane + bending) thermal stresses for the entire design basis transients were selected to encompass all expected operating conditions.

$\sigma_{ys}$ = 43.975 ksi @ 575°F for SA-508 Cl. 2 [8, 12]

Calculate $t^{1/2}$. The resulting $M_m$ value is obtained from G-2214.1[3].

$K_{Im}$ is calculated from the equation in Paragraph G-2214.1 [3]:

$$K_{Im} = M_m * \sigma_{sm}$$

$K_{Ib}$ is calculated from the equation in Paragraph G-2214.2 [3]:

$$K_{Ib} = (2/3) M_m * \sigma_{sb}$$

The total $K_{IT}$ is therefore:

$$K_{IT} = R*SF*(K_{Im} + K_{Ib})$$

where: R = correction factor, calculated to consider the nonlinear effects in the plastic region based on the assumptions and recommendations of WRC Bulletin 175 [7].

= $[\sigma_{ys} - \sigma_{pm} + ((\sigma_{total} - \sigma_{ys}) / 30)] / (\sigma_{total} - \sigma_{pm})$

SF = Safety Factor for $K_{IT}$

= 1.3 (conservatively used based on the recommendation in WRC-175 [7])

c. Compute the allowable pressure stress intensity factor, $K_{IP}$, is as follows:

$$K_{IP} = F(a/r_n)\sqrt{\pi a}\ \sigma_{pm}$$

where:

| | | |
|---|---|---|
| $r_i$ | = | actual inner radius of nozzle |
| $r_c$ | = | nozzle corner radius [14] |
| $r_n$ | = | apparent radius of nozzle = $r_i + 0.29r_c$ |
| t' | = | nozzle corner thickness |
| a | = | crack depth (inches) |
| | = | 1/4 t' |
| $F(a,r_n)$ | = | nozzle stress factor, from Figure A5-1 of [7] |
| $K_{IP}$ | = | allowable pressure stress intensity factor (ksi$\sqrt{\text{inch}}$). |
| $\sigma_{pm}$ | = | primary membrane stress, PR/t (primary bending stresses are conservatively treated as membrane stresses, so $\sigma_{pb} = 0$) |

d. Calculate the allowable stress intensity factor, $K_{IC}$, using the following relationship for a heatup/cooldown P-T curve:

$$K_{IP} = \frac{K_{IC} - K_{IT}}{2.0}$$

thus: $K_{IC} = 2.0K_{IP} + K_{IT}$

e. Calculate the temperature, $T_{1/4t}$, using the relationship from Code Case N-640 [4], as follows:

$$K_{IC} = 20.734\ e^{[0.02(T_{1/4t} - ART_{NDT})]} + 33.2 \quad \text{(eqn. from Ref. [2])}$$

where:

| | | |
|---|---|---|
| $T_{1/4t}$ | = | metal temperature at assumed flaw tip (°F), assumed equal to T, the temperature at the inner vessel wall |
| $ART_{NDT}$ | = | adjusted reference temperature for location under consideration and desired EFPY (°F) |
| $K_{IC}$ | = | allowable stress intensity factor (ksi$\sqrt{\text{inch}}$) |

thus:

$$T_{1/4t} = 50 * LN\left[\frac{K_{IC} - 33.2}{20.734}\right] + ART_{NDT}$$

f. The curve was generated by scaling the stresses used to determine the pressure and thermal stress intensity factors. The primary stresses were scaled based on pressure, while the secondary stresses were scaled based on temperature difference.

g. Repeat steps (a) through (f) for other pressures to generate a series of P-T points.

The following additional requirements were used to define the P-T curves. These limits are established in Reference [1]:

<u>*For Pressure Test Conditions (Curve A):*</u>

- If the calculated pressure, P, is greater than 20% of the pre-service hydro test pressure, the temperature must be greater than $RT_{NDT}$ of the limiting flange material + 90°F. The pre-service hydro test pressure was 1,563 psig, and the limiting flange material has an $RT_{NDT}$ of 20°F [5].

- If the calculated pressure, P, is less than or equal to 20% of the pre-service hydro test pressure, the minimum temperature is typically greater than or equal to the $RT_{NDT}$ of the limiting flange material. GE typically applies an additional 60°F margin to the $RT_{NDT}$ value and has been a standard recommendation for the BWR industry for non-ductile failure protection. For the Cooper flange material, this minimum would be 80°F (i.e., 20 + 60°F). Since the 60°F margin is only a recommendation, the minimum temperature for Cooper was set to 80°F to be consistent with past work as well as adequately encompass instrument uncertainty. The gauge's uncertainty of +/- 5°F is not applied here since the included margin just described adequately encompasses instrument uncertainty.

<u>*For Core Not Critical Conditions (Curve B):*</u>

- If the calculated pressure, P, is greater than 20% of the pre-service hydro test pressure, the temperature must be greater than $RT_{NDT}$ of the limiting flange material + 120°F. The pre-service hydro test pressure was 1,563 psig, and the limiting flange material has an $RT_{NDT}$ of 20°F [5].

- If the calculated pressure, P, is less than or equal to 20% of the pre-service hydro test pressure, the minimum temperature is typically greater than or equal to the $RT_{NDT}$ of the limiting flange material. GE typically applies an additional 60°F margin to the $RT_{NDT}$ value and has been a standard recommendation for the BWR industry for non-ductile failure protection. For the Cooper flange material, this minimum would be 80°F (i.e., 20 + 60°F). Since the 60°F margin is only a recommendation, the minimum temperature for Cooper was set to 80°F to be consistent with past work as well as adequately encompass instrument uncertainty. The gauge's uncertainty of +/- 5°F is not applied here since the included margin just described adequately encompasses instrument uncertainty.

*For Core Critical Conditions (Curve C):*

- Per the requirements of Table 1 of Reference [1], the core critical P-T limits must be 40°F above any Pressure Test or Core Not Critical curve limits. Core Not Critical conditions are more limiting than Pressure Test conditions, so Core Critical conditions are equal to Core Not Critical conditions plus 40°F.

- Another requirement of Table 1 of Reference [1] (or actually an allowance for the BWR), concerns minimum temperature for initial criticality in a startup. Given that water level is normal, BWRs are allowed initial criticality at the closure flange region temperature (ART + 60°F) if the pressure is below 20% of the pre-service hydro test pressure.

- Also per Table 1 of Reference [1], at pressures above 20% of the pre-service hydro test pressure, the Core Critical curve temperature must be at least that required for the pressure test (Pressure Test Curve at 1,100 psig). As a result of this requirement, the Core Critical curve must have a step at a pressure equal to 20% of the pre-service hydro pressure to the temperature required by the Pressure Test curve at 1,100 psig, or Curve B + 40°F, whichever is greater.

After accounting for instrument uncertainties, the resulting pressure and temperature series constitutes the P-T curve. The P-T curve relates the minimum required fluid temperature to the reactor pressure.

## 5.0 P-T Curves

Tabulated values for the P-T curves are shown in Tables 2 through 8. The resulting P-T curves are shown in Figures 1 through 3. Note that the upper vessel (non-beltline) curve is limiting for core not critical conditions for 32 EFPY.

## 6.0 References


1. U. S. Code of Federal Regulations, Title 10, Part 50, Appendix G, "Fracture Toughness Requirements," 1-1-98 Edition.

2. ASME Boiler and Pressure Vessel Code, Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components, Nonmandatory Appendix A, "Analysis of Flaws," ~~1996 Edition.~~ 1995 Edition, 1996 Addenda XXX 11/17/03

3. ASME Boiler and Pressure Vessel Code, Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components, Nonmandatory Appendix G, "Fracture Toughness Criteria for Protection Against Failure," ~~1996 Edition~~. 1995 Edition, 1996 Addenda XX 11/17/03

4. ASME Boiler and Pressure Vessel Code, Code Case N-640, "Alternative Reference Fracture Toughness for Development of P-T Limit Curves," Section XI, Division 1, Approved February 26, 1999.

5. GE Document No. GE-NE-523-159-1292 (DRF B13-01662), "Cooper Nuclear Station Vessel Surveillance Materials Testing and Fracture Toughness Analysis," Revision 0, February 1993, SI File No. COOP-05Q-202.

6. Not Used.

7. WRC Bulletin 175, "PVRC Recommendations on Toughness Requirements for Ferritic Materials," PVRC Ad Hoc Group on Toughness Requirements, Welding Research Council, August 1972.

8. CBI Stress Report DC22A7245, Revision 0, "Feedwater Nozzle Modification Cooper RPV," 3/20/80, SI File NPPD-13Q-205.

9. USNRC Regulatory Guide 1.99, Revision 2, "Radiation Embrittlement of Reactor Vessel Materials," U. S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, (Task ME 305-4), May 1988.

10. SI Calculation No. COOP-05Q-301, Revision 1, "Development of Updated Pressure Test (Curve A) P-T Curves," October 2003.

11. SI Calculation No. COOP-05Q-302, Revision 1, "Development of Updated Heatup/Cooldown (Curves B & C) P-T Curves," October 2003.

12. ASME Boiler and Pressure Vessel Code, Section III, Rules for Construction of Nuclear Power Plant Components, Division 1, Appendices, 1989 Edition.

13. Combustion Engineering Drawing No. E-232-230, Revision 3, "General Arrangement Elevation for: General Electric Co. APED 218" I.D. BWR," SI File No. NPPD-06Q-208.

14. SI Calculation NPPD-13Q-302, Revision 0, "Feedwater Nozzle Stress Analysis."

15. NPPD Memo DED 2003-005, Alan Able to Ken Thomas, dated August 14, 2003, "Instrument Uncertainty Associated With Technical Specification 3.4.9," SI File No. COOP-05Q-203.

# Table 2

## Tabulated Values for Beltline Pressure Test Curve (Curve A) for 32 EFPY

## *Pressure-Temperature Curve Calculation*

*(Pressure Test = Curve A)*

***Inputs:***

Plant = Cooper
Component = Beltline
Vessel thickness, t = 5.875 inches, so √t = 2.424 √inch
Vessel Radius, R = 110.375 inches
ART = 127.6 °F ======> 32 EFPY
Cooldown Rate, CR = 0 °F/hr
$K_{IT}$ = 0.00 ksi*inch$^{1/2}$
$\Delta T_{1/4t}$ = 0.0 °F (no thermal for pressure test)
Safety Factor = 1.50 (for pressure test)
$M_m$ = 2.24
Temperature Adjustment = 5.0 °F
Height of Water for a Full Vessel = 551.75 inches
Pressure Adjustment = 19.9 psig (hydrostatic pressure for a full vessel at 70°F)
Pressure Adjustment = 24.0 psig (Instrument Uncertainty)
Hydro Test Pressure = 1,563 psig
Flange $RT_{NDT}$ = 20.0 °F

| Gauge Fluid Temperature (°F) | 1/4t Temperature (°F) | $K_{IC}$ (ksi*inch$^{1/2}$) | $K_{IP}$ (ksi*inch$^{1/2}$) | Calculated Pressure P (psig) | Temperature for P-T Curve (°F) | Adjusted Pressure for P-T Curve (psig) |
|---|---|---|---|---|---|---|
| 80.0 | 80.0 | 41.20 | 27.47 | 0 | 80.0 | 0 |
| 80.0 | 75.0 | 40.44 | 26.96 | 641 | 80.0 | 597 |
| 82.0 | 77.0 | 40.74 | 27.16 | 645 | 82.0 | 601 |
| 84.0 | 79.0 | 41.04 | 27.36 | 650 | 84.0 | 606 |
| 86.0 | 81.0 | 41.36 | 27.58 | 655 | 86.0 | 611 |
| 88.0 | 83.0 | 41.70 | 27.80 | 661 | 88.0 | 617 |
| 90.0 | 85.0 | 42.04 | 28.03 | 666 | 90.0 | 622 |
| 92.0 | 87.0 | 42.41 | 28.27 | 672 | 92.0 | 628 |
| 94.0 | 89.0 | 42.78 | 28.52 | 678 | 94.0 | 634 |
| 96.0 | 91.0 | 43.17 | 28.78 | 684 | 96.0 | 640 |
| 98.0 | 93.0 | 43.58 | 29.05 | 690 | 98.0 | 646 |
| 100.0 | 95.0 | 44.00 | 29.33 | 697 | 100.0 | 653 |
| 105.0 | 100.0 | 45.14 | 30.09 | 715 | 105.0 | 671 |
| 110.0 | 105.0 | 46.39 | 30.93 | 735 | 110.0 | 691 |
| 115.0 | 110.0 | 47.78 | 31.85 | 757 | 115.0 | 713 |
| 120.0 | 115.0 | 49.32 | 32.88 | 781 | 120.0 | 737 |
| 125.0 | 120.0 | 51.01 | 34.01 | 808 | 125.0 | 764 |
| 130.0 | 125.0 | 52.88 | 35.26 | 838 | 130.0 | 794 |
| 135.0 | 130.0 | 54.95 | 36.64 | 871 | 135.0 | 827 |
| 140.0 | 135.0 | 57.24 | 38.16 | 907 | 140.0 | 863 |
| 145.0 | 140.0 | 59.77 | 39.85 | 947 | 145.0 | 903 |
| 150.0 | 145.0 | 62.56 | 41.71 | 991 | 150.0 | 947 |
| 155.0 | 150.0 | 65.65 | 43.77 | 1040 | 155.0 | 996 |
| 160.0 | 155.0 | 69.07 | 46.04 | 1094 | 160.0 | 1,050 |
| 165.0 | 160.0 | 72.84 | 48.56 | 1154 | 165.0 | 1,110 |
| 170.0 | 165.0 | 77.01 | 51.34 | 1220 | 170.0 | 1,176 |
| 175.0 | 170.0 | 81.61 | 54.41 | 1293 | 175.0 | 1,249 |
| 180.0 | 175.0 | 86.70 | 57.80 | 1374 | 180.0 | 1,330 |
| 185.0 | 180.0 | 92.33 | 61.55 | 1463 | 185.0 | 1,419 |
| 190.0 | 185.0 | 98.55 | 65.70 | 1561 | 190.0 | 1,517 |
| 195.0 | 190.0 | 105.42 | 70.28 | 1670 | 195.0 | 1,626 |
| 200.0 | 195.0 | 113.02 | 75.35 | 1790 | 200.0 | 1,746 |

Table 3
**Tabulated Values for Bottom Head Pressure Test Curve (Curve A)**

***Pressure-Temperature Curve Calculation***

*(Pressure Test = Curve A)*

***Inputs:***

| | | | | |
|---|---|---|---|---|
| Plant = | Cooper | | | |
| Component = | Bottom Head | (Penetrations Portion) | | |
| Vessel thickness, t = | 3.188 | inches, so √t = | 1.785 | √inch |
| Vessel Radius, R = | 110.375 | inches | | |
| ART = | 28.0 | °F ======> | All EFPYs | |
| Safety Factor = | 1.50 | | | |
| Safety Factor = | 3.00 | Bottom Head Penetrations | | |
| $M_m$ = | 1.85 | | | |
| Temperature Adjustment = | 5.0 | °F (Instrument Uncertainty) | | |
| Height of Water for a Full Vessel = | 551.75 | inches | | |
| Pressure Adjustment = | 19.9 | psig (hydrostatic pressure for a full vessel at 70°F) | | |
| Pressure Adjustment = | 24.0 | psig (Instrument Uncertainty) | | |
| Unit Pressure = | 1,563 | psig | | |
| Flange $RT_{NDT}$ = | 20.0 | °F | | |

| Gauge Fluid Temperature (°F) | 1/4t Temperature (°F) | $K_{IC}$ (ksi*inch$^{1/2}$) | $K_{IP}$ (ksi*inch$^{1/2}$) | Calculated Pressure P (psig) | Temperature for P-T Curve (°F) | Adjusted Pressure for P-T Curve (psig) |
|---|---|---|---|---|---|---|
| 80.0 | 80.0 | 91.86 | 61.24 | 0 | 80 | 0 |
| 80.0 | 75.0 | 86.28 | 57.52 | 599 | 80 | 555 |
| 82.0 | 77.0 | 88.44 | 58.96 | 614 | 82 | 570 |
| 84.0 | 79.0 | 90.70 | 60.47 | 629 | 84 | 585 |
| 86.0 | 81.0 | 93.05 | 62.03 | 646 | 86 | 602 |
| 88.0 | 83.0 | 95.49 | 63.66 | 662 | 88 | 619 |
| 90.0 | 85.0 | 98.03 | 65.35 | 680 | 90 | 636 |
| 92.0 | 87.0 | 100.68 | 67.12 | 698 | 92 | 655 |
| 94.0 | 89.0 | 103.43 | 68.95 | 718 | 94 | 674 |
| 96.0 | 91.0 | 106.30 | 70.86 | 737 | 96 | 694 |
| 98.0 | 93.0 | 109.28 | 72.85 | 758 | 98 | 714 |
| 100.0 | 95.0 | 112.38 | 74.92 | 780 | 100 | 736 |
| 102.0 | 97.0 | 115.62 | 77.08 | 802 | 102 | 758 |
| 104.0 | 99.0 | 118.98 | 79.32 | 825 | 104 | 782 |
| 106.0 | 101.0 | 122.48 | 81.65 | 850 | 106 | 806 |
| 108.0 | 103.0 | 126.12 | 84.08 | 875 | 108 | 831 |
| 110.0 | 105.0 | 129.92 | 86.61 | 901 | 110 | 857 |
| 112.0 | 107.0 | 133.86 | 89.24 | 929 | 112 | 885 |
| 114.0 | 109.0 | 137.97 | 91.98 | 957 | 114 | 913 |
| 116.0 | 111.0 | 142.25 | 94.83 | 987 | 116 | 943 |
| 118.0 | 113.0 | 146.70 | 97.80 | 1018 | 118 | 974 |
| 120.0 | 115.0 | 151.33 | 100.89 | 1050 | 120 | 1,006 |
| 122.0 | 117.0 | 156.15 | 104.10 | 1083 | 122 | 1,039 |
| 124.0 | 119.0 | 161.17 | 107.44 | 1118 | 124 | 1,074 |
| 126.0 | 121.0 | 166.39 | 110.93 | 1154 | 126 | 1,110 |
| 128.0 | 123.0 | 171.83 | 114.55 | 1192 | 128 | 1,148 |
| 130.0 | 125.0 | 177.48 | 118.32 | 1231 | 130 | 1,187 |
| 132.0 | 127.0 | 183.37 | 122.25 | 1272 | 132 | 1,228 |
| 134.0 | 129.0 | 189.50 | 126.33 | 1315 | 134 | 1,271 |
| 136.0 | 131.0 | 195.88 | 130.59 | 1359 | 136 | 1,315 |
| 138.0 | 133.0 | 202.52 | 135.01 | 1405 | 138 | 1,361 |
| 140.0 | 135.0 | 209.43 | 139.62 | 1453 | 140 | 1,409 |
| 142.0 | 137.0 | 216.62 | 144.41 | 1503 | 142 | 1,459 |
| 144.0 | 139.0 | 224.10 | 149.40 | 1555 | 144 | 1,511 |
| 146.0 | 141.0 | 231.90 | 154.60 | 1609 | 146 | 1,565 |
| 148.0 | 143.0 | 240.00 | 160.00 | 1665 | 148 | 1,621 |

## Table 4
**Tabulated Values for Feedwater Nozzle/Upper Vessel Region Pressure Test Curve (Curve A)**

# *Pressure-Temperature Curve Calculation*

*(Pressure Test = Curve A)*

***Inputs:***

| | | |
|---|---|---|
| Plant = | Cooper | |
| Component = | Upper Vessel | (based on FW nozzle) |
| ART = | 20.0 | °F ======> All EFPYs |
| Vessel thickness, t = | 5.875 | inches, so √t = 2.424 √inch |
| Vessel Radius, R = | 110.375 | inches |
| Nozzle corner thickness, t' = | 7.108 | inches, approximate |
| F(a/m) = | 1.6 | nozzle stress factor |
| Crack Depth, a = | 1.777 | inches |
| Safety Factor = | 1.50 | |
| Temperature Adjustment = | 5.0 | °F (not applied) |
| Height of Water for a Full Vessel = | 551.75 | inches |
| Pressure Adjustment = | 19.9 | psig (hydrostatic pressure for a full vessel at 70°F) |
| Pressure Adjustment = | 24.0 | psig (Instrument Uncertainty) |
| Unit Pressure = | 1,563 | psig |
| Flange $RT_{NDT}$ = | 20.0 | °F |

| Gauge Fluid Temperature (°F) | 1/4t Temperature (°F) | $K_{IC}$ (ksi*inch$^{1/2}$) | $K_{IP}$ (ksi*inch$^{1/2}$) | Calculated Pressure P (psig) | Temperature for P-T Curve (°F) | Adjusted Pressure for P-T Curve (psig) |
|---|---|---|---|---|---|---|
| 80.0 | 80.0 | 102.04 | 68.03 | 0 | 80.0 | 0 |
| 80.0 | 80.0 | 102.04 | 68.03 | 313 | 80.0 | 269 |
| 118.0 | 118.0 | 180.40 | 120.26 | 313 | 123.0 | 269 |
| 118.0 | 118.0 | 180.40 | 120.26 | 1693 | 123.0 | 1649 |
| 123.0 | 123.0 | 195.88 | 130.59 | 1839 | 128.0 | 1795 |
| 128.0 | 128.0 | 200.00 | 133.33 | 1877 | 133.0 | 1833 |
| 133.0 | 133.0 | 200.00 | 133.33 | 1877 | 138.0 | 1833 |
| 138.0 | 138.0 | 200.00 | 133.33 | 1877 | 143.0 | 1833 |

## Table 5
## Tabulated Values for Beltline Core Not Critical Curve (Curve B) for 32 EFPY

### *Pressure-Temperature Curve Calculation*
*(Heatup/Cooldown, Core Not Critical = Curve B)*

***Inputs:***

Plant = Cooper
Component = Beltline
Vessel thickness, t = 5.875 inches, so √t = 2.424 √inch
Vessel Radius, R = 110.375 inches
ART = 127.6 °F ======> 32 EFPY
Cooldown Rate, CR = 100 °F/hr
$K_{IT}$ = 7.97 ksi*inch$^{1/2}$
$\Delta T_{1/4t}$ = 0.0 °F = Conservatively assumed zero
Safety Factor = 2.00
$M_m$ = 2.24
Temperature Adjustment = 5.0 °F (Instrument Uncertainty) not applied
Height of Water for a Full Vessel = 551.75 inches
Pressure Adjustment = 19.9 psig (hydrostatic pressure for a full vessel at 70°F)
Pressure Adjustment = 24.0 psig (Instrument Uncertainty)
Hydro Test Pressure = 1,563 psig
Flange $RT_{NDT}$ = 20.0 °F

| Gauge Fluid Temperature (°F) | 1/4t Temperature (°F) | $K_{IC}$ (ksi*inch$^{1/2}$) | $K_{IP}$ (ksi*inch$^{1/2}$) | Calculated Pressure P (psig) | Temperature for P-T Curve (°F) | Adjusted Pressure for P-T Curve (psig) |
|---|---|---|---|---|---|---|
| 80.0 | 75.0 | 40.44 | 16.23 | 0 | 80.0 | 0 |
| 80.0 | 75.0 | 40.44 | 16.23 | 385 | 80.0 | 341 |
| 82.0 | 77.0 | 40.74 | 16.38 | 388 | 82.0 | 345 |
| 87.0 | 82.0 | 41.53 | 16.78 | 398 | 87.0 | 354 |
| 92.0 | 87.0 | 42.41 | 17.22 | 408 | 92.0 | 364 |
| 97.0 | 92.0 | 43.37 | 17.70 | 420 | 97.0 | 376 |
| 102.0 | 97.0 | 44.44 | 18.24 | 432 | 102.0 | 389 |
| 107.0 | 102.0 | 45.63 | 18.83 | 446 | 107.0 | 403 |
| 112.0 | 107.0 | 46.93 | 19.48 | 462 | 112.0 | 418 |
| 117.0 | 112.0 | 48.38 | 20.20 | 479 | 117.0 | 435 |
| 122.0 | 117.0 | 49.97 | 21.00 | 498 | 122.0 | 454 |
| 127.0 | 122.0 | 51.74 | 21.88 | 519 | 127.0 | 475 |
| 132.0 | 127.0 | 53.69 | 22.86 | 542 | 132.0 | 498 |
| 137.0 | 132.0 | 55.84 | 23.93 | 568 | 137.0 | 524 |
| 142.0 | 137.0 | 58.22 | 25.12 | 596 | 142.0 | 552 |
| 147.0 | 142.0 | 60.85 | 26.44 | 627 | 147.0 | 583 |
| 152.0 | 147.0 | 63.76 | 27.89 | 662 | 152.0 | 618 |
| 157.0 | 152.0 | 66.98 | 29.50 | 700 | 157.0 | 656 |
| 162.0 | 157.0 | 70.53 | 31.28 | 742 | 162.0 | 698 |
| 167.0 | 162.0 | 74.46 | 33.24 | 788 | 167.0 | 744 |
| 172.0 | 167.0 | 78.79 | 35.41 | 840 | 172.0 | 796 |
| 177.0 | 172.0 | 83.59 | 37.81 | 897 | 177.0 | 853 |
| 182.0 | 177.0 | 88.89 | 40.46 | 959 | 182.0 | 916 |
| 187.0 | 182.0 | 94.75 | 43.39 | 1029 | 187.0 | 985 |
| 192.0 | 187.0 | 101.22 | 46.62 | 1106 | 192.0 | 1,062 |
| 197.0 | 192.0 | 108.37 | 50.20 | 1190 | 197.0 | 1,147 |
| 202.0 | 197.0 | 116.28 | 54.15 | 1284 | 202.0 | 1,240 |
| 207.0 | 202.0 | 125.01 | 58.52 | 1388 | 207.0 | 1,344 |
| 212.0 | 207.0 | 134.67 | 63.35 | 1502 | 212.0 | 1,458 |
| 217.0 | 212.0 | 145.34 | 68.69 | 1629 | 217.0 | 1,585 |
| 222.0 | 217.0 | 157.14 | 74.58 | 1769 | 222.0 | 1,725 |

## Table 6
## Tabulated Values for Bottom Head Vessel Region Core Not Critical Curve (Curve B)

### *Pressure-Temperature Curve Calculation*
*(Heatup/Cooldown, Core Not Critical = Curve B)*

***Inputs:***

| | | | | |
|---|---|---|---|---|
| Plant = | Cooper | | | |
| Component = | Bottom Head | (Penetrations Portion) | | |
| Vessel thickness, t = | 3.1875 | inches, so √t = | 1.785 | √inch |
| Vessel Radius, R = | 110.375 | inches | | |
| ART = | 28.0 | °F ======> | All EFPYs | |
| Safety Factor = | 2.00 | | | |
| Stress Concentration Factor = | 3.00 | Bottom Head Penetrations | | |
| Cooldown Rate, CR = | 100 | °F/hr | | |
| $M_m$ = | 1.65 | | | |
| $K_{IT}$ = | 1.73 | ksi*inch$^{1/2}$ | | |
| Temperature Adjustment = | 5.0 | °F, Instrument Uncertainty | | |
| Height of Water for a Full Vessel = | 551.75 | inches (normal full vessel water level) | | |
| Pressure Adjustment = | 19.9 | psig (full vessel at 70°F) | | |
| Pressure Adjustment = | 24.0 | psig (Instrument Uncertainty) | | |
| Unit Pressure = | 1,563 | psig | | |
| Flange $RT_{NDT}$ = | 20.0 | °F | | |

| Gauge Temperature T (°F) | Adjusted Temperature (°F) | $K_{IC}$ (ksi*inch$^{1/2}$) | $K_{IP}$ (ksi*inch$^{1/2}$) | Calculated Pressure P (psig) | Temperature for P-T Curve (°F) | Adjusted Pressure for P-T Curve (psig) |
|---|---|---|---|---|---|---|
| 80.0 | 75.0 | 86.28 | 42.27 | 0 | 80 | 0 |
| 80.0 | 75.0 | 86.28 | 42.27 | 492 | 80 | 448 |
| 82.0 | 77.0 | 88.44 | 43.36 | 505 | 82 | 461 |
| 86.0 | 81.0 | 93.05 | 45.66 | 532 | 86 | 488 |
| 90.0 | 85.0 | 98.03 | 48.15 | 561 | 90 | 517 |
| 94.0 | 89.0 | 103.43 | 50.85 | 592 | 94 | 548 |
| 98.0 | 93.0 | 109.28 | 53.78 | 626 | 98 | 582 |
| 102.0 | 97.0 | 115.62 | 56.94 | 663 | 102 | 619 |
| 106.0 | 101.0 | 122.48 | 60.38 | 703 | 106 | 659 |
| 110.0 | 105.0 | 129.92 | 64.09 | 746 | 110 | 702 |
| 114.0 | 109.0 | 137.97 | 68.12 | 793 | 114 | 749 |
| 118.0 | 113.0 | 146.70 | 72.48 | 844 | 118 | 800 |
| 122.0 | 117.0 | 156.15 | 77.21 | 899 | 122 | 855 |
| 126.0 | 121.0 | 166.39 | 82.33 | 959 | 126 | 915 |
| 130.0 | 125.0 | 177.48 | 87.88 | 1023 | 130 | 979 |
| 134.0 | 129.0 | 189.50 | 93.89 | 1093 | 134 | 1049 |
| 138.0 | 133.0 | 202.52 | 100.39 | 1169 | 138 | 1125 |
| 142.0 | 137.0 | 216.62 | 107.45 | 1251 | 142 | 1207 |
| 146.0 | 141.0 | 231.90 | 115.08 | 1340 | 146 | 1296 |
| 150.0 | 145.0 | 248.44 | 123.36 | 1437 | 150 | 1393 |
| 154.0 | 149.0 | 266.37 | 132.32 | 1541 | 154 | 1497 |
| 158.0 | 153.0 | 285.79 | 142.03 | 1654 | 158 | 1610 |

## Table 7
## Tabulated Values for Feedwater Nozzle/Upper Vessel Core Not Critical Curve (Curve B)

### *Pressure-Temperature Curve Calculation*
*(Heatup/Cooldown, Core Not Critical = Curve B)*

***Inputs:***

| | | |
|---|---|---|
| Plant = | **Cooper** | |
| Component = | **Upper Vessel** | |
| $RT_{NDT}$ = | **20.0** | °F |
| $\sigma_{pm}$ = | **21.315** | ksi for a pressure of 1,038 psig |
| $\sigma_{pb}$ = | **0.00** | ksi for a pressure of 1,038 psig |
| $\sigma_{sm}$ = | **5.895** | ksi for a temperature of 551°F |
| $\sigma_{sb}$ = | **18.41** | ksi for a temperature of 551°F |
| $\sigma_{ys}$ = | **43.975** | ksi @ 575°F |
| Nozzle corner thickness, t' = | **7.108** | inches, approximate √t' = 2.666 √inch |
| $M_m$ = | **2.469** | |
| a (1/4 t') = | **1.777** | |
| $F(a/r_n)$ = | **1.60** | |
| $K_{IT}$ Safety Factor = | **1.30** | |
| Temperature Adjustment = | **5.0** | °F |
| Pressure Adjustment = | **24.0** | psig |
| Hydro Test Pressure = | **1563** | psig |
| Flange $RT_{NDT}$ = | **20.0** | °F |

| Pressure P (psig) | Saturation Temperature (°F) | $K_{IT}$ (ksi*inch$^{1/2}$) | $K_{IP}$ (ksi*inch$^{1/2}$) | $K_{IAllowable}$ (ksi*inch$^{1/2}$) | Calculated Temperature T (°F) | Adjusted Temperature for P-T Curve (°F) | Adjusted Pressure for P-T Curve (psig) |
|---|---|---|---|---|---|---|---|
| 0 | 212.1 | 19.6 | 0.0 | 19.6 | — | 80 | 0 |
| 200.0 | 387.9 | 39.7 | 15.5 | 70.8 | 49.7 | 80 | 176 |
| 210.0 | 391.8 | 40.1 | 16.3 | 72.8 | 52.3 | 80 | 186 |
| 220.0 | 395.6 | 40.6 | 17.1 | 74.7 | 54.7 | 80 | 196 |
| 230.0 | 399.3 | 41.0 | 17.9 | 76.7 | 57.1 | 80 | 206 |
| 240.0 | 402.8 | 41.4 | 18.6 | 78.7 | 59.3 | 80 | 216 |
| 250.0 | 406.2 | 41.8 | 19.4 | 80.6 | 61.4 | 80 | 226 |
| 260.0 | 409.6 | 42.2 | 20.2 | 82.5 | 63.3 | 80 | 236 |
| 270.0 | 412.8 | 42.5 | 21.0 | 84.5 | 65.3 | 80 | 246 |
| 331.0 | 430.9 | 44.6 | 25.7 | 96.0 | 75.4 | 80 | 307 |
| 335.8 | 432.2 | 44.8 | 26.1 | 96.9 | 76.1 | 80 | 312 |
| 336.0 | 432.3 | 44.8 | 26.1 | 96.9 | 76.1 | 80 | 312 |
| 336.5 | 432.4 | 44.8 | 26.1 | 97.0 | 76.2 | 80 | 313 |
| 336.8 | 432.5 | 44.8 | 26.1 | 97.1 | 76.3 | 140 | 313 |
| 396.8 | 447.8 | 46.5 | 30.8 | 108.1 | 84.2 | 140 | 373 |
| 456.8 | 461.4 | 48.1 | 35.5 | 119.0 | 91.0 | 140 | 433 |
| 516.8 | 473.7 | 49.5 | 40.1 | 129.7 | 96.9 | 140 | 493 |
| 576.8 | 485.0 | 50.8 | 44.8 | 140.3 | 102.1 | 140 | 553 |
| 640.0 | 496.0 | 52.0 | 49.7 | 151.4 | 107.0 | 140 | 616 |
| 670.0 | 500.9 | 52.6 | 52.0 | 156.6 | 109.2 | 140 | 646 |
| 730.0 | 510.2 | 53.7 | 56.7 | 167.0 | 113.2 | 140 | 706 |
| 734.0 | 510.8 | 53.7 | 57.0 | 167.7 | 113.5 | 140 | 710 |
| 794.0 | 519.6 | 54.7 | 61.6 | 178.0 | 117.2 | 140 | 770 |
| 854.0 | 527.8 | 55.7 | 66.3 | 188.3 | 120.6 | 140 | 830 |
| 914.0 | 535.6 | 56.6 | 71.0 | 198.5 | 123.8 | 140 | 890 |
| 974.0 | 543.1 | 57.4 | 75.6 | 208.6 | 126.8 | 140 | 950 |
| 1034.0 | 550.2 | 54.7 | 80.3 | 215.2 | 128.6 | 140 | 1010 |
| 1094.0 | 556.9 | 51.9 | 84.9 | 221.7 | 130.4 | 140 | 1070 |
| 1154.0 | 563.4 | 49.0 | 89.6 | 228.2 | 132.1 | 140 | 1130 |
| 1214.0 | 569.7 | 46.2 | 94.2 | 234.7 | 133.7 | 140 | 1190 |
| 1274.0 | 575.7 | 43.3 | 98.9 | 241.2 | 135.3 | 140 | 1250 |
| 1334.0 | 581.5 | 40.5 | 103.6 | 247.6 | 136.8 | 142 | 1310 |
| 1394.0 | 587.1 | 37.7 | 108.2 | 254.1 | 138.3 | 143 | 1370 |
| 1454.0 | 592.5 | 34.8 | 112.9 | 260.6 | 139.7 | 145 | 1430 |
| 1514.0 | 597.7 | 32.0 | 117.5 | 267.1 | 141.1 | 146 | 1490 |
| 1574.0 | 602.8 | 29.2 | 122.2 | 273.5 | 142.5 | 148 | 1550 |
| 1634.0 | 607.7 | 26.3 | 126.8 | 280.0 | 143.8 | 149 | 1610 |

**Table 8**
**Tabulated Values for Core Critical Curve (Curve C) for 32 EFPY**

## Pressure-Temperature Curve Calculation
*(Core Critical = Curve C)*

***Inputs:***

Plant = Cooper
EFPY = 32
Curve A Leak Test Temperature = 145.0 °F (at 1,100 psig)
Hydro Test Pressure = 1,563 psig
Flange $RT_{NDT}$ = 20.0 °F

| Beltline | | Bottom Head | | Upper Vessel | | Composite Curve B | | Composite Curve C | |
|---|---|---|---|---|---|---|---|---|---|
| Curve B Temperature | Curve B Pressure | Curve B Temperature | Curve B Pressure | Curve B Temperature | Curve B Pressure | Minimum Temperature | Pressure | Minimum Temperature | Pressure |
| (°F) | (psig) | (°F) | (psig) | (°F) | (psig) | (°F) | (psig) | (°F) | (psig) |
| 80 | 0 | 80 | 0 | 80 | 0 | 80 | 0 | 80 | 0 |
| 80 | 341 | 80 | 448 | 80 | 176 | 80 | 176 | 80 | 176 |
| 82 | 345 | 82 | 461 | 80 | 186 | 80 | 186 | 80 | 186 |
| 87 | 354 | 86 | 488 | 80 | 196 | 80 | 196 | 80 | 196 |
| 92 | 364 | 90 | 517 | 80 | 206 | 80 | 206 | 80 | 206 |
| 97 | 376 | 94 | 548 | 80 | 216 | 80 | 216 | 80 | 216 |
| 102 | 389 | 98 | 582 | 80 | 226 | 80 | 226 | 80 | 226 |
| 107 | 403 | 102 | 619 | 80 | 236 | 80 | 236 | 80 | 236 |
| 112 | 418 | 106 | 659 | 80 | 246 | 80 | 246 | 80 | 246 |
| 117 | 435 | 110 | 702 | 80 | 307 | 80 | 307 | 80 | 307 |
| 122 | 454 | 114 | 749 | 80 | 312 | 80 | 312 | 80 | 312 |
| 127 | 475 | 118 | 800 | 80 | 312 | 80 | 312 | 80 | 312 |
| 132 | 498 | 122 | 855 | 80 | 313 | 80 | 313 | ~~86~~ 80 | 313 11/12/03 |
| 137 | 524 | 126 | 915 | 140 | 313 | 140 | 313 | 220 | 313 |
| 142 | 552 | 130 | 979 | 140 | 373 | 140 | 373 | 220 | 373 |
| 147 | 583 | 134 | 1049 | 140 | 433 | 140 | 433 | 220 | 433 |
| 152 | 618 | 138 | 1125 | 140 | 493 | 140 | 493 | 220 | 493 |
| 157 | 656 | 142 | 1207 | 140 | 553 | 140 | 553 | 220 | 553 |
| 162 | 698 | 146 | 1296 | 140 | 616 | 147 | 583 | 220 | 583 |
| 167 | 744 | 150 | 1393 | 140 | 646 | 152 | 618 | 220 | 618 |
| 172 | 796 | 154 | 1497 | 140 | 706 | 157 | 656 | 220 | 656 |
| 177 | 853 | 158 | 1610 | 140 | 710 | 162 | 698 | 220 | 698 |
| 182 | 916 | | | 140 | 770 | 167 | 744 | 220 | 744 |
| 187 | 985 | | | 140 | 830 | 172 | 796 | 220 | 796 |
| 192 | 1062 | | | 140 | 890 | 177 | 853 | 220 | 853 |
| 197 | 1147 | | | 140 | 950 | 182 | 916 | 220 | 916 |
| 202 | 1240 | | | 140 | 1010 | 187 | 985 | 220 | 985 |
| 207 | 1344 | | | 140 | 1070 | 192 | 1062 | 220 | 1062 |
| 212 | 1458 | | | 140 | 1130 | 197 | 1147 | 220 | 1147 |
| 217 | 1585 | | | 140 | 1190 | 202 | 1240 | 220 | 1240 |
| 222 | 1725 | | | 140 | 1250 | 207 | 1344 | 220 | 1344 |
| | | | | 142 | 1310 | 212 | 1458 | 220 | 1458 |
| | | | | 143 | 1370 | 217 | 1585 | 220 | 1585 |
| | | | | 145 | 1430 | 222 | 1725 | 220 | 1725 |
| | | | | 146 | 1490 | | | | |
| | | | | 148 | 1550 | | | | |
| | | | | 149 | 1610 | | | | |

Figure 1
Pressure Test P-T Curve (Curve A) for 32 EFPY

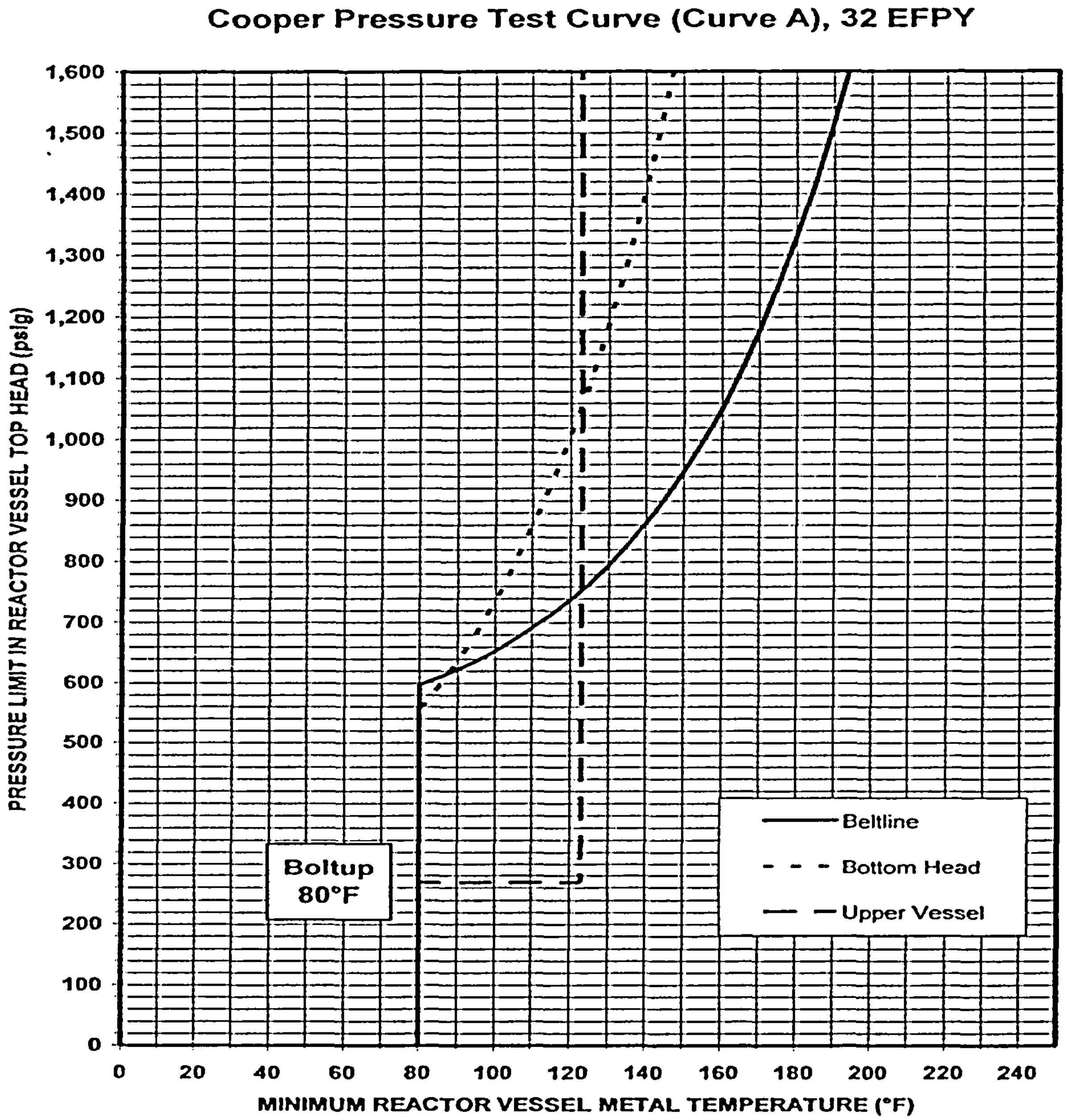


**Figure 2**
**Core Not Critical Curve (Curve B) for 32 EFPY**

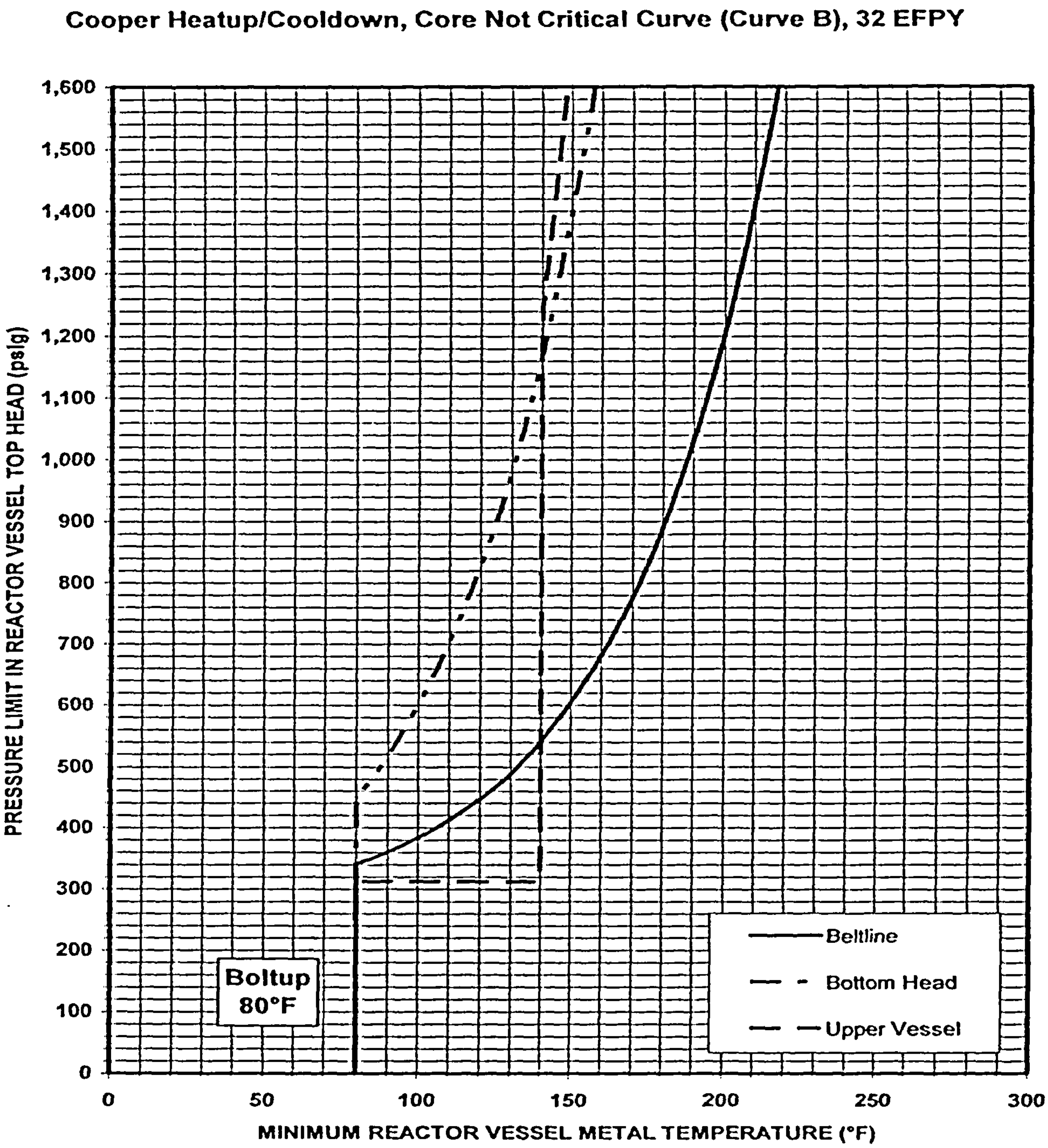
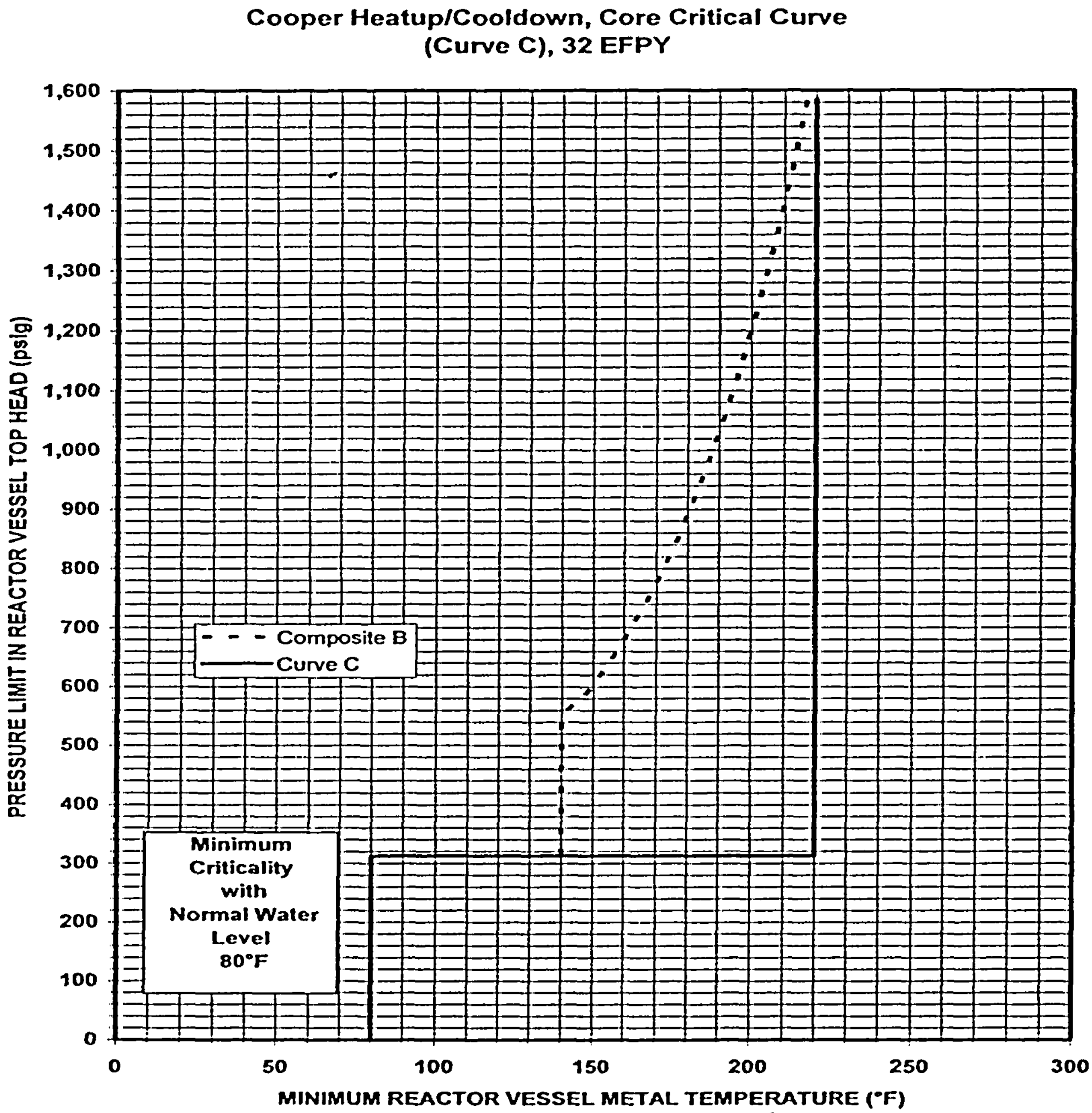


Figure 3
Core Critical Curve (Curve C) for 32 EFPY








Structural Integrity Associates, Inc.

| STRUCTURAL INTEGRITY Associates, Inc. | # CALCULATION PACKAGE | FILE No.: COOP-05Q-302<br>PROJECT No.: COOP-05Q |
|---|---|---|

**PROJECT NAME:** Develop Revised Pressure-Temperature Curves at Cooper Nuclear Station

**CLIENT:** Nebraska Public Power District (NPPD)

**CALCULATION TITLE:** Development of Updated Heatup/Cooldown (Curves B & C) P-T Curves

| Document Revision | Affected Pages | Revision Description | Project Mgr. Approval Signature & Date | Preparer(s) & Checker(s) Signatures & Date |
|---|---|---|---|---|
| A | 1-21<br>A1 – A4 In Computer Files | Draft Issue | G. L. Stevens 06/05/03 | C. R. Limpus 06/03/03<br>B. P. Templeton 06/03/03 |
| 0 | 1-21<br>A1 – A4<br>In Computer Files | Initial Issue | G. L. Stevens 08/11/03 | C. R. Limpus 08/11/03<br>B. P. Templeton 08/11/03 |
| 1 | 1-21<br>A1 – A4 In Computer Files | Revised to correct closure flange $RT_{NDT}$ and use ART values of record. | G. L. Stevens<br>[signature] 10/15/03 | C. R. Limpus<br>[signature] CRL 10/15/03<br>B. P. Templeton<br>[signature] BPT 10/15/2003 |

## Table of Contents



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## 1.0 INTRODUCTION / OBJECTIVE

This calculation updates the Cooper Nuclear Station (CNS) pressure-temperature (P-T) curves for the beltline, bottom head, and upper vessel regions. Heatup/cooldown curves are developed for 32 effective full power years (EFPY). All curves are developed using methods in the 1995 Edition, 1996 Addenda of ASME Code, Section XI, Appendix G [3], incorporating the methods specified in ASME Code Case N-640 [4].

## 2.0 CURVE DEVELOPMENT

In this section, the methodology for calculating the heatup/cooldown P-T curves is detailed. This methodology describes the equations used by the EXCEL spreadsheet (CURVE-BCr1.XLS) developed for the heatup/cooldown curves for core not critical and core critical operation, also known as Curves B and C, respectively.

## 2.1 CURVE B (HEATUP/COOLDOWN, CORE NOT CRITICAL)

There are three regions that are evaluated: (1) the beltline region, (2) the bottom head region, and (3) the feedwater nozzle/upper vessel region. The methodology used to calculate the heatup/cooldown P-T curves for each of these regions is summarized in the following subsections:

### *2.1.1 Beltline Region*

a. Assume a fluid temperature, T. The temperature at the assumed flaw tip, $T_{1/4t}$ (i.e., 1/4t into the vessel wall), is conservatively assumed to be zero and the metal temperature is assumed equivalent to the fluid temperature. The plant's temperature gauge has an uncertainty of +/- 5°F [17]. A temperature 5°F less than the initially assumed fluid temperature is used to calculate the allowable pressure, producing a lower allowable pressure, and therefore making the calculation conservative.

b. Calculate the allowable stress intensity factor, using $K_{IC}$ as per Code Case N-640 [4], and $T_{1/4t}$ as follows:

$$K_{IC} = 20.734\ e^{[0.02(T_{1/4t}-ART)]} + 33.2 \quad \text{(eqn. from Ref. [2])}$$

where:
- $T_{1/4t}$ = metal temperature at assumed flaw tip (°F)
- ART = adjusted reference temperature for location under consideration and desired EFPY (°F)
- $K_{IC}$ = allowable stress intensity factor (ksi√inch)

Updated ART values for all reactor pressure vessel materials (plates, forgings, and welds) are provided in Table 1 of Reference [12]. The limiting beltline material is the Lower-Intermediate Longitudinal Weld, having the following ART value:

ART = 127.6°F at 32 EFPY

c. Calculate the thermal stress intensity factor, $K_{IT}$, for a cooldown as follows, from ¶2214.3 of Reference [3]:

$$K_{IT} = 0.953 \times 10^{-3}\ CR\ t^{2.5}$$

where:
- $K_{IT}$ = thermal stress intensity factor (ksi√inch)
- A = 0.953 for postulated axial or circ inside surface defect of a cooldown
  = (0.753 for postulated axial or circ outside surface defect of a heatup)
- CR = heatup/cooldown rate (°F/hr)
  = 100 [5]
- t = vessel wall thickness excluding clad (inches)
  = 5.875 [8]

P-T curves for the heatup and cooldown conditions apply at a given EFPY for both *1/4t* and *3/4t* locations, thereby evaluating stresses at the respective flaw locations. For conservative simplification, the thermal gradient stress at the *1/4t* location is assumed tensile for both heatup and cooldown, which results in applying the maximum tensile stress at the *1/4t* location. It is conservative for three reasons:

1) The maximum stress is used regardless of flaw location,
2) Irradiation effects cause the allowable toughness, $K_{IC}$, at *1/4t* to be less than that at *3/4t* for a given metal temperature, and
3) No credit was taken for the lower stress for heatup per the equation above.

Note that the BWR metal temperature is always limited by steam saturation conditions during operation.

d. Calculate the allowable pressure stress intensity factor, $K_{IP}$, using the following relationship for a heatup/cooldown P-T curve [3]:

$$K_{IP} = \frac{K_{IC} - K_{IT}}{SF}$$

where: $K_{IP}$ = allowable pressure stress intensity factor (ksi√inch)

$SF = 2$

e. Compute the allowable pressure, P. The relationship for the pressure, P, to the allowable pressure stress intensity factor, $K_{IP}$, is as follows (where bending stresses are conservatively excluded and all stresses are treated as membrane) [3]:

$$K_{IP} = M_m \sigma_m$$

where:

| | | | |
|---|---|---|---|
| | $\sigma_m$ | = | membrane stress due to pressure (ksi) = PR/t |
| | P | = | pressure (ksi) |
| | R | = | vessel radius (inches) |
| | | = | 110.375 inches from [8] |
| | t | = | vessel wall thickness (inches) |
| | | = | 5.875 inches from [8] |
| | $M_m$ | = | membrane stress correction factor |
| | | = | $0.926\sqrt{t}$ for $\sqrt{t} = 2.424$ |
| | | = | 2.24 |

Thus,

$$P = \frac{K_{IP} t}{R M_m}$$

f. Apply any applicable adjustments for temperature and/or pressure to T and P, respectively. The temperature adjustment is 5°F as discussed above per Reference [17]. The pressure adjustment is 19.9 psig to account for the hydrostatic pressure of at normal vessel water level (water height = 551.75" [1] at room temperature, $\rho = 62.4$ lb/ft$^3$, so $\Delta P = (62.4*551.75)/1728$), and minus 24.0 psig (2% of 1,200 psig) [17] to account for the gauge's uncertainty. Subtracting the gauge's uncertainty produces a lower allowable pressure, making it the most conservative method.

g. Repeat steps (a) through (f) for other temperatures to generate a series of P-T points.

The resulting pressure and temperature series constitutes the P-T curve. The P-T curve relates the minimum required fluid temperature to the reactor pressure. The resulting P-T curves for the beltline region are generated from Table 1.

## Table 1: Beltline Curve B for 32 EFPY

### *Pressure-Temperature Curve Calculation*

*(Heatup/Cooldown, Core Not Critical = Curve B)*

***Inputs:***

| | | |
|---|---|---|
| Plant = | Cooper | |
| Component = | Beltline | |
| Vessel thickness, t = | 5.875 | inches, so $\sqrt{t}$ = 2.424 $\sqrt{\text{inch}}$ |
| Vessel Radius, R = | 110.375 | inches |
| ART = | 127.6 | °F ======> 32 EFPY |
| Cooldown Rate, CR = | 100 | °F/hr |
| $K_{IT}$ = | 7.97 | ksi*inch$^{1/2}$ |
| $\Delta T_{1/4t}$ = | 0.0 | °F = Conservatively assumed zero |
| Safety Factor = | 2.00 | |
| $M_m$ = | 2.24 | |
| Temperature Adjustment = | 5.0 | °F (Instrument Uncertainty) not applied |
| Height of Water for a Full Vessel = | 551.75 | inches |
| Pressure Adjustment = | 19.9 | psig (hydrostatic pressure for a full vessel at 70°F) |
| Pressure Adjustment = | 24.0 | psig (Instrument Uncertainty) |
| Hydro Test Pressure = | 1,563 | psig |
| Flange $RT_{NDT}$ = | 20.0 | °F |

| Gauge Fluid Temperature (°F) | 1/4t Temperature (°F) | $K_{IC}$ (ksi*inch$^{1/2}$) | $K_{IP}$ (ksi*inch$^{1/2}$) | Calculated Pressure P (psig) | Temperature for P-T Curve (°F) | Adjusted Pressure for P-T Curve (psig) |
|---|---|---|---|---|---|---|
| 80.0 | 75.0 | 40.44 | 16.23 | 0 | 80.0 | 0 |
| 80.0 | 75.0 | 40.44 | 16.23 | 385 | 80.0 | 341 |
| 82.0 | 77.0 | 40.74 | 16.38 | 388 | 82.0 | 345 |
| 87.0 | 82.0 | 41.53 | 16.78 | 398 | 87.0 | 354 |
| 92.0 | 87.0 | 42.41 | 17.22 | 408 | 92.0 | 364 |
| 97.0 | 92.0 | 43.37 | 17.70 | 420 | 97.0 | 376 |
| 102.0 | 97.0 | 44.44 | 18.24 | 432 | 102.0 | 389 |
| 107.0 | 102.0 | 45.63 | 18.83 | 446 | 107.0 | 403 |
| 112.0 | 107.0 | 46.93 | 19.48 | 462 | 112.0 | 418 |
| 117.0 | 112.0 | 48.38 | 20.20 | 479 | 117.0 | 435 |
| 122.0 | 117.0 | 49.97 | 21.00 | 498 | 122.0 | 454 |
| 127.0 | 122.0 | 51.74 | 21.88 | 519 | 127.0 | 475 |
| 132.0 | 127.0 | 53.69 | 22.86 | 542 | 132.0 | 498 |
| 137.0 | 132.0 | 55.84 | 23.93 | 568 | 137.0 | 524 |
| 142.0 | 137.0 | 58.22 | 25.12 | 596 | 142.0 | 552 |
| 147.0 | 142.0 | 60.85 | 26.44 | 627 | 147.0 | 583 |
| 152.0 | 147.0 | 63.76 | 27.89 | 662 | 152.0 | 618 |
| 157.0 | 152.0 | 66.98 | 29.50 | 700 | 157.0 | 656 |
| 162.0 | 157.0 | 70.53 | 31.28 | 742 | 162.0 | 698 |
| 167.0 | 162.0 | 74.46 | 33.24 | 788 | 167.0 | 744 |
| 172.0 | 167.0 | 78.79 | 35.41 | 840 | 172.0 | 796 |
| 177.0 | 172.0 | 83.59 | 37.81 | 897 | 177.0 | 853 |
| 182.0 | 177.0 | 88.89 | 40.46 | 959 | 182.0 | 916 |
| 187.0 | 182.0 | 94.75 | 43.39 | 1029 | 187.0 | 985 |
| 192.0 | 187.0 | 101.22 | 46.62 | 1106 | 192.0 | 1,062 |
| 197.0 | 192.0 | 108.37 | 50.20 | 1190 | 197.0 | 1,147 |
| 202.0 | 197.0 | 116.28 | 54.15 | 1284 | 202.0 | 1,240 |
| 207.0 | 202.0 | 125.01 | 58.52 | 1388 | 207.0 | 1,344 |
| 212.0 | 207.0 | 134.67 | 63.35 | 1502 | 212.0 | 1,458 |
| 217.0 | 212.0 | 145.34 | 68.69 | 1629 | 217.0 | 1,585 |
| 222.0 | 217.0 | 157.14 | 74.58 | 1769 | 222.0 | 1,725 |

### *2.1.2 Bottom Head Region*

The bottom head region calculations are the same as for the beltline region, except that the equation for pressure stress in a spherical shell is substituted for the cylindrical pressure stress equation and a stress intensity factor is used to account for the CRD penetrations. Thus:

a. Same as Step (a) for the beltline region.

b. Same as Step (b) for the beltline region, except that ART values for the lower head region are used. From Table 1 of Reference [12], the limiting bottom head material is the bottom head torus plates, having bounding $RT_{NDT}$ value of 28°F. The bottom head region is not affected by fluence, so this value is also valid for ART.

c. Same as Step (c) for the beltline region.

d. Same as Step (d) for the beltline region.

e. Compute the allowable pressure, P. The relationship for the pressure, P, to the allowable pressure stress intensity factor, $K_{IP}$, is as follows [3]:

$$K_{IP} = M_m \sigma_m + M_b \sigma_b$$

where:

| | | |
|---|---|---|
| $\sigma_m$ | = | membrane stress due to pressure (ksi) = 3PR/(2t) assuming a stress concentration factor of 3 for the bottom head penetrations, a standard of GE RPVs. |
| P | = | pressure (ksi) |
| R | = | vessel radius (inches) |
| | = | 110.375 inches from [8] |
| t | = | vessel wall thickness (inches) |
| | = | 3.1875 inches from [13] |
| $M_m$ | = | membrane stress correction factor |
| | = | $0.926\sqrt{t}$ for $\sqrt{t} = 2.424$ |
| | = | 2.24 |
| $\sigma_b$ | = | bending stress due to pressure |
| | = | 0 for a thin walled vessel |

Thus,

$$P = \frac{2K_{IP}t}{2.3RM_m}$$

f. Same as Step (f) for the beltline region.

g. Repeat steps (a) through (f) for other temperatures to generate a series of P-T points.

The resulting P-T curve for the bottom head region is tabulated in Table 2.

**Table 2: Bottom Head Curve B for All EFPY**

## *Pressure-Temperature Curve Calculation*

*(Heatup/Cooldown, Core Not Critical = Curve B)*

***Inputs:***

| | | |
|---|---|---|
| Plant = | Cooper | |
| Component = | Bottom Head | (Penetrations Portion) |
| Vessel thickness, t = | 3.1875 | inches, so √t = 1.785 √inch |
| Vessel Radius, R = | 110.375 | inches |
| ART = | 28.0 | °F ======> All EFPYS |
| Safety Factor = | 2.00 | |
| Stress Concentration Factor = | 3.00 | Bottom Head Penetrations |
| Cooldown Rate, CR = | 100 | °F/hr |
| $M_m$ = | 1.65 | |
| $K_{IT}$ = | 1.73 | ksi*inch$^{1/2}$ |
| Temperature Adjustment = | 5.0 | °F, Instrument Uncertainty |
| Height of Water for a Full Vessel = | 551.75 | inches (normal full vessel water level) |
| Pressure Adjustment = | 19.9 | psig (full vessel at 70°F) |
| Pressure Adjustment = | 24.0 | psig (Instrument Uncertainty) |
| Unit Pressure = | 1,563 | psig |
| Flange $RT_{NDT}$ = | 20.0 | °F |

| Gauge Temperature T (°F) | Adjusted Temperature (°F) | $K_{IC}$ (ksi*inch$^{1/2}$) | $K_{IP}$ (ksi*inch$^{1/2}$) | Calculated Pressure P (psig) | Temperature for P-T Curve (°F) | Adjusted Pressure for P-T Curve (psig) |
|---|---|---|---|---|---|---|
| 80.0 | 75.0 | 86.28 | 42.27 | 0 | 80 | 0 |
| 80.0 | 75.0 | 86.28 | 42.27 | 492 | 80 | 448 |
| 82.0 | 77.0 | 88.44 | 43.36 | 505 | 82 | 461 |
| 86.0 | 81.0 | 93.05 | 45.66 | 532 | 86 | 488 |
| 90.0 | 85.0 | 98.03 | 48.15 | 561 | 90 | 517 |
| 94.0 | 89.0 | 103.43 | 50.85 | 592 | 94 | 548 |
| 98.0 | 93.0 | 109.28 | 53.78 | 626 | 98 | 582 |
| 102.0 | 97.0 | 115.62 | 56.94 | 663 | 102 | 619 |
| 106.0 | 101.0 | 122.48 | 60.38 | 703 | 106 | 659 |
| 110.0 | 105.0 | 129.92 | 64.09 | 746 | 110 | 702 |
| 114.0 | 109.0 | 137.97 | 68.12 | 793 | 114 | 749 |
| 118.0 | 113.0 | 146.70 | 72.48 | 844 | 118 | 800 |
| 122.0 | 117.0 | 156.15 | 77.21 | 899 | 122 | 855 |
| 126.0 | 121.0 | 166.39 | 82.33 | 959 | 126 | 915 |
| 130.0 | 125.0 | 177.48 | 87.88 | 1023 | 130 | 979 |
| 134.0 | 129.0 | 189.50 | 93.89 | 1093 | 134 | 1049 |
| 138.0 | 133.0 | 202.52 | 100.39 | 1169 | 138 | 1125 |
| 142.0 | 137.0 | 216.62 | 107.45 | 1251 | 142 | 1207 |
| 146.0 | 141.0 | 231.90 | 115.08 | 1340 | 146 | 1296 |
| 150.0 | 145.0 | 248.44 | 123.36 | 1437 | 150 | 1393 |
| 154.0 | 149.0 | 266.37 | 132.32 | 1541 | 154 | 1497 |
| 158.0 | 153.0 | 285.79 | 142.03 | 1654 | 158 | 1610 |

### *2.1.3 Feedwater Nozzle/Upper Vessel Region*

The feedwater nozzle is selected to represent non-beltline/upper vessel components for fracture toughness analyses because the stress conditions at this location are the most severe that the vessel experiences. In addition to the more severe pressure and piping load stresses resulting from the nozzle discontinuity, the feedwater nozzle region experiences thermal cycling due to relatively cold feedwater flow in hotter vessel coolant.

The methodology used for the feedwater nozzle is contained in WRC-175 [7]. Thus:

a. Assume a fluid pressure, P. The pressure used is the plant's gauge pressure, which has an uncertainty of +/- 24.0 psig (2% of 1,200 psig) [17]. A pressure 24.0 psig more than that assumed is used for calculating the temperature, producing a higher calculated temperature, therefore making the calculation conservative.

b. Calculate the thermal stress intensity factor, $K_{IT}$, based on finite element stresses. The feedwater nozzle stresses were obtained from the finite element analysis results contained in Reference [8]. The maximum primary + secondary stress intensity ranges for (membrane and membrane + bending) thermal stresses were obtained for the entire design basis transients to encompass Normal and Upset Conditions. These stresses are shown below for the path defined by Elements 490 and 552 (nozzle bore blend radius location) in Reference [8, Figure S-1]:

Thermal (secondary) membrane + bending stress, $(\sigma_{sm} + \sigma_{sb})$:

The transient maximum thermal plus mechanical stress ranges were reported in [8] for elements 490 to 552. The total mechanical (membrane + bending) stresses are small in comparison to the thermal (membrane + bending) stresses and will remain included.

$(\sigma_{sm} + \sigma_{sb})$ for 552 = 24.3 ksi per Table S-4
$(\sigma_{sm} + \sigma_{sb})$ for 490 = 21.5 ksi per Table S-4

The maximum of the elements above is used to bound this analysis.

Thermal (secondary) membrane stress, $\sigma_{sm}$:

$\sigma_{sm}$ for 552 = 4.288 – 0.0 ksi per Transient 15 [p. S-73, 8] – Transient 1 (Zeroload)
$\sigma_{sm}$ for 490 = 4.680 – (-1.1215) = 5.895 ksi per Transient 17 [p. S-79] – 19 [p. S-84]

Note that the above stresses include pressure stress. Thus, the limiting condition is:

Maximum secondary bending stress, $\sigma_{sb}$ = 24.3 – 5.895 = 18.405 ksi
Secondary membrane stress, $\sigma_{sm}$ = 5.895 ksi

$t$ = 7.108 inches [9]
$\sigma_{ys}$ = 43.975 ksi @ 575°F for SA-508 Class 2 [14]

The value of $M_m$ from G-2214.1 [3] is based on a thickness of 7.108 inches, so $t^{1/2}$ = 2.666 and the resulting $M_m$ value is 2.47.

$K_{Im}$ is calculated from the equation in Paragraph G-2214.1 [3]:

$$K_{Im} = M_m * \sigma_{sm}$$

$K_{Ib}$ is calculated from the equation in Paragraph G-2214.2 [3]:

$$K_{Ib} = (2/3)\, M_m * \sigma_{sb}$$

The total $K_{IT}$ is therefore:

$$K_{IT} = R*SF*(K_{Im} + K_{Ib})$$

where: R = correction factor, calculated to consider the nonlinear effects in the plastic region according to the following equation based on the assumptions and recommendation of WRC Bulletin 175 [7]
= $[\sigma_{ys} - \sigma_{pm} + ((\sigma_{total} - \sigma_{ys}) / 30)] / (\sigma_{total} - \sigma_{pm})$
SF = safety factor for $K_{IT}$
= 1.3 (conservatively used based on the recommendation in WRC-175 [7])

c. Compute the allowable pressure stress intensity factor, $K_{IP}$, as follows:

$$K_{IP} = F(a / r_n)\sqrt{\pi a}\ \sigma_{pm}$$

where:

| | | |
|---|---|---|
| $r_i$ | = | actual inner radius of nozzle = 6.6875 inches [8] |
| $r_c$ | = | nozzle corner radius = 5.0 inches [8] |
| $r_n$ | = | apparent radius of nozzle = $r_i + 0.29 r_c$ = 8.1375 |
| $t'$ | = | nozzle corner thickness |
| | = | 7.108 inches [9] |
| a | = | crack depth (inches) |
| | = | 1/4 t' = 1.777 inches |
| $F(a, r_n)$ | = | nozzle stress factor |
| | = | 1.6 for $a/r_n$ = 0.22 from Figure A5-1 of [7] |
| $K_{IP}$ | = | allowable pressure stress intensity factor (ksi$\sqrt{\text{inch}}$). |
| $\sigma_{pm}$ | = | primary membrane stress, PR/t (primary bending stresses are conservatively treated as membrane stresses, so $\sigma_{pb}$ = 0) |

R = vessel radius (inches) = 110.375 inches [8]
t = vessel wall thickness (inches) = 5.875 inches [8]

d. Calculate the allowable stress intensity factor, $K_{IC}$, using the following relationship for a heatup/cooldown P-T curve:

$$K_{IP} = \frac{K_{IC} - K_{IT}}{2.0}$$

thus: $$K_{IC} = 2.0K_{IP} + K_{IT}$$

e. Calculate the temperature $T_{1/4t}$ based on the allowable stress intensity factor, $K_{IC}$ as per Code Case N-640 [4], as follows:

$$K_{IC} = 20.734\, e^{[0.02(T_{1/4t} - ART)]} + 33.2 \quad \text{(eqn. from Ref. [2])}$$

where: $T_{1/4t}$ = metal temperature at assumed flaw tip (°F), assumed equal to T, the temperature at the inner vessel wall
ART = adjusted reference temperature for location under consideration and desired EFPY (°F)
$K_{IC}$ = allowable stress intensity factor (ksi√inch)

thus: $$T_{\frac{1}{4}t} = 50 * LN\left[\frac{K_{IC} - 33.2}{20.734}\right] + ART$$

f. The curve was generated by scaling the stresses used to determine $K_I$; this scaling was performed after the adjustment to stresses above yield. The primary stresses were scaled by the nominal pressures, while the secondary stresses were scaled by the temperature difference of the 40°F water injected into the hot reactor vessel nozzle. The normal pressure is 1038 psig [15] (power uprate) and the hot reactor vessel temperature is 551°F [15]. Since the reactor vessel temperature follows the saturation temperature curve [App. A], the secondary stresses are scaled by $(T_{saturation} - 40) / (551 - 40)$.

g. Repeat steps (a) through (f) for other pressures to generate a series of P-T points.

Two additional requirements were used to define the lower portion of the upper vessel P-T curve. These limits are established by the discontinuity regions of the vessel (i.e., flanges), and are specified in Table 1 of Reference [10]:

- If the calculated pressure, P, is greater than 20% of the pre-service hydro test pressure, the temperature must be greater than $RT_{NDT}$ of the limiting flange material + 120°F. The pre-service hydro test pressure was 1,563 psig, and the limiting flange material has an $RT_{NDT}$ of 20°F [5].

- If the calculated pressure, P, is less than or equal to 20% of the pre-service hydro test pressure, the minimum temperature is typically greater than or equal to the $RT_{NDT}$ of the limiting flange material. GE typically applies an additional 60°F margin to the $RT_{NDT}$ value and has been a standard recommendation for the BWR industry for non-ductile failure protection. For the Cooper flange material, this minimum would be 80°F (i.e., 20 + 60°F). Since the 60°F margin is only a recommendation, the minimum temperature for Cooper was set to 80°F to be consistent with past work as well as adequately encompass instrument uncertainty. The gauge's uncertainty of +/- 5°F is not applied here since the included margin just described adequately encompasses instrument uncertainty.

# Table 3: Upper Vessel Curve B for All EFPY

## *Pressure-Temperature Curve Calculation*

*(Heatup/Cooldown, Core Not Critical = Curve B)*

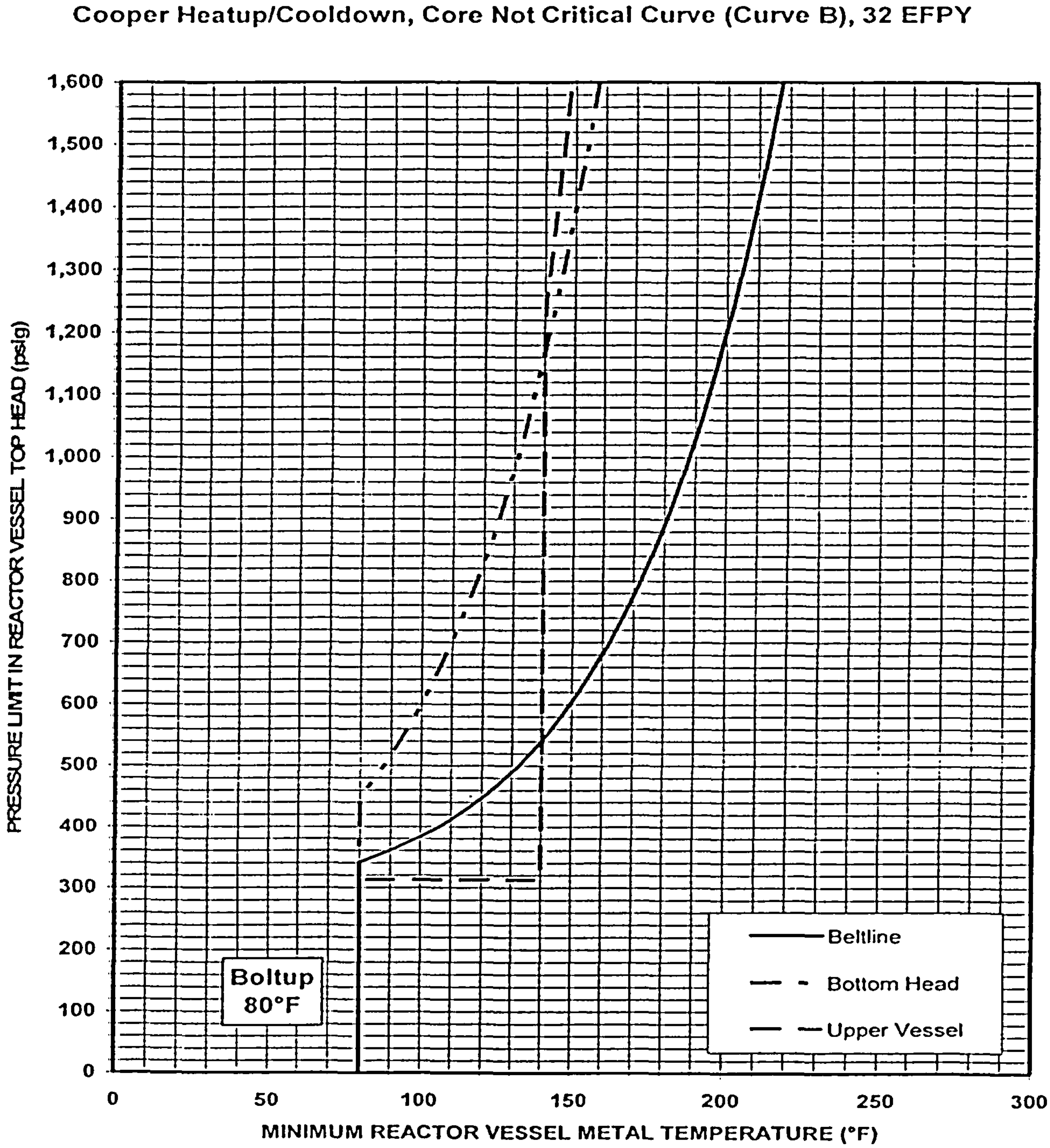
***Inputs:***

| | | |
|---|---|---|
| Plant = | Cooper | |
| Component = | Upper Vessel | |
| $RT_{NDT}$ = | 20.0 | °F |
| $\sigma_{pm}$ = | 21.315 | ksi for a pressure of 1,038 psig |
| $\sigma_{pb}$ = | 0.00 | ksi for a pressure of 1,038 psig |
| $\sigma_{sm}$ = | 5.895 | ksi for a temperature of 551°F |
| $\sigma_{sb}$ = | 18.41 | ksi for a temperature of 551°F |
| $\sigma_{ys}$ = | 43.975 | ksi @ 575°F |
| Nozzle corner thickness, t' = | 7.108 | inches, approximate √t' = 2.666 √inch |
| $M_m$ = | 2.469 | |
| a (1/4 t') = | 1.777 | |
| $F(a/r_n)$ = | 1.60 | |
| $K_{IT}$ Safety Factor = | 1.30 | |
| Temperature Adjustment = | 6.0 | °F |
| Pressure Adjustment = | 24.0 | psig |
| Hydro Test Pressure = | 1563 | psig |
| Flange $RT_{NDT}$ = | 20.0 | °F |

| Pressure P (psig) | Saturation Temperature (°F) | $K_{IT}$ (ksi*inch$^{1/2}$) | $K_{IP}$ (ksi*inch$^{1/2}$) | $K_{IAllowable}$ (ksi*inch$^{1/2}$) | Calculated Temperature T (°F) | Adjusted Temperature for P-T Curve (°F) | Adjusted Pressure for P-T Curve (psig) |
|---|---|---|---|---|---|---|---|
| 0 | 212.1 | 19.6 | 0.0 | 19.6 | --- | 80 | 0 |
| 200.0 | 387.9 | 39.7 | 15.5 | 70.8 | 49.7 | 80 | 176 |
| 210.0 | 391.8 | 40.1 | 16.3 | 72.8 | 52.3 | 80 | 186 |
| 220.0 | 395.6 | 40.6 | 17.1 | 74.7 | 54.7 | 80 | 196 |
| 230.0 | 399.3 | 41.0 | 17.9 | 76.7 | 57.1 | 80 | 206 |
| 240.0 | 402.8 | 41.4 | 18.6 | 78.7 | 59.3 | 80 | 216 |
| 250.0 | 406.2 | 41.8 | 19.4 | 80.6 | 61.4 | 80 | 226 |
| 260.0 | 409.6 | 42.2 | 20.2 | 82.5 | 63.3 | 80 | 236 |
| 270.0 | 412.8 | 42.5 | 21.0 | 84.5 | 65.3 | 80 | 246 |
| 331.0 | 430.9 | 44.6 | 25.7 | 96.0 | 75.4 | 80 | 307 |
| 335.8 | 432.2 | 44.8 | 26.1 | 96.9 | 76.1 | 80 | 312 |
| 336.0 | 432.3 | 44.8 | 26.1 | 96.9 | 76.1 | 80 | 312 |
| 336.5 | 432.4 | 44.8 | 26.1 | 97.0 | 76.2 | 80 | 313 |
| 336.8 | 432.5 | 44.8 | 26.1 | 97.1 | 76.3 | 140 | 313 |
| 396.8 | 447.8 | 46.5 | 30.8 | 108.1 | 84 2 | 140 | 373 |
| 456.8 | 461.4 | 48.1 | 35.5 | 119.0 | 91.0 | 140 | 433 |
| 516.8 | 473.7 | 49.5 | 40.1 | 129.7 | 96.9 | 140 | 493 |
| 576.8 | 485.0 | 50.8 | 44.8 | 140.3 | 102.1 | 140 | 553 |
| 640.0 | 496.0 | 52.0 | 49.7 | 151.4 | 107.0 | 140 | 616 |
| 670.0 | 500.9 | 52.6 | 52.0 | 156.6 | 109.2 | 140 | 646 |
| 730.0 | 510.2 | 53.7 | 56.7 | 167.0 | 113.2 | 140 | 706 |
| 734.0 | 510.8 | 53.7 | 57.0 | 167.7 | 113.5 | 140 | 710 |
| 794.0 | 519.6 | 54.7 | 61.6 | 178.0 | 117.2 | 140 | 770 |
| 854.0 | 527.8 | 55.7 | 66.3 | 188.3 | 120.6 | 140 | 830 |
| 914.0 | 535.6 | 56.6 | 71.0 | 198.5 | 123.8 | 140 | 890 |
| 974.0 | 543.1 | 57.4 | 75.6 | 208.6 | 126.8 | 140 | 950 |
| 1034.0 | 550.2 | 54.7 | 80.3 | 215.2 | 128.6 | 140 | 1010 |
| 1094.0 | 556.9 | 51.9 | 84.9 | 221.7 | 130.4 | 140 | 1070 |
| 1154.0 | 563.4 | 49.0 | 89.6 | 228.2 | 132.1 | 140 | 1130 |
| 1214.0 | 569.7 | 46.2 | 94.2 | 234.7 | 133.7 | 140 | 1190 |
| 1274.0 | 575.7 | 43.3 | 98.9 | 241.2 | 135.3 | 140 | 1250 |
| 1334.0 | 581.5 | 40.5 | 103.6 | 247.6 | 136.8 | 142 | 1310 |
| 1394.0 | 587.1 | 37.7 | 108.2 | 254.1 | 138.3 | 143 | 1370 |
| 1454.0 | 592.5 | 34.8 | 112.9 | 260.6 | 139.7 | 145 | 1430 |
| 1514.0 | 597.7 | 32.0 | 117.5 | 267.1 | 141.1 | 146 | 1490 |
| 1574.0 | 602.8 | 29 2 | 122.2 | 273.5 | 142.5 | 148 | 1550 |
| 1634.0 | 607.7 | 26.3 | 126.8 | 280.0 | 143.8 | 149 | 1610 |

The resulting P-T curves are shown in Figure 1 for 32 EFPY. Note that only the beltline curve differs due to irradiation effects.

Figure 1: Heatup/Cooldown, Core Not Critical P-T Curve (Curve B) for 32 EFPY

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## 2.2 CURVE C (HEATUP/COOLDOWN, CORE CRITICAL)

Curve C, the core critical operation curve, is generated from the requirements of 10CFR50 Appendix G [10]. Table 1 of Reference [10] requires that core critical P-T limits be 40°F above any Curve A or B limits when pressure exceeds 20% of the pre-service system Hydrotest pressure. Curve B is more limiting than Curve A, so limiting Curve C values are at least Curve B plus 40°F for pressures above 312 psig.

Table 1 of Reference [10] indicates that, for a BWR with water level within normal range for power operation, the allowed temperature for initial criticality at the closure flange region is ($RT_{NDT}$ + 60°F) at pressures below 312 psig (20% of pre-service hydro). This requirement makes the minimum criticality temperature 80°F for Cooper, based on an ART value of 20°F for the flange region. In addition, above 312 psig, the Curve C temperature must be at least the greater of ART of the closure region + 160°F, or the temperature required for the hydrostatic pressure test (Curve A at 1,100 psig). Therefore, this requirement causes a temperature shift in Curve C at 312 psig.

The resulting Curve C P-T curve is tabulated in Table 5 for 32 EFPY. The curve is graphically shown in Figure 2.

## Table 4: Curve C for 32 EFPY

# *Pressure-Temperature Curve Calculation*

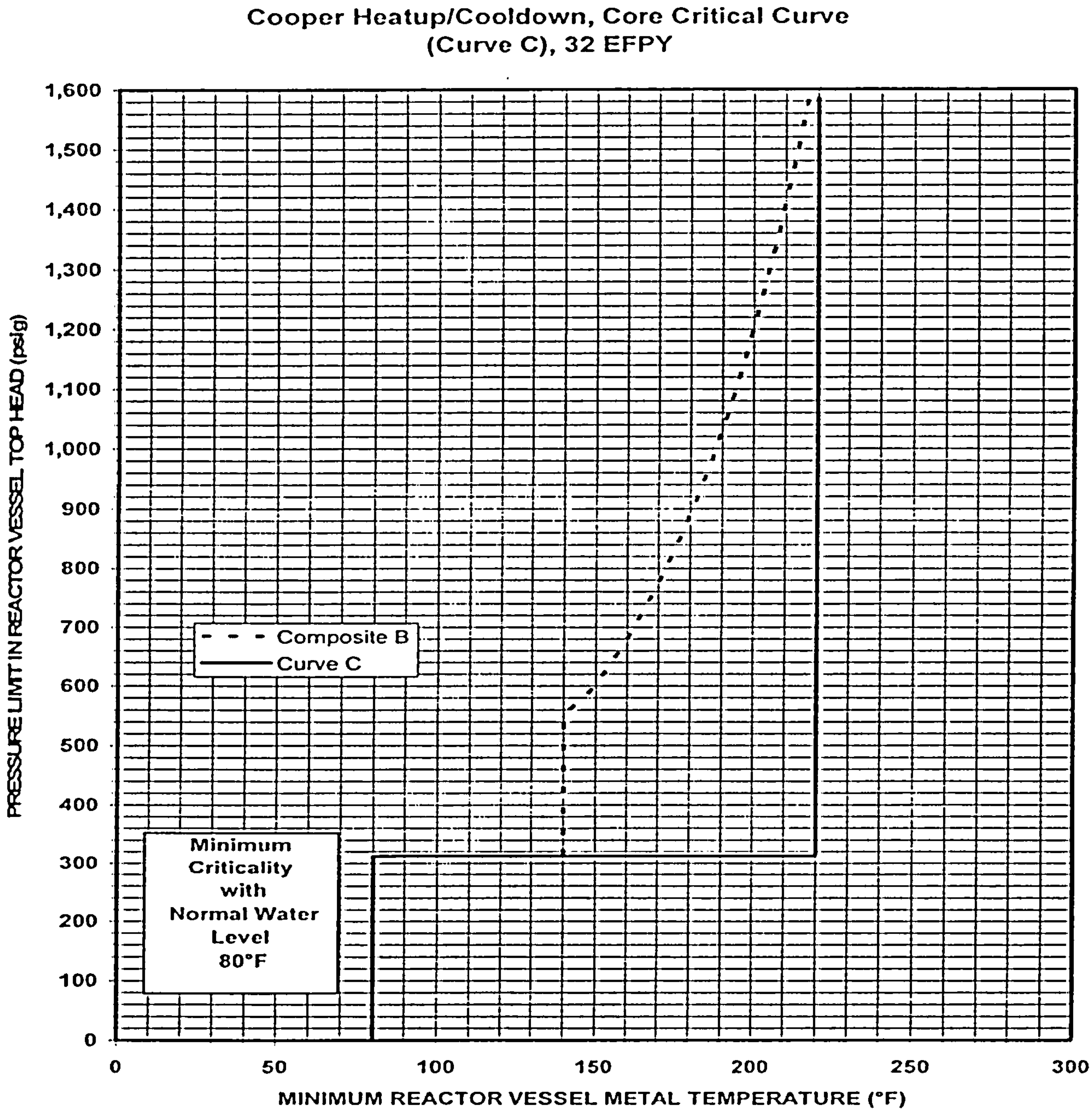
*(Core Critical = Curve C)*

***Inputs:***

Plant = Cooper
EFPY = 32
Curve A Leak Test Temperature = 145.0 °F (at 1,100 psig)
Hydro Test Pressure = 1,563 psig
Flange $RT_{NDT}$ = 20.0 °F

| Beltline Curve B Temperature (°F) | Beltline Curve B Pressure (psig) | Bottom Head Curve B Temperature (°F) | Bottom Head Curve B Pressure (psig) | Upper Vessel Curve B Temperature (°F) | Upper Vessel Curve B Pressure (psig) | Composite Curve B Minimum Temperature (°F) | Composite Curve B Pressure (psig) | Composite Curve C Minimum Temperature (°F) | Composite Curve C Pressure (psig) |
|---|---|---|---|---|---|---|---|---|---|
| 80 | 0 | 80 | 0 | 80 | 0 | 80 | 0 | 80 | 0 |
| 80 | 341 | 80 | 448 | 80 | 176 | 80 | 176 | 80 | 176 |
| 82 | 345 | 82 | 461 | 80 | 186 | 80 | 186 | 80 | 186 |
| 87 | 354 | 86 | 488 | 80 | 196 | 80 | 196 | 80 | 196 |
| 92 | 364 | 90 | 517 | 80 | 206 | 80 | 206 | 80 | 206 |
| 97 | 376 | 94 | 548 | 80 | 216 | 80 | 216 | 80 | 216 |
| 102 | 389 | 98 | 582 | 80 | 226 | 80 | 226 | 80 | 226 |
| 107 | 403 | 102 | 619 | 80 | 236 | 80 | 236 | 80 | 236 |
| 112 | 418 | 106 | 659 | 80 | 246 | 80 | 246 | 80 | 246 |
| 117 | 435 | 110 | 702 | 80 | 307 | 80 | 307 | 80 | 307 |
| 122 | 454 | 114 | 749 | 80 | 312 | 80 | 312 | 80 | 312 |
| 127 | 475 | 118 | 800 | 80 | 312 | 80 | 312 | 80 | 312 |
| 132 | 498 | 122 | 855 | 80 | 313 | 80 | 313 | 88 | 313 |
| 137 | 524 | 126 | 915 | 140 | 313 | 140 | 313 | 220 | 313 |
| 142 | 552 | 130 | 979 | 140 | 373 | 140 | 373 | 220 | 373 |
| 147 | 583 | 134 | 1049 | 140 | 433 | 140 | 433 | 220 | 433 |
| 152 | 618 | 138 | 1125 | 140 | 493 | 140 | 493 | 220 | 493 |
| 157 | 656 | 142 | 1207 | 140 | 553 | 140 | 553 | 220 | 553 |
| 162 | 698 | 146 | 1296 | 140 | 616 | 147 | 583 | 220 | 583 |
| 167 | 744 | 150 | 1393 | 140 | 646 | 152 | 618 | 220 | 618 |
| 172 | 796 | 154 | 1497 | 140 | 706 | 157 | 656 | 220 | 656 |
| 177 | 853 | 158 | 1610 | 140 | 710 | 162 | 698 | 220 | 698 |
| 182 | 916 | | | 140 | 770 | 167 | 744 | 220 | 744 |
| 187 | 985 | | | 140 | 830 | 172 | 796 | 220 | 796 |
| 192 | 1062 | | | 140 | 890 | 177 | 853 | 220 | 853 |
| 197 | 1147 | | | 140 | 950 | 182 | 916 | 220 | 916 |
| 202 | 1240 | | | 140 | 1010 | 187 | 985 | 220 | 985 |
| 207 | 1344 | | | 140 | 1070 | 192 | 1062 | 220 | 1062 |
| 212 | 1458 | | | 140 | 1130 | 197 | 1147 | 220 | 1147 |
| 217 | 1585 | | | 140 | 1190 | 202 | 1240 | 220 | 1240 |
| 222 | 1725 | | | 140 | 1250 | 207 | 1344 | 220 | 1344 |
| | | | | 142 | 1310 | 212 | 1458 | 220 | 1458 |
| | | | | 143 | 1370 | 217 | 1585 | 220 | 1585 |
| | | | | 145 | 1430 | 222 | 1725 | 220 | 1725 |
| | | | | 146 | 1490 | | | | |
| | | | | 148 | 1550 | | | | |
| | | | | 149 | 1610 | | | | |

Figure 2: Heatup/Cooldown, Core Critical P-T (Curve C) for 32 EFPY




| | Revision | A | 0 | 1 | |
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| | File No. COOP-05Q-302 | | | Page 19 of 21 | |

## 3.0 REFERENCES


1. GE Drawing No. 729E479-B, Revision 0, "Reactor Primary SYS. WTS. & Vols.," Sheet 1 of 3, SI File No. NPPD-05Q-208.

2. ASME Boiler and Pressure Vessel Code, Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components, Nonmandatory Appendix A, "Analysis of Flaws," 1995 Edition, 1996 Addenda.

3. ASME Boiler and Pressure Vessel Code, Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components, Nonmandatory Appendix G, "Fracture Toughness Criteria for Protection Against Failure," 1995 Edition, 1996 Addenda.

4. ASME Boiler and Pressure Vessel Code, Code Case N-640, "Alternative Reference Fracture Toughness for Development of P-T Limit Curves," Section XI, Division 1, Approved February 26, 1999.

5. GE Document No. GE-NE-523-159-1292 (DRF B13-01662), "Cooper Nuclear Station Vessel Surveillance Materials Testing and Fracture Toughness Analysis," Revision 0, February 1993, SI File No. COOP-05Q-202.

6. Not Used.

7. WRC Bulletin 175, "PVRC Recommendations on Toughness Requirements for Ferritic Materials," PVRC Ad Hoc Group on Toughness Requirements, Welding Research Council, August 1972.

8. CBI Stress Report DC22A7245, Revision 0, "Feedwater Nozzle Modification Cooper RPV," 3/20/80, SI File NPPD-13Q-205.

9. SI Calculation NPPD-13Q-301, Revision 0, "Feedwater Nozzle Finite Element Model."

10. U. S. Code of Federal Regulations, Title 10, Part 50, Appendix G, "Fracture Toughness Requirements," 1-1-98 Edition.

11. USNRC Regulatory Guide 1.99, Revision 2, "Radiation Embrittlement of Reactor Vessel Materials," U. S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, (Task ME 305-4), May 1988.

12. SI Calculation No. COOP-05Q-301, Revision 1A, "Development of Updated Pressure Test (Curve A) P-T Curves," October 2003.

13. Combustion Engineering Drawing No. E-232-230, Revision 3, "General Arrangement Elevation for: General Electric Co. APED 218" I.D. BWR," SI File No. NPPD-06Q-208.

14. ASME Boiler and Pressure Vessel Code, Section III, Rules for Construction of Nuclear Power Plant Components, Division 1, Appendices, 1989 Edition.

15. SI Calculation NPPD-13Q-302, Revision 0, "Feedwater Nozzle Stress Analysis."

16. C-E Power Systems, Steam Tables, Reprinted from the 1967 ASME Steam Tables, 1967.

17. NPPD Memo DED 2003-005, Alan Able to Ken Thomas, dated August 14, 2003, "Instrument Uncertainty Associated With Technical Specification 3.4.9," SI File No. COOP-05Q-203.

APPENDIX A

CURVE FIT OF SATURATION TEMPERATURE VS. PRESSURE

The following curve fit relationship was derived for saturation temperature as a function of absolute pressure for water using the data in Reference [16]:

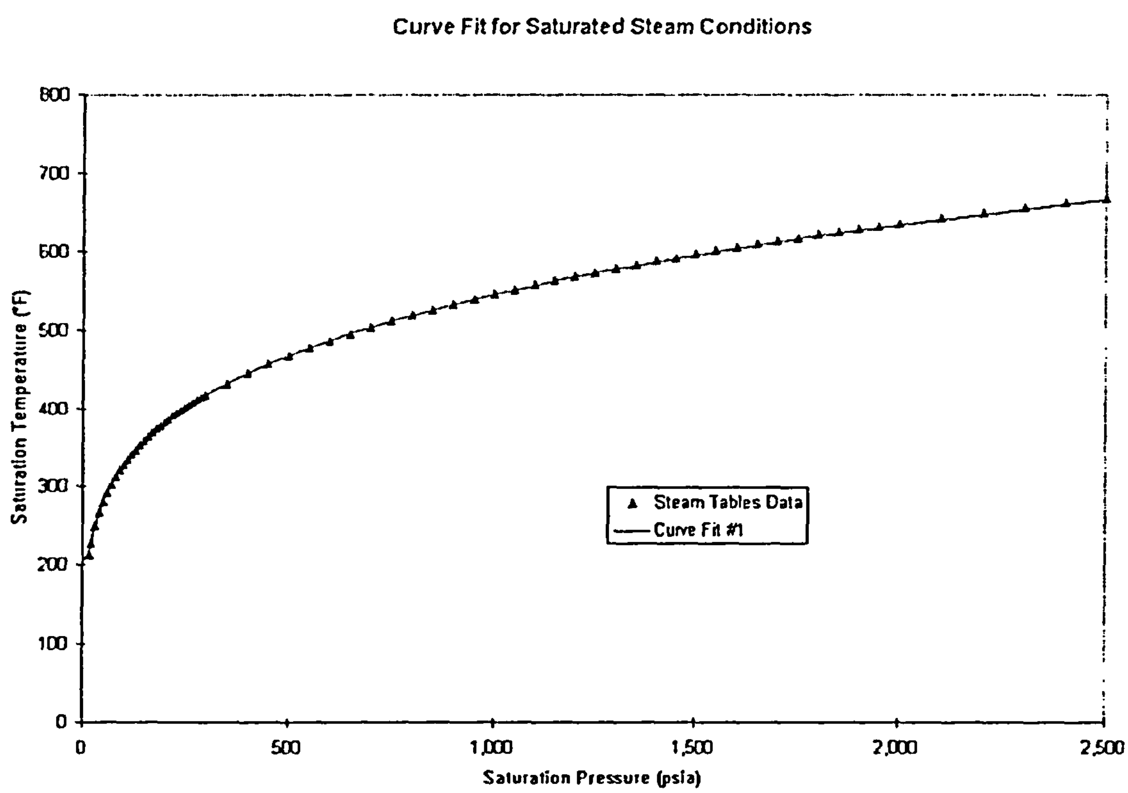
$$T_{SAT} = 119.3 * (0.7987)^{1/P_{SAT}} * P_{SAT}^{0.2198} \quad (°F)$$

$$P_{SAT} = RPVPRESS + 14.696 \quad (psia)$$

where:

| | | | |
|---|---|---|---|
| | $P_{SAT}$ | = | calculated saturation pressure (psia) |
| | $T_{SAT}$ | = | calculated saturation temperature (°F) |
| | RPVPRESS | = | measured reactor pressure (psig) |

The input data, calculated data, and a plot showing the adequacy of this relationship is provided below.

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| | **File No.** **COOP-05Q-302** | | | **Page** A2 **of** A4 | |

# *Curve Fit for Saturated Steam*

***Reference:*** Steam Table data obtained from "Steam Tables, Properties of Saturated and Superheated Steam," CE Power Systems, 7th Printing.

**Curve Fit:** $T_{sat} = 119.3*(0.7987)^{(1/Psat)} * P_{sat}^{0.2198}$

| Pressure $P_{sat}$ (psia) | Temperature $T_{sat}$ (°F) | Curve Fit $T_{sat}$ (°F) | Difference (°F) | Error (%) |
|---|---|---|---|---|
| 14.696 | 212.00 | 212.10 | 0.10 | 0.05% |
| 15 | 213.03 | 213.13 | 0.10 | 0.05% |
| 20 | 227.96 | 227.89 | -0.07 | -0.03% |
| 30 | 250.34 | 250.07 | -0.27 | -0.11% |
| 40 | 267.25 | 266.89 | -0.36 | -0.13% |
| 50 | 281.02 | 280.62 | -0.40 | -0.14% |
| 60 | 292.71 | 292.32 | -0.39 | -0.13% |
| 70 | 302.93 | 302.55 | -0.38 | -0.13% |
| 80 | 312.04 | 311.69 | -0.35 | -0.11% |
| 90 | 320.28 | 319.96 | -0.32 | -0.10% |
| 100 | 327.82 | 327.54 | -0.28 | -0.09% |
| 110 | 334.79 | 334.54 | -0.25 | -0.07% |
| 120 | 341.27 | 341.06 | -0.21 | -0.06% |
| 130 | 347.33 | 347.16 | -0.17 | -0.05% |
| 140 | 353.04 | 352.91 | -0.13 | -0.04% |
| 150 | 358.43 | 358.34 | -0.09 | -0.03% |
| 160 | 363.55 | 363.49 | -0.06 | -0.02% |
| 170 | 368.42 | 368.40 | -0.02 | -0.01% |
| 180 | 373.08 | 373.08 | 0.00 | 0.00% |
| 190 | 377.53 | 377.57 | 0.04 | 0.01% |
| 200 | 381.80 | 381.87 | 0.07 | 0.02% |
| 210 | 385.91 | 386.01 | 0.10 | 0.03% |
| 220 | 389.88 | 390.00 | 0.12 | 0.03% |
| 230 | 393.70 | 393.84 | 0.14 | 0.04% |
| 240 | 397.39 | 397.56 | 0.17 | 0.04% |
| 250 | 400.97 | 401.16 | 0.19 | 0.05% |
| 260 | 404.44 | 404.65 | 0.21 | 0.05% |
| 270 | 407.80 | 408.03 | 0.23 | 0.06% |
| 280 | 411.07 | 411.32 | 0.25 | 0.06% |
| 290 | 414.25 | 414.51 | 0.26 | 0.06% |
| 300 | 417.35 | 417.62 | 0.27 | 0.07% |
| 350 | 431.73 | 432.06 | 0.33 | 0.08% |
| 400 | 444.60 | 444.97 | 0.37 | 0.08% |

| | | | | |
|---|---|---|---|---|
| 450 | 456.28 | 456.67 | 0.39 | 0.08% |
| 500 | 467.01 | 467.39 | 0.38 | 0.08% |
| 550 | 476.94 | 477.30 | 0.36 | 0.08% |
| 600 | 486.20 | 486.54 | 0.34 | 0.07% |
| 650 | 494.89 | 495.19 | 0.30 | 0.06% |
| 700 | 503.08 | 503.33 | 0.25 | 0.05% |
| 750 | 510.84 | 511.03 | 0.19 | 0.04% |
| 800 | 518.21 | 518.34 | 0.13 | 0.03% |
| 850 | 525.24 | 525.31 | 0.07 | 0.01% |
| 900 | 531.95 | 531.95 | 0.00 | 0.00% |
| 950 | 538.39 | 538.32 | -0.07 | -0.01% |
| 1000 | 544.58 | 544.43 | -0.15 | -0.03% |
| 1050 | 550.53 | 550.31 | -0.22 | -0.04% |
| 1100 | 556.28 | 555.97 | -0.31 | -0.06% |
| 1150 | 561.82 | 561.43 | -0.39 | -0.07% |
| 1200 | 567.19 | 566.71 | -0.48 | -0.08% |
| 1250 | 572.38 | 571.83 | -0.55 | -0.10% |
| 1300 | 577.42 | 576.78 | -0.64 | -0.11% |
| 1350 | 582.32 | 581.59 | -0.73 | -0.13% |
| 1400 | 587.07 | 586.26 | -0.81 | -0.14% |
| 1450 | 591.70 | 590.80 | -0.90 | -0.15% |
| 1500 | 596.20 | 595.22 | -0.98 | -0.16% |
| 1550 | 600.59 | 599.53 | -1.06 | -0.18% |
| 1600 | 604.87 | 603.73 | -1.14 | -0.19% |
| 1650 | 609.05 | 607.83 | -1.22 | -0.20% |
| 1700 | 613.13 | 611.84 | -1.29 | -0.21% |
| 1750 | 617.12 | 615.75 | -1.37 | -0.22% |
| 1800 | 621.02 | 619.58 | -1.44 | -0.23% |
| 1850 | 624.83 | 623.32 | -1.51 | -0.24% |
| 1900 | 628.56 | 626.99 | -1.57 | -0.25% |
| 1950 | 632.22 | 630.58 | -1.64 | -0.26% |
| 2000 | 635.80 | 634.10 | -1.70 | -0.27% |
| 2100 | 642.76 | 640.94 | -1.82 | -0.28% |
| 2200 | 649.45 | 647.53 | -1.92 | -0.30% |
| 2300 | 655.89 | 653.89 | -2.00 | -0.30% |
| 2400 | 662.11 | 660.04 | -2.07 | -0.31% |
| 2500 | 668.11 | 665.99 | -2.12 | -0.32% |
| | | Maximum = | 0.39 | 0.08% |
| | | Minimum = | -2.12 | -0.32% |
| | | Average = | -0.41 | -0.07% |
| | | Std. Deviation | 0.71 | 0.12% |

| STRUCTURAL INTEGRITY Associates, Inc. | CALCULATION PACKAGE | FILE No.: COOP-05Q-301<br>PROJECT No.: COOP-05Q |
|---|---|---|

PROJECT NAME: Develop Revised Pressure-Temperature Curves at Cooper Nuclear Station

CLIENT: Nebraska Public Power District (NPPD)

CALCULATION TITLE: Development of Updated Pressure Test (Curve A) P-T Curves

| Document Revision | Affected Pages | Revision Description | Project Mgr. Approval Signature & Date | Preparer(s) & Checker(s) Signatures & Date |
|---|---|---|---|---|
| A | 1-15<br>In Computer Files | Draft Issue | G. L. Stevens<br>06/05/03 | C. R. Limpus<br>06/03/03<br>B. P. Templeton<br>06/03/03 |
| 0 | 1-21<br>In Computer Files | Initial Issue | G. L. Stevens<br>08/11/03 | C. R. Limpus<br>08/11/03<br>B. P. Templeton<br>08/11/03 |
| 1 | 1-16<br>In Computer Files | Revised to correct closure flange $RT_{NDT}$ and use ART values of record. | G. L. Stevens<br>Gary L. Stevens<br>10/15/03 | C. R. Limpus<br>CRL<br>10/15/03<br>B. P. Templeton<br>BPT<br>10/15/03 |

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## List of Figures

## 1.0 INTRODUCTION / OBJECTIVE

This calculation updates the Cooper Nuclear Station (CNS) pressure-temperature (P-T) curves for the beltline, bottom head, limiting flange and non-beltline locations (feedwater nozzle/upper vessel). The pressure test curves are developed for 32 effective full power years (EFPY). P-T curves are developed using methods in the 1995 Edition, 1996 Addenda of ASME Code, Section XI, Appendix G [3], incorporating the methods specified in ASME Code Case N-640 [4].

## 2.0 $RT_{NDT}$ DETERMINATION

Reference [5] provides $RT_{NDT}$ estimates for the Cooper reactor pressure vessel (RPV) materials in accordance with Regulatory Guide 1.99, Revision 2 (RG 1.99) [11]. An EXCEL spreadsheet (RTndt(Coop)r1.xls) was created to perform the $RT_{NDT}$ calculations for 32 EFPY. Table 7-2 of Reference [5] provides the calculated Adjusted Reference Temperature (ART) values of record produced by General Electric (GE) for Cooper Nuclear Station. A benchmark was performed to reproduce the GE ART values using the same methodology (Section 7.6.1) documented by GE [5]. Slight differences in the calculated $\Delta RT_{NDT}$ and subsequently ART values were encountered for a few non-limiting materials due to round-off. The GE values for the limiting materials were successfully reproduced and will be used since they are the docketed numbers of CNS. Table 1 shows the $RT_{NDT}$ calculations for 32 EFPY.

# Table 1: Cooper RPV Material ART 32 EFPY Calculations

| Component | Part No. | Heat No. | Initial $RT_{NDT}$ (°F) | Chemistry | | Chemistry Factor (°F) | Adjustments For 1/4t | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Cu (wt %) | Ni (wt %) | | $\Delta RT_{NDT}$ (°F) | Margin Terms | | ART (°F) |
| | | | | | | | | $\sigma_\Delta$ (°F) | $\sigma_I$ (°F) | |
| **Beltline Plates**[1] | | | | | | | | | | |
| Lower Shell Plates | G2803-1 | C2274-1 | 14.0 | 0 20 | 0.68 | 153.00 | 87.5 | 17.0 | 0.0 | 118.5 |
| | G2803-2 | C2307-1 | 0 0 | 0.21 | 0.73 | 162.80 | 93.1 | 17.0 | 0.0 | 110.1 |
| | G2803-3 | C2274-2 | -8.0 | 0.20 | 0.68 | 153.00 | 87.5 | 17.0 | 0.0 | 96.5 |
| Lower-Intermediate Shell Plates | G2801-7 | C2407-1 | -10.0 | 0.13 | 0.65 | 92.25 | 64 6 | 17.0 | 0.0 | 71 6 |
| | G2802-1 | C2331-2 | 10.0 | 0.17 | 0.58 | 125.30 | 87.7 | 17.0 | 0.0 | 114.7 |
| | G2802-2 | C2307-2 | -20.0 | 0 21 | 0.73 | 162.80 | 113.9 | 17.0 | 0 0 | 110 9 |
| **Beltline Welds**[1] | | | | | | | | | | |
| Lower Longitudinal | 2-233 | 12420 | -50.0 | 0.22 | 1.02 | 234 50 | 133 0 | 28.0 | 0 0 | 111.0 |
| Lower-Intermediate Longitudinal | 1-233 | 27204 | -50.0 | 0.19 | 0.97 | 215.65 | 149.6 | 28.0 | 0.0 | 127.6 |
| Lower to Lower-Intermediate Girth | 1-240 | 21935 | -50 0 | 0.20 | 0.69 | 175 30 | 121.6 | 28.0 | 0 0 | 99 6 |
| **Non-Beltline Regions**[2] | | | | | | | | | | |
| Closure Flange Region | ----- | ----- | 20.0 | ----- | ----- | ----- | ----- | ----- | ----- | 20.0 |
| Bottom Head Region | ----- | ----- | 28 0 | ----- | ----- | ----- | ----- | ----- | ----- | 28.0 |

| Fluence Location | Wall Thickness (in.) | | Peak Fluence at ID for 32 EFPY EOL | Attenuation @ 1/4t = $e^{-0.24x}$ | Peak Fluence @ 1/4t for 32 EFPY = f (n/cm2) | Fluence Factor, FF $f^{(0.28 - 0.10 \log f)}$ |
|---|---|---|---|---|---|---|
| | Full | 1/4t | | | | |
| Lower-Int. Shell | 5.375 | 1.344 | 1.57E+18 | 0.724 | 1.14E+18 | 0 443 |
| Lower Shell | 6.375 | 1.594 | 1 10E+18 | 0.682 | 7.52E+17 | 0 362 |

| Surveillance Adjustment | |
|---|---|
| Plates | Welds |
| 1.58 | 1.57 |

Note 1: Beltline material input per Table 7-2 of Reference [5]
Note 2: Non-beltline material input per Reference [5].

## 3.0 CURVE DEVELOPMENT

This section explains the methodology for calculating the pressure test P-T curves. This methodology describes the equations used by the EXCEL spreadsheet (CURVE-Ar1.XLS) developed for the pressure test curves, also known as Curve A.

Three regions are evaluated: (1) the beltline region, (2) the bottom head region, and (3) the feedwater nozzle/upper vessel region. The approach used for calculating the pressure test P-T curves for each of these regions is summarized in the following subsections.

### 3.1 Beltline Region

a. Assume a fluid temperature, T. The temperature at the assumed flaw tip, $T_{1/4t}$ (i.e., 1/4t into the vessel wall), is equal to the fluid temperature, as the pressure test condition neglects any thermal effects (¶G-2215 [3]). The assumed temperature that is read on the plant's gauge has an uncertainty of +/- 5°F [13]. A temperature 5°F less than that assumed is used for calculating the allowable pressure. This method will produce a lower allowable pressure, making it conservative.

b. Calculate the allowable stress intensity factor, using $K_{IC}$ as per Code Case N-640 [4], and $T_{1/4t}$ as follows:

$$K_{IC} = 20.734\, e^{[0.02(T_{1/4t} - ART)]} + 33.2 \quad \text{(eqn. from Ref. [2])}$$

where: $T_{1/4t}$ = metal temperature at assumed flaw tip (°F)
ART = adjusted reference temperature for location under consideration and desired EFPY (°F)
$K_{IC}$ = allowable stress intensity factor (ksi√inch)

$RT_{NDT}$ values for all reactor pressure vessel materials (plates, forgings, and welds) are provided in Table 1. The limiting beltline material is the Lower Longitudinal Weld, having the following ART value:

ART = 127.6°F at 32 EFPY

c. Calculate the thermal stress intensity factor, $K_{IT}$. Thermal stresses are neglected for pressure test conditions, so $K_{IT}$ = 0.

d. Calculate the allowable pressure stress intensity factor, $K_{IP}$, using the following relationship for a pressure test P-T curve [3]:

$$K_{IP} = \frac{K_{IC} - K_{IT}}{SF} = \frac{K_{IC}}{SF}$$

where: $K_{IP}$ = allowable pressure stress intensity factor (ksi√inch)
SF = 1.5

e. Compute the allowable pressure, P. The relationship for the pressure, P, to the allowable pressure stress intensity factor, $K_{IP}$, is (where bending stresses are conservatively excluded and all stresses are treated as membrane) [3]:

$$K_{IP} = M_m \sigma_m$$

| where: | | | |
|---|---|---|---|
| | $\sigma_m$ | = | membrane stress due to pressure (ksi) = PR/t |
| | P | = | pressure (ksi) |
| | R | = | vessel radius (inches) |
| | | = | 110.375 inches from [8] |
| | t | = | vessel wall thickness (inches) |
| | | = | 5.875 inches from [8] |
| | $M_m$ | = | membrane stress correction factor |
| | | = | 0.926√t for √t = 2.424 |
| | | = | 2.24 |

Thus,

$$P = \frac{K_{IP} t}{R M_m}$$

f. Apply any applicable adjustments for temperature and/or pressure to T and P, respectively. The temperature adjustment was assumed to be 5°F as discussed above. The pressure adjustment is 19.9 psig to account for the hydrostatic pressure of at normal vessel water level (water height = 551.75" [1] at room temperature, $\rho = 62.4$ lb/ft$^3$, so $\Delta P = (62.4*551.75)/1728$), and minus 24.0 psig (2% of 1,200 psig) [13] to account for the gauge's uncertainty. Subtracting the gauge's uncertainty produces a lower allowable pressure, making it the most conservative method.

g. Repeat steps (a) through (f) for other temperatures to generate a series of P-T points.

The resulting pressure and temperature series constitutes the P-T curve. The P-T curve relates the minimum required fluid temperature to the reactor pressure. The resulting P-T curves for the beltline region are generated from Table 2.

## Table 2: Beltline Curve A for 32 EFPY

### *Pressure-Temperature Curve Calculation*

*(Pressure Test = Curve A)*

***Inputs:***

| | | |
|---|---|---|
| Plant = | Cooper | |
| Component = | Beltline | |
| Vessel thickness, t = | 5.875 | inches, so √t = 2.424 √inch |
| Vessel Radius, R = | 110.375 | inches |
| ART = | 127.6 | °F ======> 32 EFPY |
| Cooldown Rate, CR = | 0 | °F/hr |
| $K_{IT}$ = | 0.00 | ksi*inch$^{1/2}$ |
| $\Delta T_{1/4t}$ = | 0.0 | °F (no thermal for pressure test) |
| Safety Factor = | 1.50 | (for pressure test) |
| $M_m$ = | 2.24 | |
| Temperature Adjustment = | 5.0 | °F |
| Height of Water for a Full Vessel = | 551.75 | inches |
| Pressure Adjustment = | 19.9 | psig (hydrostatic pressure for a full vessel at 70°F) |
| Pressure Adjustment = | 24.0 | psig (Instrument Uncertainty) |
| Hydro Test Pressure = | 1,563 | psig |
| Flange $RT_{NDT}$ = | 20.0 | °F |

| Gauge Fluid Temperature (°F) | 1/4t Temperature (°F) | $K_{IC}$ (ksi*inch$^{1/2}$) | $K_{IP}$ (ksi*inch$^{1/2}$) | Calculated Pressure P (psig) | Temperature for P-T Curve (°F) | Adjusted Pressure for P-T Curve (psig) |
|---|---|---|---|---|---|---|
| 80.0 | 80.0 | 41.20 | 27.47 | 0 | 80.0 | 0 |
| 80.0 | 75.0 | 40.44 | 26.96 | 641 | 80.0 | 597 |
| 82.0 | 77.0 | 40.74 | 27.16 | 645 | 82.0 | 601 |
| 84.0 | 79.0 | 41.04 | 27.36 | 650 | 84.0 | 606 |
| 86.0 | 81.0 | 41.36 | 27.58 | 655 | 86.0 | 611 |
| 88.0 | 83.0 | 41.70 | 27.80 | 661 | 88.0 | 617 |
| 90.0 | 85.0 | 42.04 | 28.03 | 666 | 90.0 | 622 |
| 92.0 | 87.0 | 42.41 | 28.27 | 672 | 92.0 | 628 |
| 94.0 | 89.0 | 42.78 | 28.52 | 678 | 94.0 | 634 |
| 96.0 | 91.0 | 43.17 | 28.78 | 684 | 96.0 | 640 |
| 98.0 | 93.0 | 43.58 | 29.05 | 690 | 98.0 | 646 |
| 100.0 | 95.0 | 44.00 | 29.33 | 697 | 100.0 | 653 |
| 105.0 | 100.0 | 45.14 | 30.09 | 715 | 105.0 | 671 |
| 110.0 | 105.0 | 46.39 | 30.93 | 735 | 110.0 | 691 |
| 115.0 | 110.0 | 47.78 | 31.85 | 757 | 115.0 | 713 |
| 120.0 | 115.0 | 49.32 | 32.88 | 781 | 120.0 | 737 |
| 125.0 | 120.0 | 51.01 | 34.01 | 808 | 125.0 | 764 |
| 130.0 | 125.0 | 52.88 | 35.26 | 838 | 130.0 | 794 |
| 135.0 | 130.0 | 54.95 | 36.64 | 871 | 135.0 | 827 |
| 140.0 | 135.0 | 57.24 | 38.16 | 907 | 140.0 | 863 |
| 145.0 | 140.0 | 59.77 | 39.85 | 947 | 145.0 | 903 |
| 150.0 | 145.0 | 62.56 | 41.71 | 991 | 150.0 | 947 |
| 155.0 | 150.0 | 65.65 | 43.77 | 1040 | 155.0 | 996 |
| 160.0 | 155.0 | 69.07 | 46.04 | 1094 | 160.0 | 1,050 |
| 165.0 | 160.0 | 72.84 | 48.56 | 1154 | 165.0 | 1,110 |
| 170.0 | 165.0 | 77.01 | 51.34 | 1220 | 170.0 | 1,176 |
| 175.0 | 170.0 | 81.61 | 54.41 | 1293 | 175.0 | 1,249 |
| 180.0 | 175.0 | 86.70 | 57.80 | 1374 | 180.0 | 1,330 |
| 185.0 | 180.0 | 92.33 | 61.55 | 1463 | 185.0 | 1,419 |
| 190.0 | 185.0 | 98.55 | 65.70 | 1561 | 190.0 | 1,517 |
| 195.0 | 190.0 | 105.42 | 70.28 | 1670 | 195.0 | 1,626 |
| 200.0 | 195.0 | 113.02 | 75.35 | 1790 | 200.0 | 1,746 |

## 3.2 Bottom Head Region

The bottom head region calculations are the same as for the beltline region, except that the equation for pressure stress in a spherical shell is substituted for the cylindrical pressure stress equation and a stress concentration factor is used to account for the CRD penetrations. Thus:

a. Same as Step (a) for the beltline region.

b. Same as Step (b) for the beltline region, except that ART values for the lower head region are used. Per Reference [5], the limiting bottom head material is the bottom head torus plates, having bounding $RT_{NDT}$ value of 28°F. The bottom head region is not affected by fluence, so this value is also valid for ART.

c. Same as Step (c) for the beltline region.

d. Same as Step (d) for the beltline region.

e. Compute the allowable pressure, P. The relationship for the pressure, P, to the allowable pressure stress intensity factor, $K_{IP}$, is as follows:

$$K_{IP} = M_m \sigma_m + M_b \sigma_b$$

where:

| | | |
|---|---|---|
| $\sigma_m$ | = | membrane stress due to pressure (ksi) = 3PR/(2t) assuming a stress concentration factor of 3.0 for the bottom head penetrations. The value of 3.0 was arrived at based on SI experience with similar BWR RPV parameters. |
| P | = | pressure (ksi) |
| R | = | vessel radius (inches) |
| | = | 110.375 inches from [8], assumed from beltline region |
| t | = | vessel wall thickness (inches) |
| | = | 3.1875 inches [12] |
| $M_m$ | = | membrane stress correction factor |
| | = | 2.24 for $\sqrt{t} = 2.424$ |
| $\sigma_b$ | = | bending stress due to pressure |
| | = | 0 for a thin walled vessel |

Thus,

$$P = \frac{2K_{IP}t}{2.3RM_m}$$

f. Same as Step (f) for the beltline region.

g. Repeat steps (a) through (f) for other temperatures to generate a series of P-T points.

The resulting P-T curve for the bottom head region is tabulated in Table 3.

## Table 3: Bottom Head Curve A for All EFPY

### *Pressure-Temperature Curve Calculation*

*(Pressure Test = Curve A)*

***Inputs:***

Plant = Cooper
Component = Bottom Head (Penetrations Portion)
Vessel thickness, t = 3.188 inches, so √t = 1.785 √inch
Vessel Radius, R = 110.375 inches
ART = 28.0 °F ======> All EFPYs
Safety Factor = 1.50
Safety Factor = 3.00 Bottom Head Penetrations
$M_m$ = 1.85
Temperature Adjustment = 5.0 °F (Instrument Uncertainty)
Height of Water for a Full Vessel = 551.75 inches
Pressure Adjustment = 19.9 psig (hydrostatic pressure for a full vessel at 70°F)
Pressure Adjustment = 24.0 psig (Instrument Uncertainty)
Unit Pressure = 1,563 psig
Flange $RT_{NDT}$ = 20.0 °F

| Gauge Fluid Temperature (°F) | 1/4t Temperature (°F) | $K_{IC}$ (ksi*inch$^{1/2}$) | $K_{IP}$ (ksi*inch$^{1/2}$) | Calculated Pressure P (psig) | Temperature for P-T Curve (°F) | Adjusted Pressure for P-T Curve (psig) |
|---|---|---|---|---|---|---|
| 80.0 | 80.0 | 91.86 | 61.24 | 0 | 80 | 0 |
| 80.0 | 75.0 | 86.28 | 57.52 | 599 | 80 | 555 |
| 82.0 | 77.0 | 88.44 | 58.96 | 614 | 82 | 570 |
| 84.0 | 79.0 | 90.70 | 60.47 | 629 | 84 | 585 |
| 86.0 | 81.0 | 93.05 | 62.03 | 646 | 86 | 602 |
| 88.0 | 83.0 | 95.49 | 63.66 | 662 | 88 | 619 |
| 90.0 | 85.0 | 98.03 | 65.35 | 680 | 90 | 636 |
| 92.0 | 87.0 | 100.68 | 67.12 | 698 | 92 | 655 |
| 94.0 | 89.0 | 103.43 | 68.95 | 718 | 94 | 674 |
| 96.0 | 91.0 | 106.30 | 70.86 | 737 | 96 | 694 |
| 98.0 | 93.0 | 109.28 | 72.85 | 758 | 98 | 714 |
| 100.0 | 95.0 | 112.38 | 74.92 | 780 | 100 | 736 |
| 102.0 | 97.0 | 115.62 | 77.08 | 802 | 102 | 758 |
| 104.0 | 99.0 | 118.98 | 79.32 | 825 | 104 | 782 |
| 106.0 | 101.0 | 122.48 | 81.65 | 850 | 106 | 806 |
| 108.0 | 103.0 | 126.12 | 84.08 | 875 | 108 | 831 |
| 110.0 | 105.0 | 129.92 | 86.61 | 901 | 110 | 857 |
| 112.0 | 107.0 | 133.86 | 89.24 | 929 | 112 | 885 |
| 114.0 | 109.0 | 137.97 | 91.98 | 957 | 114 | 913 |
| 116.0 | 111.0 | 142.25 | 94.83 | 987 | 116 | 943 |
| 118.0 | 113.0 | 146.70 | 97.80 | 1018 | 118 | 974 |
| 120.0 | 115.0 | 151.33 | 100.89 | 1050 | 120 | 1,006 |
| 122.0 | 117.0 | 156.15 | 104.10 | 1083 | 122 | 1,039 |
| 124.0 | 119.0 | 161.17 | 107.44 | 1118 | 124 | 1,074 |
| 126.0 | 121.0 | 166.39 | 110.93 | 1154 | 126 | 1,110 |
| 128.0 | 123.0 | 171.83 | 114.55 | 1192 | 128 | 1,148 |
| 130.0 | 125.0 | 177.48 | 118.32 | 1231 | 130 | 1,187 |
| 132.0 | 127.0 | 183.37 | 122.25 | 1272 | 132 | 1,228 |
| 134.0 | 129.0 | 189.50 | 126.33 | 1315 | 134 | 1,271 |
| 136.0 | 131.0 | 195.88 | 130.59 | 1359 | 136 | 1,315 |
| 138.0 | 133.0 | 202.52 | 135.01 | 1405 | 138 | 1,361 |
| 140.0 | 135.0 | 209.43 | 139.62 | 1453 | 140 | 1,409 |
| 142.0 | 137.0 | 216.62 | 144.41 | 1503 | 142 | 1,459 |
| 144.0 | 139.0 | 224.10 | 149.40 | 1555 | 144 | 1,511 |
| 146.0 | 141.0 | 231.90 | 154.60 | 1609 | 146 | 1,565 |
| 148.0 | 143.0 | 240.00 | 160.00 | 1665 | 148 | 1,621 |

## 3.3 Feedwater Nozzle/Upper Vessel Region

The feedwater nozzle is selected to represent non-beltline/upper vessel components for fracture toughness analyses because the stress conditions are the most severe experienced in the vessel. In addition to the more severe pressure and piping load stresses resulting from the nozzle discontinuity, the feedwater nozzle region experiences relatively cold feedwater flow in hotter vessel coolant.

The methodology used for the feedwater nozzle is contained in WRC-175 [7]. Thus:

a. Same as Step (a) for the beltline region.

b. Same as Step (b) for the beltline region, except that ART values for the feedwater nozzle/upper vessel region are used. From Reference [5], the closure flange region limiting $RT_{NDT}$ value is 20°F. The feedwater nozzle/upper vessel region is not affected by fluence, so this value is valid for ART.

c. Same as Step (c) for the beltline region.

d. Same as Step (d) for the beltline region.

e. Compute the allowable pressure, P. The relationship for the pressure, P, to the allowable pressure stress intensity factor, $K_{IP}$, is as follows [7]:

$$K_{IP} = \frac{F(a/r_n)R\sqrt{\pi a}P}{t}$$

where:

| | | |
|---|---|---|
| $r_i$ | = | actual inner radius of nozzle = 6.6875 inches [8] |
| $r_c$ | = | nozzle corner radius = 5.0 inches [8] |
| $r_n$ | = | apparent radius of nozzle = $r_i + 0.29r_c$ = 8.1375 |
| t' | = | nozzle corner thickness, approximate |
| | = | 7.108 inches [9] |
| a | = | crack depth (inches) |
| | = | 1/4 t' = 1.777 inches |
| $F(a,r_n)$ | = | nozzle stress factor |
| | = | 1.6 for $a/r_n$ = 0.22 from Figure A5-1 of [7] |
| P | = | pressure (ksi) |
| R | = | vessel radius (inches) = 110.375 inches [8] |
| t | = | vessel wall thickness (inches) = 5.875 inches [8] |
| $K_{IP}$ | = | allowable pressure stress intensity factor (ksi√inch) |

Thus, $$P = \frac{K_{IP} t}{F(a/r_n) R \sqrt{\pi a}}$$

f. Same as Step (f) for the beltline region.

g. Repeat steps (a) through (f) for other temperatures to generate a series of P-T points.

Two additional requirements were used to define the lower portion of the upper vessel P-T curve. These limits are established by the discontinuity regions of the vessel (i.e., flanges), and are specified in Table 1 of Reference [10]:

- If the calculated pressure, P, is greater than 20% of the pre-service hydro test pressure, the temperature must be greater than $RT_{NDT}$ of the limiting flange material + 90°F. The pre-service hydro test pressure was 1,563 psig, and the limiting flange material has an $RT_{NDT}$ of 20°F [5].

- If the calculated pressure, P, is less than or equal to 20% of the pre-service hydro test pressure, the minimum temperature is typically greater than or equal to the $RT_{NDT}$ of the limiting flange material. GE typically applies an additional 60°F margin to the $RT_{NDT}$ value and has been a standard recommendation for the BWR industry for non-ductile failure protection. For the Cooper flange material, this minimum would be 80°F (i.e., 20 + 60°F). Since the 60°F margin is only a recommendation, the minimum temperature for Cooper was set to 80°F to be consistent with past work as well as adequately encompass instrument uncertainty. The gauge's uncertainty of +/- 5°F is not applied here since the included margin just described adequately encompasses instrument uncertainty.

The resulting P-T curve for the feedwater nozzle/upper vessel region is tabulated in Table 4.

## Table 4: Feedwater Nozzle/Upper Vessel Region Curve A for All EFPY

## ***Pressure-Temperature Curve Calculation***

*(Pressure Test = Curve A)*

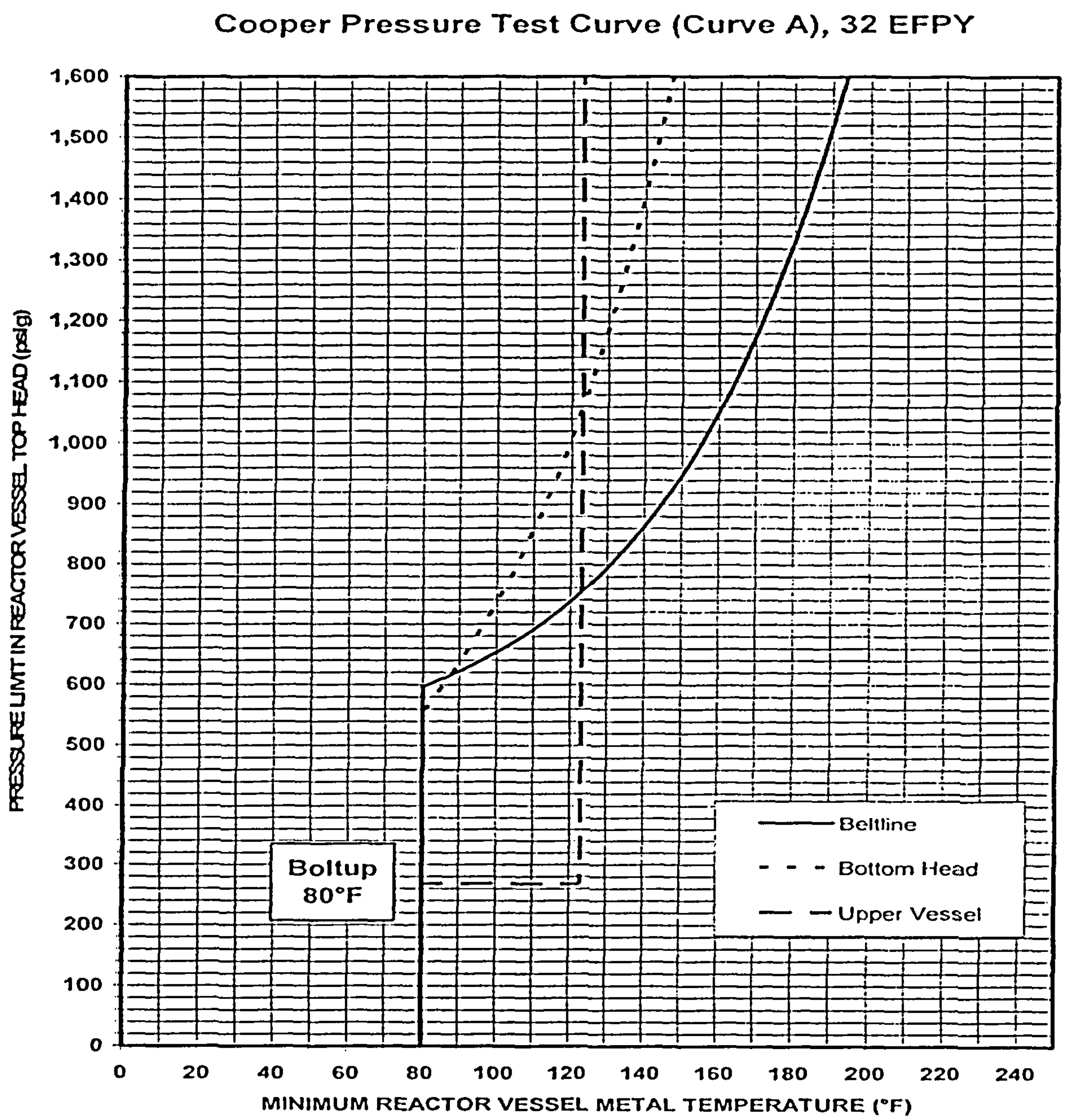
***Inputs:***

Plant = Cooper
Component = Upper Vessel (based on FW nozzle)
ART = 20.0 °F ======> All EFPYs
Vessel thickness, t = 5.875 inches, so $\sqrt{t}$ = 2.424 $\sqrt{\text{inch}}$
Vessel Radius, R = 110.375 inches
Nozzle corner thickness, t' = 7.108 inches, approximate
F(a/rn) = 1.6 nozzle stress factor
Crack Depth, a = 1.777 inches
Safety Factor = 1.50
Temperature Adjustment = 5.0 °F (not applied)
Height of Water for a Full Vessel = 551.75 inches
Pressure Adjustment = 19.9 psig (hydrostatic pressure for a full vessel at 70°F)
Pressure Adjustment = 24.0 psig (Instrument Uncertainty)
Unit Pressure = 1,563 psig
Flange $RT_{NDT}$ = 20.0 °F

| Gauge Fluid Temperature (°F) | 1/4t Temperature (°F) | $K_{IC}$ (ksi*inch$^{1/2}$) | $K_{IP}$ (ksi*inch$^{1/2}$) | Calculated Pressure P (psig) | Temperature for P-T Curve (°F) | Adjusted Pressure for P-T Curve (psig) |
|---|---|---|---|---|---|---|
| 80.0 | 80.0 | 102.04 | 68.03 | 0 | 80.0 | 0 |
| 80.0 | 80.0 | 102.04 | 68.03 | 313 | 80.0 | 269 |
| 118.0 | 118.0 | 180.40 | 120.26 | 313 | 123.0 | 269 |
| 118.0 | 118.0 | 180.40 | 120.26 | 1693 | 123.0 | 1649 |
| 123.0 | 123.0 | 195.88 | 130.59 | 1839 | 128.0 | 1795 |
| 128.0 | 128.0 | 200.00 | 133.33 | 1877 | 133.0 | 1833 |
| 133.0 | 133.0 | 200.00 | 133.33 | 1877 | 138.0 | 1833 |
| 138.0 | 138.0 | 200.00 | 133.33 | 1877 | 143.0 | 1833 |

The resulting P-T curves are shown in Figure 1 for 32 EFPY. Note that only the beltline curve differs in the figure due to irradiation effects.

Figure 1: Pressure Test P-T Curve (Curve A) for 32 EFPY




| Revision | A | 0 | 1 | |
|---|---|---|---|---|
| Preparer/Date | CRL 05/27/03 | CRL 08/11/03 | CRL 10/15/03 | |
| Checker/Date | BPT 05/27/03 | BPT 08/11/03 | BPT 10/15/03 | |

## 4.0 REFERENCES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3. ASME Boiler and Pressure Vessel Code, Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components, Nonmandatory Appendix G, "Fracture Toughness Criteria for Protection Against Failure," 1995 Edition, 1996 Addenda.

4. ASME Boiler and Pressure Vessel Code, Code Case N-640, "Alternative Reference Fracture Toughness for Development of P-T Limit Curves," Section XI, Division 1, Approved February 26, 1999.

5. GE Document No. GE-NE-523-159-1292 (DRF B13-01662), "Cooper Nuclear Station Vessel Surveillance Materials Testing and Fracture Toughness Analysis," Revision 0, February 1993, SI File No. COOP-05Q-202.

6. Not Used.

7. WRC Bulletin 175, "PVRC Recommendations on Toughness Requirements for Ferritic Materials," PVCR Ad Hoc Group on Toughness Requirements, Welding Research Council, August 1972.

8. CBI Stress Report DC22A7245, Revision 0, "Feedwater Nozzle Modification Cooper RPV," 3/20/80, SI File NPPD-13Q-205.

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13. NPPD Memo DED 2003-005, Alan Able to Ken Thomas, dated August 14, 2003, "Instrument Uncertainty Associated With Technical Specification 3.4.9," SI File No. COOP-05Q-203.

Correspondence No: NLS2004005

The following table identifies those actions committed to by Nebraska Public Power District (NPPD) in this document. Any other actions discussed in the submittal represent intended or planned actions by NPPD. They are described for information only and are not regulatory commitments. Please notify the Licensing & Regulatory Affairs Manager at Cooper Nuclear Station of any questions regarding this document or any associated regulatory commitments.

| COMMITMENT | COMMITTED DATE OR OUTAGE |
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