ELECTRIC POWER RESEARCH INSTITUTE

2015-088 BWR Vessel & Internals Project (BWRVIP)

July 15, 2015

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

Attention: Joseph Holonich

Subject: Project No. 704 – BWRVIP Response to NRC Second Request for Additional Information on BWRVIP-100, Revision 1

Reference: Letter from Joseph J. Holonich (NRC) to Dennis Madison (BWRVIP Chairman), Second Request for Additional Information Related to BWRVIP [Boiling Water Reactor Vessel Internals Project]-100, Revision 1, "BWR Vessel Internals Project – Updated Assessment of the Fracture Toughness of Irradiated Stainless Steel for BWR Core Shrouds" (TAC NO. ME8329), dated January 7, 2014

Enclosed are five (5) copies of the BWRVIP response to the NRC's second Request for Additional Information (RAI) on the BWRVIP report entitled "BWRVIP-100, Revision 1: BWR Vessel and Internals Project, Updated Assessment of the Fracture Toughness of Irradiated Stainless Steel for BWR Core Shrouds." The RAI was transmitted to the BWRVIP by the NRC letter referenced above.

Please note that the enclosed response contains proprietary information. A letter requesting that the response be withheld from public disclosure and an affidavit describing the basis for withholding this information are provided as Attachment 1. The response includes yellow shading and brackets to indicate the proprietary information. The proprietary information is also marked with the letters "TS" in the margin indicating the information is considered trade secrets in accordance with 10CFR2.390.

Two (2) copies of a non-proprietary version of the BWRVIP response to the RAI are also enclosed. This non-proprietary response is identical to the enclosed proprietary response except that the proprietary information has been deleted.

G004
NRR

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3420 Hillview Avenue, Palo Alto, CA 94304-1395 USA • 650.855.2000 • Customer Service 800.313.3774 • www.epri.com

Additional copies were sent to the PM

If you have any questions on this subject please call Ron DiSabatino (Exelon, BWRVIP Assessment Committee Technical Chairman) at 717.456.3685.

Sincerely,

Andrew McGehee, EPRI, BWRVIP Program Manager
Tim Hanley, Exelon, BWRVIP Chairman

ELECTRIC POWER RESEARCH INSTITUTE

Randy Stark
Director
EPRI

July 14, 2015

Document Control Desk
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Subject: Request for Withholding of the following Proprietary Information Included in:

BWRVIP Response to NRC's Second Request for Additional Information on BWRVIP-100, Revision 1: BWR Vessel and Internals Project, Updated Assessment of the Fracture Toughness of Irradiated Stainless Steel for BWR Core Shrouds." EPRI Technical Report 1021001.

To Whom It May Concern:

This is a request under 10 C.F.R. §2.390(a)(4) that the U.S. Nuclear Regulatory Commission ("NRC") withhold from public disclosure the report identified in the enclosed Affidavit consisting of the proprietary information owned by Electric Power Research Institute, Inc. ("EPRI") identified in the attached report. Proprietary and non-proprietary versions of the Response and the Affidavit in support of this request are enclosed.

EPRI desires to disclose the Proprietary Information in confidence to assist the NRC review of the enclosed submittal to the NRC. The Proprietary Information is not to be divulged to anyone outside of the NRC or to any of its contractors, nor shall any copies be made of the Proprietary Information provided herein. EPRI welcomes any discussions and/or questions relating to the information enclosed.

If you have any questions about the legal aspects of this request for withholding, please do not hesitate to contact me at (704) 595-2732. Questions on the content of the Report should be directed to Andy McGehee of EPRI at (704) 502-6440.

Sincerely,

Randy Stark

1300 West W.T. Harris Boulevard, Charlotte, NC 28262-8550 USA • 704.595.2732 • Mobile 704.490.2653 • nwilmshurst@epri.com

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

AFFIDAVIT

RE: Request for Withholding of the Following Proprietary Information Included In:

BWRVIP Response to NRC's Second Request for Additional Information on BWRVIP-100, Revision 1: BWR Vessel and Internals Project, Updated Assessment of the Fracture Toughness of Irradiated Stainless Steel for BWR Core Shrouds." EPRI Technical Report 1021001.

I, Randy Stark, being duly sworn, depose and state as follows:

I am the Director at Electric Power Research Institute, Inc. whose principal office is located at 3420 Hillview Avenue, Palo Alto, CA. ("EPRI") and I have been specifically delegated responsibility for the above-listed report that contains EPRI Proprietary Information that is sought under this Affidavit to be withheld "Proprietary Information". I am authorized to apply to the U.S. Nuclear Regulatory Commission ("NRC") for the withholding of the Proprietary Information on behalf of EPRI.

EPRI Information is identified in yellow shading with double square brackets. [[This sentence is an example.]] Tables containing EPRI proprietary information are identified with double square brackets before and after the object. The proprietary information is also marked with the letters "TS" in the margin indicating the information is considered trade secrets in accordance with 10CFR2.390A.

EPRI requests that the Proprietary Information be withheld from the public on the following bases:

Withholding Based Upon Privileged And Confidential Trade Secrets Or Commercial Or Financial Information (see e.g., 10 C.F.R. § 2.390(a)(4)):

a. The Proprietary Information is owned by EPRI and has been held in confidence by EPRI. All entities accepting copies of the Proprietary Information do so subject to written agreements imposing an obligation upon the recipient to maintain the confidentiality of the Proprietary Information. The Proprietary Information is disclosed only to parties who agree, in writing, to preserve the confidentiality thereof.

b. EPRI considers the Proprietary Information contained therein to constitute trade secrets of EPRI. As such, EPRI holds the Information in confidence and disclosure thereof is strictly limited to individuals and entities who have agreed, in writing, to maintain the confidentiality of the Information.

c. The information sought to be withheld is considered to be proprietary for the following reasons. EPRI made a substantial economic investment to develop the Proprietary Information and, by prohibiting public disclosure, EPRI derives an economic benefit in the form of licensing royalties and other additional fees from the confidential nature of the Proprietary Information. If the Proprietary Information were publicly available to consultants and/or other businesses providing services in the electric and/or nuclear power industry, they would be able to use the Proprietary Information for their own commercial benefit and profit and without expending the substantial economic resources required of EPRI to develop the Proprietary Information.

d. EPRI's classification of the Proprietary Information as trade secrets is justified by the Uniform Trade Secrets Act which California adopted in 1984 and a version of which has been adopted by over

forty states. The California Uniform Trade Secrets Act, California Civil Code §§3426 – 3426.11, defines a "trade secret" as follows:

> "'Trade secret' means information, including a formula, pattern, compilation, program device, method, technique, or process, that:
>
> (1) Derives independent economic value, actual or potential, from not being generally known to the public or to other persons who can obtain economic value from its disclosure or use; and
>
> (2) Is the subject of efforts that are reasonable under the circumstances to maintain its secrecy."

e. The Proprietary Information contained therein are not generally known or available to the public. EPRI developed the Information only after making a determination that the Proprietary Information was not available from public sources. EPRI made a substantial investment of both money and employee hours in the development of the Proprietary Information. EPRI was required to devote these resources and effort to derive the Proprietary Information. As a result of such effort and cost, both in terms of dollars spent and dedicated employee time, the Proprietary Information is highly valuable to EPRI.

f. A public disclosure of the Proprietary Information would be highly likely to cause substantial harm to EPRI's competitive position and the ability of EPRI to license the Proprietary Information both domestically and internationally. The Proprietary Information can only be acquired and/or duplicated by others using an equivalent investment of time and effort.

I have read the foregoing and the matters stated herein are true and correct to the best of my knowledge, information and belief. I make this affidavit under penalty of perjury under the laws of the United States of America and under the laws of the State of California.

Executed at 3420 Hillview Avenue, Palo Alto, CA being the premises and place of business of Electric Power Research Institute, Inc

Date: 7/14/2015

Randy Stark

Randy Stark

Civil Code 1189

A notary public or other officer completing this certificate verifies only the identity of the individual who signed the document to which this certificate is attached, and not the truthfulness, accuracy, or validity of that document.

(State of California)
(County of Santa Clara)

Subscribed and sworn to (or affirmed) before me on this 14th day of July, 2015 by Randy Starr, proved to me on the basis of satisfactory evidence to be the person(s) who appeared before me.

Signature Sandra K Tokunaga (Seal)

My Commission Expires 12 day of December, 2017

SANDRA K. TOKUNAGA
Commission # 2051548
Notary Public - California
San Mateo County
My Comm. Expires Dec 12, 2017

CALIFORNIA ALL-PURPOSE ACKNOWLEDGMENT **CIVIL CODE § 1189**

A notary public or other officer completing this certificate verifies only the identity of the individual who signed the document to which this certificate is attached, and not the truthfulness, accuracy, or validity of that document.

State of California)
County of Santa Clara)

On July 14, 2015 before me, Sandra K. Tokunaga, Notary Public
Date *Here Insert Name and Title of the Officer*

personally appeared Randy Stark
Name(s) of Signer(s)

who proved to me on the basis of satisfactory evidence to be the person(~~s~~) whose name(~~s~~) is/~~are~~ subscribed to the within instrument and acknowledged to me that he/~~she/they~~ executed the same in his/~~her/their~~ authorized capacity(~~ies~~), and that by his/~~her/their~~ signature(~~s~~) on the instrument the person(~~s~~), or the entity upon behalf of which the person(~~s~~) acted, executed the instrument.

I certify under PENALTY OF PERJURY under the laws of the State of California that the foregoing paragraph is true and correct.

WITNESS my hand and official seal.

SANDRA K. TOKUNAGA
Commission # 2051548
Notary Public - California
San Mateo County
My Comm. Expires Dec 12, 2017

Signature [signature]
Signature of Notary Public

Place Notary Seal Above

OPTIONAL

Though this section is optional, completing this information can deter alteration of the document or fraudulent reattachment of this form to an unintended document.

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Title or Type of Document: ______________ Document Date: ______________
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☐ Corporate Officer — Title(s): ______________
☐ Partner — ☐ Limited ☐ General
☐ Individual ☐ Attorney in Fact
☐ Trustee ☐ Guardian or Conservator
☐ Other: ______________
Signer Is Representing: ______________

Signer's Name: ______________
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☐ Partner — ☐ Limited ☐ General
☐ Individual ☐ Attorney in Fact
☐ Trustee ☐ Guardian or Conservator
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Signer Is Representing: ______________

Non-Proprietary BWRVIP Response to NRC's Second Request for Additional Information on BWRVIP-100, Rev 1

Second Request for Additional Information Related to BWRVIP-100, Revision 1, BWR [Boiling Water Reactor] Vessel and Internals Project – Updated Assessment of the Fracture Toughness of Irradiated Stainless Steel for BWR Core Shrouds Electric Power Research Institute Project No. 704

Each item from the NRC Request for Information (RAI) is repeated below verbatim followed by the BWRVIP response to that item.

RAI-8

NUREG/CR-6428 (Ref. 1) defined a lower-bound J-R curve for fully-saturated thermally aged, non-irradiated Type 308 and 316 SMAW welds as $J=40+83.5\Delta a^{0.643}$. The BWRVIP-100, Revision 1 model predicts higher fracture toughness than the Reference 1 curve, even at low fluence ($3x10^{20}$ n/cm^2).

O'Donnell et al. (Ref. 2) reports several results, including some from earlier work, for austenitic stainless steel welds irradiated to 4-5 dpa that had low, flat J-R curves that would not be bounded by the BWRVIP-100, Rev. 1 model. The welds were not thermally aged. NUREG/CR-7027 (Ref. 3) presents an alternate lower bound curve for fracture toughness of irradiated austenitic stainless steel welds and cast austenitic stainless steels. This curve is also more conservative than the BWRVIP-100, Rev. 1 model.

Although the studies described above do not report on testing of welds subject to both thermal aging and irradiation, the results suggest that either thermal aging or irradiation independently can produce fracture toughness in austenitic stainless steel welds that would not be bounded by the BWRVIP-100, Rev. 1 model.

Requested Information:

Discuss and disposition the results of the studies cited above with respect to the BWRVIP-100, Revision 1 fracture toughness model. Propose changes as necessary to ensure that the BWRVIP-100, Revision 1 model is conservative for evaluation of core shroud cracking located in the weld metal.

References:

1. NUREG/CR-6428, Effects of Thermal Aging on Fracture Toughness and Charpy-Impact Strength of Stainless Steel Pipe Welds, April 30, 1996 (ADAMS Accession No. ML052360567).

2. O'Donnell, I. J. et al, "The Fracture Toughness Behavior of Austenitic Steels and Weld Metal Including the Effects of Thermal Ageing and Irradiation," in Int. J. Pres. Ves. & Piping 65 (1996), pp. 209-220, Elsevier Science Limited.

3. NUREG/CR-7027, "Degradation of LWR Core Internal Materials Due to Neutron Irradiation," December 31, 2010, (ADAMS Accession No. ML102790482).

BWRVIP Response to RAI-8:

Because the exposure time for materials in operating BWRs exceeds one hundred thousand hours it is impractical in laboratory studies to conduct long term aging tests consistent with BWR operating conditions. Consequently, a number of laboratory experiments have been performed to assess aging effects using materials that have been aged for short times at temperatures (e.g., 752°F) significantly greater than BWR operating temperatures (550°F).

Fracture toughness tests on specimens aged for short times at temperatures significantly higher than BWR operating temperature were used to define a J-R curve for fully-saturated thermally aged, non-irradiated Type 308 and 316 SMAW welds, $J = 40+83.5 \bullet \Delta a^{0.643}$ as shown in Figure 16 in NUREG/CR-6428 (Ref. 1).

Other test programs where specimens were irradiated and tested at temperatures significantly higher than BWR operating temperature were used to define a lower bound for the ductile fracture parameter "C". This lower bound was defined as $C = 20 + 205 \bullet EXP(-0.65 \bullet dpa)$ as shown in Figure 75(b) of NUREG/CR-6960 (Ref. 2) and later as $C = 25 + 175 \bullet EXP(-0.35 \bullet dpa)$ as shown in Figure 63(b) of NUREG/CR-7027 (Ref. 3). The values of "C" in these relationships is a parameter used to describe the material resistance to ductile crack extension, J_{mat}, or $J_{mat} = C(\Delta a)^n$, where Δa is the amount of ductile crack extension and C and n are the power law coefficients. The coefficient C represents the resistance to a small amount of crack extension (1 mm) just following initial crack extension while n represents the change in crack extension for an increased load increment. The coefficient C has been observed to be generally correlated to the level of neutron fluence and is often plotted as a function of neutron fluence to provide a visual picture of the variation in stainless steel fracture toughness as a function of neutron fluence.

Stainless steel fracture toughness degradation is a complex function of the level of neutron irradiation, irradiation temperature, irradiation flux and spectrum, exposure time and temperature, test temperature, material grain orientation (TL or LT), heat treatment and element content. Currently there is no direct, quantitative correlation between exposure time, exposure temperature, irradiation level and fracture toughness, and we know of no technical basis that demonstrates that the effect on toughness from irradiation and short time thermal aging at temperatures substantially above BWR operating temperatures is equivalent to the effect on toughness from long term aging or irradiation at BWR operating temperatures. Using data obtained substantially outside BWR operating conditions only adds to the uncertainty in defining the fracture toughness for materials irradiated in BWRs.

To reduce the uncertainty associated with potential long term aging and combined irradiation effects on fracture toughness at operating BWR conditions, the industry is using test specimens manufactured from materials removed from operating reactors, many of which have accumulated up to 175,000 hours of exposure time and irradiation at 550°F, to assess material toughness (Ref.

4). The most accurate representation of the actual combined aging and irradiation effects for BWR operation are included in the data presented in BWRVIP-100, Rev. 1 and the associated "C" and "n" relationships (Ref. 5).

This is illustrated in the plot presented in Figure 1, where material irradiated in test reactors and tested at BWR operating temperature (open squares) are presented along with materials that have been irradiated in operating reactors, removed from the reactor and tested at BWR operating temperature (solid diamonds and X). Most of the data (44 of 54 experiments), including all the welds, shown at fluences greater than 1E20 n/cm^2 were obtained using specimens manufactured from material removed from operating BWRs; the remaining data were obtained from specimens (base metal and HAZ) that had been irradiated in test reactors at approximately 550°F. Also shown in Figure 1 is the bounding curve for "C" defined in BWRVIP-100, Rev. 1 in the fluence range from 1.5E20 n/cm^2 to 3E21 n/cm^2. This curve bounds all the data obtained for materials irradiated and tested at BWR operating temperature. The data in Figure 1 show that the populations of test reactor and operating reactor data are intermingled. This indicates that there is no significant aging effect at BWR operating temperature and exposure times. The bounding curve for "C" defined in BWRVIP-100, Rev. 1 is consistent with limits typically used in the ASME Code where the allowable toughness is based on a bound of most, but not all, of the available data that are associated with actual component operating conditions.

The only data points that lie outside the BWRVIP-100, Rev. 1 bound curve are data that were obtained at aging, irradiation and test temperatures that are higher than BWR operating temperatures. It is not clear whether these outliers represent a real high temperature effect or are coincidental, and possibly associated with data scatter. To assess the possibility that the outliers are due to data scatter requires a significant number of data points; however, as indicated in NUREG/CR-7027 there are not enough data available from irradiated experiments at BWR conditions to make this assessment. Consequently, the distribution associated with data scatter will be estimated using results obtained from non-irradiated welds.

Figure 2 shows a plot of "C" as a function of neutron fluence for the results from experiments using non-irradiated material (plotted for visual convenience at fluence = 2E18 n/cm^2 for welds, 2.5E18 n/cm^2 for HAZ and 3E18 n/cm^2 for base metal) and irradiated material at fluences greater than 1E20 n/cm^2. All the data shown in Figure 2 were obtained from experiments conducted at 550°F. The non-irradiated data shown in Figure 2 were obtained from Table B.9 in NUREG/CR-6004 (Ref. 6) and Table 5 in NUREG/CR-6428. The data shown for the HAZ material are reported in EPRI NP-4768 (Ref. 7). These HAZ specimens were obtained from material adjacent to low toughness welds where "C" for the weld material ranged from about 200 kJ/m^2 to 400 kJ/m^2. There is scatter in the data all along the fluence range, but some of the lowest values of "C" are seen for the non-irradiated weld data at the left of the figure.

A review of the data indicates there are three distinct groups of non-irradiated weld data shown in Figure 2. One data set, reported in NUREG/CR-6004, has low toughness where "C" ranges from approximately 150 kJ/m^2 to 400 kJ/m^2 and was obtained using 1TCT and 2TCT specimens. There are two specimens reported in NUREG/CR-6428 that appear to have intermediate toughness where "C" has values of 400 kJ/m^2 and 650 kJ/m^2, which were obtained using 1TCT specimens. The third data set, reported in NUREG/CR-6004, has high toughness where "C" ranges from approximately 600 kJ/m^2 to 1000 kJ/m^2 and was obtained using pipe specimens that contained small surface cracks. The data used to estimate the distribution for the irradiated low

toughness welds include the non-irradiated welds where "C" ranges from 150 kJ/m^2 to 400 kJ/m^2. The other data were not included because they appear to have toughness that is not consistent with the low toughness weld population, especially the results from the shallow surface flaw pipe experiments.

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Figure 63(b) in NUREG/CR-7027 presents an alternate lower bound curve for fracture toughness of irradiated austenitic stainless steel welds and cast austenitic stainless steels. The lower bound curve shown in Figure 63(b) apparently is based primarily on the data represented by the open circles. Although the origin of these data is not clear in NUREG/CR-7027, it appears that these data were irradiated and tested at temperatures substantially higher (i.e., 698°F) than BWR operating conditions (see Figure 75(b), NUREG/CR-6960).

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]] Using these high temperature data only adds to the uncertainty in defining a reasonably conservative representation of the fracture toughness for materials in operating BWRs.

The work reported by O'Donnell et al. (Ref. 8) used various irradiation and thermal aging conditions to determine the fracture toughness for austenitic stainless steel base metal and welds. These experiments included aging, irradiation and test temperatures ranging from 698°F to 1022°F, which are substantially above BWR operating temperatures. A comparison of the data reported in the O'Donnell work with data from BWRVIP-100, Rev. 1 and the estimated [["Content Deleted – EPRI Proprietary Information"]] are presented in Figure 6. TS

The comparisons in Figure 6 indicate that the irradiated data from the O'Donnell paper are either within or close to the bounding C curve defined in BWRVIP-100, Rev. 1. The two data points with low "C" values just outside (to the left of) the EPFM limit at 3E20 n/cm^2 could be a result of irradiation and testing at temperatures significantly greater than BWR operating temperature. Again, there is uncertainty in these results because the specimens were irradiated and tested at temperatures substantially higher than BWR operating temperatures.

To evaluate the sensitivity associated with the margins against failure from ductile crack extension, the toughness represented by both the [["Content Deleted – EPRI Proprietary Information"]] were compared to the margins against failure determined using the toughness represented by the BWRVIP-100, Rev. 1 bounding "C" line. [["Content Deleted – EPRI Proprietary Information"]] TS TS
The results from the margin analyses are presented in Figure 7.

The results in Figure 7 show the margins remain [["Content Deleted – EPRI Proprietary Information"]] This result indicates that there is a relatively small change in margin when the toughness is represented by either [["Content Deleted – EPRI Proprietary Information"]] relative to the BWRVIP-100, Rev. 1 bounding curve. TS TS

Inspection results from core shroud examinations show that cracks initiate in the HAZ along the weld fusion line and not in the weld. However, some cracks can propagate away from the HAZ into the base metal and, in some rare instances, across the weld perpendicular to the weld direction. The observed crack initiation and growth characteristics indicate that the crack extension generally occurs in the HAZ or the base metal; consequently, the lower bound, composite weld, HAZ and base metal fracture toughness curve in BWRVIP-100, Rev. 1 is a realistic, conservative representation of the crack initiation and growth characteristics observed in core shrouds in operating BWRs.

Based on this evaluation the BWRVIP concludes that the data base and the bounding "C" and "n" curves in BWRVIP-100, Rev 1: provide the most accurate characterization of the combined effects of aging and irradiation for materials in operating BWRs; adequately characterizes the fracture toughness for BWR operating conditions; is consistent with crack initiation and growth characteristics in the core shroud; and provides adequate margins against failure from ductile crack extension. Because there is no direct, quantitative correlation between BWR operating conditions and test results from experiments conducted at temperature significantly higher than BWR operating temperatures, the high temperature results are not used in the BWRVIP fracture toughness data base.

Based on these results the BWRVIP proposes to continue to use the BWRVIP-100, Rev. 1 bounding curve. However, weld and HAZ materials have been removed from an operating reactor and will be tested later this year. When the results from these tests, as well as results from any future tests that might be performed, are available they will be added to the data base presented in Figure 1 and Figure 4. If the results from future experiments with material removed from operating BWRs fall below the [["Content Deleted – EPRI Proprietary Information"]] shown in Figure 4, the BWRVIP-100, Rev. 1 bounding curve will be reevaluated and appropriate changes will be made to ensure that adequate margins against failure from ductile crack extension will be maintained in BWR core shrouds. TS

References:

1. NUREG/CR-6428, Effects of Thermal Aging on Fracture Toughness and Charpy-Impact Strength of Stainless Steel Pipe Welds, April 30, 1996 (ADAMS Accession No. ML052360567).
2. NUREG/CR-6960, Crack Growth Rates and Fracture Toughness of Irradiated Austenitic Stainless Steels in BWR Environments, March 2008.
3. NUREG/CR-7027, "Degradation of LWR Core Internal Materials Due to Neutron Irradiation," December 31, 2010, (ADAMS Accession No. ML102790482).
4. BWRVIP 154, Revision 2: BWR Vessels and Internals Project, Fracture Toughness in High Fluence BWR Materials, EPRI, Palo Alto, CA: 2009. 1019077.
5. BWRVIP-100, Revision 1: BWR Vessel and Internals Project, Updated Assessment of the Fracture Toughness of Irradiated Stainless Steel for BWR Core Shrouds, EPRI Technical Report 1021001, October 2010.
6. NUREG/CR-6004, Probabilistic Fracture Evaluations for Leak-Rate-Detection Applications, April 1995.
7. Topical Report NP-4768, Toughness of Austenitic Steel Pipe Welds, EPRI Research Project 1238-2, October 1986.
8. O'Donnell, I. J. et al, "The Fracture Toughness Behavior of Austenitic Steels and Weld Metal Including the Effects of Thermal Ageing and Irradiation," in Int. J. Pres. Ves. & Piping 65 (1996), pp. 209-220, Elsevier Science Limited.

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Figure 1. Comparison of Fracture Toughness Power Law Coefficient C Values Obtained from Materials Irradiated in Test Reactors with Values Determined from Materials Irradiated in Operating BWRs, Test Temperature = 550°F.

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Figure 2. Comparison of the Power Law Toughness Coefficient, C, from BWRVIP-100, Rev. 1 Irradiated Data and Bounding Curve with Non-irradiated Data, Test Temperature = 550°F.

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Figure 3. Distribution for Fracture Toughness Power Law Coefficient, C, Non-irradiated Austenitic Stainless Steel Low Toughness Welds, Test Temperature = 550°F.

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Figure 4. Comparison of the Estimated Mean, 90% and 95% Curves for Irradiated Welds with the Fracture Toughness Power Law Parameter C in BWRVIP-100, Rev. 1.

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Figure 5. Comparison Between the Data and the Bounding "C" Curve in BWRVIP-100, Rev. 1, the Estimated 90% and 95% Bounds for Irradiated Welds, and the Data Used in NUREG/CR-7027 to Construct the Bounding Toughness Curve for Austenitic Stainless Steel Welds.

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Figure 6. Comparison Between the Data and the Bounding "C" Curve in BWRVIP-100, Rev. 1, the Estimated 90% and 95% Bounds for Irradiated Welds, and the Data from O'Donnell for Austenitic Stainless Steel Welds.

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Figure 7. Comparison of Margin Against Failure by Ductile Crack Extension for the BWRVIP-100, Rev. 1 Bounding "C" Curve and the Estimated 90% and 95% Bound Curves for Irradiated Welds in the Fluence Range from 1.5E20 n/cm^2 to 3E21 n/cm^2. Shroud thickness = 1.5-inch, R/t = 58, Nominal Stress = 6 ksi and Flaw Depth for 360° Circumferential, Inside Surface Flaw = 1-inch (a/t = 0.67).