SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

BOILING WATER REACTOR (BWR) VESSEL AND INTERNALS PROJECT (BWRVIP)

REPORT TR-108705 (BWRVIP-62): "BWR VESSEL AND INTERNALS

PROJECT, TECHNICAL BASIS FOR INSPECTION RELIEF FOR

BWR INTERNAL COMPONENTS WITH HYDROGEN INJECTION"

BWRVIP

PROJECT NO. 704

1.0 INTRODUCTION

1.1 Background

By letter dated December 31, 1998 (Agencywide Documents Access and Management System (ADAMS) Accession No. 9901050050), as supplemented by letters dated August 1, 2001 (ADAMS Accession No. ML012140408), May 19, 2003 (ADAMS Accession No. ML031430145), and December 17, 2004 (ADAMS Accession No. ML043560323), the Electric Power Research Institute (EPRI) submitted for U.S. Nuclear Regulatory Commission (NRC) staff review and approval BWRVIP report TR-108705 (BWRVIP-62), “BWR Vessel and Internals Project, Technical Basis for Inspection Relief for BWR Internal Components with Hydrogen Injection.” A non-proprietary version of BWRVIP-62 was sent on March 7, 2000 and is available in ADAMS under Accession No. ML003691748. BWRVIP-62 contains a discussion of the technical basis for relief from current inspection requirements for BWR reactor vessel internal components (RVIs) that are protected from intergranular stress corrosion cracking (IGSCC) by the injection of hydrogen into the reactor coolant.

On January 30, 2001, the NRC staff issued its initial safety evaluation (SE) (ADAMS Accession No. ML010370141) for BWRVIP-62. This SE contained open items which are described in more detail in Section 3.0 of this SE. In response to the open items contained in the NRC staff’s SE of January 30, 2001, the BWRVIP provided technical information related to the implementation of the BWR Vessel Internals Application (BWRVIA) model in a letter dated August 1, 2001, followed by supplemental information in letters dated May 19, 2003, and December 17, 2004. The NRC staff has reviewed the responses, and its comments and recommendations regarding these responses are stated in Section 3.0 of this SE.

1.2 Purpose

The NRC staff reviewed BWRVIP-62 to determine whether this report provides an adequate technical basis for implementing modified inspection requirements for BWR RVIs that are protected from IGSCC based on the methods described in BWRVIP-62. This SE considered the role of neutron fluence on IGSCC, the rates of crack propagation, aspects of the physical chemistry, effects of electrochemical corrosion potential (ECP), coolant flow and noble metal chemical application (NMCA) on IGSCC susceptibility, the radiolysis and ECP models, and an assessment of the effectiveness of hydrogen injection.

1.3 Organization of the SE

Section 2.0 of this SE summarizes BWRVIP-62. Section 3.0 evaluates each topic in Section 2.0 of this SE. Section 3.0 also evaluates how the BWRVIP addressed the open items from the NRC staff's SE of January 30, 2001. Section 4.0 summarizes the conclusions resulting from this SE.

2.0 SUMMARY OF BWRVIP-62

BWRVIP-62 contains a discussion of the technical basis for implementing modified inspection requirements for BWR RVIs that are protected from IGSCC based on the methods described in BWRVIP-62 (involving the injection of hydrogen into the reactor coolant).

Section 1.0 of BWRVIP-62 describes the two primary techniques for protecting RVIs from IGSCC by means of hydrogen injection, or hydrogen water chemistry (HWC). The first of these techniques is moderate hydrogen water chemistry (HWC-M) whereby hydrogen is injected into the reactor coolant at rates higher than would typically be used to protect piping. The second of these techniques is NMCA whereby a continuous injection of a small amount of hydrogen is supplemented by an occasional batch injection of a small amount of noble metal compounds which act as catalysts for the recombination reactions. This section also presents a comprehensive survey of previous cracking events in BWR RVIs due to IGSCC and studies which indicate the effectiveness of HWC in mitigating IGSCC.

Section 2.0 of BWRVIP-62, describes radiolysis/ECP computer models used to determine the effectiveness of hydrogen injection techniques for mitigating IGSCC. The use of high purity water in BWRs for the neutron moderator and primary coolant coupled with water radiolysis due to neutron and gamma radiation, results in high ECP and increases the susceptibility of RVIs to IGSCC. The effectiveness of mitigation techniques can be assessed by directly measuring ECP (as measured by a standard hydrogen electrode) at a specific location of interest in the RVIs. However, direct ECP measurements at specific locations in the RVIs can be cumbersome due to the relative inaccessibility of some RVIs. Therefore, the technical basis described in BWRVIP-62 included supplementary techniques that do not depend on direct measurement of the ECP at specific locations in the RVIs.

The BWRVIP developed a computer model known as BWRVIP radiolysis/ECP analysis - BWRVIA, as a supplementary technique to calculate the ECP values of the reactor coolant system (RCS) at a specific component location in the RVIs. In addition, the calculated ECP values obtained from the BWRVIA model can be correlated with the measurements of other plant parameters (e.g., oxygen concentration, main steam line radiation levels, etc.). Figure 2-8 of BWRVIP-62 shows the comparison between model calculation and plant measured data including **[** **]**. The measurements agree reasonably well with calculated results considering the uncertainties in all involved variables. The BWRVIP proposes to use this BWRVIA model as a tool to monitor plant water chemistry and ECP data. The NRC staff did not review the BWRVIA model. The NRC staff did, however, evaluate the results of the application of the model, which were submitted in BWRVIP-62 and in the responses to requests for additional information (RAIs) in letters dated August 1, 2001, May 19, 2003, and December 17, 2004.

In Section 3.0 of BWRVIP-62, the current operating history is reviewed and correlated to the corresponding plant water chemistry. A conclusion is drawn that HWC-M is able to reduce crack initiation and crack growth. Methods are described using hydrogen injection and NMCA with hydrogen injection. All of the above are in combination with ECP measurements or calculations. The effect of HWC-M and NMCA on the Nitrogen-16 isotope radiation of the main steam line is discussed. The crack growth correlation developed in BWRVIP-14, "Evaluation of Crack Growth in BWR Stainless Steel Reactor Vessel Internals" (Reference 1), is used to develop expected factors of reduction in crack growth rate corresponding to the expected reduction in ECP.

Section 4.0 discusses current inservice inspection (ISI) requirements and concludes implementation of either HWC-M or NMCA would result in lower IGSCC propagation rates which would justify inspection relief. With respect to the crack growth model and radiolysis results, an inspection program for the RVIs can be developed based on factors of improvement (FOI) for plants that have implemented either HWC-M or NMCA. The FOI calculated for each RVI, based on modeling results, would be applied to revise the inspection interval established in the various BWRVIP inspection and flaw evaluation (I&E) reports. The BWRVIP will propose and request NRC staff approval of revised inspection intervals for the RVIs for plants that have implemented either HWC-M or NMCA.

3.0 <u>EVALUATION</u>

BWR austenitic stainless steel and nickel-based alloy RVIs have experienced IGSCC, leading to degradation and potential safety concerns. Therefore, the NRC staff found it necessary for BWR licensees to perform regular inspections of RVIs to provide adequate assurance of their structural integrity. The BWRVIP developed several I&E guidelines for several safety-related RVIs which were reviewed and found acceptable by the NRC staff. However, due to the difficulty and expense of these RVI inspections, licensees find it desirable to demonstrate that fewer inspections are necessary when suitable IGSCC mitigation steps are taken.

Two primary techniques have been used to ensure mitigation of IGSCC in BWR RVIs using HWC. The first technique involves utilizing higher hydrogen injection rates than would typically be used to protect recirculation piping **[ ]**. This technique is referred to as HWC-M and its goal is to provide sufficient additional hydrogen in order to lower ECP to protective levels in the lower plenum. The second protective technique is NMCA which involves a continuous injection of a small amount of hydrogen (to give a minimum threshold value of hydrogen-to-oxygen molar ratio in the single phase liquid region) supplemented by an occasional batch injection of catalytic noble metal compounds. Since both processes can protect RVIs from environmentally-assisted cracking degradation, the effective implementation of either HWC-M or NMCA at a BWR is considered an adequate basis for the implementation of a modified inspection program for RVIs.

With respect to the crack growth model and radiolysis results, an inspection program for the RVIs can be developed based on FOIs for plants that have implemented either HWC-M or NMCA. The FOI calculated for each RVI, based on modeling results, would be applied to revise the inspection interval established in the various BWRVIP I&E guidelines. The BWRVIP will propose revised inspection intervals for the RVIs for plants that have implemented either HWC-M or NMCA.

In its initial SE for BWRVIP-62 issued by letter dated January 30, 2001, the NRC staff found that the guidance provided in BWRVIP-62 is acceptable, pending the resolution of certain open items. In this SE, the NRC staff evaluates the BWRVIP response to each of these open items.

3.1 Technical Basis for HWC-M and NMCA

Section 1.0 of BWRVIP-62 provides a description of HWC techniques for mitigating IGSCC and presents evidence for the effectiveness of these techniques. The effectiveness of the HWC-M and NMCA is monitored by measuring the **[ ]**, the primary parameter in assessing the availability of hydrogen and/or noble metal compounds in the water surrounding RVIs. A protection potential of **[ ]** or below in the RCS water can be achieved by the addition of hydrogen to the feedwater or the addition of hydrogen with noble metal compounds to the RCS water. For plants implementing NMCA, noble metals, such as platinum, palladium, or rhodium, can be used as a catalyst for the recombination of hydrogen with oxygen. Consequently, the hydrogen concentration required for plants implementing NMCA will be substantially lower than that required for plants implementing HWC-M.

BWRVIP-62 also provides technical requirements for maintaining the conductivity of the RCS water at a specific threshold level so that the susceptibility of the RVIs to IGSCC is minimized. The conductivity of RCS water is affected by the presence of ionic impurities which increases the susceptibility of RVIs to IGSCC. The NRC staff has reviewed and accepted the approach taken to control the conductivity of the RCS water below a threshold level.

In its initial SE dated January 30, 2001, the NRC staff issued five open items relevant to Section 1.0 of BWRVIP-62. The five open items (grouped into four areas) previously identified were: the effect of flow rate on the RCS water ECP, the role of neutron fluence and the effect of radiation on crack growth rates, the effect of radiation on ECP, and the assessment of HWC-M effectiveness with changing radiation levels. In addition, the NRC staff evaluated an issue not previously identified as an open issue: the effectiveness of HWC-M and NMCA in deep cracks. The NRC staff's evaluation of the BWRVIP responses to the five open items and the newly identified issue, are discussed below.

3.1.1 Effect of Flow Rate on ECP and Susceptibility of RVIs to IGSCC

This open item was identified as Open Item 3.2.2 in the initial NRC staff SE for BWRVIP-62 issued by letter dated January 30, 2001. Under BWR normal water chemistry (NWC) conditions, the oxidation and reduction reactions on passive steel surfaces are limited by the mass transport of oxygen to the surface for the oxygen reduction reaction. Mass transport increases as flow increases and, thus, ECP is expected to increase with flow velocity.

By letter dated March 15, 2001, the BWRVIP submitted report TR-112314 "BWR Vessel and Internals Project, Effect of Flow Rate on Intergranular Stress Corrosion Cracking and Electrochemical Corrosion Potential" (BWRVIP-64) (ADAMS Accession No. ML010780076), for information only in response to the NRC staff's request. BWRVIP-64 discusses crack tip chemistry and the effect of flow rate on crack growth kinetics. The NRC staff did not formally review BWRVIP-64. However, the NRC staff did review Section 1.4 of BWRVIP-62, which provides data on the effect of flow rate on ECP values and crack growth rates, Figures 1-4 and 1-5, which were developed based on the detailed information provided in BWRVIP-64. The NRC staff agrees that crack growth rates remain low at higher flow rates because at higher flow rates the impurities and aggressive ions are flushed out of the crack tip region. Subsequently, the chemical concentration gradient between the tip of the crack and the bulk solution is reduced, resulting in the reduction of crack growth rates. The NRC staff concludes that the explanation provided in BWRVIP-62 regarding the effect of flow rate on the ECP and crack growth rates is a reasonable explanation to support the laboratory results and therefore, the NRC staff considers this open item closed.

3.1.2 Effectiveness of HWC-M and NMCA in Deep Cracks

This issue was not identified in the initial NRC staff SE for BWRVIP-62 issued by letter dated January 30, 2001. However, by letter dated December 17, 2004, the BWRVIP issued a supplementary response in which it discussed the effectiveness of HWC-M and NMCA in deep cracks (crack depths equal to or greater than **[ ]**. Theoretical and experimental studies have been conducted to determine crack mouth and crack tip pH and ECP and their role in IGSCC for stainless steels in HWC-M and NWC environments. The results of these studies are discussed in “Modeling of Water and Material Chemistry Effects on Crack Tip Chemistry and Resulting Crack Growth Kinetics” by Peter Andresen (Reference 2) which has been submitted to the NRC staff for information only. In cracks, the ECP gradient between the crack mouth and crack tip causes the pH at the crack tip to become more acidic and more concentrated in anionic species such as chlorides and sulfates which may be present in bulk water. The IGSCC process in NWC is driven by a combination of an aggressive crack tip environment, applied and residual stresses, and a susceptible material. In an HWC-M or NMCA environment, the ECP is low at both the crack tip and the crack mouth. Therefore, there is no ECP gradient and in the absence of a potential gradient, the pH at the crack tip stays near neutral and there is little concentration of anionic species. In an HWC-M or NMCA environment, the IGSCC process slows down because the crack tip environment is less aggressive. Studies have also shown that localized crack tip chemistry can exist in cracks when they reach depths of **[ ]** or more. However, in an HWC-M environment, crack growth tests show that deep cracks respond in the same way as shallower cracks.

Based on the information submitted for its review, the NRC staff concludes that plant operators can claim credit for an effective HWC-M environment when they: (1) maintain an established hydrogen concentration at the crack location for at least **[ ]** of the time that the plant is at power operation or hot standby conditions and (2) maintain the ECP value of RCS water at **[ ]** or below. Since the hydrogen concentration at plants implementing NMCA is lower than that at plants implementing HWC-M, the NRC staff concludes that plants implementing NMCA should maintain an established hydrogen concentration at the crack location for at least **[ ]** of the time that the plant is at power operation or hot standby conditions (i.e., a **[ ]** more time than that required at plants implementing HWC-M) in order to achieve the same protection against IGSCC in deep cracks. The NRC staff concludes that the ECP value of RCS water at the location of the crack should be maintained at **[ ]** or below to achieve protection from IGSCC.

The NRC staff understands that licensees follow the inspection guidelines that are provided in the relevant BWRVIP reports associated with each component and monitor the growth rates of deep cracks to verify that adequate protection is achieved with an effective HWC-M or NMCA environment. The NRC staff requests that the BWRVIP revise BWRVIP-62 to include the information provided in the BWRVIP letter dated December 17, 2004, which describes the effect of an HWC-M or NMCA environment on the crack growth rates of deep cracks. Therefore, the NRC staff considers this issue closed when BWRVIP-62 is revised to include the information provided in the BWRVIP letter dated December 17, 2004.

3.1.3 Role of Neutron Fluence and the Effect of Radiation on Crack Growth Rates

This issue was identified as Open Items 3.1.1 and 3.1.2 in the initial NRC staff SE for BWRVIP-62 issued by letter dated January 30, 2001. This discussion focuses on crack growth rates due to irradiation assisted stress corrosion cracking (IASCC) in RVIs with an exposure to neutron fluences up to **[ ]** n/cm^2 (i.e., E > 1 MeV). When BWRVIP-62 was originally submitted, no data was available regarding crack growth rates in welds that are exposed to a neutron fluence value of **[ ]** n/cm^2 and above. Therefore, BWRVIP-62 evaluates taking credit for HWC and/or NMCA in welds that are exposed to neutron fluences less than **[ ]** n/cm^2. To provide a technical basis for evaluating the effectiveness of HWC and/or NMCA in welds with exposure to neutron fluences equal to or greater than **[ ]** n/cm^2, the BWRVIP, by letter dated December 20, 2001, submitted for NRC staff review and approval report 10030318, “Crack Growth Rates in Irradiated Stainless Steels in BWR Internal Components” (BWRVIP-99) (ADAMS Accession No. ML020020313). BWRVIP-99 provides technical requirements for determining crack growth rates for welds exposed to neutron fluences equal to or greater than **[ ]** n/cm^2. The NRC staff, in an SE sent by letter dated July 29, 2005, approved BWRVIP-99 (ADAMS Accession No. ML052150325). BWRVIP-99 can be used for evaluating crack growth rates in welds with exposure to neutron fluences equal to or greater than **[ ]** n/cm^2 provided they comply with all the conditions specified in the NRC staff’s SE for this report. The NRC staff requests that BWRVIP-62 be revised to state that the crack growth rates specified in BWRVIP-99 shall be used for evaluating welds that are exposed to neutron fluences equal to or greater than **[ ]** n/cm^2. Based on this evaluation, the NRC staff considers this issue closed.

3.1.4 Effect of Radiation on ECP

This issue was identified as Open Item 3.2.1 in the initial NRC staff SE for BWRVIP-62 issued by letter dated January 30, 2001. Previous research work has shown that IGSCC susceptibility and crack growth rates depend on the ECP of stainless steels in BWR environments. The ECP threshold limit for IGSCC is a function of the following: radiation exposure, concentrations of impurities in the coolant, and the microstructure and composition of the steel. BWRVIP-62 states that the ECP threshold limit for IGSCC initiation in irradiated Type 304 stainless steel may be as high as **[ ]**. Since there is a limited amount of data to support this value, the NRC staff requested that the BWRVIP retain the more conservative ECP threshold limit of **[ ]** for the irradiated stainless steel materials. In its response dated August 1, 2001, the BWRVIP concurred with the NRC staff and agreed to use a ECP threshold limit of **[ ]**. Therefore, the NRC staff considers this issue closed when BWRVIP-62 is revised to include the information provided in the BWRVIP response letter dated August 1, 2001.

3.1.5 Assessment of HWC-M Effectiveness with Change in Radiation Levels

This issue was identified as Open Item 3.2.6 in the initial NRC staff SE for BWRVIP-62 issued by letter dated January 30, 2001. Previous work suggests that all radiolysis analyses have shown that radiation levels in the downcomer region have a strong effect on the rate of the hydrogen-oxygen recombination reaction. Since the radiation level in the downcomer varies throughout core life, the actual degree of mitigation due to HWC-M and/or NMCA will also vary. In its response by letter dated August 1, 2001, the BWRVIP stated that the radiolysis/ECP model (i.e., the BWRVIA model) will be used for both the beginning and end of life of a fuel cycle. The end of the fuel cycle should represent the most conservative case (i.e., there should be an increase in ECP at the end of the cycle). The NRC staff agrees with the proposal for using the BWRVIA model to calculate the total oxidant content at both the beginning and end of life of a fuel cycle, with the end of fuel cycle case being the most conservative. The BWRVIA model (discussed in Section 3.2 of this SE) takes into consideration the effect of radiation on the hydrogen-oxygen recombination reaction. These calculations should take into consideration the uncertainties that are associated with the application of the model and the additional conservative margin needed to compensate for any depletion of HWC-M at the downcomer region. The NRC staff requests that BWRVIP-62 be revised to include the information provided in the BWRVIP response to Open Item 3.2.6 sent by letter dated August 1, 2001. Therefore, the NRC staff considers this issue closed when BWRVIP-62 is revised to include the information provided in the BWRVIP letter dated August 1, 2001.

3.2 Radiolysis and ECP models

Section 2.0 of BWRVIP-62 describes radiolysis/ECP computer models used to determine the effectiveness of hydrogen injection techniques for mitigating IGSCC. Section 2.0 of BWRVIP-62 also describes the basic concepts used in the application of the mathematical BWRVIA model used to establish the effectiveness of HWC-M/NMCA. The BWRVIA model will be used to determine chemistry conditions and the ECP at various locations in the RVIs measured as a function of feedwater hydrogen injection rate. The BWRVIA model will be benchmarked against the ECP measurement made at the plant of interest or at other plants, known as “sister plants,” that are radiolytically identical and have similar operational characteristics. Previous results have indicated that plants of identical design and operation respond in a similar manner to the hydrogen injection rate. The BWRVIP defines sister plants as any pair or group of BWRs that are demonstrated to be radiolytically equivalent by a validated and benchmarked radiolysis model. Ordinarily, the effectiveness of the model can be ascertained by the measurement of the ECP of the RCS water at the location of interest in the RVIs. However, the measurement of ECP at remote locations in the RVIs is very cumbersome and not practical. Therefore, the BWRVIP proposes using the BWRVIA model to calculate the ECP value and total oxidant content of the RCS water at the location of interest.

Section 2.0 of BWRVIP-62 discusses the application of the BWRVIA model to calculate the two secondary parameters **[ ]** used to ensure the availability of HWC-M at the subject location. For the NMCA plants, the secondary parameters will include **[ ]**. BWRVIP-62 states that if a good correlation is established between the calculated ECP value and the secondary parameters, then the secondary parameters can be used to assess the availability of hydrogen and/or NMCA at the desired location. A minimum of two secondary parameters, preferably **[ ]** for HWC-M plants needs to be monitored. Additional secondary parameters for NMCA plants will include the measured value of **[ ]**. The secondary parameter data will be collected, maintained, and correlated to supplement the ECP probe data.

The BWRVIA model calculations include several parameters (e.g., mass flow, reactor power, feedwater hydrogen, oxygen). The BWRVIP also submitted data related to the application of the BWRVIA model in establishing correlation between the following parameters:

[ ]

[ ];

[ ].

The NRC staff did not review the BWRVIA model, but it evaluated the results of the application of the model, and finds that there is good agreement between the calculated and measured ECP values (at a few locations in some of the BWR RVIs). The NRC staff finds that Section 2.0 of BWRVIP-62 adequately provides the basic concepts used in the BWRVIA model which is used to calculate the ECP values of the RCS water at remote locations in the RVIs (i.e., where ECP values can not be measured easily). The NRC staff, in its initial SE dated January 30, 2001, requested that the BWRVIP discuss the validity of the BWRVIA model and the BWRVIP responses to NRC staff issues are discussed below.

The radiolysis model was discussed in Open Item 3.2.4 which was identified in the initial NRC staff SE for BWRVIP-62 issued by letter dated January 30, 2001. For the past 10 years, the radiolysis model has undergone many changes. These changes include a refinement of the description of the primary system and the dose rate modeling of the ex-core regions and an updating of the neutron/gamma dose rates (the G values). The NRC staff requested that the BWRVIP provide a discussion of the significant differences between G values used in BWRVIP-62 and the G values used in similar approaches in Taiwan and Japan for analyzing the impact of HWC (References 3 and 4). The NRC staff also requested that results from a broader range of plants be included in a revised BWRVIP-62 in order to validate the capability of the model to predict water chemistries. Although numerous correlations of in-plant measurements are given in Figures 3-1 to 3-11 of BWRVIP-62, comparative model results in the referenced Appendix A of the BWRVIP-13 report, “Modeling Hydrogen Water Chemistry for BWR Applications” (Reference 5) are not presented in terms of the proposed secondary parameters. Because of this difference in presentation, it is not possible to determine whether the model results are representative of the range of behavior observed in the reactor vessel.

In its supplementary response sent by letter dated August 1, 2001, the BWRVIP stated that the G values, reaction rate constants, and some of the radiolysis schemes in the BWRVIA model were based on state-of-the-art techniques/information from the late 1980s. At that time, the integrated set of constants gave the best correlation with plant measurements. It was recognized that model inputs would have a range of uncertainties that would in turn result in uncertainties in the predictions. The approach used to address these uncertainties was to compare the model predictions of hydrogen, oxygen, and ECP obtained from specific locations to in-plant measurements of these same parameters obtained from the same locations.

The calculated and measured hydrogen and oxygen data obtained from the recirculation system of four plants, and the comparison of measured to calculated steam hydrogen and steam oxygen data presented in BWRVIP-62, indicate a close agreement between the measured and predicted hydrogen values in the reactor water. ECP values calculated by the model were compared with plant ECP measurements obtained at mid-core, core plate, recirculation flange and bottom head drain line locations. The measured data included [ ] that were installed at the aforementioned locations. The current BWRVIA model shows good agreement with plant chemistry data, as well as with plant ECP data obtained at specific locations in a limited number of plants. However, the data that was obtained from the **[ ]** plants show inconsistencies between the calculated and measured ECP values at the lower head region. The BWRVIP did not provide any explanation for this inconsistency. The BWRVIP, however, acknowledges that the model inputs have a range of uncertainties that would in turn result in uncertainties in predictions. The BWRVIP is planning to refine the model and reduce uncertainties in the model predictions, particularly in the lower head region. The BWRVIP proposes to submit its review of the BWRVIA models discussed in References 3 and 4 of this SE, along with additional research data on the ECP model related to the lower head region. The NRC staff will review these items when they are submitted for review.

As stated above, there are inconsistencies between the calculated and measured ECP values for RVIs obtained from the lower head region. Therefore, the NRC staff concludes that the BWRVIA model requires validation which can be achieved by installing an ECP probe specifically in this region. That is, if credit is desired for HWC and/or NMCA protection for lower head region components, an ECP measurement must be made in the lower head region volume. HWC credit can be claimed for RVIs in the lower head region provided that the difference between the measured and calculated (per the BWRVIA model) ECP values is a negative number. Tolerances in ECP values, which are inherently part of ECP measurements, should be taken into account in evaluating the difference between the measured ECP value and the calculated ECP value.

The NRC staff requests that the BWRVIP update BWRVIP-62 to address the information (including figures and tables) provided in the BWRVIP response to Open Item 3.2.4 sent by letter August 1, 2001. Therefore, the NRC staff considers this issue closed when BWRVIP-62 is revised to include the information provided in the BWRVIP response dated August 1, 2001.

3.3 HWC Effectiveness Assessment

In Section 3.0 of BWRVIP-62, the BWRVIP discusses the methodology for assessing the effectiveness of the use of HWC-M and NMCA in RCS water which is essential in mitigating IGSCC in RVIs. The BWR plants are categorized based on the verification methodology used for assessing the availability of HWC-M and/or NMCA. The categorization of the BWR plants and their characteristics are shown in Table 3.1 of this SE.

Category 1 plants use hydrogen to reduce the oxygen in the RCS water, and the hydrogen availability is assessed by measuring the **[ ]** at the location of interest. These plants will use this **[ ]** as a primary parameter for ensuring the effectiveness of HWC-M at that location. In addition, the BWRVIP proposes to implement continuous monitoring of two secondary parameters (e.g., **[ ]**) to ensure the availability of HWC-M at the subject location. Details regarding the verification methodology for assessing the availability of HWC-M in Category 1 plants are discussed in Section 3.3.3.1 of this SE.

Category 2 plants use hydrogen to reduce the oxygen in the RCS water, and the hydrogen availability is assessed by calculating the **[ ]** at the location of interest by using the BWRVIA model. Details regarding the verification methodology for assessing the availability of HWC-M in Category 2 plants are discussed in Section 3.3.3.2 of this SE.

Plants implementing NMCA additions have two categories, Category 3a and Category 3b. Category 3a plants use [ ] as primary parameters followed by continuous monitoring of two secondary parameters (e.g., [ ]) to ensure the availability of NMCA at the subject location. Category 3b plants use [ ] as primary parameters followed by continuous monitoring of two secondary parameters (e.g., [ ]) to ensure the availability of NMCA at the subject location. No ECP measurements are taken in Category 3b plants. Details regarding the verification methodology used to assess the availability of NMCA in Category 3a and Category 3b plants are discussed in Section 3.3.3.3 and 3.3.3.4 of this SE respectively.

3.3.1 Physical Chemistry Aspects of the HWC and/or NMCA Program

This issue was identified as Open Item 3.2 in the initial NRC staff SE for BWRVIP-62 issued by letter dated January 30, 2001. In its response sent by letter dated August 1, 2001, the BWRVIP proposed to incorporate changes to BWRVIP-62 regarding the following topics: (1) correlation of ECP measurements with the secondary parameters, (2) conductivity transients, (3) definition of an effective HWC-M, and (4) definition of an effective NMCA program. The NRC staff's evaluation of these topics is discussed below.

3.3.1.1 ECP Measurements

The BWRVIP proposes to use two reference electrodes to [ ] as a primary parameter for Category 1 plants. The BWRVIP letter of August 1, 2001, indicates that the [ ] for Category 1 plants will be correlated with secondary parameters, preferably [ ]. The NRC staff finds that the method of using the correlated secondary parameters to assess the effectiveness of HWC-M when the ECP probes fail is acceptable. The NRC staff concludes that maintaining a good correlation between ECP measurements and the secondary parameters is essential in monitoring effective HWC-M in RVIs. Additional methods using validated BWRVIA models or sister plant data are acceptable to verify the effectiveness of HWC-M if these methods are used in conjunction with secondary parameters. It is the NRC staff's conclusion that in the absence of ECP measurements (i.e., failure of the ECP probe), reliable and continuous monitoring of secondary parameters is essential to ensure that an effective level of protection is being maintained at the location of interest in the RVIs. The NRC staff understands that the reliability and accuracy of the secondary parameters can be maintained if these parameters are validated with in-situ measurements of the ECP. The BWRVIP intends to validate the secondary parameters using an [ ]. The NRC staff accepts this approach because it has previously accepted this method in its evaluation of Open Item 3.8 contained in its SE sent by letter dated September 15, 2000 (Reference 6) for BWRVIP report TR-113932, "BWR Vessel and Internals Project, Technical Basis for Revisions to Generic Letter 88-01 Inspection Schedules (BWRVIP-75)" (Reference 7).

To ensure adequate margin, the BWRVIP proposes to use a higher [ ] for the NMCA plants [ ]. BWRVIP-62, as supplemented by the BWRVIP responses, provides data that support the aforementioned position. The NRC staff reviewed the BWRVIP data and concludes that adequate mitigation of

IGSCC in the RVIs is achieved when the [ ] is maintained when measured at a recirculation loop location for NMCA plants. This value is consistent with the value recommended by [ ]. NMCA plants will implement a monitoring program that measures two secondary parameters to evaluate the adequacy of NMCA additions. The data submitted indicates that a good correlation is achieved between the measured ECP values and the secondary parameters.

Therefore, the NRC staff concludes that Category 3a plants (i.e., plants that implement NMCA and use [ ] as a primary parameter) maintaining a [ ] (measured at a location in a recirculation loop) will adequately mitigate IGSCC in RVIs. The BWRVIP states that if a plant is unable to maintain a [ ] due to high radiation dose levels, a plant-specific analysis can be performed to demonstrate adequate mitigation at a lower [ ]. However, NRC staff approval is required when intending to take plant-specific credit for an effective NMCA program when a [ ].

3.3.1.2 Conductivity Transients

The BWRVIP response issue, sent by letter dated August 1, 2001, indicates that when the reactor water conductivity exceeds the limits specified in BWRVIP report TR-103515-R2 “BWR Water Chemistry Guidelines – 2000 edition” (BWRVIP-79) (ADAMS Accession No. ML003722483), sent by letter dated June 2, 2000, for more than [ ] hours, only the time in excess of [ ] hours should be subtracted from the acceptable HWC-M available time. The NRC staff accepts this response because it has previously accepted this method in its SE (Open Item 3.8) for the BWRVIP-75 report (References 6 and 7). The BWRVIP recommends that contributions due to soluble iron may be subtracted from the measured conductivity for plants starting up with NMCA. The NRC staff accepts this response because the soluble iron in RCS water does not participate in the corrosion process, and the soluble iron does not affect the crack growth rate in RVIs.

3.3.1.3 Effective HWC-M Program

BWRVIP-62, as supplemented by the BWRVIP responses, provides data which indicate that a reduction in crack growth rates in RVIs can be achieved by controlling and monitoring HWC-M availability and by maintaining the reactor water ECP at a value equal to or less than [ ]. The BWR Owner’s Group (BWROG) conducted in-plant measurements of ECP in 21 BWRs that are operating with HWC-M. This discussion summarizes the results associated with the effectiveness of HWC-M in recirculation system piping. The BWRVIP presented data which demonstrated that the ECP value obtained for a given feedwater hydrogen injection rate varied with component location. The BWRVIP stated that mitigation of IGSCC can be achieved when hydrogen is available for at least [ ] of the time that the plant is at power operation or hot standby conditions at an ECP value of [ ] or below. Based on the review of the data, the NRC staff agrees with this conclusion. The BWRVIP response states that when hydrogen injection is interrupted, no credit should be given for this time when calculating HWC-M availability. The interrupted time, in its entirety, should be counted as time that HWC-M is unavailable. The NRC staff concurs with this approach because it ensures that the calculation of the crack growth rate is based on a conservative calculation of the availability of HWC-M.

3.3.1.4 Effective NMCA Program

The BWRVIP in its response sent by letter dated August 1, 2001, states that effective NMCA is obtained for the plants when hydrogen is available for at least **[ ]** of the time that the plant is at power operation or hot standby conditions at an ECP value of **[ ]** or below for the reactor water. In addition, the BWRVIP reiterates that a reduction in crack growth rate in the RVIs can be achieved by controlling and monitoring the hydrogen availability and NMCA addition and by maintaining the reactor water ECP at a value equal to or less than **[ ]**. BWRVIP-62, as supplemented by BWRVIP responses, provides adequate data to substantiate this claim. The NRC staff reviewed the submitted data and concludes that adequate mitigation of IGSCC in the RVIs of a NMCA plant is achieved when the measured secondary parameters correlate to the measured reactor water ECP of **[ ]** or below.

The NRC staff requests that the BWRVIP revise BWRVIP-62 to address the information stated in the BWRVIP response to Open Item 3.2 sent by letter dated August 1, 2001. Therefore, the NRC staff considers this issue closed when BWRVIP-62 is revised to include the information provided in the BWRVIP letter dated August 1, 2001.

3.3.2 Noble Metal Chemical Application/Additions

This issue was identified as Open Item 3.2.3 in the initial NRC staff SE for BWRVIP-62 issued by letter dated January 30, 2001. In its response sent by letter dated August 1, 2001, and supplemented by letter dated May 19, 2003, the BWRVIP addressed the issue related to hydrogen-to-oxygen molar ratio (Open Item 3.2.3) in NMCA plants. Details of this Open Item and the NRC staff's evaluation are discussed in Section 3.3.1.1 of this SE. As noted in Section 3.3.1.1, the NRC staff found the BWRVIP response acceptable.

3.3.3 ECP Model

This issue was identified as Open Item 3.2.5 in the initial NRC staff SE for BWRVIP-62 issued by letter dated January 30, 2001. The BWRVIA model in BWRVIP-62 is an empirical correlation relating concentrations of H_2, O_2, H_2O_2, and flow velocity to ECP. The results from six plants indicate that individual plant data appears to cluster either above or below the trend line, indicating that ECP cannot be simply estimated on the basis of the standard deviation based on the whole population of data. However, when grouped by plant, the data do not appear to be randomly distributed about the mean trend line. The NRC staff requested that the BWRVIP address the accuracy of the ECP measurements and the discrepancies between multiple ECP measurements. The ECP models applicable to the three categories of plants are addressed in Sections 3.3.3.1 (Category 1), 3.3.3.2 (Category 2), 3.3.3.3 (Category 3a), and 3.3.3.4 (Category 3b) of this SE.

In its response sent by letter dated August 1, 2001, supplemented by letters dated May 19, 2003, and December 17, 2004, the BWRVIP stated that multiple probes of different types are used to measure the ECP and that the highest ECP value is used to assess the HWC-M effectiveness. The NRC staff agrees with this method because the most conservative ECP value is used to assess the HWC-M effectiveness.

For plants with HWC-M, the BWRVIP proposed to use the **[ ]** value as a primary parameter and use two continuously monitored secondary parameters (i.e., **[ ]**) to ensure the availability of HWC-M at the subject location. The BWRVIP stated that a good correlation will be established between the **[ ]** value and the secondary parameters so that, in the event of any failure of an ECP probe, the secondary parameters will be used to assess the hydrogen availability at the desired location. The plant will use the ECP data from the ramping test to select the hydrogen injection rate needed to ensure that the ECP value is maintained at or below **[ ]** at that location. The NRC staff agrees with this approach because this method ensures adequate HWC-M availability at the desired location when the secondary parameter values are maintained at or below the required threshold levels that correlate to an ECP value of **[ ]**. The BWRVIP also proposed to use the BWRVIA model to calculate the total oxidant at the area of interest as a function of feedwater hydrogen concentration. Based on the existing data, the BWRVIP claims that effective HWC-M availability is achieved when the total oxidant content at the area of interest is **[ ]** or less.

The BWRVIP presented data regarding the effect of RCS flow rates on crack growth rates and concluded that at high RCS flow rates the aggressive ions that enhance the corrosion process near the crack tip will be flushed out, thereby reducing the crack growth rate. The NRC staff agrees with the BWRVIP that crack growth rates are increased at low RCS flow rates. Therefore, the NRC staff concludes that a conservative prediction of crack growth rates at the area of interest can be achieved when the BWRVIA model is used to calculate ECP at the low flow rate of **[ ]**. Based on the review of the data provided in BWRVIP-62, supplemented by the BWRVIP responses, the NRC staff concludes that credit can be claimed for HWC-M when the measured ECP value of the RCS water at the subject location is **[ ]** or below, the total calculated oxidant is **[ ]** or less, and the calculated ECP value at a low RCS flow rate **[ ]** is equal to or less than **[ ]**.

3.3.3.1 ECP Model for Category 1 Plants

For Category 1 plants, when the ECP values cannot be measured at the location of interest, an appropriate BWRVIA model can be used to estimate ECP at this location. Correlation between the measured ECP value and the calculated total oxidant as a function of secondary variables (**[ ]**) using the BWRVIA is essential in assessing IGSCC mitigation at locations where the ECP cannot be measured. As proposed by the BWRVIP, a minimum concentration of feedwater hydrogen will be established such that the calculated value of the total oxidant is **[ ]** or less at the location of interest. The NRC staff reviewed the results associated with Category 1 plants and concludes that these plants shall demonstrate that the calculated total oxidant value obtained from the BWRVIA model at the desired location is **[ ]** or less and the calculated ECP value at a low RCS flow rate **[ ]** is equal to or less than **[ ]**. These calculations shall take into consideration the uncertainties that are associated with the application of the model and the additional margin used to compensate for any depletion of HWC-M at the desired location. For Category 1 plants, the implementation steps that were presented in the BWRVIP supplementary response sent by letter dated December 17, 2004, must be followed to demonstrate that an effective HWC-M is achieved in the RCS water at the desired location.

HWC credit can be claimed for RVIs at all locations where the model predicts an ECP of **[ ]** or below and a total oxidant of **[ ]** or less, provided that the difference between the measured and calculated (per the BWRVIA model) ECP values is a negative number. Tolerances in ECP values, which are inherently part of ECP measurements, should be taken into account when evaluating the difference between the measured and calculated ECP values.

As stated in Section 3.2.1 of this SE, the data that was obtained from the **[ ]** plants show inconsistencies between the calculated and measured ECP values at the lower head region. Therefore, the NRC staff concludes, as discussed in Section 3.2.1, that the BWRVIA model requires validation for RVIs in the lower head region, which can be achieved by installing an ECP probe specifically in this region.

The NRC staff requests that the BWRVIP provide all available information on inspection results to date (e.g., crack growth rates) for any component that is located in a remote location where ECP values are not measured. This data will be useful in assessing the availability of hydrogen at these locations. The NRC staff requests that BWRVIP-62 be revised to address the information (including figures and tables) provided in the BWRVIP response to Open Item 3.2.5 sent by letter dated August 1, 2001, as supplemented by letters dated May 19, 2003, and December 17, 2004. Therefore, the NRC staff considers this issue closed when BWRVIP-62 is revised to include the information provided in the BWRVIP letter dated August 1, 2001, as supplemented by letters dated May 19, 2003, and December 17, 2004.

3.3.3.2 ECP Model for Category 2 Plants

In its response to Open Item 3.2.5 sent by letter dated August 1, 2001, as supplemented by letters dated May 19, 2003, and December 17, 2004, the BWRVIP stated that since no ECP is measured for HWC-M Category 2 plants, the BWRVIA model is used to estimate the **[ ]**. These plants shall derive the ECP value based on ECP measurements in a sister plant, if available, and the details regarding sister plants are discussed in Section 3.2 of this SE.

However, if a Category 2 plant (as listed in Table 3-5 of BWRVIP-62) does not have measured ECP data from a sister plant available, then it shall derive a calculated ECP value that is low enough to assure that an ECP of **[ ]** or below is achieved for that plant design. The data plotted in Figure 6 of the BWRVIP response to Open Item 3.2.5 sent by letter dated August 1, 2001, provides a basis for selecting a bounding value for the calculated ECP for a given plant. The BWRVIA model will be used to calculate the total oxidant. If the total oxidant calculated at other plant locations is less than the concentration for the bounding value for the calculated ECP, then effective mitigation is assured at those locations. This may lead to more conservative ECPs for plants with no measured ECP or sister plant ECP data. The BWRVIP proposed to measure at least two secondary parameters (preferably, **[ ]**) to ensure protection from IGSCC. The BWRVIP further states that additional margin is provided in Category 2 plants by increasing the hydrogen injection rate so that the total oxidant from the BWRVIA model is maintained at **[ ]** or less and the ECP value at low flow **[ ]** is maintained at **[ ]** or below.

The NRC staff reviewed the BWRVIP response and concludes that, for Category 2 plants with no measured ECP values, HWC-M credit may be given for one operating cycle based on acceptable BWRVIA model predictions. The NRC staff concludes that the HWC credit can be claimed at all locations where the model predicts an ECP of **[ ]** or below and a total oxidant of **[ ]** or less. However, an ECP probe must be installed to confirm the model prediction at the next refueling outage. If the difference between the measured and calculated (per the BWRVIA model) ECP values is a negative number, then the classification of these plants may be changed from Category 2 to Category 1. Tolerances in ECP values, which are inherently part of ECP measurements, should be taken into account in evaluating the difference between the measured and calculated ECP values. Due to inconsistencies between the measured and calculated ECP values for RVIs located in the lower head region, the NRC staff concludes (as discussed in Section 3.2.1) that the BWRVIA model requires validation for RVIs located in the lower head region. This can be achieved by installing an ECP probe specifically in this region.

The NRC staff requests that the BWRVIP revise BWRVIP-62 to address the information (including figures and tables) provided in the BWRVIP response to Open Item 3.2.5 sent by letter dated August 1, 2001, as supplemented by letter dated December 17, 2004. Therefore, the NRC staff considers this issue closed when BWRVIP-62 is revised to include the information provided in the BWRVIP letter dated August 1, 2001, as supplemented by letter dated December 17, 2004.

3.3.3.3 ECP Model for Category 3a Plants

In its response sent by letter dated August 1, 2001, as supplemented by letters dated May 19, 2003, and December 17, 2004, the BWRVIP stated that for NMCA plants (Category 3a), the BWRVIP proposed to measure the ECP value at a given location, and that this **[ ]** to ensure the effectiveness of NMCA at that location. The ECP probes will be exposed to reactor water and may be located within the vessel, in the bottom head drain, in the reactor water cleanup system or in a recirculation line. A plant must conduct a hydrogen ramping test in order to determine the effect of feedwater hydrogen on ECP and select the feedwater hydrogen operating point. **[ ]**.

In addition, the BWRVIP proposed to implement continuous monitoring of two secondary parameters (i.e., **[ ]**) in order to ensure the availability of NMCA at the subject location. The BWRVIP stated that a good correlation will be established between the measured ECP value and the secondary parameters so that, in the event of any failure of an ECP probe, the secondary parameters will be used to assess the effectiveness of NMCA at the desired location. The NRC staff agrees with the approach of ensuring adequate NMCA availability at the desired location by maintaining the secondary parameter values at the required threshold levels that correlate to maintaining a measured ECP value of hydrogen of **[ ]** or below. The BWRVIP stated that a minimum molar ratio of **[ ]** should be maintained at the measured location in order to achieve a molar ratio of **[ ]** throughout the RVI locations. Based on the data provided by the BWRVIP to date, the NRC staff concludes that credit can be claimed for NMCA plants when the measured ECP values of the RCS water at the subject location is **[ ]** or below, the **[ ]** or more is maintained at the measured location, and the **[ ]**.

Establishing a good correlation between the measured ECP value and the total oxidant (calculated using the BWRVIA model) as a function of secondary variables is essential in assessing IGSCC mitigation at locations where the ECP cannot be measured. For Category 3a plants, when the ECP values cannot be measured at the location of interest, an appropriate BWRVIA model can be used to estimate ECP. The BWRVIA model is used to predict the molar ratio at various locations. A predicted molar ratio of [ ] or more in non-monitored locations will ensure effective IGSCC mitigation and NMCA for the RVIs.

NMCA credit can be claimed for RVIs at all locations where the BWRVIA model predicts an ECP of [ ] or below and a molar ratio of [ ] or more, provided the difference between the measured and calculated (per the BWRVIA model) ECP values is a negative number. However, the NRC staff's approval is required when intending to take credit for an effective NMCA program when a [ ]. Tolerances in ECP values, which are inherently part of ECP measurements, should be taken into account in evaluating the difference between measured and calculated ECP values.

For NMCA plants, BWRVIP-62 does not provide sufficient data for measured ECP to demonstrate the validity of the BWRVIA model for RVIs located in the lower head region. Since inconsistencies exist between measured and calculated ECP values for the HWC-M RVIs in the lower head region, the NRC staff determined that the BWRVIA model also requires validation for RVIs in the lower head region for NMCA plants. Therefore, the NRC staff requires validation of the BWRVIA model for NMCA plants by installing an ECP probe specifically in this region as discussed in Section 3.2.1.

For Category 3a plants, the implementation steps that were presented in the BWRVIP supplementary response sent by letter dated December 17, 2004, must be followed to obtain an effective NMCA in the RCS water. The NRC staff recommends that the BWRVIP provide all information on inspection results (i.e., crack growth rates) available to date for any component that is located in a remote location where ECP values cannot be measured. This data will be useful in assessing the availability of NMCA at these locations.

The NRC staff requests that BWRVIP-62 be revised to address the information (including figures and tables) provided in the BWRVIP response to Open Item 3.2.5 sent by letter dated August 1, 2001, as supplemented by letters dated May 19, 2003, and December 17, 2004. Therefore, the NRC staff considers this issue closed when BWRVIP-62 is revised to include the information provided in the BWRVIP letter dated August 1, 2001, as supplemented by letters dated May 19, 2003, and December 17, 2004.

3.3.3.4 ECP Model for Category 3b Plants

In its response sent by letter dated August 1, 2001, as supplemented by letters dated May 19, 2003, and December 17, 2004, the BWRVIP stated that plants in Category 3b use the [ ]. Plants will conduct a hydrogen ramping test to determine the the effect of feedwater hydrogen on the [ ] and select the feedwater hydrogen operating point. During the hydrogen ramping test, the plant shall correlate the [ ] with a minimum of two secondary parameters listed in Table 3-5, presented in the BWRVIP supplementary response sent by letter dated December 17, 2004.

The BWRVIA model predicts the molar ratio at various locations within the vessel and piping as a function of feedwater hydrogen. The model prediction for the feedwater hydrogen that is required for a [ ] shall be compared to and verified with the calculated ECP value at the location of interest. A predicted [ ] or more in the non-monitored locations will ensure effective IGSCC mitigation and NMCA.

The NRC staff reviewed the BWRVIP response and concludes that for Category 3b plants with no measured ECP values, NMCA credit may be given for one operating cycle based on acceptable BWRVIA model predictions. The NRC staff concludes that the NMCA credit can be claimed at all locations where the model predicts an ECP of **[   ]** or below and a molar ratio of 3 or more.

An ECP probe must be installed to confirm the model prediction at the next refueling outage. If the difference between the measured and calculated (per the BWRVIA model) ECP values is a negative number, then the classification of these plants may be changed from Category 3b to Category 3a. Tolerances in ECP values, which are inherently part of ECP measurements, should be taken into account when evaluating the difference between measured and calculated ECP values. For NMCA plants, BWRVIP-62 does not provide sufficient data for measured ECP to demonstrate the validity of the BWRVIA model for RVIs located in the lower head region. Since inconsistencies exist between the measured and calculated ECP values for the HWC-M RVIs located in the lower head region, the NRC staff determined that the BWRVIA model also requires validation for RVIs in the lower head region for NMCA plants. Therefore, the NRC staff requires validation of the BWRVIA model for NMCA plants by installing an ECP probe specifically in this region as discussed in Section 3.2.1.

The NRC staff requests that BWRVIP-62 be revised to address the information (including figures and tables) provided in the BWRVIP response to Open Item 3.2.5 sent by letter dated August 1, 2001, as supplemented by letters dated May 19, 2003, and December 17, 2004. Therefore, the NRC staff considers this issue closed when BWRVIP-62 is revised to include the information provided in the BWRVIP letter dated August 1, 2001, as supplemented by letters dated May 19, 2003, and December 17, 2004.

Table 3-1: Primary and Secondary Parameters to be Used in Implementation of BWRVIP-62 for Category 1, 2, 3a and 3b Plants

Category	Primary Parameters	Secondary Parameters
1. HWC-M	[ ]	[ ]
2. HWC-M [ ]	[ ]	[ ]
3a. NMCA	[ ]	[ ]
3b. NMCA [ ]	[ ]	[ ]

Key: FW: Feed Water; MSLR: Main Steam Line Radiation; MS: Main Steam

3.4 Technical Basis for Proposed Inspection Credit

Section 4.0 of BWRVIP-62 discusses crack growth rates in stainless steels and Alloy 182 welds for plants that implement HWC-M and/or NMCA. Based on the information provided, the NRC staff agrees that crack growth rates decrease when ECP values in the RCS water decrease. The FOI in crack growth rates is based on the availability of HWC-M and/or NMCA. Table 4-4 of BWRVIP-62 provides extensive information regarding the cracking history of RVIs and the degree of IGSCC mitigation provided by HWC-M and/or NMCA. The NRC staff reviewed the information and concurs that certain RVIs require higher feedwater hydrogen concentrations than others in order to acquire equivalent protection from IGSCC. Based on the FOI in crack growth rates, the BWRVIP proposed submittal of plant-specific revised inspection intervals for

RVIs protected by HWC-M or NMCA. The NRC staff will review this submittal as it becomes available. The discussion of crack growth rates in welds with exposure to neutron fluences equal to or greater than **[ ]** n/cm^2 is found in Section 3.1.3 of this SE.

4.0 CONCLUSION

The NRC staff has completed its review of BWRVIP-62 and concludes that a revised inspection program can be developed for RVIs based on the FOI for plants that have implemented HWC-M. It should be noted that BWRVIP-62 proposes no quantitative revised inspection schedules, and indicates this will be done at a later date. Therefore, at this time, the NRC staff makes no finding on the degree of modification justified over current inspection schedules.

For Category 1 plants, the NRC staff concludes that credit can be claimed for the availability of HWC-M at all locations where the BWRVIA model predicts an ECP of **[ ]** or below and a total oxidant of **[ ]** or less, when the difference between measured and calculated ECP values is a negative number. Tolerances in ECP values, which are inherently part of ECP measurements, should be taken into account in evaluating the difference between measured and calculated ECP values. Because of inconsistencies between measured and calculated ECP values for RVIs located in the lower head region, the BWRVIA model requires validation for RVIs in the lower head region. Validation of the BWRVIA model can be achieved by installing an ECP probe specifically in this region.

For Category 2 plants with no measured ECP values, HWC-M credit may be given for one operating cycle based on acceptable BWRVIA model predictions. The NRC staff concludes that the HWC credit can be claimed at all locations where the model predicts an ECP of **[ ]** or below and a total oxidant of **[ ]** or less.

An ECP probe must be installed to confirm model prediction at the next refueling outage. If the difference between the measured and calculated (per the BWRVIA model) ECP values is a negative number, the classification of these plants may be changed from Category 2 to Category 1. Tolerances in ECP values, which are inherently part of ECP measurements, should be taken into account in evaluating the difference between the measured ECP value and the calculated ECP value. Due to inconsistencies between the calculated and measured ECP values for RVIs in the lower head region, the NRC staff concludes, as discussed in Section 3.2.1, that the BWRVIA model requires validation for RVIs in the lower head region which can be achieved by installing an ECP probe specifically in this region.

For NMCA plants, a **[ ]** in lieu of **[ ]** is required which provides extra margin in ensuring effectiveness of the NMCA program. NRC staff's approval is required when intending to take credit for an effective NMCA program when a **[ ]**.

For Category 3a plants, credit can be claimed for the availability of NMCA with a **[ ]** at all locations which provides extra margin in ensuring the effectiveness of NMCA. For Category 3a plants, the NRC staff concludes that the credit can be claimed for the availability of NMCA at all locations where the BWRVIA model predicts an ECP of **[ ]** or below and a molar ratio of **[ ]** or more when the difference between a measured and calculated ECP value is a negative number. Tolerances in ECP values, which are inherently part of ECP measurements, should be taken into account in evaluating the difference between the measured ECP value and the calculated ECP value. For NMCA plants, BWRVIP-62 does not provide sufficient measured ECP data points for the RVIs in the lower head region to demonstrate the validity of the BWRVIA model. Since inconsistencies exist between the calculated and measured ECP values for the HWC-M RVIs in the lower head region, the NRC staff determined that the BWRVIA model also requires validation for RVIs in the lower head region for NMCA plants. Therefore, the NRC staff requires validation of the BWRVIA model by installing an ECP probe specifically in this region as discussed in Section 3.2.1.

For Category 3b plants with no measured ECP values, NMCA credit may be given for one operating cycle based on acceptable BWRVIA model predictions. The NRC staff concludes that the NMCA credit can be claimed at all locations where the model predicts an ECP of **[ ]** or below and a molar ratio of **[ ]** or more.

An ECP probe must be installed to confirm model prediction at the next refueling outage. If the difference between the measured and calculated (per the BWRVIA model) ECP values is a negative number, the classification of these plants may be changed from Category 3b to Category 3a. Tolerances in ECP values, which are inherently part of ECP measurements, should be taken into account in evaluating the difference between the measured ECP value and the calculated ECP value. For NMCA plants, BWRVIP-62 does not provide sufficient measured ECP data points for the RVIs in the lower head region to demonstrate the validity of the BWRVIA model. Since inconsistencies exist between the calculated and measured ECP values for the HWC-M RVIs in the lower head region, the NRC staff determined that the BWRVIA model also requires validation for RVIs in the lower head region for NMCA plants. Therefore, the NRC staff requires validation of the BWRVIA model by installing an ECP probe specifically in this region as discussed in Section 3.2.1.

For the downcomer region, the BWRVIA model (discussed in Section 3.2 of this SE) should take into consideration the effect of radiation on the hydrogen-oxygen recombination reaction. These calculations should take into consideration the uncertainties that are associated with the application of the model and the additional conservative margin to compensate for any depletion of HWC-M in this region.

The NRC staff requests that the BWRVIP provide any available information on the current and previous inspection results (i.e., crack growth rates) of any component that is located in a remote location where ECP values cannot be measured. This data will be useful in assessing the availability of HWC-M or NMCA at these locations. In addition, the growth rates of deep cracks should be monitored to verify that adequate protection is achieved in the deep crack region with effective HWC-M or NMCA.

The BWRVIP has agreed to address the following items in its future submittals.

(1) Review of reports addressed in References 3 and 4 of this SE.

(2) Future additional work on refining the BWRVIA models to reduce the inconsistencies of the calculated ECP values.

(3) Research data on the ECP model that is applicable to the lower plenum region.

The NRC staff has reviewed BWRVIP-62 and the associated responses to the Open Items in the NRC staff's initial SE. The NRC staff finds that BWRVIP-62, as modified and clarified to incorporate the NRC staff's comments above, is acceptable for providing a technical basis for inspection credit for BWR RVIs in Category 1 and 3a plants. BWRVIP-62 also provides an acceptable technical basis for allowing Category 2 and 3b plants to take inspection credit for one operating cycle, until an ECP probe can be installed. As discussed throughout this SE, the modifications that are stated in response to the NRC staff's Open Items must be incorporated in the A-version of BWRVIP-62.

5.0 REFERENCES

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5. BWR Vessel and Internals Project, "Modeling Hydrogen Water Chemistry for BWR Applications - New Results (BWRVIP-13)," TR-106068, December 1995 (ADAMS Accession No. ML9908300072).

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7. BWR Vessel and Internals Project, "Technical Basis for Revisions to Generic Letter 88-01 Inspection Schedules (BWRVIP-75)," TR-113932, October 1999 (ADAMS Accession No. ML993080249).

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