CEN-626-NP
Rev. 00

COMBUSTION ENGINEERING, INC.

September, 1995

Baltimore Gas and Electric Calver Cliffs Station

Units 1 and 2

Steam Generator Tube Repair

Using Leak Tight Sleeves

FINAL REPORT

Combustion Engineering, Inc.
Nuclear Operations
Windsor, Connecticut

LEGAL NOTICE

ABSTRACT

A technique is presented for repairing degraded steam generator tubes in pressurized water reactor Nuclear Steam Supply Systems (NSSS). The technique described alleviates the need for plugging steam generator tubes which have become corroded or are otherwise considered to have lost structural capability. The technique consists of installing a thermally treated Alloy 690 sleeve which spans the section or sections of the original steam generator tube which requires repair. The sleeve is welded to the tube near each end of the sleeve for repairs at the tube support plates or welded at the upper end and hard rolled within the tube sheet for repairs to the steam generator tube at the top of the tube sheet.

This report details analyses and testing performed to verify the adequacy of repair sleeves for installation in a nuclear steam generator tube. These verifications show tube sleeving to be an acceptable repair technique.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF APPENDICES

1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this report is to provide information sufficient to support a technical specification change allowing installation of repair sleeves in the Calvert Cliffs Units 1 and 2 Combustion Engineering designed steam generators. This report demonstrates that reactor operation with sleeves installed in the steam generator tubes will not increase the probability or consequence of a postulated accident condition previously evaluated. Also it will not create the possibility of a new or different kind of accident and will not reduce the existing margin of safety.

ABB Combustion Engineering (ABB-CE) provides two types of leak tight sleeves for steam generator tube repair. The first type of sleeve spans the parent steam generator tube at the top of the tube sheet. This sleeve is welded to the tube near the upper end of the sleeve and is hard rolled into the tube within the steam generator tube sheet. The steam generator tube with the installed sleeve meets the structural requirements of tubes which are not degraded.

The second type of sleeve spans degraded areas of the steam generator tube at a tube egg crate support, or in a free span section of tube. This leak tight sleeve is welded to the steam generator tube near each end of the sleeve. The steam generator tube with the installed welded sleeve meets the structural requirements of tubes which are not degraded.

Design criteria for both types of sleeves were prepared to ensure that all design and licensing requirements are considered. Extensive analyses and testing have been performed on the sleeve and sleeve to tube joints to demonstrate that the design criteria are met.

The effect of sleeve installation on steam generator heat removal capability and system flow rate are discussed in this report. Heat removal capability and system flow rate was considered for installation of one to three sleeves in a steam generator tube.

After sleeves are installed and inspected, a baseline examination is performed using eddy current (ET) techniques. The ET examination serves as baseline to determine if there is sleeve degradation in later operating years. The ET examination and criteria for plugging sleeved generator tubes if there is unacceptable degradation are described in this report.

Plugs will be installed if sleeve installation is not successful or if there is unacceptable degradation of a sleeve or sleeved steam generator tube. Standard steam generator tube plugs may be used to take a sleeved tube out of service.

1.2 BACKGROUND

The operation of Pressurized Water Reactor (PWR) steam generators has in some instances, resulted in localized corrosive attack on the inside (primary side) or outside (secondary side) of the steam generator tubing. This corrosive attack results in a reduction in steam generator tube wall thickness. Steam generator tubing has been designed with considerable margin between the actual wall thickness and the wall thickness required to meet structural requirements. Thus it has not been necessary to take corrective action unless structural limits are being approached.

Historically, the corrective action taken where steam generator tube wall degradation has been severe has been to install plugs at the inlet and outlet of the steam generator tube when the reduction in wall thickness reached a calculated value referred to as a plugging criteria. Eddy current examination has been used to measure steam generator tubing degradation and the tube plugging criteria accounts for ET measurement uncertainty.

Installation of steam generator tube plugs removes the heat transfer surface of the plugged tube from service and leads to a reduction in the primary coolant flow rate available for core cooling. Installation of welded and/or welded and hard rolled steam generator sleeves does not significantly affect the heat transfer removal capability of the tube being sleeved and a large number of sleeves can be installed without significantly affecting primary flow rate.

2.0 SUMMARY AND CONCLUSIONS

The sleeve dimensions, materials and joints were designed to the applicable ASME Boiler and Pressure Vessel Code. An extensive analysis and test program was undertaken to prove the adequacy of both the welded and welded-hard rolled sleeve. This program determined the effect of normal operating and postulated accident conditions on the sleeve-tube assembly, as well as the adequacy of the assembly to perform its intended function. The proposed sleeving provides for a substitution in kind for a portion of a steam generator tube. The proposed change has no significant effect on the configuration of the plant, and the change does not affect the way in which the plant is operated. Design criteria were established prior to performing the analysis and test program which, if met, would prove that both sleeve types are an acceptable repair technique. These criteria conformed to the stress limits and margins of safety of Section III of the ASME B&PV Code. The safety factors of 3 for normal operating conditions and 1.5 for accident conditions were applied. Based upon the results of the analytical and test programs described in this report the two sleeve types fulfill their intended function as leak tight structural members and meets or exceeds all the established design criteria.

Evaluation of the sleeved tubes indicates no detrimental effects on the sleeve-tube assembly resulting from reactor system flow, coolant chemistries, or thermal and pressure conditions. Structural analyses of the sleeve-tube assembly, using the demonstrated margins of safety, have established its integrity under normal and accident conditions. The structural analyses have been performed for sleeves which span the tube at the top of the tubesheet to a maximum length of [ ] inches, sleeves which span a tube support or free span length of tube with a length of [ ] inches and a combination of the sleeve types. The structural analyses performed are applicable to shorter sleeves installed at the top of the tubesheet and the tube support plate sleeves which may be installed at the Calvert Cliffs Units 1 or 2. The analyses for the different sleeve types and lengths is given in Section 8.

Mechanical testing using ASME code stress allowables has been performed to support the analyses. Corrosion testing of typical sleeve-tube assemblies have been completed and reveal no evidence of sleeve or tube corrosion considered detrimental under anticipated service conditions.

Based upon the testing and analyses performed, the proposed sleeves do not result in a significant increase in the probability of occurrence or consequence of an accident previously evaluated, create the possibility for a new or different kind of accident, or result in a significant reduction in a margin of safety.

Welding development has been performed on clean tubing, dirty tubing which has been taken from pot boiler tests and contaminated tubing taken from a steam generator. ABB-CE installed their first welded sleeves in a demonstration program at Ringhals Unit 2 in May 1984. ABB-CE's sleeving history is shown in Table 2-1. The success rate for all installed sleeves is 98%. Since 1985, no sleeve which has been accepted based on NDE has been removed from service due to degradation.

In conclusion, steam generator tube repair by installation of both types of sleeves is established as an acceptable method. If a steam generator tube which has been sleeved is found to require plugging to remove it from service a standard steam generator tube plug can be installed. Since the standard tube plug can be used, no discussion or evaluation of the tube plug is provided as part of this document.

TABLE 2-1

INSTALLATIONS OF ABB-CE'S WELDED SLEEVE

PLANT	DATE	SLEEVE QUANTITY INSTALLED
Zion 1	1/95	162
Zion 1	11/93	61
KRSKO 1	6/93	160 RTZ 14 TSP
Ginna	4/93	51
Zion 2	12/92	172
Prairie Island 1	11/92	158
ASCO 1	6/92	5 RTZ 49 TSP
Ginna	4/92	175* 63 curved
Zion 1	4/92	124
Kewaunee	3/92	16 curved
Ringhals 3	7/91	46 RTZ 22 TSP
Ginna	4/90	192 48 curved
Zion 2	4/90	83
Prairie Island 1	1/90	63
Zion 1	9/89	445

TABLE 2-1

INSTALLATIONS OF ABB-CE'S WELDED SLEEVE
(continued)

PLANT	DATE	SLEEVE QUANTITY INSTALLED
Ginna	4/89	395 107 curved
Prairie Island 1	9/88	74
Ringhals 2	5/87	571
Ginna	2/87	105
Zion 1	10/86	128
Ringhals 2	5/86	599
Ginna	2/86	36
Ringhals 2	5/85	59
Ringhals 2	5/84	18

* Straight sleeves unless otherwise noted

3.0 ACCEPTANCE CRITERIA

The objectives of installing sleeves in steam generator tubes are twofold. The sleeve must maintain structural integrity of the steam generator tube during normal operating and postulated accident conditions. Additionally, the sleeve must prevent leakage in the event of a through hole in the wall of the steam generator tube. Numerous tests and analyses were performed to demonstrate the capability of the sleeves to perform these functions under normal operating, including T_{HOT} reduction to 596° F, and postulated accident conditions. Design and operating conditions including T_{HOT} reduction for the Calvert Cliffs steam generators are defined as:

Primary Side:	596°F (hot side)[1]	2250 psia (operating)
	604°F (hot side)	2250 psia (operating)
	650°F (design)	2500 psig (design)
Secondary Side:	525°F (100% load)[1]	850 psia (100% load)
	525°F (100% load)	850 psia (100% load)
	550°F (design)	1000 psig (design)

Note 1. The temperature and pressure values represent T_{HOT} reduction.

Table 3-1 provides a summary of the criteria established for sleeving in order to demonstrate the acceptability of the sleeving techniques. Justification for each of the criterion is provided. Results indicating the minimum level with which the sleeves surpassed the criteria are tabulated. The section of this report describing tests or analyses which verify the characteristics for a particular criterion is referenced in the table.

TABLE 3-1

REPAIR SLEEVING CRITERIA

	Criterion	Justification	Results	Reference Section
1.	Sleeve is leak tight.	Leakage between primary and secondary side is prevented when steam generator tube is is breached.		4.0 7.3
2.	Sleeve-tube assembly functional integrity must be maintained for normal operating and accident conditions.	Sleeve-tube assembly meets applicable ASME Code requirements.		8.0
3.	Pressurization of annulus between sleeve and tube does not collapse sleeve at 1500 psig.	Prevention of sleeve failure for through hole in tube wall.		7.3
4.	Pressurize sleeve to 4500 psig without bursting.	Factor of safety of three (3) for normal operating conditions.		7.3
5.	Exposure of sleeve-tube assembly to various primary and secondary chemistries without loss of functional integrity.	Sleeve-tube assembly required to function under coolant chemistries.		6.0
6.	Non-destructive examination of tube and sleeve to levels of detectability required to show structural adequacy.	Periodic examination of tubes and sleeves required to verify structural adequacy.		5.0

TABLE 3-1

REPAIR SLEEVING CRITERIA
(Continued)

	Criterion	Justification	Results	Reference Section
7.	Sleeve installation does not significantly affect system flow rate or heat transfer capability of the steam generator.	Sleeve repair should not reduce power removal capability of reactor or steam generator below rated value.		10.0

4.0 DESIGN DESCRIPTION OF SLEEVES AND INSTALLATION EQUIPMENT

4.1 SLEEVE DESIGN DESCRIPTION

There are two (2) types of sleeves which may be installed in various combinations within a steam generator tube. These sleeves are shown in Figures 4-1 and 4-2. Each sleeve type has a nominal outside diameter of [ ] and a nominal wall thickness of [ ]. The sleeve material is thermally treated Alloy 690. Each of the sleeve types includes a chamfer at both ends to prevent hang-up of equipment used to install the sleeve and to inspect the steam generator tube and sleeve.

The first type of sleeve, shown in Figure 4-1, spans the expansion transition zone at the top of the tubesheet. This sleeve is up to [ ] long and includes [

]. A shorter sleeve (approximately [ ]) of the same design is used to span defective areas of a steam generator tube which exist just above the tube sheet.

The second type of sleeve, shown in Figure 4-2, spans a tube support. The sleeve is [ ] in length. The tube egg crate support sleeve is used at a tube support elevation, or on any free span section of the tube. One or two egg crate support sleeves may be used in a tube and may be used in a tube containing a expansion transition sleeve.

4.2 SLEEVE MATERIAL SELECTION

The thermally treated Alloy 690 tubing, from which the sleeves are fabricated, is procured to the requirements of the ASME Boiler and Pressure Vessel Code, Section II SB-163, Code Case N-20. Additional requirements are applied including a limit on Carbon content of 0.015 - 0.025% and a minimum annealing temperature of 1940°F (1060°C). The thermal treatment is specified at 1300°F (704°C) to impart greater corrosion resistance in potential faulted secondary side environments. The enhanced corrosion resistance is achieved in the thermal treatment by insuring the presence of grain boundary carbides and by reducing the residual stress level in the tubing.

The principal selection criterion for the sleeve material was its resistance to stress corrosion cracking (SCC) in primary and caustic faulted secondary PWR environments. ABB-CE's justification for selection of this material and condition is based on the data contained in Reference 4.7.1.

4.2.1 Field Service Performance

Five non-post weld heat treated sleeves installed at Ringhals II in 1985 and 1986 were removed in January 1990 and extensively examined. These sleeves, which had accumulated up to 22,000 EFPH of service, showed no field service degradation.

4.3 SLEEVE-TUBE ASSEMBLY

The installed sleeve is shown in Figures 4-3 and 4-4. The sleeve shown in Figure 4-3 spans the Expansion Transition Zone (ETZ) at the top of the tubesheet. If defects exist at a egg crate tube support then a Egg Crate Support (ECS) sleeve (Figure 4-4) may be used. The ECS sleeve may be installed in combination with the ETZ sleeve.

The bottom of the [ ] inch sleeve is located [ ] inches above the bottom of the tube end. The upper end of a [ ] inch ETZ sleeve is located [ ] inches above the tube sheet upper face. [ ]

[ ]

The ECS sleeve shown in Figure 4-4 is [ ] inches in length. It is approximately centered at a tube support plate. [

]

[

]

When it is considered to be of benefit, a post weld heat treatment of the sleeve weld will be added to the sleeve installation process. After the sleeve has been welded into the tube, the weld joint is heated in the range of [ ] As described in Reference 4.7.5, this time and temperature combination is sufficient to reduce the level of residual stress in Alloy 600 without resulting in detrimental effects such as grain growth or sensitization. This treatment is similar to that utilized in some operating units to heat treat the tight radius U-bends.

Qualification of the process is in accordance with the procedure described in Appendix A.

4.4 PLUGGING OF A DEFECTIVE SLEEVED TUBE

If a sleeved tube is found to have an unrepairable defect or the sleeve or sleeved tube found to have a pluggable defect, the tube can be taken out of service with standard steam generator tube plugs installed at both ends of the tube using approved methods. The Regulatory Guide 1.121 analysis for the sleeve is included in Section 8.3.

4.5 SLEEVE INSTALLATION EQUIPMENT

The equipment used for remote installation of sleeves in a steam generator is made up of the following basic systems. These systems are:

1. Remote Controlled Manipulator
2. Tool Delivery Equipment
3. Tube Brushing-Cleaning Equipment
4. Tube Size Rolling Equipment
5. Sleeve Expansion Equipment
6. Sleeve Welding Equipment
7. Nondestructive Examination Equipment
8. Sleeve Rolling Equipment
9. Sleeve Heat Treatment Equipment

These systems, when used together, allow installation of the sleeves without entering the steam generator. In this way, personnel exposure to radiation is held to a minimum.

The tooling and methods described in the following sections represent the present technology for leak tight sleeve installation. As technological advances are made in sleeve installation, the new tooling and/or processes may be utilized after they have been laboratory-verified to provide improved sleeve installation methods.

4.5.1 Remote Controlled Manipulator

The remote controlled manipulator (Figure 4-5) serves as a transport vehicle for inspection or repair equipment inside a steam generator primary head.

The manipulator consists of two major components; the manipulator leg and manipulator arm. The manipulator leg is installed between the tube sheet and bottom of the primary head and provides axial (vertical) movement of the arm. The manipulator arm is divided into the head arm, probe arm and a swivel arm. Each arm is moved independently with encoder position controlled electric motors. The swivel arm allows motion for tool alignment in both square pitch and triangular pitch tube arrays. Computer control of the manipulator allows the operator to move sleeving tools from outside the manway and accurately position them against the tube sheet.

4.5.2 Tool Delivery Equipment

The purpose of the tool delivery equipment is to support and vertically position the various tools required for the sleeving operation and to provide controlled rotation to some of the tools. Two different delivery systems may be used for the tool delivery.
[

]

[

]

4.5.3 Tube Brushing-Cleaning Equipment

4.5.4 Tube Rolling Equipment

4.5.5 Sleeve Expansion Equipment

4.5.6 Sleeve Welding Equipment

4.5.7 Nondestructive Examination

4.5.8 Post-Weld Heat Treatment Equipment

4.5.9 Sleeve Rolling Equipment

4.6 ALARA CONSIDERATIONS

The steam generator repair operation is designed to minimize personnel exposure during installation of sleeves. The manipulator is installed from the manway without entering the steam generator. It is operated remotely from a control station outside the containment building. The positioning accuracy of the manipulator is such that it can be remotely positioned without having to install templates in the steam generator.

The tool delivery equipment is designed so that the dovetail fitting quickly attaches to the manipulator. The probe pusher is designed to quickly engage the individual sleeving tools. The tools are simple in design and all sleeving operations are performed remotely using tools held by the manipulator. Each tool can be changed at the manway in 10-15 seconds. A tool operation is performed on several sleeves rather than performing each tool operation on the same sleeve before proceeding to the next sleeve. This reduces the number of tool changes which are required. Spare tools are provided so that tool repair at the manway is not required. If tool repair is necessary, the tool is removed and sleeve operation continues using a spare tool. The tool may or may not be repaired during the outage but repair is performed in an area which does not have significant radiation.

Air, water and electrical supply lines for the tooling are designed and maintained so that they do not become entangled during operation. This minimizes personnel exposure outside the steam generator. Except for the welding power source and programmer all equipment is operated from outside the containment. The welding power source and programmer is stationed about a hundred feet from the steam generator in a low radiation area.

In summary, the steam generator operation is designed to minimize personnel exposure and is in full compliance with ALARA standards.

4.7 REFERENCES TO SECTION 4.0

4.7.1 Alloy 690 for Steam Generator Tubing Applications, EPRI Report NP-6997, October 1990.

4.7.2 Sedricks, A. J., Schultz, J. W., and Cordovi, M. A., "Inconel Alloy 690 - A New Corrosion Resistant Material", Japan Society of Corrosion Engineering, 28, 2 (1979).

4.7.3 Airey, G. P., "Optimization of Metallurgical Variables to Improve the Stress Corrosion Resistance of Inconel 600", Electric Power Research Institute Research Program RP1708-1 (1982).

4.7.4 Airey, G. P., Vaia, A. R., and Aspden, R. G., "A Stress Corrosion Cracking Evaluation of Inconel 690 for Steam Generator Tubing Applications", Nuclear Technology, 55, (November, 1981) 436.

4.7.5 Hunt, E.S. and Gorman, J.A., Specifications for In-Situ Stress Relief of PWR Steam Generator Tube U-bends and Roll Transition, EPRI Report NP-4364-LD, Electric Power Research Institute, Palo Alto, CA, December 1985.

4.7.6 Krupowicz, J. J., Scott, D. B., and Fink, G. C., "Corrosion Performance of Alternate Steam Generator Materials and Designs Vol. 2: Posttest Examinations of a Seawater Faulted Alternative Materials Model Steam Generator," EPRI-NP-3044, July 1983.

4.7.7 G. Santarini et al, Recent Corrosion Results - Alloy 690, EPRI Alloy 690 Workshop, New Orleans, LA, April 12-14, 1989.

FIGURE 4-1
EXPANSION TRANSITION ZONE SLEEVE

FIGURE 4-2
<u>EGG CRATE SUPPORT SLEEVE</u>

FIGURE 4-3
EXPANSION TRANSITION ZONE SLEEVE INSTALLATION

FIGURE 4-4
EGG CRATE SUPPORT SLEEVE INSTALLATION

FIGURE 4-5
MANIPULATOR AND TOOL DELIVERY SYSTEM

FIGURE 4-6
TOOL DELIVERY EQUIPMENT

FIGURE 4-7
TUBE CLEANING EQUIPMENT

FIGURE 4-8
SLEEVE EXPANSION EQUIPMENT

FIGURE 4-9
SLEEVE WELDING HEAD ASSEMBLY

FIGURE 4-10
SLEEVE WELDING HEAD POWER SUPPLY UNIT

FIGURE 4-11
ULTRASONIC TEST EQUIPMENT

FIGURE 4-12
VISUAL TEST EQUIPMENT

FIGURE 4-13
POST WELD HEAT TREAT EQUIPMENT

FIGURE 4-14
SLEEVE ROLLING EQUIPMENT - STRAIGHT

FIGURE 4-15
SLEEVE ROLLING EQUIPMENT - CURVED

FIGURE 4-16
EDDY CURRENT TEST EQUIPMENT

5.0 SLEEVE EXAMINATION PROGRAM

5.1 ULTRASONIC INSPECTION

5.1.1 Summary and Conclusions

An ultrasonic examination is used to confirm fusion of the sleeve to the tube after welding. This test consists of introducing sound energy with a frequency of [ ] into the welded region. A rotation device enables a 360 degree scan around the tube, whereafter the ultrasonic transducer is raised approximately [ ] and the weld scanned again. A minimum of three scans are performed and if continuous fusion is shown for 360 degrees, the weld is considered acceptable. The sound beam that is used is capable of easily detecting a 0.050 inch wide milled notch made across the weld.

5.1.2 Ultrasonic Evaluation

Ultrasonic techniques are employed to confirm the presence of sleeve-tube weld fusion. The evaluations were made of Inconel 690 alloy sleeves with nominal dimensions of [ ]. The

Alloy 600 steam generator tubes are [ ]. Weld position is approximately [ ] from the end of the sleeve.

Ultrasonic energy of [ ] is emitted from a transducer through a contained water column in the vicinity of the weld. After passing into the sleeve at its entry point, the sound continues to travel until it arrives at a separation in material or to the opposite side of the material. The transducer is designed so that its energy is focused at the sleeve outer diameter wall, [ ].

When sound enters a weld with proper fusion, a reflection of sound energy may be obtained from the tube outer wall. Should no fusion exist at a given point, the sound energy will travel only as far as the sleeve outer wall. In the former case, weld fusion will be displayed on the Cathode Ray Tube (CRT) by first an interface signal where sound enters the sleeve, followed by a second signal from the tube outer surface (back wall reflection). Depending upon weld geometry, the tube backwall reflection amplitude may sometimes vary.

Where lack of fusion exists, the sound will only travel to the first reflector, which is the sleeve O.D. The display on the CRT will still show the interface signal, followed now by a more closely spaced reflection or reflections, which denotes the thickness of the sleeve (Figure 5-2).

A weld area is considered to have proper fusion where there is an absence of the sleeve back wall reflection(s).

The weld examination begins when the transducer is inserted into the tube-sleeve assembly to a position such that the transducer is aligned with the lower edge of the weld. The transducer is then rotated 360 degrees at this elevation and the degree of fusion is determined by observing the ultrasonic instrument's CRT, supplemented by other readouts. Additional scans at higher elevations can be performed to evaluate the complete weld area. Ultrasonic inspection of the weld may also be conducted by locating the probe at the upper edge of the weld and indexing down after each circumferential scan.

In this manner, the weld integrity can be assured and lack of fusion, with an area equivalent to a slot with a width of [ ], can reliably be detected. In actual tests, a lack of fusion [ ] inches wide has been reliably detected.

5.1.3 Test Equipment

Test equipment for welded sleeve inspection consists of the following components:

[ ]

[ ]

5.1.4 Defect Samples

Qualification of the ultrasonic inspection system was made through use of calibration standards, and fourteen production welds made in a mock-up.

The calibration sample (Figure 5-3) has [ ], which extend across the width of the weld. This sample was inspected prior to machining the notches into them, to insure usage of acceptable welds. The system was calibrated according to procedure, and calibration standards evaluated in the computer control mode.

The fourteen (14) production welds in the mockup were then evaluated in the same manner. Of the fourteen, three welds were found to have lack of fusion. In addition, a blow hole was indicated in one specimen found to have acceptable fusion.

5.1.5 Detailed Results

The computer output for the calibration sample and four (4) production welds are included in this report.

Each chart shows the C-scan obtained from the weld tested. In evaluating the C-scans, the light sections are areas of proper fusion, and are acceptable. The dark areas indicate lack of fusion, and when continuous across the width of weld, a leak path exists and the weld is rejectable.

Additional information on each chart includes the following:

a) Rotation (degrees). This is the angular position of the transducer measured in degrees.

b) Elevation (inches). The elevation or vertical position of the transducer within the sleeve is given in inches. This information enables approximation of the weld height and location of any lack of fusion areas.

c) Scan limits. The upper and lower scan limits for the weld are shown by the elevations indicated at the 360 degrees position.

d) Data on the top of each chart relates to information concerning the inspected tube, steam generator and time, as well as weld signal amplitude threshold values for recording. The classification of the weld is given at the bottom of the charts.

In reviewing the computer readouts for the calibration standard and production welds used, the analysis results are as follows:

5.2 EDDY CURRENT INSPECTION

5.2.1 Background

In-service inspection of the sleeved tubes will be done as part of the periodic inspection program of the steam generator tubing. Initially, however, all sleeves will be examined. A sampling program consistent with inspection requirements will be used for subsequent examinations. The inspection will be performed using the most recently developed eddy current probes and techniques for sleeving inspection. The eddy current probes that may be used include: The new advanced "+" point rotating probe, the motorized axial differential probe, motorized rotating I-coil or the rotating cross-wound bobbin coil. Other coils and/or methods will be considered for any complementary inspection capability they may provide. The discussion that follows focuses on the ET probe(s) that are most likely to be used for the primary inspection.

The objective of the installation examination is to establish baseline data on the primary pressure boundary of the sleeve-tube assembly. The examination criteria is to reliably detect 40% ASME flaws in the parent tube and/or sleeve in any region of the pressure boundary of the sleeve-tube assembly with an eddy current probe. Future qualification programs will consider more realistic flaws, including axial and circumferential cracks, as well as other improved NDE methodologies. The goal of which is to extend the capability of NDE to assure the integrity of the sleeves indefinitely.

An eddy current test (ET) has been qualified for the inspection of installed sleeves to detect flaws in the pressure boundary. The eddy current test method is a technique whereby electrical currents are induced electromagnetically from the test coil into the sleeve and parent tube material. The electrical currents are interrupted or impeded by the presence of flaws in the material which results in a change in the test coil impedance. This impedance change is processed and displayed on the test instrument to indicate the presence of a flaw.

The pressure boundary is considered to be the sleeve up to and including both joints, the steam generator tube above the upper weld and below the lower rolled joint for a ETZ sleeve or below the lower weld for a TSP sleeve. Consequently, there are four distinct regions of the pressure boundary relative to the inspection methods:

1) The sleeve between the upper weld and the lower joints, either weld or rolled depending on sleeve type.

2) The region of the steam generator tube behind the sleeve above an upper weld and below a lower weld.

3) The steam generator tube below the rolled joint of a ETZ sleeve.

4) The unsleeved region of the steam generator tube.

ABB-CE recently re-qualified eddy current inspection for installed sleeves. This qualification effort had three main objectives:

1) Assess the capabilities of the new "+" point probe in comparison to the motorized rotating axial differential probe (MRAD), I-coil probe, cross-wound bobbin and pancake coil.

2) Assure reliable detection of a 40% ASME flaw in the parent tube in and above the weld transition. This location is the worst case region for flaw detection since the signal response is influenced by the expansion geometry, weld and a large air gap.

3) Consider the requirements of EPRI Appendix H Guidelines for qualifying the inspection methodology.

The tooling and methods described in this section represent the present technology for sleeve inspection. As technological advances are made in NDE methods for sleeve inspection, the new equipment and/or processes may be utilized after they have been laboratory-verified to provide improved inspection of the pressure boundary regions of a sleeved steam generator tube.

5.2.2 Sleeved Tube Samples for Qualification Testing

The most recent qualification effort was undertaken for sleeve-in-sleeve inspection. Three samples were made for the qualification testing effort. Two of the samples were sleeve-sleeve-tube configurations that represented the material, dimensions and geometries of the as-installed sleeves. A third sample was configured to represent the worst case geometry for flaw detection. The following is a brief description of the samples:

Sample 1--Sleeve-sleeve-tube with 40% ASME flaw in tube at the top of the expansion.

Figure 5-9 shows the sample and the placement of the 40% flaw. Also shown in Figure 5-9 is the **pressure boundary**. The pressure boundary is defined as the sleeve/tube regions where their integrity is essential to prevent primary-to-secondary leakage.

Sample 2--Sleeve-sleeve-tube with 40% axial and circumferential EDM notches located at the top of the expansion. The flaws were placed 180° from each other.
Figure 5-10 shows the sample and the placement of the EDM notches. This sample was intended to show NDE detection capability surpassing the 40% ASME flaw detection criteria. In addition, this sample also provided the basis for assessing a probe's ability to characterize geometry and flaw orientation.

Sample 3--A sleeve-in-parent tube with 40% and 100% ASME flaws.

The intent of this sample was to simulate the large radial air gap (0.075 inch) between the inner sleeve and the tube. This is the most challenging region for flaw detection. Figure 5-11 illustrates this sample and the placement of the flaws.

The pressure boundary is shown in Figures 5-9 and 5-10. The boundary defines the areas of interest for flaw detection. Although flaw detection has been verified for the pressure boundary, it is likely that flaws outside the boundary will also be detected.

Welded sleeve samples were prepared for previous qualification efforts. These samples contained two full sets of ASME flaws, one set each in the parent tube and in the sleeve.

5.2.3 New Advanced "+" Point Rotating Probe for Sleeve Inspection

ABB-CE has tested a newly developed advanced rotating eddy current probe coil for sleeving inspections. It is called the "+" point probe and has advantages over existing probe coil designs. It combines the advantages of the motorized rotating axial differential probe and the rotating cross-wound bobbin by providing equal sensitivity to both axial and circumferential flaws. In this regard it is similar to the "I"-coil which also has equal sensitivity, but is not based on the "I"-coil concept.

The +point probe has unique characteristics for noise suppression as a result of the 90° opposing windings configured in the shape of a plus-point. The axial and circumferential windings provide sensitivity to both circumferential and axial flaws, respectively. The axial winding has a response 180° out of phase from the circumferential winding. As a result, the coil acts similar to a differential coil to suppress the effects of geometry and the support structure. This is a major advantage in the expansion and weld regions where it is difficult to distinguish flaws from geometry, particularly ID flaws.

The plus-point probe is built using a 3-coil probe housing with a standard pancake coil occupying one of the coil slots, the +point coil in another slot and a blank in the third slot. The +point coil is placed 120° from the pancake coil on the probe circumference. As with the standard 3-coil MRPC, this probe marks each revolution with a trigger pulse. The axial translation of the probe through the SG tube is done by the probe pusher. The result of the simultaneous rotation and axial translation is a helical scan of the tube with a pitch of about 0.040 inch per revolution.

The tests on the sleeve samples with this coil have shown very good detection sensitivity to a 40% deep, 3/16" diameter ASME flat bottom hole in the parent tube at the uppermost expansion transition. The location of the flaw was chosen as representative of the most difficult to detect scenario. The flaw location is in the pressure boundary where the signal is obscured by several geometric factors: the expansion transition, the location on the O.D. of a second tubewall and, the very large (0.075 inch) air gap between the innermost sleeve and the parent tube. Reliably detecting this flaw would mean that the test method could detect this flaw anywhere in the pressure boundary.

5.2.3.1 Summary - New Advanced "+" Point Rotating Probe

The "+" point rotating probe coil offers several advantages for sleeve inspection. Potentially, this probe coil offers the combined advantages of the motorized rotating axial differential probe and the various bobbin style probes. The probe has shown very good detection sensitivity while minimizing noise due to very large transitions. Suppression of the hydraulic expansion transition signal was accomplished using digital bandpass filtering. Further qualification testing is on-going to characterize the probe's capabilities. This probe may replace the MRAD, I-coil and bobbin coil probes. Alternately, the "+" point probe can be augmented with these other probes to provide complementary inspection capability.

5.2.3.2 Qualification Testing - New Advanced "+" Point Rotating Probe

The prototype probe coil was tested on two mock-ups of an actual sleeve-sleeve-tube configuration and a sample of sleeve-in-parent tube. One of the assemblies had a 40% deep, 3/16 inch diameter flat-bottom-hole (FBH) machined into the O.D. of the parent tube at the uppermost expansion transition. The other assembly had 40% circumferential and axial EDM notches in the same location. Data was acquired at 50 to 120 kHz. The probe coil was manufactured to operate at a center frequency of approximately 100 to 110 kHz. At 50 kHz, one standard depth-of-penetration is approximately .085 inches and at 120 kHz it is approximately .055 inches. This is a good choice for the frequency range since it corresponds to a range of 1-2 skin depths of the combined .080 inches of sleeve and tubewall.

Figure 5-12 shows the eddy current response at 50 kHz to the 40% FBH in the sleeve sample. The signal component due to the flaw is shown at about a 70° phase angle in the Lissajous display. The horizontal signal component is due to the expansion transition. The channel P1 is the 50 kHz data which has been bandpass filtered to suppress the effects of the expansion transition. The left strip chart in this figure shows the significant landmarks in the sleeve sample which are labeled A through K. Figure 5-13 shows a C-scan contour plot highlighting the flaw. Figure 5-14 shows the response to the 40% ASME flaw through the gap. Figure 5-15 shows the response to the EDM notches.

5.2.3.3 Results and Conclusions - New Advanced "+" Point Rotating Probe

The qualification tests of the "+" point rotating probe coil show that it meets the acceptance criteria for detection of the 40% ASME flaw in the expansion transition. Additionally, this qualification effort also sought to determine detection sensitivity to axial and circumferential EDM notches in conjunction with geometry. The probe shows very good detection sensitivity, a minimum of noise and very good phase separation for the critical flaw size with respect to noise. In summary, the following observations were made for the "+" point rotating probe:

1) It meets the qualification criteria for detection of 40% ASME flaw in parent tube.

2) It has good sensitivity through the air gap, although not as good as the MRAD or I-coil.

3) The probe has acceptable noise levels. The noise was higher than expected and higher than the MRAD.

4) The probe has good sensitivity to the EDM notches. The probe was less sensitive to the circumferential notch than to the axial. This was probably due to the geometry influence.

This probe coil has the best overall performance and is therefore recommended to be the primary means for sleeve inspection.

5.2.4 Motorized Rotating Axial Differential Probe

ABB-CE had previously developed a motorized rotating axial differential probe that has shown improvements in flaw detection and its characterization related to the circumferential extent when used in the welded sleeve development program. [ ] This probe has superior detection capability for circumferential flaws but has no real detection capability for axial flaws.

5.2.4.1 Summary - Motorized Rotating Axial Differential Probe

A recent improvement in the eddy current technique for the examination of sleeved steam generator tubes is the motorized rotating axial differential probe (MRAD), see Figure 5-16. The MRAD probe can be used when the suspect flaw mechanism is a circumferentially oriented flaw or when improved signal to noise ratios are desired at sleeve ends and expansion transitions. The MRAD probe will detect flaws in the sleeve and parent tube. The probe is particularly recommended when the suspected flaw is in the parent tube at the sleeve end or expansion transitions. The axial differential coil arrangement minimizes the signals from these regions while retaining a sensitivity to flaws which is equivalent to the sensitivity of standard bobbin coil, crosswound coil or segmented bobbin coil probes. The probe can be operated in the differential and absolute mode using conventional digital data acquisition and analysis methods.

5.2.4.2 Qualification Testing - Motorized Rotating Axial Differential Probe

The MRAD probe coil was tested on the two mock-ups of an actual sleeve-sleeve-tube configuration and a sample of sleeve-in-parent tube. Data was acquired at 50 to 120 kHz, although the probe coil was manufactured to operate at a somewhat higher center frequency of approximately 200 to 300 kHz. The choice of frequencies is based on necessity to be within the range of 1-2 skin depths of the combined .080 inches of sleeve and tubewall. The lower frequencies are used for detection of flaws in the parent tube. The higher frequencies are used for flaw sizing and for differentiating sleeve from parent tube flaws. Multifrequency mixing and/or digital filtering can be used for the suppression of OD deposits and geometry.

Figure 5-17 shows the response to the 40% ASME flaw through the air gap. Figure 5-18 shows the repsonse to the 40% ASME flaw in the expansion transition and Figure 5-19 shows the response to the EDM notches.

A different defect sample was used for the original qualification effort. This sample contained the following simulated flaws:

1. 60% TW x 7/64 inch diameter flat bottom hole in the SG tube OD at the weld.
2. 40% TW x 3/16 inch diameter flat bottom hole in the SG tube OD at the weld.
3. 20% TW x 3/16 inch diameter flat bottom hole in the SG tube OD at the weld.
4. 60% TW x 7/64 inch diameter flat bottom hole in the SG tube OD at the upper expansion transition.
5. 40% TW x 3/16 inch diameter flat bottom hole in the SG tube OD at the upper expansion transition.
6. 20% TW x 3/16 inch diameter flat bottom hole in the SG tube OD at the upper expansion transition.

The welded sleeve sample was tested at 50, 75, 100 and 200 kHz compared to a frequency range of 50 to 120 kHz for the sleeve-in-sleeve samples. The lower frequencies are for detection of flaws in the parent tube. The higher frequencies are used for flaw sizing and for differentiating sleeve from parent tube flaws. Other frequencies can be qualified for special test situations as they arise. Multifrequency mixing to suppress OD deposits and digital filtering can be used for signal conditioning.

5.2.4.3 Results and Conclusions - Motorized Rotating Axial Differential Probe

The surface riding feature of the MRAD probe combined with the differentiating capabilities in the circumferential direction resulted in exceptional sensitivity to the 40% ASME flaw. This probe has the lowest noise levels compared to the other probes which is of significant benefit in the expansion transition. In summary, the following observations were made for the MRAD probe:

1) It meets the qualification criteria for detection of a 40% ASME flaw in parent tube

2) It has very good sensitivity through the air gap. The large size of the coil results in greater field strength and improved signal-to-noise (S/N).

3) The probe has excellent noise immunity. The noise level was the lowest of the coils tested. This was expected due to the noise cancellation properties of a differential coil.

4) The probe has very good sensitivity to the circumferential EDM notch. The probe was not capable of detecting axial flaws which is its only major drawback.

This probe coil is recommended for supplemental examination in the event that the presence of circumferential flaws are suspected.

5.2.5 I-Coil Rotating Probe

The I-coil was developed a few years ago to address the needs of sleeving inspection. Its performance has been satisfactory even though other probe designs have since been pursued. The basic concept of this probe coil was to provide equal sensitivity to both axial and circumferential flaws.

5.2.5.1 Summary - I-Coil Probe

The I-coil design contains two diametrically opposed absolute coils configured as a differential pair. One coil is circumferentially wound, the other is axially wound. The two coils allow the probe to provide sensitivity to both circumferential and axial flaws.

5.2.5.2 Qualification Testing - I-Coil Probe

The I-coil probe was tested on the two mock-ups of an actual sleeve-sleeve-tube configuration and a sample of sleeve-in-parent tube. Data was acquired at 50 to 120 kHz, the same frequencies that the other probes were tested at. The center frequency is approximately 200 kHz. As explained above, the choice of frequencies is based on necessity to be within the range of 1-2 skin depths of the combined .080 inches of sleeve and tubewall. The lower frequencies are used for detection of flaws in the parent tube. The higher frequencies are used for flaw sizing and for differentiating sleeve from parent tube flaws.

Figure 5-20 shows the response to the 40% ASME flaw through the air gap. Figure 5-21 shows the response to the 40% ASME flaw in the expansion transition and Figure 5-22 shows the response to the EDM notches.

5.2.5.3 Results and Conclusions - I-Coil Probe

In general, this probe provides good sensitivity to the flaws with a moderate noise level. Its ability to cancel noise is limited by the fact that the differential pair is diametrically opposed so that no local noise suppression is possible. In summary, the following observations were made for the I-coil probe:

1) It meets the qualification criteria for detection of 40% ASME flaw in the parent tube.
2) It has good sensitivity through an air gap. Its response was better than the "+" point coil but not as good as the MRAD.
3) The probe has moderate noise levels. The design of this coil does not give it good noise cancellation characteristics.
4) The probe has good sensitivity to the EDM notches, although not as good as with the "+" point coil. As was evident with "+" point coil, this probe also had less sensitivity to the circumferential notch. Again, this can be attributed to the geometry influence.

This probe coil performed comparably to the "+" point coil. Its one advantage over the "+" point is that it has greater sensitivity through the air gap. The I-coil was, however, slightly less sensitive to the notches. The I-coil is a suitable back-up (2nd choice) to the "+" point.

5.2.6 Motorized Rotating Pancake Coil (MRPC) Probe

A standard MRPC probe was also used to test these samples. In concept, the pancake coil MRPC provides equal sensitivity to both circumferential and axial flaws. However, since it is an absolute coil, there is no means for noise suppression. Consequently, this probe has an overwhelming response to the large geometric transitions associated with the expansions and weld. This resulted in unacceptably low signal-to-noise responses to the flaws in the expansion areas. Although the performance of this probe was the least satisfactory, it still can be used to inspect straight sections of the sleeve and parent tube.

5.2.7 Appendix H Qualification

For future in-service inspections it may be necessary to inspect the installed sleeves using techniques qualified to EPRI Appendix H guidelines. Although it was not within the scope of this effort to develop an Appendix H qualified inspection, a qualification effort could be undertaken in the future to meet a request by a utility.

The examination plan for an Appendix H qualification would require at least 16 samples, 11 or 2/3 of which have flaws greater than or equal to 60% TW. The remaining 5 samples would have flaws less than 60% TW. The guidelines provide a standard basis for an industry accepted inspection technique that statistically assures an 80% probability-of-detection with 90% confidence.

5.2.8 Conclusions

The acceptance criteria for this inspection is based on the historical criteria of detecting a 40% OD through-wall ASME flaw in the tube pressure boundary. For the sleeve inspection this translates to detecting a 40% ASME specified flaw in the OD of the parent tube in the region that is influenced by the expansion geometry, weld and the air gap. Reliably detecting this flaw is the acceptance criteria for sleeve inspection. Three of the coils tested met this acceptance criteria. Obviously, it is desirable to find smaller and more realistic flaws which was the motivation for using EDM notches for the development effort.

The issue of flaw sizing was not addressed for the sleeve-in-sleeve. The reason is that previous qualification efforts for sleeving inspection have developed the methodology for sizing and distinguishing sleeve from parent tube flaws. The pressure boundary of the sleeve-in-sleeve is essentially the same as the sleeved tube with regard to flaw sizing. Therefore, it was not necessary to pursue this.

The information presented here is based on the most recent qualification effort for inspecting the sleeve-in-sleeve configuration. As stated above, the sleeve-in-sleeve is representative of the welded sleeve configuration with regard to the pressure boundary. The sleeve-in-sleeve configuration is more difficult to test than the welded sleeve due to the very large expansions and air gaps. Although the sleeve-in-sleeve is not welded, the weld itself is not as detrimental to eddy current sensitivity as the large expansions and air gap. Therefore, the sleeve-in-sleeve qualification in conjunction with the previous welded sleeve qualification effort establishes the current state-of-the-art inspection for welded sleeves.

The "+" point coil has the best overall performance and is therefore currently recommended as the general purpose probe for sleeve inspections. The I-coil is also a good general purpose probe and can be used as a back-up to the "+" point. The axial differential coil (MRAD) is a special purpose probe that is recommended for use when circumferential flaws are suspected. Other probes and/or techniques may be employed as technological advances are made.

5.3 VISUAL INSPECTION

5.3.1 Summary and Conclusions

Visual examinations can be performed on the sleeve to steam generator tube welds to support UT results. The welds are examined using a diameter CCD camera system or a boroscope examination system.

The lighting is supplied as an integral part of the visual examination system. Each examination is recorded on video tape for optional later viewing and to provide a permanent record of each weld's condition.

The visual inspections are performed to ascertain the mechanical and structural condition of a weld. Critical conditions which are checked include weld width and completeness and the absence of visibly noticeable indications such as cracks, pits, blow holes, burn through, etc.

5.3.2 Weld Examination

A visual examination can be made of the sleeve to tube weld using a CCD camera system or a boroscope inspection system. This system utilizes a right-angle lens for weld viewing. The tool delivery system positions the VT tool at the weld and provides 360° of tool rotation.

To perform the inspection, the optics system is inserted into the sleeve-tube assembly such that the lens is located at the weld. After checking for visual clarity and adjusting the lighting to reduce unwanted glare, the tool is rotated 360°. The tool may then be raised or lowered and the process repeated to ensure complete weld coverage. The entire examination is video-taped for a permanent record.

Prior to the inspection, the system's adequacy is checked by observing a 1/32 inch black line on an 18% neutral gray card placed in a location similar to the area to be inspected. Additionally, to obtain an aspect for size and to check the in-tube lighting, a welded sleeve-type sample with a .020 inch diameter through hole is placed over the lens.

The weld acceptance is based on the absence of cracks or other visible imperfections which would be detrimental to the integrity of the weld. Detrimental imperfections include blow holes, weld mismatch, etc. During the examination, any area which contains noticeable imperfections is examined more closely by varying the light intensity and/or the position of the lens with respect to the indication.

5.3.3 Test Equipment

The test equipment necessary to visually inspect the sleeve to tube welds consists of the following:

1. A micro camera or boroscope visual examination system with an integral lighting system, lenses and a delivery and rotational tool for inspecting the upper and lower welds.

2. 18% neutral gray card with a 1/32 inch black line.

3. Welded sleeve-tube sample with a .020 inch diameter through drilled hole.
4. Video camera and recording equipment.

5.3.4 Defect Standards

Various methods are used to determine system adequacy and to aid in determining weld acceptability.

1. System adequacy, including lighting intensity and camera system clarity, is verified by resolving a 1/32 inch black line on an 18% neutral gray card.

2. Size aspect for upper weld inspections is obtained by viewing a welded sleeve-tube sample which has a .020 inch through drilled hole.

3. Sleeve-tube welds were made with both acceptable welds and intentional weld malformities. These welds were photographed and are used as aids to examiner.

FIGURE 5-1
ULTRASONIC PROBE WITHIN A WELDED SLEEVED TUBE

FIGURE 5-2
ULTRASONIC INSTRUMENT CRT RESPONSE

FIGURE 5-3
REFERENCE STANDARD FOR 3/4 inch TUBE

FIGURE 5-4

SPECIMEN QUA-5: ACCEPTABLE WELD

FIGURE 5-5
REFERENCE STANDARD

FIGURE 5-6
SPECIMEN QUA-11: REJECTED WELD

FIGURE 5-7
SPECIMEN QUA-14: REJECTED WELD

FIGURE 5-8
SPECIMEN QUA-13: REJECTED WELD

MECHANICAL SLEEVE
CONFIGURATION

FIGURE 5-9
PRESSURE BOUNDARY DESCRIPTION AND SAMPLE FLAW LOCATION

① FLAWS ARE LOCATED AT THE TOP ROLL TRANSITION

MECHANICAL SLEEVE
CONFIGURATION

FIGURE 5-10
PRESSURE BOUNDARY DESCRIPTION AND SAMPLE FLAW LOCATION

FIGURE 5-11

FLAW SAMPLE FOR LARGE SLEEVE TO STEAM GENERATOR TUBE ANNULUS

FIGURE 5-12
RESPONSE AT 50 kHZ
NEW ADVANCED ROTATING PROBE

FIGURE 5-13
C-SCAN CONTOUR PLOT WITH A TUBE FLAW
NEW ADVANCED "+"POINT ROTATING PROBE

FIGURE 5-14

40% ASME FLAW THROUGH AIR GAP

NEW ADVANCED "+" POINT ROTATING PROBE

FIGURE 5-15
RESPONSE TO EDM NOTCHES
NEW ADVANCED "+" POINT ROTATING PROBE

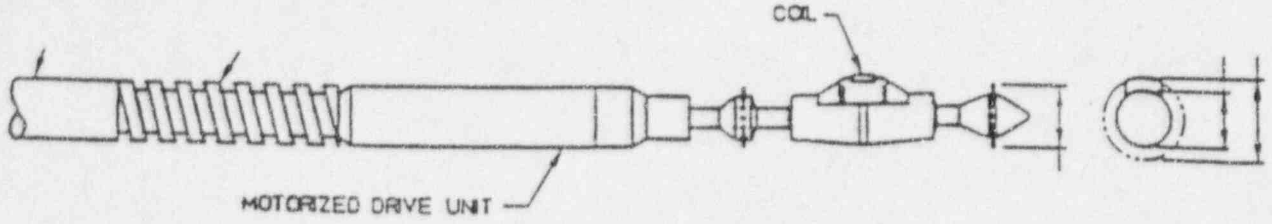


FIGURE 5-16
<u>TYPICAL MOTORIZED AXIAL DIFFERENTIAL PROBE</u>

FIGURE 5-17
40% ASME FLAW THROUGH AIR GAP
MOTORIZED ROTATING AXIAL DIFFERENTIAL PROBE

FIGURE 5-18
40% ASME FLAW IN EXPANSION TRANSITION
MOTORIZED ROTATING AXIAL DIFFERENTIAL PROBE

FIGURE 5- 19
RESPONSE TO EDM NOTCHES
MOTORIZED ROTATING AXIAL DIFFERENTIAL PROBE

FIGURE 5-20
40% ASME FLAW THROUGH AIR GAP
I-COIL PROBE

FIGURE 5-21
40% ASME FLAW IN EXPANSION TRANSITION
I-COIL PROBE

FIGURE 5-22
RESPONSE TO EDM NOTCHES
I-COIL PROBE

6.0 SLEEVE-TUBE CORROSION TEST PROGRAM

C-E has conducted a number of bench and autoclave tests to evaluate the corrosion resistance of the welded sleeve joint. Of particular interest is the effect of the mechanical expansion/weld residual stresses and the condition of the weld and weld heat affected zone. Tests have been performed on welded joints with and without a post-weld heat treatment. An outline of these tests is shown in Table 6-1. [

]

6.1 SUMMARY AND CONCLUSIONS

[ ]

6.2 TEST DESCRIPTION AND RESULTS

6.2.1 Primary Side Tests

[ ]

TABLE 6-1
STEAM GENERATOR TUBE SLEEVE CORROSION TESTS

6.2.1.1 Pure Water Stress Corrosion Cracking Tests

6.2.1.2 Above the Tubesheet (ATS) Weld Capsule Tests

6.2.1.3 ECS Sleeve Weld Capsule Tests

TABLE 6-2
ABB-CENO ACCELERATED PRIMARY SIDE SCC TESTS

TABLE 6-3
ENSA ACCELERATED PRIMARY SIDE SCC TEST

6.2.1.4 Summary - Primary Coolant Corrosion Performance

TABLE 6-4
LOCAL SLEEVE/TUBE JOINT APPLIED STRESSES

TABLE 6-5
AXIAL STRESSES IN TUBE AT SLEEVE JOINT
TUBE LOCKED AT SUPPORT

6.2.2 Secondary Side Tests

6.2.2.1 Modified Huey Tests

6.2.2.2 Capsule Tests

TABLE 6-6

SECONDARY SIDE STEAM GENERATOR TUBE SLEEVE CAPSULE TESTS

ENVIRONMENT	EXPOSURE TIME	RESULTS
A.		
B.		
C.		
D.		

6.2.2.3 Sodium Hydroxide Fault Autoclave Tests

6.2.2.4 Summary - Secondary Coolant Corrosion Performance

6.3 REFERENCES FOR SECTION 6.0

6.3.1 Satistical Analysis of Steam Generator Tube Degradation, EPRI Report NP-7493, September 1991.

6.3.2 Summary Report, Combustion Engineering Steam Generator Tube Sleeve Residual Stress Evaluation, TR-MCC-153, November 1989.

6.3.3 I. L. W. Wilson and R. G. Aspden, "Caustic Stress Corrosion Cracking of Iron-Nickel-Chromium Alloys." Stress Corrosion Cracking and Hydrogen Embrittlement of Iron Base Alloys, NACE,Houston, Texas, pp 1189-1204, 1977.

6.3.4 A. J. Sedriks, S. Floreen, and A. R. McIlree, "The Effect of Nickel Content on the Stress Corrosion Resistance of Fe-Cr-Ni in an Elevated Temperature Caustic Environment". Corrosion,Vol. 32, No. 4, pp 157-158, April 1976.

6.3.5 F. W. Pement, I. L. W. Wilson and R. G. Aspden, "Stress Corrosion Cracking Studies of High Nickel Austenitic Alloys in Several High Temperature Aqueous Solutions." MaterialsPerformance, Vol. 19, pp 43-49, April 1980.

6.3.6 P. Berge and J. R. Donati, "Materials Requirements for Pressurized Water Reactor Steam Generator Tubing." NuclearTechnology, Vol. 55, pp 88-104, October 1981.

6.3.7 G. P. Airey, A. R. Vaia and R. G. Aspden, "A Stress Corrosion Cracking Evaluation of Inconel 690 for Steam Generator Tubing Applications." Nuclear Technology, Vol. 55, pp 436-448, November 1981.

6.3.8 J. R. Crum and R. C. Scarberry, "Corrosion Testing of Inconel Alloy 690 for PWR Steam Generators." Journal of Materials for Energy Systems, Vol. 4, No. 3, pp 125-130, December 1982.

FIGURE 6-1
PURE WATER CORROSION TEST SPECIMEN

FIGURE 6-2
ATS WELD CAPSULE TEST SPECIMEN

FIGURE 6-3
ECS WELD CAPSULE TEST SPECIMEN

FIGURE 6-4
CAUSTIC CORROSION AUTOCLAVE TEST SPECIMEN

7.0 MECHANICAL TESTS OF SLEEVED STEAM GENERATOR TUBES

7.1 SUMMARY AND CONCLUSIONS

Mechanical tests were performed on mockup steam generator tubes containing sleeves to provide qualified test data describing the basic properties of the completed assemblies. These tests determined axial load, collapse, burst and thermal cycling capability. A minimum of three tests of each type were performed.

Table 7-1 summarizes the results of the mechanical testing performed on the sleeve-tube assemblies. The demonstrated load capacity of the assemblies provides an adequate safety factor for normal operating and postulated accident conditions. The load capability of the upper and lower sleeve joints is sufficient to withstand thermally induced stresses in the weld resulting from the temperature differential between the sleeve and the tube and pressure induced stresses resulting from normal operating and postulated accident conditions. The burst and collapse pressures of the sleeve provide a large safety factor over limiting pressure differential. Mechanical testing revealed that the installed sleeve will withstand the cyclical loading resulting from power changes in the plant and other transients.

7.2 CONDITIONS TESTED

The following tests were performed on the sleeve-tube assemblies at room temperature: axial pull, load cycling, burst and collapse. Loads were applied until the point of failure, or in the case of cyclic loading, until the number of cycles exceeded the expected number of cycles for the plant.

7.3 WELDED SLEEVE TEST PARAMETERS AND RESULTS

7.3.1 Axial Pull Tests

7.3.2 Collapse Testing

7.3.3 Burst Testing

7.3.4 Load Cycling Tests

TABLE 7-1

SLEEVE-TUBE ASSEMBLY MECHANICAL TESTING RESULTS*

COMPONENT AND TEST	RESULTS (MAXIMUM)	RESULTS (MINIMUM)

---

* A minimum of three tests of each type were performed.

8.0 STRUCTURAL ANALYSIS OF SLEEVE-TUBE ASSEMBLY

This analysis establishes the structural adequacy of the sleeve-tube assembly. The methodology used is in accordance with the ASME Boiler and Pressure Vessel Code, Section III. The work was performed in accordance with 10CFR50 Appendix B and other applicable U.S. Nuclear Regulatory Commission requirements.

8.1 SUMMARY AND CONCLUSIONS

Based on the analytical evaluation contained in this section and the mechanical test data contained in Section 7.0, it is concluded that both the Expansion Transition Zone (ETZ) and Egg Crate Support (ECS) sleeves decribed in this document, meet all the requirements stipulated in Section 8.0 with substantial additional margins.

8.1.1 Design Sizing

In accordance with ASME Code practice, the design requirements for tubing are covered by the specifications for the steam generator "vessel". The appropriate formula for calculating the minimum required tube or sleeve thickness is found in Paragraph NB-3324.1, tentative pressure thickness for cylindrical shells (Reference 8.1). The following calculation uses this formula.

[ ]

Where t = Min required wall thickness (in).
P = Maximum Design Tubesheet differential pressure (ksi)(per Reference 8.4)
R = Inside Radius of sleeve (in).
S_m = Design Stress Intensity (S.I.)(per Reference 8.2)

8.1.2 Detailed Analysis Summary

When installed and welded within specified tolerances, the ETZ sleeve and its upper weld and lower rolled joint, and the ECS sleeve and its two primary welds possess considerable margin against pull-out for all loading which can be postulated from operating, emergency, test, and faulted conditions.

The axial loads in the sleeve are a function of their location within the bundle and on the degree of tube/support lock-up. The most severe combination is determined to be[ ] for 100% steady state power which also envelopes the current operating parameters in

Reference 8.12 where the primary hot leg temperature is reduced.

TABLE 8-1

SUMMARY OF SLEEVE AND WELD ANALYSIS RESULTS

* - The allowables listed in Table 8-1 are in accordance with the ASME Code (References 8.1 and 8.2)

FORMULAS FOR GENERAL MEMBRANE STRESSES SUMMARIZED IN TABLE 8-1
(Note: All SI equations below are a derivation of the formula in Par. NB-3324.1 of Ref. 8.1.)

1. GENERAL PRIMARY MEMBRANE STRESS (DESIGN TUBESHEET DELTA PRESSURE)

2. MAIN STEAM LINE BREAK

Where,

3. PRIMARY PIPE BREAK (LOCA)

$$S.I_{LOCA} = \frac{\Delta PR}{t} + \frac{\Delta P}{2}$$

Where ΔP is the secondary side heatup pressure (-1.00 ksi, max. external), which is less than 6.5 ksi for instability failure to occur with this type of external pressure application. Thus, the equation for internal pressure is applicable for this ΔP external pressure value.

TABLE 8-2

SUMMARY OF ROLLED JOINT DESIGN, ANALYSIS AND TEST RESULTS

8.2 LOADINGS CONSIDERED

In this section a number of potential failure modes are examined to determine the relative safety margins for selected events. Failure loads are calculated based on minimum dimensions and compared with mechanical testing results from Section 7.0. Both calculated and measured loads are compared with the maximum postulated loads.

8.2.1 Upper Tube Weld Pullout Load

Assuming the parent tube is totally severed, the minimum load required to shear the upper tube weld is calculated. The force required to pull the expanded sleeve through the unexpanded tube is conservatively neglected.

[ ]

In the event of a main steam line break (MSLB), the secondary pressure would drop in a short time interval. The primary pressure would rise briefly then follow the drop in secondary pressure. It is conservatively assumed that the full primary pressure remains when the secondary pressure reaches zero. The maximum pullout load would be:

$$P_{MSLB} = P_{MSLB} \times \pi R_{it}^2 = (2250)\,\pi\,(.327)^2 = 756 \text{ lbs.}$$

$$\text{Safety Factor } SF_{MSLB} = 4640/756 = 6.1$$

8.2.2 Lower Sleeve Rolled Section Pushout Load

Assuming the parent tube is totally severed, the minimum load required to rupture the lower rolled section is calculated. The minimum measured test value for the pushout load is[ ]lbs., see Section 7.

Postulating a loss of primary coolant accident (LOCA) during hot standby condition (0% Power), the maximum available load would be:

Note that the LOCA pipe break accident is not controlling for this joint. See Section 8.4.

8.2.3 Weld Fatigue

Since the factors of safety are quite high for loadings due to primary stress, the failure mechanism of greatest interest is the fatigue failure mode considering the variable axial loading of the sleeve during normal operating transients.

In Section 8.6, fatigue evaluations of the upper weld, which join the sleeve to the tube will be made. It is first necessary to determine the effects that tube lock-up within the tubesheet and tube supports have on the axial loads in the sleeve during normal operation. This subject is addressed in Section 8.4.

8.3 EVALUATION FOR ALLOWABLE SLEEVE WALL DEGRADATION USING REGULATORY GUIDE 1.121

NRC Regulatory Guide 1.121 (Reference 8.3) requires that a minimum acceptable tube (or sleeve) wall thickness be established to provide a basis for leaving a degraded tube in service. For partial thru-wall attack from any source, the requirements fall into two categories, (a) normal operation safety margins, and (b) considerations related to postulated pipe rupture accidents.

8.3.1 Normal Operation Safety Margins

It is the general intent of these requirements to maintain the same factors of safety in evaluating degraded tubes as those which were contained in the original construction code, ASME Boiler and Pressure Vessel Code, Section III (Reference 8.1).

For Inconel Alloy 600 and 690 tube or sleeve material the controlling safety margin is:

"Tubes with partial thru-wall cracks, wastage, or combinations of these should have a factor of safety against failure by bursting under normal operating conditions of not less than 3 at any tube location".

From Reference 8.4, the normal operating conditions for the steam generators are:

Primary Pressure P_{pri} = 2250 psi

Secondary Pressure P_{sec} = 850 psi

Differential Pressure $\Delta P = P_{pri} - P_{sec} = 1400$ psi

Average Pressure $P_{avg} = 0.5\ (P_{pri} + P_{sec}) = 1550$ psi

Assuming the parent tube is totally severed, the sleeve is required to carry the pressure loading. The following terms are used in this evaluation.

R_{is} = sleeve nominal inside radius

$Sy_{r.m.}$ = minimum required yield strength
(per U.S. NRC Reg. Guide 1.121)

Sy_{min} = actual minimum yield strength of sleeve
(Sy = 35.2 ksi minimum at 650 °F)

8.3.2 Postulated Pipe Rupture Accidents

8.4 EFFECTS OF TUBE LOCK-UP ON SLEEVE LOADING

Objective: Conservatively determine the maximum axial loads on the sleeve (tension and compression) during normal operation.

General Assumptions: (See Figures 8-2 through 8-4).

8.4.1 Sleeved Tube, Free at Tube Support

TABLE 8-3

30 INCH SLEEVE

AXIAL MEMBER PHYSICAL PROPERTIES

	OUTSIDE RADIUS R_e (in)	INSIDE RADIUS R_i (in)	LENGTH L (in)	SECTION AREA A (in^2)	CORRESPOND. Temp. T_c (°F)	YOUNGS MODULUS E $lb/in^2 \times 10^6$	STIFFNESS $K = AE/L$ $lb/in \times 10^3$	MEAN COEF. THERM. EXP. α_m In/In °F x 10^{-6}

Reference Temperatures:
Primary (Hot) = 604°F
Secondary = 503°F
Normal Tubes = $(2\ T_{pri} + T_{sec})/3$ = 570.3°F

NOTE:
[1] α_m and E for Inconel 690 from Reference 8.2.
[2] α_m for Carbon Moly Steel from Reference 8.1.

TABLE 8-4

AXIAL LOADS IN SLEEVE WITH TUBE NOT LOCKED INTO Tube support

CONDITION	T_{pri} (°F)	T_{sec} (°F)	Sleeve Deflection δ_1 (In)	Lower Tube Deflection δ_2 (In)	Tube in Tubesheet δ_3 (In)	δ_{forced} (In)	Sleeve Load F_1 (lbs)	Sleeve Load Deflection $\Delta_1 = F_1/K_1$ (In)	Net Elongation $(\delta_1 + \Delta_1) = \delta$ (In)

*NOTE: Due to small variation, E and α_m value for normal operation, 100% power, are used.

TABLE 8-5

AXIAL LOADS IN SLEEVE WITH TUBE LOCKED INTO Tube support

CONDITION	T_{pri} (°F)	T_{sec} (°F)	$T_t = (2T_p+T_s)/3$ (°F)	Surrounding Tubes Deflection δ_3 (In)	Upper Tube Deflection δ_4 (In)	δ_{forced} (In)	Composite Member Load F_6 (lbs)	Composite Member Load Deflection $\Delta_6 = F_6/K_6$ (In)	Resultant Sleeve Load Deflection $\Delta_1' = \Delta_1 + \Delta_6$ (In)	Sleeve Load $F_1 = \Delta_1' K_1$ (lbs)

*NOTE: Due to small variation, E and α_m value for normal operation, 100% power are used.

8.4.2 Sleeved Tube, Lock-up at First Tube Support

8.4.3 Effect of Tube Prestress Prior to Sleeving

8.4.4 Lower Sleeve Rolled Section Pushout Due to Restrained Thermal Expansion

8.5 SLEEVED TUBE VIBRATION CONSIDERATIONS

The vibration behavior is reviewed since the installation of a sleeve in a tube could affect the dynamic response characteristics of the tube.

8.5.1 Effects of Increased Stiffness

Stiffness and mass have opposing influences on tube vibration. While increased stiffness tends to raise the tube natural frequency, increased mass tends to lower it. ABB/CE's vibrational testing (Reference 8.6) demonstrated among other things, that a solid rod of the same O.D. as a tube will vibrate at nearly the same frequency. However, the displacements for the stiffer rod will be significantly less.

In addition, if any contact is made between the tube and sleeve along their length, the increased damping will absorb more energy. The damping would have a significant effect on amplitude of vibration. In light of this damping effect and the other above mentioned effects resulting from a sleeve inside a tube, the vibration performance of the tube/sleeve assembly is superior over the original tube.

8.5.2 Effect of Severed Tube

8.5.3 Seismic Evaluation

It is concluded that a seismic event produces a small stress in the tube sleeve.

8.6 STRUCTURAL ANALYSIS FOR NORMAL OPERATION

A static elastic analysis of the sleeved tube assembly was performed according to the requirements stipulated in NB-3220 Section III of the ASME Code Section. This section describes the methods used to analyze the upper tube weld.

8.6.1 Fatigue Evaluation of Upper Sleeve/Tube Weld

The above described transient combinations, tabulated in Table 8-6, are inherently conservative. A stress concentration factor of four (4) was applied to the linearized primary plus secondary stresses for purposes of computing the fatigue usage factors.

The results of the analysis, including element stress tabulations at critical sections and fatigue usage factors, are contained on Appendix 8A. All stresses and usage factors are satisfactory when compared to allowable stresses. For detailed results see Section 8.1.2, Table 8-1 and Appendix 8A.

8.6.2 Evaluation of Lower Sleeve Rolled Section

TABLE 8-6

UPPER SLEEVE WELD - TRANSIENTS CONSIDERED

TABLE 8-7

LOWER SLEEVE ROLLED SECTION - TRANSIENTS CONSIDERED

8.7 REFERENCES FOR SECTION 8.0

8.1 ASME Boiler and Pressure Vessel Code, Section III for Nuclear Power Plant Components, 1965 edition through Winter 1967 addendum.

8.2 ASME Boiler and Pressure Vessel Code Case N-20, "SB-163 Nickel-Chromium-Iron Tubing (Alloys 600 and 690) at a Specified Minimum Yield of 40.0 Ksi".

8.3 U.S. NRC Regulatory Guide 1.121, "Bases for Plugging Degraded PWR Steam Generator Tubes".

8.4 ABB/CE Report CENC-1161, "Analytical Report for Baltimore Gas and Electric Power Company Steam Generator", November 1971.

8.5 "Mechanical Vibrations", 4th Edition, by J.P. Hartog, McGraw-Hill Book Co., New York, New York, pg. 432.

8.6 "Vibration in Nuclear Heat Exchangers Due to Liquid and Two-Phase Flow," By W.J. Heilker and R.Q. Vincent, Journal of Engineering for Power, Volume 103, Pages 358-366, April 1981.

8.7 ABB/CE Nuclear Services Licensing Report No. CEN-337-P, "V.C. Summer Steam Generator Tube Repair using Leak Tight Sleeves", dated August 29, 1986.

8.8 EPRI NP-1479, "Effect of Out-of-Plane Denting Loads on the Structural Integrity of Steam Generator Internals," Contractor: Combustion Engineering, August 1980.

8.9 Macon Worth's (Carolina Power & Light - Shearon Harris) fax to B. Bell on "Required Inputs for Welded Steam Generator Sleeve Analyses", dated July 13, 1995.

8.10 "Model D4 Steam Generator Thermal and Hydraulic Design Data Report for Carolina Power & Light Company - Shearon Harris Unit 1", WTD-PE-77-22 Revision 1, dated November 20, 1984.

8.11 Inconel 690, Huntington Alloys, Inc., Huntington, W. Virginia.

8.12 ABB/CE Report CR-9419-CSE95-1113, Rev. 0, "Effects of Tube Plugging on BG & E Calvert Cliffs Units 1 and 2 Steam Generator Thermal - Hydraulic Performance", July 18, 1995.

FIGURE 8-1

WELDED SLEEVE/TUBE ASSEMBLY

FIGURE 8-2

SYSTEM SCHEMATIC

FIGURE 8-3

STIFFNESS MODEL OF SLEEVE AND LOWER TUBE

FIGURE 8-4

STIFFNESS MODEL OF UPPER TUBE AND SURROUNDING TUBES

FIGURE 8-5

FINITE ELEMENT MODEL OF UPPER TUBE WELD

APPENDIX 8A

FATIGUE EVALUATION OF UPPER SLEEVE/TUBE WELD

FIGURE 8A-1

UPPER SLEEVE/TUBE WELD MODEL

TABLE 8A-1A

STRESS RESULTS, 100% STEADY STATE AXIAL LOAD

SLEEVE, SECTION 1

TABLE 8A-1A (Continuing)

TUBE, SECTION 3

TABLE 8A-1B

STRESS RESULTS, 15% STEADY STATE AXIAL LOAD

SLEEVE, SECTION 1

TABLE 8A-1B (Continuing)

TUBE, SECTION 3

TABLE 8A-1C

STRESS RESULTS, 0% STEADY STATE AXIAL LOAD

SLEEVE, SECTION 1

TABLE 8A-1C (Continuing)

TUBE, SECTION 3

TABLE 8A-2

FATIGUE EVALUATION

SECTION 1 OUTSIDE SURFACE OF SLEEVE

9.0 SLEEVE INSTALLATION VERIFICATION

9.1 WELD INTEGRITY

9.1.1 Cleaning Qualification

9.1.2 Expansion Qualification

9.1.3 Weld Qualification

9.1.4 Ultrasonic Testing Qualification

[

]

9.1.5 Post Weld Heat Treat Qualification

[

]

9.1.6 Summary

9.2 ROLLED JOINT INTEGRITY

9.3 COMMERCIAL SLEEVE INSTALLATION

ABB-CE's commercial sleeving experience is shown in Table 9-3. The success rate for all installed welded sleeves is 98%. Since 1985, no sleeve which has been accepted based on U.T. and V.T. has been removed from service due to service related degradation.

This data is also compiled in Table 9-4 indicating the number of EFPY of exposure sleeves in each of the specific plants have experienced. The steam generators in which sleeves have been installed have experienced various tube degradation mechanisms, primarily caustic secondary side attack and primary water stress corrosion cracking. In one of these units, Ringhals 2, six (6) sleeved tubes which had seen up to three (3) EFPY were removed when the steam generators were replaced in 1989 (Reference 6.4). Examination of these sleeved tubes indicated weld heights consistent with ultrasonic

9.4 REFERENCES FOR SECTION 9.0

9.4.1 Test Report on Steam Generator Tube Cleaning for Installation of Welded Sleeves, TR-MCM-126.

9.4.2 An Investigation of the Installation of Welded Sleeves in R.E. Ginna Tubing, TR-MSD-128.

9.4.3 Sleeving Centrifugal Wire Brush Development and Life Test Report, TR-ESE-705.

9.4.4 S.G. TSP/RTZ Sleeving-Tube I.D. Cleaning for 3/4 Inch O.D. X .042/.043 Wall Tubes, TR-ESE-860.

9.4.5 Steam Generator Sleeving - 3/4 inch Program, Bladder Expansion Pressure, TR-ESE-755.

9.4.6 Steam Generator Sleeving - 3/4 inch Program, Qualification of RTZ and TSP Sleeve Expansion Tools and Bladder Life Test, TR-ESE-809.

9.4.7 Ultrasonic Examination of 3/4 inch O.D. S.G. Tube to Sleeve Upper Welds, TR-400-001.

9.4.8 Qualification of the Post Weld Heat Treatment Tool for Westinghouse "D" Series Steam Generators, 00000-ESE-830.

9.4.9 Qualification of the Roll Transition Zone (RTZ) Sl[illegible] Rolled Joint, 00000-ESE-826.

TABLE 9-1
0.875 O.D. SLEEVED TUBE PWHT DATA

TABLE 9-2
0.750 O.D. SLEEVED TUBE PWHT DATA
TUBES LOCKED AT ALL SUPPORTS

TABLE 9-4
ABB-CENO S/G SLEEVE OPERATING HISTORY

Plant	Hot Leg Temp (F)	Sleeve Type (1)	Estimated EFPY of Sleeve Operation (2) <1	1	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	Total
Ringhals 2	610	STAW		16													
	600	STAW			571	599		59	16								1245
Ginna	601	STAW			51	178		183	198		408			104		36	1158
		PTAW				63		29	48		107						247
Prairie Island (4)	590	STAW												73		27	100
		STHT		117		158					62						337
Kewaunee (4)	590	PTAW				16											16
Zion 1	594	STAW		61	124			445				128					758
Zion 2 (4)	594	STAW	162	170				82									414
Ringhals 3 (4)	610	RTHT						46									46
		SPHT						22									22
KRSKO (4)	619	RTHT		164													164
		SPHT		16													16
Total			162	528	746	1014	0	866	262	0	577	128	0	177	0	63	4523
Cumulative Total			4523	4361 (3)	3833	3087	2073	2073	1207	945	945	368	240	240	63	63	

Notes:

(1) Sleeve Type designations and their totals are as follows:

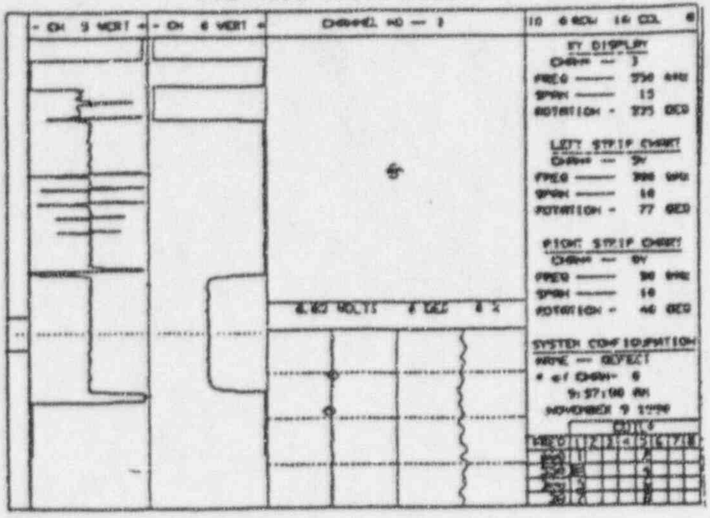
		Totals
STAW	StandardTubesheet sleeves where the welds are in the As Welded condition	3737
PTAW	Peripheral (Initially Curved) Tubesheet sleeves where the welds are in the As Welded condition	263
STHT	StandardTubesheet sleeves where the upper weld has been Post Weld Heat Treated	275
RTHT	Roll Transition sleeves where the weld has been Post Weld Heat Treated	210
SPHT	Support Plate sleeves where the welds have been Post Weld Heat Treated	38

(2) EFPY of operation is based either on data received from the plant or calculated from the load factor published in Nuclear Engineering International for the period during which the sleeves have been in place. Operating time is rounded to the neares 0.1 EFPY as of 1 July 1995

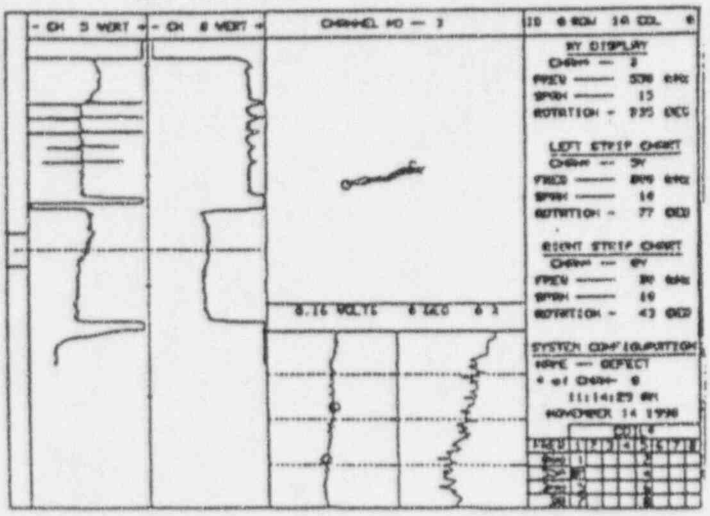
(3) 16 Sleeves which ran for a year at Ringhals 2 before T hot was reduced are included in totals for 600 F

(4) Plants inspected with I-coil or Plus Point ECT probe

Pre Heat Treat Baseline



Post Heat Treat - Oxidized Section



Post Heat Treat - Brushed Section

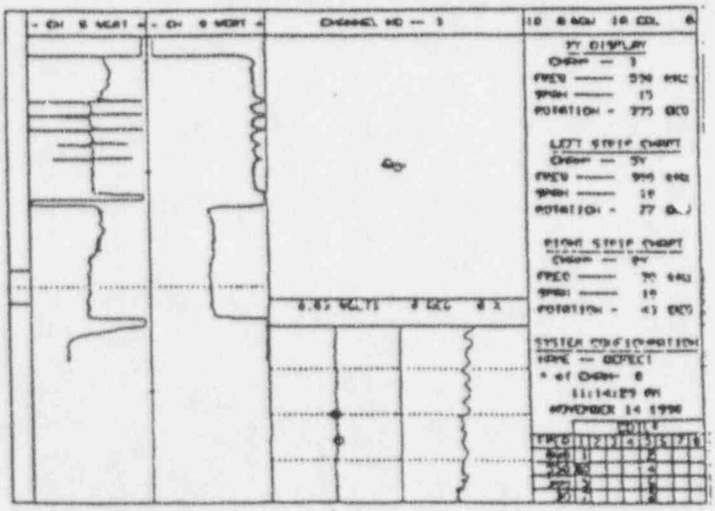


FIGURE 9-1
POST HEAT TREAT - BRUSHED SECTION

FIGURE 9-2
0.875 O.D. LOCKED TUBE TEST

FIGURE 9-3
0.875 O.D. LOCKED TUBE TEST
TEMPERATURE AND AXIAL LOAD PROFILE

FIGURE 9-4
0.750 O.D. LOCKED TUBE MOCKUP

Eggcrate Support Sleeve

FIGURE 9-5
0.750 O.D. TYPICAL TEMPERATURE PROFILES

10.0 EFFECT OF SLEEVING ON OPERATION

FIGURE 10-1
PERCENT REDUCTION IN PRIMARY SYSTEM FLOW RATE
WITH SLEEVES IN HOT LEG

FIGURE 10-2
PERCENT REDUCTION IN PRIMARY SYSTEM FLOW RATE
WITH PLUGGED TUBES

TABLE 10-1

SLEEVE TO PLUG EQUIVALENCY RATIO FOR CALVERT CLIFFS UNITS 1 and 2

CASE	SLEEVING CONFIGURATION	EQUIVALENCY RATIO SLEEVES/PLUG

APPENDIX A

PROCESS AND WELD OPERATOR QUALIFICATIONS

A.1 SLEEVE WELDING AND SLEEVE WELDER QUALIFICATION

Sleeve welding is qualified using an approved test procedure (Reference 1). The sleeving test procedure is in compliance with applicable sections of the ASME Code. Sleeve welders are qualified using test records in accordance with applicable sections of the Code.

The test procedure specifies the requirements for performing the welds, the conditions (or changes) which require requalification, the method for examining the welded test assemblies and the requirements for qualifying the welding operators. Sleeve welding is qualified by performing six consecutive welds of each type which meet specified design requirements. Welders are qualified by performing two consecutive successful welds of each type.

A.2 REFERENCES TO APPENDIX A

1. Welded Steam Generator Tube Sleeve Semi-Automatic Gas Tungsten Arc Detailed Welding Procedure Qualification, Test Procedure 00000-MCM-050.