January 30, 2001

Carl Terry, BWRVIP Chairman
Niagara Mohawk Power Company
Post Office Box 63
Lycoming, NY 13093

SUBJECT: SAFETY EVALUATION OF PROPRIETARY EPRI REPORT TR 108705, "BWR VESSEL AND INTERNALS PROJECT, TECHNICAL BASIS FOR INSPECTION RELIEF FOR BWR INTERNAL COMPONENTS WITH HYDROGEN INJECTION (BWRVIP-62)" (TAC NO. MA4468)

Dear Mr. Terry:

The NRC staff has completed its initial review of the Electric Power Research Institute (EPRI) proprietary report TR-108705, "BWR Vessel and Internals Project, Technical Basis for Inspection Relief for BWR Internal Components with Hydrogen Injection (BWRVIP-62)," dated December 1998. This report was submitted by letter dated December 31, 1998, for NRC staff review and approval.

The NRC staff, with assistance from the Argonne National Laboratory, has reviewed your submittal and finds, in the enclosed safety evaluation (SE), that the report requires additional information to be submitted. The BWRVIP-62 report brings together the physical chemistry information of several EPRI reports, but does not introduce any new data regarding the effect of fluence on irradiation assisted stress corrosion cracking (IASCC) crack growth rates. The proposed criteria for inspection relief are based on the crack growth rate model developed in EPRI TR-105873, which is limited to components with fluences $<5 \times 10^{20}$ n/cm^2. Although the report does make it clear that the 5×10^{20} n/cm^2 fluence level is a threshold to accelerated crack initiation and crack growth rate, it suggests that the effect of fluence at values higher than 5×10^{20} n/cm^2 may not be very great and that applicants for inspection relief in such cases should provide arguments on a case by case basis. However, it provides no guidance on developing the bases for this action.

The staff finds that, until additional data are available, the target threshold electrochemical corrosion potential (ECP) should remain at -230 mV. The staff also concludes that the noble metal chemical plating of stainless steel surfaces leads to a reduction in ECP in the presence of sufficient hydrogen. However, the staff requests that more detailed discussions be presented in the following areas: test facility design for flow effect on ECP and susceptibility, comparison of gamma dose rate (the G values) used in radiolysis model, validation of radiolysis model to predict water chemistries for a broader range of plants, and uncertainties in the hydrogen water chemistry (HWC) strategies.

The staff requests that you address the questions in the enclosed SE, as well as your response to other issues raised in the staff's SE, in a revised, final BWRVIP-62 report. Please inform the staff within 90 days of the date of this letter as to your proposed actions and schedule for such a revision.

Please contact C. E. (Gene) Carpenter, Jr., of my staff at (301) 415-2169, if you have any further questions regarding this subject.

Sincerely,

Jack R. Strosnider, Director
Division of Engineering
Office of Nuclear Reactor Regulation

Enclosure: As stated

cc: See next page

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U.S. NUCLEAR REGULATORY COMMISSION

OFFICE OF NUCLEAR REACTOR REGULATION

SAFETY EVALUATION OF EPRI REPORT TR-108705, DECEMBER 1998,

"BWRVIP VESSEL AND INTERNALS PROJECT, TECHNICAL BASIS FOR

INSPECTION RELIEF FOR BWR INTERNAL COMPONENTS

WITH HYDROGEN INJECTION (BWRVIP-62)"

1.0 INTRODUCTION

1.1 Background

By letter dated December 31, 1998, as supplemented by letter dated March 7, 2000, the BWR Vessel and Internals Project (BWRVIP) submitted the Electric Power Research Institute (EPRI) report TR-108705, "BWR Vessel and Internals Project, Technical Basis for Inspection Relief for BWR Internal Components with Hydrogen Injection (BWRVIP-62)", for staff review. The December 31, 1998, submittal, was a proprietary version of the report, while the March 7, 2000, submittal was the non-proprietary version of the report.

The BWRVIP requested that, based on the technical information of the report, the staff provide inspection relief for boiling water reactor (BWR) internal components. The request is based on a systematic methodology for evaluating the effectiveness of hydrogen water chemistry (HWC) for the mitigation of intergranular stress corrosion cracking (IGSCC) of reactor internals when direct measurements of the internals' corrosion potential is not feasible.

The BWRVIP-62 report contains a discussion of the justification for either inspection relief or credit for inspection of BWR internal components that are exposed to the less corrosive environment obtained through the application of moderate HWC (HWC-M) and Noble Metal Chemical Application (NMCA, previously noble metal chemical addition, or commercially as NobelChem™, a patented process of the General Electric Company, GE). Included in this justification are valid supplementary techniques that do not depend exclusively on direct measurement of the electrochemical corrosion potential (ECP) at specific locations to reliably demonstrate HWC effectiveness. The BWRVIP stated that their radiolysis/ECP model, developed and evaluated for over a decade, has been demonstrated to be in agreement with reliable chemistry measurements obtained from steam and recirculation piping at 23 BWRs, and is proposed in the BWRVIP-62 report to be an effective tool to monitor plant water chemistry/corrosion potential conditions.

1.2 Purpose

The staff reviewed the BWRVIP-62 report to determine whether the report provides acceptable levels of justification for inspection relief for BWR internal components susceptible to IGSCC. The review considered the role of fluence on IGSCC, crack propagation rate, physical chemistry aspects, effect of ECP, flow and NMCA on susceptibility, the radiolysis and ECP models, and an assessment of HWC effectiveness.

ENCLOSURE

1.3 Organization of the Report

This safety evaluation (SE) was written so as not to repeat proprietary information contained in the BWRVIP-62 report. The staff does not discuss in any detail the provisions of the guidelines not found in the non-proprietary version of the guidelines. A brief summary of the contents of the BWRVIP-62 report is given in Section 2.0 of this SE, with a detailed evaluation in Section 3.0. The conclusion is summarized in Section 4.0. The presentation of this evaluation is structured according to the organization of the BWRVIP-62 report.

2.0 SUMMARY OF BWRVIP-62 REPORT

The BWRVIP-62 report addresses the following topics in the following order:

- Technical Basis for HWC Mitigation - HWC and its effect on BWR IGSCC of the weld heat affected zone (HAZ) of type 304/316 stainless steel of reactor internal components, such as piping and the shroud, are discussed in conjunction with nickel based alloys like Alloy 600 and Alloy 182, which are also susceptible to IGSCC. A summary of the cracking events, a literature survey of the importance of the ionic impurities in the BWR coolant, and a survey of the mitigation methods, consisting of hydrogen addition to act as oxygen scavenger and noble metal addition which act as catalysts for hydrogen-oxygen recombination, are provided.

- Radiolysis and ECP Models - A discussion of ECP and the results of various reactor surveys are provided. Direct measurement is either difficult and/or inaccurate, therefore, use of the ECP relies on calculated values from modeling.

- HWC Effectiveness Assessment - The current operating history is reviewed and correlated to the corresponding plant water chemistry. It concludes that HWC is able to reduce crack initiation and crack growth. Methods are described using hydrogen injection and noble metal chemistry with hydrogen injection. All of the above are in combination with ECP measurements or calculations. The effect of HWC and the use of the noble metal chemistry on the N-16 radiation of the main steam line is discussed. The crack growth correlation developed in BWRVIP-14 (Reference 1) is used to develop expected factors of reduction in crack growth rate, corresponding to the expected reduction in ECP.

- In-service Inspection Requirements - The discussion of current in-service inspection requirements is provided and concludes that the HWC improvements would result in lower IGSCC propagation rates which would justify inspection relief.

3.0 EVALUATION

BWR austenitic stainless steel piping and reactor internal components have experienced IGSCC, leading to degradation and potential safety concerns. Therefore, regular inspections for BWR piping to provide adequate assurance of structural integrity of affected piping systems was found by the NRC staff to be necessary, as described in Generic Letter (GL) 88-01, “NRC Position on IGSCC in BWR Austenitic Stainless Steel Piping,” dated January 25, 1988.

By letter dated October 27, 1999, as supplemented by letter dated February 29, 2000, the BWRVIP submitted the EPRI report TR-113932, "BWR Vessel and Internals Project, Technical Basis for Revisions to Generic Letter 88-01 Inspection Schedules (BWRVIP-75)," for staff review. The BWRVIP-75 report proposed revisions to the extent and frequencies for piping inspection contained in GL 88-01. The proposed revisions were based on the consideration of inspection results and service experience gained by the industry since the issuance of GL 88-01, and included additional knowledge regarding the benefits of improved BWR water chemistry. The BWRVIP-75 report also provided justification for the proposed inspection criteria for Category A through E welds for the respective conditions of normal water chemistry (NWC) and HWC, making use of the criteria in the BWRVIP-62 report.

By letter dated September 15, 2000, the staff provided an initial SE regarding the BWRVIP-75 report, which contained several open items that the BWRVIP was requested to respond to. Included in these were Open Item 3.7, Reactor Water Coolant Conductivity, and Open Item 3.8, Effective HWC and NMCA Programs.

In Open Item 3.7, the staff recommended that, to qualify for the reduced inspection frequency, the average conductivity in reactor water coolant should not exceed the recommendations in the BWR Water Chemistry Guidelines, 1996 Revision (BWRVIP-29), or later revisions. The average conductivity can be calculated from the measurements made during the entire inspection interval based on the total operating time at a temperature at or above 200 ^{o}F.

In Open Item 3.8, the staff described several acceptance criteria that a licensee would need to meet in order that its HWC and NMCA programs be considered effective (i.e., qualifying for the reduced inspection schedule) for the subject piping. This Open Item also stated that a "more detailed discussion of the hydrogen vs. oxygen molar ratio will be provided in the staff's SE for the BWRVIP-62 report." This will be discussed further, below.

Inspections similar to those described in GL 88-01 may be needed for reactor internal components, and, for the safety-related internal components, the BWRVIP has defined a program of several inspection and flaw evaluation (I&E) guidelines that the staff has mostly reviewed and, with several modifications to address staff concerns, has found acceptable. However, due to the difficulty and expense of these self-imposed reactor internals inspections, licensees find it desirable to demonstrate that fewer inspections are necessary when suitable reactor internals IGSCC mitigation steps are taken.

The NRC has agreed that the environmental IGSCC mitigation technique, HWC combined with lower water conductivity, provides a basis for inspection relief for BWR recirculation piping (NRC letter to R. A. Pinelli, BWROG, "Safety Evaluation of Topical Report," NEDE-31951P, dated January 1995). Since the NRC established inspection relief criteria for recirculation piping with HWC, the HWC process has been developed along two parallel paths for mitigation of reactor internals IGSCC. The first qualified HWC technique for reactor internals involves higher hydrogen injection rates than would typically be used to protect recirculation piping. This process is referred as moderate HWC (HWC-M) and results in sufficient hydrogen addition to lower ECPs to protective levels in the lower plenum. The second protective technique involves the continuous injection of a small amount of hydrogen to give a hydrogen to oxygen molar ratio >2 in the single phase liquid region plus an occasional batch injection of catalytic noble metal compounds. This second process is referred to as noble metal chemical application (NMCA),

formally known as noble metal chemical addition, and is also known by the GE trademark NobleChem™. Since both processes can protect BWR internals from environmental assisted cracking degradation, the effective implementation of either HWC-M or NMCA implementation at a BWR is considered in the BWRVIP-62 report to be an adequate basis for inspection relief for reactor internals.

Based on the crack growth modeling and radiolysis results, a vessel internals inspection program can be developed based on factors of improvement (FOI) for plants that have implemented either HWC-M or NMCA. The FOI calculated for each internal component based on modeling results would be applied to revise the internals inspection interval established in the various BWRVIP I&E reports. The BWRVIP will propose revised inspection intervals for vessel internals for plants that have implemented either HWC-M or NMCA at a later date.

The staff has completed its initial review of the BWRVIP-62 report, and finds that the guidance provided is generally acceptable, except for the below enumerated open items. The staff requests that BWRVIP review and resolve the open items raised below, and incorporate the staff's conclusions and recommendations into a revised BWRVIP-62 report.

Also, while not specifically listed below as an open item, the staff requests that the BWRVIP address, in this revision to the BWRVIP-62 report, how the technical basis of this report addresses the concerns that have arisen due to the leakage in the CRDM housing at Oyster Creek and Nine Mile Point Unit 1. In general, the staff requests that the BWRVIP discuss how HWC (and NMCA, as applicable), is effective in the lower head regions of the reactor vessel.

3.1 Irradiation Assisted Stress Corrosion Cracking (IASCC)

Open Item 3.1.1 The Role of Fluence

The BWRVIP-62 report recognizes the importance of fluence on crack growth; however, it does not present any new data, but rather references an older EPRI report, TR-107159, "Critical Issues Reviews for the Understanding and Evaluation of Irradiation Assisted Stress Corrosion Cracking," dated November 1996, (Reference 2) which has fluence data in the range of up to 5×10^{20} n/cm^2. Some BWR internal components have accumulated fluence in excess of this amount, and are projected to reach the range of 1×10^{22} n/cm^{22} before the end of life.

Regardless of the lack of data and the explicit statements made in BWRVIP-62 that the proposed models have not been validated for fluences above 5×10^{20} n/cm^2, the report recommends to the individual utilities that they should apply for inspection relief for higher fluences from the NRC on a case-by-case basis. This recommendation is based on the observation that there exists Swiss data which indicates that IASCC growth does not take place until fluence values reach the range of 8×10^{20} n/cm^2 to 1×10^{21} n/cm^2. The BWRVIP-62 report does not specify how the inspection relief request for operating plants for which components are above the 5×10^{20} n/cm^2 exposure level would be justified. Such conclusions are neither quantified or validated; therefore, this SE applies only to fluence values of less than or equal to 5×10^{20} n/cm^2. The BWRVIP should address this issue in a revision to the BWRVIP-62 report.

Open Item 3.1.2 Crack Propagation Rate

The crack propagation rate model is based on an empirical formula for crack growth rates developed in EPRI TR-105873, BWRVIP-14, (Reference 1) and based on a correlation of stress intensity, conductivity at 25 °C (77 °F), ECP, and absolute temperature in kelvin (K). Measured rates versus ECP indicate a relationship of increasing crack growth rate with increasing ECP values (as measured by a standard hydrogen electrode, SHE). However, the report does not introduce fluence as a variable and the question of crack propagation rate at fluences at or above 5×10^{20} n/cm^2 is not dealt with. The BWRVIP should provide a technical justification for not using fluence as a variable, and should address this issue in a revision to the BWRVIP-62 report.

Open Item 3.2 Physical Chemistry Aspects of the Inspection Relief Request

The NRC staff, with the assistance from the Argonne National Laboratory (ANL), has reviewed the physical chemistry aspects of the inspection relief request. The key elements of the BWRVIP-62 report reviewed include the following: effect of ECP on susceptibility, flow effect on ECP and susceptibility, NMCA, radiolysis model, ECP model, and assessment of HWC effectiveness.

The staff has given inspection relief for the use of HWC mitigation measures for BWR stainless steel piping, four inches or greater in diameter, documented in the staff's initial safety evaluation for BWRVIP-75 (Reference 3). Credit for improvement for HWC and NMCA are given in the Table titled "Summary of Staff Proposed Modifications to BWRVIP-75." The table has incorporated separate degrees of inspection relief for the use HWC and for NMCA. The BWRVIP-75 Report uses the BWRVIP-62 report as a technical basis document for a systematic methodology for evaluating the effectiveness of HWC, with or without NMCA for the mitigation of IGSCC.

The staff has defined an "effective" HWC and NMCA program in Open Item 3.8 of the staff's SER on the BWRVIP-75 report. The elements of an "effective" (i.e., qualifying for a reduced inspection schedule) program are taken from the staff's position on BWRVIP-75 Open Item 3.8 and are repeated here:

For effective HWC programs, the ECP measurements should be -230 mV or less and be measured by at least two different reference electrodes. Alternately, secondary parameters may be monitored regularly to verify the effectiveness of HWC, when direct measurements are not available. HWC should be available at least 80 percent of the time. Conductivity transients (>0.3 uS/cm) of less than 24 hours need not be subtracted from the acceptable HWC service time. When the hydrogen injection is interrupted for less than 10 hours, the interrupt time need not be excluded from the calculation of the acceptable HWC service time as long as the ECP is below -230 mV or the secondary parameter meet the acceptance criteria.

For an acceptable NMCA program the hydrogen vs. oxygen molar ratio should be 4:1 and above; there should be a monitoring program to determine if the NMCA remains applied and to determine when the process needs to be re-applied; NMCA is only applicable when HWC is available, and should be available at greater than 90 percent of the hot operating time; conductivity transients (>0.3 uS/cm) lasting 24 hours or less, need not be subtracted from the acceptable NMCA service time.

Conformance to the above criteria should be addressed in a revision to the BWRVIP-62 report.

Open Item 3.2.1 Effect of ECP on Susceptibility

Many investigators have shown a strong dependence of IGSCC susceptibility and crack growth rate (CGR) on the ECP of stainless steels in BWR environments. The BWR Water Chemistry Guidelines - 1996 Revision (BWRVIP-29), and the latest revision, BWRVIP-79, dated March 2000) have incorporated -230 mV as the "protection potential" for IGSCC of thermally sensitized steels based on in-reactor slow strain rate tests. However, the BWRVIP-62 report indicates that the threshold ECP for IGSCC initiation in irradiated Type 304 stainless steel may be as high as -140 mV, based on the work of Indig, et al. The staff finds this conclusion to be unjustified. The -140 mV threshold is based on limited data. In addition, the "threshold" potential would be a function of the following: irradiation level, concentrations of impurities in the coolant, and the microstructure and composition of the steel. One would expect a fairly wide range of "threshold" potentials and the -140 mV value may represent a unique case.

The staff position is that, until additional data are available, the target threshold ECP should remain at -230 mV. This should be addressed in a revision to the BWRVIP-62 report.

Open Item 3.2.2 Flow Effect on ECP and Susceptibility

Under BWR 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. However, this ECP increase does not necessarily lead to an increase in susceptibility. Surface characteristics of tested specimens have shown that increased flow leads to a reduction in susceptibility for smooth surfaces and that greater surface roughness reduced the convective flows within the crack. The BWRVIP-62 report argues that the effect of flow is to move the "effective" mouth of the crack down the crack. This is based on the assumption that the convection forces penetrate far enough into the crack that the bulk concentration of impurities is maintained until the ECP decreases to a low level. Direct evidence of this phenomenon is limited. Tests performed by GE showed that, although ECP increased significantly with flow rate, the CGR decreased.

The staff requests that a more detailed description of these tests be provided.

Open Item 3.2.3 Noble Metal Chemical Application / Additions (NMCA)

BWR coolant oxygen reduction and hydrogen oxidation are assumed to be the most dominant reactions on most metal surfaces. The rates of these reactions are dependent on the ECP, which is determined by measuring the overall balance of charge. Tests have shown that materials with catalytic coatings exhibit the low crack growth rates normally associated with low ECPs, even though the nominal water chemistry in the test had high levels of dissolved oxygen and impurities. This process has been successful in preventing IGSCC in slow strain rate tests, which represent more severe loading conditions than would be expected in the reactor. In addition, long term laboratory tests and in-reactor testing indicate that the coatings remain effective for significant periods of time. The staff agrees that the plating of stainless steel surfaces with noble metals leads to a reduction in ECP in the presence of sufficient hydrogen, and agrees in general with the BWRVIP-62 report on the advantages of NMCA. However, the

BWRVIP-62 report needs to be modified to clarify that, for an acceptable NMCA program, the hydrogen vs. oxygen molar ratio should be 4:1 and above, as stated above.

Open Item 3.2.4 Radiolysis Model

For the past ten years, the radiolysis model has undergone many changes. These changes include refinement of the description of the primary system, dose rate modeling of the ex-core regions and updating of the neutron/gamma dose rates (the G values). The staff requests a discussion on the significant differences between the BWRVIP-62 report, G values and those used in similar approaches in Taiwan and Japan (References 5 and 6) to analyze the impact of hydrogen water chemistry.

The staff also requests that results from a broader range of plants be included in a revised BWRVIP-62 report 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 the BWRVIP-62 report, comparative model results in the referenced Appendix A of BWRVIP-13 (Reference 7) are not presented in terms of the proposed secondary parameters. Because of this difference, it is impossible to determine that the model results represent the range of behavior observed in-reactor.

Open Item 3.2.5 ECP Model

The ECP model in the BWRVIP-62 report is an empirical correlation relating concentrations of H_2, O_2, H_2O_2, and flow velocity to ECP. The results of six plants are presented in Figure 2.8 of the proprietary version of the BWRVIP-62 report. However, when grouped by plant, the data does not appear to be randomly distributed about the mean trend line. The individual plant data appears to cluster above or below the trend line, which would indicate that ECP cannot be simply estimated on the basis of the standard deviation based on the whole population of data. In addition, the staff notes that ECP models implicitly assume that the experimental measurements are correct. However, more extensive efforts to resolve discrepancies between multiple measurements of ECP need to be undertaken. This should be addressed in a revision to the BWRVIP-62 report.

Open Item 3.2.6 Assessment of HWC Effectiveness

The overall presentation of the strategies for monitoring the effectiveness of hydrogen water chemistries presented is adequate. However, almost all radiolysis analyses have shown that radiation levels in the downcomer region have a strong effect on the rate of hydrogen-oxygen recombination reaction. Since this radiation level in the downcomer varies throughout core life, the actual degree of mitigation achieved will also vary. The staff requests a discussion on the details or criteria to address uncertainties in the degree of mitigation associated with the change in radiation levels.

4.0 CONCLUSION

The staff with the assistance of Argonne National Laboratory reviewed the EPRI TR-108705, topical report on “BWR Vessel and Internals Project, Technical Basis for Inspection Relief for BWR Internal Components with Hydrogen Injection (BWRVIP-62)”. The BWRVIP-62 report brings together the physical chemistry information of several EPRI reports, but does not

introduce any new data regarding the effect of fluence on IASCC crack growth rates. The proposed criteria for inspection relief are based on the crack growth rate model developed in EPRI TR-105873 (BWRVIP-14) and therefore any conclusions in this SE are limited to components with fluences less than or equal to 5×10^{20} n/cm^2.

The staff finds that, until additional data are available, the target threshold ECP remain at –230 mV. The staff also concluded that the noble metal plating of stainless steel surfaces leads to a reduction in ECP in the presence of sufficient hydrogen. However, the staff requests that more detailed discussions be presented in the following areas: the test for flow effect on ECP and susceptibility, comparison of G values used in radiolysis model, validation of radiolysis model to predict water chemistries for a broader range of plants, and uncertainties in the HWC strategies.

The BWRVIP, in the subject report, proposes no quantitative revised inspection schedules and indicates this will be done at a later date; therefore, the staff makes no finding on the degree of relief justified over current inspection schedules at this time.

5.0 References

1. BWR Vessels and Internals Project, “Evaluation of Crack Growth in BWR Stainless Steel RPV Internals (BWRVIP-14)”, EPRI TR-105873, Electric Power Research Institute, Palo Alto (1996).

2. EPRI report TR-107159, “Critical Issues Reviews for the Understanding and Evaluation of Irradiation Assisted Stress Corrosion Cracking,” dated November 1996.

3. Letter from Jack R. Strosnider, USNRC, to Carl Terry, BWRVIP, Safety Evaluation of the “BWRVIP Vessel and Internals Project, BWR Vessel and Internals Project, Technical Basis for Revisions to Generic Letter 88-01 Inspection Schedules (BWRVIP-75),” EPRI Report TR-113932, September 15, 2000.

4. BWR Vessels and Internals Project, “Technical Basis for Revisions to Generic Letter 88-01 Inspection Schedules (BWRVIP-75)”, EPRI TR-113932, Electric Power Research Institute, Palo Alto CA, October 1999.

5. T. K. Yeh, M. S. Yu, C.P. Wang, F. Chu, C. S. Huang, J. T. Kao, “A Comparitive Study of the Effectiveness of Hydrogen Water Chemistry by Computer Modeling for Chinsan and Kuosheng, *“Proceedings of the Eighth International Symposium on Environmental Degradation of Materials in Nuclear Power Systems - Water Reactors,* American Nuclear Society, La Grange Park, IL (1997).

6. Y. Wada, N Shigenaka, N. Uetake, S. Uchida, “Numerical Simulation of SCC Environment in a BWR Primary Coolant System, *“Proceedings of the Eighth International Symposium on Environmental Degradation of Materials in Nuclear Power Systems - Water Reactors,* American Nuclear Society, La Grange Park, IL (1997).

7. EPRI TR-106068, “Modeling Hydrogen Water Chemistry for BWR Applications - New Results (BWRVIP-13), Electric Power Research Institute, Palo Alto, CA (1995)