January 12, 2005

Mr. Gordon Bischoff, Manager
Owners Group Program Management Office
Westinghouse Electric Company
P.O. Box 355
Pittsburgh, PA 15230-0355

SUBJECT: FINAL SAFETY EVALUATION FOR TOPICAL REPORT WCAP-15973-P, REVISION 01, "LOW-ALLOY STEEL COMPONENT CORROSION ANALYSIS SUPPORTING SMALL-DIAMETER ALLOY 600/690 NOZZLE REPAIR/REPLACEMENT PROGRAM" (TAC NO. MB6805)

Dear Mr. Bischoff:

By letter dated May 20, 2004 (ML041540226), the Westinghouse Owners Group (WOG) submitted Topical Report (TR) WCAP-15973-P, Revision 01, "Low-alloy Steel Component Corrosion Analysis Supporting Small-diameter Alloy 600/690 Nozzle Repair/Replacement Program" for the staff review. On November 30, 2004 (ML043090373), an NRC draft safety evaluation (SE) regarding our approval of WCAP-15973-P was provided for your review. By e-mail dated December 16, 2004, the WOG suggested some minor editorial changes to the draft SE which were fully adopted into the final SE, as discussed in the attachment to the final SE enclosed with this letter.

The staff has found that WCAP-15973-P, Revision 01, is acceptable for referencing in licensing applications for Combustion Engineering-designed pressurized water reactors to the extent specified and under the limitations delineated in the TR and in the enclosed SE. The SE defines the basis for acceptance of the TR.

Our acceptance applies only to material provided in the subject TR. We do not intend to repeat our review of the acceptable material described in the TR. When the TR appears as a reference in license applications, our review will ensure that the material presented applies to the specific plant involved. License amendment requests that deviate from this TR will be subject to a plant-specific review in accordance with applicable review standards.

In accordance with the guidance provided on the NRC website, we request that the WOG publish accepted proprietary and non-proprietary versions of this TR within three months of receipt of this letter. The accepted versions shall incorporate this letter and the enclosed SE between the title page and the abstract. They must be well indexed such that information is readily located. Also, they must contain historical review information, such as questions and accepted responses, draft SE comments, and original TR pages that were replaced. The accepted versions shall include a "-A" (designating accepted) following the TR identification symbol.

If future changes to the NRC's regulatory requirements affect the acceptability of this TR, Westinghouse Owners Group and/or licensees referencing it will be expected to revise the TR appropriately, or justify its continued applicability for subsequent referencing.

Sincerely,

/RA/
Herbert N. Berkow, Director
Project Directorate IV
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 694

Enclosure: Safety Evaluation

cc w/encl:
Mr. James A. Gresham, Manager
Regulatory Compliance and Plant Licensing
Westinghouse Electric Company
P.O. Box 355
Pittsburgh, PA 15230-0355

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*SE Dated January 12, 2005

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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

WCAP-15973-P, REVISION 01, "LOW-ALLOY STEEL COMPONENT CORROSION ANALYSIS SUPPORTING SMALL-DIAMETER ALLOY 600/690 NOZZLE REPAIR/REPLACEMENT PROGRAM"

WESTINGHOUSE OWNERS GROUP

PROJECT NO. 694

1.0 INTRODUCTION

Vessels and piping in the reactor coolant pressure boundary of pressurized water reactors (PWRs) are fabricated either from A 302, Grade B; SA 533, Grade B; or SA 508, Class 2 low-alloy steels (for fabrication of vessels), or SA 516, Grade 70 carbon steel (for the fabrication of piping). These materials are classified as ferritic steel materials. These components are typically clad on their internal surfaces using austenitic stainless steels to isolate the ferritic material from the primary coolant, thereby minimizing corrosion and corrosion product release into the coolant. Alloy 600 nozzles that penetrate through these components are typically joined to the vessels or piping using partial penetrating J-groove welds that are fabricated from Alloy 82/182 weld materials. These welds penetrate completely through the cladding and partially into the ferritic portions of the vessels or piping. Therefore, in the as-built condition, the ferritic material is not exposed to the borated primary coolant water. Inservice industry experience has demonstrated that these Alloy 600 nozzles and Alloy 82/182 welds are susceptible to primary water stress corrosion cracking (PWSCC) resulting in through-wall/weld cracks. The half-nozzle and the mechanical nozzle seal assembly (MNSA) repairs leave the through-wall cracks intact and potentially leaves the ferritic portions of the vessel or piping exposed to borated water.

By safety evaluation (SE) dated February 8, 2002, the NRC staff reviewed and approved, with limitations, the use of Topical Report (TR) CE-NPSD-1198-P, Revision 00, "Low-Alloy Steel Component Corrosion Analysis Supporting Small-Diameter Alloy 600/690 Nozzle Repair/Replacement Program" submitted by the Combustion Engineering Owners Group (CEOG) on February 15, 2001. The CEOG was integrated into the Westinghouse Owners Group (WOG) in 2002. Future references to the owners group will be made to as the WOG. This TR provided an evaluation on potential degradation mechanisms of these repaired components, which included corrosion, stress corrosion cracking and thermal fatigue.

By letter dated November 11, 2002, the WOG submitted TR WCAP-15973-P, Revision 00, "Low Alloy Steel Component Corrosion Analysis Supporting Small-Diameter Alloy 600/690 Nozzle Repair/Replacement Program" for staff review and approval. The WOG seeks the staff's approval of the TR in order that licensees seeking relief to use half-nozzle or MNSA

repair/replacement techniques may reference the TR as part of their basis for using the alternate repair methods on leaking Alloy 600 nozzles in the primary pressure boundary. The TR provides an evaluation on determining corrosion rates, stress corrosion cracking and thermal fatigue relevant to these alternative repair methods. A non-proprietary version of the TR was enclosed along with Calculation Report CN-CI-02-71 (Proprietary), entitled "Summary of Fatigue Crack Growth Evaluation Associated with Small Diameter Nozzles in CE Plants," dated October 28, 2002. This TR corrected errors in the thermal fatigue calculations reported in CE-NPSD-1198-P, Revision 00. These errors affect the predicted growth of thermal fatigue cracks in limiting locations. In addition, WCAP-15973-P, Revision 00, addressed concerns regarding boric acid corrosion discovered at Davis-Besse in response to NRC Bulletin 2001-01, and also revised the general corrosion rates. Clarifications were also made to the stress corrosion cracking evaluation.

By letter dated October 6, 2003, the WOG supplemented the information in the TR with additional information. However, by letter dated March 5, 2004, the WOG withdrew Revision 00 to the TR due to errors discovered in the supporting fatigue crack growth analyses. By letter dated May 20, 2004, the WOG submitted TR WCAP-15973, Revision 01, dated May 2004, and the supporting Westinghouse Calculation Report CN-CI-02-71, Revision 01, to correct the errors in Revision 00 of the TR and the calculation report. The WOG provided additional information on the calculation report by letter dated August 11, 2004.

2.0 REGULATORY REQUIREMENTS

Section 50.55a(g) of Title 10 of the *Code of Federal Regulations* (10 CFR) requires nuclear power facility piping and components to meet the applicable requirements of Section XI of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (hereafter referred to as the ASME Code). Currently, 10 CFR 50.55a endorses all versions of the ASME Code, Section XI up to the 1998 Edition through the 2000 Addenda. Although the exact wording may vary depending on the specific edition and addenda of the ASME Code used, Article IWA-4000 requires that existing flaws in ASME Code Class 1 components either be removed in their entirety or, if not removed, evaluated in accordance with the appropriate flaw evaluation provisions of Section XI of the ASME Code. For example, paragraph IWA-4310 of the 1995 Edition, with the 1995 and 1996 Addendum of Section XI to the ASME Code states:

> Defects shall be removed or reduced in size in accordance with this Paragraph. The component shall be acceptable for continued service if the resultant section thickness created by the cavity is equal to or greater than the minimum design thickness. If the resulting thickness is reduced below the minimum design thickness, the component shall be repaired or replaced in accordance with this Article. Alternatively, the defect removal area and any remaining portion of the flaw may be evaluated and the component accepted in accordance with the appropriate flaw evaluation rules of Section XI or the design rules of the Owner's Requirements and either the Construction Code, or Section III. The Repair/Replacement Program, Plan, and associated evaluation shall be subject to review in accordance with IWA-4140(c).

Therefore, if the flaw is to be left in service, an evaluation is required to be performed and reviewed by the NRC, as required by section IWA-4140(c) of the 1995 Edition, with the 1995 and 1996 Addendum of Section XI to the ASME Code, which states:

> The Repair/Replacement Program, Plans, and evaluations required by IWA-4150 shall be subject to review by enforcement and regulatory authorities having jurisdiction at the plant site.

In addition, paragraph IWB-3142.4 of the 1995 Edition, with the 1995 and 1996 Addendas of Section XI to the ASME Code provides acceptance requirements for flaws to be left in service as follows:

> Components containing relevant conditions shall be acceptable for continued service if an analytical evaluation demonstrates the component's acceptability. The evaluation analysis and evaluation acceptance criteria shall be specified by the Owner. Components accepted for continued service based on analytical evaluation shall be subsequently examined in accordance with IWB-2420(b) and (c).

IWB-2420(b) and (c) of the 1995 Edition, with the 1995 and 1996 Addendas of Section XI to the ASME Code provides information on performing successive inspections for flaws left in service and accepted by analytical evaluation:

> If components are accepted for continued service in accordance with IWB-3132.4 or IWB-3142.4, the areas containing flaws or relevant conditions shall be reexamined during the next three inspection periods listed in the schedule of the inspection program of IWB-2400. If the reexamination required by IWB-2400(b) reveals that the flaws or relevant conditions remain essentially unchanged for three successive inspection periods, the component examination schedule may revert to the original schedule for successive inspections.

Other editions of the ASME code provide similar guidance. In summary, the ASME Code requires either the removal of the flaw, or the performance of an analysis with subsequent examinations. This TR addresses the latter, by providing corrosion and fatigue analyses of the cracked Alloy 600 nozzle and/or Alloy 82/182 weld since the half-nozzle and MNSA repairs leave the flaw in service.

The discovery of leaks and nozzle cracking at the Davis-Besse Nuclear Power Station and other PWR plants has made clear the need for flaw evaluation guidelines for control rod drive mechanism (CRDM) type of penetrations and more effective inspections of reactor pressure vessel (RPV) heads and associated penetration nozzles. To ensure that the inspections are effective, the NRC issued Bulletin 2001-01, "Circumferential Cracking of Reactor Pressure Vessel Head Penetration Nozzles," Bulletin 2002-01, "Reactor Pressure Vessel Head Degradation and Reactor Coolant Pressure Boundary Integrity," Bulletin 2002-02, "Reactor Pressure Vessel Head and Vessel Head Penetration Nozzle Inspection Programs," Information Notice 2003-02, "Recent Experience with Reactor Coolant System Leakage and Boric Acid Corrosion," and Order EA-03-009, "Issuance of Order Establishing Interim Inspection

Requirements for Reactor Pressure Vessel Heads at Pressurized Water Reactors." Since there is limited flaw evaluation guidelines for these conditions, the NRC developed flaw evaluation guidelines for this application for appropriate use by the industry and the staff. The original guidelines were enclosed in the letter dated November 21, 2001, from the NRC to the Nuclear Energy Institute (NEI), and the revised guidelines were enclosed in the letter dated April 11, 2003, from the NRC to NEI.

The TR was reviewed in accordance with the requirements of 10 CFR 50.55a (Section XI of the ASME Code) and the April 11, 2003, guidelines.

3.0 EVALUATION

WCAP-15973-P, Revision 01, is only applicable to repairs/replacements of leaking Alloy 600 nozzles and/or Alloy 82/182 welds in the reactor coolant pressure boundary of Combustion Engineering (CE) plants using either the MNSA or half-nozzle repair/replacement techniques. The use of the half-nozzle or MNSA repair/replacement techniques of WCAP-15973-P, Revision 01 leaves the through-wall crack in the Alloy 600 nozzle and/or Alloy 82/182 J-groove weld intact and potentially allows the ferritic portions of the vessels or piping to be exposed to the borated reactor coolant. WCAP-15973-P, Revision 01, accomplishes the following objectives with respect to implementing these repair or replacement methods:

1. Provides an acceptable method for calculating the overall general/crevice corrosion rate for the internal surfaces of the low-alloy steel materials that are now potentially exposed to the reactor coolant, and for calculating the amount of time the ferritic portions of the vessel or piping would be acceptable if corrosive wall thinning occurs. (See Section 3.1 of this SE for the evaluation.)

2. Provides an acceptable method of calculating the thermal-fatigue crack-growth life of existing flaws in the Alloy 600 nozzles and/or Alloy 82/182 weld material into the ferritic portion of the vessels or piping. (See Section 3.2 of this SE for the evaluation.)

3. Provides acceptable bases and arguments for concluding that unacceptable growth of the existing flaw by stress corrosion into the vessel or piping is improbable. (See Section 3.3 of this SE for the evaluation.)

The main difference between the half-nozzle and the MNSA repair is that the half-nozzle provides a welded repair on the outside of the component, in contrast to the MNSA repair, which mechanically seals a leak or potential leak on the outside surface of the component. Since the complete alloy 600 nozzles are left in place, the MNSA repair is similar to the half-nozzle condition in that the cracked nozzle and/or weld will remain in place and the crevice regions will be filled with borated water. Therefore, the corrosion and crack growth evaluations of the half-nozzles also applies to the MNSA repairs. However, since this is a mechanical device in lieu of a weld, that provides both sealing and structural integrity for the leaking nozzle, additional justification is required to approve MNSA for a long-term repair. As discussed in the NRC letter dated December 8, 2003, to the WOG, an analysis of the pressure boundary component to which the MNSA is attached and an inservice inspection program to be maintained throughout the licensed life of the facility is required. As stated in a letter dated

February 18, 2004, the WOG is currently working with various Code Committees to resolve the NRC's concerns in order that the application of MNSAs can be made as a long-term repair. When these concerns are resolved, the corrosion and crack growth evaluations of WCAP-15973-P, Revision 01, with respect to the flaws left in service can be applied to the MNSA repair.

3.1 General and Crevice Corrosion Rate Evaluation (WCAP-15973-P, Revision 01)

The MNSA and half-nozzle repair/replacement designs will potentially leave the ferritic surfaces of the vessels or piping exposed to the borated reactor coolant. The WOG evaluates the potential for these surfaces to degrade by general or crevice corrosion in Section 2.0 of the TR. The WOG makes its general/creviced corrosion rate evaluation based on the relative chemistry and temperature conditions of the reactor coolant. According to a qualitative review of Figures 1 and 2 in the TR, exposure to the reactor coolant will be under crevice conditions for the MNSA designs and under bulk coolant conditions for the half-nozzle designs.

The WOG's overall corrosion rate for general corrosion of low-alloy or carbon steel materials is summarized in Equation 1 and Conclusion 1 of the TR and is based on a sum of contributing corrosion rate factors for normal operating conditions, startup conditions, and low temperature outage conditions. These "factors" are the multiplicative results of the corrosion rate values for operating conditions and the WOG's best estimate for the amount of time (as a percentage of total operating life) that a typical plant would operate in these modes. The WOG used Conclusions 2 and 3 of the TR to support the overall corrosion rate given in Conclusion 1.

The WOG used the results of laboratory corrosion studies as its bases for establishing the general corrosion rates for low-alloy or carbon steel materials during normal operating, startup, and cold shutdown modes of operation. The laboratory studies used for determining the bounding corrosion rate for normal operating conditions were performed under deaerated conditions, and simulated maximum boron, lithium, and oxygen levels in the reactor coolant under normal operating conditions for a CE-designed PWR. The laboratory studies used for determining the corrosion rates for low alloy or carbon steel materials during startup or cold shutdown conditions also simulated the boron, lithium, and oxygen levels for these conditions, but were made under aerated conditions.

During normal operating conditions, the reactor coolant system (RCS) is closed off from the reactor building environment, and the system is operated at temperatures in the range of 560-600EF and under hydrogen water chemistry conditions. At these temperatures, the concentration of dissolved oxygen in the coolant is normally maintained well below 150 parts per billion (ppb). During cold shutdown and startups, the RCS is normally opened up and exposed to the reactor building environment. Under these conditions, the concentration of dissolved oxygen in the RCS coolant is normally much higher than it would be during normal operating conditions, when the RCS is sealed off from the reactor building environment. Since the laboratory conditions for the corrosion studies were consistent with chemistry conditions in the reactor coolant during normal operating, startup, and cold-shutdown conditions, the staff concludes that the proposed corrosion rates for normal operating, startup, and cold shutdown conditions provide an acceptable basis for calculating the overall corrosion rate for ferritic carbon and low-alloy steel materials under the borated and hydrogen water chemistry

conditions for the reactor coolant. The general corrosion rates for normal operating, startup, and cold shutdown conditions is based on limited laboratory and field data. Therefore, if new laboratory or field data become available that invalidate the bounding general corrosion rates given in the TR, the staff requests that the WOG submit an addendum to the TR that will provide a summary of the analyses performed on the new data and a new overall general corrosion rate calculation that is based on the results from these analyses.

The method for calculating the general overall corrosion rate is also dependent on the amount of time the plants (in terms of percentage of total plant life) are estimated to be operating in the normal operating, startup, and cold shutdown modes of operation, in addition to the corresponding corrosion rates during each of the modes of operation as discussed above. The amount of time in these modes of operation, which are normally provided in the design basis for the plant, may vary from plant-to-plant and from the times used by the WOG in Equation (1) of the TR. In this case, when the staff used a time at normal operation of 80 percent[1], the staff calculated a general overall corrosion rate value that was approximately 40 percent in excess of the corresponding value calculated by the WOG. This demonstrates that the overall general corrosion rate for determining the repair lives of the nozzles is dependent on the plant-specific times at normal operations, startups, and cold shutdowns of a given plant.

In addition, Section 2.2 of WCAP-15973-P, Revision 01, addressed concerns regarding boric acid corrosion discovered at Davis-Besse in response to NRC Bulletin 2001-01. The TR bases its conclusion that during plant operation, boric acid corrosion is low because there is no mechanism for concentrating boric acid in the crevice region and free oxygen does not exist. Davis-Besse and similar events involving corrosion of the RCS components and fasteners exposed to the containment atmosphere (containing free oxygen) are not applicable because of the dissimilarity in the environmental conditions. However, during shutdowns and refuelings, the corrosion rate will increase since the crevice region may be filled with aerated water. The report stated that some tests using SA 533 Grade B steel mockups which contained cracked nozzles produced corrosion rates of up to two inches per year in aerated water conditions. In addition, other laboratory data showed that corrosion rates in deaerated water are minimal. Therefore, if the nozzles are not leaking, or exposed to aerated water, these corrosion rates will be minimal. As stated above, the corrosion rates are dependent on the plant-specific times at normal operations, startups, and cold-shutdowns, as well as plant-specific configurations, and therefore must be demonstrated to be applicable on a plant-specific basis.

Licensees seeking to use the methods of the TR need to perform the following plant-specific calculations in order to confirm that the ferritic portions of the vessels or piping within the scope of the TR will be acceptable for service throughout the licensed lives of their plants (40 years if the normal licensing basis plant life is used or 60 years if the facility is expected to be approved for extension of the operating license):

1. Calculate the minimum acceptable wall thinning thickness for the ferritic vessel or piping that will adjoin to the MNSA repair or half-nozzle replacement.

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1 A significant number of licensees in the industry use 80 percent as the design basis for the amount of time at normal power operations. Use of this in the NRC's independent calculation of the overall corrosion rate for general or crevice-type corrosion is based on this time.

2. Calculate the overall general corrosion rate for the ferritic materials based on the calculational methods in the TR using the general corrosion rates listed in the TR for normal operations, startup conditions (including hot standby conditions), and cold shutdown conditions, and the respective plant-specific times (in-percentage of total plant life) at each of the operating modes.

3. Track the time at cold shutdown conditions to determine whether this time exceeds the assumptions made in the analysis. If these assumptions are exceeded, the licensees shall provide a revised analysis to the NRC, and provide a discussion on whether volumetric inspection of the area is required.

4. Calculate the amount of general corrosion-based thinning for the vessels or piping over the life of the plant, as based on the overall general corrosion rate calculated in Step 2 and the thickness of the ferritic vessel or piping that will adjoin to the MNSA repair or half-nozzle replacement.

5. Determine whether the vessel or piping is acceptable over the remaining life of the plant by comparing the worst case remaining wall thickness to the minimum acceptable wall thickness for the vessel or pipe.

Plant-specific engineering evaluations that have been calculated in accordance with these methods and that demonstrate that the ferritic materials will not be thinned by general corrosion to a size less than the minimum allowable wall thickness for the component are sufficient to satisfy the acceptability by analysis provisions of Section XI for defects induced by general corrosion or crevice corrosion.

3.2 Fatigue Crack Growth Evaluation (Including Supporting Calculation Report CN-CI-02-71, Revision 01)

The WOG's MNSA and the half-nozzle repair technique for small-bore nozzle repairs in hot-leg piping, pressurizer lower head instrument nozzle, pressurizer lower head heater sleeve, and pressurizer lower shells relocates the pressure boundary from the internal surface to the external surface while leaving the flaw in the internal J-groove weld and/or nozzle. To justify not removing the flaw, the WOG performed a flaw evaluation similar to the flaw evaluation procedures of Appendix A to Section XI of the ASME Code to demonstrate the structural integrity of the pressure boundary for the life of the plant (40 years).

As stated in Section 3.3 of WCAP-15973, Revision 01, a detailed evaluation of the fatigue crack growth analysis is provided in Calculation Report CN-CI-02-71, Revision 01. A typical flaw evaluation requires determination of the initial flaw size, the applied stress intensity factor ($K_{applied}$) values, fatigue crack growth, and stability of the final crack size. These elements have been revised significantly in Calculation Report CN-CI-02-71, Revision 01, which was transmitted to the NRC on May 20, 2004, to reflect (1) the responses to the staff's requests for additional information (RAI) as addressed in a letter dated October 6, 2003, (2) the inclusion of in-surges in heatup and cooldown transients, and (3) additional modifications in the flaw evaluation methodology initiated by the WOG and the licensee after submitting Revision 00 to Calculation Report CN-CI-02-71. Therefore, the staff's discussion focuses on information in

Calculation Report CN-CI-02-71, Revision 01, and the WOG's response to the staff's RAI regarding this revision, as addressed in a letter dated August 11, 2004. Calculation Report CN-CI-02-71, Revision 00, and the WOG's response to the staff's RAI regarding it will only be addressed when necessary. The technical elements of the flaw evaluation are evaluated by the staff in the following sections.

3.2.1 Initial Flaw Size

The initial flaw is assumed to be a double-sided crack that has propagated through the J-groove weld and touches the carbon steel material that comprises the pressure boundary. The staff examined Calculation Report CN-CI-02-71, Revision 01, initial crack size calculations for the above-mentioned four components and verified that each initial flaw size represents the radial cross section of the J-groove weld (the worst possible radial crack that could exist in the weld). This approach of characterizing a leaked flaw based on the worst assumption is consistent with those in approved applications of similar nature and has become standard industry practice now. Licensees seeking to reference this TR for future licensing applications need to demonstrate that the geometry of the leaking penetration is bounded by the corresponding penetration reported in Calculation Report CN-CI-02-71, Revision 01.

3.2.2 Applied Stress Intensity Factor Values

For a flaw subjected to fatigue crack growth or any type of stress-corrosion cracking (SCC), the final crack size is needed for determining the operating time for the unit with the flawed component. Since the crack growth equation is a function of the $K_{applied}$ value, selecting the appropriate $K_{applied}$ formula in the calculation is important in the crack growth evaluation. In this application, the WOG used the Raju-Newman formulation documented in NASA Technical Memorandum 85793, "Stress-Intensity Factor Equations for Cracks in Three-Dimensional Finite Bodies Subjected to Tension and Bending Loads." One of the staff's RAIs concerns the applicability of the Raju-Newman $K_{applied}$ solution to the current application, considering the differences between the Raju-Newman model and the current model regarding relative hole size and crack geometry. The WOG replied in its October 6, 2003, response that the subject geometries are within the applicability range of the Raju-Newman $K_{applied}$ solution for crack depth to length ratios of 0.2 to 2.0 and for crack depth to plate thickness ratios of less than 0.8. Actually, four applicability criteria are associated with this Raju-Newman solution. The staff examined the other two applicability criteria that the WOG did not address and found that the subject geometries satisfy the limit of less than 0.5 for the ratio of the extended hole size (hole radius + crack length) to the component length, but does not satisfy the lower limit of 0.5 for the ratio of the hole radius to the component thickness. Physically, this means that the subject geometries have more material ahead of the crack front than that of the Raju-Newman model, and therefore using the Raju-Newman solution is conservative in this application.

Revision 01 to Calculation Report CN-CI-02-71 reveals that the calculated $K_{applied}$ values at the final flaw sizes for the four components differ significantly from their corresponding values in Revision 00. According to the August 11, 2004, response to the staff's RAI, the WOG attributed three factors for this change: (1) the use of a realistic heat transfer coefficient, instead of infinity, in the thermal analysis, (2) the use of a stress distribution postprocessing methodology based on full three dimensional finite element calculations, instead of the peak

stress value, and (3) the use of one crack model for instrument nozzles and one for heater sleeves, instead of one bounding model for both types of penetrations. These changes are justified because these actions simply take excessive conservatism out from the model and make the revised model more realistic. All three changes have the effect of reducing the calculated $K_{applied}$ values.

3.2.3 Fatigue Crack Growth

Fatigue crack growth of the flaw is calculated over a plant life of 40 years and is based on transients and cycles specified in design specifications for a typical CE plant for normal (Level A), upset (Level B), emergency (Level C), and faulted (Level D) conditions. Calculation Report CN-CI-02-71, Revision 01, further combines similar transients and eliminates relatively insignificant transients to simplify the fatigue crack growth calculation. The staff considers this simplification reasonable because all important transients such as heatup/cooldown, leak tests, and operating basis earthquake for hot legs have been captured. Turbine/reactor trips, which were included in Revision 00 to Calculation Report CN-CI-02-71 were not considered in Revision 01 because the calculations associated with Revision 00 showed only minor contribution from these transients. Hence, fatigue crack growth of the assumed flaw documented in Revision 01 is based on 500 cycles of a combined transient composed of heatup, cooldown, and leak test. The staff accepts the current transient and cycle selection since (1) inclusion of in-surges in the heatup and cooldown transients, which makes the transients more severe than those of Revision 00, represents a more realistic plant operation, and (2) the 500 heatup, cooldown, and test cycles are conservative for a 40-year operation.

Figure 6-2 (a) of Calculation Report CN-CI-02-71, Revision 01 depicts three curves: (1) the heatup curve (100EF/hr) with an in-surge, (2) the cooldown curve (100EF/hr) with two in-surges, and (3) the bi-rate (200EF/hr and 75EF/hr) cooldown curve. The first two curves are for the fatigue crack growth calculation, and the last curve in addition to the cooldown curve with the large in-surge are considered for the stability analysis of the final flaw. The pressure of these transients is based on the pressurizer saturated pressure plus 200 psi ($P_{saturated}$ + 200 psi). These generic transients are representative, but may not be bounding. Therefore, applicants who use this TR for future licensing purposes need to demonstrate that their plant-specific pressure and temperature profiles in the pressurizer water space for the limiting curves (cooldown curves) do not exceed the analyzed profiles shown in Figure 6-2 (a) of Calculation Report CN-CI-02-71, Revision 01.

The fatigue crack growth rate used in the calculations is Figure A-4300-2 of Section XI of the 1992 Edition of the ASME Code. This curve applies to carbon and low alloy ferritic steels exposed to a water environment and is considered by the staff to be appropriate for this application. Using the ASME fatigue curve and the calculated $K_{applied}$ value for the assumed initial crack geometry, the crack growth rate, and subsequently the crack growth for the first cycle can be determined. This crack growth was added to the assumed initial crack geometry to arrive at a revised crack geometry for the next round of calculation of $K_{applied}$, crack growth, and the revised crack geometry. This process is repeated cycle after cycle until all transient cycles have been exhausted. The revised crack geometry at the end of the last transient cycle is the final crack geometry.

3.2.4 Final Crack Stability Evaluation

The final step in Calculation Report CN-CI-02-71, Revision 01, consists of a flaw evaluation involving the calculation of the driving force and fracture resistance for the final flaw size. When linear elastic fracture mechanics (LEFM) is applicable, the driving force is the $K_{applied}$ and the fracture resistance is the plain strain fracture toughness (K_{Ic}) and the crack arrest fracture toughness (K_{Ia}). When elastic-plastic fracture mechanics (EPFM) is applicable, the driving force is $J_{applied}$ and its slope $\partial J_{applied} / \partial a$, and the fracture resistance is $J_{0.1}$ of the J-R curve ($J_{material}$) at a crack extension of 0.1 inch and the slope $\partial J_{material} / \partial a$ at the intersection of $J_{applied}$ and $J_{material}$. The crack stability evaluation examines the stability of a crack using either the LEFM criteria specified in IWB-3612 of Section XI of the ASME Code or the EPFM criteria specified in Regulatory Guide (RG) 1.161, "Evaluation of Reactor Pressure Vessels with Charpy Upper-Shelf Energy Less than 50 ft-lb," and Appendix C to Section XI of the ASME Code. The LEFM methodology, as described in Report CN-CI-02-71, Revision 01, is in accordance with Appendix A to Section XI of the ASME Code, and is therefore acceptable to the staff. However, the staff has concerns with the proposed EPFM methodology in two areas.

First, the WOG proposed to use a structural factor of 3 on $J_{applied}$ for the EPFM analysis. The staff believes that for current applications (flaws being identified through leaking), it is more appropriate to use the structural factors for detected flaws such as those specified for the EPFM analysis for piping, as appeared in Appendix C to Section XI of the ASME Code. Appendix C specifies 2.7 and 2.3 as structural factors for membrane and bending stresses for piping with detected flaws under the fracture modes of ductile fracture and plastic collapse. This is equivalent to structural factors of 7.29 and 5.29 on $J_{applied}$. This staff concern prompted the WOG to provide a sensitivity analysis in the August 11, 2004, response, using structural factors up to 9.0 in the crack stability evaluation. The results of the sensitivity analysis plotted in Figures 4 and 5 of the response demonstrate that the RG 1.161 criteria of $J_{applied} < J_{0.1}$ and $\partial J_{applied} / \partial a < \partial J_{material} / \partial a$ at $J_{applied} = J_{material}$ are satisfied for both the pressurizer lower shell and the pressurizer lower head heater sleeves, even when a structural factor of 9 on $J_{applied}$ is used.

The second staff concern is that the proposed methodology did not apply a margin factor of 0.749 to the J-R curve as required by RG 1.161. This is not appropriate. However, the staff's independent assessment indicates that after reducing the J-R curves of Figures 4 and 5 to 0.749 of their presented values, RG 1.161 criteria are still met.

Therefore, the calculated values using the EPFM methodology in Calculation Report CN-CI-02-71, Revision 01, meet the RG 1.161 criteria based on the WOG's sensitivity analysis, and the staff's independent assessment using a structural factor of 7.29 on $J_{applied}$ and a material margin factor of 0.749 on $J_{material}$. Licensees may use these bounding values when referencing this TR. However, if the plant-specific application is not bounded by the analysis in Calculation Report CN-CI-02-71, Revision 01, the EPFM methodology may only be used for conducting the plant-specific analysis if adjusted using a structural factor of 7.29 on $J_{applied}$ and a material margin factor of 0.749 on $J_{material}$.

In summary, the EPFM results for pressurizer lower shell and pressurizer lower head heater sleeves, which are documented in the WOG's August 11, 2004, response, are acceptable because they meet the RG 1.161 criteria with a structural factor that is equivalent to that used

in Appendix C to Section XI of the ASME Code. Further, the LEFM results tabulated in Tables 2-2, 2-4, 2-6, and 2-8 of Calculation Report CN-CI-02-71, Revision 01, for the hot-leg piping, pressurizer lower head instrument nozzles, pressurizer lower head heater sleeves, and pressurizer lower shell are also acceptable because they meet ASME Code specified criteria with additional margins. Based on the above evaluation, the staff has determined that the crack can be left in the J-groove weld at small-bore locations in the pressurizer and hot-leg piping for a plant life of 40 years.

For licensees who plan to use this TR for future licensing purposes need to demonstrate the following:

1. The geometry of the leaking penetration is bounded by the corresponding penetration reported in Calculation Report CN-CI-02-71, Revision 01.

2. The plant-specific pressure and temperature profiles in the pressurizer water space for the limiting curves (cooldown curves) do not exceed the analyzed profiles shown in Figure 6.2 (a) of Calculation Report CN-CI-02-71, Revision 01.

3. The plant-specific Charpy upper-shelf energy (USE) data showing a USE value of at least 70 ft-lb to bound the USE value used in the analysis. If the plant-specific Charpy USE data does not exist and the licensee plans to use Charpy USE data from other plants' pressurizers and hot-leg piping, then justification (e.g., based on statistical or lower bound analysis) has to be provided.

If the plant-specific application is not bounded by the analysis in Calculation Report CN-CI-02-71, Revision 01, the EPFM methodology may be used if adjusted using a structural factor of 7.29 on $J_{applied}$ and a material margin factor of 0.749 on $J_{material}$.

3.3 Stress Corrosion Cracking (WCAP-15973-P, Revision 01)

In Conclusion 4 of WCAP-15973-P, Revision 01, the WOG concluded that growth of existing flaws into the ferritic portions of the vessels or piping by stress corrosion was not plausible. The WOG's analysis for supporting this conclusion is provided in Section 3.6 of the TR. In this section, the WOG used the following arguments as its bases for concluding that there is a low probability for growing the existing cracks in the original weld metal and/or nozzle by stress corrosion into the ferritic material:

- During normal operations of the RCS in CE-designed reactors, hydrogen overpressure in the RCS significantly reduces the impurity levels of dissolved oxygen to a concentration less than 10 ppb. At these levels, the electro-chemical potential of the coolant is significantly less than required to grow a existing crack by stress corrosion.

- Even if high oxygen concentrations exist in the crevice during the initial stages of normal operations, the oxygen levels will quickly be reduced as a result of iron oxide formation on the surfaces of the ferritic steel. Since the oxygen levels in the bulk-coolant are typically less than 10 ppb during normal operations, there is no mechanism to replenish oxygen in the crevice region, and as a result the low-oxygen condition in the crevice

region will quickly be re-established. Thus, the potential to grow the existing cracks by a stress corrosion mechanism will be low.

- Other contaminants (copper ions, sulfates, halides, etc.) that could increase the potential for cracks to grow by stress corrosion are also maintained at extremely low concentrations during normal operations.

The staff typically uses !200 Mev as the threshold potential for initiating and growing cracks by stress corrosion. At chemical potentials above this value, the staff considers initiation and growth of cracks by stress corrosion to be plausible. When the chemical potential of the reactor coolant is controlled to magnitudes below this value, the staff considers the potential for cracks to initiate and grow by stress corrosion to be significantly reduced.

At a typical PWR, control of contaminants that could lead to chemical potentials above !200 MeV is accomplished by the combined efforts of the plant operators and chemistry personnel. CE-designed reactors do not have any copper alloys in their RCS, therefore incursion of copper ion contaminants is typically not an issue for CE-designed reactors. In addition, licensees maintain the RCS chemistry by use of the chemical and volume control system as the method for controlling oxygen, halide and sulfate contaminants to low levels. This includes the use of ion exchangers to purify the reactor coolant. Plant chemistry procedures require plant chemistry personnel to monitor the contaminant levels of the RCS at regular daily intervals. Implementation of design changes to better ion exchange resins and improve chemical monitoring equipment have enabled licensees to control the levels of dissolved oxygen to concentrations less than 10 ppb, and halide and sulfate contaminants to concentrations well below the maximum acceptable levels referred to in the Electric Power Research Institute (EPRI) PWR Primary Water Chemistry Guidelines (i.e., well below 150 ppb). Licensees owning CE-designed plants maintain a significant hydrogen overpressure on their RCS. These practices allow the licensees for these facilities to maintain the electro-chemical potential of the reactor coolant at levels below !200 Mev. The staff therefore concurs that the probability for growing the existing flaws by stress corrosion is extremely low at these facilities.

In addition, Section 3.6.4 of the TR provides field experience which is consistent with the laboratory observations that SCC into the ferritic portion of the component is not likely to occur at CE plants. For example, in December 2000, an Oconee-1 CRDM nozzle exhibited stress corrosion cracks in the Alloy 82 weld that propagated through the weld and also extended to the Alloy 600 nozzle. However, the crack arrested when it reached the ferritic vessel head material. Another example was the occurrence of PWSCC in the weld between a pressurizer relief valve nozzle and a safe-end at the Japanese plant, Tsuruga-2. The cracking was discovered in the weld metal and buttering, which is a nickel based alloy. However, destructive examination showed that the crack extended to the interface between the weld and low alloy steel nozzle, but did not extend into the low alloy steel. Therefore, current industry experience is consistent with current laboratory observations that SCC into the ferritic portion is not likely to occur.

Licensees seeking to implement MNSA repairs or half-nozzle repairs may use the WOG's stress corrosion assessment as the bases for concluding that existing flaws in the weld metal will not grow by stress corrosion if they conduct appropriate plant chemistry reviews and if they can demonstrate that a sufficient level of hydrogen overpressure has been implemented for the

RCS, and that the oxygen and halide/sulfate concentrations in the reactor coolant have been typically maintained at levels below 10 ppb and 150 ppb, respectively. During the outage in which the half-nozzle or MNSA repairs are scheduled to be implemented, licensees adopting the TR's stress corrosion crack growth arguments will need to review their plant-specific RCS coolant chemistry histories over the last two operating cycles for their plants, and confirm that these conditions have been met over the last two operating cycles. Plant chemistry records are covered under the scope of 10 CFR 50.70 as being items that may be designated for inspection by the NRC.

4.0 CONCLUSIONS AND CONDITIONS

The staff's review of the methods in WCAP-15973-P, Revision 01, indicates that the WOG's methods and analyses in the TR are generally acceptable. Specifically, WCAP-15973-P, Revision 01, accomplishes the following objectives with respect to implementing these repair or replacement methods:

1. Provides an acceptable method for calculating the overall general/crevice corrosion rate for the internal surfaces of the low-alloy or carbon steel materials that will now be exposed to the reactor coolant, and for calculating the amount of time the ferritic portions of the vessel or piping would be acceptable if corrosive wall thinning had occurred,

2. Provides an acceptable method of calculating the thermal-fatigue crack-growth life of existing flaws in the Alloy 600 nozzles and/or Alloy 82/182 weld material into the ferritic portion of the vessels or piping, and

3. Provides acceptable bases and arguments for concluding that unacceptable growth of the existing flaw by stress corrosion into the vessels or piping is improbable.

The staff's conclusions and conditions regarding the WOG's general corrosion assessment, thermal-fatigue crack growth assessment, and stress corrosion cracking growth assessment are provided below in Sections 4.1, 4.2, and 4.3, respectively.

4.1 General Corrosion Assessment

The calculation of the general overall corrosion rate for the ferritic materials is dependent on both the individual general corrosion rates for normal operating, startup (including hot-standby), and coldshutdown conditions provided in Section 2.3.4 of the TR, and on the plant-specific times (in terms of percentage of total plant life) that a respective nuclear plant is estimated to operate in each of these operating modes. When the staff used a time at normal operation of 80 percent, the staff calculated a general overall corrosion rate that was 40 percent higher than the value calculated by the WOG. Therefore, the general overall corrosion rate proposed in Equation 1 of the TR may or may not be conservative, depending on what the plant-specific times at normal operating, startup (including hot standby), and cold shutdown conditions are. Licensees seeking to use the methods of the TR will need to perform the following plant-specific calculations in order to confirm that the ferritic portions of the vessels or piping within the scope of the TR will be acceptable for service throughout the licensed lives of their plants

(40 years if the normal licensing basis plant life is used or 60 years if the facility is expected to be approved for extension of the operating license):

1. Calculate the minimum acceptable wall thinning thickness for the ferritic vessel or piping that will adjoin to the MNSA repair or half-nozzle repair.

2. Calculate the overall general corrosion rate for the ferritic materials based on the calculational methods in the TR, the general corrosion rates listed in the TR for normal operations, startup conditions (including hot standby conditions), and cold shutdown conditions, and the respective plant-specific times (in-percentage of total plant life) at each of the operating modes.

3. Track the time at cold shutdown conditions to determine whether this time does not exceed the assumptions made in the analysis. If these assumptions are exceeded, the licensees shall provide a revised analysis to the NRC, and provide a discussion on whether volumetric inspection of the area is required.

4. Calculate the amount of general corrosion-based thinning for the vessels or piping over the life of the plant, as based on the overall general corrosion rate calculated in Step 2 and the thickness of the ferritic vessel or piping that will adjoin to the MNSA repair or half-nozzle repair.

5. Determine whether the vessel or piping is acceptable over the remaining life of the plant by comparing the worst case remaining wall thickness to the minimum acceptable wall thickness for the vessel or pipe.

Plant-specific engineering evaluations that have been calculated in accordance with these methods and that demonstrate that the ferritic materials will not be thinned by general corrosion to a size less than the minimum allowable wall thickness for the component over the life of the plant (40 years if the normal licensing basis plant life is used or 60 years if the facility is expected to be approved for extension of the operating license) will be sufficient to satisfy the acceptability by analysis provisions of Section XI of the ASME Code for defects induced by general corrosion or crevice corrosion.

4.2 Thermal-Fatigue Crack Growth Assessment

The staff determined that the WOG's methods for calculating the thermal-fatigue repair life of the existing flaws in the original weld metal was consistent with the methods of Appendix A to Section XI of the ASME Code. Licensees seeking to reference this TR for future licensing applications need to demonstrate that:

1. The geometry of the leaking penetration is bounded by the corresponding penetration reported in Calculation Report CN-CI-02-71, Revision 01.

2. The plant-specific pressure and temperature profiles in the pressurizer water space for the limiting curves (cooldown curves) do not exceed the analyzed profiles shown in

Figure 6-2 (a) of Calculation Report CN-CI-02-71, Revision 01, as stated in Section 3.2.3 of this SE.

3. The plant-specific Charpy USE data shows a USE value of at least 70 ft-lb to bound the USE value used in the analysis. If the plant-specific Charpy USE data does not exist and the licensee plans to use Charpy USE data from other plants' pressurizers and hot-leg piping, then justification (e.g., based on statistical or lower bound analysis) has to be provided.

If the plant-specific application is not bounded by the analysis in Calculation Report CN-CI-02-71, Revision 01, the EPFM methodology may be used as adjusted in Section 3.2.4 of this SE, which uses a structural factor of 7.29 on $J_{applied}$ and a material margin factor of 0.749 on $J_{material}$.

Based on the above evaluation, the staff has determined that the crack can be left in the J-groove weld at small-bore locations for a plant life of 40 years. However, if the licensee plans on using this alternative beyond the 40 years and through the license renewal period, the thermal fatigue crack growth analysis shall be re-evaluated to include the extended period, as applicable, and submitted as a time limited aging analysis in their license renewal application as required by 10 CFR 54.21(c)(1).

4.3 Stress Corrosion Crack Growth Assessment

The WOG used water chemistry and contaminant arguments as its bases for concluding that growth of the existing flaws by stress corrosion was not a plausible mechanism. Based on the staff's assessment given in Section 3.3 of this SE, the staff concurs that the probability for growing the existing flaws by stress corrosion into carbon or low alloy steels will be low as long as concentrations of dissolved oxygen, halide, sulfate, or other harmful contaminants is sufficiently controlled at the plants, and as long as hydrogen water chemistry is implemented at the plants. Licensees seeking to implement MNSA repairs or half-nozzle replacements may use the WOG's stress corrosion assessment as the bases for concluding that existing flaws in the weld metal will not grow by stress corrosion if they meet the following conditions:

1. Conduct appropriate plant chemistry reviews and demonstrate that a sufficient level of hydrogen overpressure has been implemented for the RCS, and that the contaminant concentrations in the reactor coolant have been typically maintained at levels below 10 ppb for dissolved oxygen, 150 ppb for halide ions, and 150 ppb for sulfate ions.

2. During the outage in which the half-nozzle or MNSA repairs are scheduled to be implemented, licensees adopting the TR's stress corrosion crack growth arguments will need to review their plant-specific RCS coolant chemistry histories over the last two operating cycles for their plants, and confirm that these conditions have been met over the last two operating cycles.

4.4 Other Considerations

The WOG's general corrosion rates for normal operations, startups, and cold shutdown conditions, as applied in Equation 1 of the TR, are considered by the staff to be acceptable, as long as the existing corrosion data used to determine the bounding rates is applicable. If additional laboratory or field data becomes available that invalidates the TR's general corrosion rate values for normal operations, startups, and cold shutdown conditions, the WOG should send in an addendum to the TR that evaluates the impact of the new data of the corrosion rate values for normal operations, startups, and cold-shutdown conditions, and that provides a new overall general corrosion rate assessment for the ferritic components under assessment.

The WOG's thermal fatigue crack growth analysis is only applicable to the evaluation of a single flaw. Should the WOG desire to extend the scope of its thermal-fatigue crack growth analysis to the analysis of multiple cracks in near proximity to one another, the WOG is requested to submit an appropriate addendum to the TR that provides the new thermal-fatigue crack growth assessment for the multiple flaw orientation.

The scope of WCAP-15973-P, Revision 01, does not address any welding considerations for the MNSA or half-nozzle designs. Licensees seeking to implement half-nozzle replacements or MNSA repairs of their Alloy 600 nozzles will need to assess the welding aspects of the design and may need to submit a relief request to implement the alternatives to the requirements of the ASME Code, Section XI as required by 10 CFR 50.55a.

The staff's review of the corrections to the flaw evaluation, changes in corrosion rate and clarification of the stress corrosion cracking in carbon and low alloy steels to WCAP-15973-P, Revision 01, indicates that the changes in the evaluation and analyses are generally acceptable. The requirements addressed in Section 4.0 of this SE must be addressed, along with the following, when this TR is used as the basis for the corrosion and fatigue crack growth evaluation when implementing a half-nozzle or MNSA repair:

1. Licensees using the MNSA repairs as a permanent repair shall provide resolution to the NRC concerns addressed in the NRC letter dated December 8, 2003, from H. Berkow to H. Sepp (ADAMS Accession No. ML033440037) concerning the analysis of the pressure boundary components to which the MNSA is attached, and the augmented inservice inspection program.

2. Currently, half-nozzle and MNSA repairs are considered alternatives to the ASME Code, Section XI. Therefore, licensees proposing to use the half-nozzle and MNSA repairs shall submit the required information contained in WCAP-15973-P, Revision 01, by the conditions of this SE, to the NRC as a relief request in accordance with 10 CFR 50.55a.

Attachment: Resolution of Comments

Principal Contributors: J. Honcharik
C. F. Sheng

Date: January 12, 2005

RESOLUTION OF WOG COMMENTS

ON DRAFT SAFETY EVALUATION FOR TOPICAL REPORT WCAP-15973-P, REVISION 01, "LOW-ALLOY STEEL COMPONENT CORROSION ANALYSIS SUPPORTING SMALL-DIAMETER ALLOY 600/690 NOZZLE REPAIR/REPLACEMENT PROGRAM"

By e-mail dated December 16, 2004, the Westinghouse Owners Group (WOG) suggested some minor editorial changes to the NRC draft safety evaluation (SE) for WCAP-15973-P, Revision 01, "Low-alloy Steel Component Corrosion Analysis Supporting Small-diameter Alloy 600/690 Nozzle Repair/Replacement Program," which was provided to the WOG for their review on November 30, 2004. The following is the staff's resolution of the WOG comments.

WOG Comments:

(1) SE page 1, line 3 states "...SA 508, Grade B" -- this material should be labeled "SA 508, Class 2."

(2) SE page 10, end of line 1 contains a revision bar -- delete this bar.

(3) SE page 10, line 5, correct "resistence" to "resistance."

NRC Action: All these minor editorial comments were fully adopted into the final SE.