TRANSMITTAL SHEET

REVISION TO

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Review of Safety Analysis Reports
for Nuclear Power Plants"
(LWR Edition)

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Revision No. 1

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NUREG-75/087

U.S. NUCLEAR REGULATORY COMMISSION
STANDARD REVIEW PLAN
OFFICE OF NUCLEAR REACTOR REGULATION

SECTION 5.4.2.1 STEAM GENERATOR MATERIALS

REVIEW RESPONSIBILITIES

Primary - Materials Engineering Branch (MTEB)

Secondary - None

I. AREAS OF REVIEW

General Design Criteria 14, 15, and 31 of Appendix A of 10 CFR Part 50 require that the reactor coolant pressure boundary (RCPB) must have an extremely low probability of abnormal leakage and must be designed with sufficient margin to assure that the design conditions are not exceeded during normal operation and anticipated operational occurrences, and that the probability of rapidly propagating failure of the RCPB is minimized.

A review is made of the following areas reported in the applicant's safety analysis report (SAR). These are all related to the ASME Boiler and Pressure Vessel Code (hereafter "the Code") Class 1 and Class 2 components of pressurized water reactor (PWR) steam generators, including all components that constitute part of the reactor coolant pressure boundary.

1. Selection and Fabrication of Materials

The materials selected for the steam generator are reviewed.

Components of the steam generator are divided into two classes: Class 1, which includes material for those parts exposed to the primary reactor coolant, and Class 2, which includes materials for parts exposed to the secondary coolant water.

The selection and fabrication of materials for all Class 1 and Class 2 components of pressurized water reactor (PWR) steam generators is reviewed for adequacy and suitability and for compliance with the requirements of the Code.

Examples of materials that are currently being used for Class 1 components include the following:

Tubing	-	ASME SB-163, Ni-Cr-Fe, annealed (Inconel 600)
Tube Sheet	-	ASME SA-533, Grade A, weld-Clad with Inconel 600 on the primary coolant side
Channel Head Casting	-	ASME SA-216, Grade WCC, Class 1, weld-clad with austenitic stainless steel
or		

Channel Head Plate	-	ASME SA-533, Grade A, B, or C
Forged Nozzles	-	ASME SA-503, Class 2

Exam,'es of materials that are currently being used for Class 2 components include the following:

Shell Pressure Plates	-	ASME SA-533, Grade A, B, or C, Class 2
Bolting	-	ASME SA-193, Grade B-7
		ASME SA-540, Grade B 23 or B 24
Tube Support Plates or Grids	-	ASME SA-240
		ASME SA-479

The corrosion adequacy and suitability of all materials are reviewed. The fracture toughness properties and requirements for ferritic materials of Class 1 and Class 2 components are reviewed.

2. Steam Generator Design

The design and the fabrication procedures are reviewed to determine that the extent of crevice areas are minimized in the completed steam generators. A "tube denting" phenomenon has occurred in a number of steam generators. Based on operating experience and laboratory testing, it is believed that the denting is associated with the growth of a corrosion product (principally Fe_3O_4) in the crevice. The corrosion is caused by the concentration of steam generator water impurities in the annulus. The growth of corrosion product puts inward pressure on the tube resulting in radial deformation of the tube. As corrosion proceeds and in-plate forces accumulate, there are a number of secondary effects in the steam generator. These include (a) tube support plate hole dilation; (b) tube support plate flow hole distortion, flow slot hour-glassing; (c) tube support plate expansion with cracking between hole ligaments; (d) wrapper distortion; (e) leg displacement of the smallest radius U-bend heat tube, and (f) tube leakage.

The extent of the tube to tube sheet contact and the contact area of the tube/tube support are of particular interest. The reviewer will evaluate the design and material selection used to minimize the support plate corrosion.

The tubes are commonly welded to the tube-sheet cladding and expanded into the tube sheet by rolling or explosive-expanding (explanding). Full depth expansion is the preferred design.

3. Compatibility of the Steam Generator Components with the Primary and Secondary Coolant

The possibility of stress-corrosion cracking, denting, pitting, and wastage of the tubes as determined by the chemistry of both the primary and secondary coolants, are reviewed. The methods to be used in monitoring and maintaining the chemistry of the secondary coolant within the specified ranges are reviewed. The compatibility of austenitic and ferritic stainless steels, ferritic low alloy steels and carbon steels with the primary and secondary coolants is reviewed.

4. Cleanup of Secondary Side

The provisions for access to as well as the procedures and methods for the removal of surface deposits, sludge, and corrosion products from the secondary side of the steam generator are reviewed. These provisions are to supplement the removal of sludge by blowdown.

II. ACCEPTANCE CRITERIA

The acceptance criteria for the areas of review described in Section I of this plan are as follows:

1. Selection and Fabrication of Materials

a. The acceptable materials for steam generator components are those identified and permitted in the ASME Code, Appendix I of Section III, and specified in detail in the Code Parts A, B, and C of Section II. Any materials specified in the design to meet code-case requirements must also meet the requirements given in Regulatory Guide 1.85, "Code Case Acceptability - Materials." Any materials selected for the tube support structure should be justified on the basis of minimizing the denting and corrosion of the tubes.

b. The fracture toughness of ferritic materials used for Class 1 components in the steam generator must meet the requirements of Subarticle NB-2300, Section III of the Code and Appendix G, Article G-2000 of the Code.

c. The fracture toughness properties of the ferritic materials selected for Class 2 components in the steam generator must meet the requirements of Subarticle NC-2300 of the Code.

d. Welding qualification, weld fabrication processes and inspection during fabrication and assembly of the steam generator must be conducted in conformance with the requirements of Section III and IX of the Code.

e. The corrosion-resistant weld-deposited cladding on the tube sheet and on other primary side components must be fabricated and inspected according to the requirements given in Articles I, II, III, and IV, Part QW of Section IX of the Code.

f. The welds between the tubes and the tube sheet must meet the requirements of Section III and Section IX of the Code.

g. Onsite cleaning and cleanliness control should be in accordance with the position given in Regulatory Guide 1.37, "Quality Assurance Requirements for Cleaning of Fluid Systems and Associated Components of Water-Cooled Nuclear Power Plants," and in ANSI N45.2.1-1973, "Cleaning of Fluid Systems and Associated Components During Construction Phase of Nuclear Power Plants."

h. The processing and heat treatment of the steam generator tubing will be evaluated on a case basis. Special heat treatment to improve the corrosion resistance of the tubing should have supporting data.

2. Steam Generator Design
The steam generators must be designed to avoid extensive crevice areas where the tubes pass through the tube sheet, and where the tubes pass through tubing supports, as indicated in Branch Technical Position MTEB 5-3, "Monitoring of Secondary Side Water Chemistry in PWR Steam Generators."

At the tube/tube sheet interface, the tubes should be rolled or expanded for the full depth of the tube sheet to avoid the presence of a crevice. The tube support structure should be designed to promote high velocity flow along the tubes. This will minimize the buildup of corrosion product and sludge in the crevices of the tube/tube support structure.

3. Compatibility of the Steam Generator Tubing with the Primary and Secondary Coolant
The acceptance criteria for primary coolant chemistry are given in Standard Review Plan 5.2.3, "RCPB Materials." The secondary coolant purity should be monitored as described in Branch Technical Position MTEB 5-3.

4. Cleanup of Secondary Side
The steam generators must be designed to provide adequate access to the internals so that tools may be inserted to inspect and clean up deposits, on the tube sheet and on the tube/tube support. Procedures, such as lancing to remove deposits, should be described.

III. REVIEW PROCEDURES

The reviewer will select and emphasize material from the procedures described below, as may be appropriate for a particular case.

For each area of review, the following review procedure is followed:

1. Selection and Fabrication of Materials
The reviewer examines the materials and fabrication procedures as given in the SAR for Class 1 and Class 2 components of the steam generators, to determine the degree of conformance with the acceptance criteria stated in Section II.1, and verifies that information relative to toughness tests is in conformance with the acceptance criteria stated in Section II.1. The reviewer verifies that the tubes are properly welded and expanded into the tube sheet, and that proper care is taken to maintain cleanliness during fabrication, assembly, and installation of the unit.

2. Steam Generator Design
The reviewer examines the design of the steam generators to verify that tight crevice areas where tubes pass through the tube supports and tube plate(s) are minimized, as discussed in Section II.2.

3. <u>Compatibility of the Steam Generator Tubing with the Primary and Secondary Coolant</u>
The reviewer examines the controls to be placed on the composition of the primary and secondary coolants to determine that they meet the acceptance criteria cited in Section II.3.

4. <u>Cleanup of Secondary Side</u>
The reviewer examines the design provisions that allow implementation of the procedures and methods to be used for removal of surface deposits, sludge, and corrosion products from the tube sheet and the tube/tube support areas.

IV. <u>EVALUATION FINDINGS</u>

The reviewer verifies that sufficient information is provided in accordance with the requirements of this review plan and that his evaluation supports conclusions of the following type, which are to be included as applicable in the staff's safety evaluation report:

"The materials selected for use in Class 1 and Class 2 components will be fabricated and inspected in conformance with codes, standards, and specifications acceptable to the staff. Welding qualification, fabrication, and inspection during manufacture and assembly of the steam generator will be down in conformance with the requirements of Section III and IX of the ASME Code.

"The primary side of the steam generator is designed and fabricated to comply with ASME Class 1 criteria as required by the staff. (The secondary side pressure boundary parts of the steam generator will be designed, manufactured, and tested to ASME Class 1 criteria although the staff required classification is ASME Class 2.)*

"The pressure boundary materials of ASME Class 1 components of the steam generator will comply with the fracture toughness requirements and tests of Subarticle NB-2300 of Section III of the Code. The materials of the ASME Class 2 components of the steam generator will comply with the fracture toughness requirements of Subarticle NC-2300 of Section III of the Code.

"The crevice between the tube sheet and the inserted tube will be minimal because the tube will be expanded to the full depth of insertion of the tube in the tube sheet. The tube expansion and subsequent positive contact pressure between the tube and the tube sheet will preclude a buildup of impurities from forming in the crevice region and reduce the probability of crevice boiling.

"(The tube support plates will be manufactured from ferritic stainless steel material, which has been shown in laboratory tests to be corrosion resistant to the operating environment.)* (The tube support plates will be designed and manufactured with broached holes rather than drilled holes. The broached hole design promotes high

*Include material within parentheses as applicable.

velocity flow along the tube, sweeping impurities away from the support plates locations.) (The tube support structure will be manufactured to the egg crate design. The egg crate design eliminates the narrow annular gap at the tube supports, because the support may contact the tube at only four lines on the tube circumference, and provides almost complete washing of the tube surface with steam generator water.)*

"The onsite cleaning and cleanliness controls during fabrication (will)* conform to the recommendations of Regulatory Guide 1.37, "Quality Assurance Requirements for Cleaning of Fluid Systems and Associated Components of Water-Cooled Nuclear Power Plants." The controls placed on the secondary coolant chemistry are in agreement with staff technical positions.

"Reasonable assurance of the satisfactory performance of steam generator tubing and other generator materials is provided by (a) the design provisions and the manufacturing requirements of the ASME Code, (b) rigorous secondary water monitoring and control, and (c) the limiting of condenser in-leakage. The controls described above combined with conformance with applicable codes, standards, staff positions, and Regulatory Guides constitute an acceptable basis for meeting in part the requirements of General Design Criteria 14, 15, and 31."

V. <u>REFERENCES</u>

1. 10 CFR Part 50, Appendix A, General Design Criterion 14, "Reactor Coolant Pressure Boundary," Criterion 15, "Reactor Coolant System Design," and Criterion 31, "Fracture Prevention of the Reactor Coolant Pressure Boundary."

2. ASME Boiler and Pressure Vessel Code, Parts A, B, and C of Section II, Section III, and Section IX, American Society of Mechanical Engineers.

3. ANSI N45.2.1-1973, "Cleaning of Fluid Systems and Associated Components During Construction Phase of Nuclear Power Plants," American National Standards Institute.

4. Regulatory Guide 1.37, "Quality Assurance Requirements of Cleaning of Fluid Systems and Associated Components of Water-Cooled Nuclear Power Plants."

5. Regulatory Guide 1.85, "Code Case Applicability-Material."

6. Standard Review Plan 5.2.3, "RCPB Materials."

7. Branch Technical Position - MTEB 5-3, "Monitoring of Secondary Side Water Chemistry in PWR Steam Generators," appended.

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*Include material within parentheses as applicable.

BRANCH TECHNICAL POSITION MTEB 5-3

MONITORING OF SECONDARY SIDE WATER
CHEMISTRY IN PWR STEAM GENERATORS

A. BACKGROUND

Effective long-term rel[illegible]tion of PWR steam generators requires that operational procedures, design, and [illegible]materials be such that there is no leakage across the steam generator tubes an[illegible]r between the primary and secondary fluids maintains its integrity unde[illegible] stated in General Design Criteria 14, 15, and 31 of Appendix A of 10 C[illegible]

These objectives are general[illegible]g a water treatment to remove impurities from the water, operation procedur[illegible]ove impurities from generators, design of equipment to prevent impurities from ent[illegible]ystem, and design factors to prevent the impurities from concentrating and forming sludges or deposits, especially in crevices.

Less than thoroughly effective water treatment, operational procedures, and design factors have led to the degradation of steam generator tubing. An extensive history of stress corrosion cracking, wastage, and denting of steam generator tubing in operating PWRs, has developed; therefore we recommend the following criteria.

B. Branch Technical Position

1. Crevices between the tubing and the tube sheets or tubing supports should be minimized to prevent concentration of impurities or solids in these areas. Steam generators should be designed and built to achieve this goal.

   To minimize the deposition of corrosion products and sludge between the tubes and the supporting structure, the tube/tube support interface should be designed to promote high velocity water flow at the interface. This will improve the "washing" of this area.

2. Condenser cooling water in-leakage to the condensate has been identified as the major source of impurity ingress in the PWR secondary feedwater. The combination of impurity ingress with corrosion of copper containing alloys and corrosion product transport (Fe_3O_4, SiO_2, etc.) in the secondary water system produces sludge that is difficult to remove and is reactive to steam generator materials.

3. The methods utilized for control of secondary side water chemistry should be described. In plants having more than one steam generator, additives to each steam generator should be controlled separately. Records should be made of the following items, and summaries of the data should be available for report as requested by the Commission.

a. For plants utilizing volatile chemistry:

(1) The composition, quantities, and addition rates of additives should be recorded initially and thereafter whenever a change is made.

(2) The electrical conductivity and the pH of the bulk steam generator water and feedwater should be measured continuously.

(3) For once-through steam generators, the pH and electrical conductivity at the coolant inlet should be measured continuously.

(4) Free hydroxide concentration and impurities (particularly chloride, ammonia and silica) in the steam generator water should be measured at least three times per week.

(5) The electrical conductivity of the condensate should be measured continuously. When the conductivity changes, the cation or anion concentration (as applicable to the specific power plant) should be measured to determine if a condenser leak exists.

(6) When a condenser leak is confirmed, the leak should be repaired or plugged within 96 hours.

b. For plants utilizing phosphate treatment:

(1) The composition, quantity, and addition rate of each additive should be recorded initially and thereafter whenever a change is made.

(2) The Na/PO_4 molar ratio of the secondary coolant should be recorded initially and whenever a change is made.

(3) The electrical conductivity and pH of the bulk steam generator water and feedwater should be measured continuously.

(4) The concentration of suspended/dissolved solids and impurities (particularly free caustic, chloride, silica, and sodium) in the steam generator water should be measured daily.

(5) The concentration of dissolved solids (particularly sodium and phosphate) in the blowdown liquid should be measured once each week.

(6) The rate of blowdown should be recorded initially and whenever a change in rate is made.

(7) The hideout and reverse hideout of phosphate should be recorded. The phosphate concentration in each steam generator (or in one steam generator if this is shown to be representative of all) and in the blowdown liquid should be measured before and after each planned power level change of 10% or greater, and should be measured after each unplanned power level change of 20% or greater.

(8) The electrical conductivity of the condensate should be measured continuously. When the conductivity changes, the cation or anion concentration (as applicable to the specific power plant) should be measured to determine if a condenser leak exists.

(9) When a condenser leak is confirmed, the leak should be repaired within 96 hours.

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16. ABSTRACT (200 words or less)

Revision No. 1 to Section 5.4.2.1 of the Standard Review Plan incorporates changes that have been developed since the original issuance in September 1975, many of which are editorial in nature, to reflect current staff practice in the review of safety analysis reports for nuclear power plants.

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