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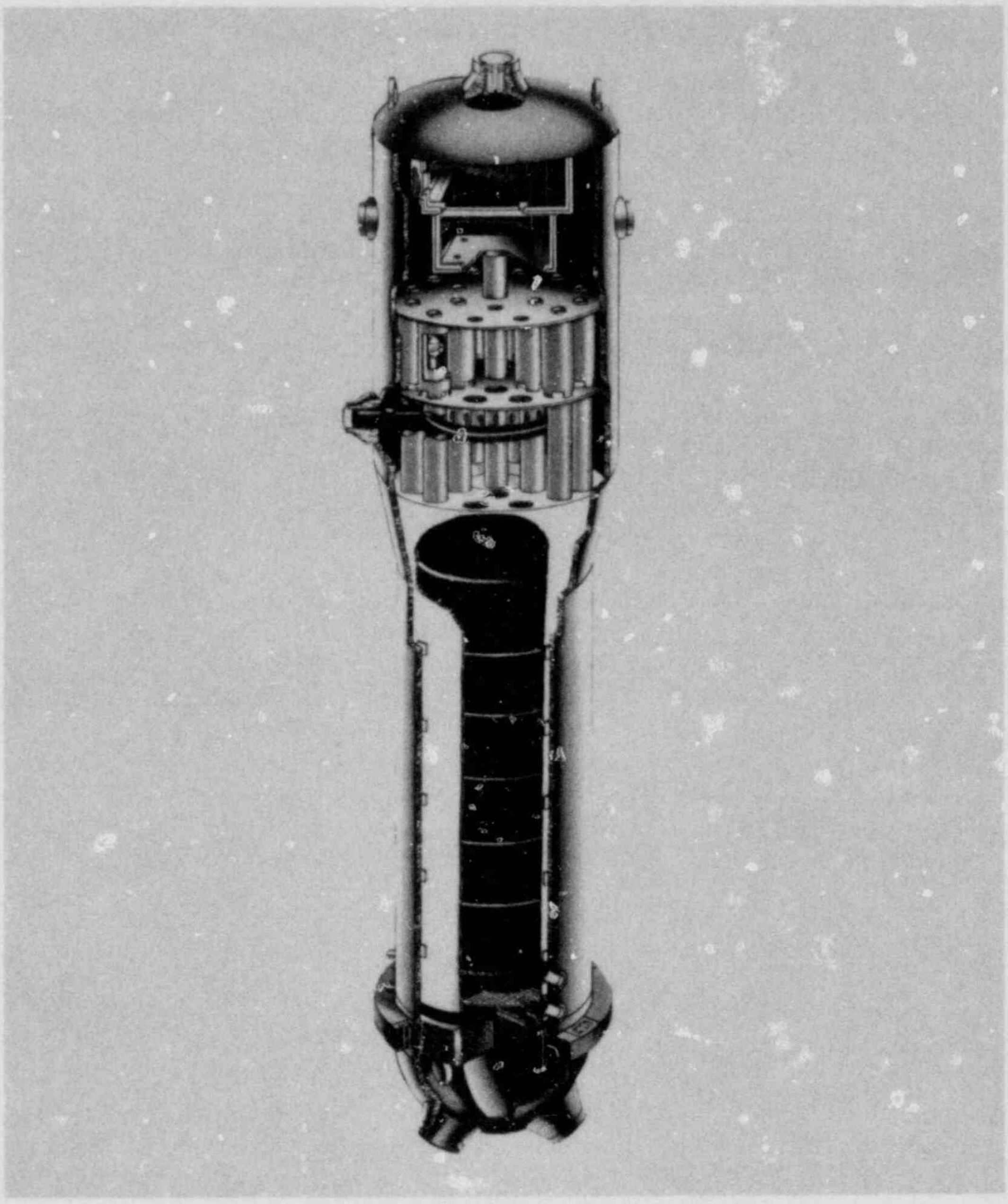
Steam Generator Sleeve Test Program
R.E. Ginna Nuclear Power Plant
NRC Docket No. 50-244

(Non-Proprietary Report)



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Babcock & Wilcox
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STEAM GENERATOR SLEEVE TEST PROGRAM

R. E. GINNA NUCLEAR POWER PLANT

NRC DOCKET NO. 50-244 (10/5/80)

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DOCUMENTATION

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I. INTRODUCTION

A. Background

Ginna Station is a Westinghouse two (2) loop pressurized water reactor plant owned by Rochester Gas and Electric. It is licensed for 1520 megawatts thermal and has a net electrical capacity of 490 megawatts.

The steam generators are Westinghouse series 44 vertical shell and U-tube units each rated at 3,130,000 lbs/hr steam flow at 725 psig. The steam generator tubing is Inconel 600 (SB-163-61T). The tubes are partially rolled into the tubesheet and seal welded.

Phosphate secondary water chemistry control was utilized from initial operation through November 1974. In December 1974 secondary water chemistry control was converted to all volatile treatment (AVT). AVT was maintained through condenser integrity and steam generator blowdown until December 1977. From January 1978 until the present full flow, deep bed condensate demineralizers have been in operation.

Steam generator tube wastage, caustic cracking, and ID cracking have been experienced at Ginna. Between March 1974 and October 1980, 121 tubes were plugged in the A-steam generator and 68 in the B for these reasons. The total number of tubes which have been plugged is 122 in the A generator and 112 in the B. During the Spring 1979 refueling outage, OD cracking of tubes in the tubesheet crevice region was first discovered. A total of 44 tubes now have been plugged in the B steam generator due to crevice cracking indications. No such indications have yet been discovered in the A steam generator. The crevice cracking occurs 2 to 3 inches below the top of the tubesheet. The cracking appears to be the result of general intergranular attack due to the presence of alkaline elements. The cracking seems to be very temperature dependent. All of the indications to date have occurred in hot leg tubes. A detailed description of the results of the Spring 1980 eddy current examinations, and a discussion of the crevice cracking phenomena, were provided in the Rochester Gas and Electric letter of April 29, 1980 to Mr. Dennis L. Ziemann, USNRC.

Since the Spring 1980 inspection, Rochester Gas and Electric has initiated several programs directed towards resolution of the crevice cracking phenomena. The existing programs are all in the areas of chemistry and plant operation and are directed towards eliminating crevice cracking. Sleeving could provide an alternative to tube plugging and thereby extend the life of the steam generators.

B. Overview of Sleeve Development Program

The sleeve development program consists of a three phase program with Babcock and Wilcox Company of Development, Design Verification, and Implementation. Specifically, the objectives of each phase of the program are:

B. Overview of Sleeve Development Program (Continued)

1. Development

During this phase, the sleeve design was developed. Materials were selected and laboratory testing and analytical work were performed. Licensing issues were assessed and the impact of sleeve installation on outage schedules was determined. All necessary materials, equipment and procedures needed for Phase 2 Design Verification have been developed and are being demonstrated.

2. Design Verification

During this phase 10 sleeves will be installed in the Ginna steam generators to verify the adequacy of the sleeve design developed during the development phase. Further laboratory testing and qualification work will be performed leading to the implementation phase.

3. Implementation

During this phase, sleeves will be installed on a large scale in tubes having unacceptable tubesheet crevice eddy current (EC) indications. Schedule for implementation has not been developed and will be dependent on confirmation of design through the Design Verification program.

II. SLEEVE DESIGN

A. General Design

The Babcock and Wilcox sealable sleeve design to be employed (see Figure 1) is 36 inches long, thin walled, composite alloy sleeve attached to the steam generator tube at both the upper and lower ends. Inconel was chosen for the base sleeve material to provide the same structural and thermal chracteristics as the original tube.

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The upper end of the sleeve will be expanded and brazed. The length of the sleeve (36 inches) will insure the braze joint being above the sludge affected region atop the tubesheet. The tube sheet is 22 inches thick and the sludge affected zone extends approximately 3 to 6 inches above the tubesheet.

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A. General Design (Continued)

The lower end of the sleeve will be explosively welded to the tube within the tubesheet roll expanded region. Explosive welding will substantially reduce the time required to install sleeves and personnel exposure to radiation. Although not anticipated to be used, as a back-up to the explosive technique, a GTAW weld procedure has also been developed.

B. Upper End Attachment

The upper end of the sealable sleeve is designed to be attached to the steam generator tube by brazing.

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Selections of the braze joint configuration, parameters, procedural techniques and filler material were made based on the results of laboratory brazing trials and mechanical property tests.

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The joints were cut apart and evaluated by metallographic examination and bend and pull tests were performed to select the best joint configuration. The leak tightness of the joints was verified by hydrotest.

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Oxides will be removed from the steam generator tube ID prior to the brazing operation to assure a good bond. About 0.001 inch of metal will be removed from the surface to get a surface suitably clean of oxide for subsequent brazing.

C. Lower End Attachment

The lower end of the sealable sleeve will be attached to the steam generator tube by explosive welding. B&W has considerable experience with explosive welding in steam generator tubes - holding U.S. Patent 3,590,877 for explosive plugging. This weld proven plug design and explosive method provides the basis for the explosive procedure for attachment of the lower end of the sealable sleeves.

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C. Lower End Attachment (Continued)

This weld configuration was developed during a series of tests until the desired configuration was achieved. The weld joints were sectioned, polished photo micrographs taken and evaluated by metallography.

B&W is licensed by the ATF Bureau of the U.S. Treasury Department as both a manufacturer and importer of high explosives (license numbers 40H07620C1-00048 and 40H07620C1-00052 respectively). For transportation purposes, the B&W explosive plugs are classified as class "C" explosive by the Bureau of Explosives. B&W has requested a similar classification for the Ginna explosive welding device.

As a back up procedure to the lower end attachment a Gas Tungsten-Arc (GTAW) seal weld was developed utilizing the same semi-automatic welding equipment used by B&W at Florida Power's Crystal River Unit #3 during the April 1980 shutdown.

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This equipment can be utilized on flush or fillet welds and can be placed in any position, including overhead.

III. SLEEVE INSTALLATION

A. Tubes to be Sleeved

Ten tubes in the "B" steam generator hot leg will be sleeved. Tubes to be sleeved will be selected by Rochester Gas and Electric. In order to provide for a good test, sleeves will be installed either in tubes which have indications of intergranular attack in the tubesheet crevice region, or in tubes which would be expected to be subject to, intergranular attack based on past inspection results. In addition, a sleeve will be installed in one tube with a through-wall defect.

B. Installation Sequence

The following installation sequence will be used to install sleeves in the preselected steam generator tubes.

1. Tube Preparation

(a) After locating the subject tube (tubes) the tube I.D. will be checked with a "GO Gauge". Insertion of the gauge should be made freely without force. If the gauge cannot be inserted another steam generator tube will be selected.

(b) Steps will be taken to insure that the tube ID is dry.

B. Installation Sequence (Continued)

(c) Tube ID will then be measured using profilometry or die test gauge.

(d) Final cleaning of the tube ID will be accomplished.

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(e) After completion of cleaning, the tube ID will be flushed and swabbed. Cleaning will continue until swab is free from dirt or particles.

2. Sleeve Brazing

(a) After completion of tube cleaning the hydraulic expansion tool will be inserted into the sleeve from the expanded end.

(b) The sleeve will be inserted into the tube.

(c) The sleeve will be hydraulically expanded at the braze region of the sleeve to deform the tube.

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(d) After completion of hydraulic expansion, the induction heating coil will be inserted into the sleeve and the brazing operation will be performed.

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The heater will then be removed.

3. Leak Test

(a) Tube and sleeve leak test plugs will be installed and a leak test will be performed.

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B. Installation Sequence (Continued)

4. Explosive Welding

   (a) Explosive cartridge will be inserted into the sleeve and clamped into adjacent tube until the cartridge flange contacts the tube.

   (b) The explosive cartridge will then be detonated.

   (c) After detonation, the sleeve will be visually inspected to examine the sleeve deformation at the explosive weld region to ensure no degradation of the structural integrity of the steam generator tube.

5. System Pressure Test

   (a) A primary system pressure test will be performed prior to return to full power to further demonstrate sleeve to tube attachment structural integrity.

C. Procedures

1. Detailed procedures have been developed for installation of the sleeves. These procedures include and provide detailed step-by-step operations for tube preparation (gauging, cleaning), hydraulic expansion and brazing, explosive welding and leak test. The installation sequence is detailed in Section B. Prior to installation of the sleeves, the following requirements will be met:

   (a) Water in the primary system must be drained below the centerline of the reactor vessel outlet nozzle.

   (b) Water must be drained from the secondary side prior to brazing and explosive welding.

   (c) Both primary manway covers and inserts will be removed.

   (d) The channel head area and tube sheet must be dry.

   (e) Air samples from inside the steam generator will be analyzed.

   (f) Radiation levels inside the channel head area will be mapped and general levels and hot spots identified.

2. Gauging Tube I.D.

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C. Procedures (Continued)

3. Cleaning

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4. Expanding

After the tube I.D. surface has been adequately cleaned, the pre-brazed sleeve with an expanding tool in position will be inserted into the tube. The sleeve is then hydraulically expanded into the tube.

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5. Brazing

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6. Pressure Test of Braze

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7. Explosive Welding

As described above, the sleeve will be explosively welded to the tube in the rolled region of the tube sheet.

D. Mock-Up Demonstration and Training

Sleeves will be installed in the Ginna steam generator mock-up to demonstrate the tools, techniques and equipment under realistic conditions. This is considered an integral and necessary part of the program to minimize delays and radiation exposure during prototype sleeve installation in the operating steam generator. Mockup installation will also serve as personnel training.

Complete procedures for tube cleaning, sleeve installation, expansion, brazing and welding will be demonstrated on the mock-up prior to use in the operating steam generator.

The chosen NDE technique and procedure will also be used on the full-size mockup.

E. Radiation Exposure Control and Estimates

All personnel to be engaged in the steam generated sleeving will receive instructions and training in and understand the radiation protection rules and guidelines in effect at the plant site. The radiation exposure for test sleeve installation has been determined based on previous measurement of radiation levels at Ginna. The projected exposure is:

Operation	Estimated Exposure
[ ] [PROPRIETARY] [ ]	
2.25 R/Sleeve x 10 Sleeves	22.5 man-rem
Gauging tubes for selection	1.0 man-rem
General exposure outside generator	2.0 man-rem
Install and remove ECT equipment for sleeve testing	3.0 man-rem
TOTAL	28.5 man-rem

Typically, the radiation exposure is accumulated for plugging 10 steam generator tubes is 4 man-rem. It should be noted that radiation exposure for sleeving will be substantially reduced in the implementation phase when, it is expected, more mechanization will be employed.

IV. DESIGN VERIFICATION

A. Tests

During process development, a number of tests were performed including hydrostatic, tensile and peel, and metallographic examinations on the upper and lower attachments. Additionally, design verification testing will be performed prior to and subsequent to installation of test sleeves in a Ginna steam generator. Testing performed prior to installation of test sleeves is directed primarily at providing adequate assurance of the mechanical integrity of the test sleeves. The testing completed prior to test sleeve installation includes:

(1) Mechanical Integrity Testing

The mechanical testing in support of the test sleeve installation is being conducted on a simulated tube/sleeve assembly. The five test specimens are constructed of adequately representative materials using the same brazing process to be utilized in the test sleeve installation. A limited number of these simulated tube/sleeve assembly specimens are being tested as follows:

A. Tests (Continued)

(a) Primary Side Hydro Test

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(b) Secondary Side Hydro Test

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(c) Structural Fatigue Testing

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(d) Primary Side Hydro Test

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(e) Tensile Test

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(2) Corrosion Testing

[Proprietary] is the material most often used for caustic corrosion resistance. Data on actual corrosion rate was not adequate in the range needed for sleeve application. To obtain data coupons of [Proprietary] were tested in a 50% caustic solution at 550°F.

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Qualification testing will be performed to insure appropriate design verification of the final production of tube/sleeve assembly to be used in the large-scale production installatin. The specific testing that will be performed is to be defined subsequent to installation of the test sleeves; however, it is presently expected that testing will address, as appropriate, the following areas:

A. Tests (Continued)

(a) Mechanical Integrity Testing

The mechanical integrity testing is expected to include tests similar to that conducted in support of the limited test sleeve installation. However, the tube/sleeve assembly test specimens will be constructed of the actual materials. Additionally, appropriate thermal and pressure cyclic testing followed by tensile testing and metallurgical examination will be performed.

(b) Corrosion Testing

Corrosion testing will be conducted in a caustic environment at about 600°F to demonstrate the expected superior corrosion resistance of the sleeving material (bi-metallic) as well as the integrity of the tube/sleeve assembly end attachments. Upon completion of a reasonably long test exposure, these specimens will be subjected to a metallurgical examination. It is anticipated that about four full configuration specimens will be tested.

(c) Vibration

The analysis conducted in support of the sleeve installation identified the need to further evaluate the response of a severed tube/sleeve assembly to flow induced and seismic excitation. While this issue may be addressed analytically, some vibrational testing may also be required.

B. Analyses

A review has been performed of all events analyzed in the Ginna Station Steam Generator Stress Report. The results of this review provided the basis for an evaluation demonstrating the structural integrity of the sleeved tube configuration for all anticipated normal operating events.

Calculations were performed which demonstrate that the tube sleeve design meets the internal design pressure and temperature requirements of paragraph NB-3324 of the ASME Code. Additional calculations have been performed which demonstrate that the sleeve has a greater external pressure load carrying capacity than the original tube.

A thermal stress analysis of the tube/sleeve assembly has been performed to determine the thermal and pressure loadings and the associated temperatures for the critical normal operating events analyzed in the Ginna Station Stress Report. Loadings at 100% power and transient conditions such as plant heatup and cooldown, plant

B. Analyses (Continued)

loading and unloading, step load transient were considered. By conservatively combining transient conditions, a limited scope fatigue test program has been structured which takes into account the actual versus test temperatures, design versus actual geometry, number of test specimens in accordance with the intent of Appendix II to Section III of the ASME Code. Successful completion of this fatigue test program wil further demonstrate the adequacy of the tube/sleeve configuration for all normal operating events anticipated during the design life of the plant.

An analysis has been performed to determine the effect of 10 sleeved tubes and full steam generator sleeving on the thermal/hydraulic performance of the Ginna Steam Generator. A design point of 90,000 GPM and a total design pressure drop of the Reactor Coolant System of 82.0 psi was considered in the analysis. Sleeving 10 tubes in one steam generator has negligible effect on the overall primary-side pressure drop and the average overall heat transfer coefficient remains practically unchanged. No adverse effects due to cavitation/erosion are expected to occur due to sleeving of 10 tubes in the generator. For a case with sleeves installed in all generator tubes, the primary side pressure drop is expected to increase by approximately 7 percent over that in the unsleeved generator. With this 7 percent pressure drop across the steam generator, the effect on the total primary system pressure drop is small. Considering this increase the effect on the RC pump flow and thus the heat transfer is negligible.

Maximum cross-flow velocities in the steam generator vary from 8.1 feet/second at the tube bundle periphery (feedwater inlet at the edge of the tubesheet) to 2.0 feet/second in the interior region of the tube bundle. Resonant frequency and mode shape calculations have been performed which demonstrate that sufficient frequency separation exists between tube resonant frequencies (34 cycles/second for a sleeved tube which has not been completely severed) and vortex shedding frequencies (8.4 cycles/second in the interior region of the bundle) to ensure that a vibrational instability will not occur.

A review has been performed utilizing the Ginna Station Steam Generator Stress Report to assess the impact of a seismic event on the tube/sleeve assembly. The installation of a sleeve in a tube increases the lowest resonant frequency from 31 cycles/second to 34 cycles/second. This change in resonant frequency will have a negligible impact on the seismic loading; therefore, the original tube design analyses confirm the adequacy of a tube/sleeve assembly.

In support of the limited test sleeve installation, analyses and tests have been conducted which demonstrate the structural adequacy of hte tube/sleeve assembly for seismic and all normal operating events

B. Analyses (Continued)

anticipated for the entire plant design life. Calculations have been performed comparing the strength of a tube with that of a sleeve. These comparisons included the burst strength of the tubing considering the hoop stress of the existing tube with full wall thickness (.050 inches) and with degraded wall thickness (.030 inches). In both cases the sleeve has a lower hoop stress than the existing tube verifying that the 40% of wall degradation plugging criteria for existing tubes is also applicable for the sleeves. Also, the comparisons of the section moduli and cross sectional areas of the sleeve with those of the tube demonstrate that the sleeve performs in bending as well as or better than a tube (with acceptable wall thickness).

C. Conformance with License Conditions

The Technical Specifications and their bases have been reviewed to determine whether changes are required to employ steam generator sleeves. Technical Specification 3.1.5 establishes a limit on primary or secondary leakage of 0.1 gpm. This limit, which was reviewed and approved by the NRC in Amendment No. 16, transmitted on May 14, 1975, ensures steam generator tube integrity under postulated accident conditions. A comparison between hoop stresses in a steam generator tube, and stresses in a sleeve has been performed. Because of the smaller diameter, a sleeve can withstand the differential pressures better than a steam generator tube. Thus, a sleeve with a through-wall crack superimposed upon wastage will perform as well as, or better than, a steam generator tube with a through-wall crack superimposed upon wastage of the same magnitude (in terms of percent wastage). Therefore, since in either case the through-wall crack length is monitored by monitoring primary to secondary system leakage, the current Technical Specification and its Bases remain valid for sleeved tubes.

Specification 4.2 governs the Inservice Inspection of steam generator tubes by references to the Ginna Station Inservice Inspection Program. No changes are required in the Specification. The Inservice Inspection program is being revised to allow steam generator tube sleeving in lieu of plugging. This document is not a part of the plant Technical Specifications and may be revised pursuant to 10CFR 50.59. Indeed, changes and subsequent implementation pursuant to 10CFR 50.59 may, on some occasions, be required to conform to 10CFR 50.55a. Thus, the change to the Inservice Inspection Program does not necessarily require NRC review and approval.

V. POST-INSTALLATION INSPECTIONS

A. Baseline Eddy Current Inspections

The NDE system including eddy current techniques, probes and driver will be used as follows for inspection to the test sleeves. The entire sleeve with the exception of the rolled area in the tubesheet will be scanned using a .610 inch diameter conventional annular differential type probe. The probe will be inserted into the proper tube/sleeve using the positioner and pulled from the tube/sleeve at approximately 0.5 feet per second using the probe driver. The information will be obtained using the Zetec MIZ-12 multifrequency eddy current instrument. Data collected simultaneously at four frequencies will be stored on an 8 channel magnetic tape recorder. The reason for using four separate frequencies is to concentrate the inspection at specific areas, namely, the sleeve itself, the tube behind the sleeve, and the tubesheet component, all in a single scan. Calibration curves constructed after initial system calibration will then be used to estimate the percentage of tube wall and percentage of sleeve wall extent of any flaw which may be detected.

After scanning with the annular probe, a radial absolute probe, with centering collars and spring loaded coil, will be used to interrogate both the brazed joints and expanded areas of the sleeve. Once again, the probe will be driven using the SM-6, but this technique calls for rotating the probe while pulling. An approximate scan rate of .5 inch per minute and 12 rpm will be used. Again multifrequency eddy current will be used to allow simultaneous inspection of sleeve, tube and tubesheet. No calibration curves will be used here. Instead, a rough estimate of flaw depth can be made by referring to calibration signals of flaws of known depth. Baseline inspection will incorporate the annual coil technique and the radial absolute technique.

B. Follow-On Inspection

Follow-on eddy current inspections for the installed sleeves will be conducted during the planned Rochester Gas and Electric outage times. The next outage is planned for April, 1981.

Follow-on inspections will continue to use the annular coil and radial absolute techniques as described above.

VI. GOAL OF TEST INSTALLATIONS

A. Fall, 1980

Ten sleeves are planned to be installed in the "B" steam generator on November 14-16, 1980. Mockup testing, demonstration and training is expected to be conducted November 3-13, 1980.

Fall, 1980 (Continued)

The primary purpose of the test sleeve installation is to show that sleeves can be installed in an operational steam generator. This will confirm field application of the laboratory developed techniques, processes and procedures. Also, an important purpose is to provide actual operational information as a part of the design verification process for the sleeves. This will provide a few sleeves with several months operational time lead over sleeves installed on a larger scale later to provide early warning if a time dependent problem should develop.

B. Later Installations

Substitution on a full scale of sleeving for plugging of tubes with unacceptable tubesheet crevice eddy current indications will be determined based on field test evaluation of the ten test sleeves to be installed in "B" steam generator and on further design verification efforts over the next few months. Based on this evaluation, Rochester Gas and Electric will determine the number of tubes and the schedule for sleeving.

FIGURE 1 - STEAM GENERATOR SLEEVE

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