February 9, 2012

MEMORANDUM TO: Aladar A. Csontos, Chief
Component Integrity Branch
Division of Engineering
Office of Nuclear Regulatory Research

FROM: Howard J. Rathbun, Mechanical Engineer ***/RA/***
Component Integrity Branch
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SUBJECT: SUMMARY OF CATEGORY 2 PUBLIC MEETING BETWEEN NUCLEAR REGULATORY COMMISSION STAFF AND REPRESENTATIVES OF THE NUCLEAR POWER INDUSTRY REGARDING PWR MATERIALS RELIABILITY AND WELD REPAIR RESEARCH

On January 24-26, 2012, the Nuclear Regulatory Commission (NRC) Office of Nuclear Regulatory Research (RES) staff hosted a Category 2 Public Meeting on PWR materials reliability and weld repair research with 38 representatives from RES, the Office of Nuclear Reactor Regulation (NRR), RES contractors, and the nuclear power industry to include EPRI, AREVA, Westinghouse, General Electric, Structural Integrity Associates, Exelon, Entergy, Dominion Engineering Incorporated, Hill Engineering, Wolf Creek Nuclear Operating Company, First Energy Nuclear Operating Company, Oak Ridge National Laboratory, and Southern Nuclear Company. The following provides a summary of items presented during the meeting arranged chronologically and by topic. Comments and questions identified by NRC staff, its contractors, and industry representatives are listed with each topic.

<u>Tuesday, January 24, 2012</u>

Mr. Dan Patten of FENOC provided a summary of the EPRI Welding Repair and Technology Center (WRTC), including its strategic plan, program life cycle, advisory structure, key activities, guidelines, benchmarking, nuclear welding program review, and the Repair Welding Handbook.

Mr. Greg Frederick of EPRI discussed the WRTC roadmap, development of new technologies for irradiated material, underwater laser welding, the fiber laser welding cell at EPRI, modeling simulation of the laser welding process, and friction stir welding. In addition, Mr. Frederick presented information on alloy 52M welding issues, including weldability, crack susceptibility,

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and narrow process controls. Mr. Frederick discussed development of a new primary water stress corrosion cracking (PWSCC) resistant alloy given hot cracking and ductility dip cracking problems with alloy 52 and 52M and computer modeling of these new alloys with Ni-30%Cr and other constituents.

Comments:

- Staff's contractors noted that weld modeling and measurement of laser, electron beam, and narrow gap welding have been established, and that these methods generally lead to reduced WRS and distortions since less heat is input to the component and often the weld shrinkage area is smaller due to less weld material being deposited. Friction stir weld models are not well developed but it appears that neglecting the metal stirring (and just modeling the reduced heating and cooling) may provide a starting point.

Mr. Jon Tatman of EPRI provided an overview of EPRI WRTC involvement in several ASME Code Cases, including N-740-2 and N-740-3 (structural weld overlays), N-754 (optimized weld overlays), N-766 (nickel alloy inlay/onlay), N-803 (ambient temperature underwater laser beam welding for PWSCC mitigation and repair), a new undesignated code case for excavate and weld repair, N-638-6 (ambient temperature temper bead rules), N-786 (full sleeve welded patch split-sleeve 360^{o} for moderate energy cases), N-789 (structural pad – full sleeve or welded patch not 360^{o}), and N-818 (full penetration butt welds in lieu of weld repair).

Comments:

- Regarding inlay/onlay (Code Case N766), this topic has been studied previously by staff's contractors where the issues with high ID weld residual stresses and ‘balloon’ shaped crack growth have been demonstrated. Regarding the sleeve repair weld method (Code Case N-786), staff's contractor mentioned that this type of repair has not been studied by NRC to date.

Mr. Francis Ku of Structural Integrity Associates (SIA) discussed an excavation weld repair (EWR) residual stress parametric study, including 2-D results, planned 3-D simulations, excavation on OD up to 50% through thickness and then refill with crack resistant alloy. The typical DM weld profile would include a 50% ID repair weld. Mr. Ku discussed changes in axial and hoop stresses due to the EWR process.

Comments:

- Staff's contractors noted that, in a scenario where a detected crack is left in service and is covered up by weld metal (A52/152) that is more corrosion resistant than A82/182, a PWSCC crack may propagate around the repair. Staff's contractors are concerned about potential lower fracture toughness of the replacement alloy.

Mr. Wei Zhang of Oak Ridge National Laboratory discussed temperature distribution experiments for use in stress predictions, including infrared camera studies, temperature dependent emissivity issues, original surface color issues, thermocouple measurement experiences and consistency between infrared results and finite element analysis results.

<u>Wednesday, January 25, 2012</u>

Mr. John Broussard of Dominion Engineering Incorporated discussed development of a welding residual stress (WRS) modeling handbook, including the original motivation for the WRS finite element validation program, the associated NRC/EPRI Memorandum of Understanding Addendum, WRS FEA mock-up phases I though IV, validations with measurements and modeling, comparison of complimentary measurement techniques, WRS measurements, variability of results provided in FEA analyses, and MRP-287 (involving PWSCC flaw evaluation guideline recommendations and a validation approach based on stress intensity factors at the crack tip).

Mr. Howard Rathbun of NRC Research discussed the WRS validation program findings, including contents of, and upcoming revisions to, a Technical Letter Report for Phase 2a, Technical Letter Report of Phase 4 submitted to NRR for information, consolidated of Technical Letter Reports into a NUREG document in the first quarter of 2012, and an Advisory Committee on Reactor Safeguards briefing tentatively scheduled for fall of 2012. Mr. Rathbun provided a summary of potential future confirmatory research work, including a mini analysis and measurement round-robin on Phase 2b nozzle mock-up, a welding parameter study, contour WRS measurements on Phase 2a mock-up, study of repair welds, vessel penetration nozzles, effects of peening and effects of WRS variability on flaw evaluation.

Comments:

- Industry representatives mentioned the need to thoroughly analyze the Phase 2a data to determine the sources of variability, particularly in the finite element results.
- An industry representative stated that it would be beneficial to compare stress results in the Phase 2a study following application of the main DMW but before the back-chip and re-weld.
- An industry representative mentioned that grinding, scotch paper, and flapper wheels can affect surface conditions of welds, leading to potential PWSCC initiation points.
- Industry representatives, staff, and staff's contractors emphasized the benefit of comparing full DMW 2-D stress contours in lieu of merely focusing on stresses along the centerline of DMW. Staff believes that this will likely require weld deposition and heat treatment modeling of the weld butter.

Mr. Matthew Kerr of NRC Research presented Phase 2a deep hole drilling measurements, the K solution methodology from API 579 (2001), variability in K solutions on elliptical crack 0^{o} and 90^{o} configurations, K solutions based on DHD values for isotropic and kinematic FEA, and Phase 4 data K-solutions calculated by himself and compared to MRP-287 industry flaw evaluation guidelines. Mr. Kerr's results show a comparable variability in WRS solutions and the corresponding K-solutions based on those measurements.

Mr. Paul Crooker of EPRI discussed planned WRS modeling improvement research for 2012-2013, including neutron diffraction measurements of WRS, expansion of the WRS data available by using other material and component samples that are available, and residual stress measurement technique improvements.

Mr. Wei Zhang of Oak Ridge National Laboratory presented information on materials characterization for WRS finite element analyses, including gleeble testing to evaluate the effect of welding on material hardening, phase transformation effects, stainless steel material testing at different temperatures, Digital Image Correlation (DIC) using speckle pattern to determine strain, and a d_o-less method for neutron diffraction measurements.

Comments:

- Regarding development of new material laws for welding that include the effects of dynamic recovery, staff's contractor believes that such a constitutive law, if developed and deemed to be an improvement over the current methods used for WRS modeling, will require development of USER subroutines for use with ABAQUS and ANSYS. This law will require (i) material constants (which could be numerous and expensive to develop) at temperature and (ii) robust solution algorithm and strategy (slow convergence of a non-robust model is not considered practical).

Mr. David Rudland of NRC Research provided an overview of the Extremely Low Probability of Rupture (xLPR) program, including a summary of version 2.0 goals. Mr. Rudland also described aspects of the xLPR program involving WRS and mitigation, including issues encountered in xLPR Version 1 associated with using a 3rd order polynomial fit for WRS, plans to include a better WRS fitting method in Version 2, and improvements planned in Version 2 to address mitigation effects on WRS fields. Mr. Rudland mentioned that Version 2 of xLPR is intended to provide a quantitative solution to the LBB issue, and could be used as a research prioritization tool.

Mr. Francis Ku of SIA discussed WRS FEA efforts and benchmarking, including heat input modeling for “nugget” bead approximation, flow stress approximation using a bi-linear stress-strain curve up to the flow stress which is thereafter perfectly plastic, annealing effects, 2-D and 3-D modeling.

Comments:

- Staff and staff's contractors believe additional clarification on differences between 2-D and 3-D results is needed, including a more detailed explanation of the fundamental basis for differences between these results.
- Staff and staff's contractors noted that SIA appears to use different material stress-strain behavior assumptions for different types of models, and that additional clarification on this topic is needed.
- Staff and staff's contractors believe that partial arc repairs should be considered since most actual repairs are partial arc, and that crack modeling in such fields is needed as well.

Mr. Bud Brust of EMC^2 discussed materials characterization and WRS work in support of xLPR, including material properties developed for WRS modeling from literature and tests, and specimen testing currently being performed on NRC/Battelle pipe test samples.

Comments:

- Staff and staff's contractor believe that a library of material parameters for the mixed (Chaboche) hardening model are needed. At present, NRC has some data for A182/82;

however, more data is needed for A52/152, A508, and stainless steel. Additional toughness data for cracks in weld and fusion zones is needed for the NRC material database.

Mr. Mike Hill of the University of California, Davis, and Hill Engineering provided a summary of contour and slitting strain-relief based WRS measurement techniques, and digital image correlation to supplement the contour method capabilities.

Thursday, January 26, 2012

Mr. Chuck Marks of Dominion Engineering Incorporated presented information on chemical mitigation of PWSCC, including hydrogen optimization for crack growth rate reduction, zinc addition to delay crack initiation, and inclusion of this work into the xLPR program.

Comments:

- Staff and staff's contractors believe additional clarification regarding data comparing crack initiation rate prior to and following zinc addition is needed; specifically, do existing flaws manifest themselves at early onset? If there are no existing flaws, is the initiation time in the presence of zinc addition much longer? Is this effect is taken into account in the presented Weibull distribution?
- Staff noted that the zinc addition data presented appears to originate solely from steam generator tube material. Staff believes that weld-specific data is needed.
- Staff noted that Farley, a plant that has performed on-line zinc addition, has observed indications in Inconel welds. Mr. Marks noted that the Farley indications were in pressurizer welds, as opposed to CRDM welds originating from a heat of material that has seen indications in other plants.

Mr. William Sims of Entergy presented information from EPRI MRP-267 regarding surface stress improvement, including water jet and laser peening in weld areas, accessibility issues that leave surface stress improvement as an only option, advantages of being able to work remotely, inspection relief based on taking credit for peening, and application of peening for bottom mounted nozzles.

Mr. Glenn White of Dominion Engineering Incorporated discussed the technical basis for MRP 267, including Japanese experience on both BWRs and PWRs, underwater fiber laser peening, laser shock peening experience in the aerospace industry, water jet peening, residual stress measurement with x-ray diffraction and progressive electro-polish, depth and magnitude of compressive stresses, effects of peening on shallow cracks in the compression zone, U-bend tests in molten magnesium chloride, and long term sustainability with creep at 450 ^{o}C and cyclic loading and NDE methods, including ultrasonic and Eddy Current. Mr. White mentioned that the peening technical basis document will include calculations that consider the effect of surface stress improvement on the stress profile of the component, and the possibility of pre-existing flaws deeper than the compressive stress zone.

Comments:

- Staff needs clarification regarding applicability of ASME BPV Code Section III stress relief requirements - are surfaces that are peened required to be stress relieved? Staff stated that proactive, asset management based peening may be acceptable under 10 CFR 50.59; additional information will be needed regarding industry plans to gain relief for inspection intervals. Staff needs clarification on what information would be submitted by a licensee wishing to gain inspection relief, and when staff should expect to begin to receive such requests.
- Staff needs additional information regarding process controls for peening, what assurances will be obtained that the desired compressive stress effect is achieved, and as much information as possible that is available from industry experience gained in Japan, including what negative consequences of peening, if any, have been observed in previous operational experience.
- Staff and staff's contractors need additional information regarding peening models and their validation and uncertainties, including crack growth models and experiments if available.
- Staff needs additional information regarding stress distributions in the region of material between peened and un-peened; specifically, do these regions constitute an area of concern for PWSCC initiation? In the event that the original planned surface area extent for peening is not able to be peened (perhaps due to outage time constraints), what concerns are raised for the interface between peened and un-peened areas?
- Staff needs additional information on the possibility of over-peening; specifically, is this possible, and what are the potential consequences?
- Staff needs information regarding comparison of flaw size detectability relative to compressive depth achieved by peening; specifically, how does detectable flaw size compare to compressive depth?
- Staff raised the question: is it required to apply greater magnitude of peening when the original residual stress is high tensile as compared to low tensile. Further, how would such peening effect be verified?
- Staff needs additional clarification regarding the effect of peening over flaws for either surface breaking or non-surface breaking flaws on stress distributions and PWSCC susceptibility.

Enclosures:
1. List of Attendees
2. Presentations
3. Agenda

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DATE	2/9/12	2/9/12

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List of Attendees

Name	Organization
Bud Auvil	SIA
John Broussard	DEI
Bud Brust	EMC^2
Helen Cothron	EPRI
Paul Crooker	EPRI
Aladar Csontos	NRC/RES
Guy DeBoo	Exelon
Robin Dyle	EPRI
Greg Frederick	EPRI
Lee Fredette	Battelle
Richard Gimple	WCNOC
Charles Graves	AREVA
Chris Habura	Bettis
Iain Hamilton	DEI
Robert Hardies	NRC/NRR
Craig Harrington	EPRI
Mike Hill	UC Davis / Hill Engineering
Matthew Kerr	NRC/RES
Doug Killian	AREVA
Francis Ku	SIA
William Mabe	Bettis
Heather Malikowski	Exelon
Chuck Marks	DEI
Bruce Newton	Westinghouse
Daniel Patten	FENOC
Dongxiao Qiao	ORNL
Howard Rathbun	NRC/RES
Rick Reid	EPRI
David Rudland	NRC/RES
William Sims	Entergy
David Smith	University of Bristol, UK
Dick Smith	SIA
Duane Snyder	GE
Zhang Wei	ORNL
Tim Wells	SNC
Glenn White	DEI
George Young	KAPL