



UNITED STATES  
NUCLEAR REGULATORY COMMISSION  
WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO AMENDMENT NO. 117 TO

FACILITY OPERATING LICENSE NO. NPF-38

ENERGY OPERATIONS, INC.

WATERFORD STEAM ELECTRIC STATION, UNIT 3

DOCKET NO. 50-382

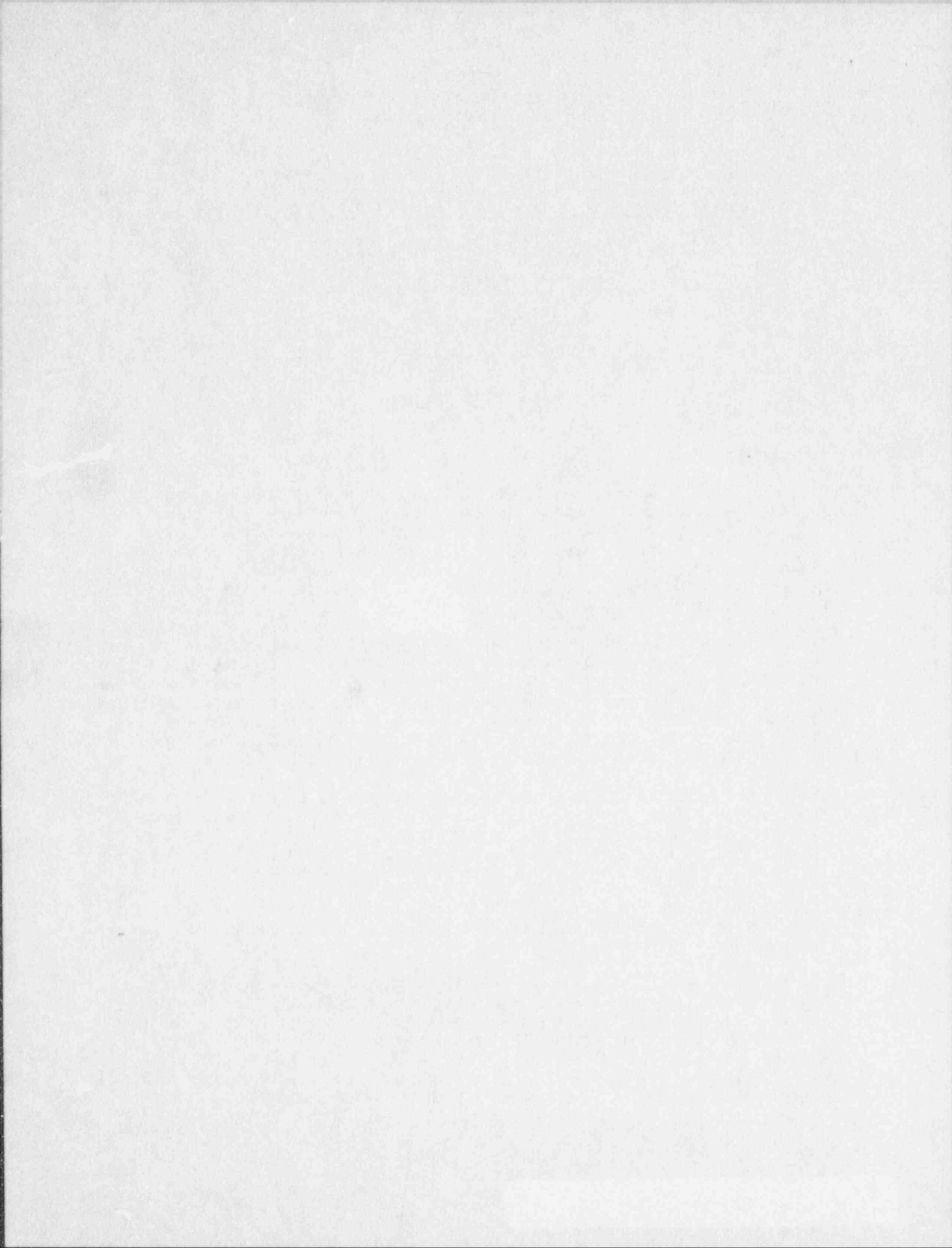
1.0 INTRODUCTION

By application dated December 6, 1993, as supplemented by letters dated May 12, August 9, and September 18, 1995, Entergy Operations, Inc. (the licensee), submitted a request for changes to the Waterford Steam Electric Station, Unit 3 (Waterford 3), Technical Specifications (TSs). The requested changes would allow installation of steam generator tube repair sleeves at Waterford 3. The proposal was for use of two types of leak tight sleeves designed by Combustion Engineering, Inc. (CE).

The two sleeve types are a tube sheet sleeve and a tube support plate sleeve. The tube sheet sleeve is installed by means of two different joint types: a rolled joint in the tube sheet end and an autogenous gas-tungsten arc weld (GTAW) at the free span end. The tube support sleeves are welded (autogenous GTAW) to the SG tube in the free span near each end of the sleeve. The material of construction for the sleeves is nickel alloy 690, a Code approved material (ASME SB-163), incorporated in ASME Code Case N-20.

Extensive analysis and testing were performed on the CE sleeves and sleeve-to-tube joints to demonstrate that Regulatory and Code design criteria were satisfied under normal operating and postulated accident conditions. The details of the sleeve qualifications are discussed in report CEN-605-P, Revision 00-P "Entergy Operations, Inc. Waterford 3 Steam Generator Tube Repair Using Leak Tight Sleeves", dated December 1992 (proprietary) and report CEN-625-P "Verification of the ABB CENO Steam Generator Tube Sleeve Installation Process and Operating Performance," dated September 1995 (proprietary).

The staff has previously reviewed closely similar CE documents supporting requests for changes to the TSs at other plants. The bulk of the technical and regulatory issues for the present request are identical to those reviewed in previous safety evaluations (SEs) concerning the use of CE leak tight sleeves. This SE will discuss only those issues that warrant revision, amplification, or inclusion based upon current experience. A summary of the principal technical issues regarding the design and use of CE leak tight



sleeves follows. Details of the prior staff evaluation of CE sleeves may be found in SE for Kewaunee Nuclear Power Plant, Docket No. 50-305, dated April 10, 1992, Arkansas Nuclear One, Unit No. 2, Docket No. 50-368, dated January 26, 1993, and Maine Yankee Atomic Power Station, Docket No. 50-309, dated April 14, 1995. These evaluations apply as well to the proposed Waterford license amendment.

The May 12, August 9, and September 18, 1995, letters provided additional information that did not change the initial proposed no significant hazards consideration determination.

## 2.0 SUMMARY OF PREVIOUS REVIEWS

Previous staff evaluations of CE sleeves addressed the technical adequacy of the sleeves in the 4 principal areas of pressure retaining component design: structural requirements, material of construction, welding, and non-destructive examination. The staff found the analyses and tests that were submitted to address these areas of component design to be acceptable.

The function of sleeves is to restore the structural integrity of the tube pressure boundary. Consequently, structural analyses were performed for a variety of loadings including design pressure, operating transients, and other parameters selected to envelope loads imposed during normal operating, upset, and accident conditions. Stress analyses of sleeved tube assemblies were performed in accordance with the requirements of the ASME Boiler and Pressure Vessel Code, Section III. These analyses, along with the results of qualification testing and previous plant operating experience were cited to demonstrate that the sleeved tube assembly is capable of restoring steam generator tube structural integrity.

The material of construction of the sleeves is nickel Alloy 690, a Code approved material (ASME SB-163), covered by ASME Code Case N-20. The staff has found that the use of Alloy 690 thermally treated (TT) sleeves is an improvement over the Alloy 600 material used in the original steam generator tubing. Corrosion tests conducted under Electric Power Research Institute (EPRI) sponsorship confirm test results regarding the improved corrosion resistance of Alloy 690 TT over that of Alloy 600. Accelerated stress corrosion tests in caustic and chloride aqueous solutions have also indicated that Alloy 690 TT resists general corrosion in aggressive environments. Isothermal tests in high purity water have shown that, at normal stress levels, Alloy 690 TT has high resistance to intergranular stress corrosion cracking in extended high temperature exposure. The NRC has concluded as a result of these laboratory corrosion tests, that Alloy 690 is acceptable to NRC as meeting the guidelines in Regulatory Guide 1.85 (Rev. 24, July 1986). The NRC staff has approved use of Alloy 690 TT tubing in replacement steam generators as well as sleeving applications.

The welding process employed to join the sleeve to the parent tube is automatic autogenous GTAW (gas-tungsten arc welding). The application of this process to the CE sleeve design was specifically qualified and demonstrated during laboratory tests employing full scale sleeve/tube mock-ups.

Qualification of the welding procedures and welding equipment operators was performed in accordance with the requirements of the ASME Code, Section IX (Welding).

The sleeve assemblies can be inspected by nondestructive techniques in accordance with the recommendations of Regulatory Guide 1.83, "Inservice Inspection of Pressurized Water Reactor Steam Generator Tubes." Nondestructive examination of sleeved tubes is conducted in two primary ways. Initial weld acceptance is performed using ultrasonic testing (UT). This NDE method is appropriate for detecting the types of weld flaws that may occur during the installation process. Service induced flaws are best detected using eddy current testing (ECT). Both techniques were developed and qualified in accordance with the ASME Code requirements and the recommendations of Regulatory Guide 1.83.

### 3.0 DISCUSSION AND EVALUATION

Recent experiences at two U.S. plants have indicated that the free span joint of a sleeved alloy 600 steam generator tube may be susceptible to stress corrosion cracking (SCC). These instances of SCC in sleeved tubes are limited to a joint type different from that proposed for Waterford. The affected joints are of the mechanically expanded type. These employ a hydraulic expansion followed by a hard roll in the center of the hydraulically expanded region. The hard roll forms the structural joint and leak limiting seal. Cracks have been detected in the alloy 600 parent tube material at the lower hard roll transition and lower hydraulic transition of free span joints. The cracks were detected after 4 to 7 years of service. Since a number of sleeved tubes with this joint type have operated up to 14 years in one of the affected units, it is clear that not all such sleeved tubes are likely to develop cracks after a given service interval.

This experience with rolled joints is not suggestive of similar difficulties with welded joints. Service times exceeding 10 years have been achieved for sleeved tubes with GTAW joints at U.S. plants. No instances of service induced SCC have occurred in any of these joints.

The staff position on sleeving considers the method unable to assure an unlimited service life for a repaired tube. The conservative view is that sleeving creates new locations in the parent tube which may be susceptible to SCC after new incubation times are expended. Incubation times are not quantified. They are observed to vary between individual steam generators and the various tubes within, based upon prior experiences with U-bend and roll transition cracking.

This staff position that sleeving has limited service life is due to the circumstances of the sleeving processes. Sleeve installation methods can enhance one or two of the conditions necessary for SCC. The primary contributor is the residual stress resulting from the various joining methods. Secondly, the local environment of the tube may be altered as a result of the formation of a wetted crevice between the tube and sleeve. Remediation of these contributors would benefit sleeved tube life. Of the two, stress relieving may be the most beneficial given the underlying causes of SCC and present sleeve designs.

In recognition of the desirability for stress relief, the licensee submitted a proposal for stress relieving the welded sleeve joint(s) to increase the resistance to SCC. The method, which is proprietary, uses a post weld heat treatment (PWHT) developed by CE, which is applied to the weld and associated heat affected zone (HAZ) of free span joints. This PWHT is designed to provide optimum stress relief of the alloy 600 parent tube. The rolled joints performed within the tube sheet effectively isolate the alloy 600 from the environment and thus are not susceptible to SCC. Stress relief of these joints is unwarranted.

EPRI conducted a study of in-situ stress relief methods and performed demonstrations. When this study was performed, the tests and proposed applications were for cold worked, as opposed to welded, alloy 600. Although the forming practices vary, cold worked versus welded, the concepts and application of the EPRI study are equally applicable to welded alloy 600, since the SCC behavior is the same. The results were documented in EPRI report NP-4364-LD, published December 1985. The most essential parameters for performing such a heat treatment were outlined and verified by feasibility and demonstration tests. Verification of the heat treatment methods included tests of comparative corrosion resistance, microstructure, and residual stress measurements. The licensee's submittal and supporting documents draw heavily upon the methods and recommendations of EPRI report NP-4364-LD.

### 3.1 Qualification of PWHT Method

For process qualification, CE constructed mock-ups of a steam generator tube bundle. The test program was conducted to verify the acceptable performance of the annealing system in meeting the established EPRI heat treating guidelines. Typically, the mock-ups consisted of several tubes held in a frame to simulate a tube sheet and a tube support plate. Tests were conducted to establish or verify the different parameters involved with the heat treating operation. These tests included:

1. positioning (elevation) of the heat source with respect to the weld joint,
2. effect of heater radial position and temperatures achieved at the weld joint due to variations in tube/sleeve diameter,

3. emissivity (black body) effects from different oxides and the tube bundle geometry,
4. relative corrosion resistance for as-welded versus heat treated joints,
5. metallurgical examination of the heat treated joint, and,
6. effect of constraint on the tube during PWHT due to tube "locking" in adjacent tube support plates (TSPs).

Heater positioning with respect to the weld joint was accomplished using previously developed tooling with a known repeatability and accuracy. With this tooling, the effect of small positioning variations of the heater were quantified by thermocouple measurements. A tolerance band for heater positioning was established that was compatible with the accuracy of the positioning device. For the positional accuracy of the tooling, the heater can deliver the correct heat treating temperature at the weld and HAZ.

The EPRI program noted that the radial position of a heater within a sleeve could have a significant effect upon the achieved temperature around the circumference. Such variations, if they exist, must fall within the recommended temperature range to achieve an acceptable stress relief. CE designed a heater that minimized radial positioning problems, and consequent temperature variations, by its having a close fit to the sleeve inside diameter. Instrumented mock-ups verified that the range of achieved temperatures was well within the EPRI recommended temperature range.

Tube emissivity affects the temperature, which can be achieved for a given input wattage to the heater. Different tube/sleeve combinations were tested using tubing aged in an autoclave to produce the range of scale thicknesses and types observed in steam generators. Using the tube array mock-ups, CE established that the heater design was able to maintain the EPRI recommended range of PWHT temperatures for these varying emissivities.

In the EPRI study, accelerated corrosion tests were performed to measure the performance of cold worked versus heat treated material. It is well established that reduction of stress is key to avoiding or minimizing the occurrence of SCC, but the correlation between two different stress levels and the consequent material service life is difficult to predict. Additionally, direct measurement of residual stresses is difficult and uncertain. To avoid these uncertainties, accelerated corrosion tests were selected to verify the benefit of the heat treatment. This test method had the benefit of more directly relating the results of the heat treatment to the desired outcome of greater resistance to SCC.

Identical samples of welded joints were produced. One group was given a PWHT. Both groups were tested simultaneously in environments known to produce SCC in alloy 600. In all cases, the stress relieved samples showed superior resistance to SCC, in agreement with theory and the EPRI results. Thus, the

technique developed by CE was verified to be beneficial in reducing weld joint susceptibility to SCC.

The combination of welding followed by PWHT poses the potential for undesirable alteration of the microstructure if the temperatures and times of exposure are excessive. Two possible deleterious effects would be sensitization or grain growth. EPRI established guidance on time and temperature for heat treating. The welding process CE employed was a low heat input process. Due to the low heat input, it was expected that the effects of welding would be minimal. Metallurgical examination of welded sleeve joints verified that adverse microstructural alteration of the materials was absent.

Next, the microstructures of welded and heat treated joints were examined. Joint samples were produced with a variety of PWHT times and temperatures. CE demonstrated that adherence to the EPRI guidelines precluded undesirable microstructural changes. Thus, the heat treatment was shown to be beneficial in reducing residual stresses without inducing undesirable microstructural changes. Additionally, for field application, the heat treatment control system is programmed to automatically limit PWHT temperature and time and to stop the process in the event of an instrument malfunction.

Recent field experience with the installation of welded sleeves with PWHT has indicated that SG tubes may be constrained ("locked") in their tube support plates, even though the TSPs are of designs which are less susceptible to this effect. The result of such tube locking is distortion of the tube (bowing or bulging) during the PWHT. After the heat treatment is completed, the bow or bulge remains. Measurements of the bowing and bulging have shown them to be of negligible values. These distortions have been analyzed and found to be immaterial to the examination, operation, and safety of the sleeved tube.

Along with the observed distortion (bowing or bulging) is a residual stress remaining after the heat treatment is completed. Strain gage measurements of this residual stress have shown it to be moderate compared to that resulting from welding (without subsequent PWHT).

### 3.2 Service Life of Sleeved Tube

Data and discussions were presented which attempted to use the accelerated corrosion test results to predict service life of the sleeve joint. During the development of the PWHT process, CE devised a service life prediction model that was based upon the accelerated corrosion test data. CE welded sleeves, without PWHT, have achieved 10 years of service without service induced problems. The accelerated corrosion tests demonstrated the PWHT joints to be superior in SCC resistance to the as-welded joints. Using these test data in the predictive model, CE estimated the stress relieved sleeve joints would last longer than the remaining licensed life of the plant. The staff has concluded that accelerated corrosion tests should provide a good qualitative assessment of relative service life for various sleeving

processes. However, quantitative estimates of service life do not have a high degree of reliability. Periodic inspection as discussed in Section 2.3 and primary-to-secondary leakage monitoring will identify any premature degradation that may occur in the sleeved joints.

### 3.3 Inspection of Sleeve Joints

For compliance with the Code and Regulatory requirements for initial and periodic examinations under the Inservice Inspection program, the sleeve assemblies can be inspected by eddy current techniques in accordance with the recommendations of Regulatory Guide 1.83, "Inservice Inspection of Pressurized Water Reactor Steam Generator Tubes."

Inspection of new sleeves is accomplished using two methods. Weld inspection is performed using ultrasonic tests (UT), with examination and acceptance criteria developed by CE and demonstrated with laboratory tests. After production welds are UT accepted, a base line multi-frequency eddy current test is performed of each new sleeve for comparison at future examinations.

For future examinations, the licensee has committed to employ an EPRI recommended, Appendix H qualified, eddy current examination method for sleeve inspections. This includes the use of Plus Point or CECCO probes, which are the present state-of-the-art.

The staff notes that other installations have performed on-site verification of the welding and UT techniques. This assures that plant specific conditions do not affect optimum performance of the welding and inspection methods prior to committing to a large production effort, should it be necessary.

### 3.4 Heat Treatment of Hydraulic Expansion Transition

Experience at other installations has shown that the hydraulic expansion transition of rolled joint sleeves may be susceptible to SCC. The staff has been monitoring these developments for potential impact on welded sleeve installations. Presently, accelerated corrosion tests of as-welded versus welded and heat treated joints indicate the hydraulic transition to have little or no susceptibility to SCC. The staff notes that the stress levels and crevice conditions at the facilities where cracks have been noted differ substantially from the joint design proposed for Waterford. The current staff position, based on currently available information, is that heat treatment of the hydraulic step is neither required nor prohibited.

### 3.5 Changes in the Technical Specifications

The licensee has proposed to revise TS 3/4.4.4, Steam Generators, to incorporate the tube sleeving as an acceptable alternative for repairing the degraded steam generator tubes. As discussed in this evaluation the staff finds the tube sleeving methods acceptable. Therefore, the changes in the TS are acceptable. In addition, there are some minor changes that are of an editorial nature, and they therefore are acceptable.



#### 4.0 SUMMARY OF FINDINGS

Based upon the review and evaluation of the information and data presented in the aforementioned CE proprietary reports (CEN-605-P and CEN-625-P), it is concluded that the request by the licensee for a proposed amendment to the Facility License to modify the TS to permit repair of steam generator tubes by installation of sleeves using the CE methodology with PWHT of the welded joints as referenced in the amended TS, is acceptable. Further, the licensee has committed to employ proven and industry accepted eddy current examination techniques for sleeve inspections. The staff understands this commitment to include employment of subsequent advances in eddy current techniques as they become commercially available and industry accepted.

The staff concludes that the proposed sleeving repairs can be accomplished to produce a sleeved tube of acceptable metallurgical properties, strength, mechanical stability, leak tightness and corrosion resistance. We also find that the pre-service integrity of the sleeved tubes can be assured by implementing the proposed sleeve installation examinations.

#### 5.0 STATE CONSULTATION

In accordance with the Commission's regulations, the Louisiana State official was notified of the proposed issuance of the amendment. The State official had no comments.

#### 6.0 ENVIRONMENTAL CONSIDERATION

The amendment changes a requirement with respect to installation or use of a facility component located within the restricted area as defined in 10 CFR Part 20 and changes surveillance requirements. The NRC staff has determined that the amendment involves no significant increase in the amounts, and no significant change in the types, of any effluents that may be released offsite, and that there is no significant increase in individual or cumulative occupational radiation exposure. The Commission has previously issued a proposed finding that the amendment involves no significant hazards consideration and there has been no public comment on such finding (59 FR 2868). Accordingly, the amendment meets the eligibility criteria for categorical exclusion set forth in 10 CFR 51.22(c)(9). Pursuant to 10 CFR 51.22(b) no environmental impact statement or environmental assessment need be prepared in connection with the issuance of the amendment.

#### 7.0 CONCLUSION

The Commission has concluded, based on the considerations discussed above, that: (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, (2) such

activities will be conducted in compliance with the Commission's regulations, and (3) the issuance of the amendment will not be inimical to the common defense and security or to the health and safety of the public.

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