PRESSURIZED WATER REACTOR OWNERS GROUP

PWROG-17090-NP-A
Revision 0

WESTINGHOUSE NON-PROPRIETARY CLASS 3

# Generic Rotterdam Forging and Weld Initial Upper-Shelf Energy Determination

**Materials Committee**

**PA-MSC-1367, Task 3**

**January 2020**

Westinghouse

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# Generic Rotterdam Forging and Weld Initial Upper-Shelf Energy Determination

# PA-MSC-1367, Task 3

**D. Brett Lynch***
RV/CV Design & Analysis

**January 2020**

Reviewer: Benjamin E. Mays*
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*Electronically approved records are authenticated in the electronic document management system

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

December 12, 2019

Mr. W. Anthony Nowinowski,
Executive Director
PWR Owners Group,
Program Management Office
Westinghouse Electric Company
1000 Westinghouse Drive, Suite 380
Cranberry Township, PA 16066

SUBJECT: FINAL SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION FOR THE PRESSURIZED WATER REACTOR OWNERS GROUP TOPICAL REPORT PWROG-17090-NP, REVISION 0, "GENERIC ROTTERDAM FORGING AND WELD INITIAL UPPER-SHELF ENERGY DETERMINATION" (EPID L-2018-TOP-0017)

Dear Mr. Nowinowski:

By letter dated April 6, 2018 (Agencywide Documents Access and Management System (ADAMS) Package Accession No. ML18114A173), the Pressurized Water Reactor Owners Group (PWROG) submitted Topical Report (TR) PWROG-17090-NP, Revision (Rev.) 0, "Generic Rotterdam Forging and Weld Initial Upper-Shelf Energy Determination" (ADAMS No. ML18114A183) for the U.S. Nuclear Regulatory Commission (NRC) review and approval. Additional information related to PWROG-17090-NP, Rev. 0 was submitted by letter dated June 12, 2019 (ADAMS No. ML19170A06), in response to a request for additional information (RAI) from the NRC staff. By letter dated October 7, 2019 (ADAMS No. ML19284A400), the PWROG submitted comments to the draft Safety Evaluation (SE) and requested that the NRC prepare the final SE for PWROG-17090-NP against Rev. 0.

The NRC staff has reviewed the TR and its supplemental information, and based on the evaluation in Section 4.0 of the enclosed SE, finds that the TR, as modified by the SE, provides conservative estimates of generic values of the unirradiated Charpy Upper-Shelf Energy (USE) for American Society of Mechanical Engineers (ASME) SA508, Class 2 (or the corresponding American Society for Testing and Materials (ASTM) A508, Class 2) reactor vessel (RV) forgings that were fabricated by the Rotterdam Dockyard Company (Rotterdam); and generic values of unirradiated Charpy USE, weight percentage copper (Cu) content, and weight percentage nickel (Ni) content for RV Submerged Arc Welds (SAWs) and Shielded Metal Arc Welds (SMAWs) based on the material classes specified in the TR.

As stated in PWROG's submittal letter dated April 6, 2018, licensees will reference the PWROG-17090-NP, Rev. 0 TR as the basis for the generic USE, Cu content, and Ni content values to demonstrate compliance with Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, Appendix G requirements for extended operating license terms when plant-specific RV material information is not available, or incomplete. This TR is for implementation by all U.S. PWRs with RVs fabricated by Rotterdam in the late 1960's and early 1970's timeframe. Applicants who utilize the TR will be required to adhere to the conditions that the NRC staff

W. Nowinowski - 2 -

impose in the SE and shall be subject to NRC staff review and approval on a case-by-case basis.

By letter dated September 11, 2019 (ADAMS No. ML1922A259), the NRC staff provided the draft SE to the PWROG for review and comment. By letter dated October 7, 2019 (ADAMS No. ML19284A400), the PWROG provided comments on the draft SE. The NRC staff's disposition table for the draft SE comments is in the SE.

In accordance with the guidance provided on the NRC website, the NRC staff requests that the PWROG publish approved versions of PWROG-17090-NP, Revision 0 within 3 months of receipt of this letter. The approved version shall incorporate this letter and the enclosed final SE after the title page. Also, the approved versions must contain historical review information, including NRC requests for additional information (RAIs) and the corresponding RAI responses. The approved versions shall include an "-A" (designating approved) following the TR identification symbol. As an alternative to including the request for RAIs and RAI responses behind the title page, if changes to the TR were provided to the NRC staff to support the resolution of RAI responses, and if the NRC staff reviewed and approved those changes as described in the RAI responses, there are two ways that the accepted version can capture the RAIs:

1. The RAIs and RAI responses can be included as an Appendix to the accepted version
2. The RAIs and RAI responses can be captured in the form of a table (inserted after the final SE) which summarizes the changes as shown in the approved version of the TR. The table should reference the specific RAIs and RAI responses which resulted in any changes, as shown in the accepted version of the TR

If future changes to the NRC's regulatory requirements affect the acceptability of these TRs, PWROG will be expected to revise the TRs appropriately or justify their continued applicability for subsequent referencing. Licensees referencing these TRs would be expected to justify their continued applicability or evaluate their plant using the revised TRs.

If you have any questions, please contact Leslie Fields at 301-415-1186.

Sincerely,

Dennis C. Morey, Chief
Licensing Processes Branch
Division of Operating Reactor Licensing
Office of Nuclear Reactor Regulation

Docket No. 99902037

Enclosure:
Final SE (Non-proprietary)

## 2.0 BACKGROUND AND REGULATORY EVALUATION

*Background – Generic RV Properties, Application to RV Fracture Toughness Evaluations*

Terms such as "generic values," "generic data," or "best estimate values," etc. are often used in industry reports and in NRC staff publications for addressing certain RV material properties that are based on statistical evaluation of a set of original fabrication data for a "class" of RV material[2]. Data sets such as those provided in the TR are developed from available RV fabrication records for multiple plants and are often applicable to certain plant and/or RV material categories. When used in licensing applications for meeting regulatory requirements discussed below, generic RV material properties are subject to review and approval by the NRC staff.

When approved by the NRC staff, generic RV material properties may be implemented in plant-specific licensing applications to demonstrate compliance with the requirements of 10 CFR Part 50, Appendix G, "Fracture Toughness Requirements." For PWR plants, generic RV material properties may also be implemented in applications for addressing the requirements of 10 CFR 50.61, "Fracture toughness requirements for protection against pressurized thermal shock events," or the requirements of 10 CFR 50.61a, "Alternate fracture toughness requirements for protection against pressurized thermal shock events," as appropriate. In applications for License Renewal (LR) and Subsequent License Renewal (SLR) under 10 CFR Part 54, generic properties may be used in RV neutron embrittlement evaluations to meet the technical information requirements for TLAAs, as set forth in 10 CFR 54.21(c)(1). TLAA evaluations related to RV neutron embrittlement, pursuant to 10 CFR 54.21(c)(1), rely upon demonstrations that the above 10 CFR Part 50 fracture toughness requirements are satisfied (or will be satisfied) for proposed extended license terms. It should be noted that while generic properties are used as inputs into time-dependent neutron embrittlement analyses, the properties themselves are fixed based on the evaluation of available RV fabrication data for the preservice (unirradiated) condition, and once approved they become incorporated into a plant's licensing basis documentation[3].

*Fracture Toughness Requirements and Guidance – Ferritic RCPB and RV Beltline Materials*

Pursuant to Section IV.A of 10 CFR Part 50, Appendix G, pressure-retaining components of the reactor coolant pressure boundary (RCPB) that are made of ferritic materials must meet the requirements of the ASME Boiler and Pressure Vessel Code (Code), Section III, as supplemented by the additional requirements set forth in paragraph IV.A.1, "Reactor Vessel Charpy Upper-Shelf Energy Requirements," and paragraph IV.A.2, "Pressure-Temperature

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[2] For generic values of the initial (unirradiated) reference temperature ($RT_{NDT}$), 10 CFR 50.61, 50.61a; and NRC Regulatory Guide 1.99, Revision 2, state that the "class" of material is generally determined for welds by the type of welding flux (e.g., Linde 80 or other), and for base metal by the material specification The material specification is generally the ASTM or ASME standard specification (e.g., ASME Section II, SA508, Class 2 or other).

[3] NRC Branch Technical Position 5-3, Position 1.3, "Reporting Requirements," states "Fracture toughness information identified by the ASME Code and by Appendix G, 10 CFR Part 50, should be reported in the final safety analysis report (FSAR) to provide a basis for evaluating the adequacy of the operating limitations given in the [technical specifications] or [pressure-temperature limits report]."

Limits and Minimum Temperature Requirements," of the Rule. With respect to Charpy USE requirements, paragraph IV.A.1.a of 10 CFR Part 50 Appendix G states:

> *Reactor vessel beltline materials must have Charpy upper-shelf energy[1] in the transverse direction [i.e., weak direction] for base metal and along the weld for weld material according to the ASME Code [Section III], of no less than 75 ft-lbs. (102 J) initially and must maintain Charpy upper-shelf energy throughout the life of the vessel of no less than 50 ft-lbs., unless it is demonstrated in a manner approved by the Director, [NRR] or Director, [NRO], as appropriate, that lower values of Charpy upper-shelf energy will provide margins of safety against fracture equivalent to those required by Appendix G of Section XI of the ASME Code.*

Note 1 of this paragraph states that Charpy USE is defined in ASTM Standard E185-82, "Standard Practice for Conducting Surveillance Tests for Light Water Cooled Nuclear Power Reactor Vessels" (Ref. 3) which is incorporated by reference in 10 CFR Part 50, Appendix H. Section 4 of ASTM E185-82 provides the following definitions that are applicable to the determination of Charpy USE based on actual Charpy V-Notch Impact Tests (also referred to in this SE as "measured" values of Charpy USE).

- Paragraph 4.17 defines the "*Charpy transition curve*" as a graphic presentation of Charpy data, including absorbed energy, lateral expansion, and fracture appearance, extending over a range including the lower shelf energy (less than (<) 5 percent shear), the transition region, and the upper-shelf energy (greater than (>) 95 percent shear).

- Paragraph 4.18 defines the "*upper shelf energy level*" as the average energy value for all Charpy specimens (normally three) whose test temperature is above the upper end of the transition region. For specimens tested in sets of three at each test temperature, the set having the highest average may be regarded as defining the upper-shelf energy.

Section IV.A of 10 CFR Part 50, Appendix G states that for ferritic materials that are part of the RV "*Beltline Region*," as defined[4] in Section II of the Rule, the values of the reference temperature ($RT_{NDT}$, also defined in Section II of the Rule) and Charpy USE must account for the effects of neutron radiation, including the results of the RV surveillance program required by 10 CFR Part 50, Appendix H. For protection of PWR RVs against pressurized thermal shock (PTS) events, 10 CFR 50.61 also requires that the $RT_{NDT}$ for RV beltline materials account for the effects of neutron radiation. The regulation at 10 CFR 50.61 defines $RT_{PTS}$ as the $RT_{NDT}$ evaluated for the "EOL Fluence" for each of the RV beltline materials, using the procedures in 10 CFR 50.61(c). The regulation of 10 CFR 50.61 defines EOL Fluence as the best-estimate neutron fluence projected for a specific RV beltline material at the clad-base-metal interface at the location where the material receives the highest fluence on the expiration date of the operating license. For PWR plants implementing the alternate PTS protection requirements of 10 CFR 50.61a, 10 CFR 50.61a(c)(1) requires that each licensee shall have projected values of $RT_{MAX-X}$, as defined in 10 CFR 50.61a(a)(6), for each RV beltline material for the EOL fluence of the material.

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[4] Section II of 10 CFR Part 50, Appendix G defines the RV beltline as the region of the RV (including welds, heat affected zones, and plates or forgings) that directly surrounds the effective height of the active core and adjacent regions of the RV that are predicted to experience sufficient neutron radiation damage to be considered in the selection of the most limiting material with regard to radiation damage.

The NRC Regulatory Issue Summary (RIS) 2014-11 (Ref. 4) identifies that the beltline definition in 10 CFR Part 50, Appendix G is applicable to all RV ferritic materials with projected neutron fluence values greater than 1.0 x $10^{17}$ n/cm$^2$ (E > 1.0 MeV), and this fluence threshold remains applicable throughout the licensed operating period. Accordingly, RIS 2014-11 states that the effects of neutron radiation must be considered for any RV locations that are predicted to experience a neutron fluence exposure greater than 1.0 x $10^{17}$ n/cm$^2$ (E > 1.0 MeV) at the end of the licensed operating period; this includes periods of extended operation for LR and SLR.

In order to account for the effects of neutron embrittlement on RV beltline materials, Regulatory Guide (RG) 1.99, Rev. 2 (Ref. 5) specifies methods for calculating projected values of Charpy USE and adjusted $RT_{NDT}$ due to neutron fluence exposure. Procedures for calculating $RT_{PTS}$ are specified directly in 10 CFR 50.61(c); and procedures for calculating $RT_{MAX-X}$ are specified in paragraphs (f) and (g) of 10 CFR 50.61a. For RV beltline materials that are not represented in the RV surveillance program, RG 1.99, Rev. 2 provides methods for direct calculation of projected values of Charpy USE and adjusted $RT_{NDT}$ based on the weight percentage Cu and Ni content and projected neutron fluence exposure of the RV beltline materials. The regulation at 10 CFR 50.61 specifies methods for direct calculation of $RT_{PTS}$ based on weight percentage Cu and Ni content and EOL fluence. Per RG 1.99, Rev. 2, only the Cu content is needed to determine the projected percentage decrease in USE as a function of projected neutron fluence per Figure 2 of the RG. Per RG 1.99, Rev. 2 and 10 CFR 50.61, both Cu and Ni content are needed in order to determine the chemistry factor (CF) for the material using CF Tables provided therein. For RV beltline materials, the product of the CF and the neutron fluence factor (FF) determines the projected mean value of the shift in $RT_{NDT}$ ($\Delta RT_{NDT}$). These procedures specify that the projected value of the adjusted $RT_{NDT}$ (or $RT_{PTS}$ under 10 CFR 50.61) is equal to the sum of the values of unirradiated (initial) $RT_{NDT}$, $\Delta RT_{NDT}$, and a margin term (M). For PWR plants implementing the alternate PTS protection requirements of 10 CFR 50.61a, calculation procedures in Paragraphs (g) and (f) of this Rule specify more detailed inputs and equations for calculating $RT_{MAX-X}$; these inputs include, among other things, Cu content, Ni content, phosphorus (P) content, manganese (Mn) content, and EOL neutron fluence.

If the RV beltline materials are represented in the RV surveillance program, RG 1.99, Rev. 2 and 10 CFR 50.61 specify methods for calculating projected USE, adjusted $RT_{NDT}$, and $RT_{PTS}$ that are based on measurements of percentage decrease in Charpy USE and $\Delta RT_{NDT}$ from Charpy impact tests of irradiated surveillance materials. For PWR plants implementing the alternate PTS protection requirements of 10 CFR 50.61a, paragraph (f)(6)(i) of this Rule specifies that the licensee shall evaluate the results from a plant-specific or integrated surveillance program if the surveillance data satisfy the criteria described in paragraphs (f)(6)(i)(A) and (f)(6)(i)(B) of this section.

*Requirements and Guidance, Preservice Fracture Toughness Tests, and Analysis of Test Data*

Pursuant to 10 CFR Part 50, Appendix G, Section III, "Fracture Toughness Tests," ferritic materials for pressure-retaining components of the RCPB must be tested in accordance with the ASME Code, Section III and, for RV beltline materials, the RV surveillance program test requirements of 10 CFR Part 50, Appendix H, in order to demonstrate compliance with the fracture toughness requirements in Section IV.A of the Rule. For an RV that was constructed to an Edition and Addenda of the ASME Code, Section III earlier than the Summer 1972 Addenda of the 1971 Edition, Section III of 10 CFR Part 50, Appendix G states the fracture toughness data and data analyses must be supplemented in a manner approved by the NRC to demonstrate equivalence with these fracture toughness requirements.

The NRC guidance in NUREG-0800, Branch Technical Position (BTP) 5-3 (Ref. 6), states that the preservice fracture toughness test requirements for plants with construction permits issued prior to August 15, 1973, may not comply with the later Codes and Regulations in all respects. Accordingly, Section B.1, "Preservice Fracture Toughness Test Requirements," of BTP 5-3 recommends that the preservice fracture toughness properties—specifically, unirradiated $RT_{NDT}$ and unirradiated Charpy USE—of the ferritic materials for these plants should be assessed by using the available test data to estimate the preservice fracture toughness properties in the same terms as the new requirements.

With respect to estimation of Charpy USE for the preservice (unirradiated) condition, Position 1.2 of BTP 5-3 specifies that if Charpy impact tests were only conducted on longitudinal specimens (i.e., Charpy V-Notch specimens oriented in the strong direction), the Charpy USE values should be reduced to 65 percent of the measured longitudinal values to estimate the transverse USE (i.e., USE for the weak direction).

For cases where there is insufficient test data in "*Certified Material Test Reports*" (CMTRs[5]) to establish measured values of these properties for a plant's own RV materials[6] using BTP 5-3 methods, the implementation of NRC-approved generic estimates based on generic data for a material "class" may be appropriate, especially for older plants. The regulations at 10 CFR 50.61, 10 CFR 50.61a, and RG 1.99, Rev. 2 have provisions that address the use of generic data to demonstrate compliance with these fracture toughness requirements. The staff's overview of criteria for use of generic data, as applied to the determination of generic values of unirradiated Charpy USE, Cu content, and Ni content, is provided below.

*Generic Values for Unirradiated Charpy USE, Cu Content, and Ni Content*

The NRC regulations and guidance in 10 CFR Part 50, Appendix G and RG 1.99, Rev. 2 do not provide explicit criteria regarding the implementation of generic unirradiated USE values for a "class" of material for the preservice condition. However, with respect to generic values of initial (unirradiated) $RT_{NDT}$ that are used for P-T limits and PTS evaluations, 10 CFR 50.61 and RG 1.99, Rev. 2 both state that if a measured value of initial $RT_{NDT}$ is not available, a generic mean value of initial $RT_{NDT}$ for the "class" of material (as specified above) may be used if there are sufficient test results to establish a mean and standard deviation ($\sigma$) for the class. Per RG 1.99, Rev. 2 and 10 CFR 50.61, the standard deviation on initial $RT_{NDT}$ is "$\sigma_I$" (referred to as "$\sigma_U$" in 10 CFR 50.61) and is incorporated into the calculation of the adjusted $RT_{NDT}$ (or $RT_{PTS}$) due to the effects of neutron embrittlement by using a margin term, "M." Equation (4) of the RG

[5] For later Editions and Addenda of the ASME Code, Section III, *Certified Material Test Reports*, as defined in NCA-9200 of ASME Section III, are required for Class 1 pressure-retaining materials, as specified in NB-2130. For impact testing of ferritic RPCB materials in accordance with NB-2300, the test results, test temperatures, specimen orientation and location, etc , as applicable, for all impact tests (Charpy V-Notch Tests and Drop Weight Tests) performed to meet the requirements of NB-2330 shall be reported in the CMTR, as specified in NB-2321 (later Editions and Addenda of ASME Section III).
[6] For the regulatory applications addressed herein, plant-specific RV materials are often identified using a specific component identifier and an identifier for the specific "heat" (stated tonnage of metal obtained from a period of continuous melting) of material used to fabricate the plant's RV weld, forging, or plate.

and Equation (2) of 10 CFR 50.61 specify the same expression for the margin term, which is shown below:

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

If only the preservice condition for the RV material is considered, the $\Delta RT_{NDT}$ term and the standard deviation on $\Delta RT_{NDT}$ ($\sigma_\Delta$) are eliminated, and the expression for the margin term on initial $RT_{NDT}$ reduces to twice the standard deviation on initial $RT_{NDT}$ ($2\sigma_I$). Thus, the generic value of initial $RT_{NDT}$ for the material class equals the mean value plus $2\sigma_I$. Equivalently, for determinations of a generic value of unirradiated Charpy USE, where only the standard deviation on the unirradiated property is considered, the appropriate value for a bounding statistical representation of the property for a class of material is the mean value minus two standard deviations (Mean – $2\sigma$), since lower USE values are more bounding (as opposed to $RT_{NDT}$, where higher values are more bounding).

If measured values of Cu and Ni content for plant-specific RV beltline materials are not available, Position 1.1 of RG 1.99, Rev. 2 and 10 CFR 50.61(c)(1)(iv)(A) provide equivalent criteria regarding the use of generic values. Specifically, if measured Cu and Ni content are unknown, "*the upper limiting values given in the material specifications*" may be used. If the material specifications provide no upper limiting values, conservative estimates (Mean + $1\sigma$) based on generic data may be used if justification is provided. If there is no information available based on measured content, material specifications, or conservative estimates (Mean + $1\sigma$) from generic data, "*0.35 percent copper and 1.00 percent nickel*" must be assumed. For calculations of $RT_{MAX-X}$, 10 CFR 50.61a(f)(3) states that if measured values of Cu, Ni, P, and Mn content are not available for the specific RV material, either the upper limiting values given in the material specifications to which the RV material was fabricated, or conservative estimates (i.e., mean plus one standard deviation) based on generic data must be used. Table 4 of 10 CFR 50.61a provides the generic values for P and Mn content, which must be used, if measured values are unknown for the specific RV material.

Finally, with respect to determination of generic values of Cu and Ni content based on evaluation of Mean + $1\sigma$ for generic data, Note 4 of 10 CFR 50.61(c)(1)(iv)(A) and Note 4 of 10 CFR 50.61a(f)(3) state: "*Data from reactor vessels fabricated to the same material specification in the same shop as the vessel in question and in the same time period is an example of 'generic data.'*"

The NRC staff applied these criteria to determine whether the TR evaluations provide acceptable generic estimates of unirradiated Charpy USE, Cu Content, and Ni content for use in plant licensing applications to demonstrate compliance with the requirements of 10 CFR Part 50, Appendix G; 10 CFR 50.61 or 50.61a; and 10 CFR 54.21(c)(1).

## 3.0 <u>OVERVIEW OF PWROG-17090-NP, REVISION 0</u>

For RVs fabricated by Rotterdam, the TR provides generic values of unirradiated Charpy USE for ASME SA508, Class 2 (or the corresponding ASTM A508, Class 2) forgings and generic values of unirradiated Charpy USE, Cu content, and Ni content for SAWs and SMAWs when no or limited plant-specific material information is available. These generic values are developed using baseline (unirradiated) test data from RV material surveillance program records and CMTRs that are available to Westinghouse. The TR identifies that the need for these generic

properties is prompted by the difficulty in identifying plant-specific material information needed to establish measured values for these properties for Rotterdam RVs fabricated in the "late 1960's to early 1970's." The proposed generic values for these material properties are as follows:

- For an SA508, Class 2 Rotterdam RV forging supplied by Rheinstahl Huttenwerke AG, the TR provides a generic lower bound Charpy USE value of 56 ft-lbs., based on the mean minus two standard deviations (Mean – 2σ) evaluation of measured USE values for the Rheinstahl Huttenwerke AG data set.

- For an SA508, Class 2 Rotterdam RV forging supplied by Fried-Krupp Huttenwerke AG, or an unknown Rotterdam RV forging supplier, the TR provides a generic lower bound Charpy USE value of 52 ft-lbs. based on the Mean – 2σ evaluation of measured USE values for the Fried-Krupp Huttenwerke AG data set, and consideration of additional Charpy USE data for other forging suppliers addressed in Section 4.3 of the TR and discussed below.

- For a Rotterdam RV SAW, the TR provides a generic lower bound Charpy USE value of 75 ft-lbs. based on the Mean – 2σ evaluation of measured USE values for the Rotterdam RV SAW data set. The TR also provides a generic upper bound Cu content of 0.23 percent by weight. and a generic upper bound Ni content of 0.56 percent by weight, both of which are based on the mean plus one standard deviation (Mean + 1σ) evaluation for the Rotterdam RV SAW Cu and Ni chemistry data.

- For a Rotterdam RV SMAW, the TR provides a generic lower bound Charpy USE value of 72 ft-lbs., which is the lowest of the "lower bound USE values" (as described in Sections 3.2 and 5.2 for the Rotterdam SMAW evaluation) for the non-outlier SMAW weld heats. The lower bound USE values are determined from measured absorbed impact energies for the SMAW Charpy V-Notch tests, which are established to be below an undetermined USE based on Charpy test temperatures at 10.4 °F or below and available percent shear data. The TR recommends a generic Cu content of 0.35 percent per RG 1.99, Rev. 2, and it provides a generic upper bound Ni content of 1.13 percent (greater than the generic Ni content of 1.00 percent provided in the RG) based on the Mean + 1σ evaluation for the Rotterdam RV SMAW Ni chemistry data.

Section 3.0 of the TR describes the methodology for analyzing the material property data for the subject Rotterdam RV forgings and welds. Section 4.0 of the TR provides the actual data sets and statistical analyses for determining the generic values of unirradiated Charpy USE for Rotterdam RV forging materials. Section 5.0 provides the data sets and analyses for determining the generic values of unirradiated Charpy USE, Cu content, and Ni content for Rotterdam RV weld materials. The NRC staff's independent evaluation of these methods and data analyses is documented in Section 4.0 of this SE The key aspects of the methodology and data analyses, as reported in TR, are summarized below.

*Generic Charpy USE Values for SA508, Class 2 Forgings in Rotterdam RVs*

The TR identifies that its generic Charpy USE values are determined by calculating the Mean – 2σ for two independent sets of measured Charpy USE values in the weak direction. The two independent data sets correspond to two Rotterdam RV forging suppliers: Rheinstahl Huttenwerke AG and Fried-Krupp Huttenwerke AG. The TR indicates that measured USE

values were determined by reviewing Charpy impact test records from available CMTRs and baseline (unirradiated) Charpy test data from RV material surveillance program records. The total number of Charpy test records for forgings supplied by Rheinstahl Huttenwerke AG is 38, and the total number of test records for Fried-Krupp Huttenwerke AG-supplied forgings is 67. Each Charpy test record corresponds to a subset of Charpy impact tests on samples (i.e., Charpy V-Notch specimens) of a specific forging material for an unnamed plant (e.g., "Inlet Nozzle 09" for "Plant D," "Upper Shell" for "Plant C," etc.). For each test record, the TR reviewed measurements of absorbed Charpy impact energies, test temperatures, and measurements of percentage shear fracture surface areas (percent shear) for the fractured Charpy specimens (i.e., the broken pieces).

For each Charpy test record, the TR determined either a measured value of the USE for that forging material—or where this is not possible due to less stringent impact testing criteria prior to 1973—a measured value of the absorbed Charpy impact energy, which is considered in the TR to be a lower bound on actual USE for that forging. For these cases, the USE is identified in the TR as being greater than or equal to (≥) the reported absorbed impact energy.

Only measured USE values for Charpy tests on forging specimens oriented in the weak direction (transverse specimens) are used to calculate the recommended Mean – 2$\sigma$ values for the two forging supplier data sets. For cases where measured USE values are available only in the strong direction (longitudinal specimens), or where the strong direction must be assumed because the Charpy V-Notch specimen orientation was not reported in the CMTR, the TR estimates USE in the weak direction using Position 1.2 of BTP 5-3; specifically, the weak direction USE is estimated to be 65 percent of the measured strong direction USE. These reduced values of measured strong direction USE are reported in the data sets as the "BTP 5-3" USE values. Separate Mean – 2$\sigma$ calculations are also reported for both the measured "BTP 5-3" USE values and the full complement of measured USE values and estimated lower bound USE values to contextualize and justify the recommended generic values. However, it must be emphasized that the TR's recommended generic USE values are set equal to the calculated Mean – 2$\sigma$ values <u>only</u> for Charpy USE data that is measured in the weak direction.

The TR states that all measured USE values for Charpy tests in both the strong and weak directions are determined as per the following criteria:

- For a given forging Charpy test record, the TR attempts to determine a value for USE based on available percent shear measurements in a manner that is consistent with ASTM E185-82. Specifically, if the Charpy test data for the forging material contains <u>*at least one*</u> impact energy measurement with greater than or equal to 95 percent shear (i.e., "≥ 95 percent shear"), but some of the impact energy measurements report no percent shear values, all impact energies approximately greater than or equal to those that are known to exhibit ≥ 95 percent shear are assumed to have ≥ 95 percent shear. All "non-outlier" impact energy measurements with ≥ 95 percent shear are averaged to determine the measured USE, which is reported in the TR for the forging test record.

- TR states that if the Charpy test record contains limited or no percent shear data, however the upper-shelf region of the Charpy curve can be clearly determined from the data provided, the USE is identified by an approximately constant energy versus temperature region. As an example, the TR identifies cases where data points at four temperatures over a 50 °F range exhibited impact energy values within a scatter of 10°F or less. TR states that the existence of the upper-shelf region is confirmed by plotting

the impact energy data and identifying if the plot levels off at higher temperatures. The reported USE represents an average of all Charpy energy values considered to be in the upper-shelf region.

In addition to measurements of actual USE, the TR also reports measured values of the absorbed Charpy impact energy in the strong direction for which actual USE is undetermined. For these cases, the reported Charpy impact energy is considered to represent a lower bound on actual USE for the forging, and the unknown USE is therefore reported to be *greater than or equal to* the reported Charpy impact energy. Further, since these impact energies are all measured in the strong direction, the TR provides BTP 5-3 estimates of absorbed impact energies in the weak direction, which are 65 percent of the measured impact energies in the strong direction. These cases are all designated in the TR as "USE ≥ XX," where the value of "XX" is a number that equals the reported Charpy impact energy, and they are also reported as "BTP 5-3" values. The TR's criteria for determining that "USE ≥ XX," where "XX" is a number that equals the reported impact energy are as follows:

- The TR states that if the test record reports percent shear values, but all data indicates a percent shear less than 95 percent, the USE is reported to be greater than or equal to the maximum Charpy impact energy. The reported impact energy is not incorporated into the calculation of the recommended Mean – $2\sigma$ value since this recommended generic value is based exclusively on the measured weak direction USE values.

- The TR states that if the test record included limited shear data or did not include shear data, and Charpy impact energies are increasing throughout the temperature range available, it is unknown if the upper-shelf has been reached. The TR states that the USE is reported to be greater or equal to the highest Charpy impact energy value available; or if the highest data point is determined to be a potential 'outlier' or a non-representative data point, the USE is reported as greater than or equal to a value less than the highest energy value based on the average of the comparable preceding data points. In these instances, the reported impact energy is not incorporated into the calculation of the generic USE.

In addition to data sets for SA508, Class 2 forgings supplied by Rheinstahl Huttenwerke AG and Fried-Krupp Huttenwerke AG, the TR also reports Charpy impact energies and USE data for several other firms who supplied SA508, Class 2 forgings to Rotterdam; these include Klöckner-Werke AG, Terni, Marrêl-Freres, and an unknown supplier. The Charpy test data from these other suppliers is independently evaluated in Section 4.3 of the TR, but due to more limited data sets for each of the other suppliers, a statistical evaluation to determine generic USE values for the other suppliers is not performed. Instead the TR shows that all measured USE values and Charpy impact energies (where USE is reported as greater than or equal to the reported Charpy impact energy, as per the above), are greater than the recommended Mean – $2\sigma$ values from the Rheinstahl Huttenwerke AG and Fried-Krupp Huttenwerke AG data sets. Based on this comparison, this section of the TR concludes that an SA508, Class 2 forging from an unknown supplier in a Rotterdam-fabricated RV would be expected to have an unirradiated Charpy USE value of at least 52 ft-lbs. Therefore, the TR recommends 52 ft-lbs. as the generic unirradiated Charpy USE value to be used for SA508, Class 2 forgings in Rotterdam RVs if the forging supplier is unknown.

*Generic Charpy USE, Copper Content, and Nickel Content for Rotterdam RV Welds*

The TR states that the Rotterdam CMTRs identify two types of welds used in the fabrication of the RVs: SMAWs and SAWs. Each type is evaluated separately. The TR states that the industry practice at the time of Rotterdam RV fabrication was to perform Charpy tests at a limited number of temperatures to show 30 ft-lbs. or more of absorbed energy at 10 °F. These tests were considered sufficient to satisfy ASME Code requirements at that time; however, the CMTRs often contain insufficient Charpy impact data to determine measured values of USE. The TR recommends a generic unirradiated Charpy USE value of 75 ft-lbs. for Rotterdam RV SAWs; this is the Mean – $2\sigma$ value for the set of seven measured unirradiated USE values from RV material surveillance programs. The TR states that the Rotterdam RV SAW data set represents every SAW material vendor and every flux type, with the exception of Linde 80 flux type. The TR emphasizes that the SAW welds of the Linde 80 flux type are specifically excluded from the Rotterdam weld analyses. The TR identifies that outside of the baseline USE measurements from the RV material surveillance programs, there is no meaningful USE information available in the CMTRs for Rotterdam SAWs. Therefore, only the seven measured USE values for SAWs from RV surveillance programs are reported in the TR.

The TR states that out of 38 SMAW Charpy test records, actual measured USE values are available for only three heats of SMAW material. The three measured USE values are 116, 130, and 134 ft-lbs. The TR does not determine a Mean – $2\sigma$ value for these three due to the statistically insignificant size of the data set. For the remaining 35 Charpy test records, the TR determined a lower bound on the USE for each SMAW based on the available Charpy impact energy data using methods similar to those described above for SA508, Class 2 forgings. If no percent shear data is available, the USE is reported as "greater than or equal to" the average of the Charpy impact energies at the test temperature, typically around 10 °F. When percent shear values are reported, and each is less than 95 percent, then the TR reports maximum Charpy impact energy for the weld test. Based on these methods, the TR determined that its recommended generic unirradiated Charpy USE value for Rotterdam SMAWs is 72 ft-lbs., which is based on the non-outlier weld heat showing the lowest of the "lower bound USE values."

In addition to the generic USE, the TR determines generic Cu and Ni weight percentages for both SAWs and SMAWs based on the calculation of Mean + $1\sigma$ for the data sets. The TR identifies this method as consistent with RG 1.99, Rev. 2, which states that conservative estimates of Cu and Ni content based on generic data may be used if justification is provided; the TR notes that for Cu and Ni content, the RG identifies "*conservative estimates*" as "*mean plus one standard deviation*." The TR further states that if a common weld metal heat and flux type combination is shared between multiple welds, the average chemistry value for the heat is considered as one data point when determining the generic weld chemistry values so as not to assign undue weight to multiple samples of weld material of the same heat. The chemistry data used in the evaluation consists of measurements from RV surveillance programs, supplemented with all available chemistry data for heats outside the surveillance programs. The TR states that the data is limited to deposited weld chemistry results, unless otherwise noted. The TR notes that the Cu content for one SAW material (Smit-Weld Heat No. 25006) is based on the weld wire analysis since deposited weld chemistry is not available.

## 4.0 STAFF EVALUATION

The NRC staff's review of PWROG-17090-NP, Rev. 0 addressed whether the TR evaluations for determining the generic properties for Rotterdam RVs are acceptable as a basis for implementation of these properties in plant licensing applications for demonstrating compliance

with RV fracture toughness requirements in 10 CFR Part 50, Appendix G; 10 CFR 50.61 or 50.61a; and TLAAs related to RV fracture toughness per 10 CFR 54.21(c)(1). The staff applied the regulatory guidance regarding the use of generic data, as set forth in Section 2.0 of this SE, to determine whether the TR evaluations provide reasonably conservative generic estimates of these properties for use in plant licensing applications that address these requirements.

4.1 Generic Unirradiated Charpy USE for SA508, Class 2 Forgings in Rotterdam RVs

The TR determines generic unirradiated Charpy USE values for SA508, Class 2 RV forgings based on calculating the Mean – $2\sigma$ value for the set of measurements of Charpy USE in the weak direction, consistent with the criteria addressed in Section 2.0 of this SE. The staff identified that the TR's evaluation of generic data sets for determining generic USE values for the ASME SA508, Class 2 forging specification is consistent with the definition of the material "class" provided in 10 CFR 50.61, 10 CFR 50.61a, and RG 1.99, Rev. 2.

The TR identifies that several firms manufactured and supplied SA508, Class 2 RV forging components to Rotterdam; the TR indicates that Rotterdam procured the forgings to fabricate the welded RVs in the late 1960's and early 1970's timeframe. The Charpy test data sets used to establish the TR's generic USE values are based on the forging suppliers. Note 4 of 10 CFR Sections 50.61 and 50.61a states: *"Data from reactor vessels fabricated to the same material specification in the same shop as the vessel in question and in the same time period is an example of 'generic data.'"* The staff determined that for multiple suppliers of SA508, Class 2 forgings to the RV fabricator (Rotterdam), the "same shop" is appropriately considered in the TR to be the same firm responsible for manufacturing the forging component. Therefore, the staff determined that these generic data sets and corresponding generic USE values are appropriately delineated for plant-specific application in a manner that is consistent with Note 4 of 10 CFR 50.61 and 50.61a.

Although this Note 4 is specifically cited for the use of generic Cu and Ni content data to demonstrate compliance with applicable PTS requirements, the NRC staff finds that the criteria in Note 4 are also relevant to the TR's application of generic data for determining generic values of unirradiated Charpy USE. The NRC staff also finds there are no criteria in 10 CFR Part 50, Appendix G or NRC guidance related to Charpy USE that would prohibit or otherwise preclude the application of Note 4 to the determination of generic unirradiated Charpy USE based on forging manufacturer. Therefore, the staff finds that the TR's classification of the generic data sets for SA508, Class 2 forgings based on the forging manufacturer, consistent with Note 4 of the PTS requirements, is acceptable.

The RV forging suppliers and the number of Charpy test records for each forging supplier are listed below:

| Forging Supplier | Number of Charpy Test Records For Forging Components Supplied to Rotterdam |
|---|---|
| Rheinstahl Huttenwerke AG | 38 |
| Fried-Krupp Huttenwerke AG | 67 |
| Klöckner-Werke AG | 8 |
| Terni | 6 |
| Marrèl-Freres | 2 |
| Unknown | 1 |

The staff reviewed the TR methods for evaluating Charpy impact test data to determine either a measured value of the USE for the forging—or where a measured USE value could not be determined—the methods for determining a lower bound on the USE for the forging based on available Charpy test data. The staff's review of these methods is documented below.

For cases where Charpy impact energy data is accompanied by at least 1 percent shear measurement greater than or equal to 95 percent shear, the staff reviewed the TR methods for determining USE based on the definitions in ASTM E185-82. Specifically, upper-shelf energy is defined as the region in the Charpy transition curve where the broken specimens exhibit greater than 95 percent shear; and upper-shelf energy level is defined as the average of absorbed impact energy values for Charpy specimens whose test temperature is above the upper end of the transition region, which is below the USE region. This definition also states that for specimens tested in sets of three at each temperature, the set having the highest average impact energy may be regarded as defining the USE. The staff determined that the TR's statement that the reported USE is the average of all *"non-outlier"* impact energy values greater than or equal to the value(s) with greater than or equal to 95 percent shear is sufficiently consistent with this definition, provided that the staff could confirm, based on review of examples, that the elimination of the outlier data point is reasonable. Therefore, in RAI correspondence, the staff requested that the PWROG provide examples of both high and low outliers that were eliminated from this calculation of the average.

In its June 12, 2019, RAI-3 response (Ref. 2), the PWROG provided an example of an uncharacteristically low impact energy and an example of an uncharacteristically high impact energy, both of which are considered to be outliers and eliminated from the calculation of the average, which is the USE reported in TR. For both the high and low outlier impact energies, the RAI response identified all the other impact energies that went into the calculation of the average, as well as the test temperatures and the available percent shear measurements. The PWROG compared the outlier impact energies with the non-outlier data that was used to determine applicable USE values for these forging components, as reported in the TR. As described below, based on its review of the high and low outlier impact energies, and its review

of PWROG's comparison of the outliers to the other data that was used to determine USE, the NRC staff was able to verify that appropriate engineering judgement was used in the elimination of the high and low outlier impact energies to determine the reported USE for these components. Therefore, the staff finds that this method for determining measured USE is acceptable.

If a Charpy test record includes no percent shear data for identifying USE, the staff reviewed the TR's reported method of determining USE by identifying an *"approximately constant energy versus temperature region"* in the Charpy data. The staff noted that the TR's example of four data points over a 50 °F temperature range exhibiting impact energy values within a scatter of 10 °F or less is appropriate for identifying the upper-shelf region because at temperatures above the transition region, impact energy values become approximately constant at or near the USE level. The staff noted that ASTM E185-82 defines the upper-shelf energy level as the average energy value for Charpy specimens whose test temperature is above the upper end of the transition region. Therefore, the staff confirmed that the USE value can be determined as the average of impact energies that are determined to be in the upper-shelf region based on low scatter over a large temperature range. The staff finds that this method for determining measured USE is acceptable.

When measured USE for the forging test record cannot be determined based on the above methods, the staff reviewed the two methods described in the TR for establishing a lower bound on the USE based on the available absorbed impact energy data.

- Based on the definitions in ASTM E185-82, the staff noted that if the test record includes percent shear values, and all are less than 95 percent, then the corresponding impact energies are not in the upper-shelf region; therefore, the staff identified that USE would be greater than or equal to the maximum absorbed impact energy with percent shear less than 95 percent. Based on the definitions in the ASTM standard, the staff finds this method for determining a lower bound on USE for the available test data to be acceptable.

- If shear data are not available, and it is seen, based on examination of impact energy data, that energies are increasing throughout the temperature range available, the staff confirmed that it would be unknown whether the USE region has been reached. The staff noted that for RV materials that were fabricated to earlier ASME Code editions, Charpy impact testing may not have occurred at temperatures above the transition region. Thus, it is reasonable for the TR to determine that USE for the material would be greater than or equal to absorbed impact energy in the transition region. The staff's review of specific cases for this situation is documented below based on its audit of Charpy test data for one of the forging suppliers.

The TR performed independent evaluations of Charpy test data for SA508, Class 2 forgings supplied by Rheinstahl Huttenwerke AG and Fried-Krupp Huttenwerke AG. The TR performed a third evaluation that addressed the other forging suppliers, which collectively includes Klöckner-Werke AG, Terni, Marrèl-Freres, and the unknown supplier. The staff's review addressed the three TR evaluations for establishing the recommended generic USE values.

*Unirradiated USE Evaluation of RV Forgings Supplied by Rheinstahl Huttenwerke*

The NRC staff confirmed that of the 38 Charpy test records that are available for Rheinstahl Huttenwerke AG forgings, there are 11 test records where measured values for unirradiated

Charpy USE were able to be determined based on the methodologies described above. The staff noted that 8 of the 11 forgings have measured USE values for both the strong and the weak directions; one forging has a measured USE value only in the strong direction; and two forgings have measured USE values only in the weak direction. For the 9 measured USE values in the strong direction, the staff confirmed that the TR correctly used Position 1.2 of BTP 5-3 to estimate the USE values in the weak direction; specifically, BTP 5-3 estimates of weak direction USE are equal to 65 percent of the measured USE values in the strong direction.

For the 11 forgings with measured values for Charpy USE, the staff's independent calculations showed the following.

- For the 10 measured USE values in the weak direction, the staff confirmed that the Mean – 2σ value for this data set is 56 ft-lbs., which is the recommended generic USE value for forgings supplied by Rheinstahl Huttenwerke AG. The staff noted that this bounds (i.e., is more conservative than) the lowest measured weak direction USE value of 64 ft-lbs.
- For the 9 BTP 5-3 estimates of USE in the weak direction, the staff confirmed that the Mean – 2σ value is 70 ft-lbs., which bounds the lowest BTP 5-3 USE value of 75 ft-lbs. The staff noted that the TR's recommended generic USE value of 56 ft-lbs. bounds these BTP 5-3 USE estimates. Therefore, based on review of all available USE data for Rheinstahl Huttenwerke AG forgings, the staff verified that the recommended generic USE value of 56 ft-lbs. is the most conservative.

<u>*BTP 5-3 Estimates of Lower Bound USE for Rheinstahl Huttenwerke Forgings*</u>

The NRC staff also confirmed that out of the 38 Charpy test records for the Rheinstahl Huttenwerke AG data set, there are 27 for which measured USE could not be established, but the available impact energy data were used to determine a lower bound on USE in the strong direction using the methods summarized above. Since all of the absorbed impact energies were measured in the strong direction, the TR determined estimates of absorbed impact energy in the weak direction to be 65 percent of the measured impact energies in the strong direction by applying BTP 5-3. The staff noted that 23 of these 27 estimates of lower bound USE are considered along with measured weak direction USE values and BTP 5-3 USE values in a separate Mean – 2σ calculation, which is 40 ft-lbs. The TR does not recommend 40 ft-lbs. as the generic USE value for Rheinstahl Huttenwerke AG forgings because the 23 BTP 5-3 estimates of lower bound USE included in this Mean – 2σ calculation do not represent actual USE for that test record. Specifically, Note "b" of the data set states that it is unknown whether the upper-shelf was reached during the test since the Charpy impact energies are increasing throughout the temperature range available, and "*the actual USE value is likely higher*."

The staff noted that the four lowest of the 23 lower bound USE estimates that were included in the Mean – 2σ calculation of 40 ft-lbs. are lower than the TR's recommended generic USE value of 56 ft-lbs. These values, which are annotated with Note "b" in the Rheinstahl Huttenwerke AG data set are 53 ft-lbs., 52 ft-lbs., and two values at 47 ft-lbs. The staff also noted that the calculation of 40 ft-lbs. excludes the four lowest of the 27 available lower bound USE estimates, which are 44 ft-lbs., 42 ft-lbs., and two values at 39 ft-lbs. Note "f" of the Rheinstahl Huttenwerke AG data set explains that the four lowest values of 44 ft-lbs., 42 ft-lbs., and two values at 39 ft-lbs. are "*excluded from statistical analysis*" because the values "*do not provide*

*accurate representation of USE,"* and *"the actual USE is likely much higher since a Charpy test with a similar absorbed impact energy has a shear value much less than 95 percent."*

The NRC staff identified that the Charpy test data used to determine the eight lowest estimates of lower bound USE needed to be reviewed to assess whether the reported impact energies are below the upper-shelf region. Therefore, as part of its TR review, the staff audited Charpy test records for the following Rheinstahl Huttenwerke AG forgings, which had the eight lowest reported absorbed impact energies:

| **Four Lowest Impact Energies, Rheinstahl Huttenwerke AG Forgings with Note "b" (Included in Mean – 2σ of 40 ft-lbs.; 40 ft-lbs. is not the recommended USE)** | | |
|---|---|---|
| Component Identification | Measured Absorbed Impact Energy, Strong Direction | BTP 5-3 Estimate of Absorbed Impact Energy, Weak Direction (i.e., "Lower Bound USE Estimates") |
| Plant D, Intermediate Shell | 82 ft-lbs. | 82 ft-lbs. X 65% = 53 ft-lbs. |
| Plant E, Inlet Nozzle 11 | 80 ft-lbs. | 80 ft-lbs. X 65% = 52 ft-lbs. |
| Plant D, Inlet Nozzle 09 | 72 ft-lbs. | 72 ft-lbs. X 65% = 47 ft-lbs. |
| Plant F, Inlet Nozzle 09 | 72 ft-lbs. | 72 ft-lbs. X 65% = 47 ft-lbs. |

| **Four Lowest Impact Energies, Rheinstahl Huttenwerke AG Forgings with Note "f" (Excluded from All Statistical Evaluations)** | | |
|---|---|---|
| Component Identification | Measured Absorbed Impact Energy, Strong Direction | BTP 5-3 Estimate of Absorbed Impact Energy, Weak Direction (i.e., "Lower Bound USE Estimates") |
| Plant E, Upper Shell | 68 ft-lbs. | 68 ft-lbs. X 65% = 44 ft-lbs. |
| Plant F, Outlet Nozzle 13 | 64 ft-lbs. | 64 ft-lbs. X 65% = 42 ft-lbs. |
| Plant D, Inlet Nozzle 11 | 60 ft-lbs. | 60 ft-lbs. X 65% = 39 ft-lbs. |
| Plant D, Outlet Nozzle 14 | 60 ft-lbs. | 60 ft-lbs. X 65% = 39 ft-lbs. |

The staff's audit of the Charpy test records for the eight forging materials included review of test temperatures, absorbed impact energies, and available percent shear measurements. The staff's review identified that the maximum absorbed impact energies in the eight Charpy test records correspond to the measured impact energy values for the strong direction that are reported in the TR. The staff's audit generally confirmed TR statements that the eight lowest impact energies are not representative of the USE for those forgings since the impact energies were increasing throughout the temperature range shown in the test record. Based on the increasing energy trends, available test temperatures, and the limited amount of shear data, the

staff found that there is sufficient evidence that the materials were likely in the transition region at the highest test temperatures documented in the records. Thus, the staff confirmed that the actual USE values for these forgings, while unknown (because it was likely not reached during the test evolution), can reasonably be expected to be higher than the measured values of absorbed impact energy for the strong direction, as reported in the TR for these eight forgings. Based on its audit of the test records, the staff found that the eight lowest impact energies do not need to be considered in the statistical evaluation of the measured USE values for determining the TR's recommended generic USE value.

The staff also noted that the other 19 BTP 5-3 estimates of lower bound USE are all greater than the TR's recommended generic value of 56 ft-lbs.; this provides additional evidence that the Mean – 2$\sigma$ value for the ten measurements of Charpy USE in the weak direction is a conservative generic estimate of unirradiated Charpy USE for this forging supplier. Therefore, the staff confirmed that 40 ft-lbs. does not warrant implementation as a generic estimate of USE for Rheinstahl Huttenwerke AG forgings. Accordingly, the staff finds that 56 ft-lbs is acceptable for implementation as a generic unirradiated Charpy USE value for SA508, Class 2 RV forgings supplied by Rheinstahl Huttenwerke AG for Rotterdam RVs.

*Unirradiated USE Evaluation of RV Forgings Supplied by Fried-Krupp Huttenwerke AG*

The NRC staff confirmed that of the 67 Charpy test records that are available for Fried-Krupp Huttenwerke AG forgings, there are 38 test records where measured values for unirradiated Charpy USE were able to be determined based on the methodologies described above. For the 38 forgings with measured USE values, the staff noted that 5 of the 38 forgings have measured USE values for both the strong and the weak directions, and the other 33 have measured USE values only in the strong direction. For all 38 measured USE values in the strong direction, the staff confirmed that the TR correctly used Position 1.2 of BTP 5-3 to estimate USE values in the weak direction. For the 38 forgings with measured values for Charpy USE, the staff's independent calculations showed the following.

- For the 5 measured USE values in the weak direction, the staff confirmed that the Mean – 2$\sigma$ value for this data set is 52 ft-lbs., *which is the recommended generic USE value for forgings supplied by Fried-Krupp Huttenwerke AG*. The staff noted that this bounds (i.e., is more conservative than) the lowest measured weak direction USE value of 62 ft-lbs.

- For the 38 BTP 5-3 estimates of USE in the weak direction, the staff confirmed that the Mean – 2$\sigma$ value is 61 ft-lbs., which is equal to the lowest of the 38 BTP 5-3 USE estimates. The staff noted that the TR's recommended generic USE value of 52 ft-lbs. bounds this BTP 5-3 USE estimate. Therefore, based on review of all available USE data for Fried-Krupp Huttenwerke AG forgings, the staff verified that the recommended generic USE value of 52 ft-lbs. is the most conservative.

*BTP 5-3 Estimates of Lower Bound USE for Fried-Krupp Huttenwerke AG Forgings*

The NRC staff also confirmed that out of the 67 Charpy test records for the Fried-Krupp Huttenwerke AG data set, there are 29 for which measured USE could not be determined, but BTP 5-3 estimates of the lower bound on USE could be determined, as per the criteria above. All of the 29 estimates of lower bound USE are considered along with the measured USE values in a separate evaluation that calculates a Mean – 2$\sigma$ value of 51 ft-lbs. The TR does not

recommend 51 ft-lbs. as the generic USE value for these forgings because the 29 BTP 5-3 estimates of lower bound USE included in this Mean – 2σ calculation do not represent actual USE for that test record. The 29 BTP 5-3 estimates of lower bound USE are annotated with either Note "b" or Note "f". Note "b" states that it is unknown whether the upper-shelf was reached during the test since the Charpy impact energies are increasing throughout the temperature range available, and "*the actual USE value is likely higher.*" Note "f" states that "*reported shear values are less than 95 percent shear, and the reported* [impact energy] *value is less than or equal to the maximum energy value of a Charpy specimen with less than 95 percent shear,*" and as a result, "*the USE is higher than the Charpy data reported.*" The staff identified that there are no lower bound USE estimates that are excluded from the Mean – 2σ calculation of 51 ft-lbs. Further, just two of the 29 lower bound USE estimates (51 ft-lbs. and 50 ft-lbs.) are lower than the TR's recommended generic USE value of 52 ft-lbs The staff determined that actual USE values for these two forgings, while unknown, would likely be higher than their reported lower bound values given that these impact energies are annotated with Note "b" identifying that impact energies are increasing throughout the temperature range available. The staff noted that all of the other 27 lower bound USE estimates are greater than the TR's recommended generic USE value of 52 ft-lbs. for this forging supplier. Therefore, the staff finds that 52 ft-lbs., based on the Mean – 2σ for the 5 measured USE values in the weak direction, is acceptable for implementation as a generic unirradiated Charpy USE value for SA508, Class 2 RV forgings supplied by Fried-Krupp Huttenwerke AG for Rotterdam RVs.

*Unirradiated USE Evaluation of RV Forgings from Other Suppliers*

The staff noted that there are 17 Charpy test records represented in a single data set provided in TR Table 7 for the other forging suppliers, which includes Klöckner-Werke AG, Terni, Marrèl-Freres, and an unknown company. In RAI correspondence, the NRC requested that the PWROG resolve the apparent inconsistency in the TR regarding the number of Charpy test records from an unknown company because in Table 2 the TR identifies that there are two forging components from an unknown supplier, whereas Table 7 of the TR lists one impact energy measurement for the unknown supplier. In its June 12, 2019, RAI-2 response (Ref. 2), the PWROG indicated that there are two SA508, Class 2 forging materials with an unknown supplier, as shown in TR Table 2 – however, only one such material is listed in TR Table 7 because the Charpy test record is not available for the other "unknown supplier" material. Accordingly, Charpy data for the other SA508, Class 2 forging component from an unknown supplier could not be included Table 7.

Out of these 17 test records, the staff noted there are two with measured USE values in the weak direction; these USE values are 134 ft-lbs. and 141 ft-lbs. There are 10 measured USE values in the strong direction, for which the TR applied BTP 5-3 to estimate weak direction USE; the staff identified that the lowest of the BTP 5-3 USE estimates is 94 ft lbs. The USE is unknown for 7 test records, but a lower bound on USE in the strong direction was established based on evaluation of available absorbed impact energy data that is established to be in the transition region (i.e., the energies are increasing throughout the temperature range available); this is same method as that used for the Rheinstahl Huttenwerke AG and Fried-Krupp Huttenwerke AG data sets, as identified in Note "b" for these data sets. As with the other SA508, Class 2 data sets, the lower bound USE values are reduced per BTP 5-3 to determine estimates of lower bound USE in the weak direction. The lowest of these BTP 5-3 estimates of lower bound USE for the other forging suppliers is 75 ft-lbs.

Considering the smaller number of records covering the three known suppliers and the unknown supplier, the staff confirmed that it is reasonable for the TR to select a lower generic USE value that could be used for SA508, Class 2 forgings in Rotterdam RVs if the forging manufacturer is unknown. For this purpose, the TR recommended that a generic USE value of 52 ft-lbs. be used for SA508, Class 2 forgings in Rotterdam RVs if the forging manufacturer is unknown. In its June 12, 2019, RAI-7 response (Ref. 2) the PWROG clarified that the generic value of 52 ft-lbs. is not intended for the suppliers Klöckner-Werke AG, Terni, or Marrél-Freres because data for all known and applicable Rotterdam RV forgings from these suppliers are provided in Table 7 of the TR for this data set. The PWROG stated that there is sufficient data in Table 7 for these components to justify a component-specific USE value that is higher than 52 ft-lbs. The staff reviewed this RAI response and confirmed that the applicable component-specific USE value (or lower bound USE estimate, as applicable) should be used for plants that can identify their forgings from among the components listed in Table 7.

With respect to a generic USE value of 52 ft-lbs. for an unknown forging supplier in a Rotterdam RV, the NRC staff considered all Charpy test data for all SA508, Class 2 forging manufacturers evaluated in the TR and noted the following:

- There are 122 Charpy impact test records evaluated in the TR.
- 52 ft-lbs. is the most bounding of the two Mean – 2$\sigma$ values for the two largest suppliers, Rheinstahl Huttenwerke AG and Fried-Krupp Huttenwerke AG.
- 52 ft-lbs. bounds all available Charpy impact test data (measured weak direction USE data, BTP 5-3 USE data, and lower bound USE estimates) from the three other known suppliers and the unknown supplier.
- For all forging suppliers, 52 ft-lbs bounds all measured USE values in the weak direction and all BTP 5-3 USE estimates for the weak direction (i.e., USE estimates based on application of BTP 5-3 to USE measurements in the strong direction).
- 52 ft-lbs bounds 21 of the 27 BTP 5-3 estimates of lower bound USE in the Rheinstahl Huttenwerke AG data set and 27 of the 29 lower bound USE estimates in the Fried-Krupp Huttenwerke AG data set.
- For the those several BTP 5-3 estimates of lower bound USE in the two largest data sets that are less than 52 ft-lbs, the staff determined based on review TR methods and audit of Charpy test records that actual USE values for these forgings, while unknown, would likely be higher than their reported lower bound values given that these impact energies are increasing throughout the temperature range available.

Therefore, based on its review of all the SA508, Class 2 Charpy test data, the staff determined that for a Rotterdam RV with SA508, Class 2 forging(s) from an unknown supplier, there is reasonable assurance the USE value for that forging would be at least 52 ft-lbs. Accordingly, the staff finds that 52 ft-lbs is acceptable for implementation as a generic unirradiated Charpy USE value for SA508, Class 2 RV forgings from an unknown supplier in Rotterdam RVs.

4.2 Generic Charpy USE, Cu Content, and Ni Content for Rotterdam RV Submerged Arc Welds and Shielded Metal Arc Welds

The TR determined generic values of unirradiated Charpy USE, Cu content, and Ni content for Rotterdam SAWs and SMAWs. Data sets for Charpy USE, Cu content, and Ni content were separately evaluated in the TR to determine the recommended generic properties for these two weld types. The NRC staff's review of these data sets and data analyses follows below.

*Rotterdam RV Submerged Arc Welds*

The NRC staff reviewed Charpy USE values and chemistry data for Rotterdam SAWs, which are provided in TR Tables 9 and 10, respectively. These tables also identify the flux types and weld wire vendors. The TR indicates that the two flux types ("SAF89" and "LW320") and six weld wire vendors identified in these tables are generically applicable to SAW materials for Rotterdam RVs, except for welds with Linde 80 flux type. SAWs with Linde 80 flux type are excluded from these generic analyses since welds with Linde 80 flux have been generically analyzed previously. The staff found that the TR adequately defined the material class for Rotterdam SAWs based on its identification of the two flux types and six wire vendors used to fabricate these welds.

The TR determines the generic unirradiated Charpy USE value for Rotterdam SAWs by calculating the Mean – 2σ for the set of seven measured values of unirradiated Charpy USE for the "Non-Linde 80" SAWs included in Rotterdam RV surveillance programs. The seven USE values are listed in TR Table 9. Note "a" of Table 9 identifies that these USE values are determined as the average of all available absorbed energy values with percent shear greater than or equal 95 percent, as per the ASTM E185-82 method that was used to determine USE for the RV forgings. As with the forgings, the staff determined that the TR's application of the ASTM E185-82 definitions for determining the seven USE values is acceptable.

The staff noted that for six of the seven Charpy USE values in Table 9, the reported USE value corresponds to a SAW for a specific unnamed plant (e.g., "Plant B"). One USE value in Table 9 corresponds to SAWs at four plants (Plants "A", "G", "H", and "I"). In its June 12, 2019, RAI-5 response (Ref. 2), the PWROG identified that each of the seven unirradiated Charpy USE values in Table 9 represents a unique heat of weld material.

The staff confirmed that the Mean – 2σ value for the set of seven baseline Charpy USE values for SAWs in Rotterdam RV surveillance programs is 75 ft-lbs. The staff noted that this recommended generic USE value bounds (i.e., is more conservative than) the lowest of the seven measured USE values, which is 82 ft-lbs. Considering that surveillance welds were selected from the amongst the core region welds (i.e., welds located in the original 40-year beltline region), the staff noted that the Mean – 2σ value of 75 ft-lbs may be reasonable for generic application to the non-Linde 80 core region SAWs in Rotterdam RVs. Additional considerations regarding the applicability of this data to *all* Rotterdam SAWs are discussed below.

The TR identifies that outside of the baseline USE measurements from RV surveillance programs, no USE information is available for Rotterdam SAWs. The TR states that the industry practice at the time of Rotterdam RV fabrication was to test Charpy specimens at 10 °F or lower to show 30 ft-lbs or more of absorbed energy, and the reporting of this test information in the Rotterdam CMTRs was considered sufficient to satisfy the fracture toughness requirements of the ASME Code at that time. The TR also states that the core region welds had the same specification requirements as the other RV welds, but for core region welds, Rotterdam was required to "aim for" both a Charpy V-Notch Transition Temperature (TTCV) and a Nil-Ductility Transition Temperature (NDTT) based on drop weight testing less than 10 °F, and to furnish additional test results relevant to TTCV and NDTT. The TR also states "*the TTCV and NDTT do not occur near the upper-shelf region, and thus, the surveillance capsule program test results are generically representative of the SAWs produced at Rotterdam for USE calculations.*" Considering this information, the staff surmised that CMTRs for non-surveillance welds would show low test temperatures and correspondingly low impact energies, which could

not be used to further support the generic USE value of 75 ft-lbs based on the surveillance weld USE data in Table 9.

The NRC staff identified that additional information was needed to confirm that the seven USE values for Rotterdam SAWs in Table 9 are representative for Rotterdam SAWs in general. In its RAI, the staff requested that the PWROG address how specification requirements and test criteria for Rotterdam SAWs support the TR determination that the baseline USE data for surveillance program SAWs in Table 9 is representative of Rotterdam SAWs in general. In its June 12, 2019, RAI-6 response (Ref. 2), the PWROG stated that based on acceptance criteria for Rotterdam RV welds, the flux/wire welds (SAWs) did not have chemistry requirements, but all welds had the same mechanical requirements, which included a minimum tensile strength of 80 ksi, a minimum absorbed Charpy impact energy of 30 ft-lbs for the average of three specimens, and a minimum absorbed Charpy impact energy 25 ft-lb for one individual specimen. The PWROG emphasized that these requirements were identical for the beltline and non-beltline SAWs; however, the core region welds had *additional* requirements to establish both the TTCV based on Charpy testing and NDTT based on drop weight testing, and to "aim for" a transition temperature of 10° F. The PWROG emphasized that these additional testing requirements for core region welds would not affect the USE, since these properties are associated with ductile-to-brittle transition, not the ductile region. Since the requirements for tensile strength and absorbed Charpy impact energy were equivalent, the PWROG stated that it is expected that all Rotterdam RV SAWs were taken from the same set of available weld metals. The PWROG identified that this is further supported by the known instances where a core region weld and a non-core region weld share the same heat number. Therefore, the PWROG concluded that the statistical analysis of the core region surveillance program SAW materials are also applicable to the non-core region SAWs.

The staff considered the RAI response statement that the same set of requirements for minimum tensile strength and absorbed Charpy impact energy were applicable to all Rotterdam RV SAW materials (core region welds and welds outside of the region), and the TR information indicating that the six SAW weld wire vendors and two flux types identified in Tables 9 and 10 are applicable to all Rotterdam SAWs (excluding Linde 80 flux type). The staff also took into consideration the RAI response statement that applicability of SAW generic USE data in Table 9 is supported by known instances where a core region weld and a non-core region weld share the same heat number. Based on consideration of this information, the staff determined that the Mean – $2\sigma$ value of 75 ft-lbs, for the seven heat-specific unirradiated USE measurements for SAWs in Rotterdam RV surveillance programs is reasonable as a conservative estimate of the unirradiated Charpy USE for Rotterdam SAWs. Therefore, the staff finds that 75 ft-lbs is acceptable for implementation as a generic unirradiated Charpy USE value for non-Linde 80 SAWs in Rotterdam RVs.

Based on its review of chemistry data provided in Table 10, the staff confirmed that measured values of Cu content are specified for 14 SAW heats. Where multiple Cu measurements (corresponding to specific flux lot numbers) are listed for a specific SAW heat and flux type, the staff confirmed that the Cu content value used in the Mean + $1\sigma$ calculation is the average of the measured Cu content values for that heat and flux type. One of the 14 Cu content values (0.17 percent) is identified as being based on the weld wire analysis, whereas all the other 13 values (as well as all Ni values addressed below) are based on the deposited content. The staff confirmed that the Mean + $1\sigma$ for the set of 14 Cu content values for Rotterdam SAW materials listed in Table 10 is 0.23 percent. Therefore, the staff determined that a generic Cu content of 0.23 percent may be used for non-Linde 80 Rotterdam SAWs if the measured value is unknown for the specific SAW material.

The staff confirmed that measured values of Ni content are available for 10 SAW heats. All 10 Ni content measurements are identified as based on the deposited weld content. The staff confirmed that the Mean + 1σ for the set of 10 Ni content values for Rotterdam SAW materials listed in Table 10 is 0.56 percent. Therefore, the staff determined that a generic Ni content of 0.56 percent may be used for non-Linde 80 Rotterdam SAWs if the measured value is unknown for the specific SAW material.

*Rotterdam RV Shielded Metal Arc Welds*

The NRC staff reviewed the available Charpy impact energy data, percent shear data, chemistry data, and weld identification information for Rotterdam SMAWs, which are provided in TR Table 12. The staff noted that there are 38 Rotterdam SMAWs addressed in TR Table 12, each of which has a unique heat number associated with it. Table 12 identifies four weld types corresponding to four vendors for the 38 heats of SMAW material listed therein. The TR states that all SMAW heats that were used in RV fabrication by Rotterdam, and that are available in the Westinghouse records, are included in Table 12. The staff determined that this information is sufficient to define the material class for Rotterdam SMAWs.

Of the 38 absorbed impact energy values reported in Table 12, the staff confirmed that there are only three measured values for Charpy USE for Rotterdam SMAWs. These values are: 130 ft-lbs, 116 ft-lbs, and 134 ft-lbs. All three USE values have percent shear values of 100 percent. The staff agreed with the TR determination that the three measured USE values do *not* constitute a data set of sufficient size to define a generic USE value based on Mean – 2σ. Therefore, the TR used a different approach to determine its recommended generic Charpy USE value of 72 ft-lbs for Rotterdam SMAWs.

As addressed in Section 2.0 of this SE, RG 1.99, Rev. 2, does not explicitly specify "Mean – 2σ" as a recommended method for determining a generic unirradiated USE based on evaluation of generic data for a "class" of material, and the USE requirements of 10 CFR Part 50, Appendix G are generally silent on this issue. Further, Position 1.3 of BTP 5-3 states that "*in the case of older plants, the* [preservice fracture toughness] *data may be estimated using procedures listed above* [Position 1.2 for plant-specific USE measurements] *or other methods that can be shown to be conservative* [emphasis added]"

For Rotterdam RV SMAWs, the staff reviewed the TR evaluation for determining a generic USE value of 72 ft-lbs by assessing whether the evaluation has been shown to be conservative, as specified in Position 1.3 of BTP 5-3. While only 3 of the 38 impact energies in Table 12 are determined to be the actual USE, the other 35 absorbed impact energies in Table 12 are reported to represent a lower bound on the USE for the test record. As with the lower bound USE values for SA508, Class 2 forgings, the actual USE values for these 35 SMAW materials are unknown, and they are identified as being "*greater than or equal to*" the reported impact energy. Of these 35 lower bound USE values, four of them have percent shear measurements that are less than 95 percent, and 31 do not have percent shear measurements. The TR identifies that all 35 lower bound USE values are based on Charpy tests completed at 10.4 °F or lower and shear values which are either unknown or less than 95 percent. The TR states that USE is typically reached at a temperature greater than 10 °F, as demonstrated by the welds with actual measured USE values, which reached the upper-shelf at temperatures of approximately 70 °F or higher.

Considering all 38 impact energies reported in Table 12 (35 lower bound USE values plus 3 actual USE values), the staff noted 72 ft-lbs for Heat No. 9092 is the second lowest value.

The staff also noted that 72 ft-lbs is the lowest of the 31 lower bound USE values that do not have percent shear measurements reported in Table 12. The staff confirmed that the lowest impact energy value in Table 12 is 63 ft-lbs for Heat No. 7359.6708; this impact energy has a corresponding percent shear value of 52 percent. Considering this percent shear measurement, and the low temperature range reported for the Charpy impact test (10.4 °F or lower), the staff found that it is reasonable to expect that actual USE for Heat No. 7359.6708 would be significantly greater than 63 ft-lbs if testing of this SMAW material had continued at higher temperatures into the upper-shelf region. On this basis, the staff determined that 63 ft-lbs for Heat No. 7359.6708 does not warrant consideration for determining the generic USE value for Rotterdam SMAWs based on the lower bound USE values listed in Table 12. Therefore, the staff finds that the lower bound USE value of 72 ft-lbs is acceptable for implementation as a generic unirradiated Charpy USE value for SMAWs in Rotterdam RVs.

Based on its review of chemistry data provided in Table 12, the staff confirmed that measured values of Cu content are available for only two SMAW heats. The staff agreed with the PWROG determination that this is insufficient data to determine a generic Cu content value. Accordingly, the staff confirmed that the default Cu content of 0.35 percent, as specified in RG 1.99, Rev. 2, would be the correct value to use if no other information is available (i.e., no heat-specific measurements, no Cu content requirements in material specifications, and no conservative estimates (Mean + 1$\sigma$) based on generic data). The staff noted that the default Cu content of 0.35 percent is conservative relative to the measured values, 0.01 percent and 0.023 percent, for Rotterdam SMAWs. Therefore, the staff finds that the RG 1.99, Rev. 2, default Cu content of 0.35 percent is acceptable for Rotterdam SMAWs if the measured value is unknown for the specific SMAW material.

The staff noted that 32 of the 38 SMAW heats listed in Table 12 have measured values of Ni content. The staff determined that this constitutes a sufficient set of measurements to determine a generic value based on Mean + 1$\sigma$ for Rotterdam SMAWs, as per RG 1.99, Rev. 2. The staff confirmed that the Mean + 1$\sigma$ for the set of 32 Ni content values for Rotterdam SMAW materials listed in Table 12 is 1.13 percent. Therefore, the staff finds that a generic Ni content 1.13 percent is acceptable for Rotterdam SMAWs if the measured value is unknown for the specific SMAW material.

The TR also recommends that if insufficient data exists to determine whether a Rotterdam RV weld is a SAW or a SMAW, then the generic values for unirradiated Charpy USE, Cu content, and Ni content for Rotterdam SMAWs can be utilized. The staff confirmed that the above generic values for unirradiated Charpy USE, Cu content, and Ni content for Rotterdam SMAWs are bounding relative to those for Rotterdam SAWs. The staff also noted that the TR affirmatively states that Rotterdam CMTRs specify only these two weld types for Rotterdam RVs. Therefore, the staff finds that the generic properties for Rotterdam SMAWs are acceptable for Rotterdam RV welds if the weld type (SAW or SMAW) is unknown and if measured values of the applicable properties are unknown for the specific weld materials.

## 5.0 <u>CONDITIONS AND LIMITATIONS</u>

There is no NRC staff-imposed condition or limitation on the use of this TR in licensing applications for addressing regulatory requirements in 10 CFR Part 50, Appendix G; 10 CFR 50.61 or 50.61a; and/or TLAA requirements in 10 CFR 54.21(c)(1). However, PWR plants referencing the TR as the basis for the generic Rotterdam RV material properties provided therein must ensure that their RV materials meet the criteria specified in the TR, as set forth below.

The generic properties provided in the TR are for implementation as conservative generic estimates for the material classes identified below *only if no measured values of unirradiated Charpy USE, Cu content, and/or Ni content are available* for the specific RV material under consideration. PWR plants that implement these generic estimates must identify their RV materials as follows:

- A PWR plant with a Rotterdam RV proposing to use the generic unirradiated Charpy USE value of 56 ft-lbs. for its RV forging(s) must identify that its forging(s) are of the SA508, Class 2 or A508, Class 2 specification and that the forging(s) were supplied by Rheinstahl Huttenwerke AG.

- A PWR plant with a Rotterdam RV proposing to use the generic unirradiated Charpy USE value 52 ft-lbs. for its RV forging(s) must identify that its forging(s) are of the SA508, Class 2 or A508, Class 2 specification. This generic unirradiated Charpy USE value may be used if the Rotterdam RV forging supplier is identified as Fried-Krupp Huttenwerke AG or if the forging supplier is unknown.

- A PWR plant with a Rotterdam RV proposing to use the generic unirradiated Charpy USE value of 75 ft-lbs. for its RV weld(s) must identify that the weld(s) are of the SAW type, that the SAWs are <u>not</u> of Linde 80 flux type, and that its SAW(s) were fabricated by Rotterdam.

- A PWR plant with a Rotterdam RV proposing to use the generic Cu content of 0.23 percent and generic Ni content of 0 56 percent for its RV weld(s) must identify that the weld(s) are of the SAW type, that the SAWs are <u>not</u> of Linde 80 flux type, and that its SAW(s) were fabricated by Rotterdam.

- A PWR plant with a Rotterdam RV proposing to use the generic unirradiated Charpy USE value of 72 ft-lbs. for its RV weld(s) must identify that the weld(s) were fabricated by Rotterdam. This generic unirradiated Charpy USE value may be used if the Rotterdam RV weld is identified as a SMAW or if the Rotterdam RV weld type is unknown.

- A PWR plant with a Rotterdam RV proposing to use the RG 1.99, Rev. 2, default Cu content of 0.35 percent and generic Ni content of 1.13 percent for its RV weld(s) must identify that the weld(s) were fabricated by Rotterdam. These values may be used if the Rotterdam RV weld is identified as a SMAW or if the Rotterdam RV weld type is unknown.

## 6.0 <u>CONCLUSION</u>

As set forth above, the NRC staff has reviewed the PWROG-17090-NP, Rev. 0, TR and has determined that the TR is acceptable for providing conservative estimates of generic unirradiated Charpy USE for ASME SA508, Class 2 (or the corresponding ASTM A508, Class 2) forgings in Rotterdam RVs; and conservative estimates of generic unirradiated Charpy USE, Cu content, and Ni content for Rotterdam SAWs and SMAWs based on the material classes specified in the TR. When measured values of unirradiated Charpy USE, Cu content, and/or Ni content are available for the specific RV materials under consideration, the measured values should be used.

The NRC staff's review has concluded that when measured values of unirradiated Charpy USE, Cu content, and/or Ni content are not available for the plant-specific Rotterdam RV materials under consideration, the generic values for the Rotterdam RV material classes identified in the TR may be used in PWR plant licensing applications for addressing regulatory requirements in 10 CFR Part 50, Appendix G; 10 CFR 50.61 or 50.61a; and/or TLAA requirements in 10 CFR 54.21(c)(1).

## 7.0 REFERENCES

1. Letter from Ken Schrader, Pressurized Water Reactor Owners Group, to USNRC Document Control Desk, April 6, 2018, Transmittal of Westinghouse Electric Company Report PWROG-17090-NP, Revision 0, "Generic Rotterdam Forging and Weld Initial Upper-Shelf Energy Determination," Westinghouse Non-Proprietary Class 3, March 2018 (ADAMS Accession No. ML18114A173).

2. Letter from Ken Schrader, Pressurized Water Reactor Owners Group, to USNRC Document Control Desk, June 12, 2019, Transmittal of the Response to Request for Additional Information, RAI 1-3 and 5-7 Associated with PWROG-17090, Revision 0, "Generic Rotterdam Forging and Weld Initial Upper-Shelf Energy Determination," Westinghouse Non-Proprietary Class 3, June 2019 (ADAMS Accession No. ML19170A106).

3. PWROG Topical Report, PWROG-17090-NP, Rev.0, "Generic Rotterdam Forging and Weld Initial Upper-Shelf Energy Determination", March 30, 2018 (ADAMS Accession No. ML18114A183).

4. American Society of Testing and Materials (ASTM) Standard E185-82, "Standard Practice for Conducting Surveillance Tests for Light Water Cooled Nuclear Power Reactor Vessels," 1982.

5. USNRC Regulatory Issue Summary 2014-11, "Information on Licensing Applications for Fracture Toughness Requirements for Ferritic Reactor Coolant Pressure Boundary Components," October 14, 2014 (ADAMS Accession No. ML14149A165).

6. USNRC Regulatory Guide 1.99, Revision 2, "Radiation Embrittlement of Reactor Vessel Materials," May 1988 (ADAMS Accession No. ML003740284).

7. USNRC NUREG-0800, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, Branch Technical Position 5-3, Draft Revision 3. "Fracture Toughness Requirements," September 2018 (ADAMS Accession No. ML18254A090).

Attachment: Comment Resolution Table

Principle Contributor: Christopher R. Sydnor, NRR/DMLR

Date: December 12, 2019

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| TOPICAL REPORT PWROG-17090-NP, REVISION 0<br>COMMENT RESOLUTION TABLE | | | | |
|---|---|---|---|---|
| Comment No. | DSE Text Location | | PWROG Comment | NRC Response |
| | Page No. | Line No. | | |
| 1 | 1 | 27 | Revise the text "SA508, Class 2" to "ASME SA508, Class 2 (or the corresponding ASTM A508, Class 2)". | The staff finds the proposed change acceptable because ASME SA508, Class 2 and ASTM A508, Class 2 are equivalent material specifications, and the change does not affect the staff's findings or conclusions. |
| | 6 | 38 | | |
| | 23 | 37 | | |
| 2 | 8 | 33 | Add "or equal to" after "greater than."<br><br>The text "or equal to" will also be added to the corresponding location in the first sentence in PWROG-17090-NP Section 3.1, Bullet 1 in the NRC-approved version of the topical report that will be issued after the Final SE is issued. This is consistent with discussions in footnote (g) of PWROG-17090-NP Table 5 and footnote (e) of PWROG-17090-NP Table 7. | The staff finds the proposed change acceptable because it ensures technical consistency and does not affect the staff's findings or conclusions. |
| 3 | 8 | 34 & 37 | Revise ">" to "≥" to be consistent with PWROG-17090-NP Section 3.1, Bullet 1. | The staff finds the proposed change acceptable because it ensures technical consistency and does not affect the staff's findings or conclusions. |
| 4 | 12 | 7 & 16 | Add "or equal to" after "greater than." | The staff finds the proposed change acceptable because it ensures technical consistency and does not affect the staff's findings or conclusions. |
| 5 | 22 | 47 | Add "of unirradiated Charpy USE, Cu content, and/or Ni content" after "measured values." | The staff finds the proposed change acceptable because it provides additional clarification for this issue, and it does not affect the staff's findings or conclusions. |
| 6 | 23 | 3 & 8 | Add "or A508, Class 2" after "SA508, Class 2." | The staff finds the proposed change acceptable because these are equivalent material specifications, and the change does not affect the staff's findings or conclusions. |

## ACKNOWLEDGEMENTS

This report was developed and funded by the PWR Owners Group under the leadership of the participating utility representatives of the Materials Committee.

## LEGAL NOTICE



## COPYRIGHT NOTICE



## DISTRIBUTION NOTICE

**PWR Owners Group**
**United States Member Participation* for PA-MSC-1367, Task 3**

| Utility Member | Plant Site(s) | Participant | |
|---|---|---|---|
| | | Yes | No |
| Ameren Missouri | Callaway (W) | | X |
| American Electric Power | D C. Cook 1 & 2 (W) | | X |
| Arizona Public Service | Palo Verde Unit 1, 2, & 3 (CE) | | X |
| Dominion Connecticut | Millstone 2 (CE) | | X |
| | Millstone 3 (W) | | X |
| Dominion VA | North Anna 1 & 2 (W) | X | |
| | Surry 1 & 2 (W) | | X |
| Duke Energy Carolinas | Catawba 1 & 2 (W) | | X |
| | McGuire 1 & 2 (W) | | X |
| | Oconee 1, 2, & 3 (B&W) | | X |
| Duke Energy Progress | Robinson 2 (W) | | X |
| | Shearon Harris (W) | | X |
| Entergy Palisades | Palisades (CE) | | X |
| Entergy Nuclear Northeast | Indian Point 2 & 3 (W) | | X |
| Entergy Operations South | Arkansas 1 (B&W) | | X |
| | Arkansas 2 (CE) | | X |
| | Waterford 3 (CE) | | X |
| Exelon Generation Co. LLC | Braidwood 1 & 2 (W) | | X |
| | Byron 1 & 2 (W) | | X |
| | TMI 1 (B&W) | | X |
| | Calvert Cliffs 1 & 2 (CE) | | X |
| | Ginna (W) | | X |
| FirstEnergy Nuclear Operating Co. | Beaver Valley 1 & 2 (W) | | X |
| | Davis-Besse (B&W) | | X |
| Florida Power & Light \ NextEra | St Lucie 1 & 2 (CE) | | X |
| | Turkey Point 3 & 4 (W) | | X |
| | Seabrook (W) | | X |
| | Pt. Beach 1 & 2 (W) | | X |
| Luminant Power | Comanche Peak 1 & 2 (W) | | X |
| Omaha Public Power District | Fort Calhoun (CE) | | X |
| Pacific Gas & Electric | Diablo Canyon 1 & 2 (W) | | X |
| PSEG – Nuclear | Salem 1 & 2 (W) | | X |
| South Carolina Electric & Gas | V C. Summer (W) | | X |
| So Texas Project Nuclear Operating Co. | South Texas Project 1 & 2 (W) | | X |
| Southern Nuclear Operating Co. | Farley 1 & 2 (W) | | X |
| | Vogtle 1 & 2 (W) | | X |
| Tennessee Valley Authority | Sequoyah 1 & 2 (W) | | X |
| | Watts Bar 1 & 2 (W) | | X |
| Wolf Creek Nuclear Operating Co | Wolf Creek (W) | | X |
| Xcel Energy | Prairie Island 1 & 2 (W) | | X |

* **Project participants as of the date the final deliverable was completed. On occasion, additional members will join a project. Please contact the PWR Owners Group Program Management Office to verify participation before sending this document to participants not listed above.**

**PWR Owners Group**
**International Member Participation* for PA-MSC-1367, Task 3**

| Utility Member | Plant Site(s) | Participant | |
|---|---|---|---|
| | | Yes | No |
| Asociación Nuclear Ascó-Vandellòs | Asco 1 & 2 (W) | | X |
| | Vandellos 2 (W) | | X |
| Axpo AG | Beznau 1 & 2 (W) | | X |
| Centrales Nucleares Almaraz-Trillo | Almaraz 1 & 2 (W) | | X |
| EDF Energy | Sizewell B (W) | | X |
| Electrabel | Doel 1, 2 & 4 (W) | | X |
| | Tihange 1 & 3 (W) | | X |
| Electricite de France | 58 Units | | X |
| Eletronuclear-Eletrobras | Angra 1 (W) | | X |
| Emirates Nuclear Energy Corporation | Barakah 1 & 2 | | X |
| EPZ | Borssele | | X |
| Eskom | Koeberg 1 & 2 (W) | | X |
| Hokkaido | Tomari 1, 2 & 3 (MHI) | | X |
| Japan Atomic Power Company | Tsuruga 2 (MHI) | | X |
| Kansai Electric Co., LTD | Mihama 3 (W) | | X |
| | Ohi 1, 2, 3 & 4 (W & MHI) | | X |
| | Takahama 1, 2, 3 & 4 (W & MHI) | | X |
| Korea Hydro & Nuclear Power Corp. | Kori 1, 2, 3 & 4 (W) | | X |
| | Hanbit 1 & 2 (W) | | X |
| | Hanbit 3, 4, 5 & 6 (CE) | | X |
| | Hanul 3, 4 , 5 & 6 (CE) | | X |
| Kyushu | Genkai 2, 3 & 4 (MHI) | | X |
| | Sendai 1 & 2 (MHI) | | X |
| Nuklearna Electrarna KRSKO | Krsko (W) | | X |
| Ringhals AB | Ringhals 2, 3 & 4 (W) | | X |
| Shikoku | Ikata 1, 2 & 3 (MHI) | | X |
| Taiwan Power Co | Maanshan 1 & 2 (W) | | X |

* **Project participants as of the date the final deliverable was completed. On occasion, additional members will join a project. Please contact the PWR Owners Group Program Management Office to verify participation before sending this document to participants not listed above.**

# TABLE OF CONTENTS

## List of Tables



## List of Figures

**Record of Revisions**

| Revision | Date | Description |
|---|---|---|
| 0 | March 2018 | Original Revision |
| -A | January 2020 | PWROG-17090-NP-A, Revision 0 incorporates the U.S. NRC Final Safety Evaluation at the beginning of the topical report and responses to the Request for Additional Information (RAIs) are in Appendix B. The following changes were made from the original revision of this document:<br>1. The wording in Section 1 of the report was revised per RAI-1 as follows.<br>"... the ***Charpy USE requirements of*** 10 CFR 50, Appendix G requirements do not apply."<br>2. The wording in Section 3.1 of the report was revised per RAI-2 as follows:<br>"The USE is set ***greater than or*** equal to the highest Charpy impact energy value available or, if the highest data point is determined to be a potential 'outlier' or a non-representative data point, the USE is set ***greater than or*** equal to a value less than the highest value based on the average of the comparable preceding data points."<br>3. The wording in Section 3.1 of the report was revised per Comment #2, of the "Topical Report PWROG-17090-NP, Revision 0 Comment Resolution Table" in the NRC safety evaluation as follows:<br>"...at least one shear data point greater than ***or equal to*** 95% ..." |

## List of Acronyms

| | |
|---|---|
| ADAMS | Agencywide Documents Access and Management System |
| ASME | American Society of Mechanical Engineers |
| ASTM | American Society for Testing and Materials (ASTM International) |
| BTP | Branch Technical Position |
| CFR | Code of Federal Regulations |
| CMTR(s) | Certified Material Test Report(s) |
| Cu | Copper |
| CVN | Charpy V-notch |
| LT | Longitudinal |
| Ni | Nickel |
| NRC | Nuclear Regulatory Commission |
| PMO | Project Management Office |
| PWR | Pressurized Water Reactor |
| PWROG | Pressurized Water Reactor Owners Group |
| RIS | Regulatory Issue Summary |
| SAW | Submerged Arc Weld |
| SMAW | Shielded Metal Arc Weld |
| TL | Transverse |
| U.S. | United States |
| USE | Upper-Shelf Energy |
| $\sigma$ | Standard Deviation |

# 1.0 INTRODUCTION

Licensees have been addressing the embrittlement of additional reactor vessel components and welds not previously within the scope of 10 CFR 50, Appendix G [Ref. 1] due to the effects of aging. 10 CFR 50, Appendix G requires that, in the transverse direction, reactor vessel beltline base metal and weld material Upper-Shelf Energy (USE) values be greater than or equal to 75 ft-lb initially, and remain greater than or equal to 50 ft-lb (68 J) throughout the lifetime of the reactor vessel. In Regulatory Issue Summary (RIS) 2014-11 [Ref. 2], the Nuclear Regulatory Commission (NRC) identified a threshold of $1 \times 10^{17}$ n/cm$^2$ (E > 1.0 MeV) for the projected end of life fluence over which the effects of embrittlement must be considered to meet the 10 CFR 50, Appendix G requirement. Extended operating durations associated with license renewals can increase the fluence for components outside the traditional beltline beyond this threshold. It should be noted that prior to exceeding $1 \times 10^{17}$ n/cm$^2$ (E > 1.0 MeV), the Charpy USE requirements of 10 CFR 50, Appendix G requirements do not apply. The materials outside the reactor vessel beltline and extended reactor vessel beltline, i.e. below the $1 \times 10^{17}$ n/cm$^2$ (E > 1.0 MeV) embrittlement threshold during the plant life, were required to meet the American Society of Mechanical Engineers (ASME) Code edition in use at the time of fabrication.

When addressing these additional components for reactor vessels fabricated by the Rotterdam Dockyard Company, some licensees have found it difficult to identify the material information required to establish the initial USE values in accordance with American Society for Testing and Materials (ASTM) E185-82 [Ref. 3], as required by 10 CFR 50, Appendix G. The difficulty in identifying material information stems from significantly less strict testing and reporting requirements at the time of fabrication of the Rotterdam reactor vessels (late 1960's to early 1970's) compared to modern ASME Code requirements.

The objective of this topical report is to provide conservative, generic USE and conservative, generic Copper (Cu) and Nickel (Ni) weight percent values that can be used for Rotterdam reactor vessel welds and forgings when no or limited material information is available. These generic values are developed utilizing data from the surveillance capsule program records and Certified Material Test Reports (CMTRs) available to Westinghouse.

# 2.0 SUMMARY OF RESULTS

After reviewing all available Charpy data for Rotterdam fabricated reactor vessel welds and forgings the following conservative conclusions have been drawn:

- For a forging with insufficient data to determine USE with material supplied by Rheinstahl Huttenwerke AG, a generic lower bound value of 56 ft-lb can be used based on a mean minus 2 standard deviations evaluation. See Section 4.1 for more details.
- For a forging with insufficient data to determine USE with material supplied by Fried-Krupp Huttenwerke AG or with an unknown Rotterdam supplier, a generic lower bound value of 52 ft-lb can be used based on a mean minus 2 standard deviations evaluation. See Section 4.2 for more details.

- For a Rotterdam Submerged Arc Weld (SAW), the USE can be set to a generic lower bound value of 75 ft-lbs, the Cu weight percent can be set to an upper bound value of 0.23, and the Ni weight percent can be set to an upper bound value of 0.56. The generic USE value is based on a mean minus 2 standard deviations evaluation. The generic chemistry values are based on a mean plus 1 standard deviation evaluation. See Section 5.1 for more details.
- For a Rotterdam Shielded Metal Arc Weld (SMAW), the USE can be set to a lower bound value of 72 ft-lbs, the Cu weight percent can be set to an upper bound value of 0.35, and the Ni weight percent can be set to an upper bound value of 1.13. The Cu value is the generic value from Regulatory Guide 1.99, Revision 2 [Ref. 7]. The Ni value is based on a mean plus 1 standard deviation evaluation. These values can also be used if the type of Rotterdam weld is unknown. See Section 5.2 and 5.3 for more details.

# 3.0 METHODOLOGY

Herein, generic USE values are determined based on the mean USE of common components minus 2 standard deviations (σ). The mean USE is based on a review of all Charpy impact energy and shear data. When data is available with reported shear greater than or equal to 95%, the USE values are established in accordance with 10 CFR 50, Appendix G [Ref. 1], which specifies that USE be calculated based on American Society for Testing and Materials (ASTM) E185-82 [Ref. 3]. In this case, USE is calculated based on an interpretation of ASTM E185-82 that is best explained by the most recent version of the ASTM E185 (2016 version).

ASTM E185-16 [Ref. 4], Section 3.1.5, defines the Charpy upper-shelf energy level as the following:

> *[T]he average energy value for all Charpy specimen tests (preferably three or more) whose test temperature is at or above the Charpy upper-shelf onset; specimens tested at temperatures greater than 83°C (150°F) above the Charpy upper-shelf onset shall not be included, unless no data are available between the onset temperature and onset +83°C (+150°F).*

ASTM E185-16 [Ref. 4], Section 3.1.6, defines Charpy upper-shelf onset as the following:

> *[T]he temperature at which the fracture appearance of all Charpy specimens tested is at or above 95% shear.*

Using the above guidelines and in compliance with ASTM E185-82 [Ref. 3], the average of all Charpy data ≥ 95% shear is reported as the USE when the shear data is available. In some instances, there may be data that are deemed 'outliers,' which are data points that are uncharacteristically high or low relative to other data at or above 95% shear. These 'outlier' data points are removed from the determination of the USE based on engineering judgment.

When transverse data do not exist, the methodology in NUREG-0800, Branch Technical Position (BTP) 5-3 [Ref. 5] Position 1.2 is used to estimate the USE. The guidance of NUREG-0800, BTP 5-3 [Ref. 5] Position 1.2, states that when estimating Charpy V-notch (CVN) USE:

> *If tests were only made on longitudinal specimens, the values should be reduced to 65% of the longitudinal values to estimate the transverse properties.*

In many cases, the CVN orientation is not reported in CMTRs. For reactor vessel material fabricated before 1973, such as the Rotterdam materials considered herein, the typical industry practice was to perform CVN tests in the strong direction. In instances where the orientation is not reported, the CVN orientation is conservatively assumed to be in the "strong direction".

Note that the terminology for the orientation of specimens used in this report is consistent with the terminology used in the CMTRs. Thus, "longitudinal" and "tangential" are used interchangeably for the "strong direction," and "transverse" and "axial" are used interchangeably to represent the "weak direction." Table 1 provides the most accurate modern terminology for the strong and weak directions, and Figure 1 provides a comparison of strong and weak direction test specimens.

**Table 1**
**Modern Charpy V-Notch Test Specimen Orientation Terminology**

| Reactor Vessel Material Type | Weak Direction | Strong Direction |
|---|---|---|
| Plate | Transverse (TL) | Longitudinal (LT) |
| Forging | Axial | Tangential |
| General | Normal to Major Working Direction | Parallel to Major Working Direction |

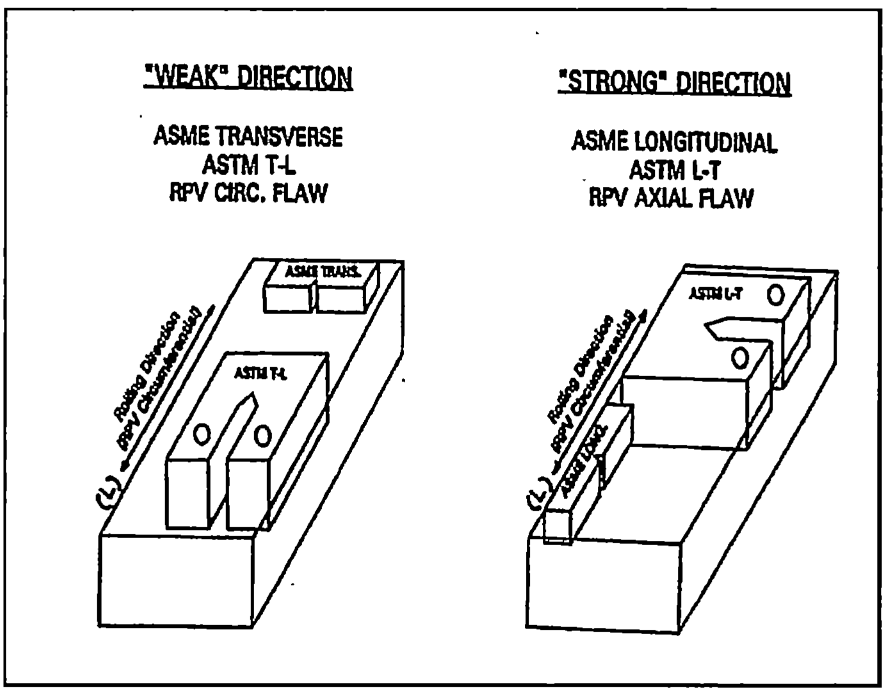


**Figure 1 Comparison of "Weak" Direction and "Strong" Direction Test Specimens**

In some cases there is not enough information to determine the USE according to ASTM E185-82 in either the weak or strong direction. In these cases, engineering judgment is used to determine how to evaluate and utilize the data. The sections below provide the methodology used to review and evaluate the forgings and welds respectively.

## 3.1 EVALUATION OF ROTTERDAM FORGING MATERIAL UPPER-SHELF ENERGY

In order to use the mean USE minus 2 standard deviations (σ) approach, the USE values are determined for all available components. The amount of available CVN data varies depending on the plant and component. In some instances there is enough information to define the USE in the transverse direction using the method of ASTM E185-82. These instances are primarily associated with testing performed to determine the limiting material for inclusion in the reactor vessel surveillance programs. There are other instances where data is only available in the longitudinal direction. In these instances BTP 5-3 [Ref. 5] is utilized to convert the data to transverse data. In other instances, enough data was obtained to develop a full Charpy curve, but shear values were not recorded. Finally, some CVN data does not report the shear and/or stops at approximately room temperature (~70°F). In these cases, insufficient data is available to determine the USE, and only approximations based on the data are available. The following discussion explains how different specific situations are addressed.

- If the CVN dataset contains at least one shear data point greater than or equal to 95%, but some data points report no shear, all data points with an impact-energy approximately equal to or greater than the impact energy of the shear data points known to be ≥ 95% are assumed to have greater than or equal to 95% shear. All non-outlier data points with known or assumed shear at ≥ 95% are averaged to determine the USE and incorporated into the calculation of the generic USE.
- If the CVN dataset contains limited or no shear data, however, the upper shelf can clearly be determined from the data provided (through visual inspection), the USE is identified and incorporated into the calculation of the generic USE. The USE is identified by an approximately constant energy vs. temperature region. For example, in some cases, data points at four temperatures over a 50°F range exhibited energy values within a 10 ft-lb scatter or less. The existence of the upper-shelf region is confirmed by plotting the impact energy data and identifying if the plot levels off at higher temperatures. The USE represents an average of all Charpy energy values considered to be in the upper-shelf region.
- If the CVN dataset reports shear values, but all data indicates a shear less than 95%, the USE is reported as greater than or equal to the maximum reported CVN impact energy, and is not incorporated into the calculation of the generic USE.
- If the CVN dataset included limited shear data or did not include shear data and Charpy impact energies are increasing throughout the temperature range available, it is unknown if the upper shelf has been reached. The USE values are conservatively determined based on the information available and the actual USE values may be higher. The USE is set greater than or equal to the highest Charpy impact energy value available or, if the highest data point is determined to be a potential 'outlier' or a non-representative data point, the USE is set greater than or equal to a value less than the highest value based on the average of the comparable preceding data points. In these instances, the USE is not incorporated into the calculation of the generic USE.

### 3.2 EVALUATION OF ROTTERDAM WELD MATERIALS UPPER-SHELF ENERGY AND CHEMISTRY

Rotterdam-supplied CMTRs which contain data on weld materials used in the fabrication of vessels by Rotterdam do not consistently specify where the materials were used. The CMTRs often contain Charpy impact data at a limited number of temperatures or at a single temperature. The industry practice at the time of fabrication of the Rotterdam reactor vessels (late 1960's to early 1970's) was to test Charpy specimens at 10°F to show 30 ft-lbs or more of absorbed energy, and the test information contained in the CMTRs was considered sufficient to satisfy the fracture toughness requirements of ASME Code at the time. Since this amount of information is not sufficient to determine a USE, and there exist instances where the weld heat is not identified for a specific weld seam, a generic USE is developed herein.

The Rotterdam CMTRs identify two types of welds used in the fabrication of the vessels, shielded metal arc welds (SMAW) and submerged arc welds (SAW). Each weld type is addressed separately.

The generic USE value for the SAWs is the mean minus 2 standard deviations ($\sigma$) value of the initial USE of the surveillance welds for all Rotterdam fabricated vessels. Outside of the baseline measurements for the reactor vessel surveillance programs, no USE information is available for Rotterdam SAW materials. As discussed previously, the weld material was typically tested at only one temperature, and insufficient data exists to determine the USE with accuracy. Therefore, only the results relevant to the reactor vessel surveillance capsule program unirradiated testing at Rotterdam and Westinghouse can be used to determine the generic USE for an unirradiated Rotterdam SAW material. The surveillance capsule programs contain weld specimens which represent every Rotterdam SAW heat vendor and every Rotterdam flux type (although not every heat-flux type combination is represented). The core region welds had the same specification requirements as the other reactor vessel welds; however, for the core region welds, Rotterdam was required to "aim for" both a Charpy V-Notch Transition Temperature ($T_{CV}$) and a Nil-Ductility Transition Temperature (NDTT) less than 10°F and to furnish additional test results relevant to $T_{CV}$ and NDTT. Both the $T_{CV}$ and NDTT do not occur near the upper-shelf region, and thus, the surveillance capsule program test results are generically representative of the SAWs produced at Rotterdam for USE calculations. Note that Linde 80 flux type welds are intentionally excluded from this analysis, as these welds have been analyzed generically previously (e.g., Reference 6), and the use of this flux type is believed to be applicable only to two of the Rotterdam fabricated reactor vessels.

The generic USE value for SMAWs deviates from the mean minus 2 standard deviations approach previously discussed, because the SMAWs Charpy tests typically do not provide enough information to determine a USE. Instead of a true USE value, a lower bound USE value is developed for each component based on the available information. If no shear is available, the lower bound USE is reported as the average of the Charpy impact energies at the test temperature, typically around 10°F. When shear values are reported and each is less than 95%, then the maximum Charpy impact energy value is reported. The generic USE value for SMAWs is then based on analysis of the lower bound USE data and corresponding shear data, as available. By reporting the USE in this manner, a conservative representation of the USE for SMAWs is provided based on the lowest possible value of USE.

In addition to the generic USE, the generic chemistry, i.e., Cu and Ni weight percentages, is

determined for both SAWs and SMAW based on the mean plus 1σ. This method is based on Regulatory Guide 1.99, Revision 2 [Ref. 7], which states that conservative chemistry estimates are a mean plus one standard deviation. If a common heat-flux type combination is shared between multiple welds, the average chemistry value for the heat is considered as one data point when determining the generic weld chemistry values as not to assign undue weight to the material, since it is representative of just one heat-flux type combination. The chemistry data used in the evaluation consists of the measurements from the reactor vessel surveillance program, supplemented with all available chemistry data for heats outside the surveillance programs. The data is limited to deposited weld chemistry results, unless otherwise noted. The chemistry analysis of the bare weld wire is excluded, as the deposition process can affect the chemistry of the weld.

# 4.0 GENERIC ROTTERDAM FORGING UPPER-SHELF ENERGY

This section reviews all Rotterdam reactor vessel forgings, including the supplier responsible for the forging, the USE in the strong direction ("known" and estimated), the estimated USE values in the weak direction determined using BTP 5-3 Position 1.2 [Ref. 5], and the USE values in the weak direction determined from the original CMTR data.

The data herein is evaluated using the guidance of 10 CFR 50.61 [Ref. 8], which states:

> *Data from reactor vessels fabricated to the same material specification in the same shop as the vessel in question and in the same time period is an example of "generic data."*

For the purposes of this evaluation, "same shop" is considered to be the same supplier responsible for the forging. Table 2 breaks down the vessel components according to the responsible supplier. Note that all reactor vessel head materials considered herein are the original plant materials.

**Table 2**
**Summary of Rotterdam Forging Suppliers**

| Supplier | Number of Components | Number of Materials with "Known" Strong-Direction USE[a] | Number of Materials with "Known" Weak-Direction USE[a] | Number of Nozzles |
|---|---|---|---|---|
| Rheinstahl Huttenwerke AG | 38 | 9 | 10 | 16 |
| Klöckner-Werke AG | 8 | 8 | 2 | 0 |
| Fried-Krupp Huttenwerke AG | 67 | 38 | 5 | 47 |
| Terni | 6 | 2 | 0 | 0 |
| Unknown | 2 | 0 | 0 | 1 |
| Marrèl-Freres | 2 | 0 | 0 | 2 |

Table 2 note contained on following page.

Table 2 Note:

a. "Known" USE values are those which could be positively identified with ≥ 95% shear values or visually. These USE values are not marked with a ≥ symbol in the following tables in this section. See the following tables and Section 3.1 for more details.

## 4.1 RHEINSTAHL HUTTENWERKE AG

Table 3 contains the forgings procured from Rheinstahl Huttenwerke AG. All forgings were manufactured to the ASTM A508, Class 2 specification and were manufactured in the late 1960s and early 1970s timeframe. Note, for USE values preceded by a "≥" symbol, the listed USE value is conservatively determined based on the information available, and the actual USE value may be higher.

Table 4 statistically evaluates the USE data for all Rheinstahl Huttenwerke AG supplied forgings. In Table 4, the mean weak-direction USE determined using BTP 5-3 estimates is identical to the USE determined using known weak-direction data. The mean minus 2 standard deviation weak-direction USE value utilizing actual weak-direction data is lower than the corresponding BTP 5-3 value due to a larger standard deviation. A value of 56 ft-lbs, corresponding to the measured weak data mean minus two standard deviations, is conservative for use when USE cannot be determined from available data for a Rheinstahl Huttenwerke AG forging as this value also bounds the BTP 5-3 mean minus two standard deviations value. The results indicate that the generic unirradiated USE in the weak-direction minus two standard deviations is greater than the 10 CFR 50, Appendix G [Ref. 1] criterion for a minimum irradiated USE of 50 ft-lbs.

The value of 56 ft-lbs is taken from the "known USE" column. Theses "known" values are identified as the values in Table 3 which do not include a "≥". This value is more appropriate than the values in the "known and estimated" USE column as the estimated data is incomplete and represents an unnecessary penalty on the generic value. The "known and estimated" USE data is shown for information, and is not recommended for use as it contains a significant amount of data that may not represent the actual USE for Rheinstahl Huttenwerke AG forgings. The "estimated" USE suppresses the mean and increases the standard deviation as a result of intentional conservatism and incomplete data.

**Table 3**
**Summary of Rheinstahl Huttenwerke AG Forgings USE Data[(a)]**

| Plant | Component | Upper-Shelf Energy (ft-lbs) | | |
|---|---|---|---|---|
| | | Strong Direction[(b)] | BTP 5-3[(c)] | Weak Direction |
| Plant A | Head Flange | 128 | 83 | N/A |
| Plant B | Head Flange | ≥ 141 | ≥ 92 | N/A |
| | Vessel Flange | ≥ 163 | ≥ 106 | N/A |
| | Upper Shell | 143[(d)] | 93 | 111[(d)] |
| | Intermediate Shell | 119[(d)] | 77 | 75[(d)] |
| | Lower Shell | 116[(e)] | 75 | 64[(e)] |
| | Bottom Head Ring | ≥ 113 | ≥ 73 | N/A |
| Plant C | Head Flange | ≥ 142 | ≥ 92 | N/A |
| | Vessel Flange | ≥ 156 | ≥ 101 | N/A |
| | Upper Shell | ≥ 105 | ≥ 68 | N/A |
| | Intermediate Shell | 133[(e)] | 86 | 88[(e)] |
| | Lower Shell | 137[(d)] | 89 | 98[(d)] |
| | Bottom Head Ring | ≥ 113 | ≥ 73 | N/A |
| Plant D | Upper Shell | ≥ 87 | ≥ 57 | N/A |
| | Intermediate Shell | ≥ 82 | ≥ 53 | N/A |
| | Lower Shell | 135[(e)] | 88 | 77[(e)] |
| | Inlet Nozzle 09 | ≥ 72 | ≥ 47 | N/A |
| | Inlet Nozzle 10 | ≥ 98 | ≥ 64 | N/A |
| | Inlet Nozzle 11 | ≥ 60[(f)] | ≥ 39[(f)] | N/A |
| | Outlet Nozzle 12 | ≥ 89 | ≥ 58 | N/A |
| | Outlet Nozzle 13 | ≥ 98 | ≥ 64 | N/A |
| | Outlet Nozzle 14 | ≥ 60[(f)] | ≥ 39[(f)] | N/A |

**Table 3**
**Summary of Rheinstahl Huttenwerke AG Forgings USE Data[(a)]**

| Plant | Component | Upper-Shelf Energy (ft-lbs) | | |
|---|---|---|---|---|
| | | Strong Direction[(b)] | BTP 5-3[(c)] | Weak Direction |
| Plant E | Upper Shell | ≥ 68[(f)] | ≥ 44[(f)] | N/A |
| | Intermediate Shell | ≥ 99 | ≥ 64 | 91[(d)] |
| | Lower Shell | 135[(e)] | 88 | 85[(e)] |
| | Inlet Nozzle 09 | ≥ 109 | ≥ 71 | N/A |
| | Inlet Nozzle 10 | ≥ 89 | ≥ 58 | N/A |
| | Inlet Nozzle 11 | ≥ 80 | ≥ 52 | N/A |
| | Outlet Nozzle 12 | ≥ 101 | ≥ 66 | N/A |
| | Outlet Nozzle 13 | ≥ 90 | ≥ 59 | N/A |
| | Outlet Nozzle 14 | ≥ 90 | ≥ 59 | N/A |
| Plant F | Upper Shell | ≥ 87 | ≥ 57 | N/A |
| | Intermediate Shell | 115[(e)] | 75 | 72[(e)] |
| | Lower Shell | ≥ 112 | ≥ 73 | 80[(d)] |
| | Inlet Nozzle 09 | ≥ 72 | ≥ 47 | N/A |
| | Outlet Nozzle 12 | ≥ 93 | ≥ 60 | N/A |
| | Outlet Nozzle 13 | ≥ 64[(f)] | ≥ 42[(f)] | N/A |
| | Outlet Nozzle 14 | ≥ 113 | ≥ 73 | N/A |

Table 3 Notes:

a. All USE values are determined by averaging available Charpy energy values with reported shear ≥ 95% (from CMTRs and surveillance program baseline reports, etc., as available) per ASTM E185-82 methods, unless otherwise noted. "N/A" indicates the information is not available.

b. The Charpy data identified with a "≥" symbol included limited shear data or did not include shear data, and it is unknown if the upper shelf has been reached, since Charpy impact energies are increasing throughout the temperature range available For USE values preceded with a "≥" symbol the USE is set equal to a value less than or equal to the highest CVN value available. For USE values preceded with a "≥" symbol the listed USE value is conservatively determined based on the information available, the actual USE value is likely higher.

c. NRC Branch Technical Position (BTP) 5-3 [Ref. 5] Position 1.2 was utilized to convert strong-direction USE data to weak-direction USE data by reducing the strong-direction energy values to 65% of the reported values.

d USE determination includes data taken from supplemental Westinghouse test records associated with the surveillance capsule program.

e. USE is the average of all available Charpy energy values with reported shear ≥ 95% per ASTM E185-82 methods. Charpy data included data taken from Reactor Vessel Surveillance Programs baseline test reports.

f. This USE value likely does not provide an accurate representation of USE The actual USE is likely much higher since a Charpy test with a similar absorbed energy has a shear value much less than 95%. Therefore, this data point is excluded from the statistical analysis.

**Table 4**
**Statistical Analysis of Rheinstahl Huttenwerke AG Forgings[a]**

| | Known USE | | | Known and Estimated USE | | |
|---|---|---|---|---|---|---|
| | **Strong Direction** | **BTP 5-3** | **Weak Direction** | **Strong Direction** | **BTP 5-3** | **Weak Direction** |
| *Mean* | 129 | 84 | 84 | 110 | 72 | 84 |
| *Standard Deviation* | 10 | 7 | 14 | 24 | 16 | 14 |
| *Mean - 2σ* | 109 | 70 | **56** | 62 | 40 | **56** |
| | | | | | | |
| *Maximum* | 143 | 93 | 111 | 163 | 106 | 111 |
| *Minimum* | 115 | 75 | 64 | 72 | 47 | 64 |
| *# of Components Included* | 9 | | 10 | 34 | | 10 |

Table 4 Note:

a. Statistical analysis of Table 3 values, unless the value is noted as excluded. "Estimated" values are identified with a "≥" symbol.

## 4.2 FRIED-KRUPP HUTTENWERKE AG FORGINGS

Table 5 contains the forgings procured from Fried-Krupp Huttenwerke AG. All forgings were manufactured to the ASTM A508, Class 2 specification or the corresponding ASME SA508, Class 2 specification and were manufactured in the late 1960s and early 1970s timeframe. Note, for USE values preceded by a "≥" symbol, the listed USE value is conservatively determined based on the information available, and the actual USE value may be higher.

Table 6 statistically evaluates the USE data for all Fried-Krupp Huttenwerke AG supplied forgings. In Table 6, the mean known weak-direction USE is greater than the weak-direction USE based on BTP 5-3 estimates. The mean minus two standard deviation weak-direction USE value utilizing actual weak-direction data is lower than the corresponding BTP 5-3 value due to a larger standard deviation. A value of 52 ft-lbs, corresponding to the measured weak data mean minus two standard deviations is conservative for use when USE cannot be determined from available data for a Fried-Krupp Huttenwerke AG forging as this value also bounds the BTP 5-3 mean minus two standard deviations value. The results indicate that the generic unirradiated USE in the weak-direction minus two standard deviations is greater than the 10 CFR 50, Appendix G [Ref. 1] criterion for a minimum irradiated USE of 50 ft-lbs.

The value of 52 ft-lbs is taken from the "known USE" column. These "known" values are identified as the values in Table 5 which do not include a "≥". This value is more appropriate than the values in the "known and estimated" USE column as the estimated data is incomplete and represents an unnecessary penalty on the generic value. The "known and estimated" USE data is shown for information, and is not recommended for use as it contains a significant amount of data that may not represent the actual USE for Fried-Krupp Huttenwerke AG forgings. The "estimated" USE suppresses the mean and increases the standard deviation as a result of intentional conservatism and incomplete data.

**Table 5**
**Summary of Fried-Krupp Huttenwerke AG Forgings USE Data[(a)]**

| Plant | Component | Upper-Shelf Energy (ft-lbs) Strong Direction[(b)] | BTP 5-3[(c)] | Weak Direction |
|---|---|---|---|---|
| Plant A | Intermediate Shell | 128[(d)] | 83 | 62[(d)] |
| | Lower Shell | 136 | 88 | 111[(e)] |
| | Bottom Head Ring | 162 | 105 | N/A |
| | Inlet Nozzle 11 | ≥ 113[(f)] | ≥ 73 | N/A |
| | Inlet Nozzle 12 | 126 | 82 | N/A |
| | Inlet Nozzle 13 | ≥ 126[(f)] | ≥ 82 | N/A |
| | Inlet Nozzle 14 | 137 | 89 | N/A |
| | Outlet Nozzle 15 | 119[(h)] | 77 | N/A |
| | Outlet Nozzle 16 | 121[(h)] | 79 | N/A |
| | Outlet Nozzle 17 | 141 | 92 | N/A |
| | Outlet Nozzle 18 | ≥ 104[(f)] | ≥ 68 | N/A |
| Plant B | Inlet Nozzle 11 | ≥ 106 | ≥ 69 | N/A |
| | Inlet Nozzle 12 | ≥ 93 | ≥ 60 | N/A |
| | Inlet Nozzle 13 | ≥ 119 | ≥ 77 | N/A |
| | Inlet Nozzle 14 | ≥ 106 | ≥ 69 | N/A |
| | Outlet Nozzle 15 | ≥ 92 | ≥ 60 | N/A |
| | Outlet Nozzle 16 | ≥ 84 | ≥ 55 | N/A |
| | Outlet Nozzle 17 | ≥ 109 | ≥ 71 | N/A |
| | Outlet Nozzle 18 | ≥ 127 | ≥ 83 | N/A |
| Plant C | Inlet Nozzle 11 | ≥ 79 | ≥ 51 | N/A |
| | Inlet Nozzle 12 | ≥ 109 | ≥ 71 | N/A |
| | Inlet Nozzle 13 | ≥ 113 | ≥ 73 | N/A |
| | Inlet Nozzle 14 | 134[(h)] | 87 | N/A |
| | Outlet Nozzle 15 | ≥ 86 | ≥ 56 | N/A |
| | Outlet Nozzle 16 | ≥ 77 | ≥ 50 | N/A |
| | Outlet Nozzle 17 | ≥ 106 | ≥ 69 | N/A |
| | Outlet Nozzle 18 | ≥ 144 | ≥ 94 | N/A |
| Plant D | Head Flange | ≥ 173 | ≥ 112 | N/A |
| | Vessel Flange | 152[(h)] | 99 | N/A |
| Plant E | Vessel Flange | ≥ 166 | ≥ 108 | N/A |

**Table 5**
**Summary of Fried-Krupp Huttenwerke AG Forgings USE Data[a]**

| Plant | Component | Upper-Shelf Energy (ft-lbs) | | |
|---|---|---|---|---|
| | | Strong Direction[b] | BTP 5-3[c] | Weak Direction |
| Plant F | Head Flange | ≥ 130 | ≥ 85 | N/A |
| | Vessel Flange | ≥ 146 | ≥ 95 | N/A |
| Plant G | Head Flange | 146 | 95 | N/A |
| | Vessel Flange | 211 | 137 | N/A |
| | Intermediate Shell | 148[d][e] | 96 | 110[d][e] |
| | Lower Shell | 156 | 101 | 123[e] |
| | Bottom Head Ring | 162 | 105 | N/A |
| | Inlet Nozzle 11 | 121 | 79 | N/A |
| | Inlet Nozzle 12 | 103 | 67 | N/A |
| | Inlet Nozzle 13 | 94 | 61 | N/A |
| | Inlet Nozzle 14 | 133 | 86 | N/A |
| | Outlet Nozzle 15 | 139 | 90 | N/A |
| | Outlet Nozzle 16 | 110 | 72 | N/A |
| | Outlet Nozzle 17 | 129 | 84 | N/A |
| | Outlet Nozzle 18 | ≥ 129[f] | ≥ 84 | N/A |
| Plant H | Head Flange | 158[g] | 103 | N/A |
| | Lower Shell | 153 | 99 | N/A |
| | Bottom Head Ring | ≥ 110 | ≥ 72 | N/A |
| | Inlet Nozzle 11 | 133[h] | 86 | N/A |
| | Inlet Nozzle 12 | 132[h] | 86 | N/A |
| | Inlet Nozzle 13 | 125[h] | 81 | N/A |
| | Inlet Nozzle 14 | 117[h] | 76 | N/A |
| | Outlet Nozzle 15 | 130[h] | 85 | N/A |
| | Outlet Nozzle 16 | 137[h] | 89 | N/A |
| | Outlet Nozzle 17 | 125[h] | 81 | N/A |
| | Outlet Nozzle 18 | ≥ 111 | ≥ 72 | N/A |
| Plant I | Head Flange | 156[h] | 101 | N/A |
| | Vessel Flange | 173[h] | 112 | N/A |
| | Intermediate Shell | 150[d] | 98 | 94[d] |
| | Bottom Head Ring | ≥ 110 | ≥ 72 | N/A |
| | Inlet Nozzle 11 | 144[g] | 94 | N/A |
| | Inlet Nozzle 12 | ≥ 130[f] | ≥ 85 | N/A |
| | Inlet Nozzle 13 | 134[g] | 87 | N/A |
| | Outlet Nozzle 15 | 122[h] | 79 | N/A |
| | Outlet Nozzle 16 | ≥ 104 | ≥ 68 | N/A |
| | Outlet Nozzle 17 | 118[g] | 77 | N/A |
| | Outlet Nozzle 18 | ≥ 129 | ≥ 84 | N/A |

Table 5 notes contained on following page.

Table 5 Notes:

a. All USE values are determined by averaging available Charpy energy values with reported shear ≥ 95% (from CMTRs and surveillance program baseline reports, etc., as available) per ASTM E185-82 methods, unless otherwise noted "N/A" indicates the information is not available.

b. Unless otherwise noted, the Charpy data identified with a "≥" symbol included limited shear data or did not include shear data, and it is unknown if the upper shelf has been reached, since Charpy impact energies are increasing throughout the temperature range available For USE values preceded with a "≥" symbol the USE is set equal to a value less than or equal to the highest CVN value available. For USE values preceded with a "≥" symbol the listed USE value is conservatively determined based on the information available, the actual USE value is likely higher.

c. NRC Branch Technical Position (BTP) 5-3 [Ref. 5] Position 1.2 was utilized to convert strong-direction USE data to weak-direction USE data by reducing the strong-direction energy values to 65% of the reported values.

d. USE is the average of all available Charpy energy values with reported shear ≥ 95% per ASTM E185-82 methods. Charpy data included data taken from Reactor Vessel Surveillance Programs baseline test reports.

e. USE determination includes data taken from supplemental Westinghouse test records associated with the surveillance capsule program.

f. All reported shear values are less than 95% shear. The reported value is less than or equal to the maximum energy value of a specimen with less than 95% shear As a result, the USE is higher than the CVN data reported.

g. USE includes averaged data points without a reported shear but assumed to be ≥ 95% shear based on comparison of the CVN data points known to be at ≥ 95% shear for the same material.

h. The dataset contained limited or no shear data; however, the USE could clearly be determined from the data provided. For this material, the upper shelf could be identified as a result of the existence of an approximately constant energy vs. temperature region. This USE represents an average of all Charpy energy values considered to be in the upper shelf region.

**Table 6**
**Statistical Analysis of Fried-Krupp Huttenwerke AG Forgings[(a)]**

| | **Known USE** | | | **Known and Estimated USE** | | |
|---|---|---|---|---|---|---|
| | **Strong Direction** | **BTP 5-3** | **Weak Direction** | **Strong Direction** | **BTP 5-3** | **Weak Direction** |
| *Mean* | 137 | 89 | 100 | 128 | 83 | 100 |
| *Standard Deviation* | 21 | 14 | 24 | 25 | 16 | 24 |
| *Mean - 2σ* | 95 | 61 | **52** | 78 | 51 | **52** |
| | | | | | | |
| *Maximum* | 211 | 137 | 123 | 211 | 137 | 123 |
| *Minimum* | 94 | 61 | 62 | 77 | 50 | 62 |
| *# of Components Included* | 38 | | 5 | 67 | | 5 |

Table 6 Note:

a. Statistical analysis of Table 5 values. "Estimated" values are identified with a "≥" symbol.

## 4.3 ROTTERDAM FORGINGS FROM OTHER OR UNKNOWN SUPPLIERS

Table 7 contains the forgings produced from suppliers other than Rheinstahl Huttenwerke AG or Fried-Krupp Huttenwerke AG. All forgings were manufactured to the ASTM A508, Class 2 specification or the corresponding ASME SA508, Class 2 specification and were manufactured in the late 1960s and early 1970s timeframe. As can be seen from the results, a generic USE is not required for any of these components. All components have a USE determined with ASTM E185-82 or the USE is able to be conservatively estimated to be significantly greater than the 10 CFR 50, Appendix G USE criterion for a minimum irradiated USE of 50 ft-lb for operating plants. Based on the data in Table 7 and the generic values determined for Rheinstahl Huttenwerke AG or Fried-Krupp Huttenwerke AG forgings, a Rotterdam forging with an unknown supplier from the late 1960's or early 1970's timeframe will have a USE value of at least 52 ft-lbs, the minimum generic value determined in this report for Rotterdam forgings.

**Table 7**
**Summary of Rotterdam Forgings from Other or Unknown Suppliers USE Data[(a)]**

| Plant | Component | Supplier | Upper-Shelf Energy (ft-lbs) | | |
|---|---|---|---|---|---|
| | | | Strong Direction[(b)] | BTP 5-3[(c)] | Weak Direction |
| Plant A | Closure Head Ring | Terni | 148 | 96 | N/A |
| | Vessel Flange | Klöckner-Werke AG | 156[(d)] | 101 | N/A |
| | Upper Shell | Klöckner-Werke AG | 152 | 99 | N/A |
| Plant B | Top Head Ring | Terni | ≥ 126 | ≥ 82 | N/A |
| Plant C | Top Head Ring | Terni | ≥ 126 | ≥ 82 | N/A |
| Plant E | Head Flange | Unknown | ≥ 144 | ≥ 94 | N/A |
| Plant F | Inlet Nozzle 10 | Marrèl-Freres | ≥ 118 | ≥ 77 | N/A |
| | Inlet Nozzle 11 | Marrèl-Freres | ≥ 115 | ≥ 75 | N/A |
| Plant G | Closure Head Ring | Terni | 148 | 96 | N/A |
| | Upper Shell | Klöckner-Werke AG | 144 | 94 | N/A |
| Plant H | Closure Head Ring | Terni | ≥ 155 | ≥ 101 | N/A |
| | Vessel Flange | Klöckner-Werke AG | 235[(e)] | 153 | N/A |
| | Upper Shell | Klöckner-Werke AG | 156 | 101 | N/A |
| | Intermediate Shell | Klöckner-Werke AG | 161[(f)] | 105 | 134[(f)] |
| Plant I | Closure Head Ring | Terni | ≥ 155 | ≥ 101 | N/A |
| | Upper Shell | Klöckner-Werke AG | 156 | 101 | N/A |
| | Lower Shell | Klöckner-Werke AG | 151 | 98 | 141[(g)] |

Table 7 notes contained on following page.

Table 7 Notes:

a. All USE values are determined by averaging available Charpy energy values with reported shear ≥ 95% (from CMTRs and surveillance program baseline reports, etc., as available) per ASTM E185-82 methods, unless otherwise noted. "N/A" indicates the information is not available

b. The Charpy data identified with a "≥" symbol included limited shear data or did not include shear data, and it is unknown if the upper shelf has been reached, since Charpy impact energies are increasing throughout the temperature range available. For USE values preceded with a "≥" symbol the USE is set equal to a value less than or equal to the highest CVN value available. For USE values preceded with a "≥" symbol the listed USE value is conservatively determined based on the information available; the actual USE value is likely higher.

c. NRC Branch Technical Position (BTP) 5-3 [Ref 5] Position 1.2 was utilized to convert strong-direction USE data to weak-direction USE data by reducing the strong-direction energy values to 65% of the reported values.

d. The dataset contained limited or no shear data, however, the USE could clearly be determined from the data provided. For this material, the upper shelf could be identified as a result of the existence of an approximately constant energy vs. temperature region. This USE represents an average of all Charpy energy values considered to be in the upper shelf region.

e. USE includes averaged data points without a reported shear but assumed to be ≥ 95% shear based on comparison of the CVN data points known to be at ≥ 95% shear for the same material.

f. USE is the average of all available Charpy energy values with reported shear ≥ 95% per ASTM E185-82 methods. Charpy data included data taken from Reactor Vessel Surveillance Programs baseline test reports.

g. USE determination includes data taken from supplemental Westinghouse test records associated with the surveillance capsule program.

## 4.4 NOZZLE UPPER-SHELF ENERGY VALUE APPLICABILITY

Since the geometry and size of nozzle forgings is different from the beltline forgings, the Rotterdam nozzle forging USE data statistics are compared to USE data statistics for all Rotterdam forgings in Table 8. No evaluation on measured weak-direction data is provided, because no measured weak-direction Charpy data is available for Rotterdam nozzle forgings.

An evaluation of Table 8 indicates that the mean of the nozzle forging USE data tend to be less than the mean of all forging USE data; however, the nozzle USE data have less scatter, which decreases the standard deviation. As a result, the mean minus two standard deviations are in good agreement when comparing the "known" USE for all Rotterdam forgings and the "known" USE for nozzle forgings. It is concluded that the forging USE values calculated herein based on all available Rotterdam forgings are applicable to the Rotterdam nozzle forgings.

Note that most of the nozzle forgings were supplied by Fried-Krupp Huttenwerke AG. A comparison of the results for all Fried-Krupp forgings in Table 6 and those for all Rotterdam forgings in Table 8 shows no difference in the mean minus 2 standard deviations results for the BTP 5-3 analyses. This observation provides further justification of the applicability of the generic USE to the nozzles.

**Table 8**
**Statistical Analysis Comparing All Rotterdam Forgings to the Rotterdam Nozzle Forgings**

| | All Components, Known USE | | Nozzles, Known USE | |
|---|---|---|---|---|
| | **Strong Direction** | **BTP 5-3** | **Strong Direction** | **BTP 5-3** |
| *Mean* | 140 | 91 | 126 | 82 |
| *Standard Deviation* | 23 | 15 | 12 | 8 |
| *Mean - 2σ* | 94 | 61 | 102 | 66 |
| | | | | |
| *Maximum* | 235 | 153 | 144 | 94 |
| *Minimum* | 94 | 61 | 94 | 61 |
| *# of Components Included* | 57 | | 24 | |

# 5.0 GENERIC ROTTERDAM WELD UPPER-SHELF ENERGY AND CHEMISTRY

The Rotterdam CMTRs identify two types of welds that were used in the fabrication of Rotterdam vessels, shielded metal arc welds (SMAWs) and submerged arc welds (SAWs). Each weld type is addressed separately in the following sections. Note that the weld type and vendor names are taken as written directly from the original records.

## 5.1 SUBMERGED ARC WELD (SAW)

This section analyzes the SAW materials available to Westinghouse and utilized by Rotterdam for the manufacturing of reactor vessels with the exception of the welds with Linde 80 flux type. Linde 80 flux type welds are excluded from this analysis and discussion, because these welds have been thoroughly analyzed previously (e.g., Reference 6). In addition, only one U.S. PWR site is believed to have Rotterdam fabricated reactor vessels which utilized the Linde 80 flux type. Thus, these materials are not considered generically for Rotterdam materials herein. Table 9 contains all available USE data for the non-Linde 80 surveillance welds produced by Rotterdam. No USE data is available outside of the reactor vessel surveillance program welds. Table 10 contains the surveillance program chemistry supplemented with all available chemistry data for SAW heats not included in the surveillance programs. The chemistry is based on measurements of the deposited weld chemistry, unless otherwise noted in Table 10.

Table 11 evaluates the USE data for all available Rotterdam SAWs. The results indicate that the average Rotterdam SAW USE minus two standard deviations of 75 ft-lbs is greater than the 10 CFR 50, Appendix G [Ref. 1] minimum irradiated USE screening criterion for operating plants (50 ft-lbs). It is also noted that all measured values are greater than the mean minus two standard deviations value of 75 ft-lbs. This conservative generic value of 75 ft-lbs can be utilized for Rotterdam SAWs when insufficient data is available to determine a weld-specific USE value.

Table 11 provides generic values of 0.23 Cu weight percent and 0.56 Ni weight percent based on a mean plus 1$\sigma$. This method is based on Regulatory Guide 1.99, Revision 2, which states that conservative chemistry estimates are a mean plus one standard deviation. If a common heat-flux type combination is shared between multiple welds, the average chemistry value for the heat is considered as one data point when determining the generic weld values as not to assign undue weight to the material, since it is representative of just one heat-flux type combination. The generic weight percent values of 0.23 for Cu and 0.56 for Ni can be utilized for Rotterdam SAWs when insufficient data is available to determine weld-specific chemistry values.

**Table 9**
**Available Rotterdam SAW USE Data**

| Plant(s) | Weld Vendor | Flux Type | USE[a] (ft-lbs) |
|---|---|---|---|
| Plant A, Plant G Plant H, & Plant I | Hoesch | LW320 | 129 |
| Plant B | Smit-Weld | SAF89 | 112 |
| Plant C | Arco Chem | SAF89 | 110 |
| Plant D | Westf. U | SAF89 | 128 |
| Plant E | Smit-Weld | SAF89 | 95 |
| Plant F | Phonix U | LW320 | 109 |
| Plant J | Bohler | LW320 | 82 |

Table 9 Note:

a. The USE value is the average of all available absorbed energy values with a shear ≥ 95% per standard ASTM E185-82 methodology. See Section 3 0 for additional details.

**Table 10**
**Available Rotterdam SAW Chemistry Data**

| Heat | Weld Vendor | Flux Type | Lot | Cu Lot Averaged[a] (wt. %) | Cu Heat Averaged (wt. %) | Ni Lot Averaged[a] (wt. %) |
|---|---|---|---|---|---|---|
| 25531 | Smit-Weld | SAF89 | 01211 | 0.10 | 0.10 | 0.18 |
| 716126 | Phonix U | LW320 | 26 | 0.10 | 0.10 | 0.05 |
| 25295 | Smit-Weld | SAF89 | 01103 | 0.33 | 0.29 | 0.17 |
| | | | 01135 | 0.25 | | N/A |
| | | | 01170 | 0.30 | | N/A |
| 4278 | Arco Chem | SAF89 | 01211 | 0.12 | 0.12 | 0.11 |
| 0227 | Bohler | LW320 | 14 | 0.19 | 0.19 | 0.56 |
| 895075 | Hoesch | LW320 | P46 | 0.04 | 0.036 | 0.72 |
| 899680 | Hoesch | LW320 | P23 | 0.03 | 0.03 | 0.75 |
| 1725 | Westf. U | SAF89 | 02275 | 0.11 | 0.11 | 0.12 |
| 801 | Arco Chem | SAF89 | 01180 | 0.16 | 0.17 | N/A |
| | | | 01211 | 0.18 | | N/A |
| 25006 | Smit-Weld | SAF89 | 01135 | 0.17[b] | 0.17 | N/A |
| | | | 01985 | 0.17[b] | | N/A |
| 25017 | Smit-Weld | SAF89 | 01197 | 0.33 | 0.33 | N/A |
| 4275 | Arco Chem | SAF89 | 02275 | 0.12 | 0.12 | 0.11 |
| 4292 | Arco Chem | SAF89 | 02275 | 0.12 | 0.12 | 0.15 |
| 721858 | Arco Chem | SAF89 | 01197 | 0.08 | 0.08 | N/A |

Table 10 Notes contained on following page.

Table 10 Notes:

a. Lot averaged chemistry values are the average of all available as-deposited weld chemistry measurements for the specific heat and flux lot combination, unless otherwise noted.
b. The chemistry value is based on the weld wire analysis since no chemistry data on the deposited content of the weld is available.

**Table 11**
**Statistical Analysis of SAW Welds**

| | USE (ft-lb) | Chemistry | |
|---|---|---|---|
| | | Heat Averaged Cu (wt. %) | Ni (wt. %) |
| *Mean* | 109 | 0.14 | 0.29 |
| *Standard Deviation* | 17 | 0.09 | 0.27 |
| *Mean - 2σ* | 75 | - | - |
| *Mean + σ* | - | 0.23 | 0.56 |
| | | | |
| *Maximum* | 129 | 0.33 | 0.75 |
| *Minimum* | 82 | 0.03 | 0.05 |
| *# of Welds* | 7 | 14 | 10 |

## 5.2 SHIELDED METAL ARC WELD (SMAW)

Table 12 identifies all SMAW heats that were used in reactor vessel fabrication by Rotterdam and that are available in Westinghouse records. Actual USE measurements are only available for three weld materials (Heat #'s 818-025612, 7565.7158, and 7703.7265) in Table 12. For these materials, the actual measured USE is greater than or equal to 116 ft-lbs. The remainder of the available data is based on Charpy tests completed at 10.4°F or lower, and shear values which are either unknown or less than 95%. The USE is typically reached at a temperature greater than 10°F, as demonstrated by the welds with actual measured USE values, which reached the upper-shelf at temperatures of approximately 70°F or higher.

Since insufficient data is available to establish an accurate mean and standard deviation, a conservative lower bound USE value will be determined based on all Charpy impact energies in Table 12. A review of Table 12 indicates that the lowest value based on an unknown shear and Charpy measurements of the specific heat is 72 ft-lbs for Heat # 9092. Heat # 7359.6708 has an impact energy of 63 ft-lbs, which is less than 72 ft-lbs; however, the Charpy test data indicates a maximum shear value of only 52%. The actual USE for Heat # 7359.6708 is therefore expected to be much greater than 63 ft-lbs. Since a USE value of 72 ft-lbs is only 9 ft-lbs greater, it is determined that 72 ft-lbs is a bounding USE value for Heat # 7359.6708. Therefore, 72 ft-lbs is considered to be a bounding and conservative USE value for a Rotterdam-fabricated SMAW with an unknown USE.

Since only two welds with test results for Cu weight percent exist, insufficient information is available to determine a generic Cu value; thus, the Regulatory Guide 1.99, Revision 2 [Ref. 7], generic value of 0.35% for Cu can be used for an unknown Rotterdam-fabricated SMAW. The

limited data available indicates that a value of 0.35% is very conservative. Per Table 13, the chemistry data indicates that a generic value of 1.13% for Ni is acceptable for unknown heats of SMAW used by Rotterdam. This value is based on the Regulatory Guide 1.99, Revision 2 mean plus one standard deviation approach. This value of 1.13% is conservative and greater than the Regulatory Guide 1.99, Revision 2 generic value of 1.0%.

**Table 12**
**Available Rotterdam SMAW USE and Chemistry Data**

| Heat | Type(a) | Vendor(a) | USE(b) (ft-lb) | Shear(c) (%) | Cu(d) (wt. %) | Ni(d) (wt. %) |
|---|---|---|---|---|---|---|
| 818-021736 | E8015-G | B&W | ≥ 91(e) | 85 | N/A | 0.87 |
| 818-022108 | E8015-G | B&W | ≥ 97 | N/A | N/A | 1.11 |
| 818-022778 | E8015-G | B&W | ≥ 77(f) | N/A | N/A | 1.07 |
| 818-023006 | E8015-G | B&W | ≥ 77(f) | N/A | 0.01 | 1.15 |
| 818-024509 | E8015-G | B&W | ≥ 77(f) | N/A | N/A | 1.06 |
| 818-024510 | E8015-G | B&W | ≥ 77(f) | N/A | N/A | 0.96 |
| 818-024790 | E8015-G | B&W | ≥ 77(f) | N/A | N/A | 0.97 |
| 818-024965 | E8015-G | B&W | ≥ 77(f) | N/A | N/A | 0.97 |
| 818-025134 | E8015-G | B&W | ≥ 77(f) | N/A | N/A | 0.95 |
| 818-025185 | E8015-G | B&W | ≥ 77(f) | N/A | N/A | 1.04 |
| 818-025186 | E8015-G | B&W | ≥ 77(f) | N/A | N/A | 1.04 |
| 818-025371 | E8015-G | B&W | ≥ 77(f) | N/A | N/A | 0.81 |
| 818-025391 | E8015-G | B&W | ≥ 77(f) | N/A | N/A | 0.90 |
| 818-025392 | E8015-G | B&W | ≥ 77(f) | N/A | N/A | 0.92 |
| 818-025561 | E8015-G | B&W | ≥ 77(f) | N/A | N/A | 0.81 |
| 818-025562 | E8015-G | B&W | ≥ 77(f) | N/A | N/A | 0.85 |
| 818-025611 | E8015-G | B&W | ≥ 77(f) | N/A | N/A | 0.87 |
| 818-025612 | E8015-G | B&W | 130(g) | 100% | 0.023 | 0.91 |
| 818-025655 | E8015-G | B&W | ≥ 77(f) | N/A | N/A | 0.76 |

**Table 12**
**Available Rotterdam SMAW USE and Chemistry Data**

| Heat | Type(a) | Vendor(a) | USE(b) (ft-lb) | Shear(c) (%) | Cu(d) (wt. %) | Ni(d) (wt. %) |
|---|---|---|---|---|---|---|
| 401W9661 | E8018-C3 | RACO | ≥ 166 | N/A | N/A | 0.97 |
| 5835.3423 | KG66ELH, E9018-G | Soudo-metal | ≥ 98 | N/A | N/A | 1.15 |
| 5835.3900 | KG66ELH, E9018-G | Soudo-metal | ≥ 80 | N/A | N/A | 1.25 |
| 6236.4063 | KG66ELH, E9018-G | Soudo-metal | ≥ 120 | N/A | N/A | 1.24 |
| 6236.4450 | KG66ELH, E9018-G | Soudo-metal | ≥ 95 | N/A | N/A | 1.13 |
| 6497.4647 | KG66ELH, E9018-G | Soudo-metal | ≥ 73 | N/A | N/A | 1.04 |
| 6497.4675 | KG66ELH, E9018-G | Soudo-metal | ≥ 83 | N/A | N/A | 1.04 |
| 6507.4705 | KG66ELH, E9018-G | Soudo-metal | ≥ 76 | N/A | N/A | 1.36 |
| 6747.5458 | KG66ELH, E9018-G | Soudo-metal | ≥ 96 | N/A | N/A | 0.90 |
| 7011.6032 | KG66ELH, E9018-G | Soudo-metal | ≥ 87(e) | 68 | N/A | 0.93 |
| 7011.6143 | KG66ELH, E9018-G | Soudo-metal | ≥ 108(e) | 74 | N/A | 0.91 |
| 7359.6708 | KG66ELH, E9018-G | Soudo-metal | ≥ 63(e) | 52 | N/A | 0.83 |
| 7565.7158 | KG66ELH, E9018-G | Soudo-metal | 116(g) | 100 | N/A | N/A |
| 7703.7265 | KG66ELH, E9018-G | Soudo-metal | 134(g) | 100 | N/A | 0.94 |
| 8640 | Molyth., E8015-G | Secher. | ≥ 103 | N/A | N/A | N/A |
| 8825 | Molyth., E8015-G | Secher. | ≥ 85 | N/A | N/A | N/A |
| 8928 | Molyth., E8015-G | Secher. | ≥ 96 | N/A | N/A | N/A |
| 9004 | Molyth., E8015-G | Secher. | ≥ 112 | N/A | N/A | N/A |
| 9092 | Molyth., E8015-G | Secher. | ≥ 72 | N/A | N/A | N/A |

Table 12 Notes (continued on following page)

a. The weld type and vendor names are taken directly from the original records.

b. The USE values are the average of all available absorbed energy values from Charpy tests completed at 10.4°F or below with no available shear data or with limited shear data (all available values are less than 95%), unless otherwise noted The actual USE values are expected to be much greater in many cases.

c. Identifies the shear value corresponding to the lower bound USE. N/A indicates that there is no shear information available. Values of 100 correspond to multiple test specimens showing 100% shear.

d. When multiple measurements are available, the chemistry values are the average of all available measurements for the heat.
e. The USE value is the maximum Charpy value recorded with a shear less than 95%, as no values of shear above 95% are recorded.
f. Mechanical test data is not available for all type E8015-G weld heats. However, a non-conformance review performed by Rotterdam determined the acceptability of the material, i.e. Charpy results greater than or equal to 30 ft-lbs at 10°F, based on Charpy tests results available for 27 different heats of type E8015-G welds. A review of these 27 heats is presented in Appendix A of this report. The review calculated a mean minus 2$\sigma$ value of 77 ft-lbs.
g. The USE value is the average of all available absorbed energy values with a shear ≥ 95% per ASTM E185-82. See Section 3.2 for additional details.

**Table 13**
**Statistical Analysis of SMAW Weld Nickel Weight Percent**

| | Ni (wt. %) |
|---|---|
| *Mean* | 0.99 |
| *Standard Deviation* | 0.14 |
| *Mean + $\sigma$* | 1.13 |
| | |
| *Maximum* | 1.36 |
| *Minimum* | 0.76 |
| *# of Materials Included* | 32 |

## 5.3 WELD ANALYSIS SUMMARY

The previous subsections provide generic information that can be used when material-specific Rotterdam SAW or SMAW information is unavailable. If insufficient data exists to determine whether a Rotterdam weld is a SAW or a SMAW, then the generic SMAW properties can be utilized. The generic SMAW USE, Cu weight percent, and Ni weight percent values are all more limiting than the corresponding SAW values. Thus, for an unknown Rotterdam weld, the USE can be set to 72 ft-lbs; the Cu weight percent can be set to 0.35; and the Ni weight percent can be set to 1.13.

# 6.0 REFERENCES


1. Code of Federal Regulations 10 CFR 50, Appendix G, "Fracture Toughness Requirements," Federal Register, Volume 60, No. 243, December 19, 1995.
2. U. S. NRC Regulatory Issue Summary (RIS) 2014-11, "Information on Licensing Applications for Fracture Toughness Requirements for Ferritic Reactor Coolant Pressure Boundary Components," October 14, 2014. *[Agencywide Documents Access and Management System (ADAMS) Accession Number ML14149A165]*
3. ASTM E185-82, "Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels," American Society for Testing and Materials, 1982.
4. ASTM E185-16, "Standard Practice for Design of Surveillance Programs for Light-Water Moderated Nuclear Power Reactor Vessels," ASTM International, December 2016.
5. NUREG-0800, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, Chapter 5 LWR Edition, Branch Technical Position (BTP) 5-3, Revision 2, "Fracture Toughness Requirements," U.S. Nuclear Regulatory Commission, March 2007. *[ADAMS Accession Number ML070850035]*
6. AREVA NP, Inc. Report BAW-2313, Revision 7, Supplement 1, Revision 1, "Supplement to B&W Fabricated Reactor Vessel Materials and Surveillance Data Information for Surry Unit 1 and Unit 2," AREVA Document No. 77-2313S-007-001, February 2017.
7. U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Regulatory Guide 1.99, Revision 2, "Radiation Embrittlement of Reactor Vessel Materials," May 1988. *[ADAMS Accession Number ML003740284]*
8. Code of Federal Regulations 10 CFR 50.61, "Fracture Toughness Requirements for Protection Against Pressurized Thermal Shock Events," U.S. Nuclear Regulatory Commission, Federal Register, Volume 60, No. 243, dated December 19, 1995, effective January 18, 1996.

# Appendix A
# Supplemental Charpy Impact Energy Data for E8015-G Electrode Welds

For some type E8015-G weld heats, mechanical test data is not available. However, a Rotterdam non-conformance review identified Charpy results for 27 separate 8015-type electrodes manufactured in the same shop as those utilized at Rotterdam within the previous 5 years. The results of this non-conformance review are documented and analyzed in Table A-1 to provide a surrogate USE for the materials without specific test data. No shear data is available.

**Table A-1**
**Supplemental Charpy Impact Energy Data for E8015-G Electrode Welds**

| Type 8015 Material Number | CVN Data at 10°F Test #1 (ft-lbs) | CVN Data at 10°F Test #2 (ft-lbs) | CVN Data at 10°F Test #3 (ft-lbs) | Averaged CVN Data (ft-lbs) |
|---|---|---|---|---|
| 1 | 91 | 95 | 95 | 94 |
| 2 | 100 | 101 | 149 | 117 |
| 3 | 65 | 76 | 89 | 77 |
| 4 | 80 | 83 | 105 | 89 |
| 5 | 88 | 90 | 100 | 93 |
| 6 | 99 | 105 | 105 | 103 |
| 7 | 70 | 84 | 75 | 76 |
| 8 | 102 | 104 | 107 | 104 |
| 9 | 84 | 92 | 95 | 90 |
| 10 | 109 | 117 | 120 | 115 |
| 11 | 118 | 118 | 125 | 120 |
| 12 | 90 | 91 | 96 | 92 |
| 13 | 65 | 90 | 91 | 82 |
| 14 | 91 | 99 | 100 | 97 |
| 15 | 95 | 100 | 103 | 99 |
| 16 | 94 | 96 | 111 | 100 |
| 17 | 87 | 94 | 97 | 93 |
| 18 | 94 | 103 | 105 | 101 |
| 19 | 105 | 110 | 118 | 111 |
| 20 | 95 | 98 | 102 | 98 |
| 21 | 98 | 98 | 103 | 100 |
| 22 | 83 | 96 | 102 | 94 |
| 23 | 105 | 119 | 120 | 115 |
| 24 | 109 | 110 | 112 | 110 |
| 25 | 95 | 95 | 110 | 100 |
| 26 | 95 | 100 | 104 | 100 |
| 27 | 94 | 97 | 99 | 97 |
| | | | Mean | 99 |
| | | | Standard Deviation | 11 |
| | | | Mean - 2σ | 77 |

# Appendix B
# CORRESPONDENCE WITH THE U.S. NRC

**UNITED STATES**
**NUCLEAR REGULATORY COMMISSION**
**WASHINGTON, D.C. 20555-0001**

FINAL SAFETY EVALUATION

BY THE OFFICE OF NUCLEAR REACTOR REGULATION

PRESSURIZED WATER OWNERS GROUP TOPICAL REPORT

PWROG-17090-NP, REVISION 0,

"GENERIC ROTTERDAM FORGING AND WELD INITIAL

UPPER-SHELF ENERGY DETERMINATION"

EPID: L-2018-TOP-0017

## 1.0 INTRODUCTION

By letter dated April 6, 2018 (Ref.1), as supplemented by letter dated June 12, 2019 (Ref. 2), the Pressurized Water Reactor Owners Group (PWROG) transmitted Topical Report (TR) PWROG-17090-NP, Revision (Rev.) 0, "Generic Rotterdam Forging and Weld Initial Upper-Shelf Energy Determination" (Ref. 3, non-proprietary version) to the U.S. Nuclear Regulatory Commission (NRC) for review and approval.

For reactor vessels (RVs) that were fabricated by the Rotterdam Dockyard Company (Rotterdam), the TR provides generic values of the unirradiated Charpy Upper-Shelf Energy (USE) for American Society of Mechanical Engineers (ASME) SA508[1], Class 2 (or the corresponding American Society of Testing and Materials (ASTM) A508, Class 2 (Ref. 4)) RV forgings; and generic values of unirradiated Charpy USE, weight percentage copper (Cu) content, and weight percentage nickel (Ni) content for RV Submerged Arc Welds (SAWs) and Shielded Metal Arc Welds (SMAWs). The PWROG's transmittal letter identifies that licensees will reference the PWROG-17090-NP, Rev. 0 report as the basis for the generic USE, Cu content, and Ni content values to demonstrate compliance with Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, Appendix G requirements for extended operating license terms when plant-specific RV material information is not available or incomplete.

As addressed in the PWROG's transmittal letter dated April 6, 2018, this TR is for implementation by all U.S. PWRs with RVs fabricated by Rotterdam in the late 1960's and early 1970's timeframe. This statement identifies the limitation on the applicability of the TR, which is addressed in the transmittal letter.

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[1] Logsdon, W.A., Begley, J.A., and Gottshall, C.L. Dynamic fracture toughness of American Society of Mechanical Engineers (ASME) SA508 Class 2a ASME SA533 grade A Class 2 base and heat affected zone material and applicable weld metals. United States: N. p., 1978. Web.

Enclosure

W. Nowinowski - 3 -

SUBJECT: FINAL SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION FOR THE PRESSURIZED WATER REACTOR OWNERS GROUP TOPICAL REPORT PWROG-17090-NP, REVISION 0, "GENERIC ROTTERDAM FORGING AND WELD INITIAL UPPER-SHELF ENERGY DETERMINATION" (EPID L-2018-TOP-0017) DATED DECEMBER 12, 2019

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40TH ANNIVERSARY
PWROG
PWR Owners Group

Program Management Office
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PWROG-17090-NP, Revision 0
Project Number 99902037

June 12, 2019

OG-19-126

U.S. Nuclear Regulatory Commission
Document Control Desk
11555 Rockville Pike
Rockville, MD 20852

Subject: PWR Owners Group
**Transmittal of the Response to Request for Additional Information, RAIs 1-3 and 5-7 Associated with PWROG-17090, Revision 0, "Generic Rotterdam Forging and Weld Initial Upper-Shelf Energy Determination", PA-MSC-1367**

References:

1. Letter OG-18-186, Transmittal of PWROG-17090-NP, Revision 0, "Generic Rotterdam Forging and Weld Initial Upper-Shelf Energy Determination," PA-MSC-1367, dated April 6, 2018

2. NRC Letter of Acceptance for Review of PWROG-17090-NP, Revision 0, "Generic Rotterdam Forging and Weld Initial Upper-Shelf Energy Determination," dated June 12, 2018

3. Email from the NRC (Drake) to the PWROG (Holderbaum), Request for Additional Information, RAIs 1-7, PWROG-17090-NP, Revision 0, "Generic Rotterdam Forging and Weld Initial Upper-Shelf Energy Determination," dated February 21, 2019

On April 6, 2018, in accordance with the Nuclear Regulatory Commission (NRC) Topical Report (TR) program for review and acceptance, the Pressurized Water Reactor Owners Group (PWROG) requested formal NRC review and approval of PWROG-17090, Revision 0 for referencing in regulatory actions (Reference 1). The report was accepted for review on June 12, 2018 (Reference 2). The NRC Staff has determined that additional information is needed to complete the review per the email dated February 21, 2019 (Reference 3).

Enclosure 1 to this letter provides formal responses to NRC RAIs 1-3 and 5-7 (Reference 3) associated with PWROG-17090-NP, Revision 0, "Generic Rotterdam Forging and Weld Initial Upper-Shelf Energy Determination," N-481 of the Primary Loop Pump Casings of Westinghouse Type Nuclear Steam Supply Systems".

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NRR

U.S. Nuclear Regulatory Commission
OG-19-126

June 12, 2019
Page 2 of 2

Correspondence related to this transmittal should be addressed to:

Mr. W. Anthony Nowinowski, Executive Director
PWR Owners Group, Program Management Office
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Cranberry Township, PA 16066

If you have any questions, please do not hesitate to contact me at (805) 545-4328 or Mr. W. Anthony Nowinowski, Program Manager of the PWR Owners Group, Program Management Office at (412) 374-6855.

Sincerely yours,

Ken Schrader, COO & Chairman
PWR Owners Group

JKS:bm

cc: PWROG PMO
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B. Lynch, Westinghouse
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Enclosures 1: LTR-SDA-19-031 (Westinghouse non-proprietary), Revision 0, RAIs 1-3 and 5-7 Responses for PWROG-17090-NP, Revision 0 (PA-MSC-1367)

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Westinghouse

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To: Thomas Zalewski

Date: June 11, 2019

From: D. Brett Lynch
Phone: (412) 342-1788

Our ref: LTR-SDA-19-031, Rev. 0

Subject: **Responses to the U.S. NRC Request for Additional Information on Generic Rotterdam Forging and Weld Initial Upper Shelf Energy Values (PWROG-17090-NP)**

Attachments: A. Responses to the U.S. NRC Request for Additional Information on Generic Rotterdam Forging and Weld Initial Upper Shelf Energy Values (PWROG-17090-NP)

References: 1. Pressurized Water Reactor Owners Group (PWROG) Report PWROG-17090-NP, Revision 0, "Generic Rotterdam Forging and Weld Initial Upper-Shelf Energy Determination," March 2018. *[Agencywide Documents Access and Management System (ADAMS) Accession Number ML18114A183]*

This letter provides Westinghouse responses to the Requests for Additional Information (RAIs) from the U.S. Nuclear Regulatory Commission (NRC) concerning the evaluation in the PWROG-17090-NP, Revision 0 report (Reference 1).

If you have any questions, please contact the undersigned.

***Electronically Approved****
Author: D. Brett Lynch
Structural Design & Analysis III

***Electronically Approved****
Reviewed: Benjamin E. Mays
Structural Design & Analysis III

***Electronically Approved****
Approved: Lynn A. Patterson, Manager
Structural Design & Analysis III

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# Attachment A
# Responses to the U.S. NRC Request for Additional Information on Generic Rotterdam Forging and Weld Initial Upper Shelf Energy Values (PWROG-17090-NP)

***Regulatory Basis for the NRC Staff's RAI Concerning Topical Report PWROG-17090-NP, Rev. 0 – Applicable to All RAI Questions***

*Title 10 of the Code of Federal Regulations, Part 50 (10 CFR Part 50), Appendix G, "Fracture Toughness Requirements," Paragraph IV.A.1, "Reactor Vessel Charpy Upper-Shelf Energy Requirements," states, in part, that reactor pressure vessel (RPV) beltline materials must have Charpy USE in the transverse direction for base material and along the weld for weld material according to the ASME Code, Section III of no less than 75 ft-lb (102 J) initially and must maintain Charpy USE throughout the life of the RPV of no less than 50 ft-lb (68 J), unless it is demonstrated in a manner approved by the NRC staff that lower values of Charpy USE will provide margins of safety against fracture equivalent to those required by Appendix G of Section XI of the ASME Code.*

*Further, Section III, "Fracture Toughness Tests," of 10 CFR Part 50, Appendix G states that to demonstrate compliance with the fracture toughness requirements this appendix, including Charpy USE requirements cited above, ferritic RPV materials must be tested in accordance with the ASME Code, Section III and, for the RPV beltline materials, the test requirements of Appendix H of 10 CFR Part 50. For an RPV that was constructed to an Edition and Addenda of the ASME Code, Section III earlier than the Summer 1972 Addenda of the 1971 Edition (under 10 CFR 50.55a), the preservice fracture toughness data and data analysis must be supplemented in a manner approved by the NRC staff, to demonstrate equivalence with the fracture toughness requirements of this appendix.*

*Supplemental fracture toughness data for RPV beltline materials, which includes ferritic RPV materials that are newly incorporated into the RPV beltline region for extended license terms, may include generic properties for a class of material to demonstrate compliance with the requirements of 10 CFR Part 50, Appendix G. The use of generic RPV material properties for a class of material to demonstrate compliance with these regulatory requirements is subject to the review and approval of the NRC staff.*

***RAI-1***

*Background: Section 1.0 of TR states that "It should be noted that prior to exceeding 1.0 x 10^17 n/cm^2 (E > 1.0 MeV), 10 CFR Part 50, Appendix G requirements do not apply."*

*Issue: The NRC staff identified that this statement is not in accordance with 10 CFR Part 50, Appendix G. While the Charpy USE requirements of 10 CFR Part 50, Appendix G are specified only for RPV beltline materials, other requirements of 10 CFR Part 50, Appendix G related to P-T limits and preservice fracture toughness testing are considered applicable to all ferritic components of the RCPB.*

*Request: Please revise this sentence to be consistent with the actual 10 CFR Part 50, App. G requirements, or delete it from the TR.*

Response: The wording will be revised so that PWROG-17090-A, Revision 1 will read as follows. The only change is underlined, italicized, and in red font.

> "In Regulatory Issue Summary (RIS) 2014-11 [Ref. 2], the Nuclear Regulatory Commission (NRC) identified a threshold of 1 x $10^{17}$ n/cm$^2$ (E > 1.0 MeV) for the projected end of life fluence over which the effects of embrittlement must be considered to meet the 10 CFR 50, Appendix G requirement. Extended operating durations associated with license renewals can increase the fluence for components outside the traditional beltline beyond this threshold. It should be noted that prior to exceeding 1 x $10^{17}$ n/cm$^2$ (E > 1.0 MeV), *the Charpy USE requirements of* 10 CFR 50, Appendix G requirements do not apply."

***RAI-2***

*Background/Issue: The staff noted the following inconsistencies in the TR.*

*i. Table 2 of the TR identifies that there are two forging records from the unknown supplier, whereas Table 7 lists only one from the unknown supplier.*

*ii. In Section 3.1, Page 4, Fourth Bullet, the TR says "[t]he USE is set equal to the highest Charpy impact energy available or if the highest data point is determined to be a potential 'outlier' or non-representative data point, the USE is set equal to a value less than the highest value based on the average of the comparable preceding data points." In the Section 4.0 data sets, these cases are reported as "USE ≥ XX" where XX is the reported Charpy impact energy.*

*Request: Please resolve the above inconsistency identified in Item (i) regarding the number of forgings from the unknown supplier. For Item (ii), please clarify whether this Section 3.1 bullet is meant to state "USE is set greater than or equal to...", rather than "USE is set equal to..." and revise accordingly.*

Response:

(i) There are two materials with an unknown supplier as shown in PWROG-17090-NP, Revision 0 (Reference A-1), Table 2. However, only one such material is listed in PWROG-17090-NP, Revision 0, Table 7, because the test record and supplier information are not available for the other "unknown supplier" material. Thus, this material was not included in PWROG-17090-NP, Revision 0, Table 7.

(ii) The wording will be revised so that PWROG-17090-A, Revision 1 will read as follows. The only change is underlined, italicized, and in red font.

"The USE is set *greater than or* equal to the highest Charpy impact energy value available or, if the highest data point is determined to be a potential 'outlier' or a non-representative data point, the USE is set *greater than or* equal to a value less than the highest value based on the average of the comparable preceding data points."

***RAI-3***

*Background/Issue: There are several places in the TR where it addresses "outlier data points" and the elimination of such data points from consideration in developing the proposed generic values for Charpy USE. The places in the TR that address outlier data points are as follows.*

*i. With respect to determining measured USE based on the definition in ASTM E185-82, Section 3.0, Page 2 of the TR states:*

*In some instances, there may be data that are deemed 'outliers,' which are data points that are uncharacteristically high or low relative to other data at or above 95% shear. These 'outlier' data points are removed from the determination of the USE based on engineering judgment.*

*ii. With respect to determining measured USE, based on the definition in ASTM E185-82 the first bullet in Section 3.1, Page 4 of the TR states:*

*If the CVN dataset contains at least one shear data point greater than 95%, but some data points report no shear, all data points with an impact-energy approximately equal to or greater than the impact energy of the shear data points known to be ≥ 95% are assumed to have greater than or equal to 95% shear. All non-outlier data points with known or assumed shear at ≥ 95% are averaged to determine the USE and incorporated into the calculation of the generic USE. [[Emphasis Added]]*

Request: *For reported USE values that were determined based on known or assumed shear greater than or equal to 95 percent, please provide examples of an uncharacteristically low impact energy and an uncharacteristically high impact energy that were considered to be outliers (i.e., impact energies eliminated from the average). For these outlier data points please include the available percent shear values, impact energies, test temperatures, and identify the reported USE value based on the average of non-outlier energies.*

Response: An example of an "uncharacteristically low impact energy" that was considered to be an outlier (i.e., an impact energy eliminated from the average) is the Plant H, vessel flange from the Klöckner-Werke AG supplier with a reported strong-direction USE of 235 ft-lbs in PWROG-17090-NP, Revision 0 (Reference A-1), Table 7. The available percent shear values, impact energies, and test temperatures for the test data considered in determining the USE are shown in Table 1 that follows, along with the outlier data point. A strong-direction data point of 174.9 ft-lbs was excluded from the calculation of the USE based on this value having a significantly lower energy (39 to 65 ft-lb loss) than the other impact energies at the same temperature or with greater than or equal to 95% shear. A review of the data points with shear data shows that when the shear is equal to 100%, the lowest impact energy is 213.7 ft-lbs. If the 174.9 ft-lbs data point is included, the strong-direction USE would be equal to 229 ft-lbs.

**Table 1 – Example of Uncharacteristically Low Impact Energy**

| Temperature (°F) | Energy (ft-lbs) | % Shear |
|---|---|---|
| -4 | 239.2 | Not available |
| 5 | 239.2 | Not available |
| 39 | 213.7 | 100 |
| 39 | 239.8 | 100 |
| 39 | 224.7 | 100 |
| 39 | 239.8 | 100 |
| 39 | 239.8 | 100 |
| 39 | 239.8 | 100 |
| 68 | 239.2 | Not available |
| 68[a] | 174.9[a] | Not available[a] |

Note:
(a) Outlier data point.

An example of an "uncharacteristically high impact energy," that was considered to be an outlier (i.e., an impact energy eliminated from the average) is the Plant G, intermediate shell from the Fried-Krupp Huttenwerke AG supplier with a reported strong-direction USE of 148 ft-lbs in PWROG-17090-NP,

Revision 0, Table 6. The available percent shear values, impact energies, and test temperatures for the test data considered in determining the USE are shown in Table 2 that follows, along with the outlier data point. A strong-direction data point of 200.0 ft-lbs that was excluded from the calculation of the USE based on the data point having a significantly higher energy (≥ 31 ft-lb greater) than the other impact energies at or above 95% shear. This approach is conservative, because the inclusion of this data point would increase the strong-direction USE to 154 ft-lbs.

**Table 2 – Example of Uncharacteristically High Impact Energy**

| Temperature (°F) | Energy (ft-lbs) | % Shear |
|---|---|---|
| 113 | 144.8 | 100 |
| 113 | 130.3 | 98 |
| 113 | 139.6 | 95 |
| 176 | 132.6 | 100 |
| 176 | 137.8 | 100 |
| 125 | 166.0 | 100 |
| 210(a) | 200.0(a) | 100(a) |
| 210 | 165.0 | 100 |
| 210 | 169.0 | 100 |

Note:
(a) Outlier data point.

***RAI-5***

***Background:*** *In reviewing generic properties for a "class" of RPV material ("class" is defined per RG 1.99, Rev. 2 and 10 CFR 50.61), the staff has traditionally looked to ascertain how multiple measurements of the property for the same heat of material are weighted (or not weighted), given that generic sets contain multiple heats for a certain material class and supplier. For example, TR Section 3.2 explains that for the purpose of evaluating Rotterdam weld chemistry (Cu and Ni content) measurements, "If a common heat-flux type combination is shared between multiple welds, the average chemistry value for the heat is considered as one data point when determining the generic weld chemistry values as not to assign undue weight to the material, since it is representative of just one heat-flux type combination."*

***Issue.*** *It is unclear to the staff if this same criterion was applied for the measured values of USE for the several suppliers of SA508, Class 2 forgings and measured USE values Rotterdam SAW welds*

***Request:***

a. *For the SA508, Class 2 forging Charpy USE data that are reported in Section 4.0 of the TR, please address whether the measured USE values and lower bound USE values represent different forging heats. If this cannot be determined for all values reported in Section 4.0, please confirm whether just the measured weak direction Charpy USE values for the two largest suppliers (used to calculated the recommended Mean – 2σ values), and the USE values for other suppliers in Table 7, can be determined to represent different forging heats.*

b. *For the Rotterdam submerged arc weld Charpy USE data that is reported in Table 9, please identify whether each line entry in the table corresponds to a different heat of weld material.*

Response:

a. The SA508, Class 2 generic USE determination weighs each component individually. For most components, the heat number is unique to that component. However, certain nozzles share a heat number, as multiple nozzle components were sometimes formed from a single heat. The generic values for SA508, Class 2 (52 ft-lbs and 56 ft-lbs) are not affected by nozzle materials sharing a heat number. The generic USE values are based on sets of data with clearly defined USE measured in the weak direction. These sets of data do not include any nozzles (or other materials which share a heat number). Thus, the conclusions in PWROG-17090-NP, Revision 0 (Reference A-1) and the generic SA508 Class 2 forging values do not rely on calculations involving any materials which share a heat number.

b. Each line entry in Table 9 of PWROG-17090-NP, Revision 0 corresponds to a different heat of weld material consistent with the criterion discussed in the RAI-5 background.

*RAI-6*

*Background: Section 3.2 of the TR states that outside of the baseline measurements for the reactor vessel surveillance programs, no USE information is available for Rotterdam SAW materials, and only the results relevant to the reactor vessel surveillance capsule program unirradiated testing at Rotterdam and Westinghouse can be used to determine the generic USE for unirradiated Rotterdam SAW material. The TR seems to indicate that the CMTR data is not useful for the Rotterdam SAW evaluation, and no measured impact energies from CMTRs can be used for determining a lower bound on USE for any Rotterdam SAWs.*

*Based on the information in the TR regarding CMTR data, the staff infers that the Charpy test temperatures for Rotterdam SAWs are so low (≤ 10 °F), and the transition temperatures are so far away from the upper shelf, that the available CMTR data would show relatively low impact energies that cannot be used to infer a lower bound on USE for that test record. The TR specifically states:*

> *The core region welds had the same specification requirements as the other reactor vessel welds; however, for the core region welds, Rotterdam was required to "aim for" both a Charpy V-Notch Transition Temperature and a Nil-Ductility Transition Temperature less than 10°F and to furnish additional test results relevant to these [transition temperatures]. Both [transition temperatures] do not occur near the upper-shelf region, and thus, the surveillance capsule program test results are generically representative of the SAWs produced at Rotterdam for USE calculations.*

*Issue: It is unclear to the NRC staff how the information quoted above demonstrates that the baseline surveillance program data in Table 9 is generically representative of all Rotterdam RPV SAWs. The NRC staff needs additional information to confirm that USE data for Rotterdam SAWs in Table 9 is representative for Rotterdam SAWs in general.*

*Request: Taking into consideration specification requirements for Rotterdam core region SAWs, please explain how the above information demonstrates that the baseline USE data for surveillance program SAWs in Table 9 is representative of Rotterdam SAWs in general.*

Response: Based on the acceptance criteria for welds furnished by Rotterdam, flux/wire welds did not have chemistry requirements and all welds had the following mechanical requirements:

Mechanical: Tensile
Min. Tensile Strength 80 ksi (56.2 kg/mm²)

Impacts
Min. 30 ft-lb (5.2 kgm/cm²) average of 3 specimens
Min. 25 ft-lb (4.3 kgm/cm²) 1 individual specimen

Core region welds had additional requirements to establish the Charpy V-Notch Transition Temperature ($TT_{cv}$) based on a full Charpy V-Notch curve (upper and lower plateaus included). Core region welds were also required to be tested to establish the Nil Ductility Transition Temperature (NDTT) based on the drop weight data. The original documentation discusses that the supplier shall "aim for" obtaining a $TT_{CV}$ and NDTT of less than 10°F (-12.2°C).

Thus, the chemical and mechanical specifications for the beltline and non-beltline SAWs were identical. The additional core region requirements to establish the $TT_{cv}$ and NDTT and to "aim for" a transition temperature of 10°F are requirements related to additional testing. These additional testing requirements will not affect the USE, since these properties are associated with ductile-to-brittle transition, not the ductile region. Since the chemical and mechanical requirements are equivalent, it is expected that the weld materials used by Rotterdam over the entire vessel were taken from the same set of available weld metals. This conclusion is supported by known instances where a core region weld and a non-core region weld share a heat number. Therefore, the statistical analysis of the core region surveillance program weld material is also applicable to the non-core region.

***RAI-7***

*Background: TR Section 4.3 provides Charpy data for SA508, Class 2 forgings procured from suppliers other than Rheinstahl Huttenwerke AG and Fried-Krupp Huttenwerke AG. This section states, "a generic USE is not required for any of these components," based on the data provided in Table 7. This section of TR then states:*

> *Based on the data in Table 7 and the generic values determined for Rheinstahl Huttenwerke AG or Fried-Krupp Huttenwerke AG forgings, a Rotterdam forging with an unknown supplier from the late 1960's or early 1970's timeframe will have a USE value of at least 52 ft-lbs, the minimum generic value determined in this report for Rotterdam forgings.*

*Issue: If the forging supplier is unknown (and if a plant-specific measured value cannot be determined), the TR recommends a generic initial USE value of 52 ft-lbs. However, it is not clear to the staff whether or not the TR recommends 52 ft-lbs as the generic value if a plant's forging supplier is identified as one of the other three firms covered in the TR: Klöckner-Werke AG, Terni, and Marrèl-Freres.*

*Request: If a plant identifies its RPV SA508, Class 2 forging supplier as Klockner-Werke AG, Terni, or Marrèl-Freres, please clarify whether or not the TR recommends a generic initial USE value of 52 ft-lbs. If the TR recommends a generic initial USE value(s) other than 52 ft-lbs for these other 3 suppliers, please identify the recommended generic value(s) and provide justification using methods consistent with the TR.*

Response: The generic value of 52 ft-lbs is NOT intended for the suppliers Klöckner-Werke AG, Terni, or Marrèl-Freres. All known and applicable Rotterdam components from these suppliers are provided in PWROG-17090-NP, Revision 0 (Reference A-1), Table 7. As shown in the table, there is sufficient data

for these components to justify a component-specific USE value that is higher than 52 ft-lbs. For example, per PWROG-17090-NP, Revision 0, Table 7, the Plant A upper shell forging can justify a USE value of 99 ft-lbs in the weak direction using the method in Branch Technical Position 5-3 (Reference A-2).

***References:***

A-1. Pressurized Water Reactor Owners Group (PWROG) Report PWROG-17090-NP, Revision 0, "Generic Rotterdam Forging and Weld Initial Upper-Shelf Energy Determination," March 2018. *[Agencywide Documents Access and Management System (ADAMS) Accession Number ML18114A183]*

A-2. NUREG-0800, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, Chapter 5 of LWR Edition, Branch Technical Position 5-3, "Fracture Toughness Requirements," Revision 4, U.S. Nuclear Regulatory Commission, March 2019. *[ADAMS Accession Number ML18338A516]*