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ATTACHMENT E

COMBUSTION ENGINEERING, INC. NON-PROPRIETARY REPORT CEN-630, "REPAIR OF ¾" O.D. STEAM GENERATOR TUBES USING LEAK TIGHT SLEEVES," JUNE 1997

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COMBUSTION ENGINEERING, INC.

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Repair of

3/4" O.D.

Steam Generator Tubes

Using Leaktight Sleeves

FINAL REPORT

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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 lower end or welded at the upper end and hard rolled at the lower end for repairs to the steam generator tube in the tube sheet region.

This report details analyses and testing performed to verify the adequacy of repair sleeves for installation in a 3/4 inch O.D. nuclear steam generator tube. These verifications show tube sleeving to be an acceptable repair technique.

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As noted in this topical report, CEN-630-P, "Repair of 3/4" O.D. Steam Generator Tubes Using Leak Tight Sleeves", the tooling and methods described represent the current technology implemented for sleeve installation and inspection. As technological advances are made in sleeve installation and/or inspection techniques, the new tooling and/or processes may be utilized after they have been laboratory verified to provide improved sleeve installation methods, or after a suitable qualification program has demonstrated improved performance. Such advances/improvements may be implemented provided that they do not involve alternative joining technology or alternative sleeve material, and provided that the 10CFR50.59 process has demonstrated that no unreviewed safety question will be created. The 10CFR50.59 process will be performed under the licensee's program.

1. 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 3/4" O.D. tube steam generators including; ABB CENO designed steam generators and Westinghouse designed Series D and E 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 repair of 3/4 inch O.D. steam generator tubes with full depth rolled or expanded tubesheet joints. The first type of sleeve spans the parent steam generator tube at the top of the tubesheet. This sleeve is welded near the upper end and hard rolled into the tube within the steam generator tubesheet. 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 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 all 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.

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 were being approached.

Historically, the corrective action taken when 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 (ET) 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

1.3 ACRONYMS

Table 1-1 (along with Table 5-1) contains a list of the acronyms used throughout this report.

TABLE 1-1

ACRONYMS USED IN REPORT

+ POINT: + Point ™

ATS: Above the Tubesheet

EFPH: Effective Full Power Hours

EPPY: Effective Full Power Years

ET: Eddy Current Testing

ETZ: Expansion/Roll Transition Zone

LOF: Lack of Fusion

PWHT: Post Weld Heat Treatment

TS: Tube Support

UT: Ultrasonic Testing

VT: Visual Testing

2. 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 these 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 these sleeve types fulfill their intended function as leak tight structural members and meet or exceed 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 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 tubesheet and tube support sleeves. The analyses for the different sleeve types and lengths are given in Section 8.

Mechanical testing using ASME code stress allowables has been performed to support the analyses. Corrosion tests 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 number of steam generators. 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 service induced degradation.

Inspection methods have been qualified capable of detecting installation or inservice flaws consistent with the calculated minimum sleeve wall or weld thickness and an appropriate growth rate for the expected flaw type.

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. No discussion or evaluation of the standard tube plug is provided as part of this document.

In conclusion, steam generator tube repair by installation of any of the two types of sleeves described herein is established as an acceptable method.

TABLE 2-1

INSTALLATIONS OF ABB-CE WELDED SLEEVES

PLANT	DATE	INSTALLED QUANTITY	INSTALLED TYPE*
Kewaunee	5/97	428	WTS
Zion 2	10/96	226	WTS
KRSKO	6/96	273	TS
		188	ETZ
Byron 1	4/96	3527	ETZ
Prairie Island 1	2/96	253	WTS
ANO 2	10/95	711	ETZ
Zion 1	10/95	911	WTS
Zion 2	1/95	162	WTS
Zion 1	11/93	61	WTS
KRSKO	6/93	160	ETZ
		14	TS
Ginna	4/93	51	WTS
Zion 2	12/92	172	WTS
Prairie Island 1	11/92	158	WTS
Ginna	4/92	175	WTS
		63	Curved WTS
Zion 1	4/92	124	WTS
Kewaunee	3/92	16	Curved WTS
Ringhals 3	7/91	46	ETZ
		22	TS
Ginna	4/90	192	WTS
		48	Curved WTS
Zion 2	4/90	82	WTS
Prairie Island 1	1/90	63	WTS
Zion 1	9/89	445	WTS

TABLE 2-1 (Continued)

INSTALLATIONS OF ABB-CE WELDED SLEEVES

PLANT	DATE	INSTALLED QUANTITY	TYPE
Ginna	4/89	395	WTS
		107	Curved WTS
Prairie Island 1	9/88	74	WTS
Ringhals 2	5/87	571	WTS
Prairie Island 1	4/87	27	WTS
Ginna	2/87	105	WTS
Zion 1	10/86	128	WTS
Ringhals 2	5/86	599	WTS
Ginna	2/86	36	WTS
Ringhals 2	5/85	59	WTS
Ringhals 2	5/84	18	WTS

* Straight sleeves unless otherwise noted

WTS - Welded Tubesheet
TS - Tube Support
ETZ - Expansion Transition Zone

3. 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-wall defect in the steam generator tube. Numerous tests and analyses were performed to demonstrate the capability of the sleeves to perform these functions under normal operating and postulated accident conditions.

Operating conditions used to bound the CE steam generators are defined as: (Pressure and temperature differences were considered in determining bounding conditions)

Primary Side: (Hot Side)	611°F (operating)	2250 psig (operating)
Secondary Side:	506°F (100% load)	815 psig (100% load)

Operating conditions used to bound the W steam generators are defined as: (Pressure and temperature differences were considered in determining bounding conditions)

Primary Side: (Hot Side)	620°F (operating)	2250 psig (operating)
Secondary Side:	526.5°F (100% load)	815 psig (100% load)

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	Section
1.	Sleeve is leak tight	Leakage between primary and secondary side is prevented.	Welded joint is leak tight and is checked using U.T., E.T. and/or V.T. Rolled joint is leak tight by monitoring torque.	4.0
2.	Sleeve-tube assembly functional integrity must be maintained.	Sleeve tube assembly meets applicable ASME Code requirements.	Structural margins maintained for all conditions.	8.0
3.	Axial load cycle without weld joint or rolled joint failure.	Bounds cycle loading from normal operating and transient cycling.	No failure of weld or rolled joint. No damage to sleeve or tube.	7.0
4.	Pressurization of annulus between sleeve and tube does not collapse sleeve at 1500 psig.	Prevention of sleeve failure for through wall defect in tube wall.	Assembly collapse at 4500 psig.	7.0
5.	Pressurize sleeve (without tube) to 4800 psig without bursting.	Factor of safety of three for N.O. conditions.	No assembly burst at up to 6500 psig.	7.0
6.	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	No detectable indication of sleeve or joint corrosion or aggravated tube corrosion.	6.0
7.	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	ECT technique developed that exceeds EPRI guidelines and Appendix H requirements.	5.0
8.	Welded 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.	System flow rate and heat transfer capability are not significantly affected.	10.0

4. 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 [ ] inches and a nominal wall thickness of [ ] inches. The sleeve material is thermally treated Alloy 690. Each of the sleeve types include a chamfer at both ends to prevent hang-up of equipment used to install the sleeve and to facilitate the inspection of the steam generator tube and sleeve.

The first type of sleeve, shown in Figure 4-1, spans the expansion transition or roll transition at the top of the tubesheet. This Expansion/Roll Transition Zone (ETZ) sleeve is up to [ ] inches long and includes a [ ]

The second type of sleeve, shown in Figure 4-2, spans a tube support or egg crate support plate. This Tube Support (TS) sleeve is [ ] inches in length. The sleeve spans a support plate elevation or can be used on a free span section of the tube.

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) for a minimum of two minutes. The thermal treatment is specified at 1300°F (704°C) for a minimum of five hours 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.

4.3 SLEEVE-TUBE ASSEMBLY

The installed sleeves are shown in Figures 4-3 and 4-4. The Expansion Transion Zone (ETZ) sleeve spans the expansion/roll transition zone at the top of the tubesheet. If defects exist at a tube support or egg crate support plate, as well as, at the top of the tubesheet, an ETZ sleeve and a Tube Support (TS) sleeve may be used.

The ETZ sleeve, shown in Figure 4-3, is [ ] inches in length or shorter. The bottom of the sleeve is located near the neutral axis of the tubesheet. [

]

[

]

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

]

[

]

When it is considered to be of benefit (based on steam generator primary and secondary side conditons), 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 while minimizing 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 sleeve welding process is in accordance with the procedure described in Appendix A.

4.4 PLUGGING OF A DEFECTIVE SLEEVED TUBE

If a sleeve or sleeved tube is found to have an unrepairable 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.

4.5 SLEEVE INSTALLATION PROCESS AND 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

[ ]

These systems, when used together, allow installation of the sleeves without personnel 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. [

]

The probe driver is a modified Zetec probe pusher or equivalent unit located outside the manway of the steam generator. A flexible conduit extending from the probe driver to an adaptor on the manipulator arm provides the guide path for the tools. The guide path adaptor is attached to the end of the manipulator arm by a dovetail fitting and manual lock. The drive wheels of the probe driver deliver the tools to the required elevations within the tube. Where positioning is critical, a hardstop attached to the tool shaft locates the tool relative to the steam generator tube end.

The tool delivery system for controlled tool rotation consists of two major components; [ ], Figure 4-6. The tool mounting plate is attached to the end of the manipulator arm by a dovetail fitting and manual lock. One or two sets of pneumatically operated fingers are used to draw-up and lock the tool mounting plate to the tube sheet. Proper alignment of the tool mounting plate to the tube sheet is assured through the actuation of three switches against the tube sheet. A spring loaded, air pressure release, quick change mount is provided on the face of the tool mounting platform for quick mounting of the probe pusher or the rolling tool elevator.

The probe pusher attaches to the tool mounting platform with the quick change mount. The probe pusher includes two double sets of drive wheels and two idler wheels. The drive wheels are powered by electric motors to insert and remove the various sleeving tools and the sleeve into the steam generator tube. Vertical positioning of the tools is accomplished by hardstops and/or verified by visual means. Controlled rotation of the weld and non-destructive examination (NDE) tools is provided by an electric motor which rotates the probe pusher relative to the tool mounting platform.

4.5.3 Tube Brushing-Cleaning Equipment

[ ]

4.5.4 Tube Rolling Equipment

[ ]

4.5.5 <u>Sleeve Expansion Equipment</u>

4.5.6 <u>Sleeve Welding Equipment</u>

4.5.7 Nondestructive Examination

Three types of nondestructive examination equipment are used during the sleeving process. They are as follows: eddy current test (ET) equipment, ultrasonic test (UT) equipment (Figure 4-11) and visual test (VT) equipment (Figure 4-12).

The ET inspection will be performed using the most recently developed eddy current probes and techniques for sleeving inspection. The eddy current probe presently being used is the new advanced +point rotating probe. Future probe designs may be used after suitable qualification demonstration has been performed. The ET fixture, with conduit, is used on the manipulator arm to position the probe.

Ultrasonic testing using an immersion technique with demineralized water as a couplant is used to inspect the tube to sleeve weld. A one-quarter inch diameter focusing transducer is positioned in the weld area and rotated by the probe pusher to scan the weld. A digital imaging system is used to acquire and store the inspection data.

Visual inspection of the steam generator tube to sleeve weld is accomplished with the use of a boroscope or micro camera system delivered and rotated by the probe pusher. Inspection data is stored on video tape.

4.5.8 Post-Weld Heat Treatment Equipment

4.5.9 Sleeve Rolling Equipment

The sleeve rolling equipment is used to expand the lower end of the ETZ into contact with the steam generator tube within the tubesheet, forming a strong leak tight joint. The rolling tool is mounted on the manipulator and positioned within the tube by a hard stop on the roll tool shaft seating against the tube sheet. The rolling tool includes a dovetail attachment for quick mounting on the manipulator. The rolling tool mounted on the manipulator, [ ] may be used in the central tubesheet region or in the periphery.

The rolling equipment consists of the air motor, tube expander, torque read-out, strip chart recorder and a torque calibration unit. The torque read-out and settings of the rolling tool are verified on the torque calibration unit prior to rolling of the sleeves. The rolling tool is located by a hardstop on the tool shaft. The hardstop positions the upper end of the tube expander within the portion of the sleeve which was hydraulically expanded during sleeve installation. The approximately 1-1/4 inch long roll is located at the nickel and metal oxide bands on the lower end of the ETZ sleeve. The sleeve is expanded to a torque which has been demonstrated by testing to provide a leak tight joint. A record of the rolling tool torque is made for further evaluation of the rolling process on the individual sleeves. A rolled joint which fails to meet the acceptance criteria may be re-rolled.

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 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.

Lead lined manway shield doors, both primary side and secondary (ventilation) side, are also employed to reduce radiation exposure.

4.7 REFERENCES TO SECTION 4.0

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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: Post Test 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/ROLL TRANSITION ZONE SLEEVE

FIGURE 4-2
TUBE SUPPORT SLEEVE

FIGURE 4-3
EXPANSION/ROLL TRANSITION ZONE SLEEVE INSTALLATION

FIGURE 4-4
TUBE SUPPORT SLEEVE INSTALLATION

FIGURE 4-5
<u>MANIPULATOR AND TOOL DELIVERY SYSTEM</u>

FIGURE 4-6
TOOL DELIVERY EQUIPMENT

FIGURE 4-7
TUBE CLEANING EQUIPMENT

FIGURE 4-8
<u>SLEEVE EXPANSION EQUIPMENT</u>

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
<u>VISUAL TEST EQUIPMENT</u>

FIGURE 4-13
<u>POST WELD HEAT TREAT EQUIPMENT</u>

FIGURE 4-14
SLEEVE ROLLING EQUIPMENT

5. SLEEVE EXAMINATION PROGRAM

During the installation process, the sleeves are examined using a combination of visual testing (VT), ultrasonic testing (UT) and eddy current testing (ET) at different stages of the installation process. The general process is described in the flow charts presented in Figures 5-1 and 5-2, which are described below.

After the description of the inspection process, the individual inspection methods will be described in additional detail.

After completion of the brush cleaning step, the first inspection is a VT process on tubes to be sleeved to confirm adequate cleaning to proceed with the welding process. Parent tube cleanliness has been identified as a critical feature of the overall welding process. A VT after cleaning is performed with a miniature remote camera inserted into the tube up to the elevation where the welding will be performed. The VT inspectors are trained using images of examples of acceptable and inadequate cleaning. In simplest terms, the cleanliness requirement is the presence of "bright, shiny metal" in the region of the tube where welding will take place. If adequate cleaning is not confirmed by the remote VT, then the cleaning process is repeated until a suitable cleanliness is achieved. The extent of this inspection program is presently 100% of tubes to be sleeved. At such time that process control is demonstrated to assure cleaning efficiency, a sampling program may be used.

Upon confirmation of cleaning, the sleeve is inserted, expanded and welded. The next inspection is performed on the ATS weld by UT to confirm a leak tight bond has been achieved by the welding process. The weld height is not measured by the UT method, but rather is controlled by the welding process qualification. A confirmation of 360 degrees of weld bond is the acceptance criteria for the UT inspection. If a lack of fusion (LOF) through the weld height is detected, then the sleeve may be identified for rewelding or plugged. After a reweld, the UT is repeated to confirm a leak tight weld. An acceptable UT result is required for any ATS weld left in service.

Prior to the UT inspection, an optional VT-1 inspection of the ATS weld may be performed, but is not required. The VT-1, as defined in ASME Section XI, is suitable for detection of incomplete welds, blow holes and weld splatter geometric irregularities in the weld. Experience has shown that the UT and ET inspections are capable of detecting these conditions, so the VT is primarily useful to help resolve uncertainties in surface conditions detected by either the UT or ET inspections. If a

VT-1 inspection is performed and a blow hole or other potentially deleterious condition (with the exception of an incomplete weld) is detected, then a noncomformance report (NCR) must be generated. Blow holes identified as within the pressure boundary portion of the weld must be repaired. Blow holes not within the pressure boundary portion of the weld are identified for additional evaluation by the ET and UT inspections.

The final inspection is performed on all installed sleeves using the ET method with a +point probe. If post weld heat treatment is performed, this inspection must be performed after the heat treatment due to the possibility of additional signals from permeability variations caused by the heat treatment process. The entire length of the pressure boundary, including the pressure boundary portion of the parent tube behind the sleeve is inspected with the ET method. The pressure boundary portion of the sleeve tube assembly is shown in Reference 5.4.3. The details of the ET inspection are described in Section 5.2 and Figure 5-2 with the associated definitions in Table 5-1.

The sleeve to tube weld joints are qualified by process control as described in Appendix A. Checks are made to ensure that the welds meet these design requirements. The welding current and voltage are recorded as the weld head rotates inside the sleeve. The recordings are examined after the welding sequence has been completed to verify that the essential parameters given in Reference 1 to Appendix A are met.

These descriptions of inspection techniques and tooling represent the current state-of-the-art practices. As new technology becomes available, advanced techniques may be substituted after a suitable qualification program has demonstrated equivalent or superior performance.

5.1 ULTRASONIC INSPECTION

5.1.1 Summary and Conclusions

An ultrasonic inspection is performed on each sleeve to tube ATS weld to confirm a leak tight fusion. The test is performed using an ultrasonic crystal with a resonant frequency of [ ] MHz (physical construction of the probe will reduce the effective output frequency to [ ] MHz, typically. Actual output frequency is documented in the transducer certification package required by procedure.) The mechanical drive device performs a scan of the weld in 2 degree increments around 360 degrees with axial step increments of [ ] inches; the scan path extends from above the weld so that the sleeve backwall is detected to below the weld until the backwall of the sleeve is detected. The inspection is demonstrated to detect a milled notch representing a weld lack of fusion (LOF) region of [ ] inch or greater. The ultrasonic signal is digitized and stored in order to provide a permanent record of the individual A scans (lower presentation on Figure 5-4), which are used to display plan view C scans (upper presentation on Figure 5-4) of the weld as well as cross sectional views in the axial direction (B' scans) and cross sectional views (B scans). For each individual sleeve inspection, a calibration confirmation is available by monitoring the response to the sleeve back wall either above or below the weld zone.

5.1.2 Ultrasonic Evaluation

The basis of the UT inspection is the detection of a reflective surface at the sleeve to tube interface to detect a condition indicative of a lack of fusion. Sound is transmitted from the sleeve inner surface through the weld to the tube outer surface. Although the reflection from the tube outer surface is typically discernible in the recorded data, this is a sufficient, but not necessary indication of fusion. Geometric distortions in the weld region may preclude detection of this tube back wall as a consistent indicator of weld fusion.

In the data acquisition phase, a C scan is displayed for the operator with a [ ] for monitoring reflections from the sleeve/tube interface. During analysis, both circumferential and axial cross sectional views of the ultrasonic reflectors are reviewed for evaluation of each weld. Detection of a [ ] reflection is an indication of a complete weld. In the absence of this signal, axial and circumferential cross sections (B and B' scans) data reviews are conducted. Locally, reflectors are compared to 20% of the sleeve backwall signal amplitude for determination of a local LOF. Using the B' scan axial cross section, a LOF condition through the weld height is discernible. Using a combination of laboratory samples and removed tubes (Prairie Island, February, 1996), unbonds as narrow as 10 degrees are detectable using this B scan analysis techniques, as reported in References 5.4.1 and 5.4.2. Sample outputs from the UT results for an acceptable weld and unacceptable LOF condition are provided in Figures 5-3 (acceptable) and 5-4 (rejectable).

5.1.3 Test Equipment

The test equipment for the ultrasonic inspection comprises the following:

1. IntraSpect Ultrasonic Imaging System

2. Sleeve Weld UT Inspection Probe, 15 MHz, 0.250" diameter crystal, sized for sleeve ID, as depicted in Figure 5-5

3. Couplant supply system, integral with the probe and driver system

4. Position device for rotational and translational motion, include encoder feedback for each axis

5. Calibration standard with machined notches for initial set up, as depicted in Figure 5-6.

5.2 EDDY CURRENT INSPECTION

5.2.1 Background

For the initial installation of sleeves, each sleeve will be inspected for a baseline and for acceptance. Over the years, the eddy current probe technology has evolved with ever increasing sensitivity in the probe response. Early sleeving programs used a cross wound bobbin coil design, which was later replaced by the I coil design and ultimately by the plus point probe design. The current practice uses the plus point probe design with the option of adopting future probe designs after suitable qualification demonstration has been performed. The description below discusses the most recent plus point probe design, which was extensively qualified for sleeve inspections in a program that exceeded the requirements of the EPRI Steam Generator Inspection Guidelines, Appendix H in effect at this writing, as described in reference 5.4.3. This qualification used a detection threshold of 40% degradation of the sleeve wall thickness rather than the 60% allowed by Appendix H to add conservatism to the process.

The ET method is used to inspect the entire sleeve region pressure boundary which has four distinct regions:

1) the sleeve between the upper weld and lower joint (either roll or weld, depending on sleeve type)

2) the pressure boundary region of the steam generator tube behind the sleeve

3) the steam generator tube below the lower rolled joint for an ETZ sleeve

4) the unsleeved portion of the steam generator tube

The first three regions are the subject of this discussion, the fourth region is handled as part of the normal tube inspection using the prevailing methods. If post weld heat treating is performed on the weld zone, the ET inspection is performed after the heat treatment.

5.2.2 Plus Point Probe Qualification Study

The plus point ET technique was extensively qualified for each of the regions identified above using laboratory samples with EDM notches and laboratory produced weld imperfections. The details of the inspection samples and results for the weld zone indications are provided in references 5.4.1 and 5.4.2 and the Appendix H qualification report is provided in reference 5.4.3. The Appendix H qualification report provides the details for both the acquisition (ACTS) and analysis (ANTS) of the inspection data.

Site specific analysis guidelines have been developed and analysts are trained and tested on the specifics of the technique. In summary, the plus point technique was demonstrated to be able to detect relevant flaw mechanisms 40% throughwall and greater in each of the regions identified above.

Particular attention was paid to the ATS weld region of the sleeve. The detailed process for the initial installation inspection is shown in the flow chart in Figure 5-2 with the companion list of acronyms in Table 5-1. For the subsequent inservice inspections, reviews of previous inspection results may be used in lieu of the VT and UT reviews mentioned in the flow chart. Either the standard +point probe or the magnetically biased style may be used for the inspection. Experience has shown that one of the most common interfering signal sources in the weld region is caused by local permeability variations, which are greatly reduced by the partial magnetic saturation provided by the magnetically biased probe.

The ET indications are separated into two broad categories, surface and subsurface. Surface indications are caused by minor weld sag which produces a signal classified as GEO for geometric. Local irregularities in the weld surface are classified as weld surface indications (WSI). In extreme cases, the WSI source could be a blow hole in the weld. Additional VT reviews are used to evaluate surface related indications prior to acceptance. With the aid of the VT data, WSI signals are resolved as blow holes outside or within the pressure boundary portion of the weld (BHA or BHB) or nondeleterious surface irregularities (WSS). If no surface condition is observed, then the signal is considered as a subsurface weld zone indication (WZI) and evaluated accordingly. For blow holes, the location relative to the pressure boundary is determined using a combination of the VT and UT results. Accordingly, the BHA (blow hole outside pressure boundary portion of the weld) condition is acceptable for service while the BHB (blow hole within the pressure boundary portion of the weld) is not.

The WZI signals may be caused by oxide inclusions in the weld or a partial void caused by a gas pocket during the welding process. Metallographic work, as reported in reference 5.4.1, has shown that these conditions occur at either the upper or lower edge of the ATS weld on the sleeve outer surface. The oxide inclusion condition is generally precluded by proper cleaning, which is verified using VT before installing the sleeve. Minor voids may occur in a small percentage of welds even with proper cleaning, but generally are very shallow. No attempt is made to distinguish inclusions from voids, nor is there an attempt to measure depth or circumferential extent for these conditions. The only acceptance criteria is based on the location relative to the pressure boundary with indications outside the pressure boundary portion of the weld (WZA) acceptable for service and indications within the pressure boundary portion of the weld (WZB) not acceptable for service. The ability to determine the true location of indications relative to the pressure boundary portion of the weld was demonstrated in the Appendix H qualification study and is reported in references 5.4.2 and 5.4.3. It is ABB-CE's position that sleeved tubes will be plugged upon detection of indications in the pressure boundary region of the sleeve. The methodology for this detection is shown in the flow charts in Tables 5-1 and 5-2.

Various other anomalous conditions may be reported by the ET analyst that would trigger a nonconformance report (NCR) and additional evaluation.

The other area of particular interest is the expansion transition zone above the weld. Here the parent tube constitutes the pressure boundary. The ability to detect 40% through wall flaws was demonstrated using EDM notches and is detailed in reference 5.4.3.

5.3 VISUAL INSPECTION

5.3.1 Summary and Conclusions

There are two visual inspections associated with the sleeving process. The first inspection is performed after the brush cleaning process for the weld region. Tubes are inspected for cleanliness prior to sleeve installation. The second, optional inspection is performed after completion of the ATS weld and is conducted as a VT-1 inspection per Section XI of the ASME Code. The VT-1 inspection is performed when needed to resolve surface indications identified by the ET or UT inspections. The VT-1 inspection is also performed for rewelds.

The VT is performed remotely by means of a miniature CCD camera inserted into the tube with the results recorded on video tape. Visual aids are provided for the inspectors for evaluation of cleaning and weld quality. A training tape with examples of weld irregularities is provided and reviewed by the VT-1 inspectors. Conditions of interest include blow holes, incomplete welds, splatter, pits and burn through.

5.3.2 Cleaning Inspection

After the cleaning operation, the parent tube in the region where the weld will be made is inspected for adequacy of cleaning. Approximately a two inch long zone is cleaned and inspected. The acceptance criteria is bright, shiny metal to assure that there is no remaining oxide on the tube surface that could affect the weld quality by producing inclusions. This process verification step is identified in the site specific traveller. The extent of this inspection program is presently 100% of tubes to be sleeved. At such time that process control is demonstrated to assure cleaning efficiency, a sampling program may be used.

5.3.3 Weld Examination

The primary inspection methods for ATS weld and sleeve acceptance are the UT and ET methods described above. An additional VT-1 inspection of the weld is optional, unless required by the site procedure for specific situations, such as repair welds. The VT-1 is also used as a supplemental technique to aid in the analysis of surface conditions reported in either the UT or ET results.

The CCD camera and right angle viewing mirror is inserted into the sleeve. The camera system is checked using a 1/32" black line on an 18% neutral gray card. Also, a sleeve sample with a 0.020" diameter through hole is used to scale the image. The VT-1 results are recorded on video tape for permanent storage.

5.4 REFERENCES

5.4.1 ABB CENO CEN-628-P Rev 01-P, "Verification of the Structural Integrity of the ABB CENO Steam Generator Welded Sleeve, March, 1996 (PROPRIETARY)

5.4.2 ABB CENO 96-3-9038T Rev 01, "POD Assessment for NDE of Sleeves", June 14, 1996

5.4.3 ABB CENO 96-OSW-003, "EPRI Steam Generator Examination Guidelines Appendix H Qualification for Eddy Current Plus-Point Probe Examination of ABB CENO Welded Sleeves", April 27, 1996 (PROPRIETARY)

TABLE 5-1
ACRONYMS USED IN ET ANALYSIS

BHA: Blow Hole Outside Pressure Boundary

BHB: Blow Hole Within Pressure Boundary

GEO: Geometric signal

LOF: Lack Of Fusion

NCR: NonConformance Report

NDD: No Detectable Degradation

PID: Positive ID retest

RMB: Retest with Magnetically Biased probe

UT: Ultrasonic Test

VT-1: Visual Test,Type 1 per ASME Code, Section XI

VT: Visual Test

WEE: Weld at Edge of Expansion

WOE: Weld Outside Expansion region

WSI: Weld Surface Indication

WSS: Weld Surface Signal

WZA: Weld Zone indication Outside Pressure Boundary

WZB: Weld Zone indication Within Pressure Boundary

WZI: Weld Zone Indication-subsurface or indeterminant

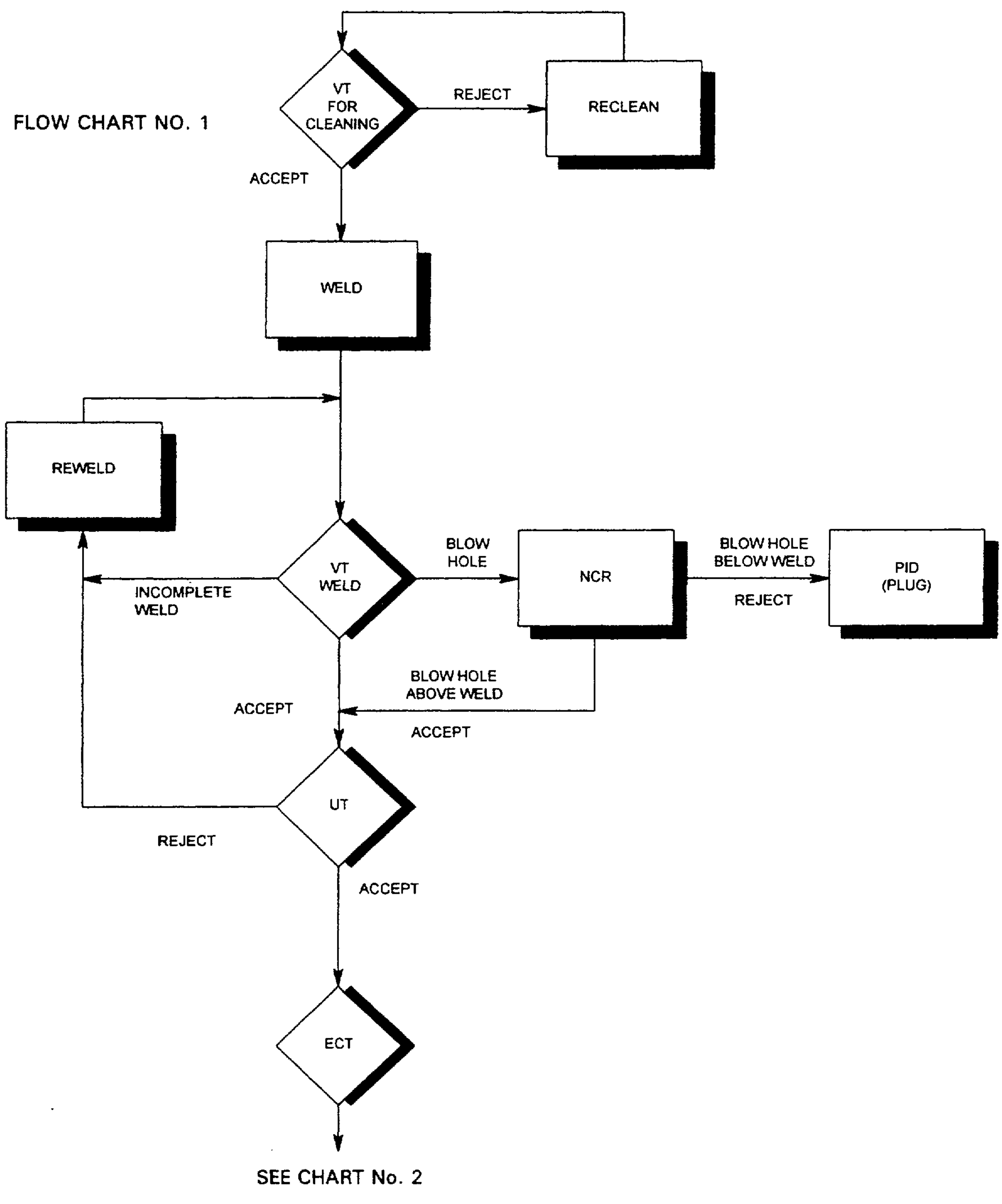

FIGURE 5-1
<u>NDE PROCESS FLOW CHART</u>

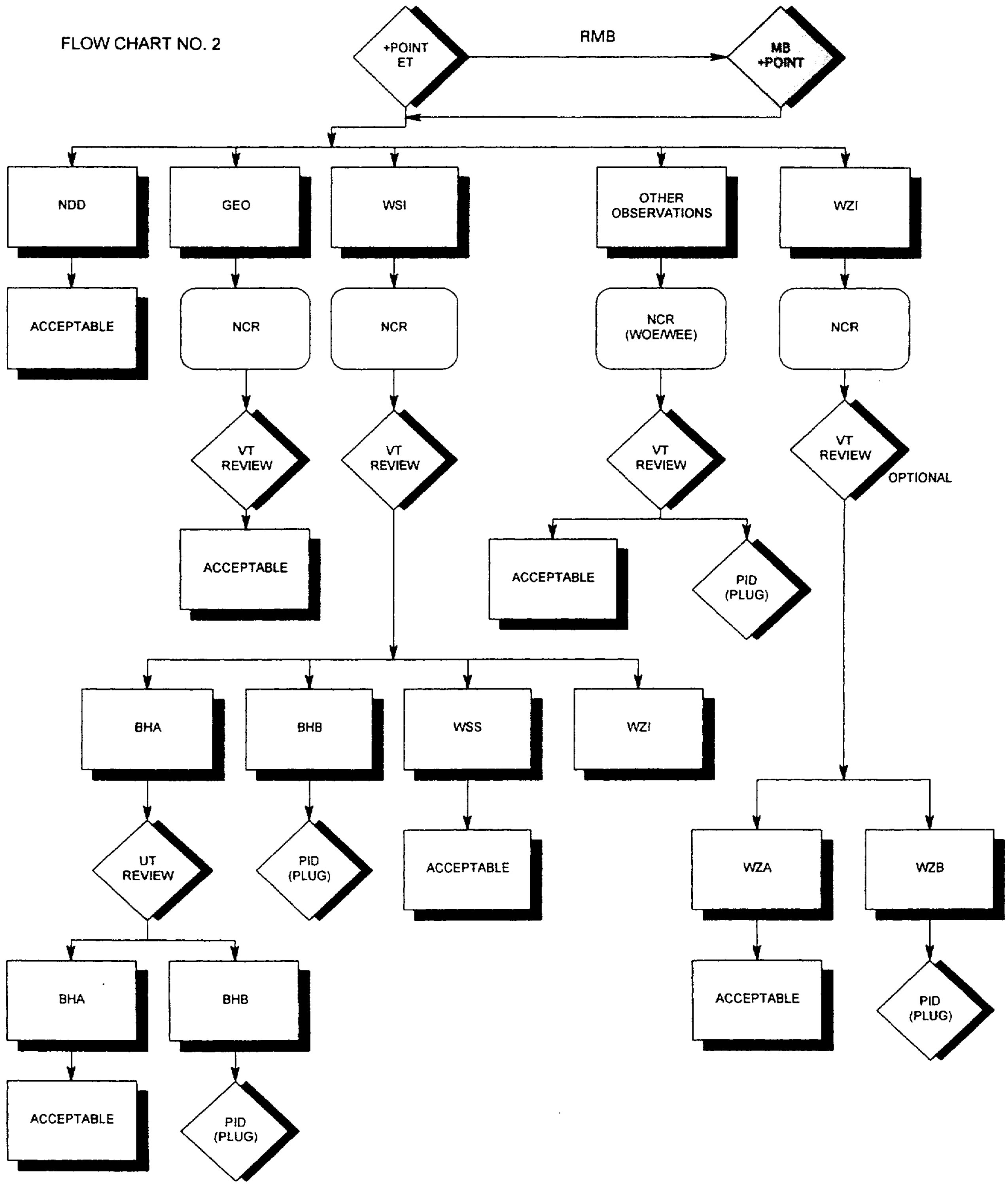

FIGURE 5-2
<u>ET PROCESS FLOW CHART</u>

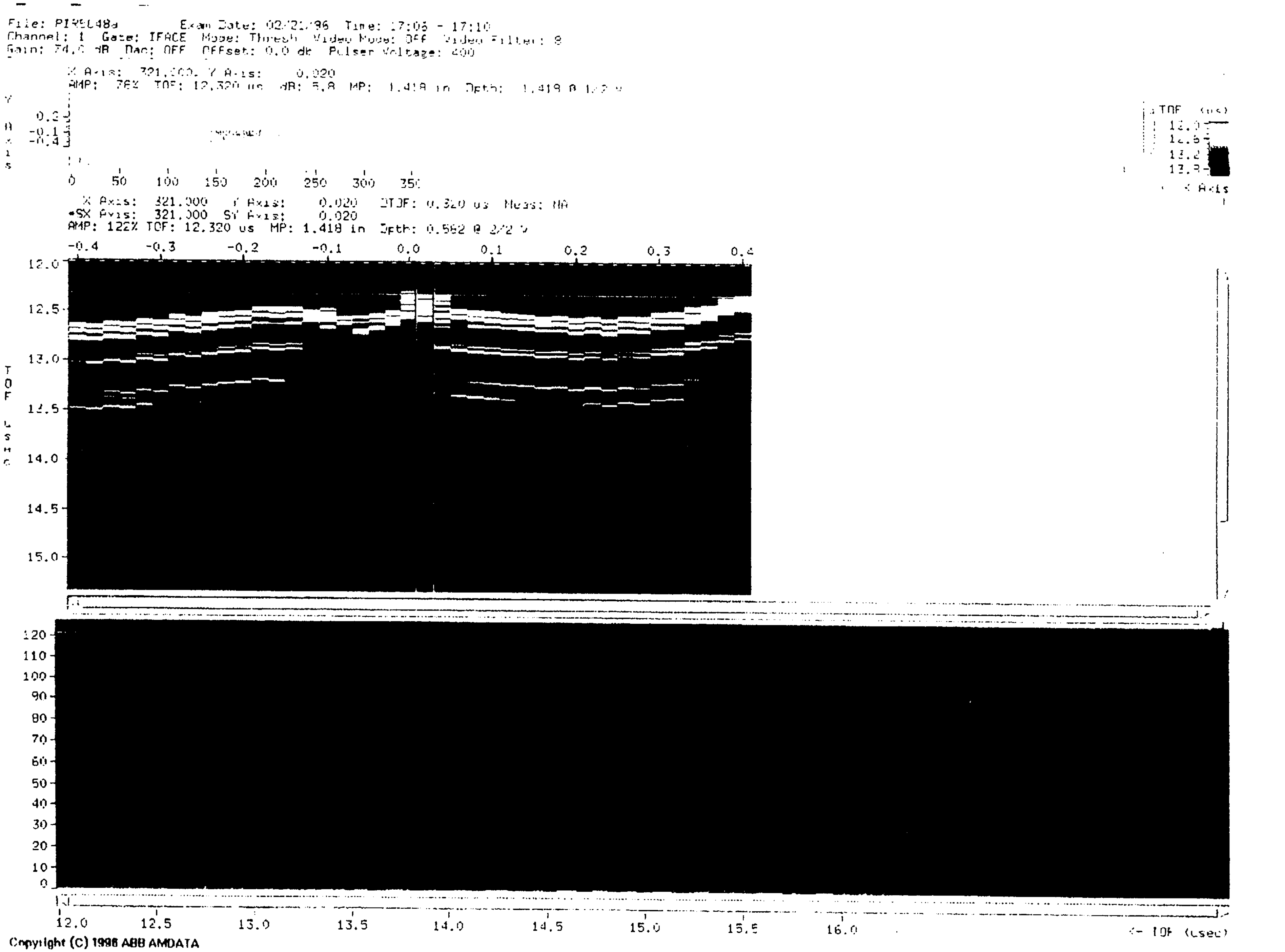

FIGURE 5-3

UT B SCAN - ACCEPTABLE

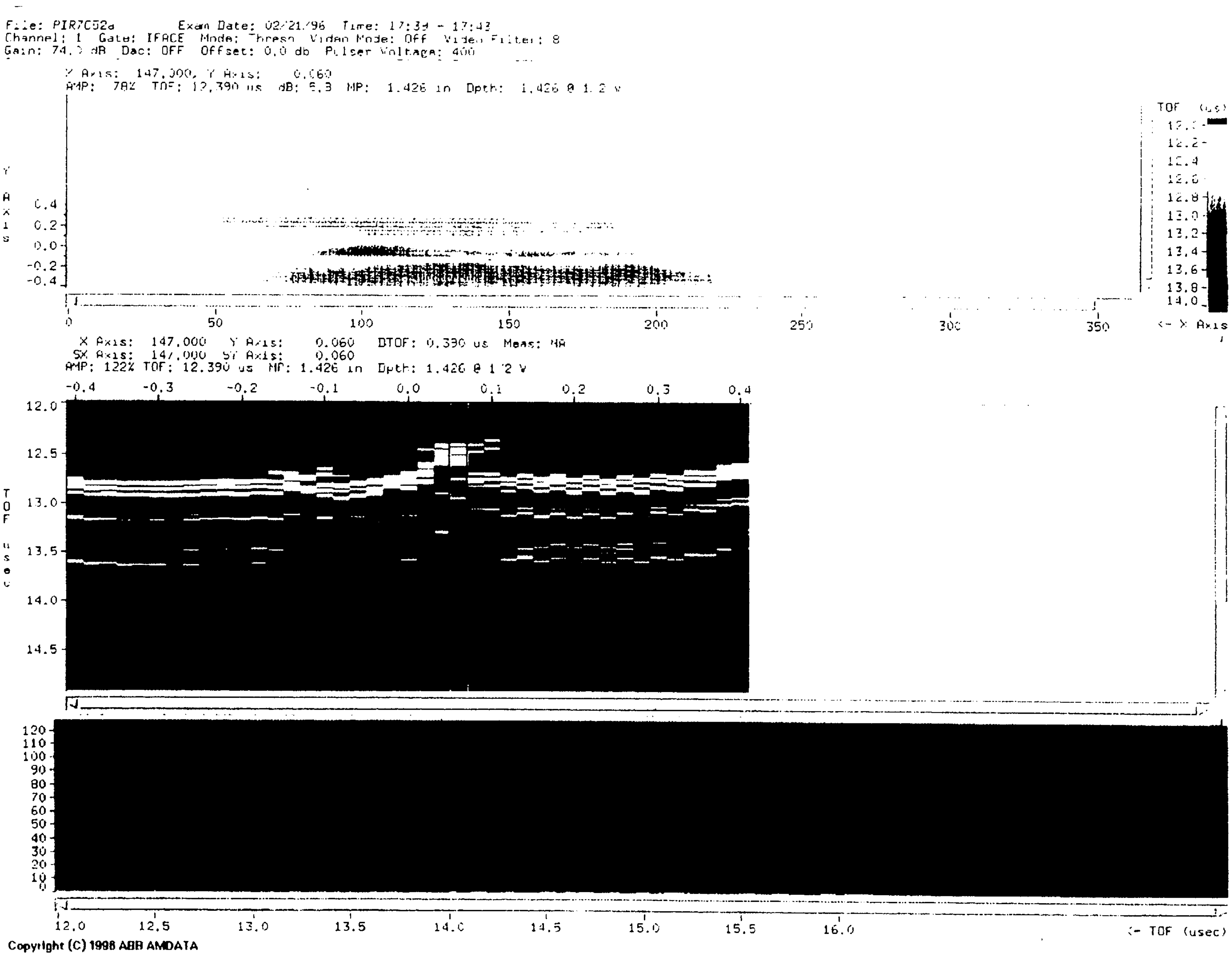

FIGURE 5-4

UT B SCAN - REJECTABLE

FIGURE 5-5
<u>UT PROBE</u>

FIGURE 5-6
UT CALIBRATION STANDARD

6. SLEEVE-TUBE CORROSION TEST PROGRAM

ABB-CE 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 TSP Sleeve Weld Capsule Tests

6.2.1.4 Summary - Primary Coolant Corrosion Performance

6.2.2 Secondary Side Tests

6.2.2.1 Modified Huey Tests

[ ]

6.2.2.2 Capsule Tests

[ ]

TABLE 6-3

SECONDARY SIDE STEAM GENERATOR TUBE SLEEVE CAPSULE TESTS

ENVIRONMENT	EXPOSURE TIME	RESULTS

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 Statistical 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
<u>TSP WELD CAPSULE TEST SPECIMEN</u>

FIGURE 6-4
CAUSTIC CORROSION AUTOCLAVE TEST SPECIMEN

7. MECHANICAL TESTS OF SLEEVED STEAM GENERATOR TUBES

7.1 SUMMARY AND CONCLUSIONS

7.2 CONDITIONS TESTED

7.3 WELDED SLEEVE TEST PARAMETERS AND RESULTS

7.3.1 Axial Pull Tests

[

]

7.3.2 Collapse Testing

[

]

7.3.3 <u>Burst Testing</u>

7.3.4 <u>Load Cycling Tests</u>

TABLE 7-1

SLEEVE-TUBE ASSEMBLY MECHANICAL TESTING RESULTS*

COMPONENT AND TEST	RESULT (MAXIMUM)	RESULT (MINIMUM)
Welded Joint Axial Load Capability		
Upward Direction		
Downward Direction		
Rolled Joint Axial Load Capability		
No slippage		
Welded Joint Cyclic Loading		
Rolled Joint Cyclic Loading		
Sleeve Burst Pressure		
Sleeve Collapse		

* 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/rolled Transition Zone (ETZ) and Tube Support Plate (TS) sleeves described in this document, meet all the requirements stipulated in Section 8.0 with substantial additional margins. In performing the analytical evaluation on the tube sleeves, the operating and design conditions for all of the ABB-CE as well as the Westinghouse operating plants with 3/4 inch Inconel 600 tubes are considered (Reference 8.2).

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 for the tube sleeve material which is Alloy 690 material with a specified minimum yield of 40.0 ksi.

[ ]

[ ]

Where t = Min. required wall thickness, in.

P = Design Tubesheet differential pressure, ksi (max. value for plants, Ref. 8.2)

R = Inside Radius of sleeve, in. (maximum value for plants considered)

S_m = Design Stress Intensity, S.I. @ 650°F maximum design (per Reference 8.16)

8.1.2 Detailed Analysis Summary

When properly installed and welded within specified tolerances, the ETZ sleeve and its upper weld and lower rolled joint, and the TS 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.

TABLE 8-1

SUMMARY OF SLEEVE AND WELD SIGNIFICANT ANALYSIS RESULTS

* - The allowables listed in Table 8-1 are in accordance with the ASME Code (Refs. 8.1 and 8.16)

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 PRIM. MEMBRANE STRESS (DESIGN TUBESHEET DELTA PRESSURE)

2. MAIN STEAM LINE BREAK FOR ABB-CE PLANTS

3. FEEDWATER LINE BREAK FOR WESTINGHOUSE PLANTS

4. PRIMARY PIPE BREAK (LOCA)

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) for an ABB-CE plant, the secondary pressure would drop in a short time interval. Without rapid operator action, subsequent to the dryout of the faulted steam generator, continued Emergency Core Cooling System (ECCS) flow, combined with the heatup of the RCS from decay heat, a gradual repressurization of the RCS will result in a maximum value of 2520 psi (Reference 8.9). Postulating a main steam line break (MSLB) accident. the maximum available load would be

In the event of a feedwater line break (FWLB) accident for a Westinghouse plant, the value of 2850 psi (Reference 8.4) is used. The maximum pullout load would be:

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 2000 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 8.4.6.

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 8.6.1, 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 8.2, the normal operating conditions for the "worst" case envelopment of steam generators from both the ABB-CE and Westinghouse plants are:

	ABB-CE	Westinghouse
Primary Pressure P_{pri}:	2250 psi	2250 psi
Secondary Pressure P_{sec}:	815 psi	877 psi
Differential Pressure $\Delta P = P_{pri} - P_{sec}$:	1435 psi	1373 psi
Average Pressure $P_{avg} = 0.5\ (P_{pri} + P_{sec})$:	1533 psi	1564 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_{rm} = minimum required yield strength (per U.S. NRC Reg. Guide 1.121, Ref. 8.3)

Sy_{min} = minimum yield strength of sleeve (Sy = 35.2 ksi min. at 650 °F, Ref. 8.16)

8.3.2 Postulated Pipe Rupture Accidents

NRC Regulatory Guide 1.121 requires the following:

"The margin of safety against tube failure under postulated accidents, such as a LOCA, steam line break, or feedwater line break concurrent with the safe shutdown earthquake (SSE), should be consistent with the margin of safety determined by the stress limits specified in NB-3225 of Section III of the ASME Boiler and Pressure Vessel Code".

The above referenced ASME code paragraph deals with "faulted conditions", where for an elastic analysis of Inconel 690 sleeves, a general membrane stress of $0.7\ S_u = 0.7(80.0) = 56.0$ ksi is allowed. In conjunction with the NRC Regulatory Guide 1.121, the following accidents are postulated:

[ ]

8.3.3 Minimum Weld Height Requirement

[ ]

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.

8.4.1 Sleeved Tube in "Worst" Case ABB-CE Plant, Free at Egg Crate Support

8.4.2 Sleeved Tube in "Worst" Case Westinghouse Plant, Free at Tube Support

8.4.3 Sleeved Tube in "Worst" Case ABB-CE Plant, Lock-up at First Egg Crate Support

[ ]

8.4.4 Sleeved Tube in "Worst" Case Westinghouse Plant, Lock-up at First Support

[ ]

TABLE 8-3A

26 INCH SLEEVE

AXIAL MEMBER PHYSICAL PROPERTIES FOR "WORST" CASE ABB-CE PLANT

NOTE:
[1] Nominal Dimensions for sleeve from Reference 8.10.
[2] α_m and E for Inconel 690 from Ref. 8.13, Part D, Tables TM-4, TE-4 (same or more conservative than Ref. 8.12).
[3] Nominal Dimensions for tubes from Reference 8.15.
[4] α_m and E for Inconel 600 from Reference 8.13, Part D, Tables TM-4, TE-4.
[5] α_m for Carbon Moly Steel from Reference 8.13, Part D, Table TE-1.

TABLE 8-3B

26 INCH SLEEVE

AXIAL MEMBER PHYSICAL PROPERTIES FOR "WORST" CASE WESTINGHOUSE PLANT

NOTE:
[1] Nominal Dimensions for sleeve from Reference 8.10.
[2] α_m and E for Inconel 690 from Ref. 8.13, Part D, Tables TM-4, TE-4 (same or more conservative than Ref. 8.12).
[3] Nominal Dimensions for tubes from Reference 8.14.
[4] α_m and E for Inconel 600 from Reference 8.13, Part D, Tables TM-4, TE-4.
[5] α_m for Carbon Moly Steel from Reference 8.13, Part D, Table TE-1.

TABLE 8-4A

AXIAL LOADS IN SLEEVE WITH TUBE NOT LOCKED INTO EGG CRATE SUPPORT FOR "WORST" CASE ABB-CE PLANT

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

TABLE 8-4B

AXIAL LOADS IN SLEEVE WITH TUBE NOT LOCKED INTO EGG CRATE SUPPORT FOR "WORST" CASE WESTINGHOUSE PLANT

[ ]

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

TABLE 8-5A

AXIAL LOADS IN SLEEVE WITH TUBE LOCKED INTO EGG CRATE SUPPORT FOR "WORST" CASE ABB-CE PLANT

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

TABLE 8-5B

AXIAL LOADS IN SLEEVE WITH TUBE LOCKED INTO TUBE SUPPORT FOR "WORST" CASE WESTINGHOUSE PLANT

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

8.4.5 Effect of Tube Prestress Prior to Sleeving

8.4.6 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 onthe 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

The natural frequency of a sleeved tube for the span between the tubesheet and the first tube support for the "worst" case situation is:

$f_n = (15.4/2\pi l^2) \times (EIg/W/l)^{0.5}$ = 38.0 HZ, (Reference 8.5)
where:
f_n = natural frequency, HZ

l = span length = 47.75 in. (maximum value in Reference 8.2)

$E = 28.78 \times 10^6$ psi (minimum value for Inconel 600 tube at 573.3°F)

I = Tube Moment of Inertia = 0.0066 in.^{4}

W = Tube Weight + Weight of Primary Water in Tube & Sleeve + Sleeve Weight + Weight of Secondary Water Displaced

W = 1.542 + 0.374 + 0.279 + 0.581 = 2.775 lb.

$g = 386$ in/sec^2

The natural frequency is based on a healthy tube span with an installed sleeve. Vibration test results of sleeved tubes (See Section 8.5.2) concluded that tube sleeves have negligible effect on the vibration characteristics of the tubes. Test results indicate a natural frequency for a completely severed tube somewhat below the healthy tube frequency, but above the seismic cut-off frequency of 33 HZ. Hence, the seismic evaluation is performed for the static equivalent load above 33 HZ.

The seismic load for a "worst" case situation, which more than envelopes the seismic curves in Reference 8.2 for loading above 33 HZ, is:

OBE = 2.25 g

In the span between the tubesheet and support the OBE seismic load is:

$w_{OBE} = (1.0 + 2.25)\ W/l = 0.189$ lb./in.

For the fixed - pinned model the maximum moment is:

$M_{OBE} = 1/8\ w_{OBE} l^2 = 53.8$ in.-lb.

Considering the sleeve cross section:

[ ]

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. Section 8.6.1 describes the methods used to analyze the upper tube weld.

8.6.1 Fatigue Evaluation of Upper Sleeve/Tube Weld

TABLE 8-6

UPPER SLEEVE WELD - TRANSIENTS CONSIDERED FOR AN ABB-CE PLANT

TABLE 8-7

UPPER SLEEVE WELD - TRANSIENTS FOR A WESTINGHOUSE PLANT

8.6.2 Evaluation of Lower Sleeve Rolled Section

TABLE 8-8

LOWER SLEEVE SECTION - TRANSIENTS CONSIDERED FOR AN ABB-CE PLANT

TABLE 8-9

LOWER SLEEVE SECTION - TRANSIENTS CONSIDERED FOR A WESTINGHOUSE PLANT

8.7 REFERENCES FOR SECTION 8.0

8.1 ASME Boiler and Pressure Vessel Code, Section III for Nuclear Power Plant Components, 1989 edition.

8.2 ABB/CE Letter Report No. CSE-96-116, "Tube Sleeve History Data for 3/4 inch Steam Generator Tubes", May 07, 1996.

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

8.4 ABB/CE License Report CEN-624-P, Rev. 00, "Carolina Power & Light Shearon Harris Steam Generator Tube Repair Using Leak Tight Sleeves", July 1995.

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, Vol. 103, Pages 358-366, April 1981 (REF-96-015).

8.7 "ANSYS" Finite Element Computer Code, Rev. 5.1, 1994, by Swanson Analysis Sys., Inc.

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 ABB/CE License Report CEN-613-NP, Rev. 01, "Arizona Public Service Co. Palo Verde Steam Generator Tube Repair Using Leak Tight Sleeves", January 1995.

8.10 ABB/CE Drawing No. D-SGNS-222-001, Rev. 02, "RTZ Sleeve for 3/4" Diameter Steam Generator Tubes".

8.11 ABB/CE Drawing No. D-SGNS-222-002, Rev. 04, "RTZ Sleeve Installation".

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

8.13 ASME Boiler and Pressure Vessel Code, Section II, Materials, 1995 edition.

8.14 Westinghouse Steam Generator Standard Information Package, Jan. 04, 1982 (REF-96-002).

8.15 ABB/CE Drawing No. E-234-622, Rev. 1, "Tube Details for SONGS II Steam Generator".

8.16 ASME Boiler and Pressure Vessel Code Case N-20-3, "SB-163 Nickel-Chromium-Iron Tubing (Alloys 600 and 690) ... at Specified Minimum Yield Strength of 40.0 ksi ..., Section III, Division 1, Class 1", November 30, 1988.

8.17 ABB/CE Report No. TR-ESE-178, Rev. 1, "Palisades Steam Generator Tube/Sleeve Vibration Tests", October 05, 1977 (REF-96-003).

FIGURE 8-1

WELDED SLEEVE/TUBE ASSEMBLY

FIGURE 8-2

SYSTEM SCHEMATIC FOR "WORST" CASE ABB-CE PLANT

FIGURE 8-3

SYSTEM SCHEMATIC FOR "WORST" CASE WESTINGHOUSE PLANT

STIFFNESS MODEL OF SLEEVE AND LOWER TUBE

FIGURE 8-5

STIFFNESS MODEL OF UPPER TUBE AND SURROUNDING TUBES

FIGURE 8-6

FINITE ELEMENT MODEL OF UPPER TUBE WELD

APPENDIX 8A

FATIGUE EVALUATION OF UPPER SLEEVE/TUBE WELD

INTRODUCTION

The analysis presented in this appendix is discussed in detail in Section 8.6.1 of this Report. The results from the two (2) finite element models considered are presented in this Appendix. The model geometry is shown in Figure 8-6 of the report. The only difference in the two models is the weld height and the number of elements. The 80 mil weld height model is based on the design geometry minimum dimension. The 20 mil model is based on the minimum required axial weld length for operating and accident conditions. All stresses and usage factors for both configurations are satisfactory when compared to allowables.

GENERAL DISCUSSION

The Finite Element Method (FEM) was incorporated in this analysis, using the ANSYS Computer Code (Reference 8.7). Figure 8-6 depicts the FEM model of the upper tube weld for both the ABB-CE and Westinghouse operating plants with Inconel 600 tubes. A tube thickness of .043 inches is conservatively used in the analysis. This will encompass the .048 inch tube design.

The lower end of the tube was assumed to be locked near the secondary side surface of the tubesheet. From Section 8.4, it was found that the sleeve develops higher compressive loadings if the tube is free to slide through the first support. Therefore, sliding at the tube-to-support interface was conservatively assumed. The FEM model consists of 2-D isoparametric elements with an axisymmetric option. The ANSYS input and output data are included in Attachment 1.

The axial loads are conservatively determined from a thermal interaction for a 30 inch sleeve length using the equations in Section 8.4. These axial loads are applied to the bottom of the sleeve finite element model. The ABB-CE operating and transient conditions are used because they result in the highest temperature differences and highest axial loads. The transients were selected on the basis of the worst case combinations as explained in Section 8.6.1. The stresses resulting from the axial load cases are combined with the 100% steady state pressure case stresses. These combined stresses are combined with the thermal case stresses resulting from the radial thermal expansion for the transients considered.

A stress concentration factor of 4 is conservatively applied to the linearized membrane plus bending stresses for the axial, radial and shear stress components. The concentration factor is applied at the sleeve outside surface located below the weld, the top and bottom of the weld, and to the inside surface of the tube location above the weld.

The minimum required axial length of weld of .023 inches was determined in Section 8.3.3. A fatigue analysis was performed using a conservative weld height of .02 inches. The finite element model used for the .08 inch weld design was modified by refining the element mesh as shown in Appendix 8A. For simplification purposes, the pressure stresses and stresses due to the radial thermal expansion were conservatively excluded. These pressure and thermal stresses result in tensile stresses which relieve the compressive stresses resulting from the axial loads.

The results of the analyses consist of the nodal stresses at the critical section, range of stress evaluation and the calculation of the fatigue usage factor.

FIGURE 8A-1

NODE AND STRESS CUT IDENTIFICATION

TABLE 8A-1A

STRESS RESULTS 100% STEADY STATE

TABLE 8A-1B

STRESS RESULTS 15% STEADY STATE

TABLE 8A-1C

STRESS RESULTS 0% STEADY STATE

TABLE 8A-1D

STRESS RESULTS FEEDWATER CYCLING

TABLE 8A-2A

RANGE OF STRESS AT WORST LOCATION

[ ]

TABLE 8A-2B

FATIGUE EVALUATION AT WORST LOCATION

FIGURE 8A-2

NODE AND STRESS CUT IDENTIFICATION FOR 20 MIL WELD

TABLE 8A-3A

STRESS RESULTS 100% STEADY STATE (.02" Weld)

TABLE 8A-3B

STRESS RESULTS 15% STEADY STATE (.02" Weld)

TABLE 8A-3C

STRESS RESULTS 0% STEADY STATE (.02" Weld)

TABLE 8A-3D

STRESS RESULTS FEEDWATER CYCLING (.02" Weld)

TABLE 8A-4A

RANGE OF STRESS AT WORST LOCATIONS (.02" Weld)

TABLE 8A-4B

FATIGUE EVALUATION AT WORST LOCATIONS (.02" Weld)

TABLE 8A-4B (Cont'd)

FATIGUE EVALUATION AT WORST LOCATIONS (.02" Weld)

APPENDIX 8B

TUBE SLEEVE HISTORY DATA

ABB
ASEA BROWN BOVERI

Inter-Office Correspondence

To: W. R. Gahwiller

cc: D. P. Siska
D. G. Stepnick
T. M. Taylor

May 07, 1996
Southeast Nuclear Service Center

SUBJECT: **TUBE SLEEVE HISTORY DATA FOR 3/4 INCH STEAM GENERATOR TUBES**

REFERENCES:

(1) CEN-601-P Rev. 0-P License Report, "Arkansas Nuclear One Unit 2 Steam Generator Tube Repair Using Leak Tight Sleeves", June 1992.
(2) CR-9417-CSE92-1119-0 Report, "Evaluation of an ABB/CE Tube Sleeve for Application in Louisiana Power & Light Steam Generators Waterford Unit 3", November 1992.
(3) CR-9417-CSE94-1119-0 Report, "Evaluation of an ABB/CE Tube Sleeve for Application in Maine Yankee Steam Generators", September 1994.
(4) CR-9417-CSE93-1128-1 Report, "Evaluation of an ABB/CE Tube Sleeve for Application in APS - Palo Verde Units 1, 2, & 3 Steam Generators", January 1995.
(5) CR-9419-CSE95-1119-0 Report, "Evaluation of an ABB/CE Tube Sleeve for Application in B.G.&E. Calvert Cliffs Steam Generators", September 1995.
(6) CENC-1272 & 1298 Reports, "Analytical Reports for Southern California Edison San Onofre Units 2 & 3 Steam Generators", September 1976 and September 1977.
(7) CEN-368-P Rev. 0-P License Report, "Florida Power & Light Co. St. Lucie Units 1 & 2 Steam Generator Tube Repair Using Leak Tight Sleeves", February 1988.
(8) CEN-337-P Rev. 0-P License Report, "V. C. Summer Steam Generator Tube Repair Using Leak Tight Sleeves", August 1986.
(9) CEN-388-P Rev. 0-P License Report, Houston Power & Light South Texas Steam Generator Tube Repair Using Leak Tight Sleeves", April 1990.
(10) CEN-401-P Rev. 0-P License Report, Ringhals 3 & 4 Steam Generator Tube Repair Using Leak Tight Sleeves", October 1990.
(11) CEN-600-P Rev. 1-P License Report, "ASCO 1 & 2 Steam Generator Tube Repair Using Leak Tight Sleeves", June 1992.
(12) CR-9417-CSE93-1115-0 Report, "Evaluation of an ABB/CE Tube Sleeve for Application in Krsko Steam Generators", June 1993.
(13) CR-9451-CSE95-1104-0 Report, "Evaluation of an ABB/CE Tube Sleeve for Application in Commonwealth Edison Byron & Braidwood Units 1 & 2 Steam Generators", April 1995.
(14) CR-9451-CSE95-1111-0 Report, "Evaluation of an ABB/CE Tube Sleeve for Application in Carolina Power & Light Shearon Harris Steam Generators", July 1995.

Southeast Nuclear Service Center (SNSC) reviewed the past tube sleeve reports for 3/4 inch steam generator tubes. References 1 through 14 contain the Section 8 structural analysis as part of the license reports. A review was also made of the other 3/4 inch steam generator tubes, primarily, the Westinghouse D2/D3/D4 Series steam generators to see if their parameters would produce a "worst" case situation greater than those plants reviewed in References 1 through 14. Table 1 on pages 3 and 4 contain the necessary parameters from the fourteen references to develop a "worst" case envelopment situation for further structural analysis of 3/4 inch tube sleeves. Those "worst" case items for "operating" plants with Inconel 600 steam generator tubes are noted in Table 1 with an asterisk (*).

For a "single" Westinghouse Plant study of all D2/D3/D4 steam generators with Inconel 600 tubes (including those plants not in the fourteen references), the ASCO 1 & 2 Plants (whose steam generators are being replaced with ones containing Alloy 800 tubes) had the largest axial load on the tube sleeve. However, the next largest axial load on the tube sleeve is the CP&L Shearon Harris Plant which still has Inconel 600 tubes in the steam generator. This axial load calculation is 939 lb. which is mainly due to the maximum difference between the primary and secondary temperatures used in the structural analysis (i.e. 93.5°F).

For a "single" ABB/CE Plant study of all the steam generators with Inconel 600 tubes (including those plants not in the fourteen references), the Waterford 3 and SONGS Plants will have the largest axial load on the tube sleeve, primarily, due to the maximum difference between the primary and secondary temperatures in the peripheral tubes for the structural analysis being 105°F.

Sincerely,

Bruce A. Bell

B. A. Bell

VERIFICATION STATUS: COMPLETE

The Safety-Related design information contained in this document has been verified to be correct by means of Design Review using Checklist in QP-3.4 of QPM-101.

Name J. D. Key (Independent Reviewer) Signature J. D. Key Date 5-7-96

BAB:bab

TABLE 1: INCONEL 690 TUBE SLEEVE FOR 3/4" DIAMETER TUBE

PARAMETER	ANO-2[1]	Waterford 3[2]	Maine Yankee[3]	APS Palo Verde[4]	BG&E Calvert Cliffs[5]	SONGS[6]	FP&L St. Lucie 1 & 2[7]
Tube Sleeve Length/Report Issue Date	42.25"/6-92	43.0"/11-92	15.5"/9-94	40.0"/1-95	30.0"/9-95	not issued	40.0"/2-88
Design Tubesheet Differential Pressure (psi) Use Max.	2250 *	2250 *	2250 *	2250 *	2250 *	2250 *	2250 *
Primary Pressure @ 100% Power (psi) Use Max.	2250 *	2250 *	2250 *	2250 *	2250 *	2250 *	2250 *
Secondary Press. @ 100% Power (psi) Use Min.	900	900	815 *	1070	850	900	815*
Primary Temp. @ 100% Power (°F)	611	611	601.8	621.2	604	611	604
Secondary Temp. @ 100% Power (°F)	532 (511**)	532 (506**)	520.3 (506**)	553	503[16]	532 (506**)	520 (500**)
Prim.-Sec. Temp. @100% Power (°F) Use Max. Difference	79 (100)	79 (105*)	81.5 (95.8)	68.2	101	79 (105*)	84 (104)
Primary Temperature @ XX% SS (°F)	554 (15%)	554 (15%)	542 (10%)	573 (15%)	543 (15%)	554 (15%)	547 (543**) (15%)
Secondary Temp. @ XX% SS (°F)	539 (15%)	539 (527**) (15%)	528 (10%)	561 (15%)	518 (15%)	539 (527**) (15%)	528 (518**) (15%)
Prim-Sec. Temp @XX% SS (°F) Use Max. Difference	15	15 (27)	14	12	25 *	15 (27)	19 (25)
Prim. Temp. @ 0% SS (°F) Use Max.	544	544	532	564	532	544	532
Sec. Temp. @ 0% SS (°F) Use Max.	544	544	532	564	532	544	532
Span Length between Tubesheet & 1st Support (in.) Use Max./Min.	28.125	28.25	46.0	47.75 *	39.0	28.25	39.63/26.13
Seismic Load Use Max.	0.35 g (OBE)	0.33 g (OBE)	0.18 g (OBE)	1.0 g (OBE)	0.5 g (OBE)	2.25 g * (OBE)	0.25 g (OBE)
Tubesheet Thickness w/ Cladding (in.) Use Min.	21.75	22.75	20.31 *	23.75	21.44	22.75	21.75 (1&2)
Secondary Pressure During LOCA	1100	1000	1000	1170	1000	1100	1000
Axial Load from Reference Report (lb.)	794	788	814	732	993	N/A	769

* - "Worst" Case Envelopment   Use Waterford 3 & SONGS Data for worst case ABB/CE Plant study   Use CP&L Shearon Harris Data for worst case Westinghouse Plant study

** - Consideration for downcomer/feedwater subcooling

(1) Reference (1)   (2) Reference (2)   (3) Reference (3)   (4) Reference (4)   (5) Reference (5)

(6) Reference (6)   (7) Reference (7)   (16) Consideration for peripheral tubes

TABLE 1: INCONEL 690 TUBE SLEEVE FOR 3/4" DIAMETER TUBE (cont'd)

PARAMETER	V.C. Summer[8,15] D3	HP&L South Texas[9] E2	Ringhals 3 & 4[10] D3	ASCO 1 & 2[11,15] D3	Krsko[12] D4	Byron & Braidwood[13] D4	CP&L Shearon Harris[14] D4
Tube Sleeve Length/Report Issue Date	40.0"/8-86	40.0"/4-90	43.0"/10-90	43.0"/5-92	17.5"/6-93	20.0"/4/95	20.0"/7-95
Design Tubesheet Differential Pressure (psi) Use Max.	1600	1600	1600	1600	1600	1600	1600
Primary Pressure @ 100% Power (psi) Use Max.	2250 *	2250 *	2250 *	2250 *	2250 *	2250 *	2250 *
Secondary Press. @ 100% Power (psi) Use Min.	964	1100	877	987	920	925	964
Primary Temp. @ 100% Power (°F)	619	626	613	620	617	618	620
Sec. Temp.** @ 100% Power (°F)	540	556	529	543	535	536	526.5
Prim.-Sec. Temp. @100% Power (°F) Use Max. Difference	79	70	84	77	82	82	93.5
Primary Temperature @ XX% SS (°F)	567 (15%)	576 (15%)	567 (15%)	567 (15%)	567 (15%)	567 (15%)	567 (15%)
Secondary Temp. @ XX% SS (°F)	556 (15%)	566 (15%)	556 (15%)	556 (15%)	556 (15%)	556 (15%)	548.5 (15%)
Prim-Sec. Temp @XX% SS (°F) Use Max. Difference	11	10	11	11	11	11	18.5
Prim. Temp. @ 0% SS (°F) Use Max.	557	567 *	557	557	557	557	557
Sec. Temp. @ 0% SS (°F) Use Max.	557	567 *	557	557	557	557	557
Feedwater Cycling (°F)	557/537	543/546	557/537	557/537	557/535	557/557	533/557
Span Length between Tubesheet & 1st Support (in.) Use Max./Min.	27.25	9.0 *	27.85	27.85	36.0	36.0	36.25
Seismic Load Use Max.	N/A	N/A	N/A	N/A	N/A	2.0 g (OBE)	1.5 g (OBE)
Tubesheet Thickness w/ Cladding (in.) Use Min.	21.15	22.65	21.18	21.18	21.18	21.18	21.18
Secondary Pressure During LOCA	1092	1198 *	1092	1091	1091	1165	1170
Axial Load from Reference Report (lb.)	754	815	804	1208	818	830	939

* - "Worst" Case Envelopment Use Waterford 3 & SONGS Data for worst case ABB/CE Plant study Use CP&L Shearon Harris Data for worst case Westinghouse Plant study
** - Consideration for downcomer/feedwater subcooling
(8) Reference (8) (9) Reference (9) (10) Reference (10) (11) Reference (11) (12) Reference (12)
(13) Reference (9) (14) Reference (14) (15) Replaced with steam generators containing Inconel 690 and Alloy 800 tubes

9. SLEEVE INSTALLATION VERIFICATION

9.1 SUMMARY AND CONCLUSIONS

The ABB-CE welded sleeve installation process and sequence has been tested to ensure the installation of a sleeve which conforms to the design criteria described in Section 3. During this testing, actual steam generator conditions, such as the influence of tubes locked at tube supports, have been considered in assessing the acceptablity of the various processes and the sequence in which they are performed.

Actual sleeve operating history, as well as the qualification test program described within this report indicate that the ABB-CE steam generator tube sleeve is capable of performing as well as, if not longer than, the original tube in which it has been installed.

9.2 SLEEVE-TUBE INSTALLATION SEQUENCE

9.2.1 Expansion/Roll Transition Zone Sleeve with Rolled Lower Joint

The ETZ Sleeve with the rolled lower joint is described in Section 4.3 and Figure 4-3. Installation is accomplished using the processes described in Section 4.5 in the following sequence:

[ ]

* Sequence may be performed interchangably

9.2.2 Tube Support Sleeve

The TS Sleeve is described in Section 4.3 and Figure 4-4. Installation is accomplished using the processes described in Section 4.5 in the following sequence:

[ ]

* Sequence may be performed interchangably

9.3 WELD INTEGRITY

Initiated in 1983, ABB Combustion Engineering has conducted a comprehensive development program to ensure weld joint integrity. Tube I.D. brushing tests, sleeve/tube expansion tests and weld parameter evaluation tests were all completed as part of the process verification.

9.3.1 Cleaning Qualification

[ ]

An additional test was conducted to determine whether the I.D. tube brushing would introduce noise interference on the bobbin coil eddy current test. A clean section of tubing was baseline tested to determine I.D. noise levels. The tubing was subsequently heat treated to produce an oxidation layer on the tube. One half of the tube section was then brushed to remove the oxide coating and the sample was retested with the bobbin coil. The results (Figure 9-1) show that the oxide does in fact generate a noise component. However, after the tubing is brushed, the noise level returns to that of the baseline (pre-heat treat) data.

9.3.2 Expansion Qualification

An extensive test program was performed to qualify the [bladder expansion] tool and process, which provides a tight sleeve/tube fit up in preparation for welding. This program considered tubing with thick, thin and nominal walls as well as tubing with different heat treatments (yield strengths).

9.3.3 Weld Qualification

[ ]

[

]

9.3.4 Ultrasonic Testing Qualification

Ultrasonic (U.T.) techniques are employed to confirm the presence of weld fusion into the tube. A test program was completed by ABB-CE to qualify the Ultrasonic Examination of sleeve/tube upper welds. Fourteen sleeve/tube weld specimens were prepared for this qualification program. Each weld was ultrasonically inspected and then hydrostatically tested to confirm U.T. results. Test results indicate complete correlation between ultrasonic and hydrostatic testing.

9.3.5 Post Weld Heat Treat Qualification

The tubing used in some steam generators has been shown to be very susceptible to the effects of Primary Water Stress Corrosion Cracking (PWSCC). As a result, these utilities must minimize the residual stress induced in the steam generator tubing associated with any repair process. If sleeving is selected as the repair method, the sleeve to tube weld joint as well as the weld heat affected zone and primary pressure boundary portion of the tube expansion requires annealing to minimize residual stresses. [

].

[

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9.3.5.1 Instrumented Analysis of Locked Tubes

A plot of the temperature profile and the axial load measured are shown in Figure 9-3. The results of this test are shown in Table 9-3. Although no measurements were taken, no abrupt changes in the tube diameter were observed along the length of the tube. It was concluded that the deformation experienced by the tube would not be detrimental either to the installation process, i.e.. in preventing the tool from being removed, or to the long term performance of the sleeve/tube joint as described in Section 5.

A similar test was performed on a two by four array of .750 inch O.D. x .042 inch wall tubes arranged in a square pitch and supported as shown in Figure 9-4. This configuration replicates the first three hot leg supports of a typical Westinghouse D3 Series generator while conservatively simulating aspects of a CE unit. In addition, this configuration is conservative when compared to a Westinghouse Series 44/51 steam generator. Four of the tubes were locked at their support (but not the FDB) location by tack welding in four locations. The other four were free from the tubesheet to Support Plate No. 8. Two Tube Support (TS) sleeves and a tubesheet sleeve were installed in each tube as shown in the figure. The tubes were instrumented with strain gages to determine the strain in the outer fibers. During the heat treatment of each sleeve the strain in the tube was recorded. A load cell was used to determine the total load in the upper most section of tube. In the case of this mockup, the heat treatment commenced at the upper most weld and proceeded toward the tubesheet. Both sleeve welds (where applicable) were treated prior to any strain gage measurements. A typical temperature/time plot is shown in Figure 9-5. The results of the test are shown in Table 9-2. As would be expected, the more times the tube segments experiences the heat treat cycle the greater the residual stress. Examination of the tube surfaces in the vicinity of the welds indicated [

].

9.3.6 Summary

In summary, ABB-CE has conducted a comprehensive development and verification program to ensure weld integrity of its leak tight sleeves. Experience has shown that oxide layers as visually confirmed to exist on the steam generator secondary side do not affect weld parameters and the abrasive cleaning method described in the report is effective in preparing the tube for welding.

9.4 ROLLED JOINT INTEGRITY

A development program was conducted to ensure the rolled joint of the ETZ sleeve was leak tight and capable of withstanding the design loads. The sleeves were rolled into mock-ups consisting of steam generator tubes which had been rolled into blocks simulating the tube sheet. The sleeves were then tested to confirm the rolled joint was leak tight both before and after cyclic load testing. Tests of the rolled joint were also conducted where process parameters such as torque, tube diameter and roll location relative to the [ ] were varied. A test matrix was used to verify the sleeve installation with sleeve rolling process parameter tolerances. The test program confirmed that the rolled joint integrity is acceptable within the allowable rolling process tolerances.

9.5 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.

9.6 REFERENCES FOR SECTION 9.0

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

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

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

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

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

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

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

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

9.6.9 Qualification of the Roll Transition Zone (RTZ) Sleeve 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 9-3
ABB CENO S/G SLEEVE OPERATING HISTORY

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 TEST

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

10.0 EFFECT OF SLEEVING ON OPERATION

Multiple plant specific analyses have been performed to determine the effects of installation of varying lengths and combinations of ETZ and TS sleeves. Sleeve lengths and various combinations of installed sleeves were used to evaluate the effect of sleeving on the hydraulic characteristics and heat transfer capability of steam generators. Using the head and flow characteristics of the pumps, in conjunction with the primary system hydraulic resistances, system flow rates have been calculated as a function of the number of sleeved tubes and the types of sleeves installed. Similarly, curves are generated from calculations that show the percent reduction in system flowrate as a function of newly plugged tubes (per steam generator). These curves are derived from plant specific information based on the following steam generator conditions :

- Number Of Open Tubes Per Steam Generator
- Number Of Tubes Sleeved
- Primary System Flowrate
- Primary Coolant Temperature

This information has been used to generate tables, such as Table 10-1, that provide hydraulic equivalency of plugs and installed sleeves, or the sleeve/plug ratio. Table 10-1 is provided as an approximation only and is based on assumed operating parameters and sleeve types for steam generators with 3/4" O.D. tubes. It must be assumed that some variations in the sleeve/plug ratio will occur from plant to plant based on operating parameters and steam generator conditions.

The overall resistance to heat transfer between the primary and secondary side of the steam generator consists of primary side film resistance, the resistance to heat transfer through the tube wall, and the secondary side film resistance. Since the primary side film resistance is only a fraction of the total resistance and the change in flow rate is so small, the effect of this flow rate change on heat transfer is negligible.
When the sleeve is installed in the steam generator tube there is an annulus between the sleeve and tube except in the sleeve-tube weld regions. Hence, there is effectively little primary to secondary heat transfer in the region where the sleeve is installed. The loss in heat transfer area associated with sleeving is small when compared to the overall length of the tube.

In summary, installation of sleeves does not substantially affect the primary system flow rate or the heat transfer capability of the steam generators.

TABLE 10-1

TYPICAL SLEEVE TO PLUG EQUIVALENCY RATIO

CASE	CONFIGURATION	RATIO (Sleeve/Plug)*
1	ETZ (1)	
2	ETZ (1) + TS (1)	
3	ETZ (1) + TS (2)	

* This ratio should be considered approximate due to plant to plant variations.

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 ASME 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.