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CONSOLIDATED EDISON COMPANY OF NEW YORK, INC.
INDIAN POINT TWO

STEAM GENERATOR SLEEVING REPORT
(Mechanical Sleeves)

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1.0 INTRODUCTION

This document contains the technical information which supports the sleeving repair process implemented in the Westinghouse designed steam generators at Indian Point Unit 2. As a result of extensive development programs in steam generator repair, Westinghouse has developed the capability to restore degraded steam generator tubes by means of a sleeve.

To date, approximately 25,000 steam generator tubes at several operating nuclear power plants world-wide have been successfully sleeved, tested, and returned to service by Westinghouse. Sleeves with mechanical, welded, and brazed joints using Alloy 600, 690, and bimetallic 625 and 690 have been installed by a variety of techniques; hands-on (manual) installation, Coordinate Transport (CT) system installation, and Remotely Operated Service Arm (ROSA) robotic installation. Westinghouse sleeving programs have been successfully implemented after approval by licensing authorities in the United States (NRC - Nuclear Regulatory Commission), Sweden (SKI - Swedish Nuclear Power Inspectorate), Japan (MITI - Japanese Ministry of International Trade and Industry), and Belgium (Vincotte).

The sleeving technology was originally developed to sleeve degraded tubes (including leakers) in Westinghouse Model 27 series steam generators. A process and remote sleeve delivery system (CT) were subsequently developed and adapted to Westinghouse Series 44 series steam generators in large scale programs at two operating plants. Current technology utilizes the latest in computer controlled process technology and robotic delivery systems in the sleeving programs. This technology facilitates sleeve installation in both Westinghouse and non-Westinghouse steam generators.

2.0 SLEEVING OBJECTIVES AND BOUNDARIES

2.1 Objectives

Indian Point Two (IPP) is a Westinghouse-designed 4 loop pressurized water reactor rated at 3,083 MWt. The unit utilizes four vertical U-tube steam generators. The steam generators are Westinghouse Series 44 containing heat transfer tubes with dimensions of 0.875 inch nominal OD by 0.050 inch nominal wall thickness.

The sleeving concept and design are based on observations that the tube degradation due to operating environmental conditions has occurred near the tubesheet areas of the tube bundle. The sleeve has been designed to span the degraded region in order to maintain the tubes experiencing degradation in service.

The sleeving program has two primary objectives:

1. To sleeve tubes in the region of known or potential tube degradation.
2. To minimize the radiation exposure to all working personnel (ALARA)

2.2 Sleeving Boundary

Tubes to be sleeved will be selected by radial location, tooling access (due to channel head geometric constraints), and eddy current indication elevations and size. An axial elevation tolerance of one inch will be employed to allow for any potential eddy current testing position indication inaccuracies and degradation growth. Tube location on the tubesheet face, sleeve length, tooling dimensions, and tooling access permitted by channelhead bowl geometry define the sleeving boundaries. Figure 2.2-1 shows estimated radial sleeving boundaries for [ ]^{a,c,e} sleeves as determined by a geometric radius computed using the clearance necessary to accommodate the combined sleeve and tool length. These are typical sleeving boundaries for a Westinghouse Series 44 steam generator and represent the maximum sleeving potential with [ ]

[ ]^{a,c,e} sleeves. The actual sleeving boundary for a specific plant may vary as a result of slight differences in the steam generator bowl geometry.

Tubes that are degraded beyond the plugging limit, outside the axial coverage provided by [ ]^{a,c,e} sleeves or outside the radial sleeving boundary of these sleeves may be plugged. The actual sleeving region may be modified based on tool length or other variables.

The actual tube plugging/sleeving map for each steam generator will be provided as part of the software deliverables at the conclusion of the sleeving effort.

The specific tubes to be sleeved in each steam generator will be determined based on the following parameters:

1. No indications beyond the elevation spanned by the sleeve pressure boundary which are greater than the plugging limit.
2. Concurrence on the eddy current analysis as to the extent and location of the degradation.

2.3 Report Applicability

[

[ ]

]^{a,c,e}

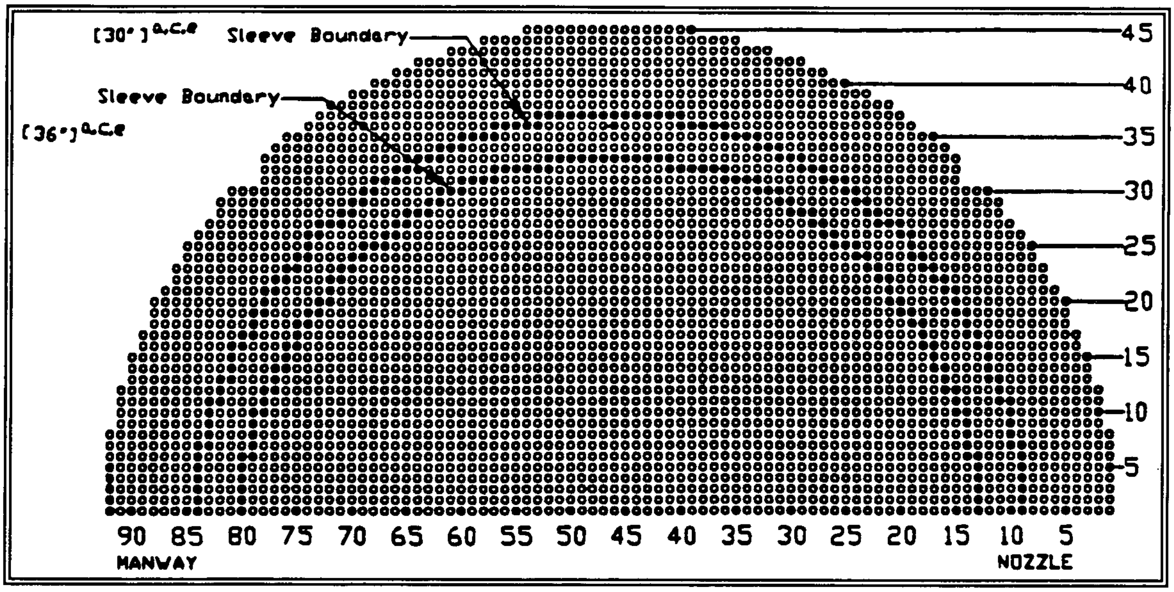


Figure 2.2-1. Sleeving Boundary [ ]^{a,c,e} Sleeves.

3.0 DESIGN

3.1 Sleeve Design Documentation

The Indian Point Unit 2 steam generators were built to the 1965 edition with the Summer 1966 Addenda of Section III of the ASME Boiler and Pressure Vessel Code, however, the sleeves have been designed and analyzed to the 1989 edition of Section III of the Code, as well as applicable Regulatory Guides. A reconciliation to the original code of construction was performed to verify compliance. The associated materials and processes also meet the requirements of the Code. The specific documentation applicable to this program are listed in Table 3.1-1.

3.2 Sleeve Design Description

The design of the sleeve, as installed, is illustrated in Figure 3.2-1. [

]^{a,c,e}

At the upper end, the sleeve contains a section (see Figure 3.2-1) which is [

]^{a,c,e} This joint is known as a hybrid expansion joint (HEJ). [

]^{a,c,e} To allow for axial tolerance in defect location, the upper joint is positioned so that the lowermost elevation of the upper sleeve joint is a minimum of 1 inch above the degraded area of the tube.

The lower sleeve joint (Figure 3.2-2) consists of a section which is [

]

[

]^{a,c,e}

This preformed section of the sleeve facilitates the seal formation and reduces the residual stresses in the sleeve.

The installed sleeve extends above the top of the tubesheet and spans the degraded region of the original tube. Its length is controlled by the insertion clearance between the channel head inside surface and the primary side of the tubesheet, and the tube degradation location above the tubesheet. The remaining design parameters such as wall thickness and material are selected to enhance corrosion resistance and to meet ASME Boiler and Pressure Vessel Code requirements. The upper joint is located so as to provide a length of free sleeve above it. This length is added so that if in the unlikely event the existing tube was severed just above the upper edge of the mechanical joint, the tube would be restrained by the sleeve limiting lateral and axial motion of the tube, and subsequent leakage. Limiting lateral motion of the severed tube would also protect adjacent tubes from impact by the severed tube. [

]^{a,c,e}

To minimize stress concentrations and enhance inspectability in the area of the upper expanded region, [

]^{a,c,e,f}

The sleeve material, thermally treated Alloy 690, is selected for its enhanced resistance to stress corrosion cracking. (See Section 3.3.2 for further details on the selection of thermally treated Alloy 690).

3.3 Design Verification - Test Programs

3.3.1 Design Verification Test Program Summary

The purpose of this program was to demonstrate the ability of a sleeve to span a degraded region in a steam generator tube and maintain the steam generator tubing primary-to-secondary pressure boundary under normal and accident conditions. This program included an assessment of the structural integrity and corrosion resistance of sleeved tubes.

The sleeve material is Alloy 690 (UNS N06690) manufactured to the requirements of ASME SB-163 with supplemental requirements of Code Case N-20. The material has been thermally treated (TT) to enhance its resistance to corrosion in steam generator primary water and secondary-side water environments. This thermally treated material has been used in previous sleeving programs.

While most previous testing was designed around sleeves for Series 44 steam generators, the standardized sleeve designed for 0.875 OD tubes may be installed in Westinghouse Series 44 or 51 steam generators. The installation of the sleeves by the combination of [ ]^{a,c,e} as proposed for Indian Point Unit 2 is the same process verified and used in previous sleeving programs. Because of the similarity in operating conditions, the results of the tests conducted on the Series 44 steam generators are considered applicable to the 51 Series steam generators as well.

The objectives of the mechanical testing programs included:

- Verify the leak resistance of the upper and lower sleeve to tube joints.
- Verify the structural strength of the sleeved tube under normal and accident conditions.
- Verify the fatigue strength of the sleeved tube under transient loads considering the remaining design life objective of the reactor plant.
- Establish the process parameters required to achieve satisfactory installation and performance. These parameters are discussed in Section 4.6.

The acceptance criteria used to evaluate the sleeve performance is leak rate based on the plant technical specifications. Over 100 test specimens were used in various test programs to verify the design and to establish process parameters. Testing encompassed static and cyclic pressures, temperatures, and loads. The testing also included evaluation of joints fabricated using Alloy 600 and Alloy 690 sleeves in Alloy 600 tubes. While the bulk of the original qualification data is centered on Alloy 600 sleeves, a series of verification tests were run using Alloy 690 sleeves to demonstrate the effectiveness of the joint formation process and design with either material. Additionally an engineering evaluation of those properties which would affect joint performance was made and disclosed no areas which would result in a change of joint performance.

The sections that follow describe those portions of the corrosion (Sections 3.3.2 - 3.3.3) and mechanical (Sections 3.3.4 - 3.3.6) verification programs that are relevant to this sleeving program.

3.3.2 Corrosion and Metallurgical Evaluation

The objectives of the corrosion evaluations were to (l) verify that thermally treated Alloy 690 is a suitable material for use in steam generator environments and (2) verify that sleeving would not have a detrimental effect on the serviceability of the existing tube or the sleeve components. The material of construction for the steam generator tubes of the Westinghouse design, including the steam generators at Indian Point Unit 2, is Alloy 600 in the mill annealed condition. Alloy 600 is a high nickel austenitic alloy that is nominally 72 percent nickel, 14-17 percent chromium, and 6-10 percent iron. The sleeving material proposed for sleeving the Indian Point Two steam generators is Alloy 690 in the thermal treated condition. Alloy 690 is also a high nickel austenitic material but contains a higher chromium content and a correspondingly lower nickel content with a nominal composition of 60 percent nickel, 30 percent chromium, and 9 percent iron.

Thermally treated Alloy 690 is recommended in lieu of mill annealed Alloy 600 or thermally treated Alloy 600. Laboratory testing has shown that thermally treated Alloy 690 has resistance to corrosion in steam generator environments that is equal or better than Alloy 600 in either of the indicated heat treated conditions. The higher chromium content of Alloy 690 is believed to be responsible for this enhanced corrosion resistance. In addition, the alloy is thermally treated to further enhance its stress corrosion cracking resistance properties.

Thermally treated Alloy 690 is the current tubing material recommended by Westinghouse for steam generator applications.

The stress corrosion cracking performance of thermally treated Alloys 600 and 690 in both off-chemistry secondary side and primary side environments has been extensively investigated. Results have demonstrated the additional stress corrosion cracking resistance of thermally treated Alloys 600 and 690 as compared to mill annealed Alloy 600 material. Direct comparison of thermally treated Alloys 600 and 690 has further indicated an additional margin of SCC resistance for thermally treated Alloy 690 (Table 3.3.2-1).

The caustic SCC performance of mill annealed and thermally treated Alloys 600 and 690 were evaluated in a 10 percent NaOH solution as a function of temperature from 288°C to 343°C. Since the test data were obtained over various exposure intervals ranging from 2000 to 8000 hours, they were normalized in terms of average crack growth rate determined from destructive examination of the C-ring test specimens. No attempt was made to distinguish initiation and propagation rates.

The crack growth rates presented in Figure 3.3.2-1 indicate that thermally treated Alloys 600 and 690 have enhanced caustic SCC resistance when compared to that of Alloy 600 in the mill annealed condition. The performance of thermally treated Alloys 600 and 690 are approximately equal at temperatures of 316°C and below. At 332°C and 343°C, the additional SCC resistance of thermally treated Alloy 690 is observed. In all instances the SCC morphology was intergranular in nature. The enhanced performance of thermally treated Alloy 690 at higher temperatures is a result of a lesser temperature dependency.

C-ring specimens were tested in 10 percent NaOH solution at 332°C to index the relative IGA resistance of Alloys 600 and 690. Comparison of the IGA morphology for these C-rings stressed to 150 percent of the 0.2 percent yield strength is presented in Figure 3.3.2-2. Mill annealed

Alloy 600 is characterized by branching intergranular SCC extending from a front of uniform IGA. Thermally treated Alloy 600 exhibited less SCC, and IGA limited to less than a few grains deep. Thermally treated Alloy 690 exhibited no SCC and only occasional areas of intergranular oxide penetrations that were less than a grain deep.

The enhancement in IGA resistance can be attributed to two factors; heat treatment and alloy composition. A characteristic of mill annealed Alloy 600 C-rings exposed to a deaerated sodium hydroxide environment is the formation of intergranular SCC with uniform grain boundary corrosion (IGA). The relationship between SCC and IGA is not well established but it does appear that IGA occurs at low or intermediate stress levels and at electrochemical potentials where the general corrosion resistance of the grain boundary area is a controlling factor. Thermal treatment of Alloy 600 provides additional grain boundary corrosion resistance along with additional SCC resistance. In the case of Alloy 690, the composition provides an additional margin of resistance to IGA and the thermal treatment enhances the SCC resistance.

The addition of oxidizing species to deaerated sodium hydroxide environments results in either a deleterious effect or no effect on the SCC resistance of thermally treated Alloys 600 and 690 and depends on the specific oxidizing specie and concentration (Table 3.3.2-2). The addition of 10 percent copper oxide to 10 percent sodium hydroxide decreases the SCC resistance of thermally treated Alloys 600 and 690, and also modifies the SCC morphology with the presence of transgranular cracks in the case of Alloy 690. The exact mechanism responsible for this change is not well understood, but may be related to an increase in the specimen potential that corresponds to a transpassive potential, which may result in an alternate cracking regime. The specific oxidizing specie and the ratio of oxidizing specie to sodium hydroxide concentration appear to effect the cracking mode. The apparent deleterious effect on SCC resistance is eliminated by lowering the copper oxide or sodium hydroxide concentration.

The primary water SCC test data are presented in Figure 3.3.2-4. For the beginning-of-fuel-cycle water chemistries, 10 of 10 specimens of mill annealed Alloy 600 exhibited SCC, while 1 of 10 specimens of thermally treated Alloy 600 had cracked in exposure times of about 12,000 hours. In the end-of-fuel cycle water chemistries, 9 of 10 specimens of mill annealed Alloy 600 exhibited SCC, while 3 of 10 specimens of thermally treated Alloy 600 had cracked. After 13,000 hours of testing, no SCC has been observed in the mill annealed or thermally treated Alloy 690 specimens in either test environment.

Continuing investigation of the SCC resistance of Alloys 600 and 690 in primary water environments has shown mill annealed Alloy 600 to be susceptible to cracking at high levels of strain and/or stress. Thermal treatment of Alloy 600 in the carbide precipitation region enhances its SCC resistance. The performance of Alloy 690, both mill annealed and thermally treated, demonstrates primary water SCC resistance and is believed to be due to alloy composition.

3.3.3 Upper and Lower Joints

All the data presented in Section 3.3.2 relative to the corrosion and the stress corrosion cracking resistance of thermally treated Alloys 600 and 690 are applicable to the sleeve.

A similar corrosion verification test program has been conducted to demonstrate the residual stresses induced in the parent tubing by the expansion process do not degrade the integrity of the tubing. Table 3.3.3-1 identifies the various tests which have been performed and the findings. A discussion of the tests follows.

Residual stresses on the OD and ID of the surrogate type 304 Stainless Steel tubing which was expanded to varying amounts of [

]^{a,c,e}

The specimen design is shown in Figure 3.3.3-2 and the test parameters are listed in Table 3.3.3-2. [

]

[

]^{a,c,e}

[

]^{a,c,e} The stresses in the sleeve, based on tube to tubesheet data, should be as shown schematically at B and C in Figure 3.3.3-1. These are judged to be acceptable, particularly in view of the corrosion resistance of the thermally treated sleeve material. Stress levels in the outer tube are also influenced by the expansion technique. For the outer tube expansion produced solely by [

]^{a,c,e} The absolute magnitude of these stresses will depend on the specific diametral expansion.

Residual stresses on the OD and ID of the surrogate type 304 Stainless Steel tubing which was expanded to varying amounts of [

]^{a,c,e}

The specimen design is shown in Figure 3.3.3-2 and the test parameters are listed in Table 3.3.3-2. [

]^{a,c,e}

[

]^{a,c,e}

No cracking was detected on the OD surface of any specimen. These results indicate that the OD stresses are below the threshold required to cause cracking in the stainless steel (less than 10 to 15 ksi).

To summarize the results of this test:

- [
-]^{a,c,e}
- [ ]^{a,c,e}

The residual stresses in a HEJ formed in a mill annealed Alloy 600 tube with a thermally treated Alloy 690 sleeve were measured using the parting/layer removal technique. The conditions of the joint were as follows:

Nominal Tube OD	0.875 inch
Nominal Sleeve OD	0.740 inch

a,c,e

The results of these tests are summarized in Figures 3.3.3-5 and 3.3.3.6. They show an excellent correlation with the $MgCl_2$ tests. The OD surface of the tube was in compression in the axial direction at all locations along the expansion transitions. The ID surface was in tension in the axial direction in the expansion transitions with the highest measured stress located at the hydraulic transition. In the circumferential direction, both surfaces of the tube were generally in compression although low tensile stresses, about 5 ksi or lower, were measured on the tube ID in the hydraulic expanded region and on the OD in the unexpanded tube near the hydraulic expansion transition. The OD surface of the sleeve was also in compression in the axial and circumferential directions except for one measurement that was in tension (about 5 ksi) in the axial direction in the [ ]^{a,c,e}. The ID surface of the sleeve had areas where the stresses were as high as about 25 ksi in either the axial or circumferential direction. Residual stresses of this magnitude should not effect the special thermally treated sleeve material.

Polythionic Acid Tests

To confirm that the $MgCl_2$ results, utilizing stainless steel surrogate tubing, are applicable to Alloy 600 tubing, a corresponding stress indexing test was performed with sensitized Alloy 600 tubing exposed to polythionic acid on the ID. The results, indicated below, support the $MgCl_2$ findings.

Material: Sensitized Alloy 600 tubing

[

]

[

]^{a,c,e}

Summary: The results of the various stress indexing tests indicate that the residual stress imposed on the parent tubing by the HEJ process are of a sufficiently low magnitude as to not constitute a concern. [

]^{a,c,e}.

Primary Water Tests

Two tests to confirm the primary water stress corrosion cracking resistance of HEJ's have been conducted. A summary of the results of these tests is as follows:

680°F Primary Water Tests:

Material: a. Alloy 600 mill annealed tubing with known susceptibility to primary water stress corrosion cracking.

b. Alloy 600 thermally treated sleeves.

Expansion Matrix:

a,c,e

Number of Specimens
4
4
3

*Not within the normal expansion ranges for HEJ field installation.

Total Expansion, ΔD, inch - [ ]^{a,c,e}

Test Environment:

Temperature: 680°F

Pressure: Primary Side - 2,850 psig
Secondary Side - 1,450 psig

Chemistry: Primary Side - Hydrogenated Pure water
Secondary Side - Pure water

Results: 2000 hour exposure with no primary to secondary leakage. Destructive examination detected no tube wall degradation.

750°F Steam Tests:

Material:

a. Alloy 600 mill annealed tubing with known susceptibility to primary and pure water.

b. Alloy 600 special thermally treated sleeves.

Expansion Matrix:

a,c,e

Number of Specimens	[ ]
2	
2	
2	

*Not within normal expansion ranges for HEJ field installation

NOTE

Total Expansion, ΔD, inch - [

]^{a,c,e}

Test Environment:

Temperature:	750°F
Pressure:	Secondary and Primary at the same pressure
Chemistry:	Hydrogenated pure water

Results: 1,700 hour exposure with no degradation of tube or sleeve defect by NDE including ID ECT and OD UT or by destructive examination.

In addition, both temperature and stress influence the time required to initiate primary water stress corrosion cracking (PWSCC). Calculations have been made using an equation suggested by the Brookhaven National Laboratory) for the prediction of PWSCC. [

]^{a,c,e}

1) R. Bandy and D. van Royen, A Model for Predicting the Initiation and Propagation of Stress Corrosion Cracking of Alloy 600 in High Temperature Water.

- For MA Alloy 600 in Primary Water:

a,c,e

- For Typical Primary Temperature Conditions:

a,c,e

Location	Temp. °K	Residual Stress ksi	Pressure (Hoop) Stress ksi	Total (Hoop) Stress ksi	a,c,e

Postulation of PWSCC at the HEJ versus Hard Roll Transition:

a,c,e

- The time to initiate PWSCC at the HEJ is calculated to be a factor of [ ]^{a,c,e}

3.3.4 Test Program for the Lower Joint

3.3.4.1 Description of Lower Joint Test Specimens

The tube/tubesheet mock-up was manufactured so that it was representative of the partially rolled tube to tubesheet joint (Figure 3.3.4.1-1) of the Series 44/51 steam generators. Indian Point Unit 2 steam generator tubes are partial depth rolled inside the tubesheet. The formation of the lower mechanical rolled joint of the tube/sleeve is simulated by the mock-up. The tube was examined with a fiberscope, [ ]^{a,c,e} cleaned by swabbing, and re-examined with the fiberscope. Then the preformed sleeve (made of thermally treated Alloy 600 or 690) was inserted into the tube and the lower joint formed. [

]^{a,c,e}

3.3.4.2 Description of Verification Tests for the Lower Joint

The as-fabricated specimens for the Series 44/51 (as discussed in Section 3.3.1, Series 51 parameters Figure 3.3.4.1-1, Lower Joint As-Rolled Test Specimen and conditions are similar to those of Series 44 parameters and conditions) were tested in the sequence described below. Note that the tests of the Alloy 690 sleeve are similar to those performed on the Alloy 600 sleeve except that the Steam Line Break (SLB) and Extended Operation Period (EOP) tests were not considered necessary based on previous data.

1. Initial leak test: The leak rate was determined at room temperature, 3,110 psi and at 600°F, 1,600 psi. These tests established the leak rate of the lower joint after it has been installed in the steam generator and prior to long-term operation.

2. The specimens were fatigue loaded for 5,000 cycles.

3. The specimens were temperature cycled for 25 cycles.

4. The specimens were leak tested at 3,110 psi room temperature and at 1600 psi 600°F. This established the leak rate after a simulation of 5 years normal operation (plant heatup/cooldown cycles) produced by steps 2 and Several specimens were removed from this test sequence at this point and were subjected to the EOP Test. See Step 7, below.

5. The specimens were leak tested while being subjected to SLB conditions.

6. The specimens were leak tested as in Step 1 to determine the postaccident leak rate.

7. The EOP test was performed after Step 4 for three as-rolled specimens.

3.3.4.3 Leak Test Acceptance Criteria

Site specific or bounding analyses have been performed to determine the allowable leakage in a steam generator from primary to secondary side during normal operation and the limiting postulated accident condition. The leak rate criteria that have been established are based on Technical Specification and Regulatory requirements. The limiting leak rate is the acceptable primary coolant leak rate to the steam generator in the loop with the failed steamline.

The limiting leak rate is the primary coolant leak rate through the steam generator in the faulted loop. The duration of the accident is assumed to be [

]^{b,d,e} The analysis assumes primary and secondary coolant initial inventories of 1.0μCi/gm and 0.1μCi/gm Dose equivalent I-131, respectively. In addition, as a result of the reactor trip, an iodine spike is initiated which increases the iodine appearance rate in the primary coolant to a value equal to 500 times the equilibrium appearance rate.

The leak rate criteria can be compared to the actual leak test results in subsequent sections to provide verification that the sleeve exhibits no leakage under simulated normal operating conditions and only minor leakage under umbrella postulated accident conditions. Any leakage observed during the leak rate test as reported in subsequent sections is within allowable limits as provided on Table 3.3.4.3-1. Leak rate measurement is based on the number of drops counted during a 10-20 minute period. Conversion to volumetric measurement is based on assuming 19.8 drops per milliliter.

3.3.4.4 Results of Verification Tests for Lower Joint

Test conditions have been designed to test the sleeve at its limit. For example, in the case of the fatigue testing, 5,000 cycles were used. This number does not represent the number of cycles expected in one year, it is the number of expected yearly cycles multiplied by a suitable factor to establish an accelerated test condition. Consequently, the test results provided are conservative in nature often exceeding actual operating conditions. In another example, the parameters of the thermal cycle test; temperature ramp, hold time and temperature gradient, are accelerated to achieve test results within an abbreviated time frame. Consequently, the test results obtained and discussed throughout the rest of this report are those of accelerated conditions designed to test the sleeve at its endurance limit. Sleeve verification tests demonstrate that under extreme, accelerated test conditions, leakage is minimal so that in the actual operating case the sleeves will perform within acceptable limits. By using that same test series for all sleeve designs it is possible to quantify the effect of a process modification or small changes in the overall design to facilitate an assessment of total sleeve performance.

Reference is occasionally made to the "leakage-reducing" qualities of the mechanical joint design. This is in reference to the phenomena (observed in the test data) which shows that as the mechanical joints operate, if they exhibited leakage at the outset of the test, the rate of leakage decreases gradually with operation, to zero in most cases. This characteristic has been observed consistently in all mechanical joint testing.

Another consistent characteristic observed in the testing of mechanical joints is that the leakage, when observed, is generally higher at room temperature conditions and, decreases as the temperature is elevated. This characteristic has lead to the almost exclusive use of the room temperature hydrostatic test in the process, tooling, personnel, procedure and demonstration phases associated with a plant specific sleeving operation.

The test results for the Series 44/51 lower joint specimens are presented in Table 3.3.4.4-1. The specimens did not leak before or during fatigue loading. After simulating five years of normal operation due to [

]^{a,c,e} All of the three as-rolled specimens were leak-tight during the Extended Operating Period (EOP) test.

For the Alloy 690 sleeve tests the following were noted:

Specimens MS-2 (Alloy 690 Sleeve): Initial leak rates at all pressures and at normal operating pressure following thermal cycling were [

]^{a,b,c,e}

Specimen MS-3 (Alloy 690 Sleeve): [

]^{a,b,c,e}

Specimen MS-7 (Alloy 690 Sleeve): [

]

[

]^{a,b,c,e}

3.3.4.5 Description of Additional Test Programs - Lower Joint with Exceptional Conditions

Additional test programs were performed to demonstrate acceptable performance of the sleeve lower mechanical joint to accommodate exceptional conditions which may exist in the steam generator tubes and anticipated conditions which may be employed during installation of sleeves.

Exceptional conditions in steam generator tube characteristics and sleeving operation process parameters included;

- shorter lengths of roller expanded lower sleeve joints
- lower applied torque values employed in shorter sleeve lower joints
- simulated circumferential cracks in tube roll transitions

The specific exceptional tube conditions and changes to the sleeving process parameters tested in the first program, are shown in Table 3.3.4.5-1.

Each process operation and sequence of operations employed in fabricating each test sample was consistent with those specified for sleeves to be installed by field procedures. In addition, the exceptional tube conditions and changes to the sleeving process parameters described in Table 3.3.4.5-1 were included in the assembly of tube and collar sub assemblies.

The as-fabricated specimens for this program were tested in the sequence described below.

1. Initial leak tests: Each specimen was checked for leak tightness prior to any verification tests. The leak tests were performed at room temperature and 2,450 psig followed by a second leak test at 600°F and 2,450 psig. These tests established the leak rate of the lower joint after it had been installed in the steam generator and prior to long-term operation.

2. Thermal Soak Test: Each specimen was subjected to an unpressurized thermal soak at 600°F for 1 hour minimum, and cooled to room temperature. After this test each specimen was subjected to the leak tests described above.

3. Thermal Cycling Test: Some specimens were subjected to a pressurized (1,600 psig) thermal cycling test from ambient to 600°F for a total of 25 cycles. After this test each specimen was subjected to the leak tests described above.

4. Fatigue Test: Some specimens were subjected to a pressurized (1,600 psi) fatigue test at 600°F for a total of 35,000 cycles. After this test each specimen was subjected to the leak tests described above.

5. Compression Tests: Some specimens were subjected to a destructive nonpressurized compression test. Some were tested at room temperature and others at 600°F to determine the buckling resistance of the sleeve.

6. Tensile Test: Some specimens were subjected to a destructive nonpressurized tensile test at 600°F to determine the resistance of the sleeve.

7. Steam Line Break Test: Some specimens were subjected to a steam line break test at 650°F and 2,560 psi. After this test each specimen was subjected to the leak tests described above.

Results from the first program are shown in Table 3.3.4.5-2.

The as-fabricated specimens for the second program were tested in the sequence described below.

1. Initial leak tests: Each specimen was checked for leak tightness prior to any verification tests. The leak tests were performed at room temperature and 3,110 psig followed by a second leak test at 600°F and 3,110 psig. These tests established the leak rate of the

lower joint after it had been installed in the steam generator and prior to long-term operation.

2. Fatigue Test: Some specimens were subjected to a pressurized (1,600 psi) fatigue test at 600°F for a total of 20,000 cycles. After this test each specimen was subjected to the leak tests described above.

3. Tensile Test: Some specimens were subjected to a destructive nonpressurized tensile test at 600°F to determine the resistance of the sleeve.

Results from the second program are shown in Table 3.3.4.5-3,

Results from both programs indicate that the lower sleeve tube joint when installed with these exceptional steam generator tube physical conditions or changes to process parameters described, will provide:

- adequate leak resistance,
- adequate structural strength under normal and accident conditions,
- adequate fatigue strength under transient loads for the remaining design life objective of the reactor plant.

3.3.5 Test Program for the Upper Hybrid Expansion Joint (HEJ)

The discussion contained in Section 3.3.4.4 is relevant to testing in general and applies in the following tests conducted on upper joints as well.

3.3.5.1 Description of the Upper HEJ Test Specimens

Two types of HEJ test specimens were fabricated for the Series 44 testing [

]^{a,c,e}

[ ]^{a,b,c}. The first type was a short specimen as shown in Figure 3.3.5.1-1. Some of these specimens were fitted with pots containing a hard sludge simulant to test the structural effects of sludge on the joint. The only type of sludge simulated in this program was hard sludge. Soft sludge effects were bounded by the hard sludge effects and by the out-of-sludge conditions. [

]^{a,b,c} Leakage was collected and measured as it issued from the annulus between the tube and sleeve. This type of specimen was used in the majority of the tests.

The second type of test specimen was a modification of the first type. It was utilized in the reverse pressure tests, i.e., for LOCA and secondary side hydrostatic pressure tests. As shown in Figure 3.3.5.1-2, the specimen was modified by [

]^{a,c,e}

[

]^{a,b,c} The possible reverse pressure test leak path is shown in Figure 2.2.5.1-2.

Only specimens like Figure 3.3.5.1-1 (excluding the sludge conditions) were used in the Alloy 690 HEJ specimen fabrication as the effects of sludge had been established in the earlier Series 44 tests.

3.3.5.2 Description of Verification Tests for the Upper HEJ

The verification test program for the HEJ was similar to that for the Lower Joint.

The HEJ was subjected to fatigue loading cycles and temperature cycles to simulate five years of normal operation and the leak rate was determined before and after this simulated normal operation. For a number of the specimens, the leak rate was also determined as a function of static axial loads which were bounded by the fatigue load. It is important to note that the fatigue load used in testing was that which was caused by loading/unloading. Hence, it was judged necessary to determine that the leak rate at static and fatigue conditions were comparable. The upper HEJ specimens were also subjected to the loadings/deflections corresponding to a steam line break (SLB) accident and the leak rate was determined during and after this simulated accident. The upper HEJ was also leak tested while being subjected to two reverse pressure conditions, a LOCA and a condition which simulated a secondary hydrostatic test. An extended operation period test was also performed.

3.3.5.3 Results of Verification Tests for the Upper HEJ

The test results are presented in Tables 3.3.5.3-1 through 3.3.5.3-5.

As can be seen from Table 3.3.5.3-1, the HEJ's formed out-of-sludge, i.e., in air, had an average initial leak rate of approximately [ ]^{b,c,e} at the normal operating condition of 600°F and 1,600 psi. After simulating five years of normal operation due to 5,000 fatigue cycles and 29 to 32 temperature cycles, the leak rate was [ ]^{b,c,e} at the normal operating condition. Furthermore, for the EOP test, i.e., after simulating thirty-five years of normal operation due to 208 temperature cycles and a total of 35,000 fatigue cycles, the leak rate was [ ].^{b,c,e}

Table 3.3.5.3-2 contains data for upper HEJ's formed out-of-sludge. It includes the same basic test data as Table 3.3.5.3-1, i.e., initial leak rate data. However, it includes static axial load leak tests, SLB and reverse pressure tests in place of the fatigue and EOP tests included in Table 3.3.5.3-1. Five of the six specimens were leaktight at normal operating conditions during the initial leak test. The leak rate during static axial sleeve loads, bounded by the fatigue load and caused by normal operating conditions was measured for four out-of-sludge HEJs. [

]^{b,c,e} These same four specimens were then subjected to the SLB temperature, pressure and axial load conditions. [ ]^{a,c,e}

[ ]

[ ]^{b,c,e} The results for the post-SLB leak test, at the same temperature and pressure conditions, were similar to the during-SLB results, [ ]^{b,c,e}

The results for the out-of-sludge HEJ reverse pressure test are shown in Table 3.3.5.3-2. For both the simulated LOCA and secondary side hydrostatic pressure test the leak rate was zero for the two specimens tested.

The process used for forming HEJ's in sludge, in Tables 3.3.5.3-3 and 3.3.5.3-4, was the reference process, per Table 4.0-1 except that the [ ]^{a,c,e} The initial leak rate of the first group of upper HEJs formed in sludge was [ ]^{b,c,e} at the normal operating condition as is shown in Table 3.3.5.3-3.

Only one specimen had a [ ]^{b,c,e} After exposure of the specimens to five years of simulated normal operation due to fatigue and temperature cycling, the average leak rate remained very low, [ ]^{b,c,e} at the 600°F and 1,600 psi condition.

The results of the reverse pressure test for the in-sludge upper HEJs are also shown in Table 3.3.5.3-3. [ ]^{a,b,c} It was also zero for the simulated secondary side hydrostatic pressure test.

Table 3.3.5.3-4 also contains data for HEJs formed in-sludge. It includes the same basic initial leak tests as Table 3.3.5.3-3. However, it includes axial load leak test and post-SLB leak tests in place of the fatigue and reverse pressure tests included in Table 3.3.5.1-2. All of the four specimens were leaktight during the initial leak test, per Table 3.3.5.3-4. Two specimens did not leak at any static axial load and two others did not leak until a compressive load of 2,950 lbs was reached. However, the two leak rates at 2,950 lbs were low, [ ]^{b,c,e} for specimens Number PTSP-23 and PTSP-33, respectively. The average leak rate for the four specimens during the SLB test was [

]^{a,c,e}

In general, the leak rates for static loads were approximately the same as for dynamic (fatigue) loads of the same magnitude. However, a specific set of specimens was not subjected to both types of loads. The test data generated for the Alloy 690 and Alloy 625/690 samples is presented in Table 3.3.5.3-5. The following observations were noted:

Specimen S-5 (Alloy 690): [ ]^{a,b,c} were found at initial leak testing at room temperature (R.T.). At 600°F, the leak rates reduced significantly and remained below [ ]^{a,b,c} during a subsequent thermal cycling test. This specimen was formed with a tube diametral bulge that was smaller than will be used in the field.

Specimens S-8 (Alloy 690); B-4, B-6, and B-7 (Alloy 625/690 - 0.740 in. Sleeve Dia.), and BA-11 (Alloy 625/690- 0.630 in. Sleeve Dia.): These five specimens all exhibited moderate to small or very small leaks, mostly during the initial leak testing at R. T. In all cases, by the end of the testing, including thermal cycling and fatigue in some cases, the leak rates had reduced to zero (or near zero), illustrating the leakage reducing characteristic of rolled joints.

Specimen BA-1 (Alloy 625/690, 0.630 Sleeve Dia.): This specimen exhibited zero leak rate at initial testing, both R.T. and 600°F. Small leak rates were found at R.T. after fatigue testing; however, they reduced to very small values, less than 0.5 drops/min. after testing. This specimen was formed with a tube diametral bulge at the low end of the field acceptance range.

3.3.6 Test Program for the Fixed/Fixed Mock-Up

3.3.6.1 Description of the Fixed/Fixed Mock-Up

The fixed/fixed full scale mock-up is shown in Figure 3.3.6.1-1. This mock-up simulated the section of the steam generator from the primary face of the tubesheet to the first support plate. The bottom plate of the mock-up represented the bottom of the tubesheet, the middle plate simulated the top of the tubesheet and the upper plate simulated the first support plate. The tubes were roll expanded into the bottom plate to simulate the tube/tubesheet joint and into the upper plate to simulate a dented tube condition at the tube support plate. The term "fixed/fixed" was derived from the fact that the tubes were fixed at these two locations. There were thirty-two tubes in two clusters of sixteen. A sludge simulant composed of alumina was formed around one cluster of sixteen. Alloy 600 sleeves, thirty inches long, were installed in the tubes by [ ].^{a,c,e} Each tube was perforated between the upper and lower joints to simulate tube degradation and thereby provide a primary-to-secondary leak path. End plugs were welded to the tubes to permit pressurization with water. No fixed/fixed mock-up tests were performed on the Alloy 690 samples based on the results of the earlier tests performed.

3.3.6.2 Description of Verification Tests for the Fixed/Fixed Mock-Up

The fixed/fixed mock-up was used first to verify the full length sleeve installation parameters and tooling. It was then used to measure the leak rate of the lower joint and upper HEJ. This leak rate was determined with the sleeve installed in a tube fixed at the tubesheet and dented at the first support plate, i.e., for the fixed/fixed condition.

3.3.6.3 Results of Verification Tests for the Fixed/Fixed Mock-Up

Table 3.3.6.3-1 contains leak test results recorded for full length sleeves formed and tested in-situ, in the fixed/fixed mock-up, in-sludge and out-of-sludge. All of the room temperature initial leak tests produced [ ]^{a,c,e}

[

]^{a,b,c} These initial leak rate results were similar to the initial leak rate results in which the short specimens were unconstrained during forming of the upper joint. Therefore, it was concluded that the results of the other several tests performed only on short specimens would be similar if the test had been performed in-situ, in the fixed/fixed mock-up. During the pre-test evaluation, it was determined that the fixed/fixed mock-up duplicated the most stringent structural loadings conditions for sleeves. Therefore, it was concluded that all of the testing with short specimens was valid. Because the Series 44 loads envelope the Series 51 loads, this testing is considered applicable to Series 51 units and consequently validates the results for both units.

3.3.7 Effects of Sleeving on Tube-to-Tubesheet Weld

The effect of hard rolling the sleeve over the tube-to-tubesheet weld was examined in the sleeving of 0.750 inch OD tubes. Although the sleeve installation torque used in a 0.075 inch OD tube is less than a 0.875 inch OD tube, the radial forces transmitted to the weld are comparable. Evaluation of the 0.075 inch tubes showed no tearing or other degrading effects on the tube weld after hard rolling. Therefore, no significant effect on the tube-to-tubesheet weld is expected for the larger 0.875 inch OD tube configuration.

3.4 Analytical Verification

This section of the report provides the analytical justification for the sleeve-to-tube assembly with hybrid expansion joints.

3.4.1 Introduction

Section 3.4 summarizes the structural analysis of the sleeve-to-tube assembly with hybrid expansion joints. The loadings considered in the analysis umbrella the conditions specified in the applicable design specification, Reference 1. The analysis includes finite element model development, a heat transfer and thermal stress evaluation, a primary stress intensity evaluation, a primary plus secondary stress range evaluation, and a fatigue evaluation for mechanical and thermal conditions. Calculations are also performed to establish minimum wall requirements for the sleeve, and a corresponding plugging limit for tubes where sleeves have been installed.

3.4.2 Component Description

The general configuration of the sleeve-to-tube assembly is shown in Figure 3.4-1. The critical portions of the assembly are the upper and lower hybrid expansion joints, and the straight unexpanded sections of the sleeve and tube between the two joints.

3.4.3 Summary of Material Properties

The material of construction for the tubing in Westinghouse designed Series 44 steam generators is a nickel based alloy, Alloy 600 in the mill annealed (MA) condition. The sleeve material is also a nickel base alloy, thermally treated Alloy 690. Summaries of the applicable mechanical, thermal, and strength properties (code minimums) for the tube and sleeve materials are provided in Tables 3.4-1, and 3.4-2, respectively. The fatigue curve used in the analysis of the laser welds corresponds to the code curve for austenitics and nickel-chromium-iron (inconel).

3.4.4 Code Criteria

The applicable criteria for evaluating the sleeves is defined in the ASME Code, Section III, Subsection NB, 1989 Edition, Reference 1. A summary of the applicable stress and fatigue limits for the sleeve and tube are summarized in Tables 3.4-3 through 3.4-6. In establishing minimum wall requirements for plugging limits, Regulatory Guide 1.121, Reference 5, is used.

3.4.5 Loading Conditions Considered

The loadings considered in the analysis represent an umbrella set of conditions for Series 44 steam generators. The analysis considers a full duty cycle of events that includes, design, normal, upset, faulted, and test conditions. A summary of the applicable transient conditions is provided in Table 3.4-7. Umbrella pressure loads for Design, Faulted and Test conditions is summarized in Table 3.4-8.

3.4.6 Analysis Methodology

3.4.6.1 Model Development

The analysis of the sleeve-to-tube assembly utilizes both conventional and finite element analysis techniques. Several finite element models are used for the analysis. Separate models are developed for the lower and upper joints. Interaction between the two models is accomplished by coupling appropriate tube and sleeve nodes. The portion of the tubesheet included in the model, a "unit cell" of the tubesheet, is based on an effective radial area surrounding the tube in the tubesheet. The tolerances used in developing the sleeve models are such that the maximum sleeve outside diameter is evaluated in combination with the minimum sleeve wall thickness. This allows maximum stress levels to be developed in the sleeve and tube.

Mechanical roll fixities between the sleeve and tube at the hard roll regions of the HEJ's are achieved by coupling the interface nodes in all directions. The interface nodes along the upper and lower hydraulic expansion regions of the HEJ were coupled in the radial direction for heat transfer and thermal stress runs. In cases where pressure may penetrate into the interface, the interface nodes along these areas were uncoupled for pressure stress runs.

The analysis also considers both an intact tube (between the upper and lower HEJ's), as well as a fully separated tube. The tube integrity conditions are simulated by varying the nodal couplings between the tube segments in the upper and lower joint models.

3.4.6.2 Heat Transfer Analysis

The first step in calculating the stresses induced in the sleeves as a result of the thermal transients, is to perform a heat transfer analysis to establish the temperature distribution for the sleeve, tube, and tubesheet. Based on a review of the transient descriptions, eight transients were selected for evaluation. They include the following events:

Small Step Load Increase
Small Step Load Decrease
Large Step Load Decrease
Hot Standby Operations
Loss of Load
Loss of Power
Loss of Secondary Flow
Reactor Trip from Full Power

The plan heatup/cooldown, plant loading/unloading and steady state fluctuation events are evaluated as pseudo steady state conditions.

In performing the heat transfer analysis, an air gap is included between the tube and the sleeve. Although this gap may be filled with secondary fluid, assuming the physical properties of air is conservative for the thermal analysis. Primary fluid physical properties are used for the gap medium above the upper HEJ.

In order to determine the appropriate boundary conditions for the heat transfer analysis, a thermal hydraulic analysis has been performed to define the primary and secondary side fluid temperatures and film coefficients as a function of time. Both boiling and convective heat transfer correlations have been considered.

3.4.6.3 Stress Analysis

Although the nominal sleeve length is 36 inches, analyses were performed for sleeves ranging from 27 to 44 inches in length. The stress and fatigue results reported below are for the limiting sleeve geometry.

In performing the stress evaluation for the sleeve models, thermally induced and pressure induced stresses are calculated separately and then combined to determine the total stress distribution. As discussed previously, a number of tube/sleeve/tubesheet interface conditions are evaluated. Separate reference pressure cases are run for both an [

]^{a,c,e} It should be noted for both sets of loads that the end cap load on the tube is not included, but is considered in a separate load case.

The analysis considers both undented and dented tubes. In the analysis of dented tubes, it is conservatively assumed that only one tube is locked-up at the first tube support plate at 100% power conditions. The following effects on stress components of the dented tubes are analyzed:

- effect of thermal conditions in the tube and wrapper/shell regions
- effect of pressure drop across the tubesheet
- effect of pressure drop across the tube support plates
- effect of interaction among the tubesheet, tube support plates, shell/wrapper, stayrods, and spacer pipes

The effects of pressure drop across the tubesheet and the tube support plates, as well as the tubesheet/tube support plate assembly interactions, are taken into account for central dented tubes, while they are neglected for the outermost tubes. The end cap pressures due to the axial pressure stress induced in the tube away from discontinuities are taken into consideration for undented tubes. For assumed dented conditions, the end cap load is not required.

Finally, thermal stresses are calculated for each steady state solution, as well as for the thermal transient solutions at those times during the transients that are judged to be limiting from a stress standpoint.

The total stress distribution in the sleeve-to-tube assembly is determined by combining the calculated stresses as follows:

$$\begin{aligned}
\sigma_{total} = & \frac{P_{PR}}{1000}\ (\sigma)\ \textit{unit primary pressure} \\
& + \frac{P_{SEC}}{1000}\ (\sigma)\ \textit{unit secondary pressure} \\
& + (\sigma)\ \textit{thermal transient stress} \\
& + \frac{P_{PR}}{1000}\ (\sigma)\ \textit{unit primary pressure for tubesheet motion} \\
& + \frac{P_{SEC}}{1000}\ (\sigma)\ \textit{unit secondary pressure for tubesheet motion} \\
& + \Delta\frac{T_{TB}}{500}\ (\sigma)\ \textit{unit load for tubesheet thermal expansion} \\
& + \Delta\frac{T_{SHL}}{500}\ (\sigma)\ \textit{unit load for shell thermal expansion} \\
& + \Delta\frac{T_{CH}}{500}\ (\sigma)\ \textit{unit load for channel head thermal expansion}
\end{aligned}$$

3.4.7 ASME Code Evaluation

The ASME Code evaluation is performed using a Westinghouse proprietary computer code. The evaluation is performed for specific "analysis sections" (ASNs) through the finite element model.

The umbrella loads for the primary stress intensity evaluation have been given previously in Table 3.4-8. The largest magnitudes of the ratio "Calculated Stress Intensity / Allowable Stress Intensity" is 0.97 for design conditions. The analysis results show the primary stress intensities for the sleeved tube assembly to satisfy the allowable ASME Code limits. A summary of the limiting stress conditions are provided in Table 3.4-9 with the tube intact, and in Table 3.4-10 for the tube in the severed condition.

The results for maximum range of stress intensity are summarized in Table 3.4-11 for the limiting set of boundary conditions. Based on the sleeve design criteria, the fatigue analysis considers a design objective of 40 years for the sleeved tube assemblies. Because of possible opening of the interface between the sleeve and the tube along the hydraulic expansion regions, the maximum fatigue strength reduction factor of 5.0 is applied in the radial direction at the "root" interface nodes of the hard roll region, which is conservative when compared to the recommended maximum fatigue strength reduction factor of 4.0. All of the cumulative usage factors are well below the allowable value of 1.0 specified in the ASME Code, and are concluded to be negligible.

3.4.8 Minimum Required Sleeve Thickness

In establishing the safe limiting condition of a tube in terms of its remaining wall thickness, the effects of loadings during both the normal operation and the postulated accident conditions must be evaluated. The applicable stress criteria are in terms of allowables for the primary membrane and membrane-plus-bending stress intensities. Hence, only the primary loads (loads necessary for equilibrium) need be considered.

The minimum required sleeve wall thickness, t_{min}, to sustain normal and accident condition loads is calculated assuming the surrounding tube is completely degraded; that is, no design credit is taken for the residual strength of the tube. For computing t_{min}, the pressure stress equation NB-3324.1 of the Code is used. That is,

$$t_{\min} = \frac{\Delta P_i \, x \, R_i}{P_m - 0.5\,(P_i + P_o)}$$

Normal/Upset Operation Loads

The limiting stresses during normal and upset operating conditions are the primary membrane stresses due to the primary-to-secondary pressure differential ΔP_i across the tube wall. During normal operation, the primary side pressure, P_i, is 2250 psi, and the secondary side pressure, P_o is 650 psi. Thus ΔP_i is 1600 psi. For upset conditions, the maximum operating condition ΔP_i is found to occur during a loss-of-load transient when the primary side pressure, P_i = 2604 psi, the secondary side pressure, P_o = 946 psi, and the resulting ΔP_i = 1658 psi.

The limits on primary stress, P_m, for a primary-to-secondary pressure differential ΔP_i, are as follows:

Normal: $P_m < S_u/3$
Upset: $P_m < S_y$

Using the pressure stress equation, the resulting values for t_{min} are 0.0211 inch for normal conditions, and 0.0190 inch for upset conditions. Thus, the minimum required wall thickness for normal/upset conditions is 0.0211 inch.

Accident Condition Loadings

LOCA + SSE:

The dominant loading for LOCA and SSE loads occurs at the top tube support plate in the form of bending stresses in the tubes. At TSP intersections below the top TSP, LOCA loads drop off dramatically. Since the sleeve is located at the sixth tube support plate or below, the LOCA + SSE bending stresses in the sleeve are quite small. The governing event for the sleeve, therefore, is a postulated secondary side blowdown, either FLB or SLB.

FLB + SSE:

The maximum primary-to-secondary pressure differential occurs during a postulated feedline break (FLB) accident. Again, because of the sleeve location, the SSE bending stresses are small. Thus, the governing stresses for the minimum wall thickness requirement are the pressure membrane stresses. For the FLB + SLB transient, the applicable pressure loads are P_i = 2650 psi, P_o = 0 psi, giving a ΔP_i = 2650 psi. (The structural analysis conservatively considers the Feedline Break transient, with a pressure drop of 2650 psi, which is outside the design basis for plants with Series 44 steam generators.) The applicable criteria for faulted loads is:

$$P_m < \text{lesser of } 0.7\ S_u \text{ or } 2.4\ S_m$$

Using the pressure stress equation, the resulting value for t_{min} is 0.0161 inch.

In summary, considering all of the applied loadings, the minimum required sleeve wall thickness is calculated to be 0.0211 inch, or 57% remaining wall for nominal operating conditions.

3.4.9 Determination of Plugging Limits

The minimum acceptable wall thickness and other recommended practices in Regulatory Guide 1.121 are used to determine a plugging limit for the sleeve. This Regulatory Guide was written to provide guidance for the determination of a plugging limit for steam generator tubes undergoing localized tube wall thinning and can be conservatively applied to sleeves. Tubes with sleeves which are determined to have indications of degradation of the sleeve in excess of the plugging limit would have to be repaired or removed from service.

As recommended in paragraph C.2.b. of the Regulatory Guide, an additional thickness degradation allowance must be added to the minimum acceptable tube wall thickness to establish the operational tube thickness acceptable for continued service. Paragraph C.3.f. of the Regulatory Guide specifies that the basis used in setting the operational degradation allowance include the method and data used in predicting the continuing degradation and consideration of eddy current measurement errors and other significant eddy current testing parameters. The conventional eddy current measurement uncertainty value of 10 percent of the tube wall thickness is appropriate for use in the determination of the operational tube thickness acceptable for continued service and thus determination of the plugging limit.

Paragraph C.3.f of the Regulatory Guide specified that the basis used in setting the operational degradation analysis include the method and data used in predicting the continuing degradation. To develop a value for continuing degradation, sleeve experience must be reviewed. To date, no degradation has been detected on Westinghouse designed mechanical joint sleeves and no sleeved tube has been removed from service due to degradation of any portion of the sleeve. This result can be attributed to the changes in the sleeve material relative to the tube and the lower heat flux due to the double wall in the sleeved region. As a conservative measure, the conventional practice of applying a value of 10% of the sleeve wall as allowance for continued degradation is used in this evaluation.

In summary, the operational sleeve thickness acceptable for continued service includes the minimum acceptable sleeve wall thickness (57% of wall thickness), and the combined allowance for eddy current uncertainty and operational degradation (20%). These terms total to 77%, resulting in a plugging limit as determined by Regulatory Guide 1.121 recommendations of 23% of the sleeve wall thickness.

3.4.10 Application of Plugging Limits

Sleeves or tubes that have eddy current indications of degradation in excess of the plugging limits must be repaired or plugged. Those portions of the sleeve or tube (shown in Figure 3.4-2) for which indications of wall degradation must be evaluated are summarized as follows:

1) Indications of degradation over the entire length of the sleeve must be evaluated against the sleeve plugging limit.

2) Indication of tube degradation of any type, including a complete break in the tube between the bottom of the upper joint and the top of the lower roll expansion, does not require that the tube be removed from service.

3) The tube plugging limit continues to apply to the portion of the tube in the upper joint and in the lower roll expansion. As noted above, the sleeve plugging limit applies to these areas also.

4) The tube plugging limit continues to apply to the portion of the tube above the top of the upper joint.

3.4.11 Analysis Conclusions

Based on the results of this analysis, the hydraulically expanded sleeve is concluded to meet the requirements of the ASME Code. The applicable plugging limit for the sleeve is 23% of the initial wall thickness.

3.4.12 References

1. ASME Boiler and Pressure Vessel Code, Section III, Subsection NB, 1989 Edition.

2. Design Specification G-676219, Westinghouse, Revision 2, May 9, 1983.

3. ASME Boiler and Pressure Vessel Code, Code Cases, Case N-20, 1989 Edition.

4. ASME Boiler and Pressure Vessel Code, Section III, Appendices, 1989 Edition.

5. USNRC Regulatory Guide 1.1.21, "Bases for Plugging Degraded PWR Steam Generator Tubes (For Comment)", August, 1976.

6. WECAN, WAPPP and FIGURES II, F. J. Bogden, Second Edition, May 1981, Westinghouse Advanced System Technology, Pittsburgh, Pa. (Proprietary)

7. J. M. Hall, A. L. Thurman, "WECEVAL, A Computer Code to Perform ASME BPVC Evaluation Using Finite Element Model Generated Stress States", Westinghouse, April, 1985. (Proprietary)

3.5 Evaluation of Operation with Flow Effects Subsequent to Sleeving

The most recent ECCS performance analysis completed for Indian Point Unit 2 was done to support operation at up to 25 percent equivalent steam generator tube plugging (SGTP). This analysis and the corresponding non-LOCA evaluation are considered applicable for the steam generator sleeving program with a combination of plugging and sleeving flow restriction equal to or less than the restriction due to 25 percent tube plugging. In addition, in support of the steam generator sleeving program, Westinghouse has done an evaluation of selected LOCA and non-LOCA transients to verify that use of sleeves resulting in a plugging equivalency of up to 25 percent will not have an adverse effect on the thermal-hydraulic performance of the plant. For the accidents as evaluated, the effect of a combination of plugging and sleeving up to the equivalent of 25 percent tube plugging would not result in any design or regulatory limit being exceeded. This result would be the same for fuel from any supplier for which a LOCA analysis with a basis of 25 percent tube plugging has acceptable results.

The items listed below were evaluated for a sleeving and plugging combination equivalent to 25 percent tube plugging and the results indicated no adverse effects.

- Large Break LOCA
- Small Break LOCA
- LOCA Hydraulic Forcing Functions
- Post-LOCA boron requirements
- Time to switch over the ECCS to hot leg recirculation

The steam generator tube rupture (SGTR) accident is analyzed to ensure that the offsite doses remain below 10CFR100 limits. The primary thermal hydraulic parameter affecting the conclusion are the extent of fuel failure assumed for the accident, the amount of primary to secondary break flow through the ruptured tube, and the mass released to the atmosphere from the ruptured steam generator. The amount of fuel failure assumed for the Indian Point FSAR SGTR analysis is 1 percent which is assumed to be independent of the transient conditions. The primary to secondary break flow and the mass released to the atmosphere are primarily dependent upon the RCS and secondary thermal hydraulic parameters.

An evaluation was previously performed for Indian Point Unit 2 which demonstrated the effect of up to 25 percent steam generator tube plugging on the SGTR analysis would be acceptable. The extent of the tube plugging will be limited such that the combined steam generator tube plugging and sleeving will not exceed an effective plugging level of 25 percent. Thus with the combined sleeving and plugging, the operating RCS temperature and steam pressure will not be reduced below the values for a 25 percent tube plugging level. On this basis, the evaluation performed for 25 percent tube plugging is applicable for the combined tube plugging and sleeving, and it is concluded that the sleeving will not change the previous conclusion that the SGTR analysis will remain acceptable.

The effect of sleeving on the non-LOCA transient analyses has been reviewed. Since the reduced RCS flow rate with 25 percent of the tubes plugged is not less than the assumed flow rate in the most recent the non-LOCA safety analyses, these analyses bound the anticipated maximum amount of steam generator tube sleeving ([ ]^{d,e} sleeves per steam generator). Therefore, the steam generator sleeve installation up to the equivalent of 25 percent plugging would not invalidate any non-LOCA safety analyses.

Evaluations of the level of sleeving and plugging discussed in this report have shown that the Reactor Coolant System flow rate will not be less than that for a 25 percent plugging level. The effect of the reduction in RCS flow rate for a 25 percent plugging level on the design transients have been previously evaluated. Any combination of plugs and sleeves which does not result in an RCS flow rate less than that for a 25 percent plugging level would not have an adverse effect on the previous evaluation of the design transients. Any smaller number of sleeves would have less of an effect.

For the Series 44 steam generators in Indian Point Unit 2, 25 percent of the total tubes (3260 tubes per S/G) equals 815 tubes in any one steam generator. The ECCS analysis model typically is set up such that a uniform steam generator tube plugging condition is modeled.

The NRC staff has required that the LOCA analysis for a plant with steam generator tube plugging model the maximum tube plugging level present in any of the plant steam generators.

Inserting a sleeve into a steam generator tube results in a reduction of primary coolant flow. For the purposes of this section, it is conservatively assumed that up to [ ]^{d,e} tubes per steam generator will be sleeved. The evaluation of flow effects for sleeving at Indian Point Unit 2 assumes the use of [ ]^{a,c,e} inch long sleeves which are expected to be long enough to span the degraded areas in the tubesheet region and to place the upper joint above the sludge pile in either the hot or cold leg side of the steam generators. The flow effects of this sleeve length bound a range of sleeve lengths ([ ]^{a,c,e} inches) which could be used in the sleeving of the Indian Point Unit 2 steam generators.

The flow reduction through a tube due to the installation of a sleeve can be considered equivalent to a portion of the flow loss due to a plugged tube. The hydraulic equivalency ratio of the number of sleeved tubes required to result in the same flow loss as that due to a plugged tube can be used to determine the allowable number of plugs and sleeves in combination. The hydraulic equivalency ratio determined at nominal conditions is independent of the fuel in the reactor. The hydraulic equivalency ratio for LOCA fluid conditions was established using flow rates based on the most recent Westinghouse analysis with Westinghouse supplied fuel. The hydraulic loss coefficients used to determine the flow reduction for nominal conditions are as follows: for an unsleeved tube [ ]^{b,c,e} for a sleeve in the hotleg end of the tube [ ]^{b,c,e}, for a sleeve in the cold leg end of the tube [ ]^{b,c,e} and for two ends sleeved [ ]^{b,c,e}. The hydraulic loss coefficients used to determine the flow reduction for LOCA conditions are as follows: for an unsleeved tube [ ]^{b,c,e} for a sleeve in the hotleg end of the tube [ ]^{b,c,e} for a sleeve in the cold leg end of the tube [ ]^{b,c,e}, and for two ends sleeved [ ]^{b,c,e}. All of these coefficients are based on the nominal tube inside diameter. The hydraulic equivalency ratios for both one and two sleeves installed into a tube have been developed as outlined in the following sections.

3.5.1 One Sleeve Per Tube

For a single [ ]^{a,c,e} inch sleeve installed in the hot leg of a tube, the primary coolant flow reduction per tube is approximately equal to [ ]^{b,c,e} percent of normal flow under nominal conditions. This reduction in primary coolant flow equates to a hydraulic equivalency ratio of [ ]^{b,c,e} sleeved tubes to one plugged tube under normal conditions. For a sleeve installed on the cold leg side the flow reduction per tube is approximately [ ]^{b,c,e} percent which equates to a hydraulic equivalency ratio of [ ]^{b,c,e}.

Using the [ ]^{b,c,e} to 1 ratio for sleeves installed on the cold leg side and the 25 percent tube plugging limit for Indian Point Unit 2, Table 3.5-1 provides an example of the number of additional plugs which could be installed based on the number sleeves installed of [ ]^{d,e} sleeves per steam generator and nominal conditions. Note that [ ]^{d,e} sleeved tubes are equivalent to approximately [ ]^{b,d,e} plugged tubes. or [ ]^{b,d,e} percent plugging.

For typical predicted LOCA fluid conditions the flow reduction for a sleeve on the hot leg side is approximately [ ]^{b,c,e} percent or a hydraulic equivalency ratio of [ ]^{b,c,e}. For a sleeve on the cold leg side the values are [ ]^{b,c,e} respectively.

For the condition presented above for Indian Point Unit 2 the most limiting equivalent plugged condition in the two steam generators occurs in steam generator 22 where 338 tubes are reported to be plugged. It is seen in Table 3.5-1 that with [ ]^{d,e} tubes sleeved there would be a margin of [ ]^{d,e} tubes (447 minus [ ]^{d,e}) available for additional plugging before exceeding the equivalent of 25 percent SGTP for nominal fluid conditions. Note, because of the larger hydraulic equivalency ratio for LOCA conditions using the nominal condition hydraulic equivalency ratio to determine plugging margin to 10 percent plugging is conservative.

3.5.2 Two Sleeves Per Tube

When a single tube has one [ ]^{a,c,e} inch sleeve on the hot-leg side and a second [ ]^{a,c,e} inch sleeve on the cold leg side the primary coolant flow loss per tube is approximately equal to [ ]^{b,c,e} percent of normal flow. This reduction in primary coolant flow equates to a hydraulic equivalency ratio of [ ]^{b,c,e} sleeved tubes to one plugged tube during nominal fluid conditions.

Using this [ ]^{b,c,e} to 1 ratio for the 25 percent tube plugging limit for Indian Point Unit 2, Table 3.5-2 provides an example of the number of additional plugs which could be installed based on the number sleeves installed of [ ]^{d,e} sleeves for [ ]^{d,e} tubes per steam generator during nominal conditions with two sleeves per tube. Note that [ ]^{d,e} double sleeved tubes are equivalent to approximately [ ]^{b,c,e} plugged tubes, or [ ]^{b,c,e} percent plugging under normal conditions.

For typical predicted LOCA fluid conditions the flow reduction for a sleeve on the both ends of the tube is approximately [ ]^{b,c,e} percent or a hydraulic equivalency ratio Of [ ]^{b,c,e}.

For the condition presented above for Indian Point Unit 2, the most limiting equivalent plugged tube condition in the two steam generators occurs in steam generator 22 where 338 tubes are reported to be plugged. It is seen in Table 3.5-2 with [ ]^{d,e} tubes double sleeved, there would be a margin of [ ]^{d,e} tubes (477 minus [ ]^{d,e}) available for additional plugging before exceeding the basis of the LOCA and non-LOCA analyses with 25 percent SGTP. Note, because of the larger hydraulic equivalency ratio for LOCA conditions Using the nominal hydraulic equivalency ratio to determine the plugging margin to 25 percent plugging is conservative.

The method and values of hydraulic equivalency and flow loss per sleeved tube outline above and in the previous section can also be used for a combination of one and two sleeves per tube. Due to the many possible combinations, such a combination is not presented in this report.

3.5.3 Flow Effects Summary

The effects of sleeving on LOCA and non-LOCA transient analyses have been reviewed. No adverse result is indicated for sleeve and plug combinations up to an equivalent of 25 percent SGTP. The existing ECCS performance analysis and the corresponding non-LOCA evaluation are considered applicable for the steam generator sleeving program with a combination of plugging and sleeving flow restriction equal to or less than 25 percent tube plugging. Steam generator sleeve installation up to the equivalent of 25 percent plugging would not invalidate any non-LOCA safety analyses or the evaluation of design transients.

The results of evaluations show that any combination of sleeving and plugging may be utilized at Indian Point Unit 2 as long as the effective SGTP of 25 percent is not exceeded. Given the maximum number of tubes which may be sleeved, Tables 3.5-1 and 3.5-2 provides the number of additional plugs per steam generator that could be installed at the present plugging levels of Indian Point Unit 2 without exceeding the 25 percent SGTP.

As a result of tube plugging and sleeving, primary side fluid velocities in the steam generator tubes will increase. The effect of this velocity increase on the sleeve and tube has been evaluated assuming a conservative limiting condition in which 25 percent of the tubes are plugged. As a reference, normal flow velocity through a tube based on numerous conservative assumptions, is approximately [ ]^{c} ft/sec, for the unplugged condition. With 25 percent of the tubes plugged, the fluid velocity through a non-plugged and non-sleeved tube is [ ]^{b,c} ft/sec, and for a tube with a sleeve, the local fluid velocity in the sleeve region is estimated at [ ]^{b,c,e} ft/sec. Because these fluid velocities are less than the inception velocities for fluid impacting, cavitation, and erosion-corrosion, the potential for tube degradation due to these mechanisms is low.

Accordingly, using the assumptions stated earlier in this section, no ECCS results more adverse than those in the existing Indian Point 2 safety analysis are indicated for equivalent tube plugging projected to occur at Indian Point Unit 2 Nuclear Power Plant with up to [ ]^{d,e} sleeves installed per steam generator using [ ]^{a,c,e} sleeves.

Table 3.1-1
ASME Code and Regulatory Requirements

Item	Applicable Criteria	Requirement
Sleeve Design	Section III	NB-3200, Analysis NB-3300, Wall Thickness
	Operating Requirements	Analysis Conditions
	Reg. Guide 1.83	S/G Tubing Inspectability
	Reg. Guide 1.121	Plugging Margin
Sleeve Material	Section II	Material Composition
	Section III	NB-2000, Identification, Tests and Examinations
	Code Case N-20	Mechanical Properties
Sleeve Joint	10CFR100	Plant Total Primary/ Secondary Leak Rate
	Technical Specifications	Plant Leak Rate

Table 3.3.2-1

Summary of Corrosion Comparison Data for Thermally Treated Alloys 600 and 690

---

1. Thermally treated Alloy 600 tubing exhibits enhanced SCC and IGA resistance in both secondary-side and primary-side environments when compared to the mill annealed condition.

2. Thermally treated Alloy 690 tubing exhibits additional SCC resistance compared to the thermally treated Alloy 600 in caustic, acid sulfate and primary water environments.

3. The alloy composition of Alloy 690 along with a thermal treatment provides additional resistance to caustic induced IGA.

4. The addition of 10 percent CuO to a 10 percent deaerated NaOH environment reduces the SCC resistance of both thermally treated alloys 600 and 690. Lower concentrations of either CuO or NaOH had no effect, nor did the additions of Fe_3O_4 and SiO_2.

5. Alloy 690 is less susceptible to sensitization than Alloy 600.

Table 3.3.2-2
Effect of Oxidizing Species on the SCC Susceptibility of Thermally Treated Alloy 600 and 690 C-Rings in Deaerated Caustic

Environment	Temperature °C	Exposure Time (Hrs)	Alloy 600 TT	Alloy 690 TT
10 Percent NaOH + 10 Percent CuO	316	4000	Increased Susceptibility*	Increased Susceptibility*
10 Percent NaOH + 10 Percent CuO	332	2000	No effect	No effect
1 Percent NaOH + 1 Percent CuO	332	4000	No effect	No effect
10 Percent NaOH + 10 Percent Fe3O4	316	4000	No effect	No effect
10 Percent NaOH + 10 Percent SiO2	316	4000	No effect	No effect

*Intergranular and transgranular SCC.

Table 3.3.3-1
Design Verification Test Program - Corrosion

a.c.e

	ISSUE	FINDINGS
1.	Corrosion and Stress Corrosion	
2.	Corrosion and Stress Corrosion Cracking of Lower Sleeve Joint	
3.	Corrosion and Stress Corrosion Cracking of Upper Joints	
4.	Corrosion and Stress Corrosion Cracking in Annulus	

Table 3.3.3-2
Residual Stresses at [ ]^{a,c,e}

a,c,e

Table 3.3.3-3
Results of Magnesium Chloride Tests at [ ]^{a,c,e}

a,c,e

[ ]

Table 3.3.3-4
Results of Magnesium Chloride Tests at [ ]^{a,c,e}

a,c,e

Table 3.3.4.3-1
Maximum Allowable Leak Rates for INDIAN POINT UNIT 2 Steam Generators

Allowable Condition	Allowable Leak Rate+	Leak Rate per Sleeve*
Normal Operation	.30 gpm	[ ]^{d,e}
	Limiting Leak Rate	Leak Rate per Sleeve*
Postulated Accident Condition (Steamline Break)	[	]^{b,d,e}

* Based on [ ]^{d,e} sleeves per steam generator.

\+ Based on 19.8 drops per milliliter.

Table 3.3.4.4-1
Test Results for as Rolled Lower Joints[(1)] (Page 1 of 3)

a,c,e

Table 3.3.4.4-1 (Continued)
Test Results for as Rolled Lower Joints[1] (Page 2 of 3)

a,c,e

Table 3.3.4.4-1 (Continued)
Test Results for as Rolled Lower Joints[1] (Page 3 of 3)

a,c,e

Table 3.3.4.5-1
Exceptional Tube Conditions and Process Parameters

a,c,e

Table 3.3.4.5-2
Test Results for Lower Joints with Exceptional Conditions for Tube and Sleeve

a,c,e

Table 3.3.4.5-3
Additional Test Results for Lower Joints with Exceptional Conditions for Tube and Sleeve

a,c,e

Table 3.3.5.3-1
Test Results for HEJ's Formed Out of Sludge (Page 1 of 2)
(Fatigue and Extended Operation Tests Included)

a,c,e

Table 3.3.5.3-1 (Continued)
Test Results for HEJ's Formed Out of Sludge (Page 2 of 2)
(Fatigue and Extended Operation Tests Included)

a,c,e

Table 3.3.5.3-2
Test Results for HEJ's Formed Out of Sludge (Page 1 of 2)
(Static Axial Load Leak Test, SLB and Reverse Pressure Test Included)(1)

a,c,e

Table 3.3.5.3-2 (Continued)
Test Results for HEJ's Formed Out of Sludge (Page 2 of 2)
Static Axial Load Leak Test, SLB and Reverse Pressure Test Included)(1)

a,c,e

Table 3.3.5.3-3
Test Results for HEJ's Formed in Sludge (Page 1 of 2)
(Fatigue and Reverse Pressure Tests Included)

a,c,e

Table 3.3.5.3-3 (Page 2 of 2)
Test Results for HEJ's Formed in Sludge
(Fatigue and Reverse Pressure Tests Included)
(Continued)

a,c,e

Table 3.3.5.3-4
Test Results for HEJ's Formed in Sludge
(Axial Load Leak Test and Post - SLB Test Included)

a,c,e

Table 3.3.5.3-5 (Page 2 of 3)
Upper HEJ Test Results

a,c,e

Table 3.3.5.3-5 (Page 3 of 3)
Upper HEJ Test Results

a,c,e

Table 3.3.6.3-1
Test Results for Full Length Sleeves Formed and Leak Tested in Fixed/Fixed Mock-Up (In Sludge and Out of Sludge)

a,b,c,e

Table 3.4-1
SUMMARY OF MATERIAL PROPERTIES
TUBE MATERIAL
MILL ANNEALED ALLOY 600

PROPERTY	TEMPERATURE (°F)						
	70	200	300	400	500	600	700
Young's Modulus psi x 1.0E06	31.00	30.20	29.90	29.50	29.00	28.70	28.20
Coefficient of Thermal Expansion in/in/°F x 1.0E-06	6.90	7.20	7.40	7.57	7.70	7.82	7.94
Density lb-sec^2/in^4 x 1.0E-04	7.94	7.92	7.90	7.89	7.87	7.85	7.83
Thermal Conductivity Btu/sec-in-°F x 1.0E-04	2.01	2.11	2.22	2.34	2.45	2.57	2.68
Specific Heat Btu-in/lb-sec^2-°F	41.20	42.60	43.90	44.90	45.60	47.00	47.90

STRENGTH PROPERTIES (ksi)							
S_m	23.30	23.30	23.30	23.30	23.30	23.30	23.30
S_y	35.00	32.70	31.00	29.80	28.80	27.90	27.00
S_u	80.00	80.00	80.00	80.00	80.00	80.00	80.00

Table 3.4-2
SUMMARY OF MATERIAL PROPERTIES SLEEVE MATERIAL THERMALLY TREATED ALLOY 690

PROPERTY	TEMPERATURE (°F)						
	70	200	300	400	500	600	700
Young's Modulus psi x 1.0E06	30.30	29.70	29.20	28.80	28.30	27.80	27.30
Coefficient of Thermal Expansion in/in/°F x 1.0E-06	7.76	7.85	7.93	8.02	8.90	8.16	8.25
Density lb-sec²/in⁴ x 1.0E-04	7.62	7.59	7.56	7.56	7.54	7.51	7.51
Thermal Conductivity Btu/sec-in-°F x 1.0E-04	1.62	1.76	1.90	2.04	2.18	2.31	2.45
Specific Heat Btu-in/lb-sec²-°F	41.70	43.20	44.80	45.90	47.10	47.90	49.00

STRENGTH PROPERTIES (ksi)							
S_m	26.60	26.60	26.60	26.60	26.60	26.60	26.60
S_y	40.00	36.80	34.60	33.00	31.80	31.10	30.60
S_u	80.00	80.00	80.00	80.00	80.00	80.00	80.00

Table 3.4-3
CRITERIA FOR PRIMARY STRESS INTENSITY EVALUATION
SLEEVE - ALLOY 690

CONDITION	CRITERIA	LIMIT (KSI)

a,c,e

Table 3.4-4
CRITERIA FOR PRIMARY STRESS INTENSITY EVALUATION
TUBE - ALLOY 600

CONDITION	CRITERIA	LIMIT (KSI)

a,c,e

Table 3.4-5
CRITERIA FOR PRIMARY PLUS SECONDARY STRESS INTENSITY EVALUATION
SLEEVE - ALLOY 600

CONDITION	CRITERIA	LIMIT (KSI)

a,c,e

Table 3.4-6
CRITERIA FOR PRIMARY PLUS SECONDARY STRESS INTENSITY EVALUATION
TUBE - ALLOY 600

CONDITION	CRITERIA	LIMIT (KSI)

a,c,e

Table 3.4-7
SUMMARY OF TRANSIENT EVENTS

CLASSIFICATION	CONDITION	CYCLES
Normal	Plant Heatup/Cooldown	200
	Plant Loading/Unloading	18300
	Small Step Load Decrease	2000
	Small Step Load Increase	2000
	Large Step Load Decrease	200
	Hot Standby Operations	18300
	Turbine Roll Test	10
	Steady State Fluctuations	1000000
Upset	Loss of Load	100
	Loss of Power	50
	Loss of Flow	100
	Reactor Trip from Full Power	500
	Operating Basis Earthquake	20
Faulted	Reactor Coolant Pipe Break	1
	Feedline Break	1
	Steamline Break	1
	Loss of Secondary Pressure	1
Test	Secondary to Primary Leak Test	800
	Subsequent Primary Side Pressure Test	55
	Subsequent Secondary Side Pressure Test	50

Table 3.4-8
UMBRELLA PRESSURE LOADS FOR DESIGN, FAULTED, AND TEST CONDITIONS

CONDITIONS	PRESSURE LOAD, PSIG PRIMARY	 SECONDARY

a,c,e

Table 3.4-9
PRIMARY STRESS INTENSITY EVALUATION

a,c,e

Primary Membrane

Location	Component	Calculated S.I. (KSI)	Allowable S.I. (KSI)	Calculated / Allowable

a,c,e

Primary Membrane + Bending

Location	Component	Calculated S.I. (KSI)	Allowable S.I. (KSI)	Calculated / Allowable

a,c,e

Table 3.4-10
PRIMARY STRESS INTENSITY EVALUATION

a,c,e

Primary Membrane

Location	Component	Calculated S.I. (KSI)	Allowable S.I. (KSI)	Calculated / Allowable

a,c,e

Primary Membrane + Bending

Location	Component	Calculated S.I. (KSI)	Allowable S.I. (KSI)	Calculated / Allowable

a,c,e

Table 3.4-11
MAXIMUM RANGE OF STRESS INTENSITY EVALUATION

Sleeve Length: 44 inches

a,c,e

Location	Component	Calculated S.I. (KSI)	Allowable S.I. (KSI)	Calculated / Allowable

a,c,e

Table 3.5-1
Sleeving Parameters Example Under Normal Conditions
(ONE SLEEVE PER TUBE)

	[ ]^{d,e} Sleeve per SG	Max. Sleeves per SG
Total equivalent plugged tubes allowed	815	815
Maximum possible sleeves	[	]^{b,d,e}
Maximum possible sleeved tubes		
Equivalent plugged tubes		
Existing plugs	338	338
Total equivalent plugged tubes	[	]^{b,d,e}
Percent equivalent SGTP (Based on 3260 tubes/SG)		
No. of additional plugs allowed		

Table 3.5-2

Sleeving Parameters Example Under Normal Conditions

(TWO SLEEVE PER TUBE)

	[ ]^{d,e} Sleeve per SG	Max. Sleeves per SG	
Total equivalent plugged tubes allowed	[	]	
Maximum possible sleeves			b,d,e
Maximum possible sleeved tubes	[	]	
Equivalent plugged tubes			
Existing plugs	338	338	
Total equivalent plugged tubes	[	]	b,d,e
Percent equivalent SGTP (Based on 3388 tubes/SG)			
No. of additional plugs allowed	[	]	

a,c,e

Figure 3.2-1. Installed Sleeve with Hybrid Expansion Upper Joint Configuration.

a,c,e

Figure 3.2-2. Sleeve Lower Joint Configuration

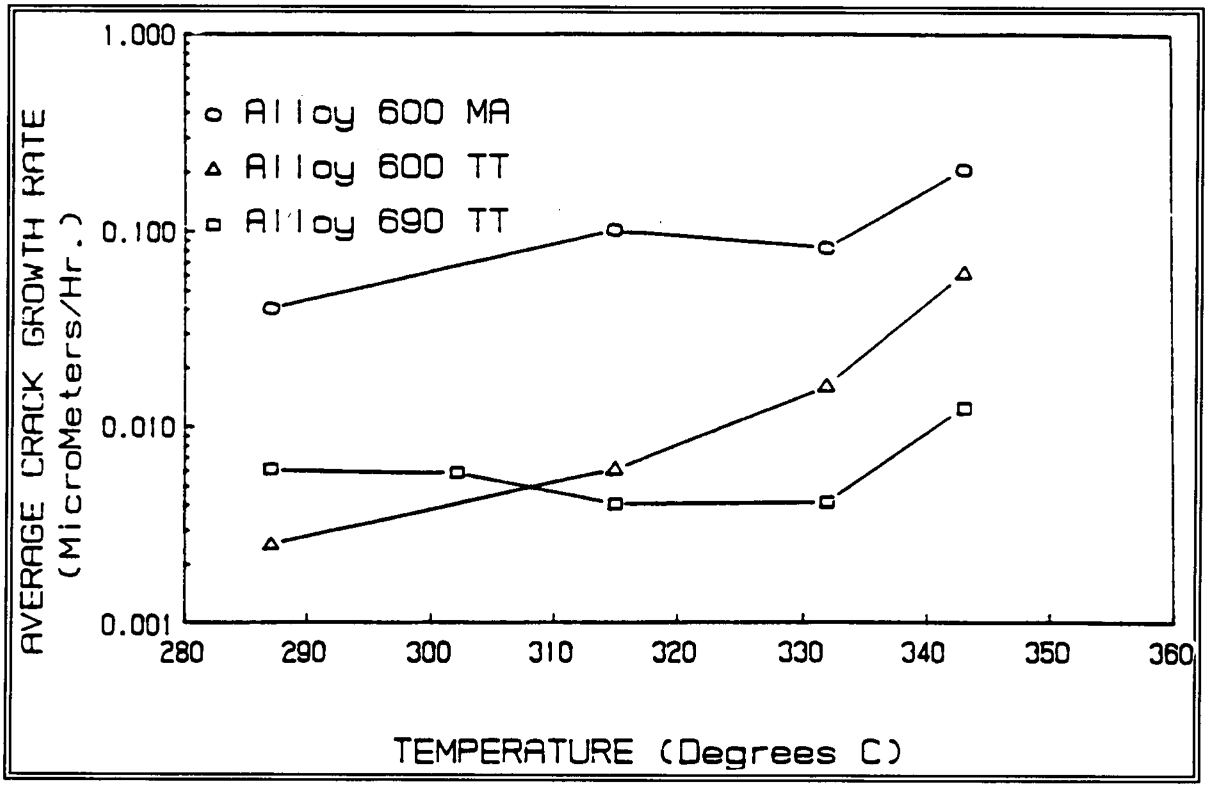


Figure 3.3.2-1. SCC Growth Rate for C-Rings (150% YS and TLT) in 10% NaOH.

a,c,e

Figure 3.3.2-2. **Light Photomicrographs Illustrating IGA After 5000 Hours Exposure of Alloy 600 and 690 C-Rings to 10% NaOH at 332°C (630°F).**

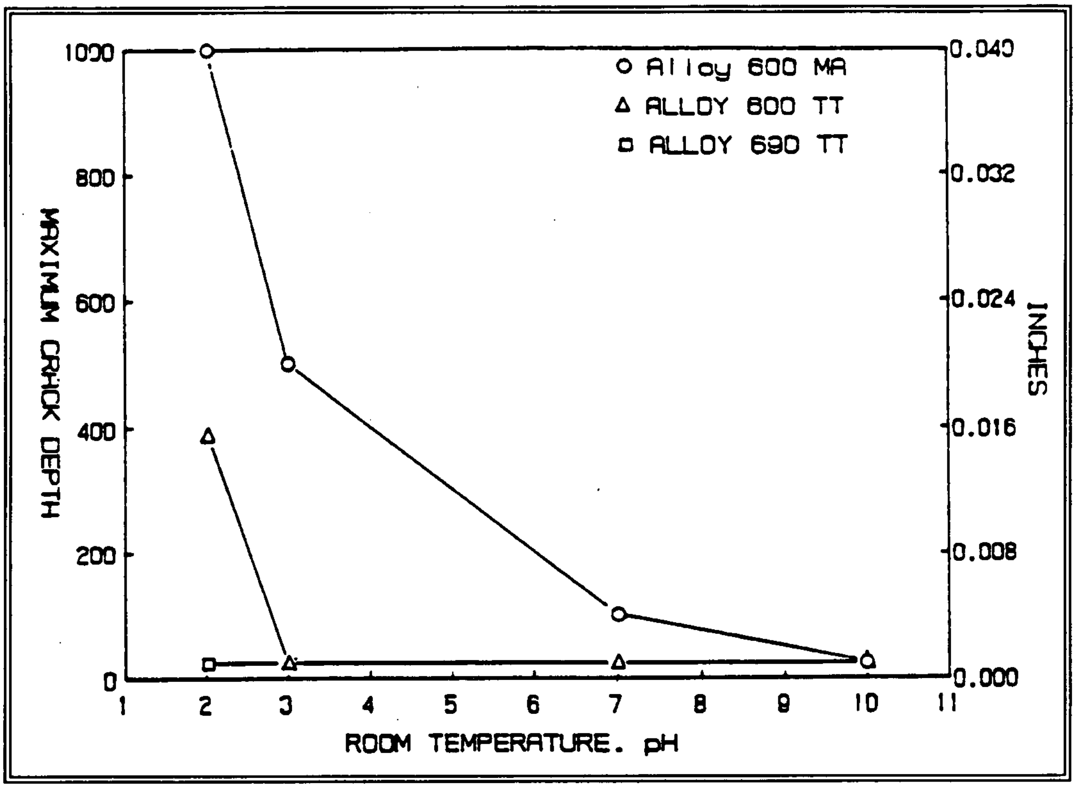


Figure 3.3.2-3. SCC Depth for C-Rings (150% YS) in 8% Sodium Sulfate.

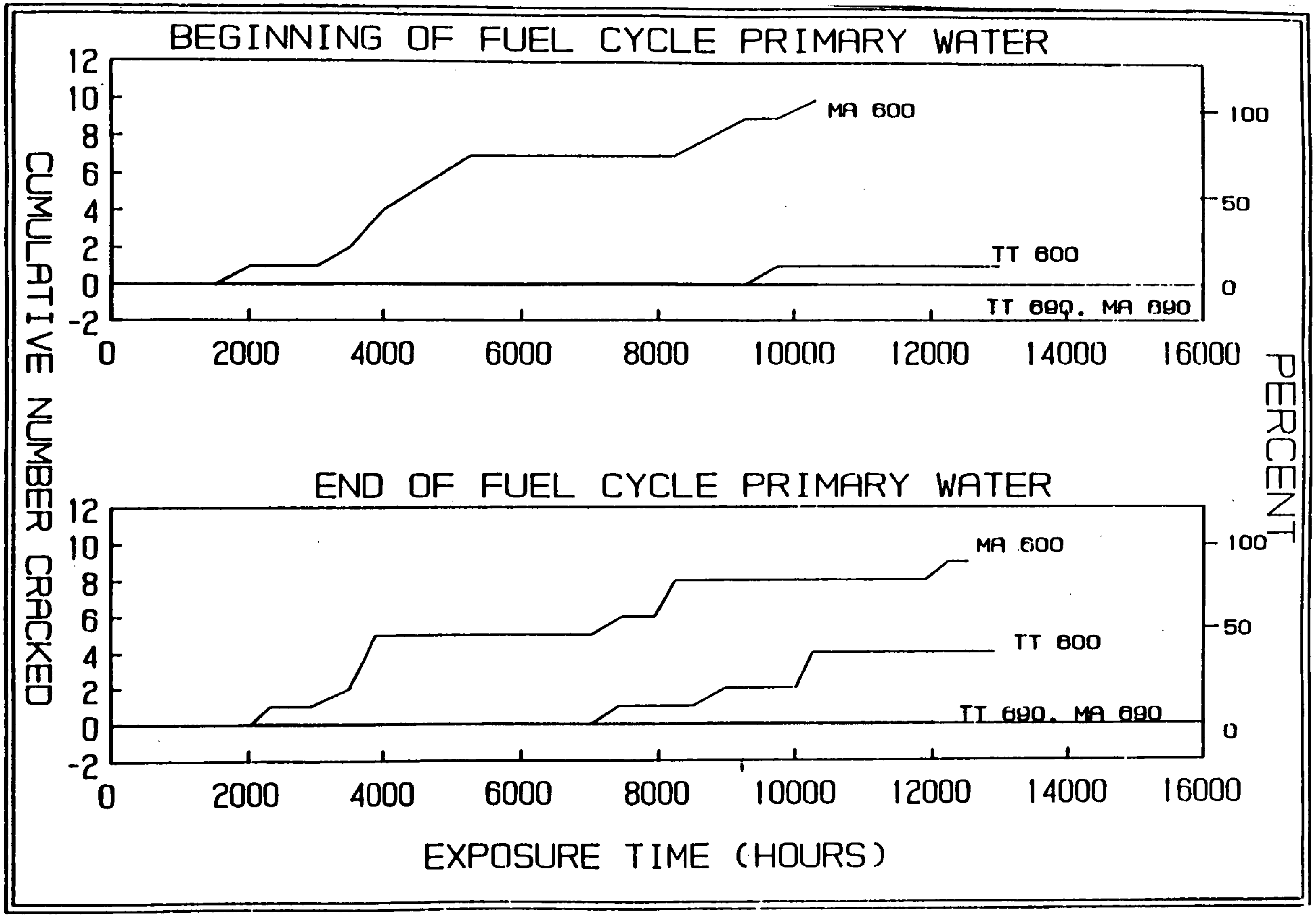


Figure 3.3.2-4. Reverse U-Bend Tests at 360°C (680°F).

a,c,e

Figure 3.3.3-1. Location and Relative Magnitude of Residual Stresses Induced by Expansion.

a,c,e

Figure 3.3.3-2. Schematic of HEJ Section of Sleeve.

a,c,e

Figure 3.3.3-3. Residual Stresses Determined by Corrosion Tests in $MgCl_2$ (Stainless Steel) or Polythionic Acid (Alloy 600).

a,c,e

Figure 3.3.3-4. Results of C-Ring Tests of Type 304 Heat No. 605947 in Boiling $MgCl_2$.

a,c,e

Figure 3.3.3-5. **Axial Residual Stresses in Tube/Sleeve Assembly at Depth of 0.001 ± .0004 in. at Five Locations Along Length of Transition.**

a,c,e

Figure 3.3.3-6. Circumferential Residual Stresses in Tube/Sleeve Assembly at Depth of 0.001 ± .0004 in. at Five Locations Along Length of Transition.

a,c,e

Figure 3.3.4.1-1. Lower Joint As-Rolled Test Specimen.

a,c,e

Figure 3.3.5.1-1.. Hybrid Expansion Joint Test Specimen.

a,c,e

Figure 3.3.5.1-2. HEJ Specimens for the Reverse Pressure Tests.

a,c,e

Figure 3.3.6.1-1. Fixed/Fixed Mock-Up - HEJ (For the HEJ In-Situ Leak Tests).

a,c,e

Figure 3.4-1. Hybrid Expansion Upper Joint/Roll Expansion Lower Joint Sleeve Configuration.

a,c,e

Figure 3.4-2. Application of Plugging Limits.

4.0 PROCESS DESCRIPTION

The sleeve installation consists of a series of steps starting with tube end preparation (if required) and progressing through sleeve insertion, [

]^{a,c,e}, and joint inspection. The sleeving sequence and process are outlined in Table 4.0-1. All these steps are described in the following sections.

4.1 Tube Preparation

There are two steps involved in preparing the steam generator tubes for the sleeving operation. These consist of light rolling (as required) at the tube end and tube cleaning.

4.1.1 Tube End Rolling (Contingency)

If gaging or tube inside diameter measurements indicate a need for tube end rolling to provide a uniform tube opening for sleeve insertion, a light mechanical rolling operation will be performed. This is sufficient to prepare the mouth of the tube for sleeve insertion without adversely affecting the original tube hard roll or the tube-to-tubesheet weld. Tube end rolling will be performed only as a contingency.

Testing of similar lower joint configurations in Model 27 steam generator sleeving programs at a much higher torque showed no effect on the tube-to-tubesheet weld. Because the radial forces transmitted to the tube-to-tubesheet weld would be lower for a larger Series 51 sleeve than for the above test configuration, no effect on the weld as a result of the roll is expected.

4.1.2 Tube Cleaning

The sleeving process includes cleaning the inside diameter area of tubes to be sleeved to prepare the tube surface for the hybrid expansion joint and the lower joint by removing frangible oxide and foreign material. Cleaning also reduces the radiation shine from the tube inside diameter, thus contributing to reducing man-rem exposure.

Tube cleaning may be accomplished by either wet or dry methods. Both processes provide tube inside diameter surfaces compatible with mechanical joint installation.

Evaluation has demonstrated that neither of these processes remove any significant fraction of the tube wall base material. The selection of the cleaning process used is dependent on the installation technique utilized, the scale of the sleeving operation (small scale vs. large scale sleeving), and the utility site specific rad-waste requirements.

Tube cleaning will be performed using a [

]^{a,c,e}

A waste handling system is used to collect the [ ]^{a,c,e} and the oxide removed from the tube ID. [

]^{a,c,e} There may also be an inlet to the suction pump which subsequently pumps the debris and water directly to the plant radioactive waste disposal system.

4.1.2.1 Dry Tube Cleaning

The dry tube cleaning process is similar to the wet cleaning process with the exception that the water jet and system needed to handle the effluent are omitted. The dry cleaning process is typically more applicable to hands-on (manual) or small scale sleeving operations.

In order to remove loose oxide debris produced by the dry cleaning operation, the tube interior is swabbed with deionized water or isopropyl alcohol soaked felt plugs to an elevation slightly less that the cleaned length, but above the top of the tube.

4.2 Sleeve Insertion and Expansion

The sleeves are fabricated under controlled conditions, serialized, machined, cleaned, and inspected. They are placed in plastic bags and packaged in protective styrofoam trays inside wood boxes. At site, the boxes are stored in a controlled area and moved to a low radiation, controlled region inside containment as required. Here the box is opened, the sleeves removed and inspected and placed in a protective sleeve carrying case for transport to the steam generator platform. If the boxes are unopened, they may be used for long term storage of residual sleeves.

[

]a,c,e This process is repeated until all the sleeves have been inserted and [ ]a,c,e

4.3 Lower Joint Seal

At the primary face of the tubesheet, the sleeve is joined to the tube by a [

]a,c,e 2 inches into the tube. The amount of mechanical expansion is controlled by torque. The tool automatically shuts off when it reaches a preset torque value.

The contact forces between the sleeve and the tube following the hydraulic expansion are sufficient to keep the sleeve from rotating during the roll expansion process. The hydraulic expansion step helps keep the magnitude of the residual stresses in the joint below the level that would have been created by hard rolling alone. The roller torque is calibrated on a standard torque calibrator prior to hard rolling operations and re-calibrated at the beginning of each shift. This control and calibration process is a technique used throughout industry in the installation of tubes in heat exchangers.]^{a,c,e}

4.4 Upper Hybrid Expansion Joint (HEJ)

The HEJ utilizes a [

]^{a,c,e}

4.5 Process Inspection Plan

In order to verify the final sleeve installation, an eddy current inspection will be performed on all sleeved tubes to verify that all sleeves received the required hydraulic and roll expansions. The basic process check on 100 percent of the sleeved tubes will be:

1. Verify presence of lower hydraulic expansion zone.
2. Measure lower hydraulic expansion and roll average diameter and verify location within the lower hydraulic expansion.
3. Verify presence of upper hydraulic expansion zone.
4. Measure upper hydraulic expansion and roll average diameter and verify location within the upper hydraulic expansion.
5. Check for the presence of any anomalies.

If it is necessary to remove a sleeved tube from service as judged by an evaluation of a specific sleeve/tube configuration, tooling and processes will be available to plug the sleeve or the lower portion of the sleeve will be removed and the tube will be plugged.

As mentioned previously, the basic process dimensional verification will be completed and evaluated for 100 percent of all installed sleeves.

4.6 Establishment of Sleeve Joint Main Fabrication Parameters

4.6.1 Lower Joint

The main parameter for fabrication of acceptable lower joints is sleeve [ ].^{a,c,e} Sleeve [ ]^{a,c,e} is determined by [ ].^{a,c,e} Accordingly, rolling torque was varied to achieve the desired sleeve [ ]^{a,c,e} in the original Series 44 program (also applicable to the Series 51). [ ]^{a,c,e} was achieved was used throughout the program verification testing.

4.6.2 Upper HEJ

The main parameter for fabrication of HEJ's which met the leak rate acceptance criteria was [ ]^{a,c,e}

In the first sleeving project performed by Westinghouse, the hydraulic expansion axial length was also evaluated. [ ]^{a,c,e} Therefore, in later programs, the HEJ hydraulic expansion axial length [ ]

[

]^{a,c,e}

Table 4.0-1

Sleeve Process Sequence Summary

a,c,e

5.0 SLEEVE/TOOLING POSITIONING TECHNIQUE

With all positioning techniques, the process actually used to install the sleeves (hydraulic expansion, mechanical rolling, etc.) will not be changed due to the use of any sleeve/tooling positioning technique. It is the processes which the sleeves are subjected to that are critical to a successful installation; the technique used to position the sleeves and tooling is not critical so long as it does not affect the sleeve installation processes.

Some techniques used to position the sleeve installation tooling are: fully robotic (ROSA) and hands-on (manual), or the combination of two or more tooling installation modes utilized is dependent upon many variables and what is mutually decided between the utility and Westinghouse.

6.0 NDE INSPECTABILITY

The Non-Destructive Examination (NDE) development has concentrated on two aspects of the sleeve system. First, a method of confirming that the joints meet critical process dimensions is required. Secondly, it must be shown that the tube/sleeve assembly is capable of being evaluated through subsequent routine in-service inspection. In both of these efforts, the inspection process has relied upon eddy current technology.

Previous sleeve installations have had baseline and subsequent in-service inspection of the sleeve tubes. Presently, no change has been observed in any of the in-service eddy current inspections compared to the baseline inspections.

6.1 Eddy Current Inspections

The eddy current inspection equipment, techniques, and results presented herein apply to the proposed Westinghouse sleeving process. Eddy current inspections are routinely carried out on the steam generators in accordance with the plant's Technical Specifications. The purpose of these inspections is to detect at an early state, tube degradation that may have occurred during plant operation so that corrective action can be taken to minimize further degradation and reduce the potential for significant primary-to-secondary leakage.

The standard inspection procedure involves the use of a bobbin eddy current probe, with two circumferentially wound coils which are displaced axially along the probe body. The coils are connected in the so-called differential mode; that is, the system responds only when there is a difference in the properties of the material surrounding the two coils. The coils are excited by using an eddy current instrument that displays changes in the material surrounding the coils by measuring the electrical impedance of the coils. Presently, this involves simultaneous excitation of the coils with several different test frequencies.

The outputs of the various frequencies are combined and recorded. The combined data yield an output in which signals resulting from conditions that do not affect the integrity of the tube are reduced. By reducing unwanted signals, enhanced inspectability of the tubing results (i.e., a higher signal-to-noise ratio). Regions in the steam generator such as the tube supports, the tubesheet, and sleeve transition zones are examples of areas where multi-frequency processing has proven valuable in providing enhanced inspectability.

After sleeve installation, all sleeved tubes are subjected to an eddy current inspection which includes a verification of correct sleeve installation for process control and a degradation for baseline purposes to which all subsequent inspections will be compared.

While there are a number of probe configurations that lend themselves to enhancing the inspection of the sleeve/tube assembly in the regions of the configuration transitions, the crosswound coil probe has been selected as offering a significant advancement over the conventional bobbin coil probe, yet retaining the simplicity of the inspection procedure.

Verification of proper sleeve installation is of critical importance in the sleeving process. The process control eddy current verification is conducted utilizing one frequency in the absolute mode with a crosswound coil probe. The purpose is to provide verification of the existence of proper [ ]^{a,c,e} configurations and also allow determination of the sleeve process dimensions both axially and radially. Figure 6.1-1 illustrates the coil response and measurement technique for a typical sleeve/tube joint.

The inspection for degradation of the sleeve/tube assembly has typically been performed using crosswound coil probes operated with multi-frequency excitation. For the straight length regions of the sleeve/tube assembly, the inspection of the sleeve and tube is consistent with normal tubing inspections. In the tube/sleeve assembly joint regions, data evaluation becomes more complex. The results discussed below suggest the limit on the volume of degradation that can be detected in the vicinity of geometry changes.

The detection and quantification of degradation at the transition regions of the sleeve/tube assembly depends upon the signal-to-noise ratio between the degradation response and the transition response. As a general rule, lower frequencies tend to suppress the transition signal relative to the degradation signal at the expense of the ability to quantify. Similarly, the inspection of the tube through the sleeve requires the use of low frequencies to achieve detection with an associated loss in quantification. Thus, the search for an optimum eddy current signal represents a trade off between detection and quantification.

Figure 6.1-2 shows typical [ ]^{a,c,e} phase angle versus degradation depth curve for the sleeve from which OD sleeve penetrations can be assessed.

In the regions of the parent tube above the sleeve, conventional bobbin coil or crosswound coil inspections will continue to be used. However, since the diameter of the sleeve is smaller than that of the tube, the fill factor of a probe inserted through the sleeve may result in a decreased detection capability for tubing degradation. Thus, it may be necessary to inspect the unsleeved portion of the tube above the sleeve by inserting a standard size probe through the U-bend from the unsleeved leg of the tube.

For the tube-sleeve combination, the use of the crosswound probe, coupled with a multi-frequency mixing technique for further reduction of the remaining noise signals significantly reduces the interference from all discontinuities (e.g. transition) which have 360° symmetry, providing enhanced visibility for discrete discontinuities. As shown in the accompanying figures, in the laboratory this technique can detect OD tube wall penetrations with acceptable signal-to-noise ratios at the transitions when the volume of metal removed is equivalent to the ASME calibration standard.

The response from the tube/sleeve assembly transitions with the crosswound coil is shown in Figures 6.1-3, 6.1-4, and 6.1-5 for the sleeve standards, tube standards and transitions, respectively. Detectability in transitions is enhanced by the combination of the various frequencies. For the cross-wound probe, two frequency combinations are shown; [

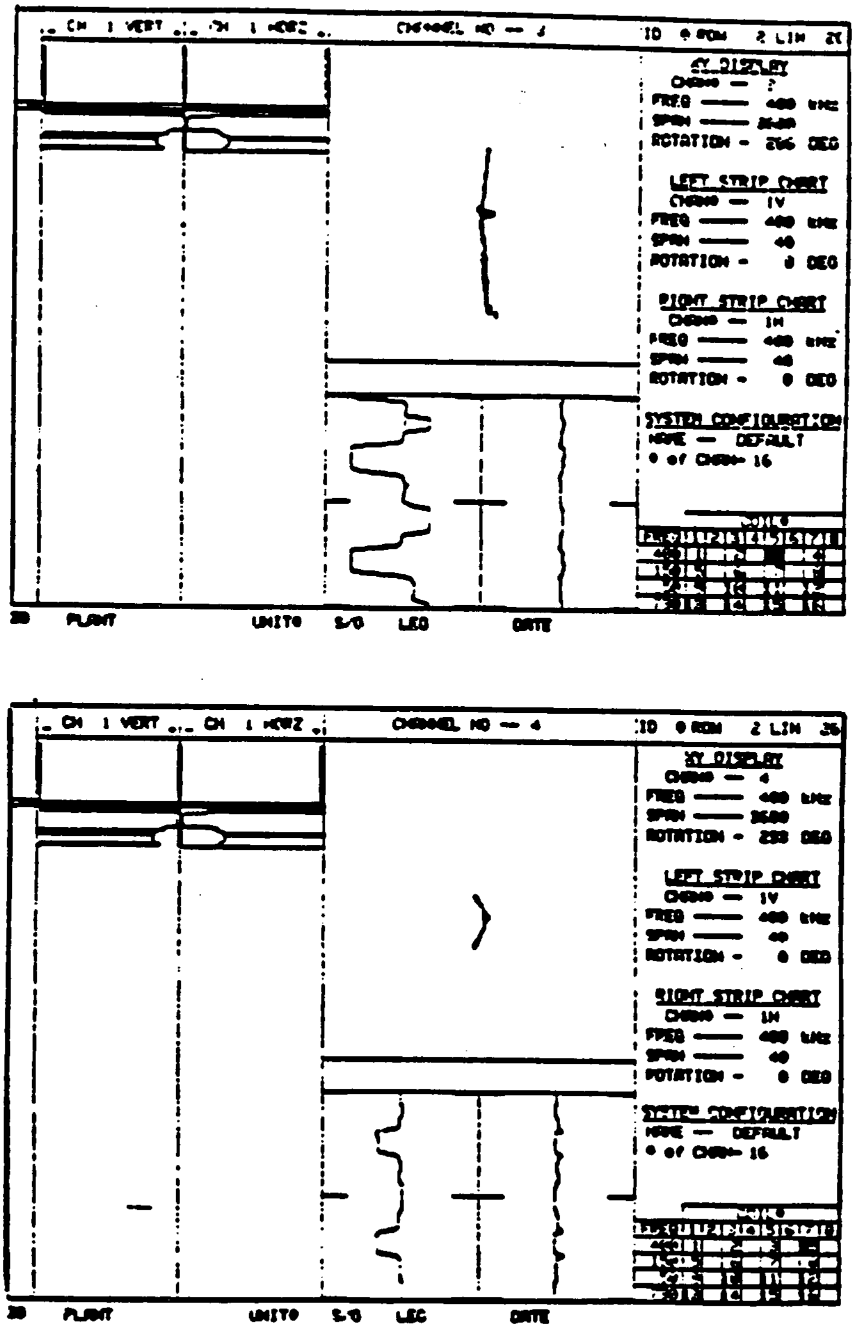
]^{a,b,c,e} Figure 6.1-6 shows the phase/depth curve for the tube using this combination. As examples of the detection capability at the transitions, Figures 6.1-7 and 6.1-8 show the responses of a 20 percent OD penetration in the sleeve and 40 percent OD penetration in the tube, respectively.

For inspection of the region at the top end of the sleeve, the transition response signal-to-noise ratio is about a factor of four less sensitive than that of the expansions. Some additional inspectability has been gained by tapering the wall thickness at the top end of the sleeve. This reduces the end-of-sleeve signal by a factor of approximately two. The crosswound coil, however, again significantly reduces the response of the sleeve end.

Figure 6.1-9 shows the response of various ASME tube calibration standards placed at the end of the sleeve using the cross-wound coil and the [ ]^{a,c,e} frequency combination. Note that under these conditions, degradation at the top end of the sleeve/tube assembly can be detected.

6.2 Summary

Conventional eddy current techniques have been modified to incorporate the more recent technology in the inspection of the sleeve/tube assembly. The resultant inspection of the sleeve/tube assembly involves the use of a cross-wound coil for the straight regions of the sleeve/tube assembly and for the transition regions. The advent of MIZ-18 digital E/C instrumentation and its attendant increased dynamic range and the availability of 8 channels for four raw frequencies has expanded the use of the crosswound coil for sleeve inspection. While there is a significant enhancement in the inspection of portions of the assembly using the cross-wound coil over conventional bobbin coils, efforts continue to advance the state-of-the-art in eddy current inspection techniques. As advanced state-of-the-art techniques are developed and verified, they will be utilized. For the present, the cross-wound coil probe represents an inspection technique that provides additional sensitivity and support for eddy current techniques as a viable means of assessing the tube/sleeve assembly.



XY DISPLAY
CHAN# — 3
FREQ — 400 kHz
SPAN — 3600
ROTATION - 266 DEG

LEFT STRIP CHART
CHAN# — 1V
FREQ — 400 kHz
SPAN — 40
ROTATION - 0 DEG

RIGHT STRIP CHART
CHAN# — 1H
FREQ — 400 kHz
SPAN — 40
ROTATION - 0 DEG

SYSTEM CONFIGURATION
NAME — DEFAULT
# of CHAN— 16

XY DISPLAY
CHAN# — 4
FREQ — 400 kHz
SPAN — 3600
ROTATION - 298 DEG

LEFT STRIP CHART
CHAN# — 1V
FREQ — 400 kHz
SPAN — 40
ROTATION - 0 DEG

RIGHT STRIP CHART
CHAN# — 1H
FREQ — 400 kHz
SPAN — 40
ROTATION - 0 DEG

SYSTEM CONFIGURATION
NAME — DEFAULT
# of CHAN— 16

Figure 6.1-1. Absolute Eddy Current Signals at 400 kHz (Front and Rear Coils).

a,c,e

Figure 6.1-2. [ ]^{a,c,e} Calibration Curve.

a,c,e

Figure 6.1-3. **Eddy Current Signals from the ASTM Standard, Machined on the Sleeve OD of the Sleeve/Tube Assembly Without Expansion (Cross Wound Coil Probe).**

a,c,e

Figure 6.1-4. Eddy Current Signals from the ASTM Standard, Machined on the Tube OD of the Sleeve/Tube Assembly Without Expansion (Cross Wound Coil Probe).

a,c,e

Figure 6.1-5. Eddy Current Signals for the Expansion Transition Region of the Sleeve/Tube Assembly (Cross Wound Coil Probe).

a,c,e

Figure 6.1-6. **Eddy Current Calibration Curve for ASME Tube Standard at [ ]^{a,c,e} and a Mix Using the Cross Wound Coil Probe.**

a,c,e

Figure 6.1-7. Eddy Current Signal From a 20 Percent Deep Hole, Half the Volume of ASTM Standard, Machined on the Sleeve OD in the Expansion Transition Region of the Sleeve/Tube Assembly (Cross Wound Coil Probe).

a,c,e

Figure 6.1-8. Eddy Current Signal From a 40 Percent ASTM Standard, Machined on the Tube OD in the Expansion Transition Region of Sleeve/Tube Assembly (Cross Wound Coil Probe).

a,c,e

Figure 6.1-9. Eddy Current Response of the ASME Tube Standard at the End of the Sleeve Using the Cross Wound Coil Probe and Multi-Frequency Combination.

7.0 ALARA CONSIDERATIONS FOR SLEEVING OPERATIONS

The repair of steam generators in operating nuclear power plants requires the utilization of appropriate dose reduction techniques to keep radiation levels As Low As Reasonably Achievable (ALARA). Westinghouse maintains an extensive ALARA program to minimize radiation exposure to personnel. This program includes: design and improvement of remote and semi-remote tooling, including state of the art robotics; decontamination of steam generators; the use of shielding to minimize radiation exposure; extensive personnel training utilizing mock-ups; dry runs; and strict qualification procedures. In addition, computer programs exist which can accurately track radiation exposure accumulation.

The ALARA aspect of the tool design program is to develop specialized remote tooling to reduce the exposure that sleeving personnel receive from high radiation fields. A design objective of a remote delivery system is to eliminate channel head entries and to complete the sleeving project with total exposures kept to a minimum. A manipulator arm can be installed on a fixture attached to the steam generator manway after video cameras and temporary nozzle covers have been installed. A control station operator (CSO) then manually operates controls to guide the manipulator arm through the manway and attach the baseplate to the tubesheet. The installation of the arm requires only one platform operator to provide visual observation and assistance with cable handling from the platform. The control station for the remote delivery system is located outside containment in a specially designed control station trailer. As previously indicated, under some conditions positioning of sleeve tooling with the base robotic system may not be practical. In these circumstances alternate techniques may be utilized, such as hands-on (manual positioning), alternate robotic or semi-remotely operated equipment or a combination of the two.

The control of personnel exposures can also be effected by careful planning, training, and the preparation of maintenance procedures for the job. This form of administrative control can help to provide that the minimum number of personnel will be used to perform the various tasks. Additional methods of minimizing exposure include the use of remote TV and radio surveillance of all platform and channel head operations and the monitoring of personnel exposure to identify high exposure areas. Local shielding will be used whenever possible to reduce the general area background radiation levels at the work stations inside containment.

7.1 Nozzle Cover and Camera Installation/Removal

The installation of temporary nozzle covers in the reactor coolant pipe nozzles in preparation of the steam generators for sleeving operations may require channel head entries. The covers are installed to prevent the accidental dropping of any foreign objects (i.e., tools, nuts, bolts, debris, etc.) into the reactor coolant loops during sleeving operations. In the event that an accident did occur, an inspection of the loop would be required and any foreign objects or debris found would be retrieved. The impact on schedule and radiation exposures associated with these recovery operations would far exceed the time and exposures expended to install or remove loop nozzle covers. Consequently, it is considered an ALARA-efficient procedure to utilize temporary nozzle covers during sleeving operations.

7.2 Platform Setup/Supervision

The majority of the radiation exposures recorded for the sleeving program is expected to result primarily from personnel working on or near the steam generator platforms and in the channel head for hands-on operations. The setup and checkout of equipment for the various sleeving processes, installation/ removal of tooling, and the operation of the tooling are the major sources of radiation exposure. In addition to channel head video monitoring systems, visual monitoring and supervision by one or more workers on the platform will be required for a major part of the sleeving schedule. Experience has shown that rapid response to equipment adjustment requirements is efficiently accomplished by having a platform worker standing by in a relatively low radiation area during operations. Worker standby stations have ranged from the low radiation fields behind the biological shield to lead blanket shielding installed on the platform. Even though radiation levels on the platform are much lower than channel head levels, a substantially larger amount of time will be spent on the platforms giving rise to personnel exposures. An evaluation of radiation surveys around the steam generators should indicate appropriate standby stations.

7.3 Radwaste Generation

The surface preparation of tubes for the installation of sleeves requires that the oxide film be removed by a honing process. A flexihone attached to a flexible rotating cable will be used to remove the oxide film on the inside surface of the steam generator tubes. The volume of solid radwaste is expected to 7-2 consist of spent hones, flexible honing cables, hone filter assemblies (optional), [ ]^{a,c,e} and the normal anti-C consumables associated with steam generator maintenance. The anti-C consumables are the utility's responsibility and will not be addressed in this report.

For the [ ]^{a,c,e} approximately thirty tubes can be honed before the hone is changed for process control and [ ].^{a,c,e} A typical estimate of the radioactive concentration from a honed tube transported by the [ ]^{a,c,e} is given in Table 7.3-1. These concentrations are based on a general area radiation level of 4R/HR. The tube hones as well as the tubes [ ]^{a,c,e} Consequently, radiation levels of the spent hones are normally 1-2 r/hr based on field measurements in previous sleeving projects.

The flexible honing cable used to rotate the hone inside the tubes is also flushed during the honing process. However, the construction of the stainless steel cable will cause radioactivity to build up over the course of the project. Radiation on segments of the cable could reach 5-10 R/Hr contact dose rates for major sleeving jobs. It is expected that an average of one cable per steam generator will be used during the sleeving project. The cables are consumables and are drummed as solid waste.

7.4 Health Physics Practices and Procedures

The Health Physics (HP) requirements will be those established by the licensee. Westinghouse will provide radiological engineering assistance, as needed to assist in coordination of the radiological aspects of the Westinghouse activities. Open communications between involved parties will be maintained so that the best possible health physics practices can be established for the sleeving program. The HP procedures of the utility will be the guidelines followed during the sleeving operation. However, in specific instances where beneficial changes to the techniques are mutually recognized but not covered in these HP procedures, appropriate changes will be made according to established change procedures.

The field service procedures which are prepared by Westinghouse for the complete setup of equipment and subsequent sleeving operations include the specific radiologically related responsibilities, prerequisites and precautions. These will further minimize exposure and control contamination.

Mock-up training at the Westinghouse Advance Tooling and Readiness Center includes the following radiological practices:

- Technical skill training while dressed in full Anti-C clothing including bubble hoods
- Identification of high radiation zones on the work platform and emphasis on minimizing stay times.
- Handling of contaminated tools and changeout of contaminated mandrels.
- Location and use of waste disposal containers.

Westinghouse implements an extensive training and qualification program to prepare supervisory, maintenance and operations personnel for field implementation of the sleeving process. Satisfactory completion of this training program verifies that the personnel addressed are qualified to perform all assigned operations from a technical as well as a radiological aspect in keeping with ALARA principals.

The qualification program consists of two phases:

Phase I - classroom
Phase II - mock-up

Phase I consists of classroom training and addresses subject material that is related to the overall sleeving program. The Phase I instructors generate and administer an examination for Phase I training of sufficient difficulty to demonstrate that a trainee has sufficient knowledge of the material presented. This examination is written. All trainees will be tested. A minimum grade of 80 percent is required. The test results shall be documented and retained for audit.

Phase II consists of hands-on and mock-up sleeving training during which the trainee must demonstrate a capability to perform a function or operation in a limited amount of time. If team training is required, each trainee must be able to perform all tasks required of the team.

7.5 Airborne Releases

The implementation of the proposed sleeving processes in operating nuclear plants has indicated that the potential for airborne releases is minimal. The major operations include [ ]^{a,c,e} and sleeve installation. Experience has shown that these sleeving processes do not contribute to airborne releases.

7.6 Personnel Exposure Estimate

The total personnel exposures for steam generator sleeving operations will depend on several plant dependant and process related factors. These may include, but not be limited to; the scope of work (quantity of sleeves, etc.), plant radiation levels, ingress/egress to the work stations, equipment performance and overall cognizance of ALARA principles. Consequently, the projection of personnel exposures for each specific plant must be performed at the completion of mock-up training when process times for each operation have been recorded. The availability of plant radiation levels and worker process times in the various radiation fields will provide the necessary data to project personnel exposure for the sleeving project.

The calculation of the total MAN-REM exposure for completing a sleeving project may typically be expressed as follows:

$$P = ((Ns\ .\ Ds) + S9)\ .\ Ng$$

P = Project total exposure (MAN-REM)
Ns = Number of sleeves installed/steam generator
Ds = Exposure/sleeve installed
S9 = Equipment setup/removal exposure per steam generator
N9 = Number of steam generators to be sleeved

This equation and appropriate variations are used in estimating the total personnel exposures for the sleeving project.

Table 7.3-1

Estimate of Radioactive Concentration in Water Per Tube Honed (Typical)

a,c,e

8.0 IN-SERVICE INSPECTION PLAN FOR SLEEVED TUBES

In addressing current NRC requirements, the need exists to perform periodic inspections of the supplemented pressure boundary. This new pressure boundary consists of the sleeve with a joint at the primary face of the tubesheet and a joint at the opposite end of the sleeve.

The in-service inspection program will consist of the following. Each sleeved tube will be eddy current inspected on completion of installation to obtain a baseline signature to which all subsequent inspections will be compared. Periodic inspections to monitor sleeve wall conditions will be performed in accordance with the inspection section of the plant Technical Specifications. This inspection will be performed with multi-frequency eddy current equipment.