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WESTINGHOUSE DELTA 75 STEAM GENERATOR DESIGN AND FABRICATION INFORMATION FOR THE VIRGIL C. SUMMER NUCLEAR STATION

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FOREWORD

This document contains information on the Westinghouse Delta 75 steam generator which has been chosen by South Carolina Electric and Gas (SCE&G) as a replacement for the original Model D3 preheater steam generator at the Virgil C. Summer Nuclear Station. As such, information is also provided on the Model D3. This document provides the following information on the Delta 75 and the original Model D3 steam generators:

- Delta 75 and Model D3 General Design Features
- Delta 75 Materials of Construction
- Material and Manufacturing Processes for Tubes, Tubesheets and Support Plates
- Welding Processes Used in Fabrication
- Heat Treatment Process
- Delta 75 and Model D3 Performance and Operational Characteristics

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1.1 GENERAL DESCRIPTION

The Delta 75 is a feedring-type steam generator with the main feedwater inlet nozzle located on the upper shell. The feedwater inlet nozzle azimuthal location on the cold side of the steam generator is the same as the original Model D3 steam generator.

The external and support interface dimensions of the replacement steam generators are essentially identical to those of the current Model D3 steam generators with only minor variations. These variations are attributed to [ ]^{c} The outside diameter of the channel head, tubeplate, and lower shell connection to the tubeplate remain the same as the Model D3. The feedwater inlet and steam outlet nozzle interfaces are designed to pass through the existing Reactor Building equipment hatch and fit within the existing plant equipment and structural layout. The main and emergency feedwater piping will be re-routed to match the feedring-type steam generator. Due to the relocation of the main feedwater inlet nozzle to the upper shell of the unit, the emergency feedwater nozzle and the narrow range water level taps have been angularly relocated on the upper shell to facilitate passage of the one-piece replacement unit through the existing Reactor Building equipment hatch. In addition, the elevation of the upper narrow range water level taps and the narrow range water level span have been increased to maintain high and low level trip response times equivalent to that of the original Model D3 steam generator. The Delta 75 feedring-type unit is compatible with the overall operation of the V. C. Summer Nuclear Station up to and including a thermal power rating of 2912 MWt.

Westinghouse has designed and supplied replacement steam generators for eight operating plants; all utilize features typical of the Model F steam generator. The Delta 75 steam generators utilize the same design features as the Model F design, which has been in operation since 1980, has more than 400,000 tubes in service, and has accumulated more than [ ]^{d} Eighty-four steam generators are presently in operation with Model F features; [ ]^{d} with nearly [ ]^{d} During this period, with nearly [ ]^{d} less than [ ]^{d} of the tubes in these steam generators have been plugged.

The Delta 75 steam generator design embodies the key characteristics of the proven Westinghouse Model F design. Many of the key Model F design features have been incorporated in the Delta 75 while others have been enhanced. The most reliable features carried over from the Model F-type steam generators include the use of [ ]^{c} Alloy 690 tube material, type 405 stainless steel tube support material, broached [ ]^{c} tube supports, hydraulically expanded tubesheet joints, and [ ]^{c} U-bend constructions. These features are described in more detail below.

The use of [ ]c Alloy 690 provides additional corrosion resistance for the tubes. The corrosion resistance has been proven not only by years of laboratory testing, but also in actual plant operation. In 16 years of installing Alloy 690 tube inserts in steam generators and in operating eight Westinghouse steam generators with Alloy 690 tubes, no indications of outer surface or inner surface tube corrosion have occurred.

The nine tube support plates in the Delta 75 steam generators are of the [ ]c broached design and are made of type 405 [ ]a,c stainless steel. The broached tube support plate reduces the tube-to-tube support plate crevice area and permits full steam/water flow in the open areas adjacent to the tube. Another modification is the use of [ ]c geometry, which provides additional dryout margin over a [ ]c contact geometry.

Another Model F feature is the use of [ ]a,c hydraulic expansion of the tubes in the tubesheets to close the crevice with minimal residual stresses. Industry experience indicates that hydraulic expansion results in one of the lowest residual stresses of any tubesheet joint process. Specifically, the [ ]d Westinghouse steam generators manufactured since 1980, with more than [ ]a hydraulically expanded tubesheet joints, show no indications of degradation.

While the early Model F steam generators had [ ]a,c nominal U-bend gaps, more recent Model F steam generators and the Delta series steam generators have [ ]a,c nominal U-bend gaps. This feature, in conjunction with tightly controlled U-bend tubing ovality and retainer ring design, has been proven through analytical assessment to [ ]a,c The square tube pitch arrangement in Model F-type steam generators has been changed to a triangular arrangement in the Delta series to enhance heat transfer area, tube stability and provide additional vibration margin. Laboratory tests indicate tube stability to be [ ]c

The Delta 75 encompasses other enhancements, such as the manufacture of AVBs using [ ]c stainless steel, adoption of a [ ]c AVB configuration, using [ ]c sets of AVBs, and tight control of AVB insertion depth, which provide enhanced AVB performance and additional reliability. Increasing the number of sets of AVBs reduces the number of tubes which are potentially affected by the vibration mechanism to which tube degradation has been attributed in some conventional steam generators. Adoption of the other features reduces wear potential of the small number of tubes which could be affected by more than a factor of twenty based on classical wear theory.

An increase in the number of primary separators from 12 in the Model D3 and 16 in the Model F to [ ]c in the Delta 75 steam generator enhance moisture separator performance. Refer to Section 1.11 for more details on the moisture separator features.

The Delta 75 utilizes [ ]a material similar to the most recent Model F type replacement steam generators. This construction minimizes the inservice inspection requirements on pressure boundary welds and eliminates longitudinal pressure boundary weld seams.

The Delta 75 feedwater distribution ring and emergency feedwater piping utilize [ ]c

The Delta 75 has access openings similar to the Model F to provide for enhanced access for maintenance and inspection. [ ]c handholes, [ ]c inspection ports, [ ]c maintenance openings, and [ ]^c manways are provided on the secondary side of the unit. [ ]^c primary manways are provided on the primary side of the unit. Refer to Section 1.3 for details of these openings.

1.2 DESIGN PARAMETERS

The design parameters for the replacement steam generators are the same as for the original steam generators as shown in Table 1-1.

1.3 DESIGN REQUIREMENTS

The Delta 75 is designed in accordance with ASME Code Section III, 1986 edition and other applicable federal, state and local laws, codes and regulations and the following major design requirements:

1.3.1 <u>Compatibility with Uprated Operating Conditions</u>

At a power level of 970.67 MWt/SG, the replacement steam generator is capable of producing steam at a pressure of 964 psia or greater and primary flow greater than 96,892 gpm with [ ]^c percent tube plugging when supplied with:

- Reactor Coolant inlet water temperature of 620 °F,
- Primary flow rates meeting the requirements of Table 1-2
- Feedwater inlet flow of 4.335×10^6 with 1 percent blowdown (i.e., 4.291×10^6 lbm/hr steam flow).

1.3.2 <u>Maximum Tube Plugging Margin or Primary Temperature Margin</u>

At best estimate conditions (i.e., Best Estimate Reactor Coolant System Flow as described in Table 6-1) and an assumed NSSS power level of 2912 Mwt, it is projected that the Delta 75 steam generator is capable of producing steam at a pressure of 964 psia, with a steam generator tube plugging margin of approximately [ ]^c This projection requires that the reactor vessel outlet temperature be maintained at 620°F. Section 6.3 discusses the primary temperature margin.

1.3.3 <u>Moisture Carryover</u>

The Delta 75 steam generator is designed to exhibit moisture carryover [ ]^c percent at full-power operating conditions. Section 6 provides additional performance and operational characteristics for the Delta 75 steam generator.

1.3.4 <u>Water Level Response Characteristics</u>

The Delta 75 steam generator high and low level trip elevations relative to the Delta 75 normal operating water level have been chosen to provide operating margin during water level excursions similar to that of the original Model D3 steam generator. Specifically, the water mass between the high and low level trip points for the Delta 75 steam generator is similar to the water mass spanning the trip points in the Model D3 steam generator. As a result, the swell and shrink margin provided between the high and low level trip points of the Delta 75 steam generator to accommodate operational transients is similar to the margin provided in the original Model D3 steam generator.

1.3.5 Steam Generator Interfaces

The Delta 75 steam generator meets the original interfaces with the exception that provisions for a [ ][c] blowdown nozzle have been made and the feedwater inlet nozzle is located in the upper shell. In addition, in order to facilitate the equipment hatch clearance requirement, the emergency feedwater inlet nozzle and water level taps have been rotated on the upper shell of the Delta 75 unit.

1.3.6 Elimination of Forward and Reverse Feed Line Flushing Requirements

The Model D3 steam generator requires limiting the temperature of the feedwater to minimize the potential for bubble collapse waterhammer or smaller scale bubble collapse within the tube bundle preheater. Bubble collapse and hydrodynamic instability were addressed in the Delta 75 steam generator design by mixing the feedwater with the recirculating water in the steam generator in the upper shell region prior to discharging it into the tube bundle. Therefore, [ ][c]

1.3.7 Maximized Tube Bundle Reliability and Use of Field Proven Features

The Delta 75 steam generator design features and configurations have been verified by test, analysis, or operational experience and emphasize principal reliability-related features of the operating Model F, including [ ][a] tube material, hydraulic tube expansion tubesheet joints, broached [ ][c] tube supports, minimum-gap U-bend supports, additional U-bend supports, broached [ ][a] flow distribution baffle, and tubesheet flow control and access features.

1.3.8 Enhanced Maintenance and Access Provisions

[ ][d] ID manways are provided on both the Delta 75 primary and secondary sides at the same locations as the 16-inch manways of the original D3 steam generator. The Delta 75 has six [ ][a] handholes located to maximize their utility for inspection and maintenance of the lower tube bundle. The Model D3 has two [ ][a] handholes and [ ][a] I.D. inspection openings located above the tubesheet secondary side face. In addition, the Delta 75 has [ ][a] inspection port openings located on the lower shell-transition cone junction at an elevation just above the top tube support plate. The Model D3 does not have these inspection openings. [ ][a] maintenance openings are also provided for periodic maintenance of the upper shell internals of the Delta 75. The Model D3 does not have these openings. [ ][c] Access provisions (ladders, grab bars, and manways) for inspection of the steam generator upper internals are also provided. Enhanced maintenance and access provisions in conjunction with channel head and divider plate electropolishing and low cobalt Inconel material selection will reduce radiation exposure.

1.3.9 Weight Restrictions

To minimize the impact on steam generator supports and seismic considerations, the total weight of each empty Delta 75 steam generator will not exceed 360 tons (720,000 lbs). The original Model D3 steam generator empty weight is [ ]^c

1.4 MAJOR DIMENSIONS AND GENERAL ARRANGEMENT

The Delta 75 is a vertical U-tube feedring-type steam generator which has outline dimensions that match the original Model D3 except for the relocation of the water level taps and main feedwater nozzle to the upper shell and the reconfiguration of upper shell small nozzles as discussed in section 1.3.5 (Figure 1-1 provides an illustration of the Delta 75 steam generator). The Model D3 is a vertical U-tube preheater steam generator utilizing cross-flow enhanced forced convection heat transfer in the lower portion of the tube bundle cold leg (Figure 1-2 provides an illustration of a Model D3 steam generator).

The Delta 75 tube bundle is [ ]^a taller than the original Model D3 tube bundle. This bundle height is similar to that of the Westinghouse 51-Series steam generator which also uses the same shell size.

The Delta 75 external pressure boundary which includes the transition cone, the upper shell elliptical head, and the channel head is constructed [ ]^c sections. The additional shell handholes provided for access to the top of the tubesheet and the area above the top of the flow distribution baffle are [ ]^c

The pressure boundary of the Model D3 was constructed of [ ]^c plate and [ ]^c forgings. The primary side channel head is a [ ]^c carbon steel material. Figure 1-3 depicts a comparison of the Model D3 and Delta 75 pressure boundary weld seams.

The use of [ ]^c construction eliminates [ ]^c The Delta 75 forged channel head is a [ ]^c

Refer to Section 2 for a list of the major materials of construction for the Delta 75 steam generator.

1.5 TUBE BUNDLE CONFIGURATION

In order to provide equivalent performance of a preheater type unit and maximum margin in a feedring type steam generator, three significant changes to tube bundle elements were made: [ ]^c

The [ ]^c tube count and [ ]^c surface area of the Delta 75 provides [ ]^{a,c} margin for the currently licensed power level up to and including an uprated power level of 2912 MWt. Section 6 provides certain information on the Delta 75 tube plugging margin.

The Delta 75 feedring steam generator provides [ ]a,c (including additional tube plugging margin for operation at a reduced primary temperature) with a simplified tube bundle design. This design simplicity is equated with higher reliability. Section 6 provides certain information on performance and operational characteristics of the Model D3 and Delta 75 steam generators.

1.5.1 Tube Bundle

The Delta 75 tube bundle has [ ]a tubes, [ ]a support plates, 1 flow distribution baffle, and [ ]a sets of U-bend supports. The Delta 75 tube size is 11/16-inch OD with a 0.040-inch wall thickness which is the same as the Model F. The Delta 75 tubes are spaced [ ]a apart in an equilateral triangular arrangement. [ ]aWestinghouse designed and manufactured steam generators using this 11/16-inch tube size have accumulated over [ ]a years of operating experience. The bundle surface area is [ ]c The peripheral annulus in the Delta 75 is [ ]c than in the Model D3, providing additional access for FOSAR (Foreign Object Search and Retrieval) and sludge lancing.

The Model D3 tube bundle has [ ]a,c tubes, [ ]a tube support and preheater baffle plates on the cold leg side, and 1 flow distribution baffle close to the secondary surface of the tubesheet. The Model D3 has 2 sets of U-bend supports. The tube size is 3/4-inch O.D. with 0.043-inch wall thickness, spaced 1.0625 inches apart in a square pitch arrangement.

1.5.2 Tube Material

The Delta 75 tube material is [ ]c Alloy 690. The Model D3 tube material is [mill annealed]a Alloy 600. Alloy 690 has been under development since the early 1970s and, based on extensive industry-wide test programs, has been determined to be the material of choice for steam generator applications. Currently, Westinghouse has [ ]a replacement steam generators in operation with Alloy 690 tubing. The use of [ ]c Alloy 690 provides additional corrosion resistance of the tube material.

The Delta 75 Alloy 690 tubing specification is in accordance with the requirements of ASME Code Case N-20-3, ASME Code Section III, ASME Code Section II Specification SB-163, and meets the EPRI Guidelines for Procurement of Alloy 690 steam generator tubing (EPRI Report NP-6743-L; Feb., 1991).

1.5.3 Tubesheet Joint

The primary function of the tube-to-tubesheet joint is to provide a structurally sound and leak-tight barrier between the primary and secondary sides of the steam generator. Except for the potential for corrosion, this functional requirement could be readily met in various ways. However, the potential for corrosion demands careful attention with respect to the tube-to-tubesheet joint and the associated manufacturing operations.

The Delta 75 tubes are [ ]c through the thickness of the tubesheet. A full depth mechanical roll expanded the tubes against the tubesheet in the Model D3. The principal technical requirements on the tube expansion process which are satisfied by the hydraulic expansion process are: (1) that the residual stresses in the expanded tube be as low as possible, (2) that the tube expansion transition be as close as possible to the secondary side of the tubesheet to minimize secondary side crevice depth, and (3) that the expanded tube be tight against the tubesheet so as to minimize the potential ingress of secondary side fluid in the tube-to-tubesheet joint interface.

1.6 TUBE SUPPORT STRUCTURE

1.6.1 Tube Support Plates

[ ]^{a} tube support plates are used in Delta 75 steam generator of the [ ]^{c} broached design. All tube supports are made of type 405 [ ]^{a} stainless steel. The broached tube support plate is designed to [ ]^{c} The broached hole configuration is shown in Figure 1-4. [ ]^{c} in the delta 75 provides additional [ ]^{c}. The Model D3 carbon steel tube support and baffle plates utilize a drilled hole with [ ]^{c}. Laboratory tests have shown a significant reduction of [ ]^{c} at the tube contact point when a flat contact geometry is present.

1.6.2 Flow Distribution Baffle

The type 405 stainless steel flow distribution baffle (FDB) of the Delta 75 is designed and located to produce a [ ]^{c} the tubesheet. This is expected to [ ]^{c} The tube holes in the FDB are of the broach design with [ ]^{c} This design has [ ]^{c} even in the presence of sludge. The Model D3 incorporates drilled baffle holes.

The Delta 75 flow distribution baffle has a [ ]^{c} opening sized in conjunction with the tube hole flow area to produce the [ ]^{c} the tubesheet.

1.6.3 U-Bend Supports

Fifteen Westinghouse tube bundles have been fabricated using an advanced assembly process. All tube diameters for each Delta 75 steam generator are measured [ ]^{a} [ ]^{c} 405 SS anti-vibration bars (AVBs) are assembled in the U-bend region of the tubes. The thickness of the four sets of U-bend AVBs [ ]^{a} When the U-bends are assembled, [ ]^{a} The nominal gap size is less than [ ]^{c} after assembly. This design, in conjunction with other features, such as the manufacture of AVBs using [ ]^{c,e} stainless steel, the adoption of a [ ]^{a} AVB configuration, the tight control of AVB insertion depths, tightly controlled U-bend tubing ovality and an enhanced AVB end retainer ring design, is expected to provide enhanced AVB performance and tubing reliability. The Model D3 steam generator has two sets of [ ]^{c} which are nominally sized [ ]^{a} less than the nominal tube to tube gap in the U-bend.

1.7 [ ]^{a,e}

Although the Delta 75 steam generator tube bundle is designed to minimize the impact of sludge, sludge inventory can accumulate. The Delta 75 steam generator has incorporated a [ ]^{a,e} feature in the steam generator recirculating loop. This [ ]^{a,e} is located in the upper shell in the center of the unit on the upper surface of the primary moisture separator deck plate as shown in Figure 1-1. The water, which passes through the tube bundle, is separated by the primary and secondary moisture separators and is directed back to the tube bundle. As the water leaves the separators, [ ]^{a,c,e} As the steam generator starts up, the feedwater flow rate is low and the circulation ratio is high. As long as there is recirculating flow within the steam generator, [ ]^{c} Calculations show that the [ ]^{a,c,e}

[ ]^{a,e} which requires no operator actions and has no operational requirements. It has [ ]^{c} used during normal maintenance to [ ]^{a,c}

The Model D3 upper shell internals do not have a [ ]^{a,e}.

1.8 BLOWDOWN AND SLUDGE REMOVAL SYSTEMS

The Delta 75 has a [ ]^{c} blowdown pipe located on top of the tubesheet in the tubelane. The blowdown pipe extends essentially the full length of the tubelane and has two end connections 180° apart on the tubesheet. It is designed to accommodate a [ ]^{a} percent feedwater flow continuous blowdown rate from a single pipe connection (two connections are provided) at full power conditions. Higher blowdown rates, of up to [ ]^{a} percent for short periods, although not usually necessary to comply with the chemistry control guidelines, can also be accommodated. The primary purpose of the blowdown line is to remove bulk fluid from the hot leg side of the tube bundle, where higher concentrations of particulates can collect.

The Model D3 has two [ ]^{c} blowdown pipes located on top of the tubesheet in the tubelane. Each of the tube blowdown pipes extends for half the tubesheet. These internal blowdown pipes are sealed off on their ends in the V. C. Summer Nuclear Station Model D3 steam generator.

1.9 WATER LEVEL CONTROL SPAN

The taller Delta 75 tube bundle requires the elevation of the lower deck plate to be higher than the Model D3 design for the V. C. Summer Nuclear Station. Since one of the design requirements is to maintain water level control characteristics consistent with the Model D3, the primary moisture separator assembly has also been raised in the Delta 75. A single-tier secondary dryer is used to accommodate raising the primary separators.

The Delta 75 steam generator narrow range water level span is [ ]^{c} The original Model D3 has a narrow range water level span of [ ]^{c} Due to the higher wide range upper tap elevation, an increased wide range span is provided on the Delta 75. The Delta 75 is designed to provide additional margin between the normal water level and the low-level trip elevation.

1.10 FEEDWATER DISTRIBUTION SYSTEM

Feedwater is introduced into the Delta 75 through a feed nozzle located in the upper shell of the steam generator. This nozzle has the same pipe weld preparation as the original Model D3 steam generator. This nozzle does not require [ ]^{c} because the feedring itself provides this function. The nozzle contains a welded thermal liner which minimizes the impact of rapid feedwater temperature transients on the nozzles and prevents feedring drainage during low-level operation. The feedring is located above the elevation of the feed nozzle to minimize the time required to fill the feed nozzle during a cold water addition transient. This is important for reducing the thermal fatigue loading on the main feed nozzle and helps to eliminate the potential for the occurrence of water hammer.

The feedring is fabricated from [ ]^{a} pipe material with a diameter of approximately [ ]^{c} The feedring is designed to uniformly distribute the feedwater flow around the upper shell in addition to limiting introduction of foreign objects greater than [ ]^{c} Top discharge [ ]^{a} utilizing [ ]^{a} pipe, spaced uniformly around the feedring, distribute the feedwater into the upper shell recirculating water pool. A design requirement for the Delta series Westinghouse steam generators is to avoid regions where steam pockets can be formed, consequently, the feedring discharges from the top.

1.11 MOISTURE SEPARATION FEATURES

1.11.1 First Stage of Moisture Separation

The primary separator system design is based on the [ ]^{a,c} diameter primary separator assemblies used in operating Model F steam generators. [ ]^{a,c} primary moisture separators are used to accommodate the 970.67 MWt/SG power level. They are arranged in two concentric rings, with [ ]^{a} separators in the outer ring and [ ]^{a} in the inner ring. The Delta 75 primary separator utilizes field proven swirl vane, riser separating, and outlet orifice design features. All of the high velocity sections in the swirl vane region and outlet areas of the separator are fabricated of [ ]^{a} material to enhance resistance to erosion-corrosion.

The Delta 75 separator downcomer cylinder does not have the Model D3 tangential nozzles on the primary separators. This feature is important in reducing the water level influence on moisture separation. A [ ]^{c} attached to the exit of the Delta 75 primary separator orifice helps to reduce the vertical component of the orifice jet velocity further separating water and steam exiting the orifice and thereby helps to minimize its potential to transport water into the secondary separators.

The Model D3 utilizes [ ]^{a} diameter separators arranged in a single circular pattern.

1.11.2 Second Stage of Moisture Separation

The Delta 75 single-tier secondary separator uses [ ]^{a,c} dryer vane banks arrayed parallel to each other and spaced across the upper portion of the steam drum. The single-tier dryer bank spacing and the total length of the banks provides about [ ]^{a,c} more second stage separating capacity than is available in the V. C. Summer Nuclear Station Model D3 steam generator two-tier dryer arrangement. This single-tier system contains slightly more hook and pocket type dryer vanes than the Model D3 two-tier design and each bank is more uniformly loaded than the vertical two-tier banks of the Model D3 separator. This parallel bank arrangement is similar to the type operating in several nuclear plants and has been tested under full-scale temperature and pressure conditions in the Westinghouse [ ]^{c} test facility.

The separator banks are designed so that the vanes may be removed for inspection. A seal welded hatch is also provided for access to the area above the dryer assembly.

Perforated plates are provided for the faces of the Delta 75 dryer banks to obtain a uniform flow through the dryer vanes. Perforated plates are also utilized on the [ ]^{c} banks of Model D3 secondary separator assembly.

All operating Model F SGs have reported moisture carryover of less than [ ]^{c} percent. The Delta 75 is designed to operate with a moisture carryover of [ ]^{c} percent or less.

1.12 STEAM NOZZLE FLOW RESTRICTOR

A steam nozzle flow-limiting device, consisting of [ ]^{c} installed into integral holes in the steam outlet nozzle, will reduce the rate of energy release into containment during a postulated steamline break. It also reduces the loads on the steam generator internals during such an event. The [ ]^{c} are secured to the steam outlet nozzle by welding the [ ]^{c} weld deposited cladding on the steam nozzle. The flow area and pressure drop characteristics of this assembly are identical to that of the Model D3 steam nozzle flow restrictor.

1.13 CHANNEL HEAD

The Delta 75 primary side channel head utilizes a single alloy steel forging with integrally forged primary nozzles, supports and manways. The Model D3 has a single carbon steel casting with the same features integral to the casting. The Delta 75 channel head primary nozzles have forged stainless steel safe ends versus weld deposited stainless steel safe ends on the Model D3 primary nozzle. The Delta 75 primary coolant exposed channel head surfaces including the divider plate are electropolished. The Model D3 channel head has an as-deposited clad surface, and the primary side exposed surfaces were not electropolished. Electropolishing of the divider plate and channel head surfaces will reduce radiation exposure during steam generator maintenance and inspection activities. The Delta 75 channel head drains and primary nozzle closure rings are the same design as the Model D3 channel head. Refer to Section 2 for material specifications for the channel head assembly cladding.

1.14 CLOSURE ASSEMBLIES FOR MANWAY, ACCESS, INSPECTION AND MAINTENANCE OPENINGS

All manways, handholes and other access openings on the Delta 75 utilize studs, nuts and washers for securing the closure covers. This permits use of stud tensioners for closure assembly and disassembly, thus reducing radiation exposure. The V. C. Summer Nuclear Station Model D3 steam generator has bolted closures.

1.15 DELTA 75 AND MODEL D3 GEOMETRIES

Refer to Table 1-3 for a comparison of the Model D3 and Delta 75 steam generator design geometries.

TABLE 1-1
MODEL D3 AND DELTA 75 SG DESIGN PARAMETERS

Parameter	Model D3	Delta 75
Design Pressure Primary Side Coolant, psig	2485	2485
Design Pressure Secondary Side, psig	1185	1185
Design Pressure Primary-Secondary Boundary Components, psi		
Maximum Primary to Secondary Differential	1600	1600
Maximum Secondary to Primary Differential	670	670
Hydrostatic Test Pressure, psig		
Primary Side	3107	3107
Secondary Side	1482	1482
Design Temperatures, °F		
Primary Side	650	650
Secondary Side	600	600
Primary-Secondary Boundary Components (Tubes and Tubesheet only)	650	650

TABLE 1-2
PRIMARY SIDE REPLACEMENT STEAM GENERATOR AVAILABLE PRESSURE LOSS

Steam Generator Coolant Flow, gpm	Available Pressure Loss, psi

[ ]c

TABLE 1-3
MODEL D3 AND DELTA 75 GEOMETRIES

	Model D3	Delta 75
OVERALL DIMENSIONS		
Overall Length, inches	812.00	[illegible]
Lower Shell ID, inches	129.38	129.38
Upper Shell ID, inches	168.50	168.50
TUBE BUNDLE DIMENSIONS		
Heat Transfer Area, sq ft	[	][a]
Number of Tubes	[	][a]
Tube OD, inches	0.750	0.688
Tube Wall, inches	0.043	0.040
Tube Material	[	][a]
Tube Pitch, inches	1.0625	0.980
Pitch Arrangement	Square	Triangular
Minimum U-Bend Radius, inches	[	][a]
Wrapper ID, inches	[	][a]
Wrapper Opening Height, inches	[	][a]
Tube Bundle Height, inches	[	][a]
Number of Tube Support Plates/ Flow Distribution Baffles	7/1 (Hot Leg)	[ ][a]
Support/Baffle Material	Carbon Steel	405 SS***
Number of U-Bend Supports	2 Sets	[ ][a]
U-Bend Support Material	Alloy 600 (Chrome Plated)	[ ][a]
MOISTURE SEPARATOR DESIGN		
Number of Primary Separators	12	[ ][a]
Primary Separator ID, inches	[ ][a]	[ ][a]
Primary Separator Design	Centrifugal	Centrifugal/Low Pressure Drop
Secondary Separator Design	Two Tier [ ][a]	Single Tier [ ][a]

* MA - Mill Annealed

[ ][a]

*** SS - Stainless Steel

a,e

Figure 1-1. DELTA 75 Feedring Steam Generator

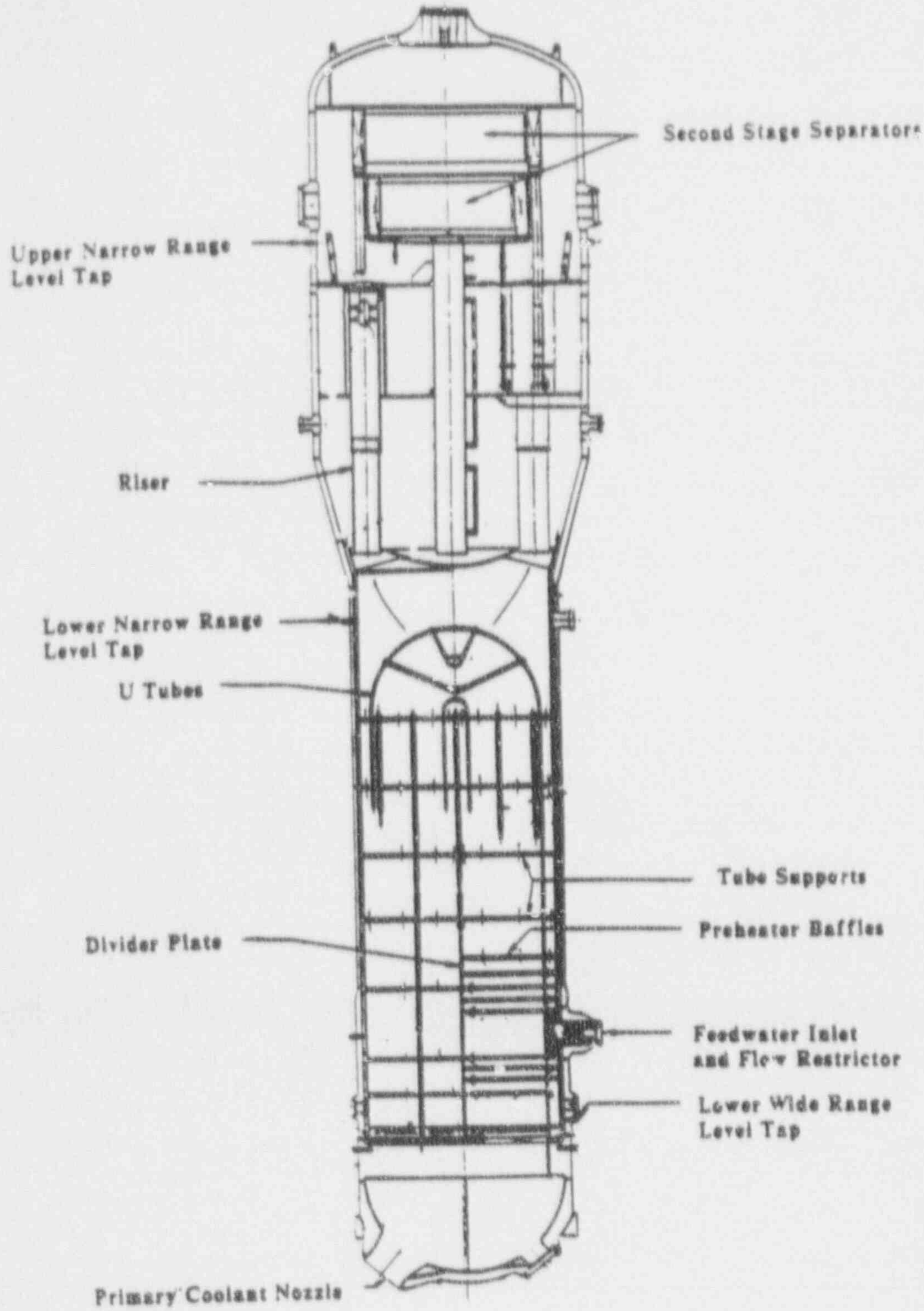

Figure 1-2. Model D3 Preheater Steam Generator

c

Figure 1-3. Steam Generator Pressure Boundary Weld Seams c

Figure 1-4. Tube Support Plate Broached Hole Configuration

SECTION 2
DELTA 75 MATERIALS OF CONSTRUCTION

2.1 DELTA 75 STEAM GENERATOR MATERIALS

The following is a list of the major materials of construction for the replacement steam generators.

A. Steam generator shells, tubesheet, channel head, and large nozzles - forgings SA508 Class 3a.

B. Tubes - SB163 Ni-Cr-Fe thermally treated Alloy 690 which is specified in accordance with the requirements of ASME Code Case N-20-3. [
]

C. Cladding

- Channel head surfaces: Austenitic stainless steel (309L/308L) weld deposited.

- Tubesheet primary side surfaces: Ni-Cr-Fe (N06082/W86182) Alloy weld deposited.

D. Tube Support Plates - SA240 Type 405 stainless steel

E. U-Bend Supports (AVBs) - [ ][c]

F. Tube Bundle Wrapper and Wrapper Transition Cone - SA516 Grade 70

G. Other Materials - These items comply with the ASME Code and other applicable industry standards.

SECTION 3
MATERIAL AND MANUFACTURING PROCESSES FOR TUBES, TUBESHEETS AND SUPPORT PLATES

3.1 MATERIAL

3.1.1 Tubes

The Westinghouse Delta 75 steam generator uses 0.688 OD x 0.040 wall [ ][a,c] Alloy 690 heat transfer tubing. The Alloy 690 tubing specification is in accordance with the requirements of ASME Code Case N-20-3, ASME Code Section III Subsection NB, ASME Section II specification SB-163, and meets the EPRI Guidelines for Procurement of Alloy 690 Steam Generator Tubing (EPRI Report NP-6743-L; February, 1991). In addition, the following supplemental Westinghouse requirements have been imposed. Westinghouse will only use tubing suppliers previously qualified by a Westinghouse designed pre-production qualification program. All tubing manufacturing processes are controlled by Westinghouse utilizing written procedures which are implemented by full-time on-site inspectors.

3.1.2 Tubesheets

The tubesheet material for the Delta 75 is SA-508 Class 3a alloy steel forging in compliance with ASME Code Section III requirements for Class 1 Components. The tubesheet is clad on the primary side with nickel-chromium-iron alloy weld consumables as given in Section 2.0.

3.1.3 Tube Support and Flow Distribution Baffle Plates

The Delta 75 tube support plates and flow distribution baffle plate are made of SA-240 Type 405 [ ][a,c] stainless steel plate in compliance with ASME Code Section III requirements for Class 1 components.

3.2 MANUFACTURING PROCESSES

3.2.1 Tubesheet Manufacturing & Drilling

Tubesheets are weld cladded with an approximately [ ][a] thickness of Inconel (Ni-Cr-Fe) Alloy material using an automatic [ ][a] process. The tubesheet cladding is

[

]a

[

]a,c

The manufacturing of tubesheets utilizes a [ ][a] gun drilling process with precision drilling capability to accurately control the diameter, true position, and perpendicularity of each drilled hole. This is accomplished with specially developed, time-proven, deep hole gun drilling techniques. Drilling is accomplished on two specially designed, [ ][a] horizontal boring mills equipped with [ ][a] gun drilling heads. The technique utilizes a proven method for machine alignment and calibration, including tubesheet setup and orientation prior to drilling. [ ][a] provide redundant position verification of machine moves. Drilling operations are controlled using [ ][a]

The tubesheet holes are drilled to a diameter nominally only [ ][a] inch larger than the unexpanded tubing OD. This [ ][c] minimizes the plastic deformation needed to expand the tube and helps to maintain [ ][c] The [ ][c] diametrical clearance is compatible with structuring (inserting the tubes through the support and flow baffle plates and tubesheet) because of the precise alignment of support and flow baffle plates with the tubesheet holes, and maintains dimensional accuracy of the tubesheet holes. Tubesheet hole positions are [ ][c,e] with an approximate 50% coverage pattern to facilitate tube location during maintenance.

3.2.2 Tube Support Plates

3.2.2.1 Drilling

Tube support plates are precision drilled using [ ][a] drilling process to accurately control hole diameter and true position of each tube support hole.

3.2.2.2 Broaching

A special tube support configuration used to radially support each steam generator tube is broach machined in each drilled hole of the tube support plates. The specially built [ ][a] broach machines used are equipped with [ ][a] and adaptive controls to maintain feed rate and tool load during broaching. [ ]^{a} techniques are employed to monitor broached machining parameters and measure broached hole dimensions.

3.2.2.3 Broached Hole Edge Radiusing

After broaching and prior to final finishing and machining, each tube support plate is [

]^{a}

3.2.3 <u>Assembly</u>

3.2.3.1 Structuring

Alignment of the tube support plates is a key factor in building a high integrity tube support structure.

The wrapper barrel, which is fabricated to controlled tolerances for roundness, is installed [ ]^{a} The wrapper is supported by attachments [ ]^{a} at each tube support plate elevation. The tube baffle and support plates are supported vertically at the proper elevation by interior spacer pipes and spacer bars on the plate periphery and radially [ ]^{a,c} between the plate edge and [ ]^{a} Elevation and parallelism of the support plates are tightly controlled through [ ]^{a} with specific control of the top support plate elevation relative to the tubesheet primary surface.

The baffle plate and support plate tube holes are aligned with the tubesheet holes using laser beam techniques, rodding, and wanding.

3.2.3.2 Tube Installation

Tubes are installed in parallel with the tube hole final cleaning, tube expansion, and tube welding. This procedure allows the tubes to be installed and [ ]^{a} expanded in cleaned tube plate holes.

3.2.3.3 [ ][a] Expansion

Tubes are [ ][a] tack expanded to facilitate tube-to-tubesheet welding and to allow helium leak testing of the welds prior to [ ][a] expansion. Westinghouse uses a [ ][a] expansion technique, instead of mechanical rolling, in order to minimize the residual stresses in the tube. Residual stresses associated with [ ][a] tack expansion are low, [ ][a] In addition, [ ][a]

3.2.3.4 Tube-to-Tubesheet Welding

Tubes are welded to the tubesheet cladding using an automatic autogenous gas tungsten arc welding (GTAW) process. The tube-to-tubesheet weld is a primary-to-secondary leakage barrier. Alloy 690 is compatible for welding with the tubesheet primary side cladding.

3.2.3.5 Helium Leak Test

Leak testing of the tube-to-tubesheet welds of the steam generator will employ [ ][a] leak detector with a low positive pressure of a [ ][a] mixture on the secondary side of the steam generator. [ ][a]

A fixture isolates the tube-to-tubesheet weld on the primary side; a vacuum is pulled in the fixture and a test for [ ][a] migration from the secondary side is performed.

The tube-to-tubesheet welds will be free from oil, grease, paint, and other contaminants (prior to helium leak testing) which might mask a leak.

3.2.3.6 Liquid Penetrant Test

The entire primary side of the tubesheet including tube welds is dye penetrant inspected to [ ][a]

3.2.3.7 [ ][a] Expansion

The tubes are expanded [ ][a,c] of the tubesheet. The principal technical requirements on the expansion process are: (1) that the residual stresses in the expanded tube be as low as possible, (2) that the tube be expanded to minimize the secondary side crevice depth, thereby reducing the potential for crevice corrosion, and (3) that the expanded tube be tight against the tubesheet so as to minimize the ingress of secondary side fluid down to the tube-to-tubesheet welds.

3.2.3.8 Profilometry

After expanding the tubes in the tubesheet, all tubes will be examined using [

]^{a,c}

3.2.3.9 Anti-Vibration Bar System

[ ]^{c} 405 SS anti-vibration bars (AVBs) are assembled in the U-bend region of the tubes to maintain tube-to-tube spacing, stiffen the tube bundle, and restrain vibration of the tubing U-bends above the top tube support plate.

Specially designed tools are used [ ]^{c} to minimize gaps between the AVB and the tubes it supports. In addition, the tubing is purchased with precise ovality control.

SECTION 4
WELDING PROCESSES USED IN FABRICATION

4.1 WELDING AND WELDMENTS

The base materials and welding processes for the Delta 75 steam generator pressure boundary weld seams and buildups, and channel head/tube plate cladding are depicted in Figure 4-1. Weld processes, weld consumables, and joint design are identified in the project design drawings. The weld procedure specification (WPS), weld procedure qualification record (PQR), and other welding-related documents for each joint, buildup, or cladding area are separately identified on a weld seam ma; drawing.

Where possible, all of the weid consumables [

]^{c} purchased as a single lot/heat size in sufficient quantity for all three steam generators. Each different combination of filler wire and flux batch are weld tested to verify its mechanical properties and chemical compliance to the applicable specification and the original PQR results. Weld metal which comes in contact with the primary coolant is specified with low cobalt content to reduce operational radiation fields and reduce radiation exposure.

[ ]a,e

Figure 4-1. Weld Processes

SECTION 5
HEAT TREATMENT PROCESS

5.1 HEAT TREATMENT

Heat treatment operations are performed on all pressure boundary material weld joints using electrical resistance, induction, and infrared heat treatment equipment. Post weld heat treatments are performed using furnaces and portable (localized) heat treatment systems equipped with electrical resistance and/or induction type heaters. All systems incorporate programmers, chart recorders, redundant thermocouples, and temperature controllers. All heat treatments, i.e., preheat, postbake after welding, and post weld heat treatment (PWHT), are performed per ASME B&PV Code Sections IX and III.

SECTION 6
PERFORMANCE AND OPERATIONAL CHARACTERISTICS MODEL D3 AND DELTA 75 STEAM GENERATORS

6.1 INTRODUCTION

The Delta 75 steam generator is a Westinghouse feedring steam generator design developed as a replacement for original preheat steam generators. The Delta 75 incorporates [ ]^{c}. The Model D3 steam generator features a split-flow preheater configuration to enhance heat transfer and maximize performance. The preheater was designed to operate at a significantly higher level of performance than a feedring steam generator with the same tube bundle surface area.

6.2 OPERATIONAL CHARACTERISTICS

The Delta 75 steam generator is designed to simplify plant operation and enhance performance by incorporating a feedring type steam generator with the largest achievable heat transfer area. This configuration maximizes thermal performance and avoids many of the operational requirements of the original Model D3 steam generator. For instance, the original Model D3 steam generator is operated with [ ]^{a} The Delta 75 steam generator is designed to operate at [ ]^{a} The normal water level for full load operation is located approximately [ ]^{a,c} inches above the secondary side surface of the tube plate for the Model D3 steam generator and approximately [ ]^{a,c} inches above the tube plate surface for the Delta 75 steam generator.

The Delta 75 steam generator is expected to operate with [ ]^{a} than the original Model D3 steam generator. The [ ]^{a} in the number of primary separators, coupled with other enhancements in the design of the Westinghouse 20 inch primary separators such as the [ ]^{c} at the riser exit, permits the Delta 75 to achieve a moisture carryover of [ ]^{a} compared to the [ ]^{a} maximum for the Model D3 steam generator.

The Delta 75 steam generator is designed to operate with a significantly [ ]^{a} than the Model D3 steam generator, which operates with a [ ]^{a} The Delta 75 steam generator will operate with [ ]^{a} The [ ]^{a} for the Delta 75 steam generator falls within the general design range for

Westinghouse feedring steam generators based on operating experience from the Model F steam generators currently in service.

The calculated primary and secondary side masses for the Delta 75 steam generator [ ][c] than the corresponding values for the Model D3 steam generator assuming both steam generator models operating at full load. This is due to the [ ][c] Table 6-1 gives the [ ][c] within the Delta 75 steam generator [ ][c] within the Model D3 by approximately [ ][c] (for both designs operating at an average primary temperature of 587.4 °F). [ ][c] for the Delta 75 steam generator is approximately [ ][c] than that of the Model D3 steam generator. As for the [ ][c] the Delta 75 steam generator is expected to operate with [ ][c] that of the original Model D3 steam generator [ ][c] A comparison of the full load performance of the Model D3 and Delta 75 steam generators is shown in Table 6-1.

6.3 STEAM GENERATOR PERFORMANCE

A primary objective in the development of the Delta 75 steam generator was to create a replacement steam generator that would combine the simplicity and reliability of a feedring steam generator with the high level of performance required to permit uprating capability to existing nuclear power plants with preheat steam generators. In order to achieve this objective, the Delta 75 tube bundle was designed with 0.688 inch OD tubes arranged in a triangular pattern to maximize heat transfer surface area without significantly [ ][c] As a result, the Delta 75 provides additional performance capability without the use of a preheater.

Table 6-1 provides a comparison of the full load best estimate performance of the Model D3 and Delta 75 steam generator designs. A comparison is provided for both the current V. C. Summer plant rating of 2787 MWt and the proposed uprated plant rating of 2912 MWt. The calculated values presented in Table 6-1 are based on a best estimate evaluation of both steam generator designs operating at a full load average primary temperature of 587.4 °F.

The Delta 75 steam generator operating at the same average primary temperature is expected to produce steam at a pressure approximately 20 psi [ ][c] the Model D3 steam generator (depending on the thermal power). For the current plant rating of 2787 MWt, the Delta 75 is expected to produce steam at [ ][a,c] for the Model D3 steam generator. This [ ][c] steam pressure translates into approximately [ ][c] i.e. the Delta 75 steam generator could successfully operate at [ ][c] at a plant rating of 2787 MWt as the Model D3 steam generator, [ ][c] For operation at the proposed uprated power of 2912 MWt, the steam pressure calculated for the Delta 75 steam generator is [ ]^{c} for the Model D3 steam generator. This 20 psi advantage in steam pressure translates into approximately [ ]^{c}

[ ]^{c} capability of the Delta 75 steam generator will allow operation at a [ ]^{c} than is currently achievable. The Delta 75 could operate with [ ]^{c} that of the current steam generator and still provide comparable performance.

TABLE 6-1

MODEL D3 AND DELTA 75 CALCULATED FULL LOAD PERFORMANCE

	Model D3	Delta 75
PLANT RATING = 2787 MWt (929.00 MWt/SG)		
PRIMARY SIDE	[	]a,c,e
Primary Flow Rate(1), gpm		
Primary Inlet Temperature(2), °F		
Primary Average Temperature(2), °F		
Primary Outlet Temperature(2), °F		
Primary Pressure Drop, psi		
Primary Side Volume, cu ft		
Primary Side Mass, lbs		
SECONDARY SIDE		
Feedwater Temperature, °F		
Steam Temperature(3), °F		
Steam Pressure(3), psia		
Secondary Pressure Drop, psi		
Secondary Side Volume, cu ft		
Secondary Side Mass, lbs		
Normal Full Load Water Level, in		
PLANT RATING = 2912 MWt (970.67 MWt/SG)		
PRIMARY SIDE	[	]a,c,e
Primary Flow Rate(1), gpm		
Primary Inlet Temperature(2), °F		
Primary Average Temperature(2), °F		
Primary Outlet Temperature(2), °F		
Primary Pressure Drop, psi		
Primary Side Mass, lbs		
SECONDARY SIDE		
Feedwater Temperature, °F		
Steam Temperature(3), °F		
Steam Pressure(3), psia		
Secondary Pressure Drop, psi		
Secondary Side Volume, cu ft		
Secondary Side Mass, lbs		
Normal Full Load Water Level, in		

[

]a,c,e