May 16, 2008

MEMORANDUM TO: Timothy R. Lupold, Chief
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Division of Engineering
Office of Nuclear Regulatory Research

FROM: Samantha Crane, Materials Engineer ***/RA/ T. Lupold for***
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SUBJECT: SUMMARY OF MEETING BETWEEN THE NUCLEAR REGULATORY COMMISSION (NRC) STAFF, INDUSTRY REPRESENTATIVES, AND ELECTRIC POWER RESEARCH INSTITUTE-MATERIALS RELIABILITY PROJECT (EPRI-MRP) REPRESENTATIVES ON ALLOY 690/52/152 RESEARCH AND AREAS OF POSSIBLE COLLABORATION

On May 1 - 2, 2008 The Nuclear Regulatory Commission (NRC) staff met with representatives of the Electric Power Research Institute (EPRI) Materials Reliability Program (MRP), General Electric (GE) Company, Bechtel Bettis Atomic Power Laboratory, Lockheed Martin Knolls Atomic Power Laboratory, Areva, Westinghouse Electric Company, Massachusetts Institute of Technology, Dominion Engineering Inc., and several utility representatives in a public meeting at NRC headquarters in Rockville, Maryland. A public meeting notice was issued on April 21, 2008 and was posted on the NRC's external (public) web page (ADAMS Accession No. ML081080191). The notice included the meeting agenda, which was also available as a handout at the meeting. A list of meeting attendees is provided as an enclosure to this memorandum.

Summary:
The purpose of the meeting was to discuss the knowledge gaps related to Primary Water Stress Corrosion Cracking (PWSCC) of Alloy 690 and its weld metals, Alloys 52 and 152, to discuss ongoing research in this area, and to discuss the possible collaboration on research to address the identified knowledge gaps. The discussions included an overview of (1) a forthcoming EPRI-MRP Alloy 690 white paper and identified knowledge gaps, (2) NRC and Industry collaborative research objectives, (3) best practices for PWSCC testing, (4) base and weld metal procurement, (5) NRC prioritization of the knowledge gaps, and (6) a review of action items. The presentations, which are enclosed, were made to facilitate discussion.

Review of MRP "A690 White Paper"

Mr. Al Ahluwalia, the Electric Power Research Institute (EPRI) Materials Reliability Program (MRP) Project Manager, gave an overview of the soon to be published MRP-237, "Materials Reliability Program: Resistance of Alloys 690, 152 and 52 to Primary Water Stress Corrosion Cracking." The white paper describes the state of knowledge related to Alloy 690 and its weld metals, Alloy 52 and 152. Out of this white paper, knowledge gaps relating to PWSCC of Alloy 690/52/152 were identified and EPRI/MRP developed a strategic plan to address these areas. It is envisioned that this strategic plan would not be solely an EPRI/MRP research plan, but would be an international industry and regulator agreed upon research plan, in which the participating entities would primarily contribute in-kind research from on-going research programs. The agreed upon strategic plan would identify areas of testing needed and prioritize them by the importance of the research and by the needed timeliness of the research.

Mr. Ahluwalia has contacted several possible collaborators who have shown interest. These entities include: NRC, EPRI-MRP, Spain's UNESA, Rolls Royce, U.S. Naval Reactor Contractors (Bechtel Bettis Atomic Power Laboratory and Knolls Atomic Power Laboratory), Japan's Central Research Institute of Electric Power Industry (CRIEPI), Japan's Institute of Nuclear Safety System (INSS), Tohoku University, Sweden's Ringhals-Vattenfall, VTT Technical Research Centre of Finland, Helsinki University of Technology (HUT), and The International Materials Aging Institute.

The next PWSCC Expert Panel Meeting will be held in Los Angeles on November 12-14, 2008. The meeting will cover A690/52/152 issues and low temperature crack propagation (LTCP). This Alloy 690/52/152 Research Collaboration will be discussed at that meeting.

Research Objectives:

Both EPRI-MRP and NRC discussed their objectives, as they relate to Alloy 690/52/152 research. Mr. Al Ahluwalia discussed the industries objectives, which included the following: investigating the material properties and behavior of Alloys 690/52/152 so that the materials' performance could be translated into inspection intervals; producing sufficient data to generate disposition curves for flaw evaluation; and determining the long term material performance for both operating reactor repairs and new reactor applications.

Ms. Samantha Crane discussed the NRC's objectives, which included the following: conducting independent experiments and analyses to support realistic safety decisions; providing information for identifying and resolving safety issues, making regulatory decisions, and promulgating regulations and guidance; generating data to evaluate safety issues involving current and new designs and technologies; providing a proactive approach to identifying and resolving PWSCC related safety issues; using resources effectively and efficiently; and reducing unnecessary duplication of effort.

"Best Practices" for PWSCC Testing (Base and Weld metals)

Crack Initiation Testing
Dr. Peter Andresen of General Electric Global Research Center began the discussion on crack initiation. He presented some of the challenges with initiation studies as well as the criteria that

would have to be met to have confidence in the data. Dr. Andresen identified many variables that have to be taken into consideration when investigating crack initiation.
Since these materials are fairly resistant to cracking, an accelerant would be needed to make the test times reasonable. Several accelerants were proposed: temperature, cold work, hydrogen fugacity, and reverse straining. Several of the participants had opinions both for and against each accelerant. It was stressed that if an accelerant were used, it would be important to quantitatively accelerate the test and understand by how much the test would be accelerated.

Dr. Andresen also discussed pragmatic initiation tests that are based on plant component data, such as steam generator tubes. The French have some experience with Alloy 600 steam generator tubes and structural components; however, these data are usually a mixture of initiation and crack growth data. The participants discussed the possibility of using Alloy 690 steam generator tube data to inform initiation testing for Alloy 690 structural components. It was suggested that the group look into the possibility of examining pulled steam generator tubes, pressurizer heater sleeves, and reactor head components if they become available.

Considering that materials are rarely completely free of defects or imperfections and current non destructive evaluation techniques do not have the resolution to capture the smallest of crack initiators, the participants discussed the possibility of performing initiation tests that start from flaws, such as hot cracks, weld defects, lack of fusion, ductility dip cracks, voids, and inclusions to determine the time to initiate a crack from a flaw of known size and geometry.

Mr. Glenn White of Dominion Engineering, Inc. made a presentation on the application of PWSCC initiation testing based on Alloy 600/82/182 experience. General Design Criteria 4 (GDC 4) in Appendix A of Part 50 of Title 10 of the Code of Federal Regulations (10 CFR Part 50), in part, states that dynamic effects associated with postulated pipe ruptures in nuclear power units may be excluded from the design basis when analyses reviewed and approved by the Commission demonstrate that the probability of fluid system piping rupture is extremely low under conditions consistent with the design basis for the piping. Mr. White stated that to demonstrate an extremely low probability of rupture, the industry could calculate the probability of rupture of pressure boundary components with input from initiation and crack propagation models. Therefore, initiation testing is necessary to inform the models. According to Mr. White, the industry would also attempt to determine relative improvement factors for Alloy 690/52/152 over Alloy 600/82/182 so that an appropriate timing for the first inspection of components made with these alloys could be established.

While the opinions on the potential benefits of initiation testing were varied, the participants agreed that a task group should be formed to prepare a proposal for comparative research on crack initiation testing.

Crack Propagation Testing
Dr. Bogdan Alexandreanu of Argonne National Laboratory started the conversation on crack propagation testing. He and Dr. Stephen Bruemmer of Pacific Northwest National Laboratory agreed that many of the labs involved have established their own effective approach for Stess Corrosion Cracking crack-growth testing. These approaches are generally based on the same concepts, but each is executed in a somewhat different way. They concluded that a detailed procedural "best practices" document is not necessary, and may even be counterproductive because it may limit creativity in determining the upper limit of an alloy’s SCC response. However, they agreed that proper control of the water environment and specimen loading is

essential along with the accurate, in-situ measurement of crack length. They noted that the parameters that need to be precisely managed include temperature, water chemistry and the stress intensity (K) for an
instrumented (by direct current potential drop) compact tension specimen in a recirculating water autoclave.

Dr. Bogdan Alexandreanu went on to say that the standards for a successful test include: continuous or nearly continuous SCC (typically intergranular) engagement across a relatively straight crack front and sufficient stress corrosion crack advance for an accurate measurement of crack growth rates. All of these aspects must be accomplished within the limits of linear elastic fracture mechanics (LEFM) validity criteria. The preferred approach is to begin with a transgranular fatigue precrack produced in air or the environment that is then coaxed into an SCC crack. The procedure – generally referred to as "transitioning" – has been best accomplished by a loading routine consisting of decreasing frequency and increasing load ratio, first promoting corrosion fatigue and then SCC. Stress corrosion response should be evaluated under constant stress intensity (K) conditions, however constant load conditions are adequate when the change in K is small during the observation period. The actual cyclic loading parameters employed vary among laboratories as do their ways of reporting the data. A single approach may not yield a successful test for different materials and test environments, and effective transitioning of SCC-resistant alloy 690/152/52 has been limited. Dr. Alexandreanu concluded that an attempt to standardize a specific method at this time would be counterproductive.

Dr. Alexandreanu recommended that crack-growth tests should include a high frequency precracking stage in the environment followed by corrosion fatigue steps at lower frequencies. Response data from the precracking stage can be used as an early indicator of the test validity by confirming a known behavior (fatigue response) and serve as a baseline for the corrosion fatigue data. It is anticipated that multiple transitioning stages will often be required to asses the PWSCC resistance of Alloy 690/152/52 materials. These steps will also generate additional corrosion fatigue data for materials comparisons. Dr. Alexandreanu stated that at a minimum, any test – even when effective transitioning to SCC has not occurred – should produce a set of otherwise very useful fatigue and corrosion fatigue data plus an indication of SCC resistance at specific K conditions. He believes that test results should include plots of crack length versus time documenting response during individual precracking, transitioning and constant K/load stages along with a summary of data in a table. This way, a database of conditions/outcomes can be created, which would lead to an improved understanding of SCC transitioning techniques for these alloys.

Dr. Peter Andresen provided a summary of the Alloy 182 Round Robin performed by members of the International Cooperative Group on Environmentally Assisted Cracking (ICG-EAC). Several Alloy 182 samples were distributed to 14 labs for testing. The labs were to follow a set of guidelines for SCC testing. The investigators used variations on the recommended methods for pre-cracking and SCC transitioning; however, several of the labs were in good agreement and obtained 100% intergranular (IG) engagement. Dr. Andresen used the results of the round robin to stress the importance of certain criteria and features of a good SCC test. These included fatigue pre-cracking to obtain full IG engagement, and straight crack fronts.

The public meeting participants discussed the possibility of setting minimum system requirements to ensure the production of high quality PWSCC lab test results. This would be

especially helpful for universities that may not have the institutional knowledge on this type of testing. Data reporting formats were discussed to enhance comparisons with other test data. The prospect of modifying an ASTM standard was raised; however, some of the participants believe that is unlikely due to prior efforts on this subject. Dr. Denise Paraventi of Bettis raised a counter argument to the minimum systems requirement. Bettis has produced data from bolt loaded samples that are equivalent to the results from Argonne National Laboratory and GE on similar samples. This data should not be thrown out because it does not meet the minimum system requirements that are being proposed, such as providing a continuous plot of crack length versus time. It can be very useful for screening purposes and to focus testing on conditions with high PWSCC susceptibility. She agreed that when forming disposition curves, it is important to have well characterized data; however, data should not be ignored or considered invalid if they do not meet specific requirements.

The group agreed that a document on minimum system requirements and reporting criteria should be created. Dr. Peter Andresen will create a straw man with the help of Dr. Bogdan Alexandreanu and Dr. Stephen Brummer that will be circulated at the next Expert Panel Meeting in November.

Base Metal Procurement for Initiation & Propagation Testing

Mr. Ahulwalia of EPRI-MRP has been in contact with ATI Allvac, a Ni-base alloy manufacturer, who has offered to give EPRI Alloy 690 for testing. They have agreed to give EPRI a 6.9 inch diameter bar of Alloy 690 weighing 300 pounds. In the future it may possible to acquire some Alloy 690 plate as well. In addition to commercially available heats, they may be willing to make special batch heats as small as 300 pounds. As part of the collaborative research program, these materials would be available to NRC and other participants as well. In addition, Mr. Ahluwalia is trying to get materials from foreign suppliers such as Mitsubishi Heavy Industries. Dr. Ron Ballinger of MIT cautioned on the use of small batch heats since there will be a greater number of variables to consider, and that these small heats may not be representative of field materials.

The group agreed that product form will be important to testing. It was suggested that the program include actual Control Rod Drive Mechanism (CRDM) material and not just bar and plate. It will also be important to investigate heat to heat variability. It was suggested that the group collaborate with a purchaser ordering large amounts of material so that we can get a bulk price on material and get multiple heats to analyze heat to heat variability.

Mr. Les Spain of Dominion Generation stressed the importance of investigating the actual heats of base metal and weld wire, as well as the forms that are being used in the plant. He commented that the plants have well documented fabrication records for the replacement components in the plant. He suggested we take an inventory of these materials and obtain the same materials from the vendors, such as Valinox, Sumitomo, and Sandvik.

Weld Metal Procurement for Initiation & Propagation Testing

Mr. Steve McCracken of EPRI began the discussion on weld metal procurement with a presentation on the EPRI Repair and Replacement Application Center (RRAC) Alloy 52 Weldability Program and the EPRI Advanced Nuclear Technology New Plant Welding Best Practices. The goals of these two programs are to develop a standardized method for

evaluating/measuring susceptibility of weld metal to solidification, liquation, and ductility-dip cracking; build a matrix of filler material chemistry with a crack susceptibility index number; identify welding and fabrication practices that minimize potential for premature failure and reduce susceptibility to known degradation mechanisms; and to disseminate these best practices to the industry for implementation in new plant construction.

Mr. Eric Reichelt of NRC's Office of New Reactors stressed the importance of having a best practice document that was focused on not only reducing residual stress, but also on reducing repairs and grinding, and setting cleanliness standards.

It was suggested that the group get together with RRAC and look into cutting compact tension specimens from their welds. RRAC can build welds and document all of the welding procedures and inputs so that the group can have well documented welds. It would also be useful if RRAC could give the group a list of conditions that lead to the worst conditions so that we could focus our testing.

The main areas of interest for weld testing focused on looking at crack growth rates in the dilution layers between either Alloy 52, or 152, and lower Cr content alloys such as Alloys 600, 82, 182, stainless steels and low alloy steel. There was also interest in starting cracks from weld defects such as hot cracks and investigating crack growth rates through the weld metals.

Mr. George Young of Lockheed Martin and Mr. Dave Waskey of Areva cautioned the group on being too narrowly focused and discussed the varied forms of high Cr content weld metals: 52, 52M (old and new), 52MSS, and 52I. It would be helpful to know which materials are being used in the plants and to contact suppliers such as Special Metals, Sandvik, and Thyssen to get the same weld rod that is being used in the plant.

NRC Prioritization of the Knowledge Gaps

Ms. Samantha Crane of NRC's Office of Nuclear Regulatory Research presented the NRC's prioritization and ranking of the knowledge gaps identified in MRP-237, "Materials Reliability Program: Resistance of Alloys 690, 152 and 52 to Primary Water Stress Corrosion Cracking." The NRC prioritization was based on importance for addressing safety and/or regulatory issues. The rankings are an averaged ranking based on input from 9 NRC staff and contractors. The results of this ranking, as well as the research that the NRC has planned to address each gap are summarized in the enclosed presentation.

Action Items

ACTION	LEAD
November 12-14 Expert Panel Meeting in Los Angeles	A. Ahluwalia
Form Task Group to discuss initiation testing	P. Andresen
Draft best practices for crack growth rate testing	Lead: P. Andresen Review: S. Bruemmer and B. Alexandreanu
Knowledge gaps ranking by EPRI-MRP (after 5/19 Meeting)	A. Ahluwalia

Inventory replacement material (May TAG Meeting)	L. Spain
Contact S. Keizer from Special Metals regarding weld metal compositions	D. Waskey
Determine which international distributers of weld wires are being used	A. Ahluwalia
Find White Paper that specifies 24% Cr for PWSCC resistance	T. Lupold
Send crack growth rate specimen geometries to RRAC	P. Andresen
Send information on welding concerns and conditions that should be tested to P. Andresen, S. Bruemmer, and B. Alexandreanu	S. McCracken
ACTION	LEAD
Extend date on Ni-based Alloy testing Addendum to the NRC-EPRI Memorandum of Understanding	R. Tregoning
Contact other potential collaborators	A. Ahluwalia, R. Tregoning
Contact EPRI Steam Generator Management Program to get additional Alloy 690 information of interest	A. Ahluwalia
Check for additional Alloy 152 weld wire of the higher susceptibility heat that was tested at Argonne National Laboratory	B. Alexandreanu
Contact international regulatory bodies for interest in collaboration	R. Tregoning

Enclosures:
As stated (15)

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As stated (15)

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List of Attendees

Name	Affiliation	Name	Affiliation
Jeff Poehler	NRC	Chuck Marks	Dominion Engineering, Inc.
Eric Reichelt	NRC	John Wilson	Exelon
Jay Collins	NRC	Leslie Spain	Dominion Generation
Ken Karwoski	NRC	Steve McCracken	EPRI
John Tsao	NRC	Kyle Amberge	PSEG Nuclear LLC
Keith Hoffman	NRC	Denise Paraventi	Bechtel Bettis, Inc.
Carol Moyer	NRC	Richard Jacko	Westinghouse Electric
Bob Hardies	NRC	George Young	Lockheed Martin
Tim Lupold	NRC	Chris Cruz	Duke Energy
Robert Tregoning	NRC	Dave Waskey	Areva
Samantha Crane	NRC	Jamie GoBell	Entergy
Stephen Bruemmer	PNNL	Peter Andresen	GE Global Research Center
Bogdan Alexandreanu	ANL	Kawaljit Ahluwalia	EPRI
		Ronald Ballinger	MIT/Exponent
		Glenn White	Dominion Engineering, Inc.