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Generic Rotterdam Forging and Weld Initial Upper-Shelf Energy Determination

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PA-MSC-1367, Task 3

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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
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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

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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
σ	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 1×10^{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 1×10^{17} n/cm^2 (E > 1.0 MeV), the 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 1×10^{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

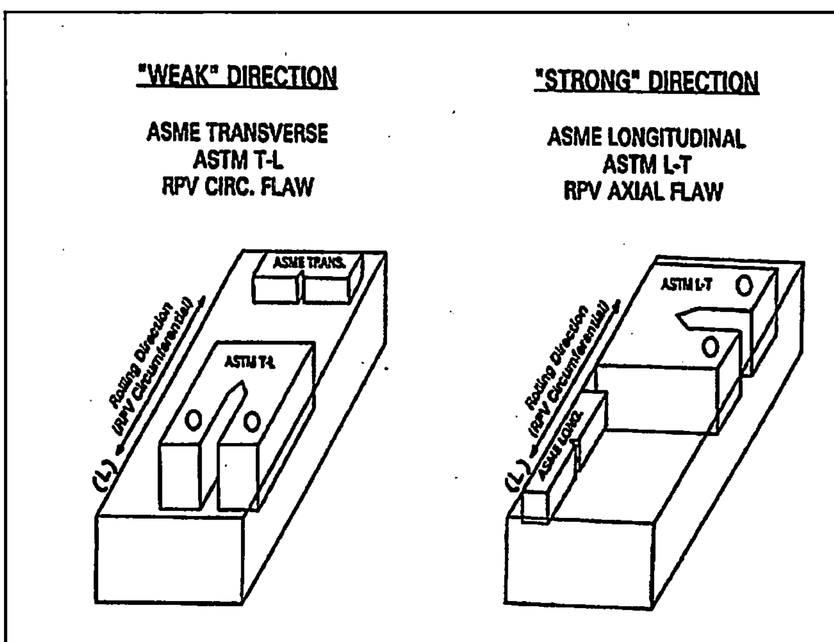

Figure 1 Comparison of "Weak" Direction and "Strong" Direction Test Specimens

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 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 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 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 (σ) 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 1σ. 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

<u>Table 12 Notes</u> (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 2σ 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 + σ	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

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