Guidelines for PWR Steam Generator Tubing Specifications and Repair

Volume 2, Revision 1: Guidelines for Procurement of Alloy 690 Steam Generator Tubing

WARNING:
Please read the Export Control and License Agreement on the back cover before removing the Wrapping Material.

Technical Report

Guidelines for PWR Steam Generator Tubing Specifications and Repair

Volume 2, Revision 1: Guidelines for Procurement of Alloy 690 Steam Generator Tubing

TR-016743-V2R1

Final Report, April 1999

EPRI Project Manager
A. R. McIlree

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

ORGANIZATION(S) THAT PREPARED THIS PACKAGE

Dominion Engineering, Inc.

ORDERING INFORMATION

Requests for copies of this report should be directed to the EPRI Distribution Center, 207 Coggins Drive, P.O. Box 23205, Pleasant Hill, CA 94523, (925) 934-4212.

CITATIONS

This report was prepared by

Dominion Engineering, Inc.
6862 Elm Street
McLean, Virginia 22101

Principal Investigator
J. Gorman

This report describes research sponsored by EPRI.

The report is a corporate document that should be cited in the literature in the following manner:

Guidelines for PWR Steam Generator Tubing Specifications and Repair, Volume 2, Revision 1: Guidelines for Procurement of Alloy 690 Steam Generator Tubing, EPRI, Palo Alto, CA: 1999. Report TR-016743-V2R1.

REPORT SUMMARY

This revised document provides guidelines for procuring Alloy 690 steam generator tubing and sleeve material.

Background

Revision 0 of the Alloy 690 Guidelines was issued in February 1991 as NP-6743-L, Volume 2. In 1998, Revision 1 to the 1991 Guidelines was begun in response to an EPRI utilities' request to reduce the number of anomalous eddy current test (ECT) signals—such as manufacturing burnish marks (MBMs)—that require follow-up during in-service inspections. EPRI members also wanted to control the microstructure to maximize resistance to intergranular attack/ stress corrosion cracking (IGA/SCC) in caustic testing. In addition, a revision would reflect improvements that had been achieved in recent years, including ECT signal to noise, inclusion content, and tubing ovality.

Objectives

To help utilities assure that tubing for new or replacement steam generators has optimum resistance to both primary and secondary side corrosion.

Approach

The project team met with three tubing suppliers in addition to Electricité de France (EDF), the Belgians, Mitsubishi Heavy Industries (MHI), Westinghouse, and Babcock & Wilcox (B&W). From these meetings, the team identified possible improvements and obtained feedback about possible effects of imposing tighter requirements.

Results

This document is suitable as a guide for utilities developing procurement specifications for tubing. It is expected that, in many cases, steam generator supplier specifications for Alloy 690 will be used for procuring tubing rather than utility-developed specifications.

EPRI Perspective

This document will serve as an update to the lessons learned since its first issue seven years ago. During this time, numerous replacement steam generators were made using Revision 0 as a guide. These updated guidelines are unique in that they contain not only a specification section but a section devoted to the bases for each requirement.

Utilities can use the specification and bases sections as a checklist to review steam generator supplier specifications. The specific limits defined in this document can be considered upper bounds.

TR-016743-V2R1

Keywords
Nuclear steam generators
Intergranular corrosion
Intergranular stress corrosion cracking
Inconel alloys

ACKNOWLEDGMENTS

Preparation of these guidelines was assisted by reviews and comments of the utilities, material suppliers, plant and steam generator suppliers, service organizations, and individuals listed below. The Electric Power Research Institute (EPRI) and Dominion Engineering, Inc., gratefully acknowledge the assistance provided by these organizations.

ABB/CE

Babcock and Wilcox

Duke Energy

Electricité de France

Entergy

Framatome

Framatome Technologies, Inc.

Laborelec

Mitsubishi Heavy Industries

Rochester Gas & Electric

Sandvik

Siemens

Southern Nuclear Company

Sumitomo

Tractebel

Valinco

Valinox

Westinghouse

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1

INTRODUCTION

The objective of these Guidelines is to assist utilities assure that tubing for new or replacement steam generators has optimum resistance to both primary and secondary side corrosion.

The specification contained in Section 2 of this guideline is an update of that in the previous guideline (NP-6743-L, Volume 2, February 1991). The specification in the 1991 guideline was based on earlier EPRI developed specifications for alloy 600 (1) and for alloy 690 (2.24), and reflected information presented at a 1989 workshop (26). The updated specification in Section 2 reflects information that has become available since 1991 as the result of subsequent research and as a result of recent production of alloy 690 tubing for new and replacement steam generators. Section 3 contains the bases for each of the requirements in the specification.

The specification contained in Section 2 is considered suitable for use as a guide in the development by a utility of a procurement specification for tubing. It is expected that, in many cases, steam generator supplier specifications for alloy 690 will be used for procurement of tubing rather than utility developed specifications. In such cases, the specification and bases in Sections 2 and 3 can be used by utilities as a checklist for review of the steam generator supplier specifications. The specific limits defined in

Section 2 should be considered as upper bounds. In order to obtain a more consistent product utilities may desire to impose more restrictive limits based upon a review of recent tubing supplier information or specific utility goals.

The Guidelines were initially prepared for use with U-bent tubes, but can be used for straight tubes for OTSGs, with appropriate changes by the Purchaser to delete requirements appropriate only to U-bent tubes.

2

SPECIFICATION FOR ALLOY 690 (UNS N06690) STEAM GENERATOR TUBING

1.0 Scope

This specification contains the requirements for the manufacture, quality assurance, examination, testing, and shipment of seamless nickel-chromium-iron Alloy 690 (UNS N06690) steam generator tubing with special requirements for chemical composition, heat-treatment, microstructure, and quality control.

2.0 Applicable Documents And Codes; Definitions

This specification incorporates the requirements of ASME SB-163 Alloy N06690 in accordance with ASME III NB-2000, as supplemented by Code Case N-20-3, and incorporates additional requirements. These additional requirements are not in conflict with ASME III NB-2000, Code Case N-20-3, or SB-163. If there are specific requirements in this document that appear to conflict with specific requirements of other referenced documents, these conflicts shall be referred to the Purchaser for resolution. Conflicts must be resolved prior to tube production.

2.1 Code of Federal Regulations

10CFR21	Reporting of Defects and Noncompliance
10CFR50 Appendix B*	Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants

*2.2 American Society for Testing and Materials (ASTM)**

E3	-	Preparation of Metallographic Specimens

* The revision or issue in effect when the purchase order is placed, unless otherwise specified by Purchaser.

E8	-	Tension Testing of Metallic Materials
E38	-	Chemical Analysis of Nickel-Chromium and Nickel-Chromium Iron Alloys
E45	-	Determining the Inclusion Content of Steel
E112	-	Estimating the Average Grain Size of Metals
E354	-	Chemical Analyses of High-Temperature Electrical, Magnetic, and Other Similar Iron, Nickel, and Cobalt-Base Alloys

2.3 United States Nuclear Regulatory Commission Regulatory Guides (RG)

RG 1.37	1973	Quality Assurance Requirements for Cleaning of Fluid Systems and Associated Components of Water-Cooled Nuclear Power Plants
RG 1.38	1977	Quality Assurance Requirements for Packaging, Shipping, Receiving, Storage, and Handling of Items for Water-Cooled Nuclear Power Plants
RG 1.85	*	Materials Code Case Acceptability, ASME Section III, Division 1

2.4 American National Standards - Reactor Plants and Their Maintenance

ANSI N45.2.1	1980	Cleaning of Fluid Systems and Associated Components During Construction Phase of Nuclear Power Plants
ANSI N45.2.2	1972	Packing, Shipping, Receiving, Storage, and Handling of Items for Nuclear Power Plants

2.5 American Society of Mechanical Engineers, Boiler and Pressure Vessel Code*

ASME SB-163		Specification for Seamless Nickel and Nickel Alloy Condenser and Heat Exchanger Tubes

* The revision or issue in effect when the purchase order is placed, unless otherwise specified by Purchaser.

ASME III	ASME Boiler and Pressure Vessel Code, Section III, Rules for Construction of Nuclear Power Plant Components
ASME Code Case N-20-3	SB-163 Nickel-Chromium-Iron Tubing (Alloys 600 and 690) and Nickel-Iron-Chromium Alloy 800 at a Specified Minimum Yield Strength of 40.0 ksi and Cold Worked Alloy 800 at a Yield Strength of 47.0 ksi. Section III, Division 1, Class 1
ASME XI	ASME Boiler and Pressure Vessel Code, Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components

*2.6 American Society for Nondestructive Testing**

SNT-TC-1A	Recommended Practice

2.7 Definitions

Final Mill Annealing. Final mill annealing is a high temperature annealing given the tubing after reduction to final size. It is performed at temperatures over 1958°F (1070°C) for the purposes of recrystallization and dissolution of precipitates, especially carbides.

Heat. A heat consists of the material from one single molten batch. If an ingot is remelted, then each remelt charge is a separate heat.

Heat Treatment. Heat treatment is a process that involves raising the temperature of the tubing material significantly above room temperature (932°F (500°C) or higher), to accomplish some objective such as recrystallization, carbide precipitation, or stress relief. "Intermediate mill annealing", "final mill annealing", "stress relief", and "thermal treatment" as used in this specification are heat treatments.

Heat Treatment Lot. A lot shall be limited to tubes that are final mill annealed during a 24 hour period or less, and to no more than 200 consecutive tube lengths. In addition, a lot shall be limited to:

- Tubes from the same heat.
- Tubes reduced to size using the same type of equipment and reduction schedule.
- Tubes subjected to the same intermediate mill annealing practice.

* The revision or issue in effect when the purchase order is placed, unless otherwise specified by Purchaser.

- Tubes which have been exposed to an essentially identical final mill annealing heat treatment, as follows:
  - Continuous final mill annealing run with essentially constant furnace temperature, speed, atmosphere, and cooling conditions.
  - Sufficiently constant tube loading (numbers of tubes and arrangement passing through the furnace, i.e., mass/unit time) to ensure that the time-temperature history of all tube material is within the limits of 3.6.1. The tube loading may include properly identified clean scrap tubes to maintain uniformity of loading.
- Tubes straightened with the same equipment and equipment setup.
- Tubes subjected to the same thermal treatment practice.

Intermediate Mill Annealing. Intermediate mill annealing is a high temperature annealing given the tubing after a reduction step. It is performed for the purposes of recrystallization and dissolution of precipitates.

Lot. See heat treatment lot.

Mill Annealing. Mill annealing is a high temperature annealing given the tubing after a size reduction step. It includes both intermediate mill annealing and final mill annealing.

Stress Relief. Stress relief is a heat treatment given to tubes to reduce residual stresses after fabrication steps such as fabrication of U-bends.

Thermal Treatment. Thermal treatment is a heat treatment given to tubes in their final state in order to develop the desired carbide distribution and to reduce residual stresses to low levels. The temperature of the thermal treatment is in the carbide precipitation range.

3.0 Technical Requirements

Steam generator tubing produced to these Guidelines shall be a highly uniform and consistent product with as low a variability in yield strength, grain size, and other parameters as practical, shall be low in residual stresses and cold work, and shall be essentially free of surface imperfections. In addition, to the extent practical, the tubing shall be manufactured and handled to minimize eddy current test (ECT) detectable anomalies such as manufacturing burnish marks (MBMs) or dents. Achieving these goals requires close attention to each step of the tube making process, starting from the initial billet and carrying on to final bending, stress relief (if applicable), inspection and packaging. Careful attention shall be paid to anomalies discovered during preproduction runs and during production. Anomalies such as surface flaws shall be evaluated for root cause and these root causes shall be addressed to prevent reoccurrence. In addition, repair methods for surface indications shall be carefully controlled to ensure that ECT signals produced by the repairs are kept as small as practical.

3.1 Material

The seamless tubing material shall be Alloy N06690 in accordance with ASME SB-163, ASME III NB-2000, ASME Code Case N-20-3, and with the additional requirements of this specification. The supplementary requirements in SB-163 shall be met to the extent specified in Section 9.0. Each tube shall be continuous with no intermediate circumferential welds.

3.2 Melting and Metal Working Practices

Melting and metal working practices shall be used that ensure a final product of high quality with respect to uniformity, homogeneity, cleanliness, cracks, galling, laps, seams and similar quality features. The Supplier shall provide a procedure for Purchaser approval which describes the operations from melting through final cold working.

3.3 Chemistry

The chemistry for ladle and product (check) analyses shall be in accordance with Table 2-1. Purchasers may wish to include more restrictive aim values based on review of the Suppliers' recent products to ensure that the current product is not significantly higher in residuals than recently produced products.

Table 2-1
Alloy 690 (N06690) Tubing Chemistry

Element	Percent
Nickel (min)	58.0
Chromium	28.5 - 31.0
Iron	9.0 - 11.0
Carbon	0.015 - 0.025
Silicon (max)	0.50
Manganese (max)	0.50
Cobalt	0.014 average for tube bundle with no heat to exceed 0.020%
Copper (max)	0.10
Sulfur (max)	0.003
Phosphorus (max)	0.015
Nitrogen (max)	0.050
Aluminum (max)	0.40
Boron (max)	0.005
Titanium (max)	0.40
Molybdenum (max)	0.2
Niobium (max)	0.1

The chemical composition of each heat shall be determined in accordance with ASTM E38 or alternate qualified methods by analysis from the ladle or from a remelted ingot. A product (check) analysis shall be performed for one sample of one piece selected randomly from each heat of finished tubing. If specified by Purchaser (Section 8), a product (check) analysis shall be performed of one piece selected randomly from each heat treatment lot of finished tubing.

Chemical analyses for carbon shall be performed using the combustion gas chromatographic or infrared method in accordance with ASTM E354 or other qualified method; the method used shall have been demonstrated to accurately determine carbon concentration to within $\pm$ 0.002%. Samples for carbon analysis shall be representative of the full wall thickness, e.g., they shall be performed using material from through-thickness drilling. Care shall be taken during removal of samples to ensure that contamination does not occur.

The results for all analyses shall be reported to the same number of decimal places as specified in Table 2-1.

3.4 Mechanical Properties

Room temperature mechanical properties of tubing following thermal treatment per 3.6.2 shall conform to the following:

	Minimum	Maximum
Ultimate Tensile Strength, ksi (MPa)	85 (586)	-
Yield Strength (0.2 percent offset), ksi (MPa)	40 (276)	55 (379)
Percent Elongation	30	-

3.5 Cleaning

3.5.1 In-process Cleaning

Prohibited materials, which are defined in Section 5.0, shall not come into contact with the tube material at any time. In addition, prior to any operations involving high temperatures, the tubing material shall be cleaned to ensure that any detrimental contaminants have been removed (detrimental materials are also defined in Section 5.0). The cleaning processes used may include alkaline detergent washing and or vapor degreasing, as long as these processes are followed by appropriate cleaning steps to ensure that no residual contaminants remain on the tube surfaces prior to any heat treatment operations. Grit blasting and acid cleaning may be used subject to the controls given in 3.5.3 and 3.5.4. Cleaning after final heat treatment is covered in 3.9.

3.5.2 Demineralized Water

The quality of the demineralized water used for final cleaning steps and before high temperature operations shall be monitored continuously using conductivity meters or equivalent and shall be checked by analysis at least once per month for compliance with Table 2-2.

Table 2-2
Demineralized Rinse Water Requirements

Chloride ion	0.05 ppm maximum
Fluoride ion	0.05 ppm maximum
Total sulfates	0.05 ppm maximum
Sodium ion	0.05 ppm maximum
Conductivity	2 micro Siemens/cm maximum
pH	5.5 to 8.0
Clarity	no turbidity, oil or sediment
Total suspended solids	0.1 ppm maximum

3.5.3 Grit Blasting

Grit blasting may be performed on tube ID surfaces; however, if grit blasting is performed on tubes after reduction to final size, the surface roughness requirements of paragraph 3.8 must still be met. If performed, grit blasting shall use zirconia. Zirconia grit blast materials shall be free of metallic particles and shall not have been previously used on non-nickel base alloys. Grit particles shall not become embedded in the tubing surfaces; examination to verify freedom from embedment shall be per 4.2.5. No grit blasting shall be performed after bending or final thermal treatment, unless qualification tests are performed to demonstrate that residual stresses resulting from use after thermal treatment are low tensile or compressive, and Purchaser approval is obtained. Grit blasting shall not obscure surface or internal defects.

3.5.4 Acid Cleaning

Acid cleaning may be performed prior to the final tube reduction step but may not be used after reduction to final size. The acid cleaning process, which may include steps such as OD polishing or ID grit blasting performed after the acid cleaning, shall be qualified by metallurgical examination of test pieces to show that it does not result in deleterious attack.

3.6 Tube Heat Treatment

3.6.1 Final Mill Anneal

Subsequent to the final tube reduction, all tubing shall be bright annealed at a metal temperature of 1958°F (1070°C) or more for two minutes minimum in a dry hydrogen furnace atmosphere. The minimum acceptable temperature above 1958°F (1070°C) shall be established by the Supplier based on the composition, microstructure and mechanical requirements of this specification. The range between hottest and coldest metal temperatures of tubes in a lot passing through the furnace shall not exceed 20°C (36°F).

The dew point of the gas shall be such that a bright annealed surface is achieved; physical standards for surface appearance after mill annealing shall be mutually agreed upon by Purchaser and Supplier. The furnace atmosphere shall be maintained on both the inside and outside surfaces. No deleterious surface chemistry changes (decarburizing, carburizing or nitriding) shall be present in the final product, as shown by metallurgical examination (see 4.2.2). Surface discolorations shall not obscure any rejectable indications and should be evaluated to understand their cause.

The metal temperatures of the hottest and coldest tubes shall be recorded. This shall be performed at least once per heat treatment lot. In addition, furnace temperature shall be continuously recorded. On a periodic basis, and prior to start of work on a tubing order, temperatures shall be recorded along the length of the coldest and hottest tubes, i.e., at tube ends and at several intermediate locations along the length of the tube. The hottest and coldest tubes shall have been identified by tests of the specific furnace involved.

No mechanical or chemical surface treatments shall be performed on the tube inside surface after final mill annealing, except that grit blasting is permitted prior to final thermal treatment, and after thermal treatment if qualified (see 3.5.3).

3.6.2 Thermal Treatment

The tubing shall be heat-treated at 1320 (+40, -0)°F (716 (+22, -0)°C) for 10 hours minimum. The thermal treatment shall be performed after final mill anneal, straightening, and grinding. Alternate thermal treatments may be proposed and used, if appropriately qualified and Purchaser approval is obtained. The furnace atmosphere shall not result in deleterious changes in the composition of the inside or outside diameter tube surfaces (decarburizing, carburizing or nitriding), as shown by metallurgical examination (see 4.2.2). Maximum cumulative time at temperature for thermal treatment plus stress relief shall not exceed 35 hours. Surface discolorations shall not obscure any rejectable indication and should be evaluated to understand their cause.

3.6.3 U-bend Stress Relief

U-bends with a bend radius less than 10 times the OD of the tube shall be stress relieved for a minimum of 2 hours at 1320 (+40, -0)°F (716 (+22, -0)°C). Requirements of Section 3.6.2 regarding atmosphere, discoloration, and total time at temperature apply to this stress relief.

3.7 Straightening and Grinding

Machine straightening shall be performed after final mill annealing. It shall not result in a total increase in yield strength of more 13.1 ksi (90 MPa). This shall be demonstrated by performance of tensile tests on tube material after final mill annealing and after final straightening. These tensile tests shall be performed, as a minimum, on the first three tubes straightened after equipment set-up, after each in-process adjustment of straightening parameters, and once per lot.

The tubing shall be supplied with a ground outer surface. A minimum of 0.0004 inch (0.01 mm) shall be removed from the wall thickness by the grinding. The grinding shall be performed after final mill annealing and before thermal treatment. The grinding process shall be demonstrated to not result in surface residual stresses higher than 20 ksi (138 MPa) tensile prior to thermal treatment.

Machine restraightening or grinding shall not be performed after final thermal treatment or nondestructive testing. However, machine restraightening or regrinding is permitted after thermal treatment if it is followed by an additional two hour period of thermal treatment and all nondestructive tests are also repeated. The total time at thermal treatment temperature shall not exceed the limit of 3.6.2.

Local manual straightness corrections following thermal treatment are permitted without subsequent stress relief as long as the radius of the bend is greater than that of any U-bends for which stress relief is required.

Surface repairs by local polishing are covered in Section 3.8.

3.8 Surface Requirements and Repair of Defects

The tubing shall be uniform in quality, sound, and free from seams, cracks, tears, laminations, and laps, and free from pitting and intergranular attack (IGA) and other injurious defects. The tubing surface shall be free from deleterious manufacturing-induced damage, such as drawing marks, as evidenced by samples not having surface conditions exceeding those of physical standards proposed by the Supplier and accepted by the Purchaser. In addition, the physical standards shall cover acceptable and unacceptable local repairs, e.g., for blending (if local repairs are allowed).

The outside surface shall have a surface finish of RMS 63 microinches (1.6 micrometers) or finer. The inside surface shall have a surface finish of RMS 20 microinches (0.5 micrometers) or finer, except 10% of the tubes for a steam generator may have an inside surface finish of RMS 63 microinches (1.6 micrometers) or finer.

After final mill annealing and before thermal treatment, defects on the outside surface may be removed as long as the minimum wall thickness is maintained, surface roughness limits are met, and the area is blended uniformly; however, local repair shall not be performed after thermal treatment of the tube in the region from the design point of contact with the tube sheet ± 3 inches (76 mm). Defect removal after final thermal treatment (or after stress relief of U-bent tubes that are stress relieved) shall be limited to hand polishing using abrasive materials unless alternate methods of defect removal (such as small hand held belt polishers) are demonstrated by test (such as X-ray measurements) to not result in tensile residual stresses exceeding 5 ksi (35 MPa). Removal of the defect shall be verified using the same method as originally used to find the defect. The defect removal process shall not embed iron on the tube outside surface. No weld repairs shall be performed.

3.9 Cleaning After Final Thermal Heat-Treatment

The tubing shall be furnished clean and ready for service in accordance with RG 1.37 and Class B of ANSI N45.2.1. The outside surface of the tubing shall be cleaned by wiping with solvent-wetted lint-free cloths. The inside surface shall be cleaned by blowing with solvent soaked lint-free plugs, followed by dry lint free plugs, using dry, oil-free air or nitrogen.

3.10 Bending

Bending may be performed without an internal mandrel or using an internal plastic cylindrical mandrel. Internal metal mandrels shall not be used. Acceptance criteria for bends are covered in the supplementary requirements of SB-163 and the supplementary requirements of this specification (Section 9.0).

4.0 Acceptance Criteria And Tests

Some of the tests and inspections required in this specification are based on a sample per heat treatment lot. Refer to Section 2.7 for definitions of "heat treatment lot" and related terms.

4.1 Compliance with Surface Requirements

The tubing shall be inspected in accordance with the requirements of Section 6 of this specification. The tubing surfaces shall meet the requirements of Sections 3.8 and 6.

4.2 Metallographic Evaluation

Metallographic evaluation shall be performed on each lot of tubing in accordance with ASTM E3. This evaluation shall be performed on material in the final condition, i.e., after final mill annealing and thermal treatment, except that tests for inclusions shall be performed on ingot material.

4.2.1 Microstructural Evaluation

One sample per lot shall be evaluated to verify that the desired carbide microstructure has been achieved. This microstructure is one with continuous or nearly-continuous carbides at grain boundaries, and few intragranular carbides. Carbide banding shall be minimized and acceptance limits on carbide banding shall be covered in reference photomicrographs mutually agreed upon by the Supplier and Purchaser. The microstructure shall be evaluated using longitudinal sections taken near the inner surface, close to the mid wall, and near the outer surface. The fields used for evaluation of microstructure shall be randomly selected.

The microstructure at the OD surface shall be evaluated to verify that the surface layer of recrystallized grains is minimized.

The microstructure shall be evaluated using an etching procedure and acceptance criteria (reference photomicrographs) mutually agreed to by Purchaser and Supplier. The bromine-methanol and glyceregia-hot oxalic acid etching techniques are suggested for use, but are not required.

4.2.2 General and Intergranular Attack, and Freedom from Deleterious Carburization, Decarburization, and Nitriding

Transverse samples from one tube per lot in the finished condition shall be evaluated metallographically around the full circumference on the inside and outside diameters. There shall be no IGA or general corrosion on the inside or outside surfaces. In addition, the tube material shall be evaluated at a magnification of 500X to verify that it is free from deleterious carburization, decarburization and nitriding as demonstrated by the material not exceeding amounts of these conditions shown on reference photomicrographs prepared by Supplier and agreed to by Purchaser.

4.2.3 Grain Size

The grain size, as shown in both longitudinal and transverse sections, shall be determined once per lot per ASTM E-112. The grain size shall not exceed ASTM 5, i.e., the grain size number shall not be less than ASTM 5. The grain size spread shall not exceed two ASTM units.

4.2.4 Inclusions

Testing shall be performed according to ASTM E45 Method A on bar samples corresponding to the top and bottom position of one ingot per heat. Reporting shall be per Method A of ASTM E45, except that the method JK charts for Method D may be used. Each specimen shall be examined at least at the edge and mid-radius positions using fields that are selected randomly from these areas.

Maximum inclusion rating:

Oxides and sulfides

Type	A		B		C		D	
	T	H	T	H	T	H	T	H
	1.0	0.5	3.0	1.0	1.0	0.5	1.5	1.0

Ti-Carbonitrides

Type	B		D	
	T	H	T	H
	3.0	3.0	4.0	3.0

Purchasers may wish to define more restrictive values and aim values based on review of recent heats from their selected Supplier to ensure that they receive product representative of the Suppliers' recent product or to ensure improved material cleanliness and homogeneity.

4.2.5 Freedom from Grit Embedment

If grit blasting is performed on any tubing in a lot, one sample per lot shall be removed from a grit blasted area and examined using stereomicroscopy at a magnification of 60x to verify the absence of embedded grit particles at the inner surface.

4.2.6 Surface Condition

One sample per lot shall be examined on the ID and OD surfaces using a stereoscopic microscope to verify that the surface condition meets the requirements of Section 3.8 (Note: surface roughness shall be checked per Section 6.4.8).

4.3 Mechanical Properties, Expansion, and Hydrostatic Tests

Tests shall be in accordance with ASME SB-163 and the following additional requirements. All tests shall be performed after the thermal treatment.

4.3.1 Mechanical Properties

Room temperature mechanical properties shall be determined on one sample per lot in accordance with ASTM E8.

4.3.2 Expansion (Flare) Test

The flare test required by SB-163 for each random length tube shall not produce any cracks, breaks, linear defects, or other injurious defects.

4.3.3 Hydrostatic Test

Each tube shall show no evidence of leakage during hydrostatic testing at an internal hydrostatic pressure set to result in the fiber stress specified in Supplementary Requirement S1.3.1.2 of SB-163. The water used for hydrostatic testing shall meet the requirements of Table 2-2.

5.0 Prohibited And Detrimental Materials

5.1 Prohibited Materials

Red lead-graphite-mineral oil or molybdenum disulfide lubricants shall not be used, i.e., these materials are prohibited from contact with the tube material at any time. Metallic lead, mercury, cadmium, or other low melting temperature metals or alloys are also prohibited from contact with the tube material at any time.

5.2 Detrimental Materials

The tubing shall not come in contact with materials, compounds, or elements that could have a deleterious effect on the satisfactory performance of the tubing in steam generators used in pressurized water reactors. A program and procedures shall be in place to control the use of all consumables which contact the tubing during manufacturing, inspection, and shipping operations. Examples of consumable materials include adhesives, cutting fluids, lubricants and/or oils, labels, tapes, marking materials, NDT materials (dye penetrants, removers, emulsifiers, developers, cleaning agents, ultrasonic testing couplants), abrasives, grinding and cutting wheels, solvents, wrapping materials, etc. This program should include the control of consumables that contain detrimental materials in excess of the amounts in Table 2-3.

Table 2-3
Detrimental Materials

Total chloride	200 ppm
Total fluoride	200 ppm
Total sulfur	200 ppm
Total phosphorus	250 ppm
Total lead	1 ppm
Total mercury	1 ppm
Antimony, arsenic, bismuth, cadmium, gallium, indium, magnesium, silver, tin, zinc	200 ppm each, 500 ppm total
Aluminum, copper	250 ppm each

Detrimental material controls apply to all surfaces of the tubes prior to or during heat treatment and to all cleaned surfaces. Material analysis records should be available to the Purchaser for review. Products that contain detrimental materials may be used if:

1. There is no transfer of detrimental materials to the surface of the tubing, or
2. The detrimental material is removed from tubing surfaces prior to heat treatment or shipment, as applicable, and
3. Freedom from detrimental material on the tubing surface is demonstrated by qualification tests, and reports of the tests are available for Purchaser review.

During heat-treatment, if fuel or combustion gases can come into contact with the tube material, the fuel shall not contain sulfur more than 0.5 percent by weight or 30 grains maximum per 100 ft^3.

6.0 Quality Assurance Program Requirements

For all the work covered under this specification, there shall be in effect a written QA Program in compliance with the provisions of 10CFR50 - Appendix B and the quality assurance requirements required by specified codes and standards. The QA program manual shall be submitted to the Purchaser for approval. After Purchaser's approval, should significant changes to this QA Program become necessary which may affect performance of work covered in this specification, the Supplier shall, prior to implementation, submit such changes to the Purchaser for review and approval. The Supplier's approved QA Program is subject to audit by the Purchaser's Quality Assurance Representative (PQAR) to ensure compliance with applicable purchase documents.

If an ASME III QA Program Manual is submitted with the intent of complying with 10CFR50, Appendix B, the submittal shall be accompanied by a letter signed by an authorized official of the Supplier's company specifically stating this fact and identifying those parts or services, if any, not covered by the ASME III program. For those parts or services not covered by the ASME III QA program, the Supplier shall also submit, to the Purchaser, the applicable QA Program Manual in compliance with 10CFR50 - Appendix B. Unless specific exceptions are noted, the ASME QA program shall be applied to all pressure parts and services furnished under the specification. The entire QA program submittal shall be subject to the Purchaser's approval.

6.1 Identification and Control of Materials, Parts and Components

The Supplier shall establish and maintain a system for the identification and control of materials. These measures shall ensure that identification of the item is maintained by heat number and lot number, either on the item or on records traceable to the item during shipment and use of the item. These identification and control measures shall be designed to prevent the use of incorrect or defective material.

6.2 Supplier's Responsibilities for Subsuppliers

The Supplier shall identify, in purchase documents to his subsuppliers, all applicable quality and QA requirements imposed by the Purchaser specification on the Supplier and shall ensure compliance thereto.

6.3 Notification and Hold Points

The Purchaser shall have the right to establish notification points for which the Supplier shall give prior notification to the Purchaser. In addition, the Purchaser may establish temporary notification points if they deem them necessary to ensure resolution of temporary quality problems. Notification points require receipt of notification at least five working days in advance of the scheduled first time of performance. The Purchaser's Quality Control Representative (PQCR) will witness the event or will authorize the Supplier to Proceed without Purchaser witnessing of the event.

Selection of notification requirements shall reflect the fact that tube fabrication is a continuous process. Purchaser witnessing of notification point activities must not interfere with production work.

The Purchaser may require that activities performed without proper notification be repeated for PQCR observation at the Supplier's expense.

If specified in the purchaser order, the Supplier shall not carry work beyond designated hold points until released in writing by Purchaser's representative.

6.4 Requirements for Nondestructive Examination, Visual Inspection, Dimensional Inspection, and Surface Roughness Check

The eddy current (ECT) and ultrasonic (UT) testing per ASME Section III, paragraph NB 2550, required by 6.4.3 and 6.4.4 below, shall be performed on straight tubing subsequent to ID grit blasting (if performed), straightening and OD polishing, and may be performed prior to or after thermal treatment.

ECT in accordance with Section XI of the ASME Code required by 6.4.5a below shall be performed subsequent to straightening and OD polishing, and shall be performed with the tubes in the U-bent condition. The tubes may be inspected in a horizontal orientation.

Continuous records shall be kept of all NDE.

6.4.1 Personnel

Only personnel certified as Level II or III to SNT-TC-1A shall interpret the results of examinations.

6.4.2 Procedures

Except as stated below Supplier shall submit applicable nondestructive testing procedures, including examination report forms, for review and approval by the Purchaser prior to implementation. In addition, when the Supplier subcontracts work including nondestructive examinations required by this specification, the subcontractor procedures shall be reviewed and approved by the Purchaser. These procedures shall be submitted after review and approval by the Supplier.

If nondestructive test procedures required by this specification have previously been submitted and approved, a statement may be submitted in lieu of the procedure which will be subject to concurrence by the Purchaser prior to implementation. The statement shall clearly identify the procedure, including revision or issue number, the date of submittal, the project and contract number for which it was submitted. In addition, it shall be affirmed that the procedure is exactly as previously submitted and is applicable to this specification.

6.4.3 Ultrasonic Tests

All tubing shall be ultrasonically examined per ASME Section III, NB-2550, and the following additional requirements:

a. Ultrasonic examination shall be performed in two circumferential directions and two axial directions.

b. The reference standard shall be permanently identified and supplied with the material examined under this specification.

c. The reference standard shall contain both axial and transverse notches on both inner and outer surfaces.

d. The reference notches shall be of the buttress (square type) configuration, shall have a maximum length of 0.5 inches (12.7 mm), maximum depth of 0.004 inches (0.10 mm), and maximum width of 0.040 inches (1.0 mm).

6.4.4 Eddy Current Tests

At least two, and possibly three ECT examinations shall be performed. The first is the ASME Section III, NB 2550 inspection covered in the next paragraph that is normally performed using encircling coils. It is performed on tubes after final mill annealing, ID blasting if any, rotary straightening and OD polishing. The second inspection is an inspection of the final tubes using field type inservice inspection equipment and practices with ID bobbin coils covered in paragraph 6.4.5, and is performed on tubes after U-bending. The third inspection may be combined with either of the above inspections and is for signal to noise. It is performed using either field type inservice inspection equipment or using encircling coils that have been calibrated to provide the same signal to noise results as field type equipment.

All tubing shall be eddy current examined in accordance with ASME Section III, NB 2550. The calibration standard shall have reference notches per 6.4.3, including a 1/16" (1.59 mm) diameter through wall hole, except that axial notches are not required, and it shall also have three 1/32" (0.8 mm) diameter flat bottom holes, $\leq$ 1/32" deep, at one axial location at 120°.

6.4.5a Eddy Current Tests - Inservice Inspection Type

All tubes shall be ECT inspected using field type equipment and procedures as specified by the Purchaser in the final as-bent condition, after stress relief if applicable, to ensure an acceptable level of freedom from unacceptable MBM and other anomalous ECT indications such as roll restart and end of U-bend signals. The Purchaser shall specify the technical requirements to be met. The intent is that the technical requirements be consistent with those of the latest EPRI PWR Steam Generator Examination Guidelines (TR-107569 or successor), but that tube vendors do not have to meet the full quality requirements of the Examination Guidelines. The low frequency signal in the absolute mode shown below shall be used for detection of MBMs:

Tube Wall Thickness, in. (mm)	Frequency, kHz
0.050 (1.27)	100
0.045 (1.14)	120
0.043 (1.09)	140
0.040 (1.02)	150
0.037 (0.94)	200

Signals shall be recorded and disposed of as indicated in the list below. The 0.5 and 2 volt values given below are for 3/4" OD tubes; these values will vary depending on tube dimensions and should be specified in the purchaser order. The purchaser may wish to define more restrictive criteria.

- All anomalous signals above the noise level shall be recorded.
- All signals above 0.5 volts and below 2.0 volts shall be evaluated for depth using phase angle methods. Indicated depths over 10% of wall shall be cause for rejection of the tube.
- All signals of 2.0 or more volts shall be cause for rejection of the tube.
- The Purchaser shall indicate the numbers of signals below 0.5 volts and between 0.5 and 2.0 volts that are acceptable, if such indications are allowed.

6.4.5b Eddy Current Tests - Signal to Noise Ratio (S/N)

All tubes shall be eddy current inspected to establish a (S/N) ratio. The (S/N) ratio shall be 15 to 1 or higher for any fixed 0.5 meter length of any tube (straight portions - if tubes are inspected after bending, acceptance criteria for bent portions shall be specified in the purchase order). The purchaser may wish to specify in the purchase order that the (S/N) criteria be defined over a shorter length than 0.5 meters. The (S/N) shall be as measured using a field type ID bobbin coil at the upper basis frequency (See Paragraph 6.4.5b and Table 3-2 in Section 3). Tube inspection for (S/N) shall be accomplished using eddy current test frequency, procedures, instrumentation settings and test coil parameters, e.g., fill factor and coil spacing, representative of expected inservice inspection test conditions. Details of the examination procedures should be established by negotiation guided by the principles presented in Bases, Section 3, Paragraph 6.4.5. If the Supplier wishes to use encircling coils for the (S/N) inspection, this shall be subject to Purchaser approval and the encircling coil method shall be demonstrated to provide the same results as the field method, as further discussed in Bases, Section 3, Paragraph 6.4.5.

6.4.6 Visual and Tactile Inspection

All tubes shall be visually inspected with the naked eye and tactilely inspected with a cotton glove while in the straight condition. No cracks, linear indications, or large scratches are acceptable. Visual and tactile standards for scratches shall be mutually agreed upon between the Supplier and Purchaser.

6.4.7 Dimensional Inspection

All straight tubes shall be dimensionally inspected to verify compliance with purchase order requirements (Section 8).

All bent tubes shall be inspected to verify that bend radius and leg length dimensions have been met.

The frequency of inspection of bent tubes for ovality, wall thickness, and diameter shall be as specified in the ordering data (Section 8). Acceptance criteria for the bent tubes are contained in the supplementary requirements of SB-163 and in the supplementary requirements of this specification (Section 9).

If specified in the purchase order (Section 8), special dimensional inspections of all tubes shall be performed to verify compliance with dimensional requirements at antivibration bar contact locations.

6.4.8 Surface Roughness Checks

One percent of the tubes per lot shall be checked using a profilometer for inner and outer surface roughness. Surface roughness measurement techniques shall be mutually agreed upon by Purchaser and Supplier.

6.5 Documentation

6.5.1 Records System

A records system shall be established and maintained to provide documentary evidence of the quality of items and activities affecting quality. The quality assurance (QA) records shall include results of reviews, inspections, tests, and audits, monitoring of work performance, and material analyses. Records shall, as a minimum, identify the inspector or data recorder, date inspection was performed, type of observation, procedures used, results, acceptability, and action taken with any deficiencies noted. Records of relevant supporting data shall also be maintained. All quality verification records, procedures, and qualifications shall be identifiable to the item or activity involved. These records shall be retrievable and available for examination.

6.5.2 Documentation Checklist

Prior to the start of fabrication, the Supplier shall prepare and submit to the Purchaser, for review and approval, a preliminary Documentation Checklist detailing the quality assurance documents which will be required to comply with this specification and referenced codes and standards. This Checklist shall itemize, by document type, documents that will be submitted to the Purchaser for information or approval and records which will document the results of inspections and tests. Upon completion of tubing fabrication, testing, and inspection, but prior to release for shipment, the Checklist shall be finalized to show the procedures actually used and the records which document the results of all inspections and tests performed. The final Documentation Checklist shall be verified for accuracy and completeness and submitted to the PQCR.

6.5.3 Document Submittals

This specification requires specific documents to be formally submitted to the Purchaser for information or review and approval. If these documents are changed subsequent to submittal, the Supplier shall resubmit the revised document(s) to the Purchaser for information or review and approval consistent with the original requirement. Any document required by this specification which is produced by a subsupplier of the Supplier shall first be reviewed and noted as being approved by the Supplier and then submitted to the Purchaser for review and approval.

6.5.4 Supplier's Documentation

QA documents are a deliverable item. The Supplier's QA organization shall approve the documents and then present them to the Purchaser. The Supplier shall assemble all QA records into two identical sets. Each page of each document submitted shall be clearly identified and numbered. Each individual document shall be legible and suitable for microfilming. No information shall be recorded closer than 5/8 in. (16 mm) to the binding edge or closer than 1/4 in. (6 mm) to any other edge of the paper.

Documents that have been submitted with a previous shipment on this order/contract shall not be duplicated. However, a statement shall be furnished to the Purchaser itemizing, by document, the documents previously furnished for each item of equipment and the date of that previous submittal.

6.5.5 Final Inspection and Check of Records

The Supplier shall be responsible for inspecting the item(s) and checking the applicable records, prior to shipment, to verify that all specification requirements have been complied with. Two complete sets of all documents required to comply with this specification shall be submitted to the Purchaser. Acceptance of the completed sets of records does not relieve the Supplier of responsibility for compliance with specification requirements.

After completion, but prior to submittal of these records, the Supplier shall complete and submit a Certificate of Compliance. The Certificate of Compliance supplied as part of the specification is a document which certifies that the inspection(s) and test(s) required by the specification have been satisfactorily completed and that all of the requirements of this specification, and applicable codes and standards, have been met. The Certificate of Compliance shall be completed and signed by the Supplier's quality representative and submitted to the Purchaser, together with the other documentation applicable to the shipment.

6.5.6 Shipping Release

The Supplier's completed Certificate of Compliance must be included in each shipment. This requirement also applies to shipments from the Supplier's suppliers when item(s) are to be shipped directly to the Purchaser or its contractors.

6.5.7 Record Retention

All records required by this specification, applicable regulations, codes, and standards, or generated as a result of the Supplier's QA Program, shall be retained in the Supplier's file for the period specified in the ordering data after the contract requirements for manufacture have been complied with. At the expiration of this period, the Purchaser or his authorized agent shall be provided the option of receipt and/or the Supplier's continued retention of the file contents. No quality assurance records shall be destroyed or otherwise disposed of without written permission from the Purchaser.

6.6 Documentation Supplied by Supplier to Purchaser's Quality Assurance and Control Representatives with the Shipment

6.6.1 NDE Reports

An inspection report shall be prepared by the Supplier for each required NDE and shall include the following in addition to the information required by ASME III:

a. Purchaser's purchase order number

b. Name of part

c. Method or technique

6.6.2 Certified Materials Test Report

A Certified Materials Test Report in accordance with ASME Section III shall be furnished for each lot of material supplied and shall include at least the following:

a. Material chemistry and heat number

b. Mechanical properties

c. Metallographic evaluation results:

- Microstructure (photomicrographs shall be provided and shall identify the alloy, heat number, lot number, final mill anneal, thermal and stress-relief heat-treatment temperatures and times, etchant, and magnification)
- Check for IGA
- Check for fabrication defects
- Grain size
- Ingot inclusion rating

d. Flare test results

e. Hydrostatic test results

f. Results of nondestructive tests

   — Ultrasonic

   — Eddy Current (three types, including (S/N))

6.6.3 Heat-Treatment Documents

The Supplier shall provide a record of the tube processing which includes the following:

a. Actual hottest and coldest metal temperature during final mill annealing and thermal treatment

b. Actual time at or above the minimum required temperature during final mill annealing and thermal treatment

For continuous furnace heat treatments, this information shall include the periodic metal temperature measurements required by 3.6.1, together with the recorded furnace temperature.

6.6.4 Certificate of Compliance

The Supplier shall provide a Certificate of Compliance per 6.5.5.

6.7 Purchaser Witnessing of Inspections

The Purchaser or his authorized representative shall have the right to witness any inspections or tests. Purchaser notification shall be handled per 6.3.

7.0 Shipment

The Supplier shall package and ship the tubing in accordance with requirements as defined in ANSI N45.2.2, Class B and RG 1.38. The packaging procedure to be used shall be documented in a procedure prepared by Supplier and approved by Purchaser.

The tubing shall be delivered clean, free from organic material or films (oil, grease, paint, crayon), moisture, chemical residue, preservative, chips, or foreign matter.

Each tube shall be sealed at both ends with a nonmetallic cap or plug. If specified by Purchaser, each tube shall be individually sleeved in a plastic sleeve which is sealed at each end. The tubes shall be packed in sturdy cases in a manner that ensures that there is no movement of tubes and there is no contact between tubes. The packing and marking material must conform to the detrimental material requirements of Section 5 of this specification.

Each tube shall be tagged with a unique identification number traceable to all other pertinent records, such as purchase order number, CMTR, etc. The shipment package shall be clearly identified as to alloy type and purchase order number.

8.0 Ordering Requirements

Purchasing Documents shall specify the following:

1. Title and date of this specification
2. Whether check analyses of chemistry are required for each lot (see Section 3.3).
3. Tube dimensions and tolerances (see Section 6.4.7)
    - Outside diameter
    - Wall thickness
    - Total length (if straight), or leg length (if U-bend)
    - U-bend radii (if applicable)
    - Straightness
    - Frequency of inspection of U-bends (if applicable)
    - Special dimensions and tolerances for antivibration bar contact areas
4. Quantity
5. Compliance with 10CFR21
    - The purchase order shall include the following statement:
    - The steam generator tubing provided under this purchase order is a basic component of a Nuclear Regulatory Commission (NRC) licensed facility or activity. Accordingly, the Supplier is subject to the provisions of Part 21, Chapter 1 of Title 10 of the Code of Federal Regulations.

6. Whether any hold points are required and, if so, at what stage of manufacture (see 6.3).

7. The acceptance criteria for the field type eddy current test of 6.4.5a should be specified, including acceptable numbers of signals below 0.5 volts and between 0.5 and 2.0 volts.

8. The eddy current test signal to noise ratio requirements to be met by the tubing should be specified. Inspection parameters such as reference defect type and location, inspection frequency, probe diameter, and coil spacing should be specified. If tubes are to be inspected after bending, acceptance criteria for bent portions should be specified separately from those for straight portions (acceptance criteria for straight portions are covered in Bases, Section 3, 6.4.5).

9. Length of Record Retention in accordance with paragraph 6.5.7.

10. Whether individual sleeving of tubes is desired (see 7.0).

11. Any supplementary requirements (Section 9.0) to be met.

12. Additional tubing row numbers that shall be stress-relieved, if additional rows beyond those required by 3.6.3 are to be stress relieved.

9.0 Supplementary Requirements

Supplementary Requirements S1 and S2 of SB-163 apply to tubes purchased to this specification. In addition, the Purchaser shall specify if the following supplementary requirements are to be included:

9.1 The thickness reduction due to bending shall not exceed 12 percent of the initial thickness. The thickness reduction measurements shall be taken at the extrados of the transition zone between the bent and unbent straight leg regions of the tubing and in the extrados of the apex region. Buckling, determined as the difference between the outside diameter at the largest crest and the outside diameter at the adjacent valley, shall not exceed 3 percent of the nominal outside diameter. Ovality, determined as the ratio of the difference between maximum and minimum outside diameters to the nominal diameter, shall not exceed 3 percent, except for the inner two rows of 7/8" tubing, where it shall not exceed 4.5 percent.

9.2 Product (check) analyses shall be performed of the chemical composition for each lot as described in Section 3.3.

9.3 The calibration notches required for ECT per 6.4.4 shall be "v" notches, i.e., shall have sharp ends.

9.4 If specified by the Purchaser, pre-production qualification shall be performed. The size and nature of the preproduction should take into consideration whether the order is a repeat order, or is otherwise highly similar to previous production. Assuming that a new (non repeat) order is involved, a lot of 50 tubes shall be manufactured, inspected and tested as required by this specification and the additional requirements given below. All of the test and examination results for the pre-production lot shall meet specification requirements. Purchaser agreement with the results of the pre-production lot examinations and tests shall be obtained before commencing actual tube production, unless the Supplier and Purchaser agree that it is permissible to start production before all preproduction examination and test data are available and analyzed.

1. A total of 15 tubes shall be bent, if U-bends are covered by the purchase order. Five shall have the minimum specified radius, five shall have the minimum radius without use of an internal mandrel, and five shall have the minimum radius which is not stress relieved.

2. A total of 10 tubes shall be inspected for signal to noise ratio per Section 6.4.5.

3. All final mill annealing furnace loads shall be instrumented to determine the metal temperature distribution in the furnace loads, and to verify that temperature uniformity is in accordance with specification requirements.

4. The following tests shall be performed of samples removed from either end and the middle of the coldest tube and the hottest tube of the 50 tube pre-production lot, for tubes in the final mill annealed condition, final mill annealed, straightened, and polished condition, and thermally treated condition:

   a. Tensile test at room temperature

   b. Microhardness test of ID and OD surface and transversely across tube wall (for information).

   c. Residual stress measurement using split ring method, with the stress determined using (for information):

      $$S = 1.10\, E\, t\, (D_f - D_o) / D_f D_o$$

      where

E	=	modulus of elasticity
t	=	wall thickness
D_f	=	diameter after splitting
D_o	=	diameter before splitting

d. Metallurgical examinations for microstructure, grain size, and freedom from fabrication defects, corrosion attack, and grit embedment.

e. Surface finish of ID and OD surfaces.

3

BASES FOR ALLOY 690 SPECIFICATION

This document describes the bases for the requirements in the alloy 690 steam generator tubing specification. The paragraph numbering used parallels that of the specification.

Preparation of the 1991 issue of the Alloy 690 Guidelines is described in the original 1991 issue (31). An update to the 1991 Guidelines was initiated in 1998 in response to a desire expressed by EPRI utilities to strongly reduce the number of anomalous ECT signals such as manufacturing burnish marks (MBMs) that require followup during inservice inspections, and to control the microstructure so as to maximize the resistance to intergranular attack/stress corrosion cracking (IGA/SCC) in caustic tests as shown by recent testing (32, 33). It was also desired to revise the Guidelines to reflect improvements in ECT signal to noise ratio, inclusion content, tubing ovality, etc. that have been achieved in recent years.

EPRI and DEI met with the three tubing suppliers (Valinox, Sandvik, and Sumitomo) and also discussed the Guidelines with Electricité de France (EDF), the Belgians, Mitsubishi Heavy Industries (MHI) and Babcock & Wilcox (B&W). From these meetings EPRI and DEI identified possible improvements to the Guidelines, and obtained some feedback with regard to the possible effects of imposing tighter requirements. Reports of each of these meetings were prepared and are available at EPRI. A review meeting with nuclear steam system suppliers (NSSSs) and steam generator suppliers was held on July 22-23, 1998 to discuss proposed changes to the Guidelines (34).

1.0 Scope

The scope section does not contain requirements. It was slightly broadened from the alloy 600 specification (1) to indicate that it contains special requirements for quality control.

2.0 Applicable Documents and Codes; Definitions

This first introductory section does not contain any requirements.

2.1 Code of Federal Regulations

This section invokes NRC required reporting (10CFR21) and quality assurance requirements (10CFR50 Appendix B). These requirements are mandatory for US nuclear plants.

2.2 ASTM Specifications

This section lists ASTM specifications commonly used for nickel alloy tubes. The specifications are invoked by specific reference elsewhere in the alloy 690 specification. It should be noted that Section 3.3 allows use of methods for chemistry analysis in addition to those covered by the specifications listed in 2.2, as long as the methods are qualified.

2.3 NRC Documents

- Regulatory Guide 1.37 invokes ANSI Standard N45.2.1 (discussed below) for cleaning, and also invokes some supplementary cleanliness requirements. These requirements are mandatory for US nuclear plants, except where a utility has negotiated an exception with the NRC.
- Regulatory Guide 1.38 invokes ANSI Standard N45.2.2 (discussed below) for packing, shipping, etc., and also invokes some supplementary requirements. These requirements are mandatory for US nuclear plants, except where a utility has negotiated an exception with the NRC.
- Regulatory Guide 1.85 allows use of material to Code Case N-20-3. This, in effect, gives NRC approval to the use of alloy 690 as steam generator tubing.

2.4 ANSI Standards

ANSI Standards N45.2.1 and N45.2.2 are standards containing requirements for cleanliness and packing, shipping, etc. They contain detailed requirements applicable to all nuclear plant safety related components. Because they are invoked by the NRC via regulatory guides (see above), they are mandatory except where a utility has negotiated an exception with the NRC.

2.5 ASME Boiler and Pressure Vessel Code

This section invokes ASME SB-163 and section NB-2000 of ASME Section III. These portions of the ASME Code are the applicable ones for nickel alloy steam generator tubes. Since the NRC invokes the ASME Code, these sections are mandatory for steam generator tubes. This section also invokes Code Case N-20-3, which incorporates requirements for alloy 690 into the ASME Code, thus allowing its use. Finally, this section lists ASME Section XI, since this section of the Code covers eddy current inspections of the type done in plants, and it is desired to have inspections performed of the tubes to make sure that they are compatible with ASME Section XI inspections.

2.6 American Society for Nondestructive Testing

This section invokes SNT-TC-1A, which is required by the nondestructive examination section.

2.7 Definitions

The definitions are intended to ensure that terms used in the specification such as "lot" and "thermal treatment" are understandable in an unambiguous way.

The definition of "heat treatment lot" was revised to increase the maximum size from 150 to 200 tubes. The 150 tube limit was a historical value without a firm technical basis, and that the increase to 200 reflects a judgement that the demonstrated consistency of the product warrants use of a larger number. In addition, increasing the lot size results in economies since it reduces the numbers of tests and reports required.

The definition of "heat treatment lot" ties it to material from the same base material heat which has been final mill annealed in a relatively short final mill annealing run. Limiting the lot to tubes from the same heat and final mill annealing run is based on the tube properties being most significantly affected by base material chemistry and by final mill annealing. Requirements for a lot regarding earlier mill anneal conditions and for tube reduction parameters are that these operations be to the same "schedule" and "practice" for all of the material in the lot, i.e., to the same nominal conditions. It has not been found necessary to require that these fabrication steps be performed using the same pieces of equipment in continuous runs for all material in a lot; sufficient uniformity of the material in a lot is achieved without this requirement.

A requirement was added in 1999 to tie the definition of lot to the same thermal treatment practice to ensure that the material all receives the same nominal thermal treatment. Requiring a lot to be thermally treated in the same furnace charge is not considered necessary since experience shows that minor changes in time and temperature of thermal treatment do not significantly affect material properties or microstructure. It had been proposed to make a similar requirement for stress relief (i.e., to require material in a lot to be stress relieved using the same stress relief practice). This change was not incorporated since the tube mills indicated that it would cause problems as a result of some lots having a range of bend radii, with some tubes being stress relieved and others not being stress relieved. In addition, experience shows that the stress relief, since it is performed at the same nominal conditions as the longer thermal treatment and for a shorter time, has a negligible effect on properties and microstructure.

A requirement was added that all tubes in a lot be straightened with the same equipment and equipment setup, since straightening has a significant effect on material properties.

3.0 Technical Requirements

A new preamble or introductory statement was added in 1999 emphasizing the need for the tubing to be as homogeneous as practical, as free of surface imperfections, cold work, and residual stresses as practical, and as free of ECT anomalous signals as practical. This change is based on recommendations from Duke Energy and stems from their experience with procuring tubing for replacement steam generators. It is recognized that this change does not have quantitative enforceable limits, but is included to provide the correct tone to the Guidelines. More quantitative or explicit requirements are included in later sections.

3.1 Material

This section invokes the applicable ASME specification (SB-163) and Section III of the ASME Code. In addition, it prohibits use of intermediate circumferential welds. This requirement is included because SB-163 requires tubes to be seamless, i.e., to not have longitudinal seam welds, but does not specifically prohibit intermediate circumferential welds. Intermediate circumferential welds are undesirable because they increase the probability of material defects being present and also increase the possibility of corrosion problems arising during service.

3.2 Melting and Metal Working Practices

The selection of melting and metal working practices is left to the Supplier, but Supplier is required to document the practices and to obtain Purchaser approval. This approach was taken to provide Supplier with flexibility to optimize its practices, while still giving the Purchaser sufficient control to ensure the needed quality.

3.3 Chemistry

The specified material chemistry limits were revised in 1999 as indicated in Table 3-1. The reasons for the changes are described in the paragraphs following the table. In addition, words were added indicating that the utility may wish to include more restrictive aim values based on review of the supplier's past product to ensure that the current product does not deviate significantly from this past product or to provide improved cleanliness and homogeneity.

Table 3-1
1991 vs. 1999 Chemistry Limits

Element	% - 1991 GL	% - 1999 GL
Nickel (min)	58.0	58.0
Chromium	28.0 - 31.0	28.5-31.0
Iron	7.0 - 11.0	9.0 - 11.0
Carbon	0.015 - 0.025	0.015 - 0.025
Silicon (max)	0.50	0.50
Manganese (max)	0.50	0.50
Cobalt	0.015 average with no heat to exceed 0.020	0.014 average for tube bundle with no heat to exceed 0.020
Copper (max)	0.50	0.10
Sulfur (max)	0.010	0.003
Phosphorous (max)	0.015	0.015
Nitrogen (max)	0.05	0.050
Aluminum (max)	0.50	0.40
Boron (max)	0.007	0.005
Titanium(max)	0.50	0.40
Molybdenum (max)	0.2	0.2
Niobium (max)	0.1	0.1

The general reason for changing the chemistry limits was to tighten limits where industry experience indicates that it is practical with the objective of ensuring reduced variability in the material. Comments on changes to specific elements are as follows:

- Chromium: The minimum chromium level was raised from 28.0% to 28.5% to reflect BWC practice, and since higher chromium is in the direction of improved corrosion performance. The change also serves to tighten the composition range.

- Iron: The minimum iron was raised from 7.0% to 9.0% to reflect much of industry's practice, and to minimize concerns about possible long range ordering reactions that might possibly lead to embrittlement after long time at temperature (35). The change also serves to tighten the composition range.

- Cobalt: The average cobalt was reduced from 0.015% to 0.014% to reflect industry experience and because the lower the cobalt the better from a radiation dose rate standpoint. The average was clarified as applying to a tube bundle because it is the tube bundle average that controls the cobalt contribution of the steam generator to the coolant, not the value of a single lot.

- Copper: The maximum value was reduced from 0.50% to 0.10% to reflect industry experience and since copper from the tube material adds to copper in the oxide film, which is believed to be deleterious from a corrosion susceptibility standpoint.

- Sulfur: The maximum sulfur content was reduced from 0.010% to 0.003% to reflect industry practice, since sulfur is known to be deleterious to nickel based alloys, and to tighten the composition range.

- Aluminum: The maximum aluminum content was reduced from 0.50% to 0.40% to reflect industry practice and to tighten the composition range.

- Boron: The maximum boron content was reduced from 0.007% to 0.005% to reflect industry practice and to tighten the composition range.

- Titanium: The maximum titanium content was reduced from 0.50% to 0.40% to reflect industry practice and to tighten the composition range.

Material chemistry is required to be determined for each heat from the ladle or remelted ingot. In addition, one check analysis is required for each heat using material from the final tubing. This serves to verify that nothing in the processing resulted in deleterious changes in the chemistry. In general, chemistry variations from lot to lot are expected to be small, and to not warrant chemical analysis for each lot. However, the option is provided for the Purchaser to require chemistry to be determined for each lot.

The option has been provided for use of "alternate qualified methods" when performing chemical analyses since a variety of methods are being used with satisfactory results, in addition to those listed in early draft EPRI specifications (1 and

2.24). The intent is that the Supplier shall have test results available to verify that the methods used are, in fact, qualified.

3.4 Mechanical Properties

The room temperature yield strength value of 40 ksi was retained to be consistent with Code Case N-20-3. In this regard, having as low a yield strength as practical consistent with other design requirements is considered desirable from an SCC resistance standpoint. As discussed in the 1991 Guidelines (31), there was some consideration given to raising the minimum value to about 42 ksi to provide increased leak before break protection. However, this approach was not adopted here for the following reasons:

- The increased corrosion resistance of alloy 690 as compared to alloy 600 results in a reduced need for leak before break protection.
- It is considered that minimizing susceptibility to corrosion (by use of a lower strength alloy) is more important than leak before break considerations.
- Plant experience with leakage rates of SCC cracks indicates that leak rates are often much lower than expected based on tests. This tends to invalidate the leak before break approach.

The room temperature UTS value was revised in 1999 from 80 to 85 ksi to be consistent with SB-163, and to still meet the 80 ksi limit of Code Case N-20-3. Alloy 690 routinely meets the 85 ksi value with substantial margin..

It should be noted that Code Case N-20-3, Table 4, implies that material with a room temperature yield strength of 40 ksi is expected to have a 650°F yield strength of 35.2 ksi, and the Code Case requires that the 35.2 ksi value be used for analyses. However, alloy 690 material with a 40 ksi room temperature yield generally does not have a 35.2 ksi yield strength at 650°F, but rather a significantly lower value. For example, Table Y-1 of Section II-D of the ASME Code indicates that alloy 690 with a 40 ksi room temperature yield strength will have a 650°F yield strength of 30.9 ksi. The Code Case does not require material to be tested to show that the 35.2 ksi value is met, but does state that it should be used in analyses. Meeting a high temperature minimum yield strength of 35.2 ksi is not desirable since it would require having a minimum room temperature yield strength of about 45 or 46 ksi. Assuring this high a minimum yield strength would probably require lowering the mill anneal temperature, which is undesirable from a corrosion resistance standpoint. It is understood that a new Code Case is in the process of being issued and that it will use updated elevated temperature values consistent with current production.

The maximum yield strength value of 55 ksi (379 MPa) was selected to keep the yield strength range as tight as practical (13 ksi - 90 MPa) while still allowing a minimum yield strength of 42 ksi (290 MPa) to be used, if desired for leak before break reasons. A tight range between minimum and maximum yield strength values is desired since it ensures a high degree of uniformity in the tubing. Keeping the yield strength within a 13 ksi (90 MPa) range was found to be practical during manufacture of tubing for Ringhals 2 replacement steam generators (7). In addition, Sandvik and Valinox indicated that a 13 ksi (90 MPa) range can be met (17 & 18). Staying within this range is facilitated by keeping the carbon content within tight limits, as specified in Section 3.3.

Hardness requirements are not included. This is based on the consensus of people working on alloy 690 that taking hardness measurements does not serve a useful purpose. Assurance that the tubing has the desired mechanical properties is provided by the specified tensile property tests. In addition, the flare test performed on each tube length provides assurance that excessive hardening has not occurred.

3.5 Cleaning

3.5.1 In-process Cleaning

The requirements in this section ensure that harmful contaminants (e.g., sulfur) are not incorporated into the material during processing. This subject is further discussed in Section 5.

3.5.2 Demineralized Water

Water quality requirements are based on information provided by Duke Energy (34), and are considered to be consistent with standard industrial practice. Requirements for periodic checking and continuous conductivity monitoring are included to provide assurance that the water meets purity requirements.

3.5.3 Grit Blasting

Requirements for grit blasting are included, and grit blasting is permitted prior to thermal treatment. However, tube suppliers indicate (17 & 18) that grit blasting of the ID results in a surface roughness that is marginal with respect to meeting the RMS 20 microinches (0.5 micrometers) value specified in Section 3.8 for 90% of the tubes, though it is compatible with the 63 microinch (1.6 micrometers) value allowed for up to 10% of the tubes. Accordingly, the specified ID requirements are compatible with use of grit blasting as a repair method for limited amounts of tubing, but may not be with grit blasting the ID of all tubes. See section 3.8 for a discussion of the reasons for the ID surface roughness requirements.

Grit blasting is prohibited after thermal treatment, unless special qualification tests are performed to show that it results in low tensile stresses, since it could introduce undesirable stresses or superficial cold work.

Use of aluminum oxide grit was prohibited in the EPRI alloy 600 specification (1) and SGOG alloy 690 specification (2.24). It is understood that the reason for this prohibition is concern that embedded grit particles could be left in the tubes, and that they would be more deleterious in the reactor coolant system if they were aluminum oxide than if they were zirconia. Both Sandvik and Valinox indicated (17 & 18) that zirconia performs satisfactorily, and can be used if desired.

3.5.4 Acid Cleaning

Acid cleaning is permitted prior to final reduction to size since acid cleaning is generally necessary after hot working steps to remove scale. Acid cleaning is not permitted after final reduction to size (which is performed cold) because of concerns that it could lead to grain boundary ditching, which would be deleterious in regard to corrosion resistance.

Selection of the acid cleaning solution is left to the Supplier, but is subject to qualification to ensure that it does not result in grain boundary ditching.

Valinox requested that the Guidelines be revised to permit use of acid cleaning after final cold reduction but prior to final mill annealing as long as it is properly qualified and monitored, i.e., demonstrated by process qualification to not result in grain boundary etching or other deleterious attack on a range of microstructures, and shown by periodic metallurgical examination to not have attacked in-process material. Valinox indicates that acid cleaning would provide some technical and economic advantages. In addition, they indicate that with alloy 690 the concerns that developed with acid cleaning of alloy 600 (grain boundary etching) are not applicable since alloy 690 is highly resistant to acids. During the July 22-23, 1998 review meeting, the review group recommended that the change not be accepted at this time, since no qualification test data have been provided (34). In other words, if Valinox or others want to have the Guidelines revised to accept acid cleaning after final cold reduction, they first need to perform qualification testing and provide the qualification data to EPRI for review.

3.6 Tube Heat Treatment

3.6.1 Final Anneal

The minimum temperature for final mill annealing was changed from the 1940°F (1060°C) value in the 1991 Guidelines to 1958°F (1070°C). Testing indicates that final mill anneal over 1958°F (1070°C) is required to assure optimum corrosion resistance in high temperature CERTs in caustic (33). All tube suppliers indicate that a minimum temperature of 1958°F (1070°C) is satisfactory. In addition, it is believed that all alloy 690 tubing supplied to US utilities has been mill annealed at temperatures above the new 1070°C minimum.

The temperature range limit of 36°F (20°C) is intended to ensure that material heat treatment does not vary significantly from tube to tube or along the length of the tube. Excessive variations in mill annealing temperature could significantly affect mechanical properties, microstructure and corrosion resistance. The requirement was modified to clarify that the 20°C (36°F) temperature difference between hottest and coldest tubes applies to a single lot, and not to all tubes in a bundle. This does not change the original intent, which was to limit the temperature variation of tubes with the same composition and processing history. In addition, Valinox indicated that they adjust their furnace temperature based on the heat's carbon content. They indicate that, if the 20°C (36°F) limit is applied to all material in a tube bundle, they would need to limit carbon content to a tighter band.

The furnace gas conditions are required to result in bright annealing with no significant surface discoloration, carburizing, etc. Use of physical standards for judging the acceptability of the bright annealing is understood to be standard practice (18). The use of reference photomicrographs for judging the acceptability of carburization, decarburization, and nitriding is considered necessary to provide enforceable standards; since there are no industry-wide accepted reference photomicrographs, the Supplier is required to develop them for Purchaser acceptance.

The temperature recording requirements are directed at providing a record that demonstrates that uniform mill anneal temperatures were obtained.

Requirements on cooling rate were included in earlier draft specifications. These were primarily directed at controlling carbides in the microstructure. Cooling rate requirements were not included in the 1991 and later versions because it has been found that thermal treatment is the main control on carbides, and since the slower carbide precipitation kinetics in alloy 690, as compared to alloy 600, make it impractical to achieve the desired microstructure by cooling rate control (18).

3.6.2 Thermal Treatment

The minimum thermal treatment time was increased in 1999 from 5 to 10 hours, with no change in temperature. This change reflects current industry practice. In addition, it is in the right direction for increasing resistance to IGSCC in caustic tests. Tube suppliers indicate that 10 hours is acceptable.

The temperature range specified for thermal treatment, 40°F (22°C), was selected consistent with comments from Sandvik and Valinox (17, 18). Both tube suppliers indicated that a tighter range, such as 25°F (14°C), was too tight to be practical, and that they had performed tests that demonstrate that larger variations of thermal treatment temperatures result in acceptable microstructure and other properties.

The maximum time at thermal treatment temperatures is set at 35 hours to ensure that excessive thermal treatment plus stress relief does not place the tubing in an unqualified condition, i.e., a condition which has not been thoroughly qualified by test.

3.6.3 U-bend Stress Relief

A U-bend stress relief of 2 hours at 1320°F (716°C) minimum is specified for smaller radius U-bends. General experience with many alloys indicates that high residual stresses associated with small radius bends increase the risk of stress corrosion cracking.

3.7 Straightening and Grinding

The limit on increase in yield stress from straightening ensures that excessive cold work is not introduced by the straightening. In 1999, the limit was increased from 11.6 ksi (80 MPa) to 13.1 ksi (90 MPa). Increasing the allowed amount of strengthening from 80 to 90 MPa reflects the fact that the higher mill anneal temperatures currently being used result in lower as-annealed yield strengths, and thus that a small amount of additional strengthening is sometimes desirable. In addition, there is no known deleterious effect of strengthening at the 90 MPa level as opposed to the 80 MPa level.

A requirement was added in 1999 to check the amount of strengthening at least once per lot. Sandvik indicated that this frequency is reasonable. This frequency, together with the requirements to check each time the equipment is adjusted, seems sufficient to ensure that excessive strengthening is not occurring.

A ground outer surface is specified to obtain a known condition which, after thermal treatment to reduce stresses, has been shown by extensive testing to be compatible with good corrosion behavior. The amount of grinding specified as a minimum, 0.0004 inches (0.01 mm), is based on recommendations received from Valinox (18). Valinox indicated that 0.0004 inches (0.01 mm) grinding has been shown to reliably remove surface imperfections formed by tube manufacture, and is consistent with standard French practice. In addition, Valinox indicated increasing the amount of material removed makes it more difficult to maintain smoothness, as well as increasing costs.

INCO indicates (10) that they do not consider grinding to be necessary as long as a defect free surface is obtained by the manufacturing method used. While this position appears to be reasonable based on technical considerations, the lack of experience with unground outer surfaces is considered to make it unwise to delete the requirement for grinding.

A requirement was added in 1999 that residual stresses associated with grinding be shown to not result in stresses higher than 20 ksi (138 MPa) tensile, measured before thermal treatment. This requirement was added to take advantage of the position taken by vendors that properly controlled grinding results in compressive or low tensile stresses. It also ensures that grinding stresses will be negligible after thermal treatment, since thermal treatment is expected to significantly reduce the stresses caused by the grinding.

No grinding or machine straightening is permitted after final thermal treatment to assure that residual stresses and cold work in the final tube are minimized (see end of Section 3.8 for a discussion regarding final full surface buffing). Local manual straightening is permitted, as long as the radius of the bend is greater than that for U-bends for which stress relief is required.

3.8 Defects and Surface Requirements

The requirements in this section regarding defects and outer surface roughness are standard ones from earlier alloy 600 and 690 specifications (1 and 2.24), except that use of physical standards is required as a basis for evaluating the acceptability of surface defects caused by manufacturing. The use of physical standards is considered necessary because of the difficulty of quantifying in words exactly what is acceptable in regard to scratches, minor laps, minor tears, etc.

The roughness limit of 20 microinches (0.5 micrometers) for the inner surface is tighter than the 63 microinch (1.6 micrometer) value in earlier SGOG and EPRI specifications. The tighter value is used since a smoother surface reduces corrosion product release rates and since it was found to be practical by SSPB (6 and 12). Allowing 10% of the tubes for a steam generator to have an ID surface roughness of 63 microinch (1.6 micrometer) is the result of tube supplier comments (17,18) to the effect that, in order to allow use of grit blasting as an occasional repair method, it is necessary to allow the higher surface roughness on the repaired tubing.

Defect removal after thermal heat treatment is limited to hand polishing using abrasive materials (e.g., abrasive paper or Scotch Brite), unless alternate methods are qualified, in order to ensure that residual stresses associated with defect removal are low. Qualification of alternate local repair methods is required to show that residual stresses developed by the method are compressive. This is a change from the 1991 version, which limited stresses to 20 ksi tensile (138 MPa). The change was made since tensile stresses are undesirable from a corrosion resistance standpoint and since tube suppliers indicate that it is practical to require compressive stresses.

In 1999, the words "smoothly blended" were replaced with "blended uniformly" to make the wording consistent with the ASME Code, Section III, NB-2558, and also to minimize the amount of material that needs to be removed when a surface imperfection is polished out. This is intended to minimize the number of rejectable MBM signals and reflects the fact that the amplitude of ECT signals increases as the amount of material removed increases. In addition, for shallow imperfections of the kind permitted by the Guidelines, the benefit in terms of stress concentration factors and resulting peak stresses at blended areas of "smooth blending" versus "blended uniformly" is judged to be insignificant.

The prohibition on local repair after thermal treatment of the tube in the region from the design point of contact with the tube sheet $\pm$ 3 inches is directed at preventing cold work of the OD surface at the location where the expansion transition will be located, and also in the sludge pile region. Expansion transition strains would result in high residual stresses if the strains occurred in a region where the surface had been cold worked, since cold work increases the yield stress. The high stresses that could occur in cold worked material, together with the cold work itself, would significantly increase susceptibility to SCC.

An approach that has been used for several recent tubing orders in Europe to address MBMs and other surface indications such as scratches, and has been used for all Japanese plant alloy 690 steam generators, is to perform final full surface buffing (FFSB) after thermal treatment. This process involves machine buffing of the full length of straight tubes after thermal treatment using Scotch Brite. In Europe it has involved removal of about 1 to 3 μm of material, while in Japan it has involved removal of about 20 μm from the diameter. Sandvik and Valinox both report that it results in compressive residual stresses on the straight tubes. Valinox reports that SCC tests done with boiling magnesium chloride of Type 316L stainless steel samples show that it has no effect on the number of cracks developed in row 9, 10 and 11 U-bends, nor on SCC of hard roll or hydraulic expansion transitions (all buffed and unbuffed hard rolled specimens cracked and no hydraulically expanded specimens cracked). However, some concerns remain that the increased cold work and higher post-deformation tensile residual stresses at expansion transitions and U-bends could increase susceptibility to SCC under field conditions. In addition, the cold worked surface layer might possibly increase susceptibility to corrosion of straight tube regions, e.g., in sludge piles and at tube supports. It is considered that additional qualification testing should be performed, with satisfactory results, before the method is included in the Guidelines.

3.9 Cleaning After Final Thermal Heat-Treatment

The cleaning requirements in this section reflect actual mill practice, i.e., solvent wiping of the OD and blowing with solvent soaked lint free plugs.

3.10 Bending

Prohibition against use of metal mandrels and allowing use of cylindrical plastic mandrels is based on experience with alloy 600 U-bends. Bends made with metal ball mandrels have exhibited increased susceptibility to primary water stress corrosion cracking (apparently as result of damage and residual stresses at the inner surface), while U-bends made with plastic cylindrical mandrels have performed better.

4.0 Acceptance Criteria And Tests

4.1 Surface Requirements

Reference has been made to Sections 3.8 and 6 for surface requirements in order to not unnecessarily duplicate requirements.

4.2 Metallographic Evaluation

Metallographic evaluation is a standard requirement for alloy 600 and alloy 690. Since thermal treatment can strongly affect carbide precipitation, metallographic evaluation must be performed on material in the final thermally treated condition in order to assure that tests for carbide microstructure are meaningful.

4.2.1 Microstructural Evaluation

A requirement to perform a microstructural evaluation is included since extensive testing has shown that the carbide microstructure has a strong influence on the caustic SCC resistance of the tubing.

A requirement to minimize carbide banding was added in 1999 based on concerns expressed by some utilities that carbide banding leads to undesirable non homogeneity. However, EPRI and DEI know of no cases where carbide banding has led to unacceptable performance of alloy 600 or alloy 690 tubing. For this reason, an absolute prohibition on carbide banding was not included.

A requirement that the fields used for evaluation of microstructure be randomly selected was added in 1999 to ensure that the fields evaluated are representative of the material, and not biased by selection of fields with better than average microstructure.

A requirement was added in 1999 to evaluate the microstructure at the OD surface to verify that the surface layer of recrystallized grains is minimized. A recrystallized surface layer typically is produced during thermal treatment, and it probably does not have optimum carbide decoration. The typical thickness of this layer is about 3 to 10 μm. The intent of this paragraph is to limit the depth of the layer so that its adverse effects on susceptibility to SCC are minimized.

Use of the bromine-methanol or glyceregia-hot oxalic acid etching methods was suggested in the 1991 Guidelines based on reports of good results (30). However, some problems have been experienced with the bromine-methanol etching technique, as documented in technical articles by Sandvik (36). Sandvik has developed an alternate etching technique (HCl swabbing followed by an HCl-alcohol electrolytic etch) which they suggest be used. Use of alternate techniques is considered acceptable as long as they are appropriately qualified.

4.2.2 General and Intergranular Attack

This section requires that examination of transverse sections of the tubing not reveal evidence of general corrosion or intergranular attack (IGA). Experience has shown that properly made tubing does not show evidence of such attack. Further, many years of testing of alloy 600 have shown that grain boundary ditching significantly increases susceptibility to pure water SCC, and it is believed that grain boundary ditching of alloy 690 would similarly increase its susceptibility to SCC and IGA.

During visits with tube suppliers, they suggested that transverse samples only be required for preproduction lots, and not be required for production lots. However, the review group at the July 22-23, 1998 meeting considered that transverse specimens should be tested for each lot as a quality control check (34).

4.2.3 Grain Size

An upper limit on grain size (ASTM 5) is imposed since very large grains are undesirable from a fatigue resistance standpoint. In addition, if the grain size approaches that of the wall thickness, concerns arise that the grains could result in excessive anisotropy and that the grain boundaries could present a relatively easy through thickness path for corrosion attack. Large grains are also undesirable since they could make the tubing more difficult to inspect by ultrasonic means; this consideration limits grain size to a maximum of about ASTM 5 (17, 18).

A lower limit is not imposed on grain size since requirements for mechanical properties provide sufficient controls to ensure an acceptable product. In this regard, it should be recognized that very small grains are undesirable since they indicate that the mill anneal temperature was not high enough to dissolve all carbides; this would make it probable that insufficient carbon was put into solution by the mill anneal to properly decorate grain boundaries during thermal treatment. However, such a condition is prohibited by the upper limit imposed on yield strength, which is not compatible with very fine grains. In addition, microstructural checks to verify proper carbide decoration of grain boundaries provide further protection against such conditions.

A requirement that the average grain sizes of the lots for a tube bundle be within a spread of two ASTM units was added in 1999 and is directed at ensuring that the tube material be as homogeneous as practical.

Grain size is required to be determined and recorded since knowing the grain size is often useful in later evaluations of metallurgical or corrosion questions.

4.2.4 Inclusions

Requiring low inclusion contents in high nickel alloys has become standard practice, though there is no known correlation between microcleanliness and steam generator tube performance. The listed limits given in the 1991 Guidelines and the testing method (Method A) were based on INCO recommendations (10) and industry input (26).

In 1999 the limits on titanium carbonitride inclusions were tightened to reflect current commercial practice and also in response to utility desires to have as uniform and clean a product as practical. The limits for oxides and sulfides were not changed.

A requirement that the evaluation of inclusions be performed using fields that are selected randomly in the designated areas (edge and mid radius) was added in 1999 and is intended to ensure that the fields evaluated are representative of the material, and not biased by selection of fields with better than average inclusions.

A suggestion was added in 1999 that "aim" values be considered. The reason for this suggestion is that use of reduced specifications and aim values can help ensure against a dirtier material being produced than previously provided by the specific supplier or to improve cleanliness and homogeneity.

4.2.5 Embedment of Grit

The requirement to inspect metallurgical samples at a magnification of 60x for grit embedment is included to assure that the prohibition against grit embedment in 3.5.3 is met. Laborelec (24) noted that, during development work for shot peening of roll transitions, they found that it was necessary to use much higher magnifications than 60x to find embedded ceramic fragments. In fact, they found use of an SEM to be necessary. However, the shot peening experience is not considered directly applicable to grit blasting of tubing since the shot peening involved perpendicular impingement of the ceramic shot, while grit blasting of tubing involves low angle impingement. The "gentler" nature of grit blasting is evidenced by the absence of significant compressive layers from grit blasting, while shot peening develops a compressive layer of about 4 mils thickness. Because of the gentler nature of the grit blasting, embedment of small particles is not considered likely. Support for this conclusion is the absence of any reports of problems due to grit embedment. Accordingly, the use of a quick check with a stereo microscope, as opposed to a detailed SEM examination, is considered sufficient.

4.2.6 Surface Condition

This section requires one sample per lot to be examined using a stereo microscope to verify that the surface conditions specified in 3.8 are met. The intent is that the observed surface be compared to physical standards that have been agreed upon between the Supplier and Purchaser to ensure that conditions such as excessive scratching, draw marks, etc., are not present.

1991 issue 4.3 - Sensitization Tests

Requirements for sensitization tests were deleted in 1999. All of the tube suppliers indicate that sensitization tests of alloy 690 are meaningless and provide no useful information. This is a result of the high chromium content of alloy 690. In addition, research (2.14) indicates that sensitization is not a real concern with alloy 690. This is attributed to the high chromium content of alloy 690 (about 30%), which makes local grain boundary chromium depletion to sensitization levels unlikely.

4.3 Mechanical Properties, Expansion, and Hydrostatic Tests

The tensile, flare, and hydrostatic test requirements listed are standard ones used for steam generator tubing. The tensile test, of one sample per lot, verifies that mechanical properties meet specification requirements. The flare test checks for ductility and for freedom from defects that can cause tube splitting. The hydrostatic test verifies the absence of through wall defects and of defects that seriously reduce tube burst strength. The pressure specified for the hydrostatic test is that required by the supplementary requirements of SB-163 for U-bent tubes. This pressure is also appropriate for straight tubes because of the relatively high minimum yield strength of 40 ksi (276 MPa).

The optional bending test included in earlier draft specifications was deleted because it served no clearly defined purpose. Ductility is checked by the tensile test and by the flare test and, thus, the bending test is not required for ductility confirmation purposes.

5.0 Prohibited And Detrimental Materials

5.1 Prohibited Materials

The prohibited materials are commonly prohibited from contact with nickel alloys because of concerns that they can lead to SCC or other deleterious corrosive attack.

5.2 Detrimental Materials

The 1991 version of this section was taken from the earlier alloy 600 and alloy 690 specifications (1 and 2.24), with minor clarifications. Section 5.2 and Table 2-3 were replaced in 1999 to clarify the requirements and eliminate confusion caused by the wording in the 1991 version.

The limit on sulfur content of fuel is based on the known aggressiveness of sulfur towards nickel base alloys at high temperature. In 1999, the prohibition against use of fuel with high sulfur was clarified to indicate that it only applies if fuel or combustion gases can come into contact with the tube material. This is because there is no technical reason to limit the sulfur content if the fuel or combustion gases do not come into contact with the tube material.

6.0 Quality Assurance Program Requirements

The requirements in this section, except for the requirements in subsections 6.4.3 through 6.4.8, are standard quality assurance requirements taken from earlier specifications (1 and 2.24), with minor modification. The bases for the requirements in 6.4.3 through 6.4.8 are as follows.

6.4.3 Ultrasonic Tests (UT)

Standard ASME Code inspection requirements are invoked. However, the ASME Code does not require axial UT of small diameter tubing. Since axial UT is desirable to verify the absence of circumferentially oriented defects, it has been added as a requirement. In addition, detailed requirements regarding reference specimens are added to ensure that the UT is sensitive to the types of defects of concern in steam generator tubes.

The reference specimen notch depth for UT examination required by the ASME Code (NB-2552 in Section III) is 0.004 inches. However, a 0.003 inch depth has been used for some recent orders and is achievable. Keeping surface defects as small as practical is desirable for both corrosion resistance and inservice inspection reasons. Accordingly, utilities may want to consider use of the smaller notch.

6.4.4 Eddy Current Tests (ECT) Per Section III

Standard ASME Code inspection requirements are invoked, with some minor tightening of calibration notch dimensions to reflect current practice (21, 25)). The reference specimen notch depth for ECT examination required by the ASME Code (NB-2554 in Section III) is 0.004 inches. However, a 0.003 inch depth has been used for some recent orders and is achievable. Keeping surface defects as small as practical is desirable for both corrosion resistance and inservice inspection reasons. Accordingly, utilities may want to consider use of the smaller notch. On the other hand, a utility recently evaluated use of a 0.003 inch notch from a cost - benefit standpoint, and concluded that it was not warranted (34).

6.4.5a Eddy Current Tests - Inservice Inspection Type

The intent of this inspection is to ensure that tubes in the final condition are inspected using field type equipment and procedures and, when so inspected, have a minimum number of ECT signals, such as MBMs, roll restart signals, and U-bend end signals, that will require follow-up during inservice inspections. The purchaser may wish to define more restrictive criteria to minimize future inspection requirements. However, achieving low numbers of such signals may result in some increased cost, necessitating taking cost vs. benefit tradeoffs into account. Accordingly, it is left to the Purchaser to determine the specific technical requirements to be met, including the number of MBMs and other anomalous signals that are acceptable.

6.4.5b Eddy Current Tests for Signal to Noise Ratio

The control of tube noise introduced during tube manufacturing is important. If it is not adequately regulated, inservice inspection capability can be degraded. Excessive noise can:

- Mask small amplitude eddy current signals resulting in the non-detection of tube wall degradation.
- Require a decrease in the plugging limit because of excessive sizing error.
- Cause a forced outage due to masking or incorrect sizing of small amplitude indications from a repairable defect.

Controlling the tube noise is particularly important for pilgered tubing. The use of pilgering for final reduction during tube manufacturing, rather than drawing, can cause larger tube inner diameter variations which are readily sensed as background noise during eddy current inservice inspections. This noise is characteristic of the pilgering process and is often referred to as "pilger noise." While tubing manufacturers have made significant progress in reducing pilgering noise, it still tends to be higher than that of drawn tubing.

Tube noise level is controlled by specifying a minimum acceptable (S/N) ratio. It is considered that a (S/N) of 3:1 is adequate for defect detection, but that a higher value, e.g., 10:1 or higher, is required for defect sizing and characterization, with 15:1 or better being desirable. Recent tube manufacturing experience has shown that 15:1 is achievable for any fixed 0.5 meter length of any tube (straight portions), and this value was therefore included in the 1999 revision of these Guidelines. However, the purchaser may wish to specify in their purchase order that the (S/N) criteria be defined over a length shorter than the 0.5 meter specified to reduce ECT (S/N) signals during inservice inspections.

The reference signal amplitude used to calculate (S/N) shall be established using an inside diameter (ID) differential bobbin coil probe and a calibration tube containing four (4) through-wall holes spaced 90° apart in the same plane. The calibration tube shall be representative of the production tubing and the through-wall holes shall meet the dimensions and tolerances shown in Figure 3-1. An ID bobbin coil will provide the most reliable measurement of (S/N) and is the recommended method; however, an outside diameter (OD) encircling coil may be used if adequate correlation ($r \geq 0.8$) between external and internal (S/N) measurements has been demonstrated.

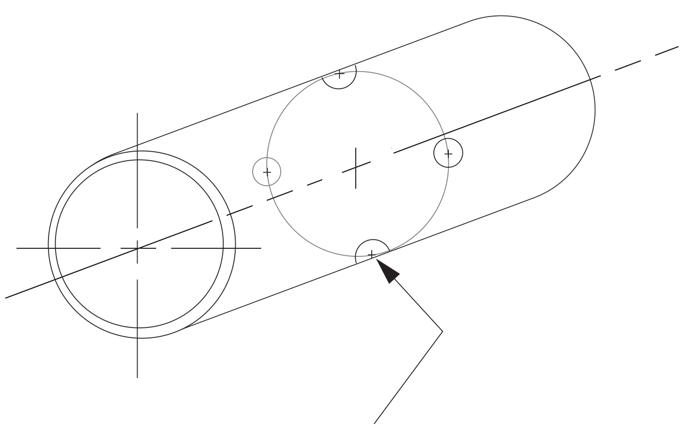

Figure 3-1
Calibration Hole Dimensions

Table 3-2 specifies (S/N) requirements as a function of eddy current test frequency measured using an ID differential bobbin coil. Measurement of (S/N) ratio need only be accomplished at a single frequency within the frequency range specified in Table 3-2 for a given wall thickness. Figure 3-2 can be used to determine acceptable (S/N) values for test frequencies not explicitly stated in the table.

Table 3-2
Alloy 690 (S/N) Ratio Requirements[1]

OD	Wall Thickness	Ref. Hole Diameter	Minimum (S/N), at Indicated Frequency (KHz)					
in. (mm)	in. (mm)	in. (mm)	100	240	400	550	650	750
5/8(15.9)	0.037 (0.94)	0.026 (0.66)				19:1	17:1	15:1[2]
11/16 (17.5)	0.040 (1.02)	0.026 (0.66)			20:1	17:1	15:1[2]	
3/4 (19.1)	0.043 (1.09)	0.026 (0.66)		21:1	18:1	15:1[2]		
7/8 (22.2)	0.050 (1.27)	0.033 (0.840)	21:1	18:1	15:1[2]			

(1) The (S/N) shall meet the indicated value for any fixed 0.5 meter length of any tube (straight portions).
(2) For a given wall thickness, the upper basis frequency is the highest frequency listed in the table.

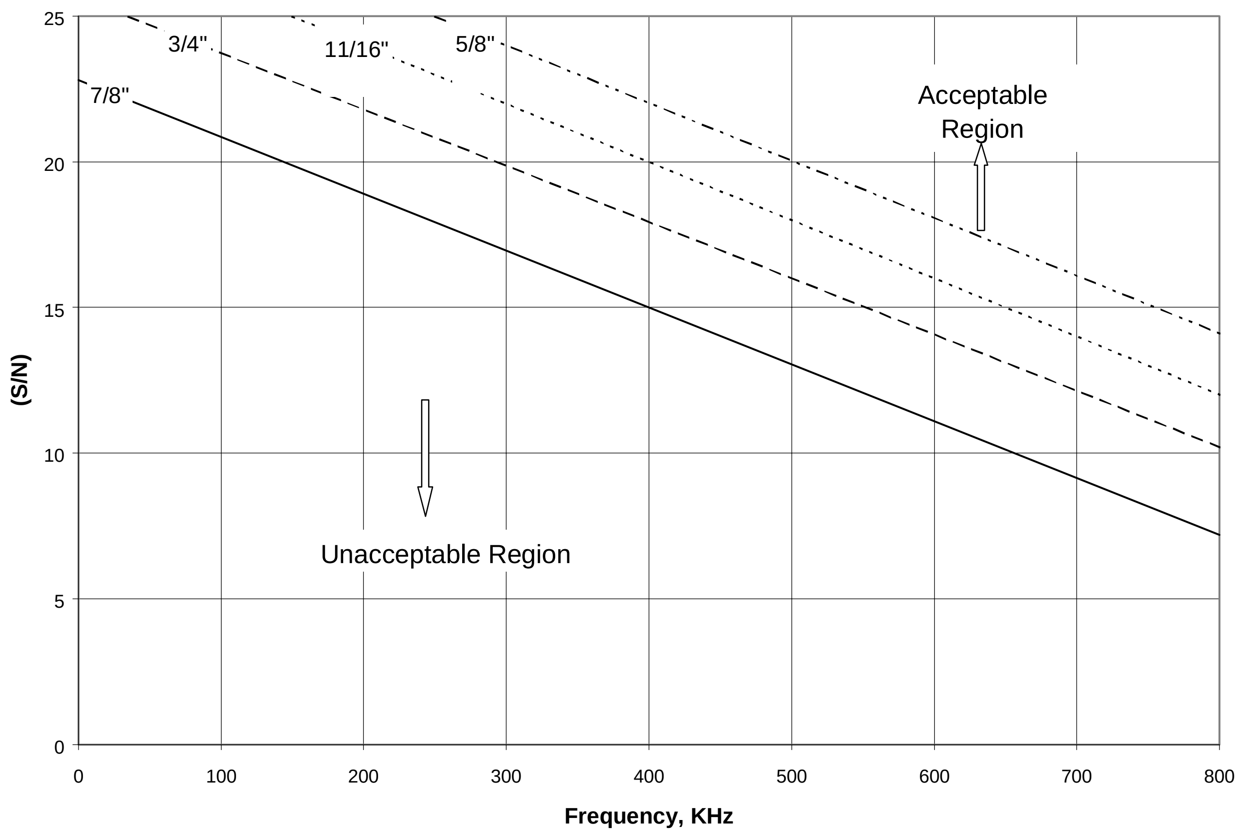

Figure 3-2
Alloy 690 (S/N) Ratio Requirements - Graphical Representation

All tubes shall be tested along their full length and the results shall be permanently recorded and provided to the Purchaser as part of the Certified Material Test Report (CMTR). The tubes shall be tested after straightening and OD polishing and may be tested before or after thermal treatment. If tested after bending, the results for the full length shall be recorded, but only the results for the straight portions need to meet the requirements of this Section. Requirements for bent portions should be established by discussion between the Purchaser and Supplier and specified in the purchase order.

6.4.6, 6.4.7, and 6.4.8 Visual Inspection, Dimensional Inspection, and Surface Roughness Checks

These requirements are intended to ensure that specification requirements in these areas are met. The specification, in many cases, requires that purchaser order requirements be met, in lieu of specifying detailed technical requirements. The reason for taking this approach is that the inspection requirements depend strongly on steam generator design and manufacturing methods, and thus cannot be specified until the steam generator manufacturer has been selected and design finalized.

7.0 Shipment

The requirements in this section are standard ones and are taken from earlier alloy 600 and 690 specifications (1 and 2.24), except that:

- Reference to MIL-STD-129 has been deleted and replaced with brief requirements for marking.
- The requirement to individually package each tube has been made a Purchaser option. Neither the SSPB nor French specifications (6 & 11) require individual tube packaging. Also, while sleeving provides additional protection against contamination of surfaces, it also could lead to some potential for condensation.
- A requirement has been added for the Supplier to submit a packaging procedure for Purchaser approval.
- The requirements for information to be included on the tag for each tube have been simplified.

8.0 Ordering Requirements

The requirements in this section are standard ones and are taken from earlier alloy 600 and 690 specifications (1 and 2.24), with minor changes to reflect other changes in the specification.

9.0 Supplementary Requirements

Supplementary Requirements S1 and S2 of SB-163 are required by the ASME Code for high strength and U-bent tubes. The other supplementary requirement in SB-163 (S3) is judged to not be applicable.

Supplementary requirement 9.1 in Section 9 for bent tubes has been retained from earlier specifications (1 and 2.24). The requirements for stress relief in the earlier specifications have been deleted since mandatory requirements have been added to 3.6.3. In 1999, the requirements for ovality were tightened from the 5% value in the 1991 version to 3%, except for row 1 of 7/8" diameter tubes, to reflect current industry practice.

Supplementary requirement 9.2, covering product (check) analyses of chemical composition for each lot (in addition to ladle analyses and check analyses of each heat), is included as an option since some organizations (e.g., SSPB (6)) have required analyses for each lot. Other specifications (1, 2.24, and 11) have required only one product analysis per heat, rather than for each lot.

Old (1991 issue) supplementary requirement 9.3, for sensitization tests, was deleted in 1999 since all of the tube suppliers indicate that sensitization tests of alloy 690 are meaningless and provide no useful information. This is a result of the high chromium content of alloy 690.

Supplementary requirement 9.3, covering the type of notch used for ECT, was included at the recommendation of SSPB. It is understood that KWU specified use of a sharp tipped notch, apparently to better simulate the type of defect expected to actually occur in tubing.

Supplementary Requirement 9.4, covering a preproduction qualification run, is included to provide assurance that the specific tube manufacturing parameters and limits to be used for production will result in highly uniform acceptable tubes. The requirements were largely taken from the preproduction run requirements of the SSPB specification (6). The split ring test method was taken from Sandvik's report of the pre-production run for Ringhals 2 (7). In 1999, the requirements for preproduction lots were revised to provide more flexibility to reflect specific situations such as repeat orders, where full preproduction lots may not be warranted. This is to provide for cases such as where an order is essentially identical with the previous order and there is no interruption in manufacturing, and there is less value in having full preproduction lots. Also in 1999, the requirements were modified to indicate that, if the Supplier and Purchaser agree, it is permissible to start production before all preproduction examination and test data are available and analyzed. The reason for making this latter change is to provide for cases where schedule pressure is such that starting production before completion of the evaluation of examination and test data from the preproduction run is worth the risk of having to scrap some material. The level of risk will, of course, depend on how similar the new order is to previous production.

4

REFERENCES

Information used in developing this alloy 690 specification made use of information from the following sources.

1. A. A. Stein (S&W), "Specification for Alloy 600 Steam Generator Tubing," EPRI Research Project S-303-12, Electric Power Research Institute, Palo Alto, CA 94304, final report dated January 1986.

2. C. E. Shoemaker (EPRI), M. Cordovi (INCO), and A. A. Stein (S&W) editors, Proceedings: Workshop on Thermally Treated Alloy 690 Tubes for Nuclear Steam Generators, NP-4665S-SR, Electric Power Research Institute, Palo Alto, CA 94304, July 1986. The presentations in these proceedings were as follows:

   2.1. C. Scarberry et al. (INCO), "Carbon Solubility in Alloy 690."

   2.2. M. Martin (INCO), "Drawing and Annealing Parameters for Inconel Alloy 690 Tubing."

   2.3. Perrat (Framatome) and D. Vuillaume (Valinox), "Selection of Annealing Temperatures for Thermally Treated Alloy 600 and Alloy 690 SG Tubing."

   2.4. Norberg (Sandvik), The Influence of Composition and Heat Treatment on Microstructure and Materials Properties of Sandvik Sanicro 69 (Alloy 690).

   2.5. M. Owens (CE), "Characterization and Comparison of Thermally Treated Alloy 690 and Alloy 600 Steam Generator Tubing."

   2.6. E. Sessions (Westinghouse), "Processing of Alloy 690 Thermally Treated Tubing."

   2.7. L. Nelson and S. Floreen (KAPL), "Evaluation of Alternative Alloys for Tubing in PWR Steam Generators."

   2.8. A. Cordovi (Consultant), "The Corrosion Resistance of Alloy 690 in PWR Steam Generators."

2.9.A. R. J. Jacko et al. (Westinghouse), "An Overview of Laboratory Tests Conducted by Westinghouse to Qualify Alloy 690 Steam Generator Tubing."

2.9.B. R. G. Aspden (Westinghouse), "Metallurgical Etches for Alloy 690."

2.10. Nagano et al. (Sumitomo) and T. Yonezawa et al. (Mitsubishi), "Effect of Alloying Elements and Heat Treatment on the Corrosion Resistance of Alloy 690."

2.11. M. Rentler (CE), Laboratory Corrosion Test Results of Alloys 600 and 690 Steam Generator Tubing Exposed to Faulted Secondary Side Chemistry Environments.

2.12. Yonezawa et al. (Mitsubishi) and H. Nagano et al. (Sumitomo), "Evaluation of the Corrosion Resistance of Alloy 690."

2.13. P. Miglin (B&W), "The Corrosion Performance of Alloys 690 and 600 in High-Temperature Caustic with Contaminants."

2.14. Gimond (Framatome), "The Corrosion Performance of Alloy 690."

2.15. J. Jacko (Westinghouse), "Stress Corrosion Testing of Candidate Steam Generator Tubing Materials."

2.16. B. Lumsden (Rockwell International), "Effects of Oxides on the Corrosion Resistance of Alloys 690 and 600 in High Temperature Caustic."

2.17. A. Page and A. McMinn (SWRI), "Relative Stress Corrosion Susceptibilities of Alloys 690 and 600 in Simulated Boiling Reactor Environments."

2.18. P. Miglin (B&W), "Comparison of SCC Behavior of Alloy 600 to Alloy 690 Steam Generator Tubing."

2.19. Perrat and C. Gimond (Framatome), "Some Steam Generator Fabrication Aspects for Alloy 690 Tubing."

2.20. E. Sessions (Westinghouse), "Wear of Alloy 690 Tubing."

2.21. T. Schoenberg (CE) and F. L. Ko (AECL), "Fretting Wear of Alloy 600 and Alloy 690 Steam Generator Tubing in Simulated PWR Secondary Environments."

2.22. E. Shoemaker (EPRI), "Possible Anisotropy or Texturing in Alloy 690."

2.23. Perrat (Framatome) and D. Vuillaume (Valinox), "Comparison of French Specifications and Fabrication Programs - Alloys 600 and 690."

2.24. A. Stein (S&W), "Proposed SGOG Alloy 690 Steam Generator Tubing Specification - Preliminary Draft."

3. K. Smith (Framatome), A. Klein (Westinghouse), P. Saint-Paul (EdF), and J. Blanchet (CEA), "Inconel 690: A Material with Improved Corrosion Resistance for PWR Steam Generator Tubes,"<u>Second International Symposium on Environmental Degradation of Materials in Nuclear Power Systems - Water Reactors, Sep 1985, Monterey, California</u>, pp. 319 -328, ANS, La Grange Park, Illinois 60525, 1986.

4. J. M. Sarver et al.(INCO), "Effect of Carbide Precipitation on the Corrosion Behavior of Inconel Alloy 690," Paper no. 95, <u>Corrosion 87</u>, March 1987, NACE.

5. K. Norring (Studsvik), J. Engstrom (SSPB), and P. Norberg (Sandvik), "Intergranular Stress Corrosion Cracking in Steam Generator Tubing Testing of Alloy 690 and Alloy 600 Tubes," <u>Proceedings of the Third International Symposium on Environmental Degradation of Materials in Nuclear Power Systems - Water Reactors</u>, TMS, 1988

6. "Specification for Alloy 690 Steam Generator Tubing," SSPB, Appendix 4, Revision 1 (specification used for production of tubing for Ringhals 2 replacement steam generators).

7. P. Norberg and Forsman (Sandvik), "Evaluation of Trial Run Steam Generator Tubing in Sandvik, Sanicro 69 (Alloy 690)," Sandvik, June 9, 1986.

8. T. Yonezawa, et al., "Effect of Heat Treatment on Corrosion Resistance of Alloy 690," <u>Proceedings of Second International Symposium on Environmental Degradation of Materials in Nuclear Power Systems - Water Reactors, Sep 1985, Monterey, California</u>, pp. 593 - 600, ANS, La Grange Park, Illinois 60525, 1986.

9. Not used.

10. Telephone discussions, J. Martin, INCO and J. Gorman, DEI, Feb. 1, 1988 and June 9, 1988, and letter dated July 1, 1988, INCO (J. Martin) to EPRI (A. McIlree).

11. Letter dated Jan. 27, 1988, K. Smith (Framatome) to J. Gorman (DEI), with attached French Specification M4105, and follow-up telephone conversation on Feb. 1, 1988.

12. Letter dated February 4, 1988, I. Multer (SSPB) to J. Gorman (DEI).

13. G. Frederick (Electrobel), P. Hernalsteen (Tractionel), and J. Stubbe (Laborelec), "Roll Expansion Repair Methods Qualification," Research Project S303-27.

14. <u>Huntington Alloys Handbook</u>, 12M 9/80 S-9, Fifth edition, Huntington Alloys, Inc., Huntington, West Virginia, 25720, 1970.

15. Meeting among EdF, Framatome, EPRI and DEI at EdF laboratories, Moret-sur-Loing, France on April 28, 1988.

16. Meeting among SSPB, EPRI, and DEI in Vallingby, Sweden on May 2, 1988.

17. Meeting among Sandvik, EPRI and DEI in Sandviken, Sweden on May 5, 1988.

18. Meeting among Valinox, EPRI and DEI in Montbard, France on May 6, 1988, with followup meeting in Washington on July 6, 1988, and related correspondence.

19. Meeting among EPRI, Laborelec, and DEI at Laborelec, Linkebeek, on April 29, 1988, and several followup telephone conversations between D. Dobbeni (Laborelec) and J. Gorman (DEI).

20. Letter from Mitsubishi to EPRI (T. Yonezawa to A. McIlree) dated October 13, 1988.

21. Letter dated November 10, 1988 from NYPA to EPRI (N. Nilsen to A. McIlree) with marked up specification and with subsequent telephone discussions between N. Nilsen and J. Gorman.

22. Telefax transmittal from Laborelec to Dominion Engineering (D. Dobbeni to J. Gorman) dated December 9, 1988, with followup telephone discussions.

23. Telephone discussions between J. Martin (INCO) and J. Gorman (DEI) and between D. Vuillaume (Valinox) and J. Gorman on December 14, 1988.

24. Telephone discussions between J. Stubbe (Laborelec) and J. Gorman (DEI) on December 9 and 12, 1988.

25. Westinghouse specification B163C05, Thermal Treated Alloy 690 Tubing for Sizewell B Steam Generator, Rev. F., 4/8/87

26. <u>Proceedings: 1989 EPRI Alloy 690 Workshop</u>, EPRI NP-6750-SD, April 1990.

27. K. Yamanaka and T. Yonezawa, "Optimum Time and Temperature of TT Alloy 690," <u>Proceedings: 1989 EPRI Alloy 690 Workshop</u>, EPRI NP-6750-SD, April 1990.

28. D. L. Harrod and R. E. Gold, "Mechanical Properties of Alloy 690 Production Tubing," Proceedings: 1989 EPRI Alloy 690 Workshop, EPRI NP-6750-SD, April 1990.

29. J. R. Crum, et al., "A New Thermal Treatment for Alloy 690," Proceedings: 1989 EPRI Alloy 690 Workshop, EPRI NP-6750-SD, April 1990.

30. D. B. Lowenstein and J. A. Gorman, Microstructure Etching and Carbon Analysis Techniques, EPRI NP-6720-SD, April 1990.

31. Guidelines for PWR Steam Generator Tubing Specifications and Repair, Volume 2: Guidelines for Procurement of Alloy 690 Steam Generator Tubing, EPRI NP-6743-L, Volume 2, February 1991.

32. Notes of Telephone Conversation re Alloy 690 Guidelines Among Rick Eaker, Dan Mayes and Michael Keck (March 17 only) (Duke Energy) and Jeff Gorman (DEI) on March 10 and 17, 1998.

33. P. E. Doherty, et al., "Mechanical/Electrochemical Performance of Alloy 690 Steam Generator Tubing," Proceedings Eighth International Symposium on Environmental Degradation of Materials in Nuclear Power Systems - Water Reactors, p157-166, ANS, 1997.

34. "July 22-23, 1998 Report of Meeting Alloy 690 Guidelines Revision," October 26, 1998.

35. Laborelec document "Possible Effects of Long- and Short-Range Ordering on In-Service Performance of Nickel-Based Alloys Used for Steam Generator Tubes," undated, in EPRI SGPO files.

36. J. Frodigh, "Some Factors Affecting the Appearance of the Microstructure in Alloy 690," Proceedings Eighth International Symposium on Environmental Degradation of Materials in Nuclear Power Systems - Water Reactors, p138-148, ANS, 1997.

WARNING: This Document contains information classified under U.S. Export Control regulations as restricted from export outside the United States. You are under an obligation to ensure that you have a legal right to obtain access to this information and to ensure that you obtain an export license prior to any re-export of this information. Special restrictions apply to access by anyone that is not a United States citizen or a Permanent United States resident. For further information regarding your obligations, please see the information contained below in the section titled "Export Control Restrictions."

Export Control Restrictions
Access to and use of EPRI Intellectual Property is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or permanent U.S. resident is permitted access under applicable U.S. and foreign export laws and regulations. In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI Intellectual Property, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case by case basis an informal assessment of the applicable U.S. export classification for specific EPRI Intellectual Property, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes. You and your company acknowledge that it is still the obligation of you and your company to make your own assessment of the applicable U.S. export classification and ensure compliance accordingly. You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of EPRI Intellectual Property hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

About EPRI

EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

EPRI. Electrify the World

TR-016743-V2R1

Printed on recycled paper in the United States of America

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com