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SUBJECT: Submits response to S Penn re core shroud evaluations for NMP,Unit 1.S Penn expressed several concerns re studies performed by util & contractors.

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April 30, 1999
NMP1L 1432

U. S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, DC 20555

RE: Nine Mile Point Unit 1
Docket No. 50-220
DPR-63

Subject: ***Response to Dr. S. Penn Regarding Core Shroud Evaluations, Nine Mile Point Unit 1 (NMP1)***

Gentlemen:

In a letter to Niagara Mohawk Power Corporation (NMPC) dated April 27, 1999, the Nuclear Regulatory Commission (NRC) provided a copy of Dr. Steven Penn's letter dated March 25, 1999. In his letter, Dr. Penn presented his analysis of the NRC's safety evaluation of November 2, 1998, and the related studies that were submitted by NMPC in support of the schedule extension for reinspecting the core shroud vertical welds at NMP1.

Specifically, Dr. Penn expressed several concerns regarding the studies performed by NMPC and its contractors. In its letter dated April 27, 1999, the Staff requested that NMPC provide written comments to the NRC addressing Dr. Penn's expressed concerns. NMPC's responses to Dr. Penn's concerns are provided in the Attachment to this letter. Specifically, Dr. Penn's concerns are grouped into five topics in the Attachment with corresponding NMPC responses.

In summary, NMPC does not agree with the key assertions and conclusions of Dr. Penn. First, the assertion that improper research procedures were followed is not valid. The procedures followed were appropriate for the task and were accurately described and used conservatively. The application of the results appropriately considered the uncertainty associated with the measurements and accounted for the potential measurement error.

Further, the assertion that the scientific method was not followed and that the material evaluation results were biased is inconsistent with the facts. Appropriate engineering judgement was applied during testing. The analysis methods and presentation of results

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were consistent with the parameters investigated. NMPC's evaluation of the core shroud included industry peer review with the participation of several industry experts from outside NMPC.

With respect to fluence effects, NMPC conservatively considered the relationship between fluence and cracking patterns. The total fluence is below 5E20 neutrons/cm^2 allowing application of Electric Power Research Institute (EPRI) Report titled "Evaluation of Crack Growth in BWR Stainless Steel RPV Internals (BWRVIP-14)." Also, the crack growth rates applied are conservatively bounded in the irradiated PLEDGE analysis and are bounded by the disposition crack growth rate in the BWRVIP-14 EPRI Report.

To support determination of fluence effects, samples of the NMP1 core shroud were taken and numerous diverse tests and evaluation methods were performed which established the nature of the cracking. This included the following: optical metallographic evaluation, scanning electron microscopy, chemical composition, fluence measurements, microhardness measurements, tensile tests, and Electrochemical Potentiokinetic Reactivation (EPR) measurements. Specifically, the results of the optical metallographic evaluation showed no evidence of irradiation assisted cracking. The combined results demonstrate that the material behavior is consistent with typical 304 stainless steel core shroud material in the 1 to 5E20 neutrons/cm^2 (E greater than 1 Mev) fluence field and that the mechanism is Intergranular Stress Corrosion Cracking (IGSSC).

Accordingly, NMPC has concluded that the generic BWRVIP-14 EPRI Report as approved by the Staff is directly applicable to NMP1 and further testing or analysis is not required of the core shroud sample to ensure the safe operation of the unit.

NMPC also received in the Staff's letter dated April 27, 1999, a copy of Dr. Penn's letter dated April 15, 1999, which contained several suggestions regarding the current core shroud inspection program. The scope of the inspection program for the NMP1 core shroud for refueling outage (RFO) 15 satisfies or exceeds the recommendations of EPRI Report titled "Guidelines for Reinspection of BWR Core Shrouds (BWRVIP-07)" for a repaired shroud. In addition, the NRC has approved the scope of inspections for RFO15 for NMP1. NMPC believes that the inspection plan already reflects consideration of Dr. Penn's concerns regarding the inspection of base metal, horizontal welds, ring segment welds and tie rods. After reviewing Dr. Penn's letter dated April 15, 1999, NMPC has concluded that no changes are required to the inspection program.

Very truly yours,

Richard B. Abbott

Richard B. Abbott
Vice President - Nuclear Engineering

RBA/KWK/kap
Attachment

xc: Mr. H. J. Miller, Regional Administrator, Region I
Mr. S. S. Bajwa, Director, Project Directorate I-1, NRR
Mr. G. K. Hunegs, Senior Resident Inspector
Mr. D. S. Hood, Senior Project Manager, NRR
Records Management

ATTACHMENT

INTRODUCTION

Niagara Mohawk Power Corporation (NMPC) has reviewed the concerns raised by Dr. Penn in his March 25, 1999 letter. The letter indicated that several serious errors exist in the NMPC studies which undermine the conclusions reached by NMPC and the Nuclear Regulatory Commission (NRC) that the crack growth may be safely assumed to be below (2.2E-5 in/hr). NMPC has reviewed in detail the technical concerns raised in his letter. A discussion of the specific points raised by Dr. Penn is provided.

The evaluation presented below considers the full breadth of information provided by NMPC both on a plant specific basis and through the Boiling Water Reactor Vessel Internals Project (BWRVIP). It is in the context of all the information that the specific measurements and tests were evaluated to reach the conservative conclusion that the crack growth rate applicable to the core shroud vertical weld is the BWRVIP-14 disposition crack growth rate of 2.2E-5 in/hr.

It appears that Dr. Penn has assumed that the NMPC conclusions or the NRC acceptance of the NMPC application of the BWRVIP-14 disposition crack growth rate was based on the Electrochemical Potentiokinetic Reactivation (EPR) measurements or on the tensile test data. These studies serve only to establish additional margin above that required since the BWRVIP-14 disposition crack growth rate bounds furnace sensitized 304 stainless steel components having a high degree of sensitization. The BWRVIP-14 crack growth correlation bounds crack growth rates in stainless steel up through the 5E20 neutrons/cm^2 ($E > 1$ Mev) fluence level without the need for any supplemental analyses or evaluations of EPR or tensile properties.

EVALUATION

Presented below is NMPC's evaluation of Dr. Penn's concerns. Specifically, NMPC has requested each individual contributor responsible for the work referenced by Dr. Penn to review his concerns to determine if any errors were made. Furthermore, NMPC requested each of these contributors to review Dr. Penn's letter in total to determine if any possibility exists that the boat sample data was applied in a manner which could have resulted in non-conservative conclusions regarding the potential crack growth rate related to the core shroud vertical weld structural examinations.

The evaluation, as presented below, includes the following:

1. Management of EPR Test Results

2. EPR Measurements and Double Loop to Single Loop Conversions

3. Tensile Tests

4. EPR Inputs to Irradiated PLEDGE Calculations

5. Interpretive Report

This evaluation has been developed by the NMPC Nuclear Engineering Design Organization with input from appropriate contributors as described above.

1. *Management of EPR Test Results*

Dr. Penn has questioned the laboratory procedures applied to evaluate EPR measurements of the degree of sensitization carried out with the Ishikawajima Heavy Industries (IHI) field-testing equipment. He has asserted that the scientific method was not followed and that the experimenter biased results through invalid data analysis procedures.

Background discussion of application of IHI field tester

It was recognized that EPR measurements had not been attempted previously for radioactive core shroud boat samples. It was judged that it was worthwhile to evaluate the degree of sensitization independently of microstructural features, then compare the EPR results to the estimate of sensitization made using the boat sample microstructural features and engineering judgement (metallurgical team with extensive experience in Boiling Water Reactor Intergranular Stress Corrosion Cracking (BWR IGSCC) phenomena).

The comparison was semi-qualitative in nature, because assessments of Degree of Sensitization (DOS) from microstructural features are based upon known principles of corrosion and engineering judgement of the personnel evaluating the microstructures. Experience is a significant factor in this task. The team that reviewed the NMP1 microstructures and compared features with other core shroud microstructures has been extensively involved with IGSCC technology for many years. The microstructure was judged to be moderately sensitized in the weld Heat Affected Zone (HAZ). It was also compared to other sensitized stainless steel samples which confirmed the level of sensitization and which could be used to benchmark the EPR level. The method applied to measure EPR response in the core shroud boat samples was the only practical method available for these measurements, and the I_r/I_a (i.e., reverse polarization peak current/anodic polarization process peak current) results obtained were judged to be consistent with the sensitization assessment of the microstructures of the boat samples. The IHI EPR field method produces a numerical ratio with which degree of sensitization is evaluated. Even though the method yields a numerical result, it is only used in this study to evaluate a low, moderate or high degree of sensitization. There

are many variables to control in the EPR test that can influence the precise numerical value. Therefore the test results, though measured carefully, were only used in a comparative sense to confirm, if possible, the metallographic evaluation.

This confirmation led to the conclusion that the core shroud samples were "moderately sensitized." However, the estimates of crack growth rates included several considerations and were not solely based upon the assessment's initial level of sensitization in the austenitic stainless steel. General Electric (GE) used this information in conjunction with other EPR understanding and then predicted the IGSCC crack growth rates as described in their report.

With this goal in mind, it was useful to examine the I_r/I_a ratios to estimate degree of sensitization – high, moderate, low (this is the normal procedure for the IHI field unit). The IHI field test is based upon a double loop (DL) technique. It was developed to assess the presence of sensitization without a grain size correction. This assists in minimizing the effects of test variables inherent to field-testing. Most EPR measurements reported in the literature are based upon single loop (SL) tests, which require a metallographic sample and includes a measurement of grain size to normalize the current density, given in terms of coulombs per square centimeter. The GE model was based on SL EPR measurements. Therefore, a conversion curve was used to relate the IHI ratios to SL values. It should be remembered that this conversion was not necessary to evaluate the qualitative agreement between EPR and microstructures. It did assist in the physical understanding of the measurement for those unfamiliar with the DL ratios and allowed a tie to the input used in the GE PLEDGE model, one of the models used in the overall assessment.

No equipment was available to perform the SL EPR measurements in the hot cell which were needed to define this relationship. Therefore, it was necessary to generate a conversion curve externally (GE), based upon laboratory equipment DL ratios and SL values. The connecting link was that the measurements were made on the same two calibration check standards provided with the IHI equipment. One standard was sensitized and the other was not. This mechanism, while not ideal from an experimentation standpoint, was the only means available to attempt the conversion experimentally.

The IHI field ratios by themselves provide sufficient evidence that the materials are moderately sensitized, and that this is consistent with the microstructural features seen on the samples. To attempt to infer anything more is not justified based upon the testing performed.

EPR Testing

Appendix 1 to the Altran Technical Report 97181-TR-03, Rev. 0, provides the Framatome Technologies Incorporated (FTI) report on "Degree of Sensitization EPR Testing Results for the Nine Mile Point Unit 1 Boat Samples," letter report from Kevin

Hour to Brian Hall (Framatome Technology, Inc, January 14, 1998). This report describes the EPR testing performed at McDermott Technology, Inc. with the IHI field tester.

The EPR tests were repeated until the technicians had sufficient command of the testing procedures so that consistent values could be obtained with the equipment. This included preparation of the test surfaces, masking the areas to be tested, preparation of the electrolyte, and mounting of the test cell. The record runs for the standards were performed and recorded. The test values were consistent with the engraved number on the standards.

Next the tests were performed on the core shroud boat samples. It should be noted that these two samples were mounted in a metallurgical mount that exposed the weld, HAZ, and base material away from the weld. Precisely masking the test area and locating the test cell is difficult, especially for a radioactive sample that must be prepared rapidly and at arms length.

With this background in mind, the following input is provided regarding the "aberrations in the analysis" noted by Dr. Penn on pages 5 and 6 of his March 25, 1999 letter.

Standard "S"

Run #1 – There are many variables that can account for high numbers such as the ones cited for sample V-9. It was decided to retest the sample and replace that EPR value with two additional tests. Both of these were reported and have been included in the test analysis. There are no rules for EPR testing regarding the elimination of inconsistent test results; however, the practice followed is consistent with mechanical testing rules of American Society of Testing and Materials (ASTM) and American Society of Mechanical Engineers (ASME) where a single sample result appears out-of-line with other test results.

Weld V-9

There were four tests made on the V-9 sample, and two of the tests were discounted (Run #1 and Run #4) because of difficulty related to working with the radioactive samples and masking the test area.

Run # 1 – The operator acknowledged that the preparation of the test area (masking) might be in error. This was based upon the observation of a large area of discoloration under the mask after the test. This indicates a mask that is not tight and has experienced a creviced attack from the electrolyte. A high value will result from this condition. The value was discarded, not because it was high, but because evidence of creviced corrosion was observed.

Run # 4 – Observation of the test sample after the run indicated that the masked test area included both base material and weld material. This is well known to yield erroneous results since the weld has a different composition and will also contain ferrite. The electrochemical response will be different from the base material and HAZ. This value was also discarded, not because it was high, but because evidence was clear that the wrong area had been tested.

Weld V-10

Run #1 – The ratio value for this run was much higher than the other two initial test values. The reason was unknown, and no record of erroneous sample preparation was indicated. However, there are many variables that can account for high numbers such as the ones cited for sample V-9 above. The sample area was positioned away from the HAZ that exhibited very little sensitization in the metallographic evaluation. Therefore the EPR response clearly was inconsistent with the metallographic evidence. It was decided to retest the sample and replace that EPR value with two additional tests. Both of these were reported and have been included in the test analysis. There are no rules for EPR testing regarding the elimination of inconsistent test results; however, the practice followed is consistent with mechanical testing rules of ASTM and ASME where a single sample result appears out-of-line with other test results.

Run #5 – The negative IR value was noted in the documentation. The negative IR values are appropriately considered an absolute value based on the IHI reference standard testing and is consistent with IHI field testing practice.

316 Calibration Sample

The use of the type 316 medium sensitization sample can only create confusion and was not used in the study. It was referenced for completeness only. The description in the report discusses the confusing effects of the molybdenum content on surface oxides and the IHI EPR testing manual alerts the tester to the test parameter changes required for molybdenum bearing materials. It was felt that the use of this sample would be confusing. (Note: there are also no standards, only IHI reference papers and GE Corporate Research and Development (CR&D) understanding from other DL EPR studies.)

2. *EPR Measurements and Double Loop to Single Loop Conversions*

The following is provided in response to Dr. Penn's comments regarding "calibration of the sensitization data" described on pages 7 through 13 of his March 25, 1999 letter.

Dr. Penn undertook efforts to examine the DL EPR measurements and has made several comments regarding the actual measurements themselves and the approaches used in analyzing the data. He first questioned the use of the McDermott calibration data due to the differences from the IHI quoted calibration values for the standards. He

also questioned the elimination of some data because of either experimental difficulties that were not explained in detail or high values caused by improper sampling of duplex microstructure regions. He questioned the conclusions regarding SL EPR values because of concerns about the method used to convert the DL values to SL values. Finally, even though there was no discussion of using the data directly to set the modeling parameter, he suggested that it was appropriate to use a statistical approach to set the initial EPR value used in the Irradiated PLEDGE modeling. Each of his concerns are addressed below.

The purpose of the DL EPR measurements was to develop additional information on the level of sensitization in the NMP1 boat samples. These measurements were not used to set the EPR value directly and were only one source of information that was used to evaluate the amount of sensitization in the NMP1 material. Other information was used to select the initial EPR (EPRo) input for the PLEDGE assessment and this will be discussed in the next section.

The DL EPR measurements made by McDermott Labs are valid even though there are differences from the values reported for the two IHI standards. The IHI DL EPR field cell was developed with the major objective to screen sensitized material from non-sensitized material, not to reproducibly discern small differences in the level of sensitization of austenitic stainless steels. The actual magnitude of the measured values will depend on several experimental parameters. The IHI DL EPR cell uses a small area which can influence the magnitude of the measurement. The DL EPR laboratory procedures used by GE CR&D are different and measure the DL EPR response over a larger area. The measurements conducted at GE CR&D have been used to develop more quantitative information on the level of sensitization in materials and have good repeatability. For example, the differences between techniques did lead to much lower readings for the annealed material using the laboratory method. The systematic differences can be attributed to the experimental procedural and equipment differences.

As Dr. Penn has stated, there are several important steps in making the DL to SL conversion. However, it is important first to recognize that the SL values were determined directly on the two IHI standards. These SL values were determined in the laboratory following ASTM procedures that were first developed by GE engineers. Therefore, they are consistent with the values used as the basis for GE modeling activities. They properly benchmark the two IHI standards: one annealed (non sensitized) and one given a full furnace sensitization treatment. As such, these SL values can be assigned to the IHI material standards.

After determining the SL values for the standards, the DL to SL conversion can be made in three ways using (1) the DL values reported by IHI, (2) the DL values measured by McDermott Labs with the IHI field DL procedures, or (3) the DL values measured by GE CR&D based on Japanese laboratory procedures. All three sets of DL measurements characterize the level of sensitization in the two standards even though the magnitudes are different. It is our opinion that the McDermott Labs measurements

on the standards are the most representative for this evaluation in that they were made using the same equipment, the same relative sampling area and the same electrolyte batch that were used for the hot cell measurements on the boat samples V-9 and V-10. The interpolation between these standard values gives a good assessment of the level of sensitization in the two boat samples. In the submittal, the GE CR&D relationship was also used to provide a check, thereby giving an assessment of the upper range of EPR values for the boat sample material. There was no intent to use the data in a statistical manner. The data were used to benchmark the level of sensitization, not to assign a specific number. It should also be noted that the EPR values of interest are those that were measured in the HAZ region where cracking is found. The McDermott data clearly confirm that the material in this HAZ region is only moderately sensitized. The higher DL EPR value from the duplex weld metal reported by McDermott should be discounted as the weld metal is not representative of the weld HAZ where the cracking was observed. In fact, the duplex weld metal is not susceptible to IGSCC and therefore, the DL EPR value is not relevant.

One can interpolate directly using the measured DL values provided by McDermott Labs. This is consistent with the graphical depiction of the conversion in the report providing a means of assessing the level of sensitization. Table 1 provides the SL EPR values that were determined based on the McDermott DL EPR measurements and the GE CR&D SL EPR measurements on the IHI standards. All of the SL EPR values are less than the EPRo (initial value) of 10.8 coulombs(C)/cm^2 and the approximate value of 15 C/cm^2 assigned by the model to the material at a fluence of 4E20 neutrons/cm^2. As discussed in the next section, equally important are the optical metallographic information that was used to evaluate sensitization. This is also consistent with the converted SL values.

Table 1: DL EPR Measurements on NMP1 Boat Samples and Corresponding SL EPR Values Calculated Using McDermott DL EPR Calibration

Testing Lab	Sample	Location	Technique	DL EPR Value (Ir/Ia)	SL EPR Value (C/cm^2)
McDermott	V10	HAZ-#2	IHI Field	0.169	5.7
McDermott	V10	HAZ-#3	IHI Field	0.161	5.1
McDermott	V10	HAZ-#4	IHI Field	0.044	0.3
McDermott	V10	HAZ-#5	IHI Field	0.122	2.8
McDermott	V9	HAZ-#2	IHI Field	0.096	1.7
McDermott	V9	HAZ-#3	IHI Field	0.064	0.7

Conversion Equation: $SL_{EPR\,(McD)} = 266*(DL_{EPR\text{-}McD})^{2.165}$ where (McD) is McDermott

3. *Tensile Tests*

The following addresses Dr. Penn's three comments that are related to tension tests performed at McDermott Technology Inc. (now Babcock Wilcox (B&W) Services, Inc.) for the NMPC boat samples removed from NMP1 in 1997, as described on pages 13 and 14 of his March 25, 1999 letter.

Dr. Penn stated (comment 1, page 13 of his letter): "On the top of page 9 of the report, the author discusses the relationship between the measured yield strength, the bulk yield strength, and the cross sectional geometry. The author should have provided an estimate for the geometric correction factor for the irradiated samples. Certainly the correction is smaller for the harder materials, but I doubt the contribution is truly negligible for these size samples."

This point of view is well taken and tension tests were performed on full size and miniature tension specimens made of unirradiated Type 304 stainless steel to determine the geometric correlation factors. This effort, however, was not successful due to low yield strength. An alternative approach would be to heat treat a material so that it possessed similar yield strength compared to the V-9 or V-10 materials and then machine specimens needed to establish the geometric correction factors. The concerns about this approach were described as follows:

1. Validation of simulated materials might not be easy and a set of guidelines needed to be established prior to performing the validation evaluation.

2. This process was time-consuming and the results might not be useful.

It was eventually decided to look for research results that would provide a valid lower limit of yield strength for a specific miniature specimen design. The Oak Ridge National Laboratories (ORNL's) design [Reference 1] has a lower limit of 67 ksi (could be lower, however, no data points below 67 ksi) while the Pacific Northwest Laboratories (PNL's) design [Reference 2] has a lower limit of 38 ksi. As described in the report, the tensile data from V-9 and V-10 boat samples were valid and no correction factor was needed based on the following observations.

1. A higher yield strength for the irradiated material (50 ksi compared to 38 ksi), and

2. A lower specimen width to specimen thickness ratio compared to that of PNL.

Finally, the data were reviewed with GE Nuclear Energy (NE) engineers to further demonstrate their validity. The yield strength at 550 °F for 304 stainless steel irradiated to a fluence of 1 to 3E20 neutrons/cm^2 would be in the range of

approximately 50 to 60 ksi according to GE's design curves. This is consistent with Babcock & Wilcox Services Incorporated (BWSI's) data.

Dr. Penn's comment about an effort to estimate the geometric correction factor was carried out by BWSI during this project, and based on the aforementioned discussion, it was concluded that a geometric correction factor was not necessary.

Dr. Penn stated (comment 2, page 14 of his letter): "At the bottom of page 9, the authors discuss the effect of radiation on yield strength. This point deserves much greater elaboration. The effect of radiation on metals is a field that has been extensively studied. I find it hard to believe that the author could not find more evidence to support his approximations than three data points from a single source. The data shows that the fluence estimates and the increase in yield strength are not in strong disagreement, but it is not a very rigorous argument."

Indeed, extensive study has been performed on radiation effects on materials, most notably, reactor vessel steel (low alloy steel) and fuel cladding material (zircaloy). In this project, a specific material (solution annealed Type 304 stainless steel) had been irradiated to a fluence between 1E20 and 3E20 neutrons/cm^2 and had to be tested at a specific temperature (550 °F). This quickly reduced the amount of data available for comparison purpose. Actually, data are usually generated by those who have more interest in obtaining such data, such as design companies including GENE. GENE's design curve is based on more laboratory data and should be considered to increase the confidence in the assessment.

Dr. Penn stated (comment 3, page 14 of his letter): "Several factors can change the yield strength in a metal including heat treatment and irradiation. Samples V-9 and V-10 were exposed to different fluence levels and different heat treatment during welding. By themselves, these tensile tests do not allow us to separate the relative contributions to the increased yield strength. We are told that the V-10 sample was taken from the HAZ while the V-9 sample was outside the HAZ, so there should be different contributions to the change in yield strength due to the welding process. The authors need to estimate the change in yield strength that might arise from the welding process. In addition, while the ratio of the fluence at the V-9 sample to the fluence at the V-10 sample is independent of total fluence, the change in yield strength due to fluence is highly nonlinear in pure metals. I don't have ready access to the change in material properties for 304 stainless steel due to high energy neutron flux (nor is that material covered in the report) but I believe that the yield strength rises rapidly with fluence and then tapers off and asymptotically approaches a value below the ultimate strength. This relationship should be exploited in order to provide an upper limit on the fluence seen by the boat samples."

It is impossible to estimate relative contributions of fluence and welding on the change in the material yield strength from tests performed in this project. Nor were these tension tests designed for such a purpose. An example, where the base metal and weld

metal (sometimes HAZ material as well) are both tested to determine the limiting material (usually the weld metal), can be seen in the Reactor Vessel Surveillance Program (RVSP). In the RVSP case, both vessel steel base metal and weld metal specimens are installed in a RVSP capsule for irradiation and the capsule is withdrawn from the vessel for testing after irradiation. In this case, the fluences received by those specimens are comparable and the difference in the test data is attributed to welding. Tension test data are helpful in monitoring the material property change due to irradiation. However, tensile testing by itself is not enough to provide meaningful data allowing one to determine if materials have adequate fracture toughness.

The purpose of the tension test was to determine material property after irradiation; the fluence issue was never considered until BWSI tried to validate the test results. The fluence calculation was independently performed by FTI and was based on dosimetry obtained from the V-9 and V-10 samples. We fail to see the logic in determining the relative contributions of fluence and welding on the change in the material yield strength in order to provide an upper limit on fluence seen by the boat samples. Actually, there is no such precedence and the uncertainty is very high.

It should be noted that the microhardness values measured on the boat samples provide supporting information regarding fluence level (comparison of measurements between V-9 and V-10) and the differences between the HAZ and the base metal hardness measured on the V-9 sample. The relative hardness levels support the fluence estimates developed from radiochemical analyses because the V-10 sample measured lower hardness than the V-9 sample.

Dr. Penn correctly pointed out that that the yield strength rises rapidly with fluence and then tapers off and asymptotically approaches a value below the ultimate strength. For Type 304 stainless steel, the change of yield strength versus neutron fluence is depicted in Figure 1. Please note the last data point at E22 neutrons/cm^2 is obtained from Pressurized Water Reactor (PWR) baffle bolts (made of Type 347 stainless steel) tensile pull performed by FTI at a PWR reactor site and is for information only. It is noted that in the neutron fluence range of interest, the yield strength increases rapidly with increasing fluence. The argument that the boat samples might have received larger than the calculated fluences due to the fact that boat samples yield strength might have been in a range where the yield strength tapers off and asymptotically approaches a value is not valid.

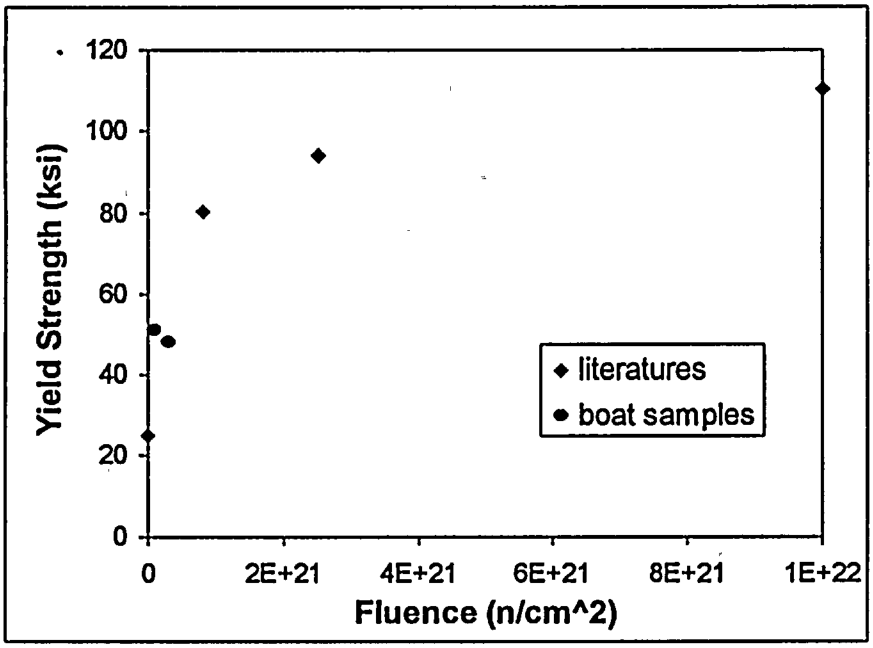

Figure 1 Yield Strength Versus Neutron Fluence

4. *EPR Inputs to Irradiated PLEDGE Calculations*

The following addresses Dr. Penn's comments regarding "assessment of crack growth rates" on pages 14 and 15 of his March 25, 1999 letter.

Dr. Penn expressed concerns that the reported DL EPR measurements from the boat sample could lead one to project higher sensitization and thereby higher predicted crack growth rates. To address this concern, the following discussion is given to review the several different considerations that were used in the selection of the EPRo. The discussion also covers the modifications to the initial sensitization level that are included in the Irradiated PLEDGE model to account for the cumulative fluence effects.

There were several important considerations given to the selection of the input parameters that were used in the Irradiated PLEDGE analysis. (It should be noted that the PLEDGE analysis was complemented by other crack growth evaluations that did not require any specific sensitization parameter. All evaluations are given in report General Electric Nuclear Energy (GENE) B13-10869-113, February 1998.) The initial EPR selection is one of the parameters which are used in the Irradiated PLEDGE analysis. The others include conductivity, corrosion potential and fluence. The input EPR parameter, EPRo, was selected to be representative of the initial level of weld sensitization in the NMP1 vertical type 304 HAZ regions. This value was assigned prior to the boat sample DL EPR measurements, but with a good understanding of the level of sensitization present. Several different types of information were used. The first source of information was the metallography that was performed for several different regions of both the V-10 and the V-9 samples. The optical metallographic

assessments of the weld HAZs were compared with other welds for which SL EPR measurements were available. The amount of ditching from oxalic etching in the sample was used to evaluate the level of carbide precipitation and concomitant grain boundary depletion. This optical method allows one to survey a larger region of grains and their boundaries than other techniques. This assessment led to the assignment of an EPR value of 5 C/cm^2 to the V-10 boat sample, which was the more sensitized sample.

The second approach made use of existing EPR measurement information from many as-welded heat affected zones of austenitic stainless steel piping. Earlier studies have shown that the SL EPR values range from 5 to 15 C/cm^2 for welded pipe containing up to 0.07 weight percent (w/o) carbon. The selection of a value of 10.8 C/cm^2 agrees with the 0.05 to 0.06 w/o carbon level in the shroud material.

The third approach was the use of a life cycle assessment to benchmark the actual depth of the cracking in the shroud. This assessment was based on the entire time of operation with a focus on the water chemistry history. This evaluation established that the depth of cracking was consistent with a moderate level of sensitization (approximately 6 C/cm^2). The DL EPR measurements made in the McDermott hot cell in the HAZ region, where cracking was found in the V-10 weld, are considered to be complementary due to the difficulty of making measurements in the hot cell and the need to use the field DL procedure due to the availability of the IHI equipment. The first three sources all established that the initial EPR value (EPRo) was a good choice. The DL EPR measurements confirmed that choice.

The Irradiated PLEDGE model makes use of an initial EPR value. However, this value only serves as a starting level of sensitization that is increased by the action of the core environment as the shroud accumulates fluence. This higher EPR value was used in making the prediction of the crack growth rate for NMP1's next cycle of operation. In summary, the three approaches described above established that an initial value of 10.8 C/cm^2 was an appropriate conservative starting value for the moderately sensitized shroud vertical weld HAZ. At the current fluence level for the NMP1 shroud, the EPR value used by the model was approximately 15 C/cm^2. This obviously represents added conservatism in this parameter to account for irradiation effects.

5. *Interpretive Report*

The following input is provided in response to Dr. Penn's comments regarding the "interpretive metallurgical report" described on pages 15 through 18 of his March 25, 1999 letter.

Dr. Penn has indicated that the data should have been plotted as discrete points with error bars for position and depth uncertainty. The interpretive report was provided by NMPC as a top-level description of the Ultrasonic Testing (UT) findings and not as a laboratory report. The detailed treatment of the core shroud UT uncertainty was handled consistent with the generic guidance approved by the NRC Safety Evaluation

Report (SER) on the BWRVIP-01, "BWR Core Shroud Inspection and Flaw Evaluation Guidelines."

Dr. Penn has indicated that the left side of the V10 weld was only mapped at a few locations. This is incorrect. The UT mapping of the V9 and V10 welds was performed to an equal degree for both sides of the weld. The interpretive report simply showed the maximum depth and length of the indications identified on the left side.

Dr. Penn has suggested that the relative contribution of fluence to the rate of cracking was not established and implies that it should have been investigated. In this regard, he has misconstrued the intent of the metallurgical tests and the application of the results. The metallurgical evaluations established that the material condition of the shroud is bounded by the generic assessments performed for core shroud cracking and the behavior of IGSCC cracking in the fluence regime below 5E20 neutrons/cm^2 (E> 1 Mev). The BWRVIP-14 disposition crack growth rate bounds crack growth below this fluence level.

The NMP1 specific crack growth assessment conservatively included irradiated PLEDGE evaluations to address the affect of the fluence in this regime on IGSCC crack growth rate. These analyses supplement the generic analyses and show that the BWRVIP-14 disposition crack growth rate conservatively bounds the NMP1 core shroud vertical weld cracking.

CONCLUSIONS

Regarding Dr. Penns' concluding major points:

1. The assertion that improper research procedures were followed is not valid. The procedures followed were appropriate for the task and were accurately described and used conservatively. The application of the results appropriately considered the uncertainty associated with the measurements and accounted for the potential measurement error.

2. The assessment of the level of material sensitization was based on multiple evaluations of the degree of sensitization including the EPR measurements. The NMP1 specific crack growth assessments bounded the uncertainty associated with the material degree of sensitization.

3. The assertion that the scientific method was not followed and that the material evaluation results were biased is inconsistent with the facts. Appropriate engineering judgment was applied during testing and the analysis methods and presentation of results were consistent with parameters investigated.

4. The tensile tests were compared to irradiated test data for irradiated stainless steel components. The testing shows that the base material and the HAZ

material retain good ductility. The measured values are also consistent with the data reviewed for material in this fluence range. Recently published BWRVIP-66, Section 3.1, Figure 3-2a, also shows agreement with the measured values.

5. The suggested relationship between fluence and cracking patterns has been considered. It has been determined that the cracking rates are conservatively bounded in the irradiated PLEDGE analysis and are bounded by the BWRVIP-14 disposition crack growth rate.

The testing performed on the NMP1 boat samples included several diverse evaluation methods and tests: optical metallographic evaluation, scanning electron microscopy, chemical composition, fluence measurements, microhardness measurements, tensile tests, and EPR measurements. The combined results demonstrate that the material behavior is consistent with typical 304 stainless steel core shroud material in the 1 to 5E20 neutrons/cm^2 (E>1 Mev) fluence field and is bounded by the BWRVIP generic evaluations for core shroud weld crack growth.

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