May 1, 2001

Mr. Mark Reddemann
Site Vice President
Kewaunee and Point Beach Nuclear Plants
Nuclear Management Company, LLC
6610 Nuclear Road
Two Rivers, WI 54241

SUBJECT: KEWAUNEE NUCLEAR POWER PLANT - EXEMPTION FROM THE REQUIREMENTS OF 10 CFR PART 50, APPENDIX G, APPENDIX H, AND SECTION 50.61 (TAC NO. MA8585)

Dear Mr. Reddemann:

Wisconsin Public Service Corporation (WPSC) submitted letters dated June 7, 1999, and February 4, 2000, and Nuclear Management Company, LLC (NMC) submitted letters dated September 26, December 18, 2000, and March 12, 2001, requesting a license amendment with exemption requests. WPSC was succeeded by NMC as the licensed operator of the Kewaunee Nuclear Power Plant (KNPP). By letter dated October 5, 2000, NMC (the licensee) requested the Nuclear Regulatory Commission (NRC) staff continue to process and disposition licensing actions previously docketed and requested by WPSC.

The NRC has approved, subject to the conditions cited in the enclosed exemption (Enclosure 1), the enclosed exemptions from specific requirements of Appendix G and Appendix H to Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50 and 10 CFR 50.61 for the KNPP. Specifically, the NRC has issued: (1) an exemption to establish the use of a new methodology to meet the requirements of Appendix G to 10 CFR Part 50; (2) an exemption to establish the use of a new methodology to meet the requirements of 10 CFR 50.61; and (3) an exemption to modify the basis for the KNPP reactor pressure vessel (RPV) surveillance program (required by Appendix H to 10 CFR Part 50) to incorporate the acquisition of fracture toughness data. Your new methodology, modified by the NRC staff, for assessing the RPV circumferential beltline weld as given in Appendix A to the enclosed safety evaluation (Enclosure 2), is based on the use of the 1997 Edition of American Society for Testing and Materials Standard Test Method E-1921 and American Society for Mechanical Engineering Code Case N-629. This action is in response to your letter dated June 7, 1999, as supplemented on February 4, 2000, September 26, December 18, 2000, and March 12, 2001.

Your letters dated June 7, 1999, as supplemented on February 4, September 26, and December 18, 2000, also included a request to amend your license to change certain Technical Specifications. The letter dated December 18, 2000, requested the Technical Specification changes be withdrawn; however, you requested that the NRC staff continue to process the exemptions. By letter dated March 12, 2001, you agreed to use your new methodology as modified by the NRC staff. You agreed to incorporate information obtained as part of KNPP's surveillance capsule program into the evaluation of the KNPP RPV, using the revised methodology. You also agreed to obtain the following information regarding KNPP's reactor vessel radiation surveillance capsule:

(a) A valid measurement of the fracture toughness-based T_0 parameter for the KNPP RPV surveillance weld,

(b) An estimate of the Charpy V-notch 30 ft-lb transition temperature shift for the surveillance weld, and

(c) An estimate of the upper shelf energy drop for the surveillance weld.

A copy of the exemption and the NRC staff's safety evaluation are enclosed. The exemption is being forwarded to the Office of the Federal Register for publication.

Sincerely,

/RA/
John G. Lamb, Project Manager, Section 1
Project Directorate III
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Docket No. 50-305

Enclosures: As stated

cc w/encls: See next page

(a) A valid measurement of the fracture toughness-based T_0 parameter for the KNPP RPV surveillance weld,

(b) An estimate of the Charpy V-notch 30 ft-lb transition temperature shift for the surveillance weld, and

(c) An estimate of the upper shelf energy drop for the surveillance weld.

A copy of the exemption and the NRC staff's safety evaluation are enclosed. The exemption is being forwarded to the Office of the Federal Register for publication.

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Enclosures: As stated

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

NUCLEAR MANAGEMENT COMPANY, LLC

KEWAUNEE NUCLEAR POWER PLANT

50-305

EXEMPTION

1.0 BACKGROUND

Nuclear Management Company, LLC (the licensee) is the holder of Facility Operating License No. DPR-43, which authorizes operation of the Kewaunee Nuclear Power Plant (KNPP). The license provides, among other things, that the facility is subject to all rules, regulations, and orders of the U.S. Nuclear Regulatory Commission (the Commission) now or hereafter in effect.

The facility consists of a pressurized water reactor located on the licensee's KNPP site in Kewaunee County, Wisconsin.

2.0 REQUEST

By letter dated June 7, 1999, as supplemented February 4, September 26, December 18, 2000, and March 12, 2001, Wisconsin Public Service Corporation (WPSC) proposed three exemptions and a license amendment which affect the licensing basis of the KNPP reactor pressure vessel (RPV). Subsequently, WPSC was succeeded by Nuclear Management Company, LLC (NMC), as the licensed operator of the KNPP. By letter dated October 5, 2000, NMC (the licensee) requested the Nuclear Regulatory Commission (NRC)

staff continue to process and disposition licensing actions previously docketed and requested by WPSC. By letter dated December 18, 2000, the licensee withdrew the license amendment.

The three exemptions requested by the licensee address portions of the following regulations: (1) Appendix G to 10 CFR Part 50, which sets forth fracture toughness requirements for ferritic materials of pressure-retaining components of the reactor coolant pressure boundary of light water nuclear power reactors to provide adequate margins of safety during any condition of normal operation, including anticipated operational occurrences and system hydrostatic tests, to which the pressure boundary may be subjected over its service lifetime; (2) 10 CFR 50.61, which sets forth fracture toughness requirements for protection against pressurized thermal shock (PTS) events; and (3) Appendix H to 10 CFR Part 50, which requires the establishment of a RPV material surveillance program.

The licensee requested an exemption from Appendix G to 10 CFR Part 50 to replace the required use of the existing Charpy V-notch and drop weight-based methodology and allow the use an alternate methodology to incorporate the use of fracture toughness test data for evaluating the integrity of the KNPP RPV circumferential beltline weld based on the use of the 1997 Edition of American Society for Testing and Materials (ASTM) Standard Test Method E 1921 (E 1921-97) and American Society for Mechanical Engineering (ASME) Code Case N-629. The exemption is required since Appendix G to 10 CFR Part 50, through reference to Appendix G to Section XI of the ASME Code pursuant to 10 CFR 50.55(a), requires the use of a methodology based on Charpy V-notch and drop weight data.

The licensee requested an exemption from 10 CFR 50.61 to use an alternate methodology to allow the use of fracture toughness test data for evaluating the integrity of the KNPP RPV circumferential beltline weld based on the use of the 1997 Edition of ASTM E 1921-97 and ASME Code Case N-629. The exemption is required since the methodology for

evaluating RPV material fracture toughness in 10 CFR 50.61 requires the use of the Charpy V-notch and drop weight data for establishing the PTS reference temperature (RT_{PTS}).

The licensee requested an exemption from Appendix H to 10 CFR Part 50 to modify the basis for the KNPP RPV surveillance program to allow the acquisition and use of fracture toughness data instead of the Charpy V-Notch impact testing required by Appendix H to 10 CFR Part 50. The exemption is required since Appendix H to 10 CFR Part 50 does not address the testing of surveillance specimens for direct measurement of fracture toughness.

3.0 DISCUSSION

10 CFR 50.12(a)(2)(ii) enables the Commission to grant exemptions from the requirements of Part 50 when special circumstances are present such that application of the regulation in the particular circumstances would not serve the underlying purpose of the rule, or is not necessary to achieve the underlying purpose of the rule.

The underlying purpose of Appendix G to 10 CFR Part 50 is to set forth fracture toughness requirements for ferritic materials of pressure-retaining components of the reactor coolant pressure boundary of light water nuclear power reactors to provide adequate margins of safety during any condition of normal operation, including anticipated operational occurrences and system hydrostatic tests, to which the pressure boundary may be subjected over its service lifetime.

The methodology underlying the requirements of Appendix G to 10 CFR Part 50 is based on the use of Charpy V-notch and drop weight data. The licensee proposes to replace the use of the existing Charpy V-notch and drop weight-based methodology by a fracture toughness-based methodology to demonstrate compliance with Appendix G to 10 CFR Part 50. The NRC staff has concluded that the exemption is justified based on the licensee utilizing the fracture toughness methodology specified in Appendix A of the NRC staff safety evaluation

(SE), dated May 1, 2001. The use of the methodology specified in Appendix A of the NRC staff SE will ensure that P-T limits developed for the KNPP RPV will continue to be based on an adequately conservative estimate of RPV material properties and ensure that the pressure-retaining components of the reactor coolant pressure boundary retain adequate margins of safety during any condition of normal operation, including anticipated operational occurrences. Also, when additional fracture toughness data relevant to the evaluation of the KNPP RPV circumferential weld is acquired as part of the KNPP surveillance program, this data must be incorporated into the evaluation of the KNPP RPV using the methodology of Appendix A of the NRC staff SE. With these conditions, which were agreed to by licensee letter, dated March 12, 2001, the licensee's requested exemption from the use of the Charpy V-notch and drop weight-based methodology required by Appendix G to 10 CFR Part 50 may be granted in accordance with 10 CFR 50.12(ii) in that special circumstances are present since application of the regulation in the particular circumstances is not necessary to achieve the underlying purpose of the rule. The foregoing exemption only modifies the methodology to be used by the licensee for demonstrating compliance with the requirements of Appendix G to 10 CFR Part 50, and does not exempt the licensee from meeting any other requirement of Appendix G to 10 CFR Part 50.

The underlying purpose of 10 CFR 50.61 is to establish requirements which ensure that a licensee's RPV will be protected from failure during a PTS event by evaluating the fracture toughness of RPV materials.

The licensee seeks an exemption to 10 CFR 50.61 requirement to use a methodology for the "determination of adjusted/indexing reference temperatures." The licensee proposes to use ASME Code Case N-629 and the methodology outlined in its submittal, which are based on the use of fracture toughness data, as an alternative to the Charpy V-notch and drop weight-based methodology required by 10 CFR 50.61 for establishing the PTS RT_{PTS}. The NRC staff

has concluded that the exemption is justified based on the licensee utilizing the methodology specified in Appendix A of the NRC staff SE, dated May 1, 2001. The use of the methodology specified in Appendix A of the NRC staff SE will ensure the PTS evaluation developed for the KNPP RPV will continue to be based on an adequately conservative estimate of RPV material properties and ensure the RPV will be protected from failure during a PTS event. Also, when additional fracture toughness data relevant to the evaluation of the KNPP RPV circumferential weld is acquired as part of the KNPP surveillance program, this data must be incorporated into the evaluation of the KNPP RPV using the methodology of Appendix A of the NRC staff SE. With these conditions, which were as agreed to by licensee letter, dated March 12, 2001, the licensee's requested exemption from the use of the Charpy V-notch and drop weight-based methodology required by 10 CFR 50.61 may be granted in accordance with 10 CFR 50.12(ii) in that special circumstances are present since application of the regulation in the particular circumstances is not necessary to achieve the underlying purpose of the rule. The foregoing exemption only modifies the methodology to be used by the licensee for demonstrating compliance with the requirements of 10 CFR 50.61, and does not exempt the licensee from meeting any other requirement of 10 CFR 50.61.

Appendix H to 10 CFR Part 50 requires that, "[f]or each capsule withdrawal, the test procedures and reporting requirements must meet the requirements of ASTM E 185-82 [the 1982 edition] to the extent practicable for the configuration of the specimens in the capsule." ASTM Standard Practice E 185-82 requires Charpy V-Notch impact testing, but does not address the testing of surveillance specimens for direct measurement of fracture toughness, either as a requirement or as an optional action. The exemption would permit the licensee to utilize alternative surveillance program testing requirements and permit the acquisition of fracture toughness data for the surveillance weld as the basis for the KNPP RPV surveillance program.

The underlying purpose of Appendix H to 10 CFR Part 50 is to acquire data to, "...monitor changes in the fracture toughness properties of ferritic materials in the reactor vessel beltline region of light water nuclear power reactors which result from exposure of these materials to neutron irradiation and the thermal environment." As discussed in the NRC staff SE, dated May 1, 2001, the licensee's alternate surveillance program requirements and the acquisition of data will adequately monitor the change in RPV fracture toughness and provide input to the approved fracture toughness-based methodology for RPV integrity. Therefore, the NRC staff concludes that this exemption may be granted because the special circumstances required by 10 CFR 50.12(a)(ii) are present in that application of the regulation [i.e., the Charpy V-Notch-based testing practices specified by Appendix H to 10 CFR Part 50] in the particular circumstances is not necessary to achieve the underlying purpose of the rule.

4.0 CONCLUSION

Accordingly, the Commission has determined that, pursuant to 10 CFR 50.12(a), the exemptions are authorized by law, will not endanger life or property or common defense and security, and is, otherwise, in the public interest. Therefore, the Commission hereby grants Nuclear Management Company, LLC, exemptions from portions of the requirements of Appendix G to 10 CFR Part 50; 10 CFR 50.61; and, Appendix H to 10 CFR Part 50, to allow an alternative methodology that is based on using of fracture toughness test data for evaluating the integrity of the KNPP RPV circumferential beltline weld with the following conditions:

(1) The licensee must utilize the methodology specified in Appendix A of the NRC staff SE, dated May 1, 2001;

(2) When additional fracture toughness data relevant to the evaluation of the KNPP RPV circumferential weld is acquired as part of the KNPP surveillance program, this data must be incorporated into the evaluation of the KNPP RPV using the methodology of Appendix A of the NRC staff SE; and

(3) The licensee must obtain the following regarding the next surveillance capsule: (a) a valid measurement of the fracture toughness-based T_0 parameter for the KNPP RPV surveillance weld, (b) an estimate of the Charpy V-notch 30 ft-lb transition temperature shift for the surveillance weld, and (c) an estimate of the upper shelf energy drop for the surveillance weld.

Pursuant to 10 CFR 51.32, an environmental assessment and finding of no significant impact has been prepared and published in the *Federal Register* (66 FR 21787). Accordingly, based upon the environmental assessment, the Commission has determined that the granting of this exemption will not result in any significant effect on the quality of the human environment.

This exemption is effective upon issuance.

Dated at Rockville, Maryland, this 1st day of May 2001.

FOR THE NUCLEAR REGULATORY COMMISSION

/RA/
John A. Zwolinski, Director
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

REGARDING AMENDMENT OF THE KEWAUNEE NUCLEAR POWER PLANT LICENSE

TO INCLUDE THE USE OF A MASTER CURVE-BASED METHODOLOGY

FOR REACTOR PRESSURE VESSEL INTEGRITY ASSESSMENT

DOCKET NO. 50-305

1.0 INTRODUCTION

Wisconsin Public Service Corporation (WPSC) submitted letters dated June 7, 1999, and February 4, 2000, and Nuclear Management Company, LLC (NMC) submitted letters dated September 26, 2000, December 18, 2000, and March 12, 2001, requesting a license amendment with exemption requests. WPSC was succeeded by NMC, as the licensed operator of the Kewaunee Nuclear Power Plant (KNPP). By letter dated October 5, 2000, NMC (the licensee) requested the Nuclear Regulatory Commission (NRC) staff continue to process and disposition licensing actions previously docketed and requested by WPSC.

By letter dated June 7, 1999, the licensee proposed an extensive suite of changes which affect the licensing basis of the KNPP reactor pressure vessel (RPV).[1] These proposed changes were developed to incorporate the use of Master Curve fracture toughness (K_{JC}) test data for evaluating the integrity of the KNPP RPV circumferential beltline weld. In the submittal, the licensee requested NRC staff approval of a new methodology for assessing the RPV circumferential beltline weld based on the use of the 1997 Edition of American Society for Testing and Materials (ASTM) Standard Test Method E 1921 (E 1921-97) and American Society for Mechanical Engineering (ASME) Code Case N-629.[2-3] The licensee submittal included: (1) exemption requests to establish the use of this new methodology to meet the requirements of Appendix G to Title 10 of the Code of Federal Regulations Part 50 (10 CFR Part 50), and 10 CFR 50.61; (2) an exemption request to modify the basis for the KNPP RPV surveillance program (required by Appendix H to 10 CFR Part 50) to incorporate the acquisition of fracture toughness data; (3) a license amendment to revise the existing KNPP RPV pressure-temperature (P-T) limit curves; and (4) a reassessment of the KNPP RPV's compliance with 10 CFR 50.61 (concerning pressurized thermal shock (PTS) for both end of license (EOL) and end of license extended (EOLE) conditions). A series of Westinghouse topical reports (WCAPs) were included as attachments [4-8] to the licensee's June 7, 1999, submittal to provide additional detail to support requested exemptions and license amendments.

By letter dated July 16, 1999, the NRC staff notified the licensee that an acceptance review had been completed of their June 7,1999, submittal and the NRC staff had concluded that the

ENCLOSURE

submittal was incomplete.[9] In particular, the NRC staff noted that the licensee had not adequately addressed all sources of material and fluence uncertainty which contribute to the amount of margin to be included in the RPV evaluation. On February 4, 2000, the licensee responded to the NRC staff's letter and provided sufficient information to address the identified inadequacies.[10] The NRC staff met with the licensee on July 6, 2000, to discuss the status of the NRC staff's evaluation of the submittal and identified two open items requiring additional licensee input. The NRC staff formally requested, in the written summary of the July 6, 2000, meeting, a response from the licensee regarding these open items. This meeting summary was published on July 20, 2000, and the licensee responded to the open items by letter dated September 26, 2000.[11, 12]

The licensee letters dated June 7, 1999, as supplemented on February 4 and September 26, 2000, also included a request to amend the license to change certain Technical Specifications. The licensee letter dated December 18, 2000, requested the Technical Specification changes be withdrawn; however, the licensee requested that the NRC staff continue to process the exemptions. Finally, by letter dated February 21, 2001, the NRC requested that the licensee agree to use the methodology given in Appendix A to this SE and surveillance program requirements cited in the exemption approval and in this SE as the basis for the NRC staff's approval of the licensee's exemption request.[13] The licensee responded by letter dated March 12, 2001, and agreed to utilize the methodology given in Appendix A of this SE and to meet the requested surveillance program requirements.[14] Although the licensee's submittal included a reassessment of the KNPP RPV's compliance with 10 CFR 50.61 for both EOL and EOLE conditions, the NRC staff did not evaluate the condition of the KNPP RPV at EOLE fluence for the purpose of justifying the integrity of the RPV to that fluence value. Rather, the NRC staff evaluated the $ART_{T0\text{-}EOLE\text{-}ID}$ value of the KNPP RPV using the NRC staff's methodology only for comparison to the value determined from the licensee's methodology. This comparison was necessary to determine whether the licensee's proposed methodology was at least as conservative as the NRC staff's methodology.

2.0 <u>REGULATORY CRITERIA</u>

The changes to the KNPP licensing basis proposed by the licensee address three fundamental regulations related to the RPV: Appendix G to 10 CFR Part 50; Appendix H to 10 CFR Part 50; and 10 CFR 50.61. Appendix G to 10 CFR Part 50 specifies fracture toughness requirements for ferritic materials of pressure-retaining components of the reactor coolant pressure boundary of light water nuclear power reactors to provide adequate margins of safety during any condition of normal operation, including anticipated operational occurrences and system hydrostatic tests, to which the pressure boundary may be subjected over its service lifetime." Appendix H to 10 CFR Part 50 requires the establishment of a material surveillance program to, "monitor changes in the fracture toughness properties of ferritic materials in the reactor vessel beltline region of light water nuclear power reactors whcih result from exposure of these materials to neutron irradiation and the thermal environment." 10 CFR 50.61 requires that an appropriate evaluation be performed to demonstrate that a facility's RPV is adequately protected against pressurized thermal shock (PTS) events. 10 CFR 50.60, which invokes the requirements of Appendices G and H to 10 CFR Part 50, also provides that "proposed alternatives to the described requirements in Appendices G and H of this part or portions thereof may be used when an exemption is granted by the Commission under [10 CFR] 50.12."

Appendix G to 10 CFR Part 50, incorporates by reference the methodology described in Appendix G to Section XI of the ASME Boiler and Pressure Vessel Code as the basis for the requirements given in Appendix G to 10 CFR Part 50, by stating that P-T limits, "...must be at least as conservative as limits obtained by following the methods of analysis and the margins of safety of Appendix G of Section XI of the ASME Code." Pursuant to 10 CFR 50.55a, this incorporation includes editions of the ASME Code through the 1996 Addenda to the 1995 Edition. These editions of the ASME Code use testing of Charpy V-notch and drop weight specimens to index the fracture toughness properties of RPV materials by developing an

indexing parameter, the nil-ductility reference temperature, RT_{NDT}. Likewise, the same testing practices were used for establishing the technical basis for the assessment of PTS in 10 CFR 50.61. The RPV surveillance program of Appendix H to 10 CFR Part 50, which incorporates the use of the 1982 Edition of ASTM Standard E 185 for defining testing and reporting requirements, is also based on the use of Charpy V-notch testing to monitor the embrittlement of RPV steels caused by neutron irradiation.[15]

Specific to the evaluation of the KNPP P-T limits, one additional regulatory provision must also be considered. By letter dated August 6, 1998, the licensee requested that they be permitted an exemption to the requirements of 10 CFR 50.60 and Appendix G to 10 CFR Part 50, for the purpose of applying ASME Code Case N-588 for their P-T limits calculations.[16] The NRC granted this exemption request on November 25, 1998.[17] The methodology in Appendix G to Section XI of the ASME Code requires the licensee to postulate a flaw in each RPV material from either the exterior or interior surface (whichever would be most limiting) of the vessel to a depth of 1/4 of the vessel thickness and oriented such that the flaw would extend vertically along the axis of the vessel (i.e., an “axially-oriented” flaw). This orientation of the flaw results in the largest principal pressure loads being applied to the flaw and results in a conservative analysis for the possibility of flaw propagation. ASME Code Case N-588 modifies this methodology by permitting the licensee to postulate a circumferentially-oriented flaw instead of an axially-oriented flaw when analyzing their circumferential RPV weld. The justification for this allowance is documented in the exemption and safety evaluation (SE) dated November 25, 1998.

3.0 LICENSEE EVALUATION

For the purpose of this SE, the evaluation submitted by the licensee will be discussed in four parts. First, the licensee’s treatment of exemption requests to establish the use of an alternative methodology (based on Master Curve technology) for meeting the requirements of 10 CFR 50.61 will be presented. Next, the licensee’s program for conducting future RPV surveillance activities and their request for exemptions from Appendices G and H to 10 CFR Part 50, to establish a basis for acquiring and utilizing fracture toughness (K_{JC}) data as part of this program will be addressed. The third topic will be a discussion of the Master Curve-based methodology that the licensee submitted for applying fracture toughness data to the assessment of the KNPP RPV circumferential weld. Finally, the results (i.e., P-T limits and PTS assessments) obtained by the licensee using their proposed methodology will be discussed.

3.1 Exemption from 10 CFR 50.61

In their June 7, 1999, submittal, the licensee requested exemptions from 10 CFR 50.61, Appendix G to 10 CFR Part 50, and Appendix H to 10 CFR Part 50, in accordance with 10 CFR 50.12. The licensee described the exemption to 10 CFR 50.61, as an exemption from the methodology for the “determination of adjusted/indexing reference temperatures.” The licensee identified the use of ASME Code Case N-629 and the methodology outlined in Reference 8 as their proposed alternative to the Charpy and drop weight-based methodology used in 10 CFR 50.61, for establishing the PTS reference temperature (RT_{PTS}). The licensee requested approval of this exemption based on 10 CFR 50.12(a)(ii), “[a]pplication of the regulation in the particular circumstances...is not necessary to achieve the underlying purpose of the rule.” The licensee concluded that their proposed methodology would adequately evaluate the integrity of the KNPP RPV and ensure that the RPV is protected from failure by

PTS, thus, achieving the underlying purpose of 10 CFR 50.61, without requiring the use of the Charpy V-notch and drop weight-based methodology specified in 10 CFR 50.61.

The licensee also cited 10 CFR 50.12(a)(iii) regarding, "[c]ompliance [with the Rule] would result in undue hardship..." if the licensee were required to continue to use a Charpy and drop weight-based approach as an additional basis for this exemption request. Based on the licensee's evaluation of P-T limits and PTS (discussed in Section 3.4), their proposed Master Curve-based methodology would result in a significant reduction in the fracture toughness reference temperature. The licensee concluded that this reduction would provide additional operating margin by the establishment of less restrictive operational requirements (i.e., P-T limits). Likewise, the licensee stated, an RT_{PTS} value further from the screening limits imposed by 10 CFR 50.61, would obviate the need for the licensee to consider thermal annealing or engineering evaluations to continue to demonstrate an acceptable level of RPV integrity relative to PTS concerns.

3.2 Exemptions from Appendices G and H to 10 CFR Part 50, and the RPV Surveillance Program

Three subtopics from the licensee's submittal are addressed in this section. The first is the licensee's identification of a need to request an exemption from Appendix H to 10 CFR Part 50, to incorporate the acquisition of fracture toughness data into the KNPP licensing basis as part of the KNPP RPV surveillance program and to relax Charpy V-notch testing requirements. The second is the licensee's request for an exemption from Appendices G and H to 10 CFR Part 50, to utilize data based on fracture toughness testing as the basis for their evaluation of the KNPP RPV circumferential beltline weld. Finally, the last topic is the information submitted by the licensee regarding the basis for, and structure of, the KNPP RPV surveillance program after approval of a Master Curve-based methodology for RPV integrity assessment.

3.2.1 Exemption from Appendix H to 10 CFR Part 50

The licensee noted that an exemption specific to Appendix H to 10 CFR Part 50, was required to permit direct measurement of fracture toughness from RPV surveillance program specimens and to incorporate fracture toughness testing as part of the KNPP RPV surveillance program for future surveillance capsule withdrawals. Appendix H to 10 CFR Part 50, requires that, "[f]or each capsule withdrawal, the test procedures and reporting requirements must meet the requirements of ASTM E 185-82 [the 1982 edition] to the extent practicable for the configuration of the specimens in the capsule." ASTM Standard Practice E 185-82 requires Charpy V-Notch impact testing, but does not address the testing of surveillance specimens for direct measurement of fracture toughness (K_{JC}), either as a requirement or as an optional action. Therefore, the licensee's exemption request, per the requirements of 10 CFR 50.60(b), was to obtain NRC staff approval for an alternative to the requirements of Appendix H to 10 CFR Part 50 to permit the acquisition of fracture toughness data by direct measurement for their surveillance weld.

The licensee proposed to use the 1998 edition of ASTM Standard Practice E 185 (ASTM E 185-98) to define the surveillance program testing requirements as an alternative to ASTM E 185-82. ASTM E 185-98 provides the user the option in Paragraph 9.4 to perform fracture toughness testing, "...in accordance with the procedures and requirements of [ASTM Standard] Practice E 636, [ASTM Standard Test] Method E 1820, or [ASTM Standard Test] Method E 1921." Specifically, the licensee confirmed that ASTM Standard Method E 1921-97

would be used to define the methodology for the fracture toughness testing of future RPV surveillance program materials relevant to the assessment of the KNPP RPV circumferential beltline weld. The licensee noted that ASTM E 1921-97 had already been used to acquire the data that had been used to develop their Master Curve-based methodology (discussed in Section 3.3) and define the results (Section 3.4) of applying this methodology to the KNPP RPV circumferential weld as part of this application.

However, ASTM E 185-98, Paragraph 9.2, also requires the user to obtain a full Charpy impact curve from the surveillance material as well. As clarified in the licensee's September 26, 2000, letter, due to specimen limitations, the licensee has proposed to also eliminate this requirement for the testing of their surveillance weld. The technical details of this request are addressed in Section 3.2.3.2 below. It is sufficient to note here that this request was incorporated in the licensee's request for an exemption from Appendix H to 10 CFR Part 50, since it represents a reduction from the Charpy V-notch impact testing that would otherwise be required by Appendix H to 10 CFR Part 50. Note, the Charpy V-notch impact testing requirements for the KNPP surveillance plate and correlation monitor material will be maintained. Charpy V-notch impact testing of heat affected zone (HAZ) materials would be discontinued to provide for the fabrication of additional reconstituted weld samples.

The underlying purpose of Appendix H to 10 CFR Part 50, is to acquire data to, "...monitor changes in the fracture toughness properties of ferritic materials in the reactor vessel beltline region," in order that RPV integrity assessments may be performed. With the approval of a Master Curve-based methodology for RPV integrity assessment, the licensee concluded that this exemption should be granted under 10 CFR 50.12 (a)(ii), since "[a]pplication of the regulation [i.e., the Charpy V-Notch-based testing practices specified by Appendix H to 10 CFR Part 50] in the particular circumstances would not serve the underlying purpose or is not necessary to achieve the underlying purpose of the rule." As addressed above, this exemption would permit a reduction in the Charpy impact testing requirements and permit the acquisition of fracture toughness data for the surveillance weld as the basis for the KNPP RPV surveillance program.

3.2.2 Exemptions from Appendices G and H to 10 CFR Part 50

The licensee identified that Appendix G to 10 CFR Part 50, through reference to specifications in Appendix H to 10 CFR Part 50 requires that Charpy V-notch and drop weight testing be used to establish the fracture toughness of RPV materials (via an indexing methodology) and to monitor the changes in their fracture toughness due to irradiation. Thus, the licensee concluded that an exemption, similar to that requested for 10 CFR 50.61, was required to enable the use of the data from the testing practices discussed in 3.2.1 above for Appendix G to 10 CFR Part 50 (i.e., P-T limit) applications.

The licensee requested this exemption from the requirement to rely on Charpy and drop weight-based test data under 10 CFR 50.12(a)(ii). 10 CFR 50.12(a)(ii) provides for the granting of an exemption given that, "[a]pplication of the regulation in the particular circumstances...is not necessary to achieve the underlying purpose of the rule." The licensee concluded that given the NRC staff's approval of a Master Curve-based methodology for assessing KNPP RPV material properties, application of Charpy and drop weight-based testing would not be necessary to achieve the underlying purposes of Appendix G to 10 CFR Part 50.

3.2.3 KNPP RPV Surveillance Program

As discussed previously, the licensee identified that changes to the KNPP RPV surveillance program were necessary to support their proposal to use a Master Curve-based methodology for the evaluating the integrity of the KNPP RPV circumferential weld. Prior sections of this SE addressed the licensee exemption requests to reconcile the regulatory basis for making these changes. The technical changes to the KNPP RPV surveillance program proposed by the licensee will be discussed further in this section. These proposed RPV surveillance program changes can be addressed in two parts: (1) the testing of unirradiated archive material and the reconstitution and testing of material from previously tested KNPP and Maine Yankee surveillance capsules to obtain fracture toughness data; and (2) plans for future testing of additional surveillance capsules from the KNPP RPV surveillance program to provide additional fracture toughness data for the KNPP surveillance weld.

3.2.3.1 Testing of Archive Material and Previously-Tested RPV Surveillance Capsule Material

As part of the basis for the submittal, the licensee performed fracture toughness tests on materials taken from unirradiated archive materials and previously tested surveillance capsules. Details regarding the fracture toughness testing of these materials were provided by the licensee in Reference 5. The materials tested included samples of the surveillance welds from both the Maine Yankee and KNPP RPV surveillance programs. The testing of these materials was determined to be relevant since both surveillance welds were manufactured with the same weld wire heat (1P3571) as was used to fabricate the KNPP RPV circumferential beltline weld.

The fracture toughness testing of unirradiated archive weld material from the KNPP and Maine Yankee surveillance welds was conducted in two parts. For the KNPP surveillance weld, unirradiated archive material was located at Westinghouse and tested as part of a Westinghouse Owners Group program on Master Curve testing. Unirradiated fracture toughness data was acquired for the KNPP surveillance weld using three types of specimens: previously-untested precracked Charpy V-notch (PCVN) specimens, reconstituted PCVN specimens, and previously-untested 1/2T compact tension (CT) specimens. The reconstituted PCVN specimens were fabricated in accordance with ASTM Standard E 1253, "Guide for Reconstitution of Irradiated Charpy Specimens."[18] Unirradiated fracture toughness data for the Maine Yankee surveillance weld was acquired as part of a Combustion Engineering (CE) Reactor Vessel Working Group program from archived Maine Yankee surveillance weld material. Previously-untested PCVN specimens were tested to obtain unirradiated data from the Maine Yankee surveillance weld.

When discussing irradiated specimens, the phrase "previously-tested" refers to specimens which were removed from KNPP or Maine Yankee RPV surveillance capsules as part of either facility's RPV surveillance program and tested in accordance with the requirements of Appendix H to 10 CFR Part 50. As such, the Charpy V-notch specimens from these capsules would have been originally broken as impact specimens rather than tested in three-point bending for fracture toughness (K_{JC}) data. Therefore, all PCVN data reported from the testing of irradiated KNPP and Maine Yankee surveillance materials were reconstituted specimens, with the reconstitutions performed in accordance with ASTM E 1253. The irradiated material from which these reconstituted specimens were produced came from KNPP surveillance capsule S (irradiated to a fluence of 3.36×10^{19} n/cm^2 (E>1.0 MeV)) and Maine Yankee surveillance capsule A-35 (irradiated to a fluence of 6.11×10^{19} n/cm^2 (E>1.0 MeV)). In

addition, previously-untested 1X Wedge Opening Loading (WOL) specimens were also available for testing from KNPP surveillance capsule S. Only material germane to the evaluation of the limiting KNPP circumferential weld (i.e., weld material from CE weld wire heat 1P3571) was tested for fracture toughness data as part of this program. All testing of irradiated reconstituted PCVN specimens and irradiated 1X-WOL specimens was conducted for the licensee by Westinghouse.

The data points obtained from the testing of unirradiated KNPP and Maine Yankee surveillance weld material as PCVNs, reconstituted PCVNs, and 1/2T-CT specimens are given in Table 1. The data points obtained from the testing of reconstituted PCVN specimens and 1X-WOL specimens from KNPP surveillance capsule S are provided in Table 2. Table 3 documents the data from the testing of reconstituted PCVN specimens made from Maine Yankee surveillance capsule A-35 material. In each of these tables, the direct K_{JC} measurement is given in column 2 and the measurements corrected to the size of a 1T-CT specimen (as specified in ASTM Standard E 1921-97) are given in column 3.

3.2.3.2 Future KNPP RPV Surveillance Program Testing

During the NRC staff's evaluation of the licensee exemption request regarding the future KNPP RPV surveillance program and Appendix H to 10 CFR Part 50, the NRC staff concluded that additional information beyond that provided in the licensee's June 7, 1999, and February 4, 2000, submittals was required. In the NRC staff's meeting summary regarding the July 6, 2000, meeting, the NRC requested that the licensee provide additional information to more fully explain the details of what testing would be included in the KNPP RPV surveillance program if a Master Curve-based methodology were approved for the evaluation of the KNPP circumferential RPV weld.[11] The following information was provided in the licensee's September 26, 2000, response to the NRC staff's request.

Two additional RPV surveillance capsules, capsule N and capsule T, remain in the KNPP RPV as part of the KNPP surveillance program. The licensee's current plans are to remove either capsule N or capsule T from the KNPP RPV when the fluence of the capsule reaches a value that will be equal to or slightly greater than the projected fluence of the KNPP RPV beltline weld corresponding to sixty years of operation. Removal of the next capsule (in 2003 or 2004) at this fluence value also addresses the requirement in the KNPP surveillance program to withdraw a capsule at greater than EOL, but less than two times EOL, fluence. The remaining capsule will be held as a standby capsule.

When the next surveillance capsule is pulled, the licensee intends to test the forging and correlation monitor material in accordance with the Charpy and tensile testing methods prescribed in ASTM E185-82. These activities will be consistent with the definition of the current KNPP RPV surveillance program and in accordance with the requirements of Appendix H to 10 CFR Part 50. Currently, the licensee has no plans to measure the fracture toughness properties of the correlation monitor or forging materials. Finally, for reasons discussed below, the licensee proposed that, as part of the exemption request, HAZ Charpy V-notch specimen testing no longer be required.

In addition, the next surveillance capsule will contain eight weld metal (manufactured from weld wire heat 1P3571) and eight HAZ specimens (whose associated weld metal is also from weld wire heat 1P3571). With the approval of a Master Curve-based methodology for evaluating the

KNPP RPV circumferential beltline weld, the emphasis of the KNPP RPV surveillance program will be on obtaining additional fracture toughness data from these specimens. The licensee intends to manufacture PCVN weld specimens from the end tabs of untested HAZ specimens to avoid excessive deformation of the end tabs as a result of impact testing. These reconstituted PCVN specimens will be tested in three-point bending in accordance with the requirements of ASTM E 1921-97. Additional weld metal specimens from the surveillance capsule will be tested in three point-bending until a sufficient number of K_{JC} data points has been acquired to obtain a valid T_0 value. The remaining weld metal specimens will then be used to construct a partial Charpy V-notch impact transition curve with the focus on defining the 30 ft-lb transition temperature. Upper shelf energy projections for the beltline materials will continue to be based upon testing methods described in ASTM E 185-82, although limited testing of the weld metal may occur due to a higher priority need to define RT_{T0} and the 30 ft-lb Charpy transition temperature. No other ASTM E 185-82 testing or reporting requirements will be affected by the licensee proposed surveillance program changes.

3.3 Licensee's Methodology for Application of a Master Curve-Based Methodology

With the acquisition of fracture toughness data per ASTM E 1921-97 as discussed above, the licensee developed a methodology to apply the available data to evaluate the integrity of the KNPP RPV. The licensee methodology was presented as plant-specific Master Curve-based methodology, although features within the methodology could support the development of a generic Master Curve-based methodology. The licensee's methodology was based on the application of ASTM Standard E 1921-97 for the acquisition and evaluation of the surveillance data and the use of ASME Code Case N-629 for determining a material reference temperature, RT_{T0}, for the circumferential RPV weld based on Master Curve data. In addition, the licensee's methodology addressed the evaluation of systematic differences (e.g., chemical composition differences, fluence level differences) between the test data and the conditions for which the RPV weld was being evaluated, as well as uncertainties in the calculational methodology. Finally, the licensee addressed the concern of whether any non-conservative bias existed in the acquisition of fracture toughness data from PCVN specimens due to possible loss of constraint or other issues. The detailed discussion which follows regarding the licensee's approach was principally documented in WCAP-15075 and the licensee's February 4 and September 26, 2000, submittals.

3.3.1 Basic Methodology for the Determination of RT_{T0}

The basic structure established in the licensee submittal for the use of fracture toughness data was based on using that data to index the K_{Ic} (static, plane-strain, lower bound) fracture toughness curve from the ASME Code. This approach was consistent with the approach taken in ASME Code Case N-629 and was similar to the methodology currently endorsed in NRC regulations (i.e., 10 CFR 50.61), based on Charpy V-notch and drop weight testing, which develops the nil-ductility reference temperature, RT_{NDT}, as an indexing parameter. The use of an indexing methodology is explicitly apparent in the development of facility P-T limits and is implicitly incorporated into the determination of the RPV's pressurized thermal shock reference temperature (RT_{PTS}).

However, even though both the currently-accepted methodology and the new Master Curve-based methodology proposed by the licensee are similar, there are some significant differences as well. The current Charpy V-notch and drop weight-based methodology establishes an

unirradiated $RT_{NDT,}$ and then relies on surveillance data from the testing of Charpy specimens and/or general material embrittlement models incorporated into Regulatory Guide 1.99, Revision 2, to predict the amount this value will shift due to a given level of neutron radiation exposure. This "initial plus shift" methodology has been consistently used to assess RPV embrittlement in the U.S. The licensee's Master Curve-based approach, however, proposed that "direct measurement" of fracture toughness (K_{JC}) can be made on irradiated specimens and that this data can be used to directly assess the material condition of the RPV. Fundamentally, the licensee proposed that both the initial properties of the surveillance material and the change in material properties due to irradiation would be directly reflected in the irradiated fracture toughness data, obviating the need to use an "initial plus shift" approach. However, while in theory this could be plausible, the licensee's methodology also acknowledged that some modifications to the data acquired from the surveillance weld specimens would be necessary if the chemical composition (i.e., copper and nickel content) of the surveillance weld was not equivalent to that of the RPV weld, or if the surveillance data points were not acquired at fluence levels corresponding to the fluence levels of interest for RPV regulatory applications. These modifications will be discussed further in Section 3.3.2 below, but note that reliance on the acquisition of unirradiated fracture toughness data was incorporated into the licensee-proposed methodology to assess the "shift" in fracture toughness properties in order to account for actual chemical composition and fluence differences.

The fracture toughness data in Tables 1 through 3 was then evaluated through the Master Curve methodology in ASTM E 1921-97 to yield the index temperature, $T_{0,}$ given in column 4 of Table 4. Per ASTM E 1921-97, T_0 is defined as the temperature at which the median fracture toughness value for a data set is expected to be 100 MPa√m (90.9 ksi√in) via a single temperature maximum likelihood methodology. The data in column 5 of Table 4 is the T_0 value determined by combining data sets obtained from the testing of different size specimens at different test temperatures through a multi-temperature maximum likelihood Master Curve methodology. At this time, ASTM has only formally endorsed the single temperature maximum likelihood methodology, however, the multi-temperature method has been proposed for incorporation into a revision of ASTM E 1921.

The next step in the licensee methodology was to define a relationship between the measured value of T_0 and the RPV material indexing parameter, RT_{T0}. For this, the licensee referenced ASME Code Case N-629. As addressed in the technical basis document which supported the passage of Code Case N-629, the ASME Code representatives established a relationship between T_0 and RT_{NDT} by examining how the use of each parameter would locate the lower bound K_{Ic} fracture toughness curve relative to the original database of ASTM Standard E 399 valid K_{Ic} data which was used to develop the ASME Code K_{Ic} curve.[19-21] Based on the analysis in the Code Case N-629 technical basis document, the appropriate relationship was chosen as:

[Eqn. 1] $$RT_{T0} = T_0 + 35\ °F$$

where RT_{T0} is the Master Curve-based equivalent of RT_{NDT}. The licensee's analysis elected to use this relationship to define RT_{T0}, but provided an alternative evaluation (discussed further in Section 3.3.3) which asserted that this relationship included some amount of "implicit" margin beyond that contained in the currently-accepted methodology. Hence, the licensee concluded that RT_{T0} was not a like-for-like replacement for RT_{NDT}, but rather a more conservative indexing parameter relative to available, ASTM E 399 valid, K_{Ic} fracture toughness data.

3.3.2 Assessment of Systematic Differences Between Surveillance Data and RPV Conditions

The methodology submitted by the licensee also addressed the need to adjust the test results to make the data acquired relevant to the evaluation of the KNPP RPV weld at conditions of interest, EOL and EOLE. The EOL fluence value cited at the clad-to-base metal interface for the KNPP circumferential weld was 3.34×10^{19} n/cm^2 (E > 1.0 MeV). The EOLE fluence value for the same location was given to be 5.06×10^{19} n/cm^2 (E > 1.0 MeV). Since the fluence level associated with KNPP surveillance capsule S was nearly equivalent to the EOL RPV fluence, the licensee chose to determine the EOL RPV material properties based on that data set. The licensee then chose to assess the EOLE RPV material properties based on the testing of materials from Maine Yankee surveillance capsule A-35, which had achieved a fluence level greater than that projected for the KNPP RPV EOLE condition.

The major adjustment developed in the licensee's submittal was to address differences in chemical composition (copper content, nickel content) between the KNPP surveillance weld, the Maine Yankee surveillance weld, and the best-estimate chemical composition of the KNPP RPV circumferential weld. This adjustment was characterized in the licensee's original submittal as a "heat uncertainty" term (implying some relationship to uncertainties and margins), but based on NRC staff feedback, the licensee adopted a more appropriate characterization of this adjustment as a normalization procedure in later correspondence. The different chemical composition values associated with each weld were established through a substantial effort on the part of the industry to respond to NRC Generic Letter (GL) 92-01, and differences in the values reflect differences in the state of knowledge about each weld.[22] Copper and nickel content measurements have been made on both the KNPP and Maine Yankee surveillance welds, hence, specific copper and nickel values can be attributed to each of these welds. No specific measurements exist for the KNPP RPV circumferential weld. As a result of GL 92-01 activities, "best-estimate" chemical compositions were assigned to RPV welds for which no specific chemistry measurements existed. These best-estimate values were determined by assessing all available chemistry data from samples which represented the weld wire heat of interest (in this case, weld wire heat 1P3571) and the NRC staff concluded that such determinations were consistent with the requirements of 10 CFR 50.61(c)(1)(iv)(A).[23, 24] The copper and nickel contents assigned to each of these welds are given in Table 5.

In the section below, it is important to note that two different quantities will be referenced often: the T_0 value for a surveillance capsule and the "T_0 shift" value for a surveillance weld. The T_0 value for a particular surveillance capsule is the absolute T_0 value determined from testing material specimens from that capsule at the neutron fluence level that it received. The "T_0 shift" value is the difference between the T_0 value from the testing of the capsule specimens and the T_0 value for unirradiated baseline specimens manufactured from the same surveillance weld. As discussed in Reference 8, the methodology proposed by the licensee for adjusting the available surveillance data to the KNPP RPV conditions was based on assessing the shift in T_0 between the unirradiated and irradiated conditions. This reliance on assessing the change in material properties is consistent with the current regulatory structure which assesses radiation embrittlement by examining the shift of the transition region (30 ft-lb energy level) of a material's Charpy V-notch testing curve. The licensee methodology relied even more heavily on the current methodology by using the embrittlement trend curves represented by the models in Regulatory Guide 1.99, Revision 2 (RG 1.99, Rev. 2) and 10 CFR 50.61, as the assumed basis for assessing the shift in T_0 with fluence.[25] The licensee analysis first calculated the shift

in T_0 for the KNPP surveillance weld, 292 °F [148 °F - (-144 °F)] at 3.36 x 10^{19} n/cm^2 (E > 1.0 MeV) and for the Maine Yankee surveillance weld, 390 °F [232 °F - (-158 °F)] at 6.11 x 10^{19} n/cm^2 (E > 1.0 MeV). Next, the licensee fitted the RG 1.99, Rev. 2 embrittlement model, as described by the equation below to the T_0 shift data:

[Eqn. 2] Shift (in T_0 or Charpy curve transition) = $(CF)(f^{(0.28 - 0.1\log f)})$

where f is the fluence in units of 10^{19} n/cm^2 and CF is the so-called "chemistry factor" which is a measure of a material's radiation sensitivity and based on a material's chemical composition in the absence of material-specific surveillance data. CF's based on the copper and nickel content of an RPV material are given in tabular form in both RG. 1.99 Rev. 2 or in 10 CFR 50.61. The chemistry-based CF values for each of these welds is also given in column 4 of Table 5. It is notable that although this model form was developed to characterize the radiation-induced shift in Charpy transition temperature of RPV materials, the licensee assumed it to be a reasonable fit to T_0 shift data as well and was used in the licensee's methodology in the absence of a model developed specifically from the existing database of T_0 shift data. This approach is consistent in principle with the use of surveillance data to develop a material-specific chemistry factor in the current Charpy-based methodology, except that a minimum of two data points are required from any given surveillance weld in the current methodology. In the licensee Master Curve-based approach, two surveillance data points exist for weld wire heat 1P3571, but come from different surveillance welds with different nominal chemistry values.

The licensee fit to the available T_0 shift data forced the embrittlement model to go through the point indicated by the surveillance specimen testing. By specifying the fluence and the T_0 shift, the CF attributed to each surveillance weld was then calculated using Eqn. 2. A CF of 222 °F was calculated for the KNPP surveillance weld based on its single data point, and a CF of 271 °F was calculated for the Maine Yankee surveillance weld based on its single data point. Based on these results, the licensee predicted that for the best-estimate chemistry of the RPV circumferential weld, the CF would be 248 °F. The licensee arrived at this conclusion by assuming that the relative irradiation sensitivities of each of the surveillance welds and of the RPV weld were defined by their chemical compositions. In effect, this means that the "spacing" between the CFs shown in Table 5 (based only on each weld's copper and nickel content) should also be assumed for the "spacing" of the CFs based on T_0 shift surveillance data. Therefore, the CF of the RPV circumferential weld was predicted to be 53.6 percent of the way between the 222 °F value for the KNPP surveillance weld and the 271 °F value for the Maine Yankee surveillance weld, or 248 °F.

From these surveillance-based CF values, corrections to adjust the actual, measured T_0 values were calculated. The licensee then plotted trend curves for T_0 shift with fluence using the RG 1.99, Rev. 2 model form and CFs of 222 °F, 248 °F, and 271 °F. Since the KNPP Capsule S surveillance weld T_0 value would be used to assess RPV integrity at EOL conditions, the licensee examined the separation between the KNPP surveillance weld T_0 shift trend curve and the trend curve representing the KNPP RPV weld. The separation between these curves at the KNPP EOL fluence was 35 °F. Likewise, since the Maine Yankee Capsule A-35 surveillance weld T_0 value would be used to assess RPV EOLE, the licensee compared the trend curve representing the Maine Yankee surveillance weld to the KNPP RPV trend curve at EOLE conditions. The separation in that case was -32 °F (i.e., the RPV trend curve is below the surveillance weld trend curve). These correction factors, +35 °F and -32 °F, would be applied to the absolute T_0 values (not the T_0 shift value) from the surveillance weld capsule tests to

complete the licensee's methodology for normalizing the surveillance capsule results to the chemistry values representing the KNPP RPV circumferential weld.

One final adjustment to the T_0 value derived from the Maine Yankee data should also be discussed here. Since Maine Yankee surveillance capsule A-35 was irradiated to a fluence of 6.11 x 10^{19} n/cm^2 (E > 1.0 MeV), its level of exposure exceeded that projected for the KNPP RPV circumferential weld at EOLE conditions, 5.06 x 10^{19} n/cm^2 (E > 1.0 MeV). Therefore, based on the embrittlement trend curves discussed above, the licensee proposed a correction value to relate the Maine Yankee Capsule A-35 T_0 data point to the EOLE condition of the RPV circumferential weld. The licensee determined that this adjustment would be a -10 °F correction (i.e., the T_0 value from the surveillance capsule was to be reduced by 10 °F). For the EOL assessment, the fluence of the KNPP surveillance capsule was sufficiently close to that for the KNPP RPV circumferential weld, 3.36 x 10^{19} n/cm^2 (E > 1.0 MeV) versus 3.34 x 10^{19} n/cm^2 (E > 1.0 MeV), that no correction of this type was proposed.

3.3.3 Assessment of Uncertainties and Margins

A critical element in establishing a Master Curve-based methodology for RPV integrity assessments is the ability to define adequate, explicit margins to be included to address uncertainties in the evaluation. In the original submittal, the licensee concluded that since their proposed methodology was based on the "direct measurement" of the fracture toughness of 1P3571 weld samples irradiated to fluences consistent with, or in excess of, EOL and EOLE RPV conditions, an appropriate margin term would be that associated with the statistical uncertainty of the Master Curve methodology itself. This led the licensee to propose that a margin of 24 °F be adopted for their proposed methodology when using the Maine Yankee surveillance data and calculating for RPV EOLE conditions, and a margin of 16 °F be used when using the KNPP surveillance data and calculating for RPV EOL conditions. The licensee compared this position to the conditions in the current regulatory structure which permit a zero contribution to the margin if actual test data are available for establishing a material's initial RT_{NDT} value and a "reduced" margin contribution if "credible" Charpy V-notch surveillance data are used in the RPV integrity evaluation.

By letter dated July 16, 1999, the NRC staff informed the licensee that their original Master Curve submittal did not clearly address sources of uncertainty (and hence margin) that are explicitly identified in 10 CFR 50.61. The NRC staff noted that 10 CFR 50.61 states that margin shall be added, "to account for uncertainties in $RT_{NDT(U)}$, copper and nickel contents, fluence and the calculational procedures." In the case of 10 CFR 50.61, $RT_{NDT(U)}$, the unirradiated nil-ductility reference temperature, is the characteristic measurement of unirradiated material properties, and uncertainty in it is to potentially be replaced by an assessment of the uncertainty associated with the unirradiated fracture toughness properties in the licensee methodology. As noted previously, these concerns are not to be confused with attempts to normalize surveillance data to the best-estimate chemical composition or fluence of the RPV circumferential weld, but rather reflect the uncertainty in defining what is the best-estimate chemical composition or fluence of the RPV circumferential weld.

In their February 4, 2000, response to the NRC staff's letter, the licensee provided additional information concerning their margin assessment. Regarding accounting for fluence uncertainty, the licensee noted that the fluence values cited for the KNPP RPV at EOL and EOLE were based on assuming a unit capacity factor of 95 to 97 percent throughout the remainder of the

current and extended life of the facility. Since this was deemed to be substantially in excess of the more realistic capacity factor of 85 percent, the licensee argued that the use of these conservative fluence projections was sufficient technical justification for not explicitly considering fluence uncertainties in the original analysis.

In order to address NRC staff concerns over the issue of assessing weld wire heat 1P3571 weld initial property and chemistry variability, the licensee posited several arguments. First, the licensee noted that in addition to the 24 °F (or 16 °F for EOL conditions) of explicit margin that was included in the original licensee analysis, an additional 18 °F existed as a result of the $RT_{T0} = T_0 + 35$ °F relationship. The licensee argued that to determine the necessary adder to ensure RT_{T0} maintained the same level of implicit margin as in the current Charpy and drop weight-based methodology, one should consider only the single material, plate HSST-02, which defined the lower limits of the ASME Code K_{IC} curve. If only this material is considered, then an adder of 17 °F is required to position the K_{IC} curve in the same location (i.e., with the same amount of separation between the actual HSST-02 K_{IC} data and the curve) as it would be located considering Charpy and drop weight data. Hence, the licensee concluded that when both explicit margin and implicit margin (beyond that incorporated in the current methodology) were considered, their original submittal contained 42 °F (or 34 °F for EOL conditions) of total margin. Although references to this information can be found in the licensee's original submittal, it was not clear that the licensee intended to credit this feature of their assessment to address NRC staff concerns until their February 4, 2000, response.

Next, the licensee addressed the issue of initial property uncertainty. In their, February 4, 2000, response, the licensee again concluded that:

> [s]ince the Master Curve technology [as applied by the licensee] directly measures the properties of an irradiated material, it does not require measurements of unirradiated material properties to determine fracture toughness. The only place initial properties are used is in the ratio procedure; note that any variation in initial properties has little effect on the ratio procedure as used in the licensee evaluation. Therefore, uncertainties associated with the measurement of initial properties do not affect the calculation of RT_{T0}.

Finally, the licensee directly addressed the issue of chemical composition variability and its effect on margin term determination. The licensee proposed that a probabilistic analysis be performed to determine the effect of copper and nickel distributions on the expected embrittlement behavior of the KNPP RPV circumferential weld. The licensee examined the bases for the PTS rule (10 CFR 50.61) given in Commission Paper SECY-82-465 and concluded that the historical estimated standard deviation for copper (σ_{Cu}) of 0.03 wt% and the measured standard deviation for nickel (σ_{Ni}) of 0.042 wt% would be used in their principal analysis.[26] Distributions were assumed to be normal around the best-estimate values and a simple Monte Carlo analysis was performed. The licensee used the RG 1.99, Rev. 2 model, assuming it to be applicable for this purpose, to assess the impact of the distribution sampling on the change in material properties. The licensee assumed that this calculation would suffice to define the margin term since initial property and fluence considerations had already been dismissed as noted above. This analysis resulted in the calculation of the 1σ level margin term (i.e., the 1σ level of uncertainty on the shift in T_0) as 17 °F. The licensee concluded that the use of margin term based on the 1σ level of uncertainty would be adequate and consistent with the current regulations and regulatory guidance since actual T_0 surveillance test results were

being used in the analysis and the regulations currently permit a 1σ uncertainty on shift to be assumed when “credible” Charpy surveillance data are used.[25] An additional analysis was included by the licensee in which a σ_{Cu} was taken to be 0.08 wt%, a value which is bounding when compared to chemistry data gathered for weld wire heat 1P3571 as part of GL 92-01 activities. This resulted in a 1σ uncertainty level margin term of about 38 °F. The licensee concluded that this result would be overly conservative with respect to the bases for the current regulations given in SECY-82-465.

In summary, the final position presented by the licensee was that 18 °F of implicit margin beyond that in the current regulatory structure and 24 °F (or 16 °F for EOL) of explicit margin had been included in the original submittal. Based on their conclusions regarding fluence, initial property, and chemistry uncertainties, the licensee determined that this sum of the implicit and explicit margin, 42 °F, (or 34 °F for EOL) was sufficient for the evaluation of the KNPP RPV circumferential weld.

3.3.4 Assessment of Bias in the Use of PCVN Specimens in Master Curve Testing

During the NRC staff’s July 6, 2000, meeting with the licensee, the NRC raised a question about the licensee submittal concerning the potential for a non-conservative bias in T_0 based on the licensee’s extensive use of PCVN data. This potential for a bias to exist was postulated by the NRC staff based upon issues such as loss of constraint (i.e, evolution of excessive yielding) when the small PCVN specimens where tested. In the NRC staff’s July 20, 2000, meeting summary, the NRC requested that the licensee provide a response regarding what the magnitude of the bias could be given the data used in the licensee submittal.

In their letter dated September 26, 2000, the licensee explained that a comparison of their results based solely on data from PCVN specimens and their results based on data from a combined data set of PCVN specimens and 1X-WOL specimens showed a 4 °F difference, with the data set containing only PCVN specimens providing a lower (less conservative) value for T_0. Therefore, the licensee concluded that if a methodology based on data from only PCVN specimens were employed (consistent with the methodology cited by the NRC staff at the July 6, 2000, meeting as the basis for the NRC staff’s review of this submittal), then a 4 °F bias term could be included. However, the licensee noted that the methodology they submitted used available data from both PCVN and larger specimens. Hence, the licensee concluded that a bias term did not need to be incorporated into their proposed methodology.

3.3.5 Licensee Methodology for Addressing Through-Wall Material Properties

In proposing to adopt a Master Curve-based methodology as the basis for evaluating the integrity of the KNPP RPV circumferential weld, the licensee also chose to utilize this methodology for the development of RPV P-T limits. Since RPV P-T limits are based on the evaluation of postulated flaws which extend 1/4 of the thickness of the RPV wall out from the clad-to-base metal interface on the vessel ID and in from the OD of the vessel, it is necessary to determine the material properties of the RPV circumferential weld at through-wall locations. In the following discussion the “1/4 T” location refers to the through-wall location one-quarter of the distance from the clad-to-base metal interface to the vessel OD. Likewise, the “3/4T” location refers to the through-wall location one-quarter of the distance in from the vessel OD toward the clad-to-base metal interface on the vessel ID.

The licensee methodology for addressing through-wall material property changes was documented in Chapter 4 of WCAP-14728, Revision 1, and relies heavily on paralleling the methodology found in current regulatory guidance. This is due to the fact that the only general approach that has been accepted in the U.S. for assessing through-wall attenuation of fluence and its effect on material property changes is given in RG 1.99 Rev. 2 and is based on fundamental considerations regarding microstructural property changes with irradiation. As will be shown below, using such a general approach requires an inherent dependance on an "initial property + shift + margin" methodology. The licensee, however, contended that since common data is used to determine the initial, unirradiated T_0 value and to determine the shift in T_0, this methodology may still be considered to result in a more "direct" measurement of irradiated material properties than the current Charpy and drop weight-based methodology.

The licensee's methodology used the effective "T_0 shift"-based CF of 248 °F developed for the KNPP RPV as discussed in Section 3.3.2. The EOL fluence at the clad-to-base metal interface (3.34×10^{19} n/cm^2 (E > 1.0 MeV)) was then attenuated using the displacements per atom (dpa)-based attenuation function provided in RG 1.99, Rev. 2:

[Eqn. 3] effective fluence (at depth x) = fluence (at clad-to-base metal interface) * exp (-0.24 * x)

The term "effective fluence" is used here since the dpa-based attenuation function does not give a true measure of the neutron fluence with E > 1.0 MeV at a given depth, but rather provides an "effective fluence" weighted by the relative effectiveness of neutrons at various energies to cause fine-scale microstructural damage within the RPV steel. The licensee determined the effective fluence at the 1/4T location to be 2.26×10^{19} n/cm^2 and the effective fluence at the 3/4T location to be 1.04×10^{19} n/cm^2 at EOL.

In keeping with the form of the methodology in RG 1.99, Rev. 2, a fluence factor (FF) was calculated for the 1/4T and 3/4T depths based on the effective fluences at those through-wall locations. The FF was calculated as:

[Eqn. 4] $$FF = f^{(0.28 - 0.1*\log f)}$$

where f was the effective fluence in units of 1×10^{19} n/cm^2 at a given depth. Using Eqn. 2, the FFs, and the CF of 248 °F, projected shifts in T_0 for the RPV circumferential weld were determined. The projected shift in T_0 for the 1/4T depth at EOL was given as 303 °F, while the projected shift in T_0 for the 3/4T location was given as 250 °F. These projected T_0 shift values were then combined with an "initial RT_{T0}" value based on the evaluation of fracture toughness data acquired from the testing of unirradiated samples of the Maine Yankee and KNPP surveillance welds and a margin term. The results of this procedure are more fully discussed in the following section.

3.4 <u>Licensee's Results for PTS and P-T Limits Assessments</u>

This section summarizes the licensee's results for developing final adjusted reference temperatures based on T_0 data (ART_{T0}) to characterize the KNPP RPV circumferential weld. While the nomenclature used in this section does not precisely parallel that used in the licensee's submittals, conceptually similar values are given in the information docketed by the licensee in References 4 and 6, and the licensee responses to NRC staff questions. ART_{T0} values calculated here will be the sum of an appropriate RT_{T0} (i.e., T_0 + 35 °F) value, a margin

term, and adjustments to account for chemistry differences between the surveillance welds and the KNPP RPV circumferential beltline weld. ART_{T0} values as discussed in this section will be dependent on the length of operating time and through-wall position being analyzed. To summarize:

$ART_{T0\text{-}EOL\text{-}ID}$ = The reference temperature at the clad-to-base metal interface at the end of the current operating license and compared to the PTS screening criteria.

$ART_{T0\text{-}EOLE\text{-}ID}$ = The reference temperature at the clad-to-base metal interface at the end of an extended (60 year) operating license and compared to the PTS screening criteria.

$ART_{T0\text{-}EOL\text{-}1/4T}$ = The reference temperature at a depth 1/4 of the way through the RPV wall thickness at the end of the current operating license, relevant to the discussion of RPV P-T limits.

$ART_{T0\text{-}EOL\text{-}3/4T}$ = The reference temperature at a depth 3/4 of the way through the RPV wall thickness at the end of the current operating license, relevant to the discussion of RPV P-T limits.

As mentioned previously, EOL RPV conditions were evaluated using the surveillance data derived from the testing of KNPP surveillance capsule S material. The T_0 value calculated for the EOL RPV clad-to-base metal interface fluence based on this data was 148 °F. Therefore, the RT_{T0} was calculated to be 183 °F. An explicit margin of 16 °F was then added along with a +35 °F adjustment for the differences in best-estimate chemistry between the KNPP surveillance weld and the KNPP RPV circumferential weld. These adjustments brought the value of $ART_{T0\text{-}EOL\text{-}ID}$ as calculated by the licensee to 234 °F for an EOL fluence of 3.34×10^{19} n/cm^2 (E > 1.0 MeV). This value is below the PTS screening criteria of 300 °F for circumferential welds specified in 10 CFR 50.61 and supports continued operation of the KNPP RPV through EOL.

For EOLE RPV conditions, data derived from the testing of the Maine Yankee surveillance capsule A-35 was used. The T_0 value calculated for the EOLE RPV clad-to-base metal interface fluence based on this data was 222 °F. Therefore, the RT_{T0} was calculated to be 257 °F. An explicit margin of 24 °F was then added along with a -32 °F adjustment for the differences in best-estimate chemistry between the Maine Yankee surveillance weld and the KNPP RPV circumferential weld. These adjustments brought the value of $ART_{T0\text{-}EOLE\text{-}ID}$ as calculated by the licensee to 249 °F for an EOLE fluence of 5.06×10^{19} n/cm^2 (E > 1.0 MeV). This value is below the PTS screening criteria of 300 °F for circumferential welds specified in 10 CFR 50.61.

The licensee then determined the values of $ART_{T0\text{-}EOL\text{-}1/4T}$ and $ART_{T0\text{-}EOL\text{-}3/4T}$ to be applied toward the determination of KNPP P-T limits. As noted in Section 3.3.5, the T_0 shift values calculated by the licensee for the 1/4T and 3/4T locations were 303 °F and 250 °F, respectively. The licensee cited an “initial RT_{T0}" value of -109 °F, based on the fracture toughness data acquired from the testing of unirradiated samples from the Maine Yankee and KNPP surveillance welds.

This corresponded to a use of a -144 °F unirradiated T_0 based on the fracture toughness test results from all available test specimen (i.e., PCVNs, reconstituted PCVNs, and 1/2T-CTs). For calculations carried out to assess EOL conditions, as was noted above for $ART_{T0\text{-}EOL\text{-}ID}$, the licensee used an explicit margin term of 16 °F based on the uncertainty in the test methodology associated with the determination of the irradiated T_0 value for the KNPP surveillance capsule S specimens. Therefore, when this information was combined, the licensee's results for $ART_{T0\text{-}EOL\text{-}1/4T}$ and $ART_{T0\text{-}EOL\text{-}3/4T}$ were:

[Eqn. 5]

$$ART_{T0\text{-}EOL\text{-}1/4T} = \text{Initial } RT_{T0} + T_0 \text{ shift} + \text{Margin}$$
$$= -109\ °F + 303\ °F + 16\ °F = 210\ °F$$

[Eqn.6]

$$ART_{T0\text{-}EOL\text{-}3/4T} = \text{Initial } RT_{T0} + T_0 \text{ shift} + \text{Margin}$$
$$= -109\ °F + 250\ °F + 16\ °F = 157\ °F$$

Again, however, although explicit calculation of these values was carried out in the manner shown, the licensee contended that since the same unirradiated T_0 data was used to establish both the "Initial RT_{T0}" value and the RPV CF value which would define the T_0 shift assigned to the RPV weld, the unirradiated T_0 data effectively "cancels out" of the calculation and the final values are controlled directly by the results from the testing of the irradiated samples.[4]

The licensee then used the information regarding the $ART_{T0\text{-}EOL\text{-}1/4T}$ and $ART_{T0\text{-}EOL\text{-}3/4T}$ values for the KNPP RPV circumferential weld to propose a modification to the KNPP cooldown P-T limits. The licensee had submitted the current KNPP cooldown P-T limit curves (see Figure 1), which they believed to be acceptable through 33 effective full-power years (EFPY) of operation, for NRC staff review and approval on November 25, 1998. Several of the P-T cooldown limit curves were of a composite nature, with the limits at the lower pressure and temperature end being set by the material properties of the KNPP RPV intermediate shell forging and the limits at the higher pressure and temperature end being set by the material properties of the KNPP RPV circumferential weld. This resulted from the licensee's use of ASME Code Case N-588 (see Section 2.0) which permitted the licensee to postulate a circumferentially-oriented flaw when evaluating the KNPP RPV circumferential weld.

Based on the $ART_{T0\text{-}EOL\text{-}1/4T}$ and $ART_{T0\text{-}EOL\text{-}3/4T}$ values calculated above, the licensee concluded that the P-T cooldown limit curves, after approval for the use of the Master Curve-based approach, would no longer include composite curves. Rather, the material properties of the KNPP forging would be limiting and, along with other specific considerations given in Appendix G to 10 CFR Part 50 regarding RPV closure flange materials, would define the entire cooldown curve for all temperature rates of change. These new P-T cooldown limit curves (see Figure 2), for up to 33 EFPY of operation, were submitted by the licensee as proposed Technical Specification Amendment No. 160, and were included in Attachment 3 to the licensee's June 7, 1999, submittal. Other P-T limit curves, which were already entirely defined by the material properties of the limiting KNPP forging, were not affected by this submittal. However, the submittal did request that the restriction to 28 EFPY, which was placed on all KNPP P-T limit curves (heatup, cooldown, leak test), be lifted and that all P-T limit curves be approved for use to 33 EFPY, since the reason for the restriction (the validity of the cooldown limits) had been addressed by the licensee's June 7, 1999, submittal.

4.0 NRC STAFF EVALUATION

The NRC staff has completed its review of the licensee submittal. The NRC staff has examined this submittal by considering questions regarding: (1) regulatory implementation of a Master Curve-based methodology for RPV integrity assessment, (2) RPV surveillance program modifications necessary to support a Master Curve-based methodology, (3) the technical adequacy of the methodology proposed by the licensee for using the available data to assess the KNPP RPV and, (4) the justification for proposed plant-specific licensing actions given the approval of an acceptable Master Curve-based methodology. In some cases, the NRC staff's position regarding a subject area has been developed to specifically address aspects which are likely to be unique to the review of this submittal. In other cases, more general conclusions, which would be equally relevant to the current licensee submittal and to future Master Curve-based submittals from other licensees, have been provided.

Regarding regulatory implementation of a Master Curve-based methodology for RPV integrity assessment, the licensee determined that three exemptions were necessary to implement a Master Curve-based methodology for RPV integrity assessment. Although, the details of the NRC staff's assessment regarding these issues of regulatory implementation will be somewhat different from those submitted by the licensee, fundamentally the NRC staff has determined that exemptions to the requirements of 10 CFR 50.61, and Appendices G and H to 10 CFR Part 50 are necessary for this application. The NRC staff has concluded that the need for such exemptions is not specific to the licensee submittal and could be equally applicable (depending on scope of application) to Master Curve submittals from other licensees. The NRC staff's detailed evaluation of the requested exemptions is provided in Sections 4.1 through 4.2.2 below.

Concerning RPV surveillance program modifications necessary to support a Master Curve-based methodology, the NRC staff has reviewed the additional information submitted by the licensee in their September 26, 2000, letter. The NRC staff has concluded that the RPV surveillance program modifications proposed by the liensee for incorporating the acquisition of fracture toughness data are acceptable. The NRC staff's detailed conclusions regarding the KNPP surveillance program are provided in Section 4.2.3 below.

On the subject of the technical adequacy of the methodology proposed by the licensee for using their available data to assess the KNPP RPV, the NRC staff has identified a number of technical aspects in the methodology proposed by the licensee with which the NRC staff disagrees. However, sufficient information was provided for the NRC staff to develop an acceptable approach based on modifying the licensee's methodology for utilizing the available licensee data to evaluate the integrity of the KNPP RPV. For convenience, the methodology which results from the modifications made by the staff to the licensee's methodology will be referred to herein as "the NRC staff's methodology" to differentiate it from the original methodology submitted by the licensee. The NRC staff's methodology is discussed in detail in section 4.3 below and serves as the basis for the NRC staff's approval of a Master Curve-based methodology for KNPP. Finally, the results obtained by using the NRC staff's methodology to evaluate both RPV P-T limits and the compliance of the KNPP RPV with the requirements of 10 CFR 50.61 through EOL are discussed in Section 4.4. It should be noted, however, that the NRC staff did not evaluate the condition of the KNPP RPV at EOLE fluence for the purpose of justifying the integrity of the RPV to that fluence value. Rather, the NRC staff evaluated the $ART_{T0\text{-}EOLE\text{-}ID}$ value of the KNPP RPV using the NRC staff's methodology only for comparison to the value determined from the licensee's methodology. This comparison was necessary to

determine whether the licensee's proposed methodology was at least as conservative as the NRC staff's methodology.

4.1 <u>Exemption to 10 CFR 50.61</u>

The underlying purpose of 10 CFR 50.61 is to establish requirements which ensure that a licensee's RPV will be protected from failure during a PTS event by evaluating the fracture toughness of RPV materials. The basis of 10 CFR Part 50.61 is that a material parameter, RT_{PTS}, is established for each RPV beltline material and this value is compared to screening limits given in 10 CFR Part 50.61 (270 °F for axial welds, plates, and forgings; 300 °F for circumferential welds). These screening limits were established based on probabilistic fracture mechanics evaluations performed in the early 1980s.[26]

Specific methodologies for the determination of plant-specific RT_{PTS} values were established to ensure that consistency would be maintained between the basis for their calculation and the screening criteria in 10 CFR Part 50.61. 10 CFR Part 50.61(c) notes, "RT_{PTS} must be evaluated using the same procedures used to calculate RT_{NDT} [the nil-ductility transition reference temperature], as indicated in paragraph (c)(1) of this section, and as provided in paragraphs (c)(2) and (c)(3) of this section." These sections go on to define the procedures to be based on the use of Charpy V-notch and drop weight test data. Because the licensee seeks permission to use a Master Curve fracture toughness-based methodology for demonstrating compliance with 10 CFR Part 50.61 in lieu of the Charpy V-notch and drop weight-based methodology given in 10 CFR 50.61, the NRC staff has determined that an exemption is required.

Further, the NRC staff has concluded that the "general approach" (i.e., the definition of a new indexing parameter, ART_{T0}, which when determined from irradiated and unirradiated fracture toughness data under appropriate conditions, replaces RT_{PTS}) taken by the licensee to develop this new fracture toughness-based methodology is consistent with the existing framework of 10 CFR Part 50.61. Since both the existing and proposed indexing methodologies are linked to an acceptable database of ASTM E 399 valid K_{IC} data, the NRC staff concluded that the fundamental technical basis exists for comparing the existing screening criteria of 10 CFR Part 50.61 to the ART_{T0} values developed through the "general" licensee Master Curve-based approach. Provided all necessary technical considerations are addressed (see Section 4.3 below), indexing parameter values determined through Master Curve evaluation of fracture toughness data provide an acceptable technical alternative for meeting the underlying purpose of the rule. Hence, based upon the licensee's acceptance of the use of the Master Curve-based methodology summarized in Appendix A to this SE and discussed in detail in Section 4.3, the staff has concluded that the requested exemption from 10 CFR 50.61 may be granted.[14]

4.2 <u>Exemptions to Appendices G and H to 10 CFR Part 50, and the RPV Surveillance Program</u>

4.2.1 <u>Exemption to Appendix H to 10 CFR Part 50</u>

10 CFR Part 50.60 invokes the requirements of Appendix H to 10 CFR Part 50 regarding the establishment of a RPV surveillance program to monitor changes in the fracture toughness of RPV materials due to exposure to neutron irradiation and the thermal environment. Further, 10 CFR Part 50.60(b) requires that licensees who propose to invoke alternatives to the described requirements in Appendix H to 10 CFR Part 50 obtain NRC approval via an

exemption per the requirements of 10 CFR Part 50.12. Appendix H to 10 CFR Part 50 then establishes that testing and reporting of surveillance data be done in accordance with the 1982 Edition of ASTM Standard E 185 (ASTM E 185-82), and ASTM E 185-82 requires, in part, that Charpy V-notch testing be performed to assess the change in fracture toughness of the RPV surveillance materials. This emphasis on the use of Charpy testing is, therefore, consistent with the technical bases of the current evaluational methodologies, as discussed in Section 4.1 above, for demonstrating compliance with the requirements of 10 CFR Part 50.61 and Appendix G to 10 CFR Part 50.

Since the underlying purpose of the Appendix H-required RPV surveillance program is to provide meaningful data to support the RPV integrity evaluations required by Appendix G to 10 CFR Part 50 and 10 CFR 50.61, the NRC staff has concluded that if the methodology employed by the licensee to demonstrate compliance with the requirements of 10 CFR 50.61 and Appendix G to 10 CFR Part 50 were to be based on fracture toughness test data instead of Charpy V-notch test data, corresponding changes in the definition of the KNPP RPV surveillance program would also be required. Further, since the testing requirements specified in Appendix H to 10 CFR Part 50 mandate Charpy V-notch testing, the NRC staff agrees with the licensee's conclusion that an exemption to the requirements of Appendix H to 10 CFR Part 50 is required as part of the licensee's overall submittal in order to establish fracture toughness testing as the basis of the KNPP RPV surveillance program.

Based on the NRC staff's review of RPV surveillance program modifications submitted by the licensee and discussed in detail in Section 4.2.3 below, the NRC staff has concluded that an adequate surveillance program can be defined to support the licensee's Master Curve-based methodology. The RPV surveillance program requirements, discussed in Section 4.2.3.2 and summarized Section 5.0 Item (3) below, which were accepted by the licensee in Reference 14 establish the basis for an adequate RPV surveillance program for meeting the underlying purpose of Appendix H to 10 CFR Part 50. Hence, in accordance with the provisions of 10 CFR Part 50.12(ii), the NRC staff has concluded that based on the licensee's acceptance of these alternative surveillance program requirements, an acceptable technical basis exists for granting the requested exemption from the Charpy V-notch testing requirements of Appendix H to 10 CFR Part 50.

4.2.2 Exemption to Appendix G to 10 CFR Part 50

10 CFR Part 50.60 invokes the requirements of Appendix G to 10 CFR Part 50, which sets forth fracture toughness requirements for ferritic materials of pressure-retaining components of the reactor coolant pressure boundary of light water nuclear power reactors to provide adequate margins of safety during any condition of normal operation, including anticipated operational occurrences and system hydrostatic tests, to which the pressure boundary may be subjected over its service life (i.e., requires the establishment of P-T limit curves to adequately protect RPVs during heatup, cooldown, and hydrostatic/leak testing). 10 CFR Part 50.60(b) requires that licensees who propose alternatives to the described requirements in Appendix G to 10 CFR Part 50 obtain NRC approval via an exemption per the requirements of 10 CFR Part 50.12. The methodology given in Appendix G to 10 CFR Part 50, like that discussed in Section 4.1.1 above regarding PTS evaluations, is based on the use of Charpy V-notch and drop weight data. This is evident since Appendix G to 10 CFR Part 50 invokes, through reference to 10 CFR Part 50.55(a), the requirements and methodology given in Appendix G to ASME Code Section XI for P-T limit curve development. 10 CFR 50.55(a)

approves the use of versions of ASME Code Section XI through the 1996 Addenda to the 1995 Edition. All editions of Appendix G to ASME Code Section XI through the 1996 Addenda to the 1995 Edition incorporate Charpy and drop weight-based methodologies for defining a reference temperature (RT_{NDT}) used to develop facility P-T limits. Hence, the NRC staff has concluded that the licensee proposal to replace the use of the existing Charpy and drop weight-based methodology by a Master Curve fracture toughness-based methodology for demonstrating compliance with Appendix G to 10 CFR Part 50, requires an exemption per the condition established in 10 CFR Part 50.60(b).

Further, consistent with what was noted in Section 4.1 above regarding PTS evaluations, the NRC staff has concluded that the “general approach” taken by the licensee to develop this new Master Curve fracture toughness-based methodology is consistent with the existing framework of Appendix G to 10 CFR Part 50 and Appendix G to ASME Code Section XI. Provided all necessary technical considerations are addressed (see Section 4.3 below), indexing parameter values determined through Master Curve evaluation of fracture toughness data provide an acceptable technical alternative for meeting the underlying purpose of the rule. Hence, based upon the licensee’s acceptance of the use of the Master Curve-based methodology summarized in Appendix A to this SE and discussed in detail in Section 4.3, the staff has concluded that the requested exemption from 10 CFR 50.61 may be granted.[14]

4.2.3 KNPP RPV Surveillance Program

The licensee’s proposed changes to the KNPP surveillance program can be discussed in two parts. The first part considers the incorporation of data from the fracture toughness (K_{JC}) testing of archival material and reconstituted specimens fabricated from the materials in KNPP surveillance capsule S and Maine Yankee surveillance capsule A-35. The second part considers the surveillance program modifications to be incorporated into the testing of future KNPP surveillance capsules.

4.2.3.1 Testing of Archive Material and Previously Tested RPV Surveillance Capsules

The details of the licensee’s program for acquiring fracture toughness data for materials samples manufactured from archival material and previously tested surveillance capsules were addressed in WCAP-14279, Revision 1. The NRC staff’s conclusions below were based on the review of information in this topical report.

First, the NRC staff confirmed that the material samples cited by the licensee adequately represented the KNPP RPV circumferential weld such that they can be considered in the KNPP RPV integrity evaluations. The NRC staff concluded that the fracture toughness data from these surveillance welds could be used for this purpose since both the KNPP and Maine Yankee surveillance welds were reported to have been fabricated with the same weld wire heat (1P3571) as the KNPP RPV circumferential weld and were subjected to similar post-weld heat treatment conditions. In addition, for the irradiated materials from KNPP surveillance capsule S and Maine Yankee surveillance capsule A-35, the NRC staff confirmed that the irradiation conditions (irradiation temperature, neutron flux) to which these materials were exposed adequately represented the irradiation conditions for the KNPP RPV, within the allowable limits of ASTM E185. The irradiation temperature conditions for the KNPP RPV and surveillance capsule were reported to be nearly identical to those for the Maine Yankee surveillance capsule ($\pm 1\ ^\circ F$), and this information was confirmed through an independent NRC database.[27]

Next, the NRC staff examined questions about specimen fabrication (i.e., reconstitution) and testing practices. Regarding the reconstituted PCVN specimens, the NRC staff confirmed that acceptable guidelines (ASTM Standard E 1253) were used to ensure that valid results should have been acquired in the licensee's testing activities. The NRC staff also noted that an acceptable practice, ASTM E 1921-97, had been used to define the testing procedure used for obtaining fracture toughness data.

Therefore, based on the conclusions above regarding material similarity, irradiation conditions, and specimen reconstitution and testing practices, the NRC staff concluded that the data cited in Reference 5 was acceptable for the evaluation of the integrity of the KNPP RPV. With the approvals granted in this safety evaluation, the licensee may therefore be permitted to incorporate this data into the KNPP licensing basis.

4.2.3.2 Future RPV Surveillance Program Testing

The NRC staff has reviewed the surveillance program submitted by the licensee in their letter dated September 26, 2000. The NRC staff's review was predicated on determining the minimum acceptable KNPP surveillance program to adequately monitor radiation damage to the KNPP RPV through the end of its current operating license.

Based on the data submitted in Reference 5, the NRC staff has concluded that two data points, one from KNPP surveillance capsule S and one from Maine Yankee surveillance capsule A-35, have been acquired to evaluate the fracture toughness properties of the KNPP RPV circumferential weld. Although the Maine Yankee and KNPP surveillance welds exhibit markedly different material properties, particularly with the regard to chemical composition and thus radiation sensitivity, given appropriate adjustments (as incorporated in the NRC staff's methodology in Section 4.3) for these differences, the two data points can be used as an acceptable combined data set for evaluating the KNPP RPV circumferential weld. Further, these two data points represent fluence values consistent with the projected EOL fluence of the KNPP RPV circumferential weld and with nearly two times the projected EOL fluence. As such, they represent a range in fluence values which adds additional robustness to the conclusions drawn from the data.

The NRC staff has concluded that the KNPP proposal to remove and test one additional surveillance capsule at a fluence level corresponding to the projected fluence for the KNPP RPV circumferential weld at 60 years of operation is acceptable to monitor radiation damage to the KNPP RPV through the end of its current, forty year, operating license. This will provide the licensee with an additional data point at a fluence approximating 1.5 times the EOL fluence for the RPV circumferential weld and thus represent another data point at an intermediate fluence with respect to the two data points which have already been acquired. In addition, the removal and testing of the next KNPP surveillance capsule at such a fluence level also completes the current KNPP surveillance program requirements (considering the withdrawal schedule requirements of ASTM E 185-82, which is cited in the KNPP updated safety analysis report (USAR) as the basis for the KNPP withdrawal schedule).[28]

The NRC staff's conclusion regarding the overall acceptability of the licensee's surveillance program, however, is also predicated on the licensee achieving the following with the testing of the surveillance specimens from the next KNPP surveillance capsule: (a) a valid measurement of the fracture-toughness based T_0 parameter for the KNPP RPV surveillance weld; (b) an

estimate of the Charpy 30 ft-lb transition temperature shift for the KNPP RPV surveillance weld; and, (c) an estimate of the upper shelf energy drop for the KNPP RPV surveillance weld. These conditions on the staff's approval were accepted by the licensee in Reference 14. The licensee may obtain a valid measurement of the T_0 parameter for the RPV surveillance weld using: (1) original PCVN weld specimens, (2) reconstituted PCVN weld specimens fabricated from HAZ specimens, or (3) reconstituted PCVN weld specimens fabricated from the end tabs of original, broken weld specimens. If reconstituted specimens from the end tabs of previously broken specimens are used, appropriate limits on the amount of plastic deformation that can be present in the end tabs shall be considered. Further, reconstituted PCVN specimens must be fabricated following the guidance in ASTM E 1253. The licensee must obtain an estimate of the Charpy 30 ft-lb transition temperature shift for their surveillance weld inasmuch as this information will provide a rare data point for the comparison of radiation-induced shifts in the Charpy 30 ft-lb value and the value of T_0. Finally, the licensee must obtain an estimate of the upper shelf energy drop for the surveillance weld to address issues regarding low energy ductile tearing which cannot be adequately evaluated by data taken in the ductile-to-brittle failure transition region.

Note, these conditions are not intended to specify that a full Charpy V-notch impact curve is required for the surveillance weld material, only that the licensee must provide a written explanation in their next surveillance capsule report as to how these conditions were met. Furthermore, regarding reporting requirements, the NRC requires that all information specified in paragraphs 11.1 through 11.2.3 of ASTM E 1921-97 be reported for the surveillance weld fracture toughness testing performed on samples from the next KNPP surveillance capsule. The NRC staff also requests that the next KNPP surveillance capsule report provide all information specified in paragraphs 11.1 through 11.2.3 of ASTM E 1921-97 for the fracture toughness specimens from KNPP surveillance capsule S, Maine Yankee surveillance capsule A-35, and any unirradiated specimens which were tested as part of the basis for the current licensee submittal. The NRC staff requests this information so that a comparisons can be made at that time between the results from the next surveillance capsule and the previously-cited results.

In summary, the NRC staff has concluded that the licensee may use ASTM E 185-98 to define the requirements for evaluating transition temperature properties from the testing of weld specimens (either original or reconstituted) from the next KNPP RPV surveillance capsule. This capsule will be removed and tested at a fluence level approximately equal to the projected fluence for the KNPP RPV circumferential weld after sixty years of operation. Other testing requirements (e.g., tensile testing) remain as stipulated in ASTM E 185-82. The NRC staff has also concluded that fracture toughness testing data shall be the basis of their surveillance program for the KNPP RPV weld and that the licensee does not need to acquire a complete Charpy impact curve, as required by ASTM E 185-98, for this material. In addition, for the HAZ specimens, no Charpy V-notch testing is required. Finally, the testing requirements for other materials, the KNPP surveillance plate and correlation monitor material, remain as defined in ASTM E 185-82.

4.3 NRC Staff's Methodology for Application of a Master Curve-Based Methodology

The development of an acceptable Master Curve-based methodology for the evaluation of a RPV material was the central component of the licensee submittal. The other aspects of this

submittal which have been discussed previously: exemptions to 10 CFR 50.61 and Appendices G and H to 10 CFR Part 50 to implement such a methodology; revisions to the KNPP surveillance program to incorporate the acquisition of fracture toughness data; etc., were contingent on the development of an acceptable methodology. Therefore, the majority of the NRC staff's review effort was focused on evaluating the methodology submitted by the licensee, raising and resolving technical concerns regarding the proposed methodology, and, eventually, developing modifications to the licensee's methodology such that the resulting methodology was acceptable to the NRC staff for the use of the KNPP fracture toughness data.

In order to complete this review, the NRC staff considered a wide range of information regarding the Master Curve technology and RPV material properties. This not only included the information submitted by the licensee, but also: (1) technical information associated with consensus Codes and Standards organizations (ASTM, ASME) activities on the Master Curve technology; (2) information developed through the NRC's Office of Nuclear Regulatory Research as part of established programs to evaluate the use of this technology; (3) information submitted by the industry to address previous NRC initiatives on RPV integrity issues; and (4) documentation of the NRC's basis for the current regulatory structure and methodologies for ensuring that RPV integrity is maintained.[19, 29, 23, 24, 26] The methodology addressed in this section, developed by and acceptable to the NRC staff, was a product of the NRC staff's review of all this information.

However, even with this effort, the NRC staff acknowledges that the state of knowledge regarding some specific technical topics associated with this application may be improved upon in the future. The NRC staff's methodology incorporates appropriate consideration of margins to be applied to account for RPV material property uncertainty, fluence uncertainty, and potential biases due to the use of PCVN testing, for example, which are subjects on which the existing state of knowledge could be improved upon. Hence, while the methodology discussed in this SE is acceptable, the NRC staff acknowledges that it reflects a technical approach which is still under development. Additional "conservatisms" in this methodology may be identified in the future and potentially such conservatisms may be reduced/removed provided that a sufficient technical justification can be made for their reduction/removal.

A detailed, mathematical description of the complete NRC staff methodology for KNPP is provided in Appendix A to this SE. The methodology in Appendix A is the methodology which is acceptable to the NRC staff and the basis for the NRC staff's approval of the licensee's submittal. The licensee agreed to utilize the methodology in Appendix A in Reference 14. Since use of the Appendix A methodology has been stipulated as a condition of the NRC's granting of the requested exemptions, the methodology of Appendix A is incorporated into the KNPP licensing basis.

4.3.1 Basic Methodology for the Determination of RT_{T0}

As discussed in Section 3.3.1, the methodology submitted by the licensee uses fracture toughness data to establish an indexing parameter, $RT_{T0,}$ to position the K_{Ic} (static, plane strain, lower bound) fracture toughness curve from the ASME Code. The NRC staff finds that this is a generally acceptable approach for utilizing fracture toughness data within the current regulatory framework (i.e., 10 CFR 50.61, Appendix G to 10 CFR Part 50, etc.). This would be as opposed to a methodology which could be proposed to directly utilize not only the T_0 parameter, but also the general Master Curve "shape" through the fracture toughness transition

region; a proposal which would require significant additional evaluation to understand the relation of such an approach to the current regulatory structure.

The NRC staff has also concluded that the licensee position that “direct measurement” of fracture toughness properties in the irradiated condition is, in theory, an acceptable basis upon which to utilize the Master Curve technology to evaluate the material properties of RPVs is acceptable. However, as noted during the NRC staff’s review of the KNPP submittal, the concept of “direct measurement” of RPV material properties must be clearly understood if it is to applied in an acceptable manner. The NRC staff’s position is that “direct measurement,” in its strictest sense, results from obtaining and testing material samples from the RPV material itself. Fracture toughness data derived from other sources (in the KNPP submittal, data obtained from the testing of irradiated samples of surveillance welds made with the same weld wire heat as the RPV weld) does not represent “direct measurement” of RPV material properties in the irradiated condition. Testing of surveillance weld materials which are linked to the RPV weld in question by the same weld wire heat number is considered by the NRC staff to be an application of “surrogate” material testing. Necessary “adjustments” and margins to account for the use of “surrogate” materials are further discussed in Sections 4.3.2 and 4.3.3.

As substantiated in the licensee submittal, a mechanism for adjusting data must be established to relate the data derived from their “direct measurement” of the KNPP and Maine Yankee surveillance weld fracture toughness properties in the irradiated condition to the KNPP RPV circumferential weld. The NRC staff has concluded, as did the licensee, that an implicit reliance on evaluating the “shift” in T_0 between the unirradiated and irradiated conditions for the KNPP and Maine Yankee surveillance welds must to used to make these adjustments. Therefore, while both the licensee and the NRC staff methodologies may be considered to be “more direct” paths to establishing the KNPP RPV circumferential weld material properties at EOL and EOLE conditions when compared to the current Charpy V-notch and drop weight-based “initial plus shift” approach, neither can be accepted as a definitive “direct measurement” approach to establishing the material properties of the RPV weld. This issue of “adjustments,” and associated effects on uncertainties and margins, will be discussed in Section 4.3.3.
Regarding the licensee’s proposal to utilize the methods of ASTM E 1921-97 to define the procedures for obtaining and evaluating the fracture toughness data via the Master Curve technology, the NRC staff has concluded that this use of this Standard is acceptable. Use of ASTM E 1921-97 will provide acceptable values of T_0 from the testing of KNPP and Maine Yankee surveillance weld samples in both the irradiated and unirradiated conditions and the NRC staff finds with the values obtained by the licensee and given in column 4 of Table 4 to be acceptable. However, at this time, the NRC staff does not endorse the use of the multi-temperature maximum likelihood methodology for combining data for different size specimens to obtain “overall T_0" values as shown in column 5 of Table 4. The NRC staff may reconsider its position on the multi-temperature method for this purpose once action within the governing ASTM Standards organization has been completed and a revision to E 1921 published. The NRC staff’s evaluation will therefore be restricted to the evaluation of data derived from the testing of PCVN specimens.

Finally, the NRC staff has concluded that the licensee’s use of ASME Code Case N-629 to define an acceptable expression for calculating the RT_{T0} parameter is acceptable. As noted in Section 3.3.1, ASME Code Case N-629 states that RT_{T0} shall be calculated as given in Eqn. 1, $RT_{T0} = T_0 + 35$ °F. This definition of RT_{T0} is accepted by the NRC staff based on the supporting evaluations provided in the technical basis document for ASME Code Case N-629. These

evaluations demonstrated that defining RT_{T0} in this manner would result in a parameter which, when comparing to the data base of ASTM E 399 valid K_{Ic} fracture toughness data cited in the technical basis document, would position the lower bound ASME Code K_{Ic} fracture toughness curve with nearly the same degree of "implicit" conservatism as RT_{NDT}.[19] Furthermore, this NRC staff position is consistent with NRC representatives' votes which favored passage of ASME Code Case N-629 during the ASME Code consensus process. The NRC staff's evaluations regarding the issue of "implicit" margins within the definition of the RT_{T0} parameter are discussed in Section 4.3.3.

4.3.2 Assessment of Systematic Difference Between Surveillance Data and RPV Conditions

As noted previously, given the licensee proposal to rely on "direct measurement" of the fracture toughness of irradiated surveillance weld samples from the KNPP and Maine Yankee surveillance programs, a necessary development in the licensee and NRC staff methodologies was a way to adjust the test results to the EOL and EOLE conditions of the KNPP RPV circumferential weld. As part of the NRC staff's methodology, general provisions were developed in these "adjustments" to account for differences in fluence, best-estimate chemical composition, and irradiation temperature (although in the KNPP case, no meaningful irradiation temperature differences existed). In effect, implementing these adjustments defined the entire structure (outside of separable activities to determine appropriate margins and a PCVN bias term) of the NRC staff's methodology as given in Appendix A to this SE. Finally, it should be noted that all of the aforementioned adjustments were consistent with similar adjustments required in the current Charpy V-Notch and drop weight-based methodology by the provisions of 10 CFR 50.61 and the guidance in RG 1.99, Rev. 2.

The methodology developed by the NRC staff for implementing these adjustments was consistent with that proposed by the licensee in that it depends on "shift in T_0" for the KNPP and Maine Yankee surveillance welds between the unirradiated and irradiated conditions and the embrittlement model in RG 1.99, Rev. 2 to characterize the shifts. A fundamental difference, however, was that while the licensee methodology evaluated EOL RPV conditions from data derived from KNPP surveillance capsule S material and EOLE RPV conditions from data derived from Maine Yankee surveillance capsule A-35, the NRC staff's methodology was developed to ensure that both data points could be integrated into the evaluation of any specified RPV condition. The NRC staff's position was that the integration of data in this manner: (1) provided a more robust and defensible evaluation of any specified RPV condition, (2) was consistent with current guidelines related to data sufficiency established in RG 1.99, Rev. 2 and 10 CFR 50.61, for the use of plant-specific Charpy results, and (3) provided a framework for the integration of additional future data points into the evaluation of the KNPP RPV circumferential weld.

The general procedure established by the NRC staff is discussed below, with a more condensed, mathematical documentation of the methodology provided in Appendix A. The goal is to obtain estimates of T_0 for the KNPP RPV circumferential weld at a specified condition. For example, if considering EOLE conditions at the clad-to-base metal interface, two independent estimates of this value can be established from the KNPP surveillance capsule S and Maine Yankee surveillance capsule A-35 data points, called $T_{0\text{-EOLE-ID-K-S}}$ and $T_{0\text{-EOLE-ID-MY-A35}}$, respectively.

To demonstrate, $T_{0\text{-EOLE-ID-K-S}}$ would be determined as:

[Eqn.7] $T_{0\text{-EOLE-ID-K-S}} = T_{0\text{-K-S}} - (\Delta T_{0\text{-K-S}} - \Delta T_{0\text{-EOLE-ID-K-S}})$

In this case, $T_{0\text{-K-S}}$ is the T_0 value determined from the testing of PCVN specimens from KNPP surveillance capsule S, $\Delta T_{0\text{-K-S}}$ is the shift in the value of T_0 between unirradiated specimens from the KNPP surveillance weld and the samples from KNPP surveillance capsule S, and $\Delta T_{0\text{-EOLE-ID-K-S}}$ is the estimated shift in T_0 for the KNPP RPV circumferential weld based on the observed shift in the KNPP surveillance weld. The expression above could be rewritten to show that it is merely the value of T_0 established for the KNPP RPV surveillance weld in the unirradiated condition plus the estimated shift in T_0 for the KNPP RPV circumferential weld based on the observed shift in the KNPP surveillance weld. The expression above is used, however, to parallel the licensee's intent of not "explicitly" using the T_0 values from unirradiated specimen testing in the calculation.

The value of $\Delta T_{0\text{-EOLE-ID-K-S}}$ is then calculated as:

[Eqn. 8] $\Delta T_{0\text{-EOLE-ID-K-S}} = [\Delta T_{0\text{-K-S}} - (t_{IRR\text{-}RPV} - t_{IRR\text{-}K\text{-}S})] * (FF_{EOLE\text{-}ID} / FF_{K\text{-}S}) * (CF_{RPV} / CF_{K\text{-}S})$

and it is this relationship which quantitatively adjusts the observed shift in T_0 from the testing of KNPP surveillance capsule S to the EOLE fluence, irradiation temperature, and best-estimate chemistry of the KNPP RPV circumferential weld. Although in this specific case no irradiation temperature difference exists between the surveillance capsule and the RPV, the $(t_{IRR\text{-}RPV} - t_{IRR\text{-}K\text{-}S})$ term enables a one degree shift per degree difference in irradiation temperature adjustment if such a difference existed. The $(FF_{EOLE\text{-}ID} / FF_{K\text{-}S})$ term adjusts for fluence difference between the peak, clad-to-base metal interface fluence for RPV circumferential weld and the fluence for KNPP surveillance capsule S. As noted before, this relies on the use of the "fluence factor" (FF) calculation from RG 1.99, Rev. 2 and thus, assumes that although the magnitudes may be different, the "shape" or "dependence" of the shift in T_0 with increasing fluence can be expressed by the same functional form as the shift in Charpy V-notch 30 ft-lb energy level. Likewise, the $(CF_{RPV} / CF_{K\text{-}S})$ term which adjusts for chemical compositional (i.e., radiation sensitivity) differences between the surveillance weld and the KNPP RPV circumferential weld is based upon the tabulated "chemistry factor" values from RG 1.99, Rev. 2. Using the information in Table 5, CF_{RPV} is determined from the best-estimate chemistry for the KNPP RPV circumferential weld and $CF_{K\text{-}S}$ is determined by the specific chemistry of the KNPP surveillance weld. Table 6 provides the fluences and FF values for all materials and conditions relevant to the evaluation of the KNPP RPV circumferential weld.

In summary, the NRC staff's approach to implementing adjustments to data acquired from the testing of surveillance welds to account for RPV conditions is fundamentally similar to that proposed by the licensee, yet somewhat more general. The NRC staff has concluded, based on observations made from an available data base of T_0 shift values (including both plate and weld materials), that the use of the RG 1.99, Rev. 2 fluence function adequately describes the "dependence" of the shift in T_0 with increasing fluence in the absence of an embrittlement model specifically based on T_0 shift data.[30, 31] Further, characterization of material "irradiation sensitivity" based on CFs from RG 1.99 Rev. 2 for the purpose of scaling T_0 values from RPV surveillance weld testing to KNPP RPV circumferential properties was also found to be acceptable.

Additional discussion regarding use of the methodology described above to integrate multiple data points into the evaluation of the KNPP RPV circumferential weld at a specified condition will be presented in Section 4.3.5.

4.3.3 Assessment of Uncertainties and Margins

As noted in Section 3.3.3, the ability to adequately determine the explicit margins to be applied when using a Master Curve-based methodology is a critical element for ensuring that RPV integrity will be maintained when the methodology is used. This topic also represents the major area of disagreement between the methodology accepted by the NRC staff and the one proposed by the licensee. The NRC staff has concluded that the margins which were suggested to exist in the licensee methodology are, in some cases, unfounded. In total, the NRC staff has concluded that the margins proposed by the licensee are inadequate to ensure that RPV integrity will be maintained when all sources of uncertainty identified in 10 CFR 50.61 are considered. Below, the NRC staff has provided its assessment of margins proposed by the licensee and the basis for the margins endorsed by the NRC staff as incorporated into the methodology in Appendix A.

4.3.3.1 Assessment of Implicit Margin in the Definition of RT_{T0}

Two sources of margin were cited to exist within the licensee methodology. The first was an "implicit" margin of 18 °F from the licensee's conclusion that the definition of RT_{T0} as (T_0 + 35 °F) was "more conservative" than RT_{NDT}-based approaches for positioning the ASME Code K_{IC} curve. The NRC staff rejects the licensee contention (see also Section 3.3.3) that only the data from plate HSST-02 (i.e., the lowest data in the original K_{IC} database) should be considered when determining what adder should be applied to T_0 to make RT_{T0} an acceptable replacement for RT_{NDT}. The ASME Code K_{IC} curve could only have been established as a "lower bound" curve given the existence of an extensive K_{IC} data base from many different RPV grade materials. That is, although the shape of the ASME Code K_{IC} curve may have been defined by the HSST-02 data, one can only have confidence in the lower bound nature of the ASME Code K_{IC} curve given the existence of the entire database.

Hence, the NRC staff concluded that to determine the appropriate adder to T_0, one must look at how RT_{T0} and RT_{NDT} position the ASME Code K_{IC} curve for each material from the original K_{IC} data base.[20] To integrate this information for the purpose of establishing an appropriate adder to T_0, the NRC staff reexamined a previously-published statistical analysis on this subject.[32] Reference 31 presented an analysis which first calculated the mean sum of squares distance between the data in the original K_{IC} data base and K_{IC} curve as indexed by RT_{NDT} for each material. Next, the analysis varied the adder to T_0 until the mean sum of squares distance between the data in the original K_{IC} data set and K_{IC} curve as indexed by RT_{T0} for each material produced the same value for mean sum of squares distance as with RT_{NDT}. By this method, it was concluded that an adder of 33 °F achieved this equality. The NRC staff considered this to be an acceptable analysis for comparing the "conservatism" inherent to each indexing parameter since it: (1) utilized all data from the original K_{IC} data base and (2) provided a "stable" interpretation which would likely be only minimally affected by the addition of new data to the K_{IC} data base. Analyses like that proposed by the licensee, based on only the small K_{IC} data set from the testing of plate HSST-02, could be subject to considerable instability if another RPV material were tested and found to be more limiting than plate HSST-02 and/or if more data from the testing of plate HSST-02 significantly changed the analysis. In addition, the NRC staff

could not conclude, from the documentation in the ASME Code technical basis document, that the ASME Code group responsible for ASME Code Case N-629 considered there to be additional implicit margin on the order of 18 °F when the code case was approved.

To summarize, on the subject of additional, implicit margin in the definition of RT_{T0} relative to the use of RT_{NDT} in the current regulatory structure, the NRC staff concluded that, at most 2 °F of implicit margin existed (the difference between the ASME Code Case N-629 adder of 35 °F and the 33 °F adder acceptable to the NRC staff). The NRC staff rejects the licensee's contention that 18 °F of implicit margin exists and the NRC staff credits the 2 °F amount of additional, implicit margin in the methodology given in Appendix A.

4.3.3.2 Assessment of Explicit Margins to Account for Material and Fluence Uncertainties

As noted in the NRC staff's July 16, 1999, letter to the licensee, 10 CFR 50.61 requires that "explicit" margin shall be added, "to account for uncertainties in the values of $RT_{NDT(U)}$, copper and nickel contents, fluence, and the calculational procedures." The NRC staff concluded that the original the licensee proposal to only utilize the statistical uncertainty in the determination of T_0 from the testing of material from KNPP surveillance capsule S and Maine Yankee surveillance capsule A-35 was inadequate to address all of the sources of uncertainty noted above. The NRC staff concluded that the probabilistic assessments provided by the licensee along with their letter of February 4, 2000, were an appropriate mechanism for evaluating the effects of some sources of uncertainty. However, the NRC staff concluded that the analyses submitted by the licensee did not effectively address uncertainty in initial material fracture toughness and did not fully investigate the margin required to address uncertainties in the irradiation embrittlement behavior of the KNPP RPV circumferential weld. Hence, the NRC staff undertook to perform its own analysis of the "explicit" margin to be added to account for the all sources of uncertainty noted above, and the method and results of the NRC staff's analysis are discussed below.

First, the NRC staff examined those sources of uncertainty which would directly contribute to the uncertainty in the irradiation embrittlement behavior of the KNPP RPV circumferential weld. This included uncertainty in copper content, nickel content, and fluence. The NRC staff chose to establish mean values and uncertainties for two case studies, as shown in Table 7. Case 1 uses mean copper and nickel contents, and uncertainties (1σ level) in each, for weld wire heat 1P3571 based on information submitted by the Combustion Engineering Owners Group in response to NRC GL 92-01, Revision 1.[23, 24] Case 2 uses the same mean values and the same uncertainty in nickel content, but invokes a different uncertainty in copper content based on an assessment of the variability in copper from data for all CE copper-coated weld wire heats. The NRC staff concluded, based on the aforementioned data, that although mean copper contents may vary significantly from one CE copper-coated weld wire heat to another, consistency in the uncertainty in the mean is expected between such heats. Thus, the pooling of data from many such heats was acceptable for estimating the copper uncertainty, but not the mean copper value, for weld wire heat 1P3571. The best-estimate fluence was taken to be 4.7×10^{19} n/cm^2 (E > 1.0 MeV) at 51 EFPY from the licensee's February 4, 2000, submittal based on assuming an 85 percent capacity factor and an uncertainty of ±20 percent. Again, the mean values for each of these inputs would have some effect on the Monte Carlo analysis to assess overall uncertainty in irradiation embrittlement behavior, however, for this particular evaluation, they were of secondary importance since the mean values fell in regions where the

behavior of the available embrittlement models are relatively "stable." All distributions in the analysis were assumed to be normal.

The result of the NRC staff's analysis showed that, depending on the level of truncation assumed for each input distribution (2σ, 3σ, none), slightly varying answers could be obtained. When the NRC staff analyzed Case 1, the calculated values for overall uncertainty at the 1σ level were between 29 °F and 33 °F. Using the reduced copper uncertainty in Case 2, the calculated values for overall uncertainty at the 1σ level were between 25 °F and 29 °F. The NRC staff noted that while any of the various values could be selected based on engineering judgment, it would be difficult to develop a definite case for the selection of one over another based solely on the information from this analysis. Therefore, as discussed below, additional considerations were incorporated to define a precise value to be used in the NRC staff's Master Curve-based methodology from the range of equally-acceptable values resulting from the Monte Carlo analysis. However, this Monte Carlo-based approach, which correctly assesses the necessary margin based on the uncertainties associated with the KNPP RPV circumferential weld material (as opposed to "margin" evaluations derived solely from the analysis of available test data), is the only fundamentally acceptable basis available at this time for defining the necessary margin to address these uncertainties.

The NRC staff also noted that the value given in RG 1.99, Rev. 2, which is linked to addressing these same uncertainties, σ_{Δ}, has an accepted value of 28 °F, although the basis for this value of σ_{Δ} is not directly the product of a Monte Carlo-based evaluation.[25] Also, the methodologies of RG 1.99, Rev. 2 have already been utilized by both the licensee and the NRC staff as the basis for adjusting T_0 data from the KNPP and Maine Yankee surveillance welds to the chemistry and fluence of the KNPP RPV circumferential weld, hence, establishing a precedent for the consideration of information from RG 1.99, Rev. 2 in this analysis. In the absence of compelling evidence from the Monte Carlo-based analysis to alter the established value used to address copper, nickel, and fluence uncertainties, the NRC staff concluded that a value of 28 °F is acceptable for this purpose within the context of the NRC staff's Master Curve-based methodology as well. Given the parallels that will be developed with the margins methodology in RG 1.99, Rev. 2, this 28 °F value will be identified as $\sigma_{\Delta T0}$ in the remainder of this discussion.

The remaining issue to be addressed is the incorporation of margin to account for uncertainty in the initial fracture toughness properties of the KNPP RPV circumferential weld. Although, as discussed in Sections 4.3.1 and 4.3.2, the licensee proposed to utilize "direct measurement" of fracture toughness properties in the irradiated condition as the basis for their Master Curve-based methodology, actual test data was only derived from surveillance weld samples, not the RPV circumferential weld itself. The initial material properties of these "surrogate" surveillance weld samples cannot be demonstrated to be precisely the same as those of the RPV weld since no actual results exist from the testing of the RPV weld for comparison. In the case of the licensee submittal, this necessitates the incorporation of margins into the methodology to relate the data from these "surrogate" materials to the KNPP RPV circumferential weld. Information which relates the "surrogate" surveillance welds to the KNPP RPV circumferential weld (same welding flux, similar post-weld heat treatments, etc.) helps to establish the expected degree of initial property similarity of these "surrogates" to the RPV weld and the amount of margin required.

The NRC staff examined the existing data base of fracture toughness test results relevant to Master Curve evaluation for weld wire heats used by CE for fabricating RPVs. The NRC staff

considered the fact that previous analyses to develop a generic unirradiated nil-ductility reference temperature concluded that welds manufactured from Linde weld fluxes 1092, 0124, and 0091 were sufficiently similar in their initial properties (and microstructures) to be grouped together. Hence, the initial NRC staff assumption was that at least observations of weld-to-weld variability of initial fracture toughness properties, if not the absolute fracture toughness values themselves, from welds made with these same weld fluxes would also constitute an analyzable population. The NRC staff identified CE weld wire heats (87986, 87984, 33A277, 1P3571, and tandem weld 20291/12008) for which a significant amount of fracture toughness data existed. All data from each weld wire heat was pooled and random sampling performed to generate a distribution of T_0 values for each weld wire heat. The distributions were assumed to be normal and a 1σ value of each distribution of T_0 values calculated. The results of this analysis are shown in Table 8. The NRC staff concluded that a bounding value of 14 °F could be established for uncertainty in the initial properties (henceforth referred to as σ_{IT0}) based on this analysis for the given CE weld wire heats and, further, that such value would also address uncertainties in the "calculational procedures" as required by 10 CFR 50.61. The NRC staff, however, recognizes that while this analysis is adequate to support the KNPP evaluation this topic area is one in which additional analyses and/or additional data may refine the value in the future.

This value of σ_{IT0} was then included in a square-root-sum-of-squares (SRSS) summation with $\sigma_{\Delta T0}$ to provide the complete "explicit" margin to be applied in the NRC staff's analysis.

In summary, the "explicit" margin, M, was calculated as:

[Eqn. 9] $$M = 2 * \sqrt{(\sigma_{IT0}^2 + \sigma_{\Delta T0}^2)} = 2 * \sqrt{(14^2 + 28^2)} = 62.5\ ^\circ F$$

This methodology for combining these two margin terms is consistent with the technical basis established in RG 1.99, Rev. 2 and 10 CFR 50.61. The multiplier of 2 is enforced to provide sufficient margin such that the final analysis is, given the assumptions above, interpreted to be bounding at the 2σ level on the expected material properties of the KNPP RPV circumferential weld. This level of conservatism is consistent with that which is incorporated into the technical bases which support the PTS screening criteria found in 10 CFR 50.61.

4.3.4 Assessment of Bias in the Use of PCVN Specimens in Master Curve Testing

With respect to the Master Curve methodology, issues regarding the use of small specimen testing, adequate constraint, and the potential for non-conservative bias in test results arose as far back as the passage of ASTM Standard E 1921-97. To summarize the issue, if the size and geometry of the specimens tested are insufficient to maintain an adequate level of constraint at the crack tip, excessive yielding (plasticity) may result. This excessive yielding may be manifest as an apparent increase in load carrying capacity (due to the work absorbed in plastically deforming the material) and thus, an overestimation of the fracture toughness of the material. To mitigate the potential for such effects, a constraint limit for the purpose of data censoring was established in ASTM E 1921-97 for Master Curve-related testing.

In Figure 3, "T_0 PC-CVN" is the T_0 value determined for a particular material based upon the testing of PCVN specimen sets per ASTM E1921-97 (including the censoring limit) and "T_0 Ref." is the T_0 value calculated for the same material from larger specimens. Thus, the ordinate axis in Figure 3 represents the difference in calculated values of T_0 with negative

values indicative of a potentially non-conservative bias in the T_0 value determined from the PCVN data set. This T_0 differential was then plotted relative to the constraint parameter, M_0, which is the non-dimensional deformation level associated with K_0, the 1T equivalent K_{JC} value associated with the 62.3 percent cumulative failure probability from the data derived from the PCVN testing of the material. A large M_0 value means that the PCVN data set for the material exhibited a lower load carrying capacity, a correspondingly higher degree of constraint, and less potential for "bias" when compared to large specimen test results. Each data point shown represents a different material and the points shown are limited to those materials for whom a "T_0 Ref." value could be determined from sets of 1T-CT or larger test specimens. The NRC staff chose to impose this restriction to ensure that a clear constraint differential could exist between PCVN data set and the "reference" data set used to determine "T_0 Ref." Table 9 provides the value of the M_0 constraint parameter calculated for each irradiated and unirradiated data set relevant to the KNPP evaluation.

From Figure 3, the NRC staff concluded that although a statistically significant bias of 8.5 °F was evident in the data, no defined trend with M_0 was able to be resolved. The NRC staff also observed other data points for which "T_0 Ref." values could be calculated from specimens as small as 0.5T-CTs. With the inclusion of this additional data, a trend of increasing PCVN bias with decreasing M_0 may have been resolvable, but the complication of including data wherein the size (and thus the expected constraint) of the specimens used to define "T_0 Ref." was nearly the same size as the PCVN specimens would have made any such conclusions highly speculative. It can, however, be noted that with regard to addressing bias related to the licensee application, either interpretation would have yielded the same net effect in the NRC staff's overall methodology.

The NRC staff acknowledges that the lack of a definable trend in Figure 3 calls into question whether the observed bias from PCVN test results can be simply addressed as a matter of specimen constraint. Other theories have been postulated, including consideration of specimen geometry and T-stress, to explain the observed differences in PCVN and CT specimen results. The NRC staff recognizes that additional research in this area may help to better define this issue and modify the conclusions of this SE. However, the NRC staff concludes, at this time, that the assumption of a 8.5 °F bias in PCVN-based T_0 values relative to values obtained with larger size CT specimens, to be applied to each unirradiated and irradiated PCVN data set in the licensee submittal, is adequate to address this potential source of non-conservatism in the NRC staff's methodology as given in Appendix A to this SE.

The methodology developed by the NRC staff, however, includes sufficient flexibility to incorporate specific bias values for each of the four PCVN data sets relevant to this evaluation of the KNPP RPV circumferential weld should additional information demonstrate that different bias values are appropriate. To provide this flexibility, each of these four data sets must be addressed separately since the effect of bias on the evaluation of the shift in T_0 must be assessed given the NRC staff's methodology discussed in Section 4.3.2 above. As such, the effect of "accounting for bias in PCVN data" in the NRC staff's methodology cannot be easily discussed as a stand alone item, but must instead be presented as it is integrated into achieving results from the overall NRC staff methodology. This integration of bias into the NRC staff's methodology is addressed in Appendix A and discussed further in Section 4.3.5 below.

4.3.5 Overall NRC Staff Methodology for KNPP Master Curve-Based Evaluation

This section brings together aspects of the NRC staff's methodology discussed in Section 4.3.2, the assessment of margins discussed in Section 4.3.3, and evaluation of PCVN testing bias covered in Section 4.3.4. Again, the general procedure established by the NRC staff is discussed below through an example, with a more condensed, mathematical documentation of the methodology provided in Appendix A.

Section 4.3.2 described the NRC staff's methodology for determining the two estimates of the T_0 value for the KNPP RPV circumferential weld (at a given through-wall location and given number of EFPY of operation) based on the data from the testing of material from KNPP surveillance capsule S and Maine Yankee surveillance capsule A-35. For the KNPP RPV circumferential weld material properties at the clad-to-base metal interface at EOLE conditions, these estimates were called $T_{0\text{-EOLE-ID-K-S}}$ and $T_{0\text{-EOLE-ID-MY-A35}}$, respectively. Correspondingly, two estimates of a T_0-based PTS reference temperature to replace RT_{PTS} can be determined from these estimates of T_0 and can be called $ART_{T0\text{-EOLE-ID-K-S}}$ and $ART_{T0\text{-EOLE-ID-MY-A35}}$, respectively. These estimates for a T_0-based reference temperature are determined from the use of ASME Code Case N-629, plus the consideration of margin and PCVN testing bias and are determined as:

[Eqn. 10] $$ART_{T0\text{-EOLE-ID-K-S}} = T_{0\text{-EOLE-ID-K-S}} + 33\ ^\circ F + 62.5\ ^\circ F + B_{PCVN\text{-K-S-U}}$$

[Eqn. 11] $$ART_{T0\text{-EOLE-ID-MY-A35}} = T_{0\text{-EOLE-ID-MY-A35}} + 33\ ^\circ F + 62.5\ ^\circ F + B_{PCVN\text{-MY-A35-U}}$$

where the 33 °F value comes from the 35 °F adder given in ASME Code Case N-629 minus the 2 °F of implicit margin discussed in Section 4.3.2, 62.5 °F is the margin term from Section 4.3.3, and B values are adjustments added to account for PCVN testing bias. It should be noted that the 33 °F and 62.5 °F values are invariant and would apply to any KNPP RPV integrity evaluation (i.e., determining appropriate PTS or P-T limit reference temperatures at EOL or EOLE conditions), whereas the bias term (as discussed below) and the T_0 estimates (as discussed in Section 4.3.2) from the two surveillance capsules may change based on the adjustments required to evaluate a specific RPV condition and through-wall location.

Working through how the bias in the T_0 values determined for each of the four relevant data sets from the KNPP submittal (the unirradiated and irradiated PCVNs from the KNPP surveillance weld and the unirradiated and irradiated PCVNs from the Maine Yankee surveillance weld) affects the overall methodology:

[Eqn. 12] $$B_{PCVN\text{-K-S-U}} = B_{PCVN\text{-K-U}} + [(FF_{X\text{-}Y} / FF_{K\text{-}S}) * (CF_{RPV} / CF_{K\text{-}S}) * (B_{PCVN\text{-K-S}} - B_{PCVN\text{-K-U}})]$$

[Eqn. 13] $$B_{PCVN\text{-MY-A35-U}} = B_{PCVN\text{-MY-U}} + [(FF_{X\text{-}Y} / FF_{MY\text{-}A35}) * (CF_{RPV} / CF_{MY\text{-}A35}) * (B_{PCVN\text{-MY-A35}} - B_{PCVN\text{-MY-U}})]$$

where $B_{PCVN\text{-K-U}}$ is the bias associated with the unirradiated PCVN data from the KNPP surveillance weld, $B_{PCVN\text{-MY-U}}$ is the bias associated with the unirradiated PCVN data from the Maine Yankee surveillance weld, $B_{PCVN\text{-K-S}}$ is the bias associated with the irradiated PCVN specimens from KNPP surveillance capsule S, and $B_{PCVN\text{-MY-A35}}$ is the bias associated with the irradiated PCVN specimens from MY surveillance capsule A-35. Again, these representations provide the general form for determining $B_{PCVN\text{-K-S-U}}$ and $B_{PCVN\text{-MY-A35-U}}$ if different bias values are established for each of the four PCVN data sets relevant to this evaluation. The FF and CF ratios are as discussed in Section 4.3.2 and must be incorporated since the bias in each data set affects how the shifts in T_0 for the KNPP surveillance weld and the Maine Yankee

surveillance weld are applied to the evaluation of PTS for the KNPP RPV circumferential beltline weld at EOLE. For the present evaluation, the use of a constant 8.5 °F bias value for each of the PCVN data sets in this evaluation results in $B_{PCVN\text{-}K\text{-}S\text{-}U}$ and $B_{PCVN\text{-}MY\text{-}A35\text{-}U}$ both being calculated to be 8.5 °F as well.

Considering Eqns. 10 and 11, the two estimates of a T_0-based PTS reference temperature to replace RT_{PTS} for EOLE conditions ($ART_{T0\text{-}EOLE\text{-}ID}$ to be consistent with the terminology introduced in Section 3.4), from the NRC staff's methodology can be determined to be $ART_{T0\text{-}EOLE\text{-}ID\text{-}K\text{-}S}$ = 298.5 °F and $ART_{T0\text{-}EOLE\text{-}ID\text{-}MY\text{-}A35}$ = 277.5 °F. The best-estimate value for $ART_{T0\text{-}EOLE\text{-}ID}$ is then the average of these two, or 288 °F. As additional surveillance capsules are tested, additional estimates of $ART_{T0\text{-}EOLE\text{-}ID}$ will be obtained and will be averaged with the above values to give an updated best-estimate for $ART_{T0\text{-}EOLE\text{-}ID.}$

Similar calculations have been completed by the NRC staff to evaluate the PTS reference temperature at EOL for the KNPP RPV circumferential weld and the proposed KNPP P-T limit amendment. The results of all these calculations are discussed further in Section 4.4 below. Table 10 also provides a comparison of similar values which can be extracted from, if they do not readily fall out of, the NRC and the licensee methodologies. The information in Table 10 provides a means of comparing the implicit or explicit components which contribute to the ART values determined by the NRC and the licensee for the RPV circumferential weld at the clad-to-base metal interface for EOL and EOLE conditions.

4.4 NRC Staff Results for PTS and P-T Limits Assessments

In addition to the example discussed in Section 4.3.5 which calculated $ART_{T0\text{-}EOLE\text{-}ID}$ utilizing the methodology acceptable to the NRC staff, the NRC staff has also determined values of $ART_{T0\text{-}EOL\text{-}ID,}$ $ART_{T0\text{-}EOL\text{-}1/4T}$, and $ART_{T0\text{-}EOL\text{-}3/4T}$ (defined in Section 3.4) which are important to the evaluation of PTS and P-T limits for the KNPP RPV at the end of its current operating license. These values were determined using the same methodology as discussed in Section 4.3.2, Section 4.3.5, and Appendix A, with only the appropriate modifications to reflect the fluence level of interest. The NRC staff concurred with the licensee's use of the attenuation function from RG 1.99, Rev. 2 (see Section 3.3.5, Eqn. 3) for the purpose of determining fluences at the 1/4T and 3/4T locations based on the direct calculation of the clad-to-base metal (E > 1.0 MeV) fluence at EOL conditions.

All relevant information from the licensee submittals for the determination of $ART_{T0\text{-}EOL\text{-}ID}$, $ART_{T0\text{-}EOL\text{-}1/4T}$, and $ART_{T0\text{-}EOL\text{-}3/4T}$ has been given in Tables 4 through 8. Again, for each of these parameters, two estimates of their value would be established, one based on the fracture toughness data from the testing of PCVN specimens from KNPP surveillance capsule S and the other based on fracture toughness data from the testing of PCVN specimens from Maine Yankee surveillance capsule A-35. The two estimates for each parameter were then averaged to provide the best-estimate value for each. The NRC staff's best-estimate values for $ART_{T0\text{-}EOLE\text{-}ID}$, $ART_{T0\text{-}EOL\text{-}ID}$, $ART_{T0\text{-}EOL\text{-}1/4T}$, and $ART_{T0\text{-}EOL\text{-}3/4T}$ are summarized in Table 11.

Based on these results, the NRC staff reached the following conclusions. First, the value of $ART_{T0\text{-}EOL\text{-}ID}$, which replaces the calculated value of RT_{PTS} at EOL conditions, was 271 °F. This value was below the screening criteria given in 10 CFR 50.61 and the methodology developed by the NRC staff makes the determination of $ART_{T0\text{-}EOL\text{-}ID}$ consistent with the bases for the screening criteria. Therefore, this evaluation supported continued operation of the KNPP RPV

through EOL. In addition, the values of $ART_{T0\text{-}EOL\text{-}1/4T}$ and $ART_{T0\text{-}EOL\text{-}3/4T}$ were 247 °F and 196 °F, respectively. These values did not support the revised cooldown P-T limit curve (shown in Figure 2) submitted by the licensee, which was based on the licensee's determination of $ART_{T0\text{-}EOL\text{-}1/4T}$, and $ART_{T0\text{-}EOL\text{-}3/4T}$ as 210 °F and 157 °F, respectively. The values calculated for $ART_{T0\text{-}EOL\text{-}1/4T}$ and $ART_{T0\text{-}EOL\text{-}3/4T}$ by the NRC staff indicate that at the higher pressure and temperature portion of the cooldown curves the KNPP RPV circumferential weld will continue to be the limiting material. Hence, the composite nature of the current KNPP P-T limit curves (shown in Figure 1) must be maintained. It should be noted, however, that all of the aforementioned values must be recalculated when additional surveillance data or other information is acquired with could affect the conclusions of this SE.

However, in the NRC staff SE which granted approval for the current KNPP P-T limits, the staff noted that the restriction on the validity of the P-T limits to 28 EFPY of operation was imposed because the NRC staff calculated the cooldown curves in Figure 1 to be 5 to 7 °F non-conservative at 33 EFPY.[33] This was based on the NRC staff's conclusion that the EOL 1/4T and 3/4T reference temperatures for the KNPP RPV circumferential weld (under the Charpy V-notch and drop weight-based methodology) would be 256 °F and 210 °F, respectively. Reestablishing the EOL 1/4T and 3/4T reference temperatures as 247 °F and 196 °F, respectively, using the NRC staff's methodology for a Master Curve-based approach, "corrects" for this 5 to 7 °F non-conservatism in the current KNPP cooldown P-T limit curves and would justify, if requested by the licensee, their use through 33 EFPY of operation. The NRC staff's prior conclusion, that the other current KNPP P-T limit curves (e.g., the heatup limit curves, which were based on the material properties of the most limiting KNPP beltline forging and the limiting RPV closure flange material) would be acceptable through 33 EFPY, remains valid.

5.0 NRC STAFF CONCLUSIONS

In summary, based on the information submitted by the licensee and the independent evaluation by the NRC staff, the NRC staff concludes:

(1) The exemptions to Appendices G and H to 10 CFR Part 50 and 10 CFR 50.61 requested by the licensee to implement a Master Curve-based methodology for the evaluation of the integrity of the KNPP RPV circumferential weld are necessary to implement such a methodology. Further, the licensee's exemption requests should be approved pursuant to the criteria of 10 CFR 50.12(a)(ii), "[a]pplication of the regulation in the particular circumstances...is not necessary to achieve the underlying purpose of the rule," provided that the licensee utilizes the Master Curve-based methodology developed by the NRC staff in Appendix A of this SE as an acceptable alternative to the Charpy V-notch and drop weight-based methodology which serves as the basis for Appendices G and H to 10 CFR Part 50 and 10 CFR 50.61.

(2) The PCVN fracture toughness test data cited in WCAP-14279, Revision 1 (Reference 5 to this SE) is acceptable for the evaluation of the integrity of the KNPP RPV. With the approvals granted in this safety evaluation, the licensee may therefore be permitted to incorporate this data into the KNPP licensing basis and utilize it within an acceptable Master Curve-based methodology for the evaluation of KNPP RPV integrity.

(3) The NRC staff has concluded that the KNPP proposal to remove and test one additional surveillance capsule at a fluence level corresponding to the projected fluence for the

KNPP RPV circumferential weld at sixty EFPY of operation is acceptable to monitor radiation damage to the KNPP RPV through the end of its current, forty year, operating license. The NRC staff's conclusion is dependent on the licensee achieving the following with the testing of the surveillance specimens from the next KNPP surveillance capsule. One, the licensee must obtain a valid measurement of the T_0 parameter for the RPV surveillance weld. Two, the licensee must obtain an estimate of the Charpy 30 ft-lb transition temperature shift for their surveillance weld. Three, the licensee must obtain an estimate of the upper shelf energy drop for surveillance weld. Note, these performance goals are not intended to specify that a full Charpy V-notch impact curve is required for the surveillance weld material, only that the licensee must provide a written explanation in their next surveillance capsule report as to how these performance goals were achieved. In addition, for the HAZ specimens, no Charpy V-notch testing is required. Finally, the testing requirements for other materials, the KNPP surveillance plate and correlation monitor material, remain as defined in ASTM E 185-82.

(4) As implied in (1), the NRC staff does not approve the Master Curve-based methodology proposed by the licensee. Rather, the NRC staff only approves the use of the Master Curve-based methodology documented in Appendix A to this SE for the evaluation of the integrity of the KNPP RPV circumferential weld. The methodology of Appendix A addresses all issues associated with the use of the PCVN fracture toughness (K_{JC}) data for this specific purpose, including adequate adjustments of surveillance data to RPV conditions (see Section 4.3.2), an acceptable margin value (see Section 4.3.3), and a treatment of potential non-conservative bias in PCVN test results (see Section 4.3.4). Improvements to this methodology may be incorporated, with NRC staff approval, based on acquisition of additional data to address the aforementioned issues. Aspects of this methodology may have generic implications for the application of fracture toughness test data to other facility's RPVs.

(5) The NRC staff accepts that, based on the currently available data, the appropriate values at projected EOL and EOLE conditions for the KNPP RPV circumferential weld to compare to the PTS screening criterion of 300 °F are 271 °F and 288 °F, respectively. Hence, relative to PTS concerns, continued operation of the KNPP RPV is justified though projected EOL conditions. It should be noted, however, that all of the aforementioned values must be recalculated when additional surveillance data or other information is acquired which could affect the conclusions of this SE.

(6) The revised cooldown P-T limit curves (Figure 2) submitted by the licensee based on their evaluation of the properties of the KNPP RPV circumferential weld are not approved. However, based on results from the NRC staff's Master Curve-based methodology, it appears that the validity of the current KNPP RPV cooldown P-T limit curves (Figure 1) can be extended from 28 to 33 EFPY if requested by the licensee.

6.0 REFERENCES

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2. American Society for Testing and Materials Standard E 1921-97, "Standard Test Method for the Determination of Reference Temperature, T_0, for Ferritic Steels in the Transition Range," December 10, 1997.

3. American Society for Mechanical Engineers Code Case N-629, "Use of Fracture Toughness Test Data to Establish Reference Temperature for Pressure Retaining Materials, Section XI, Division 1," approved May 4, 1999.

4. WCAP-14278, Revision 1, "Kewaunee Heatup and Cooldown Curves for Normal Operation," T. Laubham, C. Kim, September 1998, non-proprietary.

5. WCAP-14279, Revision 1, "Evaluation of Capsules from the Kewaunee and Capsule A-35 from the Maine Yankee Nuclear Plant Reactor Vessel Radiation Surveillance Programs," C. Kim, E. Terek, and S. Anderson, September 1998, non-proprietary.

6. WCAP-14280, Revision 1, "Evaluation of Pressurized Thermal Shock for the Kewaunee Reactor Vessel," E. Terek, R. Lott, and C. Kim, September 1998, non-proprietary.

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12. K. H. Weinhauer (WPSC) to U. S. Nuclear Regulatory Commission Document Control Desk, “Proposed Technical Specification Change Regarding Heatup and Cooldown Limit Curves and Request for Exemption to 10 CFR 50.60, 10 CFR 50.61, and Appendices G and H of Part 50,” September 26, 2000.

13. J. G. Lamb (USNRC) to M. Reddemann (NMC), “Kewaunee Nuclear Power Plant - Request for Exemption from the Requirements of 10 CFR 50, Appendices G and H, and 10 CFR 50.61 (TAC No. MA8585),” February 21, 2001.

14. K. A. Hoops (NMC) to U. S. Nuclear Regulatory Commission Document Control Desk, “Request for Exemption from the Requirements of 10 CFR Part 50, Appendices G and H, and 10 CFR 50.61(Master Curve),” March 12, 2001.

15. American Society for Testing and Materials Standard E 185, “Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels, E 706 (IF).”

16. M.L. Marchi (WPSC) to U. S. Nuclear Regulatory Commission Document Control Desk, ”Request for 10 CFR 50.60 Exemption - Use of ASME Code Cases N-514 & N-588,” August 6, 1998.

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Attachment: Appendix A

Principal Contributor: Matthew Mitchell

Date: May 1, 2001

Table 1 - Fracture Toughness Data Obtained from the Testing of Unirradiated KNPP and Maine Yankee Surveillance Weld Material

Specimen	K_{JC} (ksi√in)	$K_{JC(1T)}$ (ksi√in)
KNPP PCVN specimens tested at -200 °F		
WPS201	108.0	89.4
WPS202	61.8	52.8
WPS205	67.4	57.2
WPS206	61.3	52.3
WPS207	66.1	56.1
WPS208	79.5	66.8
WPS209	79.1	66.5
WPS210	81.1	68.0
Reconstituted KNPP PCVN specimens tested at -200 °F		
RKW1	91.0	75.9
RKW3	77.4	65.1
RKW6	59.1	50.5
RKW7	73.7	62.2
RKW8	91.0	75.9
RKW10	102.4	84.9
RKW11	61.7	52.7
KNPP 0.5T-CT specimens tested at -187 °F		
WPS101	86.2	75.4
WPS102	63.7	56.5
WPS103	85.5	74.8
WPS104	71.8	63.3
WPS105	72.3	63.7
WPS106	48.6	43.8
WPS107	67.4	59.6
Maine Yankee PCVN specimens tested at -200 °F		
CO4-4	62.0	52.9
CO4-5	67.2	57.0
CO4-2	88.0	73.5
CO4-7	88.4	73.7
CO4-8	90.4	75.4
CO4-3	94.5	78.7
CO4-6	95.5	79.4

Table 2 - Fracture Toughness Data Obtained from the Testing of Irradiated KNPP Surveillance Weld Material from KNPP Surveillance Capsule S

Specimen	K_{JC} (ksi√in)	$K_{JC(1T)}$ (ksi√in)
Reconstituted KNPP PCVN specimens tested at 136 °F		
W24	97.9	81.3
W19	68.1	57.7
H17	131.7	108.1
H18	119.3	98.3
W23	124.4	102.3
H20	144.4*	114.8
H19	78.0	65.6
W17	100.6	83.5
H21	103.8	86.1
Reconstituted KNPP PCVN specimens tested at 59 °F		
W21	53.3	46.4
W20	59.2	51.0
W22	64.5	55.2
1X-WOL specimens tested at 136 °F		
W5	70.4	70.4
W6	55.9	55.9

* - Exceed the K_{JC} limit of ASTM E1921-97 and was censored accordingly.

Table 3 - Fracture Toughness Data Obtained from the Testing of Irradiated Maine Yankee Surveillance Weld Material from Maine Yankee Surveillance Capsule A-35

Specimen	K_{JC} (ksi√in)	$K_{JC(1T)}$ (ksi√in)
Reconstituted Maine Yankee PCVN specimens tested at 210 °F		
322	72.6	61.3
36a	54.7	47.1
313	95.3	79.3
37la	152.0*	124.2
33u	65.6	55.8
375	78.4	65.9
37lb	76.0	64.0
37ua	100.8	83.6
H21	103.8	86.1

* - Exceed the K_{JC} limit of ASTM E1921-97 and was censored accordingly.

Table 4 - T_0 Values Determined by the Licensee from Various Data Sets Given in Tables 1 through 3

Data Sets	$K_{JC(1T)median}$ (ksi$\sqrt{in}$)	Test Temp. (°F)	T_0 (°F) per ASTM E1921-97 (Single Temperature Methodology)	Combined T_0 Values Based on Multi-Temperature Methodology (°F)
KNPP Unirradiated 0.5T-CTs	62.6	-187	-129	-144
KNPP Unirradiated PCVNs	64.2	-200	-148	
KNPP Reconstituted Unirradiated PCVNs	66.6	-200	-154	
Maine Yankee Unirradiated PCVNs	68.3	-200	-158	-158
KNPP Surv. Capsule S Irradiated PCVNs	100.2	136	136	148*
Maine Yankee Surv. Capsule A-35 Irradiated PCVNs	77.2	210	223**	223**

* This value includes the data from the testing of 1X-WOL specimens at 136 °F.

** This corrected value was provided in the licensee letter dated September 26, 2000.[12] The original value cited by the licensee, and incorporated into the discussion in Section 3.0, was 232 °F.

Table 5 - Chemical Compositions and Chemistry Factors for the KNPP Surveillance Weld, the Maine Yankee Surveillance Weld, and the KNPP RPV Circumferential Weld

Material	Copper Content	Nickel Content	CF from RG 1.99 Rev. 2 Tables (°F)	CF based on Licensee Interpretation of Fracture Toughness Data (°F)
KNPP Surveillance Weld	0.219	0.724	187.2	222
Maine Yankee Surveillance Weld	0.351	0.771	237.2	271
KNPP RPV Circumferential Weld	0.287	0.756	214.0	248

Table 6 - Fluences and Fluence Factors for Specific Surveillance Capsule and RPV Circumferential Weld Locations and Conditions

Item	Operating Time	Through-Wall Location	Effective Fluence Accepted by NRC Staff (in n/cm^2, E > 1.0 MeV)	Fluence Factor
KNPP Surveillance Capsule S	Not Applicable	Not Applicable	3.36×10^{19} *	1.32
Maine Yankee Surveillance Capsule A-35	Not Applicable	Not Applicable	6.11×10^{19} *	1.44
KNPP RPV Circumferential Weld	End of Licence (33 EFPY)	Clad-to-Base Metal Interface	3.34×10^{19} **	1.32
KNPP RPV Circumferential Weld	End of Licence (33 EFPY)	1/4T Depth	2.26×10^{19} **	1.22
KNPP RPV Circumferential Weld	End of Licence (33 EFPY)	3/4T Depth	1.04×10^{19} **	1.01
KNPP RPV Circumferential Weld	End of Extended Licence (51 EFPY)	Clad-to-Base Metal Interface	4.7×10^{19} ***	1.39

* Value from WCAP-14279, Revision 1 (Reference 5).
** Value from WCAP-14278, Revision 1 (Reference 4).
*** Value from the licensee letter dated February 4, 2000 (Reference 10).

Table 7 - Input Parameters Chosen for Two NRC Staff Monte Carlo Case Studies to Assess Margin Value to be Applied to the KNPP Evaluation

Case	Mean Copper Content	Mean Nickel Content	1σ Level Uncertainty in Copper	1σ Level Uncertainty in Nickel	Fluence Distribution
1	0.287	0.756	0.072	0.042	4.7×10^{19} ± 20 percent
2	0.287	0.756	0.05	0.042	4.7×10^{19} ± 20 percent

Table 8 - Results of NRC Staff Monte Carlo-based Analysis of the Variability in Unirradiated T_0 for Combustion Engineering RPV Weld Wire Heats

Combustion Engineering Weld Wire Heat/Heats	Weld Flux	1σ Uncertainty in Unirradiated T_0 from Monte Carlo Simulation (in °F)
20291/12008 **	Linde 1092	14.0
1P3571*	Linde 1092	10.8
87986	Linde 0124	9.6
87984	Linde 0124	13.2
33A277	Linde 0091	13.3

* Weld wire heat found in the KNPP RPV Circumferential weld.
** Limiting weld wire heat on which the NRC staff's uncertainty in T_0 for the KNPP evaluation is based.

Table 9 - Constraint Parameter M_0 and Bias Value Associated with Relevant KNPP and Maine Yankee Surveillance Weld PCVN Data Sets

Data Set	Constraint Parameter M_0	Bias Value Assumed in NRC Staff Evaluation (in °F)
Unirradiated KNPP Surveillance Weld PCVNs	121	8.5
Unirradiated Maine Yankee Surveillance Weld PCVNs	111	8.5
KNPP Capsule S Irradiated Surveillance Weld PCVNs	61	8.5
Maine Yankee Capsule A-35 Irradiated Surveillance Weld PCVNs	81	8.5

Table 10 - Comparison of Implicit and Explicit Components Used to Determine ART Values for the KNPP RPV Circumferential Weld at the Clad-to-Base Metal Interface Via the NRC and the Licensee Methodologies

	At EOL Conditions		At EOLE Conditions[9]	
	NRC	Licensee	NRC	Licensee
T_0[1]	167 °F[2]	183 °F[3]	184 °F[2]	190 °F[4]
RT_{T0}	T_0 + 33 °F[5]	T_0 + 35 °F[6]	T_0 + 33 °F	T_0 + 35 °F
Explicit Margin	62.5 °F	16 °F	62.5 °F	24 °F
PCVN Bias	8.5 °F[7]	0 °F[8]	8.5 °F	0 °F
ART_{T0}	271 °F	234 °F	288 °F	249 °F

[1] "T_0" in this table refers to the estimated value of T_0 for the RPV weld at the specified condition after all chemistry and fluence adjustments were made to the data sets of interest.

[2] Although this value is not explicitly calculated in the NRC methodology, it represents the "average" T_0 which would be calculated from the KNPP and Maine Yankee PCVN data using the NRC methodology.

[3] Value based on all KNPP surveillance weld fracture toughness data alone.

[4] Value based on all Maine Yankee surveillance weld fracture toughness data alone.

[5] Based on ASME Code Case N-629 definition of RT_{T0} with 2 °F of implicit margin removed.

[6] The licensee claims that this relationship contains 18 °F of implicit margin relative to the current impact test-based approach.

[7] As with note [1], "average" bias adjustment applied to the KNPP and Maine Yankee surveillance data.

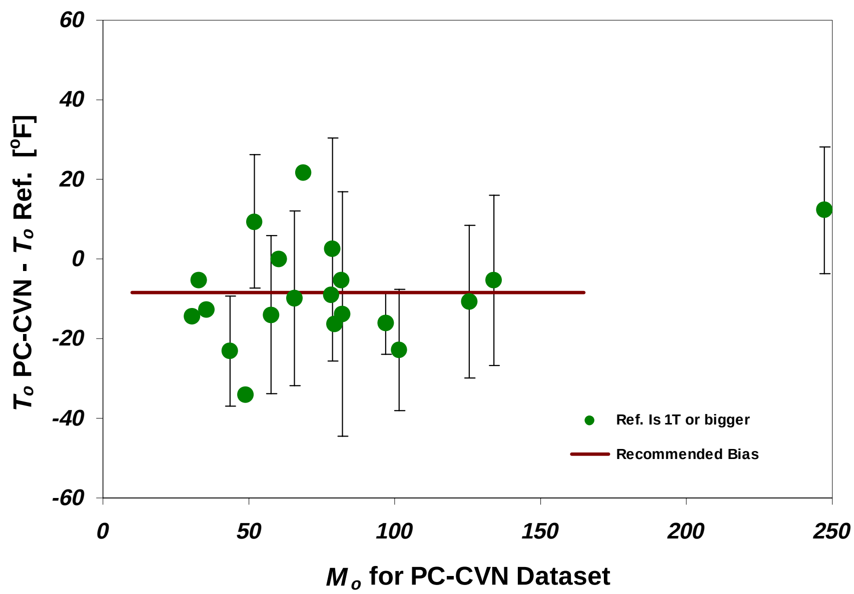
[8] The licensee claimed that no bias term was required for their methodology, but noted that a 4 °F bias term might be necessary for the NRC methodology which is based on only the available PCVN fracture toughness test data.

[9] The EOLE fluence chosen by the licensee was 5.1 x 10^{19} n/cm^2 based on assuming a conservative future capacity factor of 97 percent. The EOLE fluence chosen by the NRC was 4.7 x 10^{19} n/cm^2 based on a 85 percent future capacity factor.

Table 11 - NRC Staff Best-Estimate Values for KNPP RPV Circumferential Weld Integrity Evaluation Indexing Parameters

Parameter	Application	NRC Staff Value
$ART_{T0\text{-}EOL\text{-}1/4T}$	P-T Limit Determination	247 °F
$ART_{T0\text{-}EOL\text{-}3/4T}$	P-T Limit Determination	196 °F
$ART_{T0\text{-}EOL\text{-}ID}$	PTS Evaluation at EOL	271 °F
$ART_{T0\text{-}EOLE\text{-}ID}$	PTS Evaluation at EOLE	288 °F

Figure 3 - Plot of Available Data Sets Containing Both PCVN and 1T-CT or Larger Data to Estimate the Bias in PCVN T_0 Results as a (Potential) Function of the Constraint Parameter, M_0 for the PCVN data set.



APPENDIX A

NRC Staff-Approved Methodology for the Application of PCVN Fracture Toughness Data for the Evaluation of the KNPP RPV Circumferential Weld

The methodology of this Appendix applies the fundamental data and calculational relationships given above for the purpose of KNPP RPV integrity evaluations. To do so, an index parameter relevant to the integrity evaluation being performed must be specified (for example, in a pressure-temperature limit evaluation, the material reference temperature at the 1/4T depth at EOL, $ART_{T0(EOL\ 1/4T)}$). Two estimates of the index parameter are then determined. The first estimate (from Calculation #1) is based on the data acquired from the testing of Maine Yankee Surveillance Capsule A-35 material. The second estimate (from Calculation #2) is based on the data acquired from the testing of KNPP Surveillance Capsule S material. These two estimates are then averaged to provide the best-estimate of the index parameter. In the methodology which follows, a generic "index parameter" is defined, $ART_{T0\text{-}X\text{-}Y,}$ corresponding to a generic condition of interest at "operating time X" and KNPP RPV circumferential weld "through-wall location Y."

When additional, irradiated fracture toughness data is obtained as part of the KNPP surveillance program, an additional entry must be made under the "Fundamental Data" heading similar to those in items (1) and (2) below. This data will provide the basis from obtaining a third estimate of any relevant index parameter, and all three estimates will be averaged to provide the best-estimate of the index parameter.

Fundamental Data

(1) Maine Yankee Surveillance Capsule A-35, PCVN Surveillance Weld Samples

Unirradiated T_0 = -158 °F

Fluence = 6.11 x 10^{19} n/cm^2 (which corresponds to a $FF_{MY\text{-}A35}$ = 1.44 from RG 1.99, Rev. 2)

Irradiated T_0 = $T_{0\text{-}MY\text{-}A35}$ = 223 °F

$\Delta T_{0\text{-}MY\text{-}A35}$ = (223 °F - (-158 °F)) = 381 °F

$CF_{MY\text{-}A35}$ = 237.2 °F (0.351 % Cu, 0.771 % Ni, based on RG 1.99, Rev. 2 Tables)

$t_{irr\text{-}MY\text{-}A35}$ = The irradiation temperature of Maine Yankee Surveillance Capsule A-35 = 532 °F

$B_{PCVN\text{-}MY\text{-}U}$ = bias associated with unirradiated Maine Yankee surv. weld PCVN data = 8.5 °F

$B_{PCVN\text{-}MY\text{-}A35}$ = bias associated with irradiated Maine Yankee Surv. Capsule A-35 PCVN data = 8.5 °F

Fundamental Data (Continued)

(2) KNPP Surveillance Capsule S, PCVN Surveillance Weld Samples

Unirradiated T_0 = -151 °F (average of -154 and -148 from whole and reconstituted PCVNs)

Fluence = 3.36 x 10^{19} n/cm^2 (which corresponds to a $FF_{K\text{-}S}$ = 1.32)

Irradiated T_0 = $T_{0\text{-}K\text{-}S}$ = 136 °F

$\Delta T_{0\text{-}K\text{-}S}$ = (136 °F - (-151 °F)) = 287 °F

$CF_{K\text{-}S}$ = 187.2 °F (0.219 % Cu, 0.724 % Ni, based on RG 1.99, Rev. 2 Tables)

$t_{irr\text{-}K\text{-}S}$ = The irradiation temperature of KNPP Surveillance Capsule S = 532 °F

$B_{PCVN\text{-}K\text{-}U}$ = bias associated with unirradiated KNPP surveillance weld PCVN data = 8.5 °F

$B_{PCVN\text{-}K\text{-}S}$ = bias associated with irradiated KNPP Surveillance Capsule S PCVN data = 8.5 °F

(3) KNPP RPV Circumferential Weld

EOL Clad-to-Base Metal Interface Fluence = 3.34 x 10^{19} n/cm^2 (which corresponds to a FF = 1.32)

EOL 1/4T Depth Effective Fluence = 2.26 x 10^{19} n/cm^2 (which corresponds to a FF = 1.22)

EOL 3/4T Depth Effective Fluence = 1.04 x 10^{19} n/cm^2 (which corresponds to a FF = 1.01)

EOLE Clad-to-Base Metal Interface Fluence = 4.7 x 10^{19} n/cm^2 (which corresponds to a FF = 1.39)

CF_{RPV} = 214.0 °F (0.287 % Cu, 0.756 % Ni, based on RG 1.99, Rev. 2)

$t_{irr\text{-}RPV}$ = The irradiation temperature of the KNPP RPV = 532 °F

Fundamental Calculational Relationships

$RT_{T0} = T_0 + 33\ ^\circ F$ (with 2 °F implicit margin already removed to reduce the 35 °F adder of ASME Code Case N-629 to 33 °F)

$$\text{Margin} = M = 2\sqrt{(\sigma_{IT0}^2 + \sigma_{\Delta T0}^2)} = 2\sqrt{(14^2 + 28^2)} = 62.5\ ^\circ F$$

$$T_{0\text{-RPV-SURV CAPSULE}} = T_{0\text{-SURV CAPSULE}} - (\Delta T_{0\text{-SURV CAPSULE}} - \Delta T_{0\text{-RPV-SURV CAPSULE}})$$

$T_{0\text{-RPV-SURV CAPSULE}}$ = the T_0 estimate for the RPV material based on data from a particular surveillance capsule

$T_{0\text{-SURV CAPSULE}}$ = the T_0 value obtained from the testing of material from a particular surveillance capsule

$\Delta T_{0\text{-SURV CAPSULE}}$ = the shift in T_0 observed by comparing the results of testing performed on unirradiated material and material from a particular surveillance capsule

$\Delta T_{0\text{-RPV-SURV CAPSULE}}$ = the estimated shift in T_0 for the RPV material based on comparing the results of testing performed on unirradiated material and material from a particular surveillance capsule, and adjusting for fluence and chemistry differences

$$ART_{T0\text{-RPV-SURV CAPSULE}} = T_{0\text{-RPV-SURV CAPSULE}} + 33\ ^\circ F + M + B_{PCVN\text{-MY-A35-U}}$$

$ART_{T0\text{-RPV-SURV CAPSULE}}$ = the adjusted reference temperature for the RPV material based on data from a particular surveillance capsule

$B_{PCVN\text{-RPV-SURV CAPSULE}}$ = the PCVN bias term to be applied as part of the RPV evaluation based on the use of PCVN data from a particular surveillance capsule

$$\text{Best Estimate } ART_{T0\text{-RPV}} = \sum_{i=1}^{n} (ART_{T0\text{-RPV-SURV CAPSULE } i}) / n$$

Calculation #1: Determination of Index Parameter $ART_{T0\text{-}X\text{-}Y}$ Estimate based on PCVN Data from Maine Yankee Surveillance Capsule A-35

To obtain an estimate of $ART_{T0\text{-}X\text{-}Y}$, a method is established for normalizing the Maine Yankee Surveillance Capsule A-35 PCVN data to the RPV fluence and best-estimate chemistry information at operating time “X” (usually EOL or EOLE) and through-wall location “Y” (usually the clad-to-base metal interface, 1/4T depth, or 3/4T depth). This first estimate of the parameter will be called $ART_{T0\text{-}X\text{-}Y\text{-}MY\text{-}A35}$.

All known relationships which could be used to perform this normalization are in terms of shift (i.e., RG 1.99, Rev. 2). Therefore, appropriate adjustments to calculate how much different the RPV material’s projected shift would be when compared the chemistry and fluence of the Maine Yankee Surveillance Capsule A-35 data are made and applied to the absolute T_0 value determined from the irradiated material testing.

Mathematically:

$$T_{0\text{-}X\text{-}Y\text{-}MY\text{-}A35} = T_{0\text{-}MY\text{-}A35} - (\Delta T_{0\text{-}MY\text{-}A35} - \Delta T_{0\text{-}X\text{-}Y\text{-}MY\text{-}A35})$$

where: $T_{0\text{-}X\text{-}Y\text{-}MY\text{-}A35}$ is the estimate of the KNPP RPV circumferential weld T_0 value at operating time X and through-wall location Y based on Maine Yankee Surveillance Capsule A-35 PCVN data

$T_{0\text{-}MY\text{-}A35}$ = 223 °F $\qquad$ $\Delta T_{0\text{-}MY\text{-}A35}$ = 381 °F

$\Delta T_{0\text{-}X\text{-}Y\text{-}MY\text{-}A35}$ is the projected shift in T_0 for the KNPP RPV circumferential weld at operating time X and through-wall location Y based on the shift in T_0 observed for the Maine Yankee Surveillance Capsule A-35 data and correcting for fluence and chemistry differences

$\Delta T_{0\text{-}X\text{-}Y\text{-}MY\text{-}A35}$ is given by:

$$\Delta T_{0\text{-}X\text{-}Y\text{-}MY\text{-}A35} = [\Delta T_{0\text{-}MY\text{-}A35} - (t_{irr\text{-}RPV} - t_{irr\text{-}MY\text{-}A35})] * [(FF_{X\text{-}Y} / FF_{MY\text{-}A35}) * (CF_{RPV} / CF_{MY\text{-}A35})]$$

where: $(FF_{X\text{-}Y} / FF_{MY\text{-}A35})$ corrects the Maine Yankee Surveillance Capsule A-35 data to the RPV circumferential weld fluence at operating time X and through-wall location Y.

$(CF_{RPV} / CF_{MY\text{-}A35})$ corrects the Maine Yankee surveillance weld chemistry to the RPV circumferential weld best-estimate chemistry.

$(t_{irr\text{-}RPV} - t_{irr\text{-}MY})$ would, if necessary, correct the irradiation temperature of Maine Yankee Surveillance Capsule A-35 to the irradiation temperature of the KNPP RPV. Since the irradiation temperatures are the same, this term is zero.

From the above, $T_{0\text{-}X\text{-}Y\text{-}MY\text{-}A35}$ has been determined. $ART_{T0\text{-}X\text{-}Y\text{-}MY\text{-}A35}$ is then given by:

$$ART_{T0\text{-}X\text{-}Y\text{-}MY\text{-}A35} = T_{0\text{-}X\text{-}Y\text{-}MY\text{-}A35} + 33\ °F + M + B_{PCVN\text{-}MY\text{-}A35\text{-}U} = T_{0\text{-}X\text{-}Y\text{-}MY\text{-}A35} + 95.5\ °F + B_{PCVN\text{-}MY\text{-}A35\text{-}U}$$

where $B_{PCVN\text{-}MY\text{-}A35\text{-}U}$ is the bias associated with using the PCVN fracture toughness data from Maine Yankee Surveillance Capsule A-35 and the unirradiated PCVN fracture toughness data from the Maine Yankee surveillance weld. $B_{PCVN\text{-}MY\text{-}A35\text{-}U}$ is given by:

$$B_{PCVN\text{-}MY\text{-}A35\text{-}U} = B_{PCVN\text{-}MY\text{-}U} + [(FF_{X\text{-}Y} / FF_{MY\text{-}A35}) * (CF_{RPV} / CF_{MY\text{-}A35}) * (B_{PCVN\text{-}MY\text{-}A35} - B_{PCVN\text{-}MY\text{-}U})]$$

Calculation #2: Determination of Index Parameter $ART_{T0\text{-}X\text{-}Y}$ Estimate based on PCVN Data from KNPP Surveillance Capsule S

To obtain an estimate of $ART_{T0\text{-}X\text{-}Y}$, a method is established for normalizing the KNPP Surveillance Capsule S PCVN data to the RPV fluence and best-estimate chemistry information at operating time "X" (usually EOL or EOLE) and through-wall location "Y" (usually the clad-to-base metal interface, 1/4T depth, or 3/4T depth). This second estimate of the parameter will be called $ART_{T0\text{-}X\text{-}Y\text{-}K\text{-}S}$.

All known relationships which could be used to perform this normalization are in terms of shift (i.e., RG 1.99, Rev. 2). Therefore, appropriate adjustments to calculate how much different the RPV material's projected shift would be when compared the chemistry and fluence of the KNPP Surveillance Capsule S data are made and applied to the absolute T_0 value determined from the irradiated material testing.

Mathematically:

$$T_{0\text{-}X\text{-}Y\text{-}K\text{-}S} = T_{0\text{-}K\text{-}S} - (\Delta T_{0\text{-}K\text{-}S} - \Delta T_{0\text{-}X\text{-}Y\text{-}K\text{-}S})$$

where: $T_{0\text{-}X\text{-}Y\text{-}K\text{-}S}$ is the estimate of the KNPP RPV circumferential weld T_0 value at operating time X and through-wall location Y based on KNPP Surveillance Capsule S PCVN data.

$T_{0\text{-}K\text{-}S} = 136\ ^\circ F$ $\Delta T_{0\text{-}K\text{-}S} = 287\ ^\circ F$

$\Delta T_{0\text{-}X\text{-}Y\text{-}K\text{-}S}$ is the projected shift in T_0 for the KNPP RPV circumferential weld at operating time X and through-wall location Y based on the shift in T_0 observed for the KNPP Surveillance Capsule S data and correcting for fluence and chemistry differences.

$\Delta T_{0\text{-}X\text{-}Y\text{-}K\text{-}S}$ is given by:

$$\Delta T_{0\text{-}X\text{-}Y\text{-}K\text{-}S} = [\Delta T_{0\text{-}K\text{-}S} - (t_{irr\text{-}RPV} - t_{irr\text{-}K\text{-}S})] * [(FF_{X\text{-}Y} / FF_{K\text{-}S}) * (CF_{RPV} / CF_{K\text{-}S})]$$

where: $(FF_{X\text{-}Y} / FF_{K\text{-}S})$ corrects the KNPP Surveillance Capsule S data to the RPV circumferential weld fluence at operating time X and through-wall location Y.

$(CF_{RPV} / CF_{K\text{-}S})$ corrects the KNPP surveillance weld chemistry to the RPV circumferential weld best-estimate chemistry.

$(t_{irr\text{-}RPV} - t_{irr\text{-}K\text{-}S})$ would, if necessary, correct the irradiation temperature of KNPP Surveillance Capsule S to the irradiation temperature of the KNPP RPV. Since the irradiation temperatures are the same, this term is zero.

From the above, $T_{0\text{-}X\text{-}Y\text{-}K\text{-}S}$ has been determined. $ART_{T0\text{-}X\text{-}Y\text{-}K\text{-}S}$ is then given by:

$$ART_{T0\text{-}X\text{-}Y\text{-}K\text{-}S} = T_{0\text{-}X\text{-}Y\text{-}K\text{-}S} + 33\ ^\circ F + M + B_{PCVN\text{-}K\text{-}S\text{-}U} = T_{0\text{-}X\text{-}Y\text{-}K\text{-}S} + 95.5\ ^\circ F + B_{PCVN\text{-}K\text{-}S\text{-}U}$$

where $B_{PCVN\text{-}K\text{-}S\text{-}U}$ is the bias associated with using the PCVN fracture toughness data from Maine Yankee Surveillance Capsule A-35 and the unirradiated PCVN fracture toughness data from the Maine Yankee surveillance weld. $B_{PCVN\text{-}K\text{-}S\text{-}U}$ is given by:

$$B_{PCVN\text{-}K\text{-}S\text{-}U} = B_{PCVN\text{-}K\text{-}U} + [(FF_{X\text{-}Y} / FF_{K\text{-}S}) * (CF_{RPV} / CF_{K\text{-}S}) * (B_{PCVN\text{-}K\text{-}S} - B_{PCVN\text{-}K\text{-}U})]$$

Calculation #3: Determination of Best-Estimate Value for $ART_{T0\text{-}X\text{-}Y}$

Having determined two estimates of $ART_{T0\text{-}X\text{-}Y}$ from Calculations #1 and #2, these estimates can the be used to develop a final best-estimate value as follows:

$$ART_{To\text{-}X\text{-}Y} = (ART_{T0\text{-}X\text{-}Y\text{-}MY\text{-}A35} + ART_{T0\text{-}X\text{-}Y\text{-}K\text{-}S}) \; / \; 2$$

$ART_{T0\text{-}X\text{-}Y}$ may then be used as the appropriate materials property parameter for PTS or P-T limits evaluations, as applicable.