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Dear Don:

Subject: Assessment of the NDE conducted on South Texas Project bottom mounted instrumentation nozzles, under JCN J-2614, Task Order No. 7 and TAC No. MB8435.

The work performed for assessing the nondestructive examinations (NDE) conducted on the South Texas Project (STP) bottom mounted instrumentation (BMI) nozzles and reported here was covered by two different NRC programs. The travel and staff time for reviewing the demonstration of NDE technologies for application to the potential problem of leakage of BMI nozzles was covered by RES program JCN Y6882. The travel and staff time to witness the NDE data collection and analysis at STP was covered by JCN J2614 under Task Order No. 7. However, the NDE vendor encountered delays and the time allocated for witnessing the NDE activities split with 9 days under contract J-2614, Task Order No. 7 and 2 days under contract Y6882. This split was agreed to by the contract technical monitors. The review of the STP BMI nozzles final NDE reports was covered by J2614, Task Order No. 7.

Two inservice inspection (ISI) vendors proposed to STP to conduct the NDE inspections on the BMI nozzles. STP staff quickly assembled some mockups and requested that each vendor demonstrate their technologies on the mockups. The technologies being demonstrated were basically the same technologies that each vendor had been using for the inspection of control rod drive mechanisms (CRDMs) but adapted to BMI nozzles. The demonstration was to address the NDE capabilities to detect, locate, characterize and size flaws located on the ID or OD and with either an axial or circumferential orientation. This was to be demonstrated in three phases:

- Phase 1 to be a non-blind demonstrations at the Vendor's facility
- Phase 2 to be monitored blind demonstrations at the Vendor's facility
- Phase 3 to be a (non-blind demonstrations at STP on a full scale mockup

Phase 1 was intended to provide the vendor with known mockups so that they could refine their equipment and procedures using relevant product forms and flaws. Phase 2 was a blind demonstration to allow an objective and unbiased assessment of each NDE technique, procedure and vendor. This includes false calls, flaw detection, flaw sizing and location accuracy. Phase 3 would be a demonstration on a full scale mockup designed to address the

BMI nozzles if the unit has been at operating temperature more than 90 days since the last BMI penetration inspection and the outage is expected to exceed 72 hours. The procedure also requires that a minimum of two BMI thermal shield panels must be removed. Shields #5 and #12 are easiest to remove and are normally removed. Generally 3 of the 12 panels are removed for the inspection and these are selected to be at about 120 degrees to each other in order to provide best inspection coverage. The inspection takes 10-15 minutes to conduct and includes using a flashlight looking for boric acid deposits. A camera is also used to document the examination with 5 pictures being recorded from each portal (where the BMI thermal shield is removed). The BMI nozzles were VT-2 inspected at the outage in November 2002. Then the inspection was repeated at the latest outage and on April 12, 2003 two areas with boric acid deposits were detected. The STP representative noted that the inspection is influenced by which panels are removed. He also noted that for Nozzle #46 the area where the boric acid deposit was located had been thoroughly examined each on inspection. In the case of Nozzle #1, the inspection in April 2003 was better than that from November 2002 because the panels removed provided better access. It needs to be noted that Nozzle #46 had very small leakage, only 3.5 mg could be scraped off the bottom head, while Nozzle #1 had 150 mg removed from the bottom head. The STP representative indicated that there were a number of potential causes for false calls resulting from peeling of the Carboline 4674 surface coating, "cooked" duct tape, visqueen, and leaching from the concrete that ends up running down on to the bottom head (this is probably calcium carbonate).

Overall the boric acid walk down at STP appears to be a good program and it is consistently applied as there is a single person that conducts this examination every time. My only comment is that the procedure calls for at least two of the BMI thermal shields being removed for the inspection but the practice was upgraded to remove at least 3 BMI thermal shields. I would like to see the procedure up graded to reflect this so that if this STP representative is not available for conducting the boric acid walk down, others will know what needs to be done in order to conduct an effective inspection.

Over the course of the next 10 days, a number of inspection related activities took place. This included reviewing all procedures, the demonstration

- of the manually pulled ET bobbin coil nozzle ID test and
- of the 18 coil ET array for inspecting the surface of the J-groove weld,
  along with observation of the data collection and analysis of
- the UT nozzle bore examinations,
- enhanced VT examinations of the J-groove weld crowns
- ET bobbin coil examination of the BMI nozzle ID and
- ET array coil emanation of the J-groove welds.

I did not witness the phased array UT from the RPV outside surface looking for wastage, the ET ID profilometry or the helium gas bubble test. However, in all cases I did review the procedures and the final reports.

Since these demonstrations were conducted on specimens that had flaws, the performed demonstrations served several purposes. They provided useful insights to the types of signals that should be expected during the actual inspection, and they provided insights into the signals that should be expected if planar flaws existed in the BMI nozzle inspection zones. The detection and characterization of the flaws in these demonstration mockups provide reasonable assurance that if planar crack like flaws exist in the STP BMI nozzles, the flaws should be detected and characterized with the techniques being deployed.

Most NDE inspections are conducted on good materials and thus they do not provide any signals of indications. This is also the case for most of the inspections and data that was reviewed. I propose to address this review by focusing on the two nozzles where boric acid had been detected by VT, some comments about indications associated with other nozzles, and some comments about the inspection techniques.

It should be noted that the ultrasonic transducers selected for these inspections were based on the French experience with inspection of some 500 BMI nozzles in French reactors. The scanner was the same one used for conducting inspections in France, and it had the useful feature of automatically collecting calibration data when the transducer exited the BMI nozzle. Thus, a calibration check is performed after each BMI nozzle inspection to insure high quality data.

The ultrasonic inspections consisted of using TOFD, a zero degree focused probe, and a phased array. The phased array is a new technology that is rapidly evolving. The phased array technology was being deployed to detect wastage of the lower head carbon steel. The leakage from nozzles #1 and #46 was extremely small thus, if there was any wastage it was expected to be small. This was a first deployment of this technology and there is a lot of development work that is needed for this application in order to build the case for the amount of wastage that can be reliably detected. No wastage was detected for the nozzles inspected.

The zero degree focused probe was designed to provide a highly focused sound field at the interface between the OD of the nozzle and the J-groove weld. The sound field had a spot size of 1 mm and provided some very useful information about reflectors at this location. Many reflectors were detected in a number of nozzles and their source was not determined. However, it is expected based on my many years experience of characterizing fabrication flaws in reactor pressure vessel steels that these are most likely lack of fusion. The boat samples being removed from nozzles #1 and #46 should provide some evidence of the source. In addition, if there is a crack there is the potential to get a loss of back surface signal as was found in the inspection results on nozzles #1 and #46.

The TOFD technique that was deployed is the same technology that has been used for several years to inspect CRDMs. The only challenge regarding BMI nozzles is the radius of curvature. The TOFD typically uses higher angles such as 60 degrees. For the BMI nozzles this angle needs to be reduced to about 30 degrees because of the ID curvature. The disadvantage of this is that there is a much smaller lateral wave signal and changes in this signal for ID surface breaking defects becomes more subtle. A number of nozzles had indications that were located near the root of the J-groove weld but partially in the nozzle wall. It is thought that this is an artifact from construction where after the initial pass and dye penetrant testing, repairs were made that resulted in gouging the OD of the nozzle. Although this is repaired, the TOFD is sensitive to the change in microstructure and provides a signal at this location. This case has been made but not validated. However, since some nuclear power plants are replacing their upper heads, it will hopefully be a part of the programs to confirm the cause of these signals. Overall the TOFD data was very high quality with good signal-to-noise ratio.

The enhanced VT (EVT) examination was performed with state-of-the-art equipment. The calibration standard used a number of features including 0.0005 inch (125 microns) and 0.001 inch (250 microns) diameter wires. Detection of these wires was strictly related to where and how the lighting was positioned. This VT provided some good information about the grinding and in some cases where grinding nicks were located on the OD of the nozzles. Its use for the detection of cracks is dependent on the crack opening dimension. Cracks with a large crack opening dimension (100 microns) such as those found in BWR core shrouds have been found by EVT. If the degradation in the BMI nozzles is a PWSCC process then the crack opening dimension is probably an order of magnitude smaller, around 10 microns, in which case it is unlikely that EVT would be able to detect it. Based on the other NDE that was performed, the flaws found in nozzles #1 and #46 are axial and would appear to only break the surface over a short length. The helium bubble test also showed the leakage occurring in the crown of the J-groove weld where there are a lot of grinding marks making the identification of a short and tight crack very challenging. The final report of the VT work indicated that there were a number of locations where it appeared that the surface was stained and in others where it was noted that there was a slight amount of metal removed. The boat samples that are being taken may also provide some valuable data on these conditions.

The ET array probe provided some complimentary data on the J-groove weld crown. The challenge is to be able to inspect the blend zone from the BMI nozzle OD as it transitions onto the crown of the J-groove weld. This technique was deployed with a manual manipulator and the demonstrations were designed to inspect the bulk of the J-groove weld and buttering. In order for this technique to effectively inspect the blend zone more development work is needed. This inspection was only conducted on a small number of nozzles and the array was partially destroyed during the last inspection. However, this data did support the position that there were no cracks out into the J-groove weld or buttering but it did not effectively examine the blend zone.

The ET bobbin coil testing was performed on the ID of the nozzle to determine if there were any surface breaking indications. There was no equipment available to conduct an automated scan so this testing was performed by inserting the coil and collecting the data as the coil was removed manually. This was only applied to a few nozzles but it did support the position that there was an ID breaking indication on nozzle #1 and there was an indication on nozzle #46 but that it was not ID surface breaking. This was obviously a very limited set of inspection results but it did provide data that was consistent with other NDE measurements.

ET profilometry was performed on the ID of the repaired BMI nozzles and the only thing found was a slight amount of distortion. The maximum distortion found was 0.032 inches (0.8 mm).

The helium leak test was performed for the first time on BMI nozzles in the U. S. This is not a standard type of test for most nuclear applications but it did provide confirmatory evidence of a through wall leak for nozzle #1. Neither nozzle tested (#1 and #46) provided any leak information when the external helium pressure was at 100 psig. But when it was raised to 150 psig, there were bubbles evident on the ID of the vessel for nozzle #1. It was estimated that there was on bubble per second being leaked.

Nozzle #1

The NDE inspection data on this nozzle indicated that there was one planar type of flaw that extended from above the J-groove weld to the annulus. This was confirmed by TOFD UT data, zero degree UT data, and the helium bubble test. ET bobbin coil data supported the presence of a surface breaking indication on the ID of the nozzle. All of these NDE results were consistent in supporting the location of a flaw in the same location. This is powerful evidence when complimentary NDE techniques provide a similar interpretation. The final test will be the confirmation based on the planned boat sample.

There were two other embedded indications that were detected with the TOFD. They were not surface connected, but STP conservatively assumed that they were PWSCC. These indications are thought to be associated with the original construction as previously discussed. This issue may be resolved based on destructive testing of CRDMs removed from service that exhibit similar responses.

Nozzle #46

The TOFD data indicates that there are two planar indications. One of these extends from above the J-groove weld to the annulus and it can be seen in the zero degree data also. The other appears to be embedded and does not break any surface. This non surface breaking flaw is the one that has been selected for destructive testing and it should provide some very useful insights as to the type of degradation process that is causing it. The ET bobbin coil data was found to provide supportive evidence in that it had responses that there were indications present but they were not nozzle ID surface breaking.

Conclusions

Overall, a program was put in place on a very tight time schedule that has produced high quality NDE inspection results. This began with the development of test specimens containing reasonable flaws and geometries and demonstration of the NDE techniques prior to their deployment. These tests provided assurance that if there were flaws in many locations of the BMI nozzles, they could be detected and characterized. There were a number of new techniques being deployed for the first time and all for the first time on BMI nozzles in the U. S. There are further improvements that need to be achieved in the techniques to quantify their effectiveness and to speed up the inspection process. Ultimately, how good the NDE inspections were is to be in part validated by the planned destructive testing of the boat samples that are in progress of being removed from nozzles #1 and #46.

Very truly yours,

Steven R. Doctor

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cc: BL Grenier
RL Bywater
WC Sifre
DA Jackson

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