UNITED STATES
NUCLEAR REGULATORY COMMISSION
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February 10, 1997

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FROM: Keith R. Wichman, Acting Chief
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Division of Engineering
2/10/97

SUBJECT: Staff Review of Weld Defects in CE Designed Steam Generator Tube Sleeves

During the Prairie Island Unit 1 (PI-1) January 1996 steam generator (SG) tube inspection, 61 eddy current (EC) indications were found in the upper weld region of Combustion Engineering (CE) designed welded tubesheet sleeves. Five pulled sleeve/tube assemblies were examined by CE with oversight by the Electric Power Research Institute. The results were documented in a March 1996 CE report, "Verification of the Structural Integrity of the ABB CENO Steam Generator Welded Sleeve" [Reference 1]. The EC indications were the result of either or both of two weld conditions: circumferentially oriented oxide inclusions or weld suckback on the sleeve outside diameter. CE also documented axially oriented oxide inclusions not detected by the eddy current test inspections (ET). There was no evidence of inservice induced degradation. The weld defects were the result of a change to the sleeve installation process instituted in 1991. The faulty installation process potentially affected sleeves installed during or after 1991 at the following plants: ANO-2, Ginna (the affected steam generators have since been replaced), Kewaunee and Zion-1 and -2.

The staff reviewed References 1-3 that supported PI-1 and Zion-2 operability assessments. The operability assessments were generic and thus the staff review applied to the other similarly affected licensees. However, for completeness of record, the staff reviewed all other licensees' (except for Ginna where the affected steam generators had since been replaced) responses to the two Requests

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+ RO-4-2B

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References

Reference 1: Verification of the Structural Integrity of the ABB CENO Steam Generator Welded Sleeve, Combustion Engineering, Inc., CEN-628-P, proprietary version, Revision 0, March 1996.

Verification of the Structural Integrity of the ABB CENO Steam Generator Welded Sleeve, Combustion Engineering, Inc., CEN-628-NP, nonproprietary version, Revision 0, March 1996.

Reference 2: Letter from Michael D. Wadley (Northern States Power Company) to NRC Document Control Desk, "January 1996 Steam Generator Sleeving Issues Ninety Day Response Letter," dated Jun 27, 1996.

Reference 3: Letter from R. Tuetken (Commonwealth Edison Company) to NRC Document Control Desk, "Response to Request for Additional Information Pertaining to ABB-CE Sleeving Zion Station Units 1 and 2," dated July 8, 1996.

Reference 4: Letter from M.L. Marchi (Wisconsin Public Service Corporation) to NRC Document Control Desk, "Response to Request for Additional Information Pertaining to ABB Combustion Engineering Sleeves," dated July 10, 1996.

Reference 5: Letter from D.C. Mims (Entergy Operations, Inc.) to NRC Document Control Desk, "Additional Information Pertaining to Arkansas Nuclear One, Unit 2 Steam Generator Tube Sleeves," dated November 26, 1996.

Reference 6: Letter from M.L. Marchi (Wisconsin Public Service Corporation) to NRC Document Control Desk, dated September 23, 1996, "Response to NRC Request for Additional Information Related to CE Sleeve Inspection Plans."

Reference 7: Letter from D.C. Mims (Entergy Operations, Inc.) to NRC Document Control Desk, dated November 22, 1996, "Additional Information - Eddy Current Indications in Combustion Engineering Designed Welded Steam Generator Tube Sleeves."

Reference 8: Letter from J.H. Mueller (Commonwealth Edison Company) to NRC Document Control Desk, dated December 23, 1996, "Zion Station Units 1 and 2, Response to Request for Additional Information."

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for Additional Information (RAIs) [References 4-8]. Since safety evaluations on the operability assessments were not required, the staff prepared the attached summary to document the results of its review. The attachment to this memorandum summarizes the staff review of CE's and the licensees' responses to upper weld defects found in CE designed SG tube sleeves during SG tube inservice EC inspections. The staff concludes CE and the affected licensees have taken appropriate steps to ensure adequate integrity of CE designed welded steam generator tube sleeves. We recommend sending a copy of this summary to the licensees and placing a copy in the Public Document Room.

References

Reference 1: Verification of the Structural Integrity of the ABB CENO Steam Generator Welded Sleeve, Combustion Engineering, Inc., CEN-628-P, proprietary version, Revision 0, March 1996.

Verification of the Structural Integrity of the ABB CENO Steam Generator Welded Sleeve, Combustion Engineering, Inc., CEN-628-NP, nonproprietary version, Revision 0, March 1996.

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Reference 6: Letter from M.L. Marchi (Wisconsin Public Service Corporation) to NRC Document Control Desk, dated September 23, 1996, "Response to NRC Request for Additional Information Related to CE Sleeve Inspection Plans."

Reference 7: Letter from D.C. Mims (Entergy Operations, Inc.) to NRC Document Control Desk, dated November 22, 1996, "Additional Information - Eddy Current Indications in Combustion Engineering Designed Welded Steam Generator Tube Sleeves."

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Staff Review of Upper Weld Defects in CE Designed Steam Generator Tube Sleeves

Background

During the Prairie Island Unit 1 (PI-1) January 1996 steam generator (SG) tube inspection, 61 eddy current (EC) indications were found in the upper weld region of Combustion Engineering (CE) designed welded tubesheet sleeves. Discovery of most of the indications was the result of the licensee employing a new, more sensitive EC probe (the Plus Point probe) for its periodic inspection of SG tubes. These indications were characterized as circumferential cracklike indications or volumetric indications. All sleeved tubes with the circumferential cracklike indications were removed from service (four tubes were pulled; seven tubes were plugged). The sleeved tubes with volumetric indications were evaluated for location. Sleeved tubes with volumetric indications located by EC below the centerline of the sleeve weld were removed from service; the remaining sleeved tubes were left in service (one tube was pulled; sixteen tubes were plugged; thirty four tubes were left in service).

The five pulled sleeve/tube assemblies were examined by CE with oversight by the Electric Power Research Institute. The results were documented in a March 1996 CE report, "Verification of the Structural Integrity of the ABB CENO Steam Generator Welded Sleeve" [Reference 1]. The EC indications were the result of either or both of two weld conditions: circumferentially oriented oxide inclusions or weld suckback on the sleeve outside diameter. CE also documented axially oriented oxide inclusions not detected by the eddy current test inspections (ET). There was no evidence of inservice induced degradation. The weld defects were the result of a change to the sleeve installation process instituted in 1991. The faulty installation process potentially affected sleeves installed during or after 1991 at the following plants: ANO-2, Ginna (the affected steam generators have since been replaced), Kewaunee and Zion-1 and -2. The Plus Point probe was subsequently used to inspect the sleeve upper weld at these plants and similar indications were reported.

Root Cause of Weld Indications

Prior to welding, the inner diameter of the parent tube at the desired weld location must be cleaned of service induced oxides. CE demonstrated the formation of oxide inclusions and significant weld suckback is a result of improper surface preparation. To prevent future occurrence, CE revised the tube cleaning procedure and adopted a post cleaning visual test inspection (VT). After the wire brush cleaning step, every tube is given a VT using a remote fiber optic camera system to confirm adequate surface cleaning. CE incorporated these modifications into new generic topical reports, "Repair of Westinghouse Series 44 and 51 Steam Generator Tubes Using Leak Tight Sleeves," and "Repair of 3/4" O.D. Steam Generator Tubes Using Leak Tight Sleeves" [References 2 and 3].

Sleeve Inspections

For compliance with the Code and regulatory requirements, initial and periodic nondestructive examinations (NDE) of steam generator tubes and sleeves are performed. Sleeve welds were historically accepted based on VT and ultrasonic test (UT) inspections. ET was used for an initial baseline inspection for comparison with later required periodic inspections. The reason for the different types of NDE being used for initial acceptance versus periodic reinspection is due to the differences between potential flaws from initial installation defects and service induced degradation. The different NDE techniques have normally been better suited for the respective types of anticipated flaws.

Visual Inspections

Historically, after completion of a sleeve weld, a VT was performed as required based on process control feedback; the VT was not performed on 100% of the welds. The acceptance criteria was observation of a complete weld around the circumference and the absence of blowholes below the weld centerline (the weld centerline is considered the pressure boundary). All VTs were recorded. A VT was performed for all installed sleeves at Zion-1, Zion-2, ANO-2 and for the sleeves installed during the 1996 outage at PI-1. A VT was performed as described above at Ginna, Kewaunee and for earlier PI-1 sleeve campaigns.

Based on the PI-1 event, CE revised its visual inspection requirements as documented in the topical reports for welded sleeves [References 2 and 3]. A visual inspection is performed after brush cleaning the weld region prior to sleeve installation and is required for all sleeve installations. Acceptance criteria is the presence of bright, shiny metal. A second visual inspection of the weld itself is required only to resolve surface indications identified by the eddy current test (ET) results and thus is not performed on every weld.

CE demonstrated the VT inspection of the weld region is capable of ensuring a properly prepared surface, ready for welding. CE demonstrated the VT inspection of the weld itself is capable of detecting and locating the position of blowholes, porosity, and weld irregularities. Only blowhole indications located below the weld centerline are rejectable indications. The VT inspection detects and locates indications without relying on either UT or ET inspection results. Because blowholes are readily detected and located by either UT or ET, a VT inspection after welding is not a requirement.

Ultrasonic Inspections

Historically, a UT was performed on all welds. Prior to October 1995, an analog UT system was used with a threshold amplitude C scan (plan view of weld) and was based upon the absence of a mid-wall reflection. If the sleeve outside diameter wall reflection was readily apparent, it signified lack of fusion with the parent tube. When fusion existed, the mid-wall reflection (mid-wall of the fused sleeve and tube combination) would not appear since no interface would exist. All UT C scans were recorded. The acceptance criteria

was 360° fusion. Acceptable weld height was controlled via the weld process parameters; there was no explicit acceptance criteria. In October 1995, the UT system was updated to a digital system that stored the UT signals as well as produced the C scan. This system allowed reanalysis of recorded data using A scans (single wave form) and B scans (circumferential cross sectional view of weld). The calibration method and standard amplitude threshold C scan display were not changed.

The PI-1 event led CE to discover that lack of fusion caused by axially oriented oxide inclusions from a poorly cleaned weld would not be detected since the oxides did not cause a large sound reflection. In response, CE revised its UT acquisition and analysis procedures. The UT now uses full amplitude C scans, with B and B' (axial cross sectional view of weld) scans available for screening. The back wall signal from the outside of the parent tube is also monitored for presence in the fused area and the signal strength is examined for excessive attenuation. Attenuation beyond the normal amount can be interpreted, along with other signal artifacts, as either a weld that is too narrow or one with inclusions or patches of unfused material. The acceptance criteria is 360° fusion. The size of the UT beam is greater than the minimum acceptable weld height; thus acceptable UT results ensures adequate weld height. The modified UT procedure was extensively tested on laboratory produced welds containing oxide inclusions, lack of fusion and blowholes. Samples were destructively examined and the metallurgical sections compared with the UT results. Comparison of results demonstrated the revised UT procedure was highly reliable for detecting these types of weld defects.

CE demonstrated the UT inspection is capable of detecting and locating the position of blowholes, lack of fusion, and structurally significant axially oriented oxide inclusions. Lack of fusion or the presence of oxide inclusions through the height of the weld and blowholes located below the weld centerline are rejectable indications. The UT inspection detects and locates these types of indications without relying on either VT or ET inspection results. All welds continue to require a UT prior to acceptance for service. The CE sleeve topical reports were revised to incorporate the changes in the UT acquisition and analysis discussed above [References 2 and 3].

Eddy Current Inspections

Historically, ET was performed on all welds to provide a baseline for future comparisons with inservice inspections. Thus there were no specified initial acceptance criteria for the ET results since the information was only for baseline comparison with later inservice inspections. CE used ET results as an additional check for the existence of blowholes in the weld, but the results were always confirmed with a VT to evaluate the position of the blowhole with respect to the weld centerline.

The original ET used two cross wound bobbin probes. Subsequently, the I coil was used to provide improved sensitivity to circumferential cracks in the parent tube. The I coil was replaced by the Plus Point probe for even greater sensitivity and improved noise reduction. The Plus Point probe was first used for CE sleeve inspections in 1995.

The PI-1 event led CE to discover that circumferentially oriented oxide inclusions and weld suckback are not detectable by UT (neither the historical UT process nor the current enhanced UT process) but are detectable by the Plus Point probe. CE modified its generic topical reports for sleeve installation to require ET as part of the initial weld acceptance. The revised ET procedure was extensively tested on laboratory produced welds containing oxide inclusions, weld suckback and blowholes. Samples were destructively examined and the metallurgical sections compared with the ET results. Comparison of results demonstrated the revised ET procedure was highly reliable for detecting these types of weld defects.

CE demonstrated the ET inspection is capable of detecting and locating the position of structurally significant circumferentially oriented oxide inclusions, weld suckback and blowholes [Reference 4]. Indications located below the weld centerline are rejectable. The ET inspection detects and locates these types of indications without relying on either VT or UT inspection results. CE has shown the oxide inclusions and weld suckback originate in the upper or lower edge of the weld, reducing ambiguity in the ET analysis. Before blowholes located above the weld centerline are accepted, a review of the UT results is required to ensure no partial lack of fusion or oxide inclusions exists below the blowhole which could form a leak path. All welds require an ET prior to acceptance for service. The CE generic topical reports for sleeve installation were revised to incorporate these changes in the ET requirements [References 2 and 3].

Operability Assessments

CE reviewed the ET data for all sleeve/tube assemblies with Plus Point probe EC indications in the upper weld region of the sleeve at ANO-2, Ginna, PI-1, Zion-1 and Zion-2. From the Plus Point ET data, CE concluded the types and range of signals observed were comparable to those reported for the PI-1 pulled sleeve/tube assemblies. CE also reviewed the digitized UT data available at ANO-2, PI-1, and Zion-1. No axially oriented oxide inclusions were noted in the UT reviews; however, the UT data was acquired using the threshold amplitude methodology described earlier. CE asserts the available B scans were sufficient to detect axially oriented oxide inclusions. Based on these reviews, CE concluded the structural and leakage integrity assessments that confirmed a safety issue did not exist for PI-1 applied also to those plants with sleeves left in service with similar indications.

The enhanced UT acquisition and analysis techniques described earlier has the capability of detecting axially oriented oxide inclusions not detectable by historic UT techniques. Despite the results of the review discussed above, the question arose as to whether a reanalysis of previously installed CE sleeves using the enhanced UT process was warranted. The industry position in this regard is that the combination of historic UT and recent ET inspections of previously installed CE sleeves provide adequate assurance that the upper weld is leaktight and structurally sound. Licensees argued axially oriented oxide inclusions exist in combination with other types of weld indications (e.g., circumferentially oriented oxide inclusions and weld suckback) that are readily detectable by ET inspections with the Plus Point probe.

The metallurgical results discussed in Reference 1 indicate that up to 10% of welded sleeves may contain an axially oriented oxide inclusion existing alone. However, the leakage and structural assessments indicate these oxide inclusions are insignificant and do not represent a safety concern. Thus the staff concludes requiring licensees to reperform the UT inspection of previously installed sleeves is unwarranted.

Future Inspections of CE Designed Welded SG Tube Sleeves

For upcoming SG tube inservice inspections, Kewaunee, PI-1 and Zion-2 committed to performing a 100% ET inspection of previously installed CE designed welded SG tube sleeves using the Plus Point probe following the ET guidelines established in References 2 and 3. ANO-2 committed to performing a 100% ET inspection of previously installed welded CE sleeves that had EC indications from the previous inspection plus 20% of the remaining previously installed welded CE sleeves. Zion-1 plugged all sleeved tubes with EC indications during the January 1996 outage. Ginna replaced steam generators in June 1996. PI-1 and ANO-2 also plan to reexamine with the enhanced UT technique all sleeves with EC indications in the upper weld of the sleeve.

Kewaunee and Zion-2 completed these ET inspections. All sleeves identified as having weld zone indications were removed from service regardless of location with respect to the weld centerline. Reinspection of previously installed sleeves using the enhanced UT technique was generally not performed (Zion-2 did reinspect eleven previously installed sleeves suspected of leaking using the enhanced UT methodology and found no rejectable indications).

All affected licensees plan to adopt the applicable revised CE topical reports prior to the future installation of CE designed welded SG tube sleeves. The licensees also plan to provide the following information within 90 days following the installation of CE designed welded SG tube sleeves:

1) number of sleeves successfully installed and
2) number of sleeves installed and then rejected and the reasons for rejection.

Conclusions

CE ascertained the root cause of the weld indications and revised procedures to prevent recurrence. In addition, CE provided additional defense-in-depth through improved NDE techniques and requirements. CE demonstrated adequate leakage and structural integrity exists for previously installed sleeves that possibly contain upper weld defects. The NRC staff concludes CE and the affected licensees have taken appropriate steps to ensure adequate integrity of CE designed welded SG tube sleeves.

References

1. Verification of the Structural Integrity of the ABB CENO Steam Generator Welded Sleeve, Combustion Engineering, Inc., CEN-628-P, proprietary version, Revision 01, March 1996.

Verification of the Structural Integrity of the ABB CENO Steam Generator Welded Sleeve, Combustion Engineering, Inc., CEN-628-NP, nonproprietary version, Revision 01, March 1996.

2. Repair of Westinghouse Series 44 and 51 Steam Generator Tubes Using Leak Tight Sleeves, Combustion Engineering, Inc., CEN-629-P, proprietary version, Revision 00, July 1996.

Repair of Westinghouse Series 44 and 51 Steam Generator Tubes Using Leak Tight Sleeves, Combustion Engineering, Inc., CEN-629-NP, nonproprietary version, Revision 00, July 1996.

3. Repair of 3/4" O.D. Steam Generator Tubes Using Leak Tight Sleeves, Combustion Engineering, Inc., CEN-630-P, proprietary version, Revision 01, November 1996.

Repair of 3/4" O.D. Steam Generator Tubes Using Leak Tight Sleeves, Combustion Engineering, Inc., CEN-630-NP, nonproprietary version, Revision 01, November 1996.

4. EPRI Steam Generator Examination Guidelines Appendix H Qualification for Eddy Current Plus-Point Probe Examination of ABB CE Welded Sleeves, ABB Combustion Engineering Nuclear Operations Field Services, Report Number 96-OSW-003-P, proprietary version, Rev. 00, April 27, 1996.

EPRI Steam Generator Examination Guidelines Appendix H Qualification for Eddy Current Plus-Point Probe Examination of ABB CE Welded Sleeves, ABB Combustion Engineering Nuclear Operations Field Services, Report Number 96-OSW-003-NP, nonproprietary version, Rev. 00, April 27, 1996.

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