Response to Action Item 5-6 Section 5.4.2.1

MCB Issue List Regarding APR-1400, FSAR Section 5.4.2.1

Issue #1 (AI 5-6.1)

Final Safety Analysis Report (FSAR) Section 5.4.2 refers to no cavitation in steam generators that are "identical to the APR 1400 steam generators." The ability to meet Title 10 of the Code of Federal Regulations (10 CFR) Part 50, Appendix G, General Design Criteria (GDC) 14, 15, 31, and 32 for steam generator tubes is based, in part, on an understanding of operating experience with degradation mechanisms.

Provide more information about degradation from cavitation in steam generators and operating experience with the APR1400 design.

a. Where are the identical steam generators in operation?
b. What is the operating experience with respect to cavitation?
c. What is the operating experience with other degradation mechanisms?
d. Is the documentation of this experience available to the NRC staff?"

Response

a. Based on the design concept and configuration of the reactor coolant system, the steam generators of the APR1400 are almost the same as the OPR1000's. Therefore, Section 5.4.2 will be revised as follows:

   From - "No cavitation has been reported to date in steam generators that are identical to the APR1400 steam generator"
   To - "No cavitation has been reported to date in the OPR1000 steam generators which are almost the same in the design concept and configuration to the APR1400 steam generators."

b. There has been no cavitation degradation in steam generators of the OPR 1000 plants. It is unlikely to occur because the primary side operating pressure (2250 psi) is much higher than the saturation pressure (1723 psi @ 615℉) inside the steam generator tubes and the secondary side flow path is smooth.

c. There are no other degradation mechanisms experienced in the components of the steam generators of the OPR 1000 plants except for the steam generator tubes. For the tubes, the OPR1000 steam generators have experienced PWSCC, ODSCC, and wear. However, SCCs would not be of further concern for the APR1400 steam generator tubes because the tubes are fabricated with Alloy 690TT (thermally treated). Wear would also not be an impacting degradation mechanism because there has been a design modification to the steam generator internals to mitigate the wear. The number of affected tubes due to wear in recently built OPR1000 plants has been reduced dramatically after the design change (See the response to issue #6).

Response to Action Item 5-6 Section 5.4.2.1

d. There is no documentation of cavitation experience. For the tubes, the OPR1000 steam generators experience PWSCC, ODSCC, and wear. The staff may review the ISI examination results for the steam generator tubes of the OPR1000 plants.

Impact on DCD
DCD 5.4.2 will be revised as indicated in the attached markup.

Impact on PRA
There is no impact on the PRA.

Impact on Technical Specifications
There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports
There is no impact on any Technical, Topical or Environmental Reports.

5.4.2 Steam Generators

The two steam generators are designed to transfer 4,000 MWt from the RCS to the secondary system, producing approximately 8.141 × 10^6 kg/hr (17.95 × 10^6 lb/hr) of 70.30 kg/cm^2A (1,000 psia) saturated steam, when provided with 232.2 °C (450 °F) feedwater. Moisture separators and steam dryers in the shellside of the steam generator limit the moisture content of the steam to maximum 0.25 wt% during normal operation at full power. The steam generator design parameters are listed in Table 5.4.2-1. The steam generators, including the tubes, are designed to withstand the consequences of the design transients of Table 3.9-1 so that the ASME Code allowable stress limits are not exceeded for the specified number of cycles. All transients have been established based on conservative assumptions of operating conditions in consideration of supporting system design capabilities.

The steam generator is designed to provide reasonable assurance that critical vibration frequencies are well out of the range that are expected during normal operation and during abnormal conditions. The tubing and tubing supports are designed and fabricated with considerations given to both secondary side flow induced vibrations and reactor coolant pump induced vibrations. In addition, the steam generator assemblies are designed to withstand the blowdown forces resulting from a steam line break and feedwater line break. The two accidents are not considered simultaneously.

Vapor bubbles are generated if the static pressure in a flowing liquid is dropped below the saturated pressure corresponding to the liquid temperature. The region of the flow where bubbles exist is the cavitating region, whereas the observed damage is at the location of the bubble collapse. In the APR1400 steam generator, a pressure drop inside the tubes is not as significant as a cavitation, which can occur because the operating pressure of 158.19 kg/cm^2A (2,250 psia) inside the tubes is much higher than the saturation pressure of 121.13 kg/cm^2A (1,723 psia) of the maximum coolant temperature of 323.8 °C (615 °F) in the steam generator, and the flow paths of tubes from the tube inlet to the tube outlet are smooth enough not to cause a sudden drop of velocity of flow. The secondary side flow path outside-tubes is also smooth on the secondary side so that cavitation does not occur. ~~No cavitation has been reported to date in steam generators that are identical to the APR1400 steam generators.~~

Revise. “No cavitation has been reported to date in the OPR1000 steam generators which are almost the same in the design concept and configuration to the APR1400 steam generators.”

Response to Action Item 5-6 Section 5.4.2.1

MCB Issue List Regarding APR-1400, FSAR Section 5.4.2.1

Issue #2 (AI 5-6.2)

FSAR Section 5.4.2 has a short paragraph on degradation mechanisms and states that pinholes in tubes and cracks in tubes and tube-to-tubesheet welds are “the more probable modes of tube failure.” Industry experience in the U.S. with Alloy 690 tubing is that wear is the predominant degradation mechanism, and no cracking has been observed. A small pinhole leak occurred in one SG as the result of damage from packaging and shipping (NRC Information Notice 2004-16).

Revise FSAR Section 5.4.2 to provide additional justification for the assertion regarding the “more probable modes of tube failure.” This additional justification should address:

a. The operating experience with pinhole leaks and small cracks in tubes and tubesheet welds, including any “failures” that occurred.
b. Why these mechanisms are considered “more probable” than wear and other mechanisms.
c. How the materials, design, and inspection of the APR 1400 steam generators address this degradation.

Response

a. There has been no experience with pinhole leaks and small cracks in Alloy 690 steam generator tubes and tubesheet welds in nuclear power plants in Korea. The only degradation found for Alloy 690 tubes is wear.

b. The definition of “more probable modes” in the fifth paragraph of FSAR 5.4.2 will be modified by adding wear, because the OPR1000 steam generators with Alloy 600 have experienced PWSCC, ODSCC, and wear. The revised sentence of the FSAR 5.4.2 will be:

> ”The more probable modes of tube failure, which may result in leaks, are the results from involving the occurrence of pinholes, small cracks or wear in the tubes and of cracks in the seal welds between the tubes and tubesheet.”

c. The following process and examinations for steam generator tube fabrications will address the more probable modes of tube failure in APR 1400.

   Tubes are made of Alloy 690TT, and their tube to tubesheet welds are produced with Alloy 152/52/52M. Those materials are resistant to the various degradations due to corrosion. For the concern of wear, the steam generator design of the APR1400 has been modified to address this issue. (See the response to the issue #6 for the design changes against wear.)

Response to Action Item 5-6 Section 5.4.2.1

During the tube fabrication, all the tubes are examined by UT (Ultrasonic Test) and ECT (Eddy Current Test) in accordance with ASME B&PV Code Section III NB-2550 ("Examination and Repair of Seamless and Welded Tubular Products and Fittings"). In addition, inservice inspection type and signal to noise ECT are performed. Also, all the tubes are visually and tactilely inspected to detect surface flaws.

There is a procedure to prevent the tube damage during packing and transportation. In general, tubes with different row numbers are separated by vertical plywood spacers wrapped with a polyethylene sleeve. In each row, tubes are prevented from contacting each other by using polyethylene clips. Tube load vertical locking is assured by a foam type spacer (Polyethylene) inserted into a space between the upper tube and the wooden spacer of the comb fixture.

After the tube expansion and tube-to-tubesheet seal weld in the steam generator manufacturing, all the tubes are inspected by profilometry ECT through the tubesheet thickness (including tube expansion, transition, and unexpanded zone) and examined by liquid penetrant method for seal weld joints to ensure the integrity of tube and seal weld. The requirement for liquid penetrant test is free of any indication.

During operation, all tubes are inspected by bobbin ECT in accordance with ISI program.

Impact on DCD
DCD 5.4.2 will be revised as indicated in the attached markup.

Impact on PRA
There is no impact on the PRA.

Impact on Technical Specifications
There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports
There is no impact on any Technical, Topical or Environmental Reports.

The steam generator tube material is thermally treated NiCrFe Alloy 690 (ASME SB-163). The outside diameter is 19.05 mm (0.75 in) with 1.0668 mm (0.042 in) nominal wall thickness. An analysis is performed to establish the maximum allowable tube wall degradation for the steam generator tubes in accordance with the requirements of NRC RG 1.121 (Reference 8). Load conditions considered are maximum tube differential pressures during normal operation and faulted load conditions. The margin of safety against tube rupture under normal operating condition is not less than 3.0, and the margin of safety against tube failure under postulated accidents, such as a loss of coolant accident, main steam line break, or feedwater line break concurrent with an SSE, are consistent with the margin of safety determined by the stress limits specified in the ASME Code.

~~The more probable modes of tube failure, which result in smaller break areas, are the results from involving the occurrence of pinholes or small cracks in the tubes and of cracks in the seal welds between the tubes and tubesheet.~~ Detection and control of steam generator tube leakage are described in Subsection 5.2.5.

Revise. "The more probable modes of tube failure, which may result in leaks, are the results from involving the occurrence of pinholes, small cracks or wear in the tubes and of cracks in the seal welds between the tubes and tubesheet."

The concentration of radioactivity in the secondary side of the steam generators is dependent on the concentration of radionuclides in the reactor coolant, the primary-to-secondary leak rate, and the rate of steam generator blowdown. The specific activities that are expected in the secondary side of the steam generators during normal operation are given in Section 11.1.

The recirculation water within the steam generators contains volatile additives necessary for proper chemistry control. These and other chemistry considerations for the steam generators are discussed in Subsection 10.3.5.

5.4.2.1 Steam Generator Materials

5.4.2.1.1 Selection, Processing, Testing, and Inspection of Materials

The pressure boundary materials used in the construction of the steam generators are listed in Table 5.2-2. These materials are in accordance with ASME Section III. The Code Cases used in the fabrication of the steam generators are described in Subsection 5.2.1.

Response to Action Item 5-6 Section 5.4.2.1

MCB Issue List Regarding APR-1400, FSAR Section 5.4.2.1

Issue #3 (AI 5-6.3)

For compliance with 10 CFR Part 50, Appendix A, GDC 1, GDC 30, and 10 CFR 50.55a, the materials used for the steam generators are acceptable if they are selected, fabricated, tested and inspected (during fabrication and manufacturing) in accordance with the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code). FSAR Section 5.4.2.1 is unclear about processing, testing and inspection of materials used for the steam generator Class 1 and Class 2 pressure boundaries (other than cladding).

Revise the text of FSAR Section 5.4.2.1 to identify that the selection, fabrication, testing, and inspection of all steam generator pressure boundary materials will meet the ASME Code requirements. Subsection 5.4.2.1 should also identify the FSAR Subsections that address these topics.

Response

Following sentence will be added at the end of the first paragraph of FSAR 5.4.2.1.1.

> "The selection, fabrication, testing, and inspection of all steam generator pressure boundary materials meet the applicable ASME Code requirements as described in FSAR Section 5.2.3."

Impact on DCD

DCD 5.4.2.1.1 will be revised as indicated in the attached markup.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical or Environmental Reports.

The steam generator tube material is thermally treated NiCrFe Alloy 690 (ASME SB-163). The outside diameter is 19.05 mm (0.75 in) with 1.0668 mm (0.042 in) nominal wall thickness. An analysis is performed to establish the maximum allowable tube wall degradation for the steam generator tubes in accordance with the requirements of NRC RG 1.121 (Reference 8). Load conditions considered are maximum tube differential pressures during normal operation and faulted load conditions. The margin of safety against tube rupture under normal operating condition is not less than 3.0, and the margin of safety against tube failure under postulated accidents, such as a loss of coolant accident, main steam line break, or feedwater line break concurrent with an SSE, are consistent with the margin of safety determined by the stress limits specified in the ASME Code.

The more probable modes of tube failure, which result in smaller break areas, are the results from involving the occurrence of pinholes or small cracks in the tubes and of cracks in the seal welds between the tubes and tubesheet. Detection and control of steam generator tube leakage are described in Subsection 5.2.5.

The concentration of radioactivity in the secondary side of the steam generators is dependent on the concentration of radionuclides in the reactor coolant, the primary-to-secondary leak rate, and the rate of steam generator blowdown. The specific activities that are expected in the secondary side of the steam generators during normal operation are given in Section 11.1.

The recirculation water within the steam generators contains volatile additives necessary for proper chemistry control. These and other chemistry considerations for the steam generators are discussed in Subsection 10.3.5.

5.4.2.1 Steam Generator Materials

5.4.2.1.1 Selection, Processing, Testing, and Inspection of Materials

The pressure boundary materials used in the construction of the steam generators are listed in Table 5.2-2. These materials are in accordance with ASME Section III. The Code Cases used in the fabrication of the steam generators are described in Subsection 5.2.1.

Add. “The selection, fabrication, testing, and inspection of all steam generator pressure boundary materials meet the applicable ASME Code requirements as described in FSAR Section 5.2.3.”

Response to Action Item 5-6 Section 5.4.2.1

MCB Issue List Regarding APR-1400, FSAR Section 5.4.2.1

Issue #4 (AI 5-6.4)

The cladding on the primary side of the tubesheet is listed in FSAR Table 5.2-2 as "weld deposited NiCrFe alloy." This material will form part of the reactor coolant pressure boundary since it is joined to the steam generator tube ends. Therefore, the selection, processing, fabrication, and testing of this cladding must meet the requirements of 10 CFR Part 50, Appendix A, GDC 1, GDC 30, and 10 CFR 50.55a.

Revise FSAR Table 5.2-2 to identify the specific cladding alloy (or alloys). In addition, revise FSAR Table 5.2-2 to provide the thickness of the cladding and the total thickness of the tubesheet and cladding.

Response

The cladding materials of tubesheet primary side are Ni-Cr-Fe alloys, whose material specifications are SFA-5.11 [ENiCrFe-7] and SFA-5.14 [ERNiCrFe-7(A), EQNiCrFe-7(A)]. The cladding materials of primary head, stay, and nozzles are stainless steels, whose material specifications are SFA-5.4 [E309L-16, E308L-16], SFA-5.9 [ER309L, ER308L, EQ309L, EQ308L], and SFA-5.22 [E309LT1-1, E308LT1-1].

The thickness of tubesheet cladding and base metal is 0.19 inch and 25.5 inches (minimum), respectively. Therefore, the total thickness of the tubesheet and cladding is 25.69 inches (minimum).

The Table 5.2-2 (2 of 5) of FSAR will be revised to identify the specific cladding material specifications for tubesheet cladding materials of the steam generator. "Tubesheet cladding" row in Table 5.2-2 (2 of 5) will be revised as follows:

From - "Weld-deposited NiCrFe alloy"
To - "SFA-5.11 [ENiCrFe-7] and SFA-5.14 [ERNiCrFe-7(A), EQNiCrFe-7(A)]"

Also, the tubesheet thickness will be added at the end of last paragraph of FSAR 5.4.2.1.1 as follows:

"The thickness of tubesheet cladding and base metal is 4.8 mm (0.19 inch) and 647.7 mm (25.5 inches) minimum, respectively."

Impact on DCD

DCD Table 5.2-2 (2 of 5) and DCD 5.4.2.1.1 will be revised as indicated in the attached markup.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Response to Action Item 5-6 Section 5.4.2.1

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical or Environmental Reports.

Table 5.2-2 (2 of 5)

Component	Material Specification
Steam Generator	
Primary head	SA-533 Type B Class 1 or SA-508 Grade 3 Class 1
Primary nozzles	SA-508 Grade 3 Class 1
Primary head cladding (1)	Weld deposited austenitic stainless steel with 5FN-18FN delta ferrite or NiCrFe alloy
Tubesheet	SA-508 Grade 3 Class 1 or Class 2
Divider Plate (1)	SA-240 Type 410S
Tubesheet stay	SA-508 Grade 3 Class 1 or Class 2
Tubesheet cladding (1)	~~Weld deposited NiCrFe alloy~~
Tube (1), (3)	NiCrFe Alloy 690 (SB-163)
Tube supports	ASTM A240, Type 409
Secondary shell (4)	SA-533 Type B Class 1 or SA-508 Grade 3 Class 1
Secondary head (4)	SA-508 Grade 1, Grade 1a or Grade 3 Class 1, or SA-533 Type B Class 1
Secondary nozzles (4)	SA-508 Grade 1, Grade 1a, Grade 3 Class 1 or Grade 3 Class 2
Secondary nozzle safe ends (4)	SA-508 Grade 1 or 1a
Secondary instrument nozzles (4)	SA-106 Grade B, SA-333 Grade 6
Secondary studs and nuts	SA-540 Grade B24, or SA-193 Grade B7
Primary studs and nuts	SB-637 N07718

Revise. “SFA-5.11 [ENiCrFe-7] and SFA-5.14 [ERNiCrFe-7(A), EQNiCrFe-7(A)]”

The corrosion-resistant cladding (NiCrFe alloy or austenitic stainless steel) on the tubesheet and on other primary side components is weld-deposited, fabricated, and inspected according to the requirements in Section III NB and Part QW of Section IX of the ASME Code.

Add. "The thickness of tubesheet cladding and base metal is 4.8 mm (0.19 inch) and 647.7 mm (25.5 inches) minimum, respectively."

5.4.2.1.2 Steam Generator Design

5.4.2.1.2.1 Design Description

The steam generator is illustrated in Figure 5.4.2-1. Moisture-separating equipment in the shell side of the steam generators limits moisture content of the exit steam. Manways and handholes are provided for access to the steam generator internals. Reactor coolant enters at the bottom of each steam generator through a single inlet nozzle, flows through the U-tubes, and leaves through two outlet nozzles. A vertical divider plate separates the inlet and outlet plenums in the lower head.

The steam generator with integral economizer (Figures 5.4.2-2 and 5.4.2-3) is in most respects similar to earlier U-tube recirculating steam generators. The basic difference is that instead of introducing feedwater only through a sparger ring to mix with the recirculating water flow in the downcomer channel, feedwater is also introduced into a separate, but integral section of the steam generator. A semi-cylindrical section of the tube bundle, at the cold leg or exit end of the U-tubes, is separated from the remainder of the tube bundle by vertical divider plates. Feedwater is introduced directly into this section and pre-heated before discharge into the evaporator section.

The economizer section is designed in consideration of operating transients, startup and standby operation, and accident conditions such as loss of feedwater flow and feedwater line break. The structural design of the various parts is adequate to withstand the thermal and pressure loadings from these various conditions, consistent with the appropriate load classifications and design rules in ASME Section III, Appendix G.

The components of the steam generator economizer section are designed for the primary stresses that occur due to the blowdown associated with a feedline break. The divider plates, which separate the economizer region from the evaporator region of the secondary side, are supported from the vessel shell and the central cylindrical support welded to the

Non-Proprietary

Response to Action Item 5-6 Section 5.4.2.1

MCB Issue List Regarding APR-1400, FSAR Section 5.4.2.1

Issue #5 (AI 5-6.5)

The staff does not have a clear understanding of how the design meets 10 CFR Part 50, Appendix A, GDC 14, GDC 15, and GDC 31 with respect to the use of austenitic stainless steel for the steam generators. FSAR Table 5.2-2 lists weld-deposited austenitic stainless steel as one option for the primary head cladding. However, FSAR Subsections 5.4.2.1.1 and 5.4.2.1.4 suggest there could be other applications for austenitic stainless steel.

Revise the FSAR Section 5.4.2.1 to clarify how austenitic stainless steel is used for the steam generators, and identify where it is used for the Class 1 or Class 2 pressure boundary.

Response

There is no austenitic stainless steel used for the primary and secondary side pressure boundary of steam generator in APR 1400. The following sentence will be added at the end of the last paragraph of FSAR 5.4.2.1.1 as follows:

"There is no austenitic stainless steel that is used for the primary and secondary side pressure boundary of the APR1400 steam generators."

Impact on DCD

DCD 5.4.2.1.1 will be revised as indicated in the attached markup.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical or Environmental Reports.

The corrosion-resistant cladding (NiCrFe alloy or austenitic stainless steel) on the tubesheet and on other primary side components is weld-deposited, fabricated, and inspected according to the requirements in Section III NB and Part QW of Section IX of the ASME Code.

Add. "There is no austenitic stainless steel that is used for the primary and secondary side pressure boundary of the APR1400 steam generators."

5.4.2.1.2 Steam Generator Design

5.4.2.1.2.1 Design Description

The steam generator is illustrated in Figure 5.4.2-1. Moisture-separating equipment in the shell side of the steam generators limits moisture content of the exit steam. Manways and handholes are provided for access to the steam generator internals. Reactor coolant enters at the bottom of each steam generator through a single inlet nozzle, flows through the U-tubes, and leaves through two outlet nozzles. A vertical divider plate separates the inlet and outlet plenums in the lower head.

The steam generator with integral economizer (Figures 5.4.2-2 and 5.4.2-3) is in most respects similar to earlier U-tube recirculating steam generators. The basic difference is that instead of introducing feedwater only through a sparger ring to mix with the recirculating water flow in the downcomer channel, feedwater is also introduced into a separate, but integral section of the steam generator. A semi-cylindrical section of the tube bundle, at the cold leg or exit end of the U-tubes, is separated from the remainder of the tube bundle by vertical divider plates. Feedwater is introduced directly into this section and pre-heated before discharge into the evaporator section.

The economizer section is designed in consideration of operating transients, startup and standby operation, and accident conditions such as loss of feedwater flow and feedwater line break. The structural design of the various parts is adequate to withstand the thermal and pressure loadings from these various conditions, consistent with the appropriate load classifications and design rules in ASME Section III, Appendix G.

The components of the steam generator economizer section are designed for the primary stresses that occur due to the blowdown associated with a feedline break. The divider plates, which separate the economizer region from the evaporator region of the secondary side, are supported from the vessel shell and the central cylindrical support welded to the

Response to Action Item 5-6 Section 5.4.2.1

MCB Issue List Regarding APR-1400, FSAR Section 5.4.2.1

Issue #6 (AI 5-6.6)

The discussion of tube supports in FSAR Subsection 5.4.2.1.2.2 states that this design has been proven to reduce wear in operating reactors.

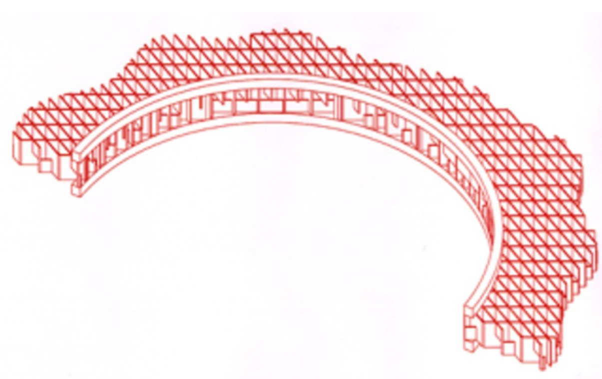
Revise FSAR Subsection 5.4.2.1.2.2 to provide additional justification for the assertion. If it is based on operating experience outside the United States, provide information on this foreign operating experience to facilitate the staff's review.

Response

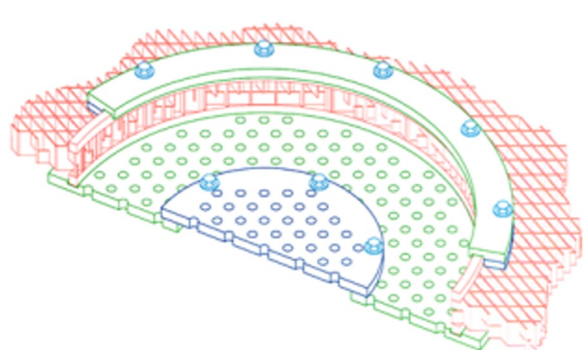
Eggcrate flow distribution plate (EFDP) has been adopted to mitigate the concentrated flow into the central cavity region so as to reduce the localized wear. Up to Han-bit NPP Units 5&6 (OPR1000), there had been no EFDP. Han-ul NPP Units 5&6 (OPR1000) is the first of kind steam generator to equip the EFDP.
Figure-1 shows the schematics before and after the installation of EFDP.

Comparison of tube wear status at U-bend region between those NPPs provides an additional justification how the EFDP design reduce the tube wear at central cavity region effectively. Tables 1 & 2 summarize the tube wear status (number of indications and number of tubes with indications) at U-bend region of Han-bit Units 5&6 and Han-ul Units 5&6 based on the recent eddy current test (ECT) results performed during their 6th in-service inspection (ISI).
For the APR1400 steam generator, thermal-hydraulic analysis had been performed to investigate the optimum number of EFDP to be installed. Figure-2 presents the axial mass flux at central cavity region according to the number of EFDPs for OPR1000 and APR1400 steam generators. There is no such benefit to have two or more EFDPs. Thus, there is one EFDP at the uppermost full eggcrate for APR1400 steam generator.

Figure-1. Before and After Installation of Eggcrate Flow Distribution Plate



[Before Installation of EFDP]



[After Installation of EFDP]

Response to Action Item 5-6 Section 5.4.2.1

Figure-2. Axial Mass Flux of OPR1000 and APR1400 SG according to Number of EFDPs

TS

[OPR1000]

[APR1400]

Non-Proprietary

Response to Action Item 5-6 Section 5.4.2.1

Table-1. Tube Wear Status at U-bend Region of Han-bit Units 5&6[1]

TS

Note)

1. Commercial Operation Dates of Han-bit Units 5&6 are May 2002 and December 2002, respectively. 6th ISI dates of Han-bit Units 5&6 are August 2009 and March 2010, respectively.

Non-Proprietary

Response to Action Item 5-6 Section 5.4.2.1

Table-2. Tube Wear Status at U-Bend Region of Han-ul Units 5&6[(1)]

TS

Note)

1. Commercial Operation Dates of Han-ul Units 5&6 are July 2004 and April 2005, respectively. 6th ISI dates of Han-ul Units 5&6 are November 2011 and October 2012, respectively.

Response to Action Item 5-6 Section 5.4.2.1

The following statement will be added in Subsection 5.4.2.1.2.2:

> “The operating experiences related to the tube wear status at Korean Nuclear Power Plants provide a justification for the assertion.”

Impact on DCD
DCD 5.4.2.1.2.2 will be revised as indicated in the attached markup.

Impact on PRA
There is no impact on the PRA.

Impact on Technical Specifications
There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports
There is no impact on any Technical, Topical or Environmental Reports.

One set of eggcrate flow distribution plate is installed at the full eggcrate of steam generator to prevent the secondary-side flow from concentrating into central cavity. This design has been proven to effectively reduce localized wear since having been applied to previous nuclear power plants. The flow distribution plate is fixed onto the square-section ring in the full eggcrate with retainer ring segment and hexagon head cap screws. The cover plate is provided in the center of the flow distribution plate for manufacturing process. Lock washers and initial preloads for the cap screws are applied.

Add. "The operating experiences related to the tube wear status at Korean Nuclear Power Plants provide a justification for the assertion."

Steam Generator Tubes an

To limit the potential for the tubes to be dented, the tube support structures are fabricated from stainless steel Type 409 material (see Table 5.2-2). Tube denting is associated with the corrosion of tube support structures and creates a hard corrosion product that fills the crevice between the tube and the tube support. Dents can result in the restriction of primary coolant flow and stress-corrosion cracking of the tubes.

To limit the susceptibility of steam generator tubes to corrosion and to optimize the corrosion resistance of the microstructure, the APR1400 steam generator tubes are made of NiCrFe Alloy 690 that is thermally treated (TT). To reduce residual stresses in the U-bent region of short-radius (less than or equal to 279.4 mm [11 in]) U-bent tubes, the U-bent region of short-radius tubes is stress-relieved after bending. The materials that support the tubes and other materials on the secondary side, such as flow distribution plate and eggcrate flow distribution plate, are stainless steels that are sufficiently resistant to degradation to provide reasonable assurance that the tubes will remain adequately supported and to reduce the potential for the generation of loose parts, which can result in loss of tube integrity.

In addition, to prevent PWSCC, thermally treated alloy 690 (690TT) and 52/52M/152 weld metals are used for the steam generators. An additional discussion of the avoidance of stress corrosion cracking for Ni-base alloys is included in Subsection 5.2.3.5.

Tube Fastening to Tubesheet

The method of fastening tubes to the tubesheet conforms to the requirements of ASME Sections III and IX. Tube expansion into the tubesheet is such that no voids or crevices occur along the length of the tube in the tubesheet. The tube is expanded into the

Response to Action Item 5-6 Section 5.4.2.1

MCB Issue List Regarding APR-1400, FSAR Section 5.4.2.1

Issue #7 (AI 5-6.7)

FSAR Subsection 5.4.2.1.2.2 has a topic called, “Tube Fastening to Tubesheet,” which states that the fastening methods, “conform to the requirements of ASME Code Sections III and XI.” It describes expansion of the tube into the tubesheet but does not describe the requirements for welding the tube end to the tubesheet cladding.

Revise FSAR Subsection 5.4.2.1.2.2 to state that the welds joining the tube ends to the tubesheet cladding are structural welds that meet all of the requirements of Section NB-3200 of the Section III of the ASME Code.

Response

According to Subsection 5.4.2.1.2.2, tube fastening to tubesheet conforms to the requirements of ASME Code Sections III and IX. The joint classification will be added in the DCD 5.4.2.1.2.2.

Impact on DCD

DCD 5.4.2.1.2.2 will be revised as indicated in the attached markup.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical or Environmental Reports.

One set of eggcrate flow distribution plate is installed at the full eggcrate of steam generator to prevent the secondary-side flow from concentrating into central cavity. This design has been proven to effectively reduce localized wear since having been applied to previous nuclear power plants. The flow distribution plate is fixed onto the square-section ring in the full eggcrate with retainer ring segment and hexagon head cap screws. The cover plate is provided in the center of the flow distribution plate for manufacturing process. Lock washers and initial preloads for the cap screws are applied.

Steam Generator Tubes and Other Secondary Non-pressure Boundary Material

To limit the potential for the tubes to be dented, the tube support structures are fabricated from stainless steel Type 409 material (see Table 5.2-2). Tube denting is associated with the corrosion of tube support structures and creates a hard corrosion product that fills the crevice between the tube and the tube support. Dents can result in the restriction of primary coolant flow and stress-corrosion cracking of the tubes.

To limit the susceptibility of steam generator tubes to corrosion and to optimize the corrosion resistance of the microstructure, the APR1400 steam generator tubes are made of NiCrFe Alloy 690 that is thermally treated (TT). To reduce residual stresses in the U-bent region of short-radius (less than or equal to 279.4 mm [11 in]) U-bent tubes, the U-bent region of short-radius tubes is stress-relieved after bending. The materials that support the tubes and other materials on the secondary side, such as flow distribution plate and eggcrate flow distribution plate, are stainless steels that are sufficiently resistant to degradation to provide reasonable assurance that the tubes will remain adequately supported and to reduce the potential for the generation of loose parts, which can result in loss of tube integrity.

In addition, to prevent PWSCC, therm
metals are used for the steam genera
stress corrosion cracking for Ni-base a

Add. "The tubes are welded to the tubesheet cladding after the primary side of the tubesheet is weld clad with nickel-chromium-iron alloy. These fusion welds comply with Sections III and IX of the ASME Code. The tube-to-tubesheet weld is designed to satisfy the allowable limits described in NB-3200 of the Section III of the ASME Code."

Tube Fastening to Tubesheet

The method of fastening tubes to the tubesheet conforms to the requirements of ASME Sections III and IX. Tube expansion into the tubesheet is such that no voids or crevices occur along the length of the tube in the tubesheet. The tube is expanded into the

Response to Action Item 5-6 Section 5.4.2.1

MCB Issue List Regarding APR-1400, FSAR Section 5.4.2.1

Issue #8 (AI 5-6.8)

To meet the requirements of 10 CFR Part 50, Appendix A, GDC 14, GDC 15, and GDC 31 with respect to steam generator design, the design should limit the potential for tube degradation and thermal treatment for stress relief of "tight-radius" tube U-bends should be performed. The discussion of "Steam Generator Tubes and other Secondary Non-Pressure Boundary Material," in FSAR Subsection 5.4.2.1.2.2, states that for the APR 1400 this applies to tubes with a bend radius of less than or equal to 11 inches. The figures in FSAR Section 5.4.2 indicate that most of the tubes are square-bends rather than U-bends, so it is unclear how the stated 11 inch bend radius limit applies.

Revise FSAR Section 5.4.2.1.2.2 to clearly explain which rows of steam generator tubes are U-bends, which rows are square-bends, and which rows are thermally treated for stress relief.

Response

The following paragraph about steam generator tube bending and thermal treatment for stress relief will be added at the end of first paragraph of FSAR Section 5.4.2.1.2.2:

> "There are 13,102 tubes installed in an APR1400 steam generator. Tube bundle has 175 rows and 207 lines (columns). Tubes in row number 1 through 17 are U-bends and tubes in row number 18 through 175 are square-bends. Maximum bend radius of U-bend tube is 11 inches for row number 17. The bend radius of all square-bend tubes is 10 inches. All the U-bend tubes (row number 1 through 17) are thermally treated for stress relief."

Impact on DCD

DCD 5.4.2.1.2.2 will be revised as indicated in the attached markup.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical or Environmental Reports.

eliminates the possibility of a condensation-induced water hammer in the economizer feedwater line.

5.4.2.1.2.1.3 Thermal Stratification at Feedwater nozzle

NRC Bulletin 79-13 (Reference 10) addresses the effect of thermal stratification that leads to cracking of the feedwater line.

The APR1400 feedwater lines are designed to minimize thermal stratification. The feedwater lines are angled downward from the horizontal to minimize the potential for thermal stratification.

Thermal stratification could occur in the horizontal sections of piping when the incoming feedwater flow rate is low and there is a large temperature difference between the incoming feedwater and the steam generator coolant, which results in a density difference. Fluctuations in the elevation of the interface between the hot and cold coolants cause thermal fatigue damage.

As shown in Figure 5.4.2-1, the upward bend using a goose-neck design is incorporated to avoid the stratified flows in the piping connecting the thermal sleeve in the downcomer feedwater nozzle to the downcomer feedwater piping inside the steam generator.

5.4.2.1.2.2 Material Design

The design of the APR1400 steam generators limits the potential for degradation so the integrity of the steam generator, including the tubes, is maintained during the operating period between inspections. Degradation of the steam generator tubes and other secondary side components that could affect tube integrity is manageable through the steam generator program (see Subsection 5.4.2.2). In addition, degradation of steam generator RCPB materials is manageable through the inservice inspection program (See Subsection 5.2.4).

Add. "There are 13,102 tubes installed in an APR1400 steam generator. Tube bundle has 175 rows and 207 lines (columns). Tubes in row number 1 through 17 are U-bends and tubes in row number 18 through 175 are square-bends. Maximum bend radius of U-bend tube is 11 inches for row number 17. The bend radius of all square-bend tubes is 10 inches. All the U-bend tubes (row number 1 through 17) are thermally treated for stress relief."

Response to Action Item 5-6 Section 5.4.2.1

MCB Issue List Regarding APR-1400, FSAR Section 5.4.2.1

Issue #9 (AI 5-6.9)

FSAR Subsection 5.4.2.1.2.2 states, “One set of eggcrate flow distribution plate is installed at the full eggcrate of steam generator to prevent the secondary-side flow from concentrating into central cavity.” In Figure 5.4.2-1, the flow distribution plate (FDP) appears to be the central portion of the uppermost full eggcrate support. If this is correct, it is not clear how this eggcrate FDP is different than the rest of the eggcrate at that level. It is also unclear whether tubes pass through the FDP, or only fluid passes through the FDP.

Revise the statement above from FSAR Subsection 5.4.2.1.2.2 to explain the function of the eggcrate FDP and how the design is different than the rest of the eggcrate at that level.

Response

Eggcrate flow distribution plate (EFDP) has been adopted to mitigate the concentrated flow into the central cavity region installed at the uppermost full eggcrate. The EFDP is a stainless steel (SA-240 Type 405) perforated plate with Φ0.75 inch circular flow holes in a triangular array (the pitch is 1.875 inches). No tubes pass through the EFDP and only secondary side fluid passes through the EFDP. The eggcrates (including the one at that level) are composed of strips intersecting at an angle of 60 degrees as shown in Figure 5.4.2-4 in the DCD Tier 2.

TS

Response to Action Item 5-6 Section 5.4.2.1

Impact on DCD
DCD 5.4.2.1.2.2 will be revised as indicated in the attached markup.

Impact on PRA
There is no impact on the PRA.

Impact on Technical Specifications
There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports
There is no impact on any Technical, Topical or Environmental Reports.

Add. "uppermost"

Revise. "mitigate"

[illegible]t of eggcrate flow distribution plate is installed at the full eggcrate of steam generator to ~~prevent~~ the secondary-side flow from concentrating into central cavity. This design has been proven to effectively reduce localized wear since having been applied to previous nuclear power plants. The flow distribution plate is fixed onto the square-section [illegible] full eggcrate with retainer ring segment and hexagon head cap screws. The cover plate is provided in the center of the flow distribution plate for manufacturing process. Lock [illegible] loads for the cap screws are applied.

Add. "eggcrate"

Add. "eggcrate"

Steam Gen[illegible]

Add. "Eggcrate flow distribution plate is a stainless steel perforated plate with circular flow holes. No tubes pass through the eggcrate flow distribution plate and only secondary side fluid passes through the eggcrate flow distribution plate."

To limit the [illegible] fabricated from stainless steel Type 409 material (see Table 5.2-2). Tube denting is associated with the corrosion of tube support structures and creates a hard corrosion product that fills the crevice between the tube and the tube support. Dents can result in the restriction of primary coolant flow and stress-corrosion cracking of the tubes.

To limit the susceptibility of steam generator tubes to corrosion and to optimize the corrosion resistance of the microstructure, the APR1400 steam generator tubes are made of NiCrFe Alloy 690 that is thermally treated (TT). To reduce residual stresses in the U-bent region of short-radius (less than or equal to 279.4 mm [11 in]) U-bent tubes, the U-bent region of short-radius tubes is stress-relieved after bending. The materials that support the tubes and other materials on the secondary side, such as flow distribution plate and eggcrate flow distribution plate, are stainless steels that are sufficiently resistant to degradation to provide reasonable assurance that the tubes will remain adequately supported and to reduce the potential for the generation of loose parts, which can result in loss of tube integrity.

In addition, to prevent PWSCC, thermally treated alloy 690 (690TT) and 52/52M/152 weld metals are used for the steam generators. An additional discussion of the avoidance of stress corrosion cracking for Ni-base alloys is included in Subsection 5.2.3.5.

Tube Fastening to Tubesheet

The method of fastening tubes to the tubesheet conforms to the requirements of ASME Sections III and IX. Tube expansion into the tubesheet is such that no voids or crevices occur along the length of the tube in the tubesheet. The tube is expanded into the

Non-Proprietary

Response to Action Item 5-6 Section 5.4.2.1

MCB Issue List Regarding APR-1400, FSAR Section 5.4.2.1

Issue #10 (AI 5-6.10)

In order for the staff to evaluate the effect of design features on tube integrity, revise FSAR Section 5.4.2.1 to describe the SG tube pattern and spacing.

Response

The following statement will be added in Section 5.4.2:

“Straight portion of tube is triangular array with 25.4 mm (1.00 in) pitch. U-bend portion of tube is rotated square array with 31.27 mm (1.231 in) pitch.”

Please note that the tube array and pitch for OPR1000 and APR1400 steam generators are identical.

Impact on DCD

DCD 5.4.2 will be revised as indicated in the attached markup.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical or Environmental Reports.

The steam generator tube material is thermally treated NiCrFe Alloy 690 (ASME SB-163). The outside diameter is 19.05 mm (0.75 in) with 1.0668 mm (0.042 in) nominal wall thickness. An analysis is performed to establish the maximum allowable tube wall degradation for the steam generator tubes in accordance with the requirements of NRC RG 1.121 (Reference 8). Load conditions considered are maximum tube differential pressures during normal operation and faulted load conditions. The margin of safety against tube rupture under normal operating condition is not less than 3.0, and the margin of safety again [illegible] steam line break, or feedwater line break concurrent with an SSE, are consistent with the margin of safety determined by the stress limits specified in the ASME Code.

Add. "Straight portion of tube is triangular array with 25.4 mm (1.00 in) pitch. U-bend portion of tube is rotated square array with 31.27 mm (1.231 in) pitch."

The more probable modes of tube failure, which result in smaller break areas, are the results from involving the occurrence of pinholes or small cracks in the tubes and of cracks in the seal welds between the tubes and tubesheet. Detection and control of steam generator tube leakage are described in Subsection 5.2.5.

The concentration of radioactivity in the secondary side of the steam generators is dependent on the concentration of radionuclides in the reactor coolant, the primary-to-secondary leak rate, and the rate of steam generator blowdown. The specific activities that are expected in the secondary side of the steam generators during normal operation are given in Section 11.1.

The recirculation water within the steam generators contains volatile additives necessary for proper chemistry control. These and other chemistry considerations for the steam generators are discussed in Subsection 10.3.5.

5.4.2.1 Steam Generator Materials

5.4.2.1.1 Selection, Processing, Testing, and Inspection of Materials

The pressure boundary materials used in the construction of the steam generators are listed in Table 5.2-2. These materials are in accordance with ASME Section III. The Code Cases used in the fabrication of the steam generators are described in Subsection 5.2.1.

Response to Action Item 5-6 Section 5.4.2.1

MCB Issue List Regarding APR-1400, FSAR Section 5.4.2.1

Issue #11 (AI 5-6.11)

Compliance with ASME Code Section III (NB-2160, NB-3121, NC-2160, and NC-3121) requires an appropriate allowance for corrosion and other forms of degradation. FSAR Subsection 5.4.2.1.2.2 states that the corrosion allowance for carbon and low alloy steels is 1/16 inch and that other materials have “sufficiently high corrosion resistance.”

Revise FSAR Subsection 5.4.2.1.2.2. to explain the meaning of “sufficiently high corrosion resistance,” identify the corrosion allowance for the materials deemed to have “sufficiently high corrosion resistance,” and provide the basis for the corrosion allowance specified for each of these materials for the design life of the plant.

Response

The materials of primary and secondary side Code class 1,2 and 3 parts of the APR1400 steam generator include: 1) austenitic stainless steel cladding, Alloy 690 base metal and Alloy 52(M)/ 152 weld metals (divider bar, its welds, and tubesheet cladding) and martensitic stainless steel type 410S (divider plate) for primary side components, and 2) low alloy steel (shells, large diameter nozzles, etc.), carbon steel (top head, large diameter safe ends and small nozzles), and Alloy 690 (tubes) for secondary side components.

According to the experiments done by Combustion Engineering[1)], the following general corrosion rates were determined after exposure to AVT chemistry faulted with concentrated, acidified fresh water for 249 days:

For type 347 stainless steel: 0.013 - 0.048 mils per year (mpy)
For type 405 and 409 ferritic stainless steel: 0.028 - 0.061 mpy
For 1010 carbon steel: 0.135 - 0.524 mpy
For A508 class 2 low ally steel: 0.122 - 0.380 mpy

For primary water condition with or without zinc, the general corrosion rates in Table 1 were determined by the Westinghouse[2)]:

Table 1. Approximate Corrosion Rate at 3.5 Months

Material	Corrosion			
	with Zn		without Zn (mdm)	
	mdm	mpy [1)]	mdm	mpy [1)]
304SS	1.1	0.00055	3.5	0.00175
316SS	1.3	0.00065	3.5	0.00175
600MA	1.5	0.00075	2.6	0.0013
600TT	0.5	0.00025	2.1	0.00105
690TT	0.2	0.0001	1.3	0.00065

Response to Action Item 5-6 Section 5.4.2.1

Note 1): The mpy values are not reported by the Westinghouse, but are converted with approximate conversion factor of 1mdm ≈ $5x10^{-4}$ mpy.

That is, for primary water conditions, the severity of general corrosion is austenitic stainless steel > Alloy 600 > Alloy 690.

However, carbon or low alloy steels, or Alloy 690 are the only materials used for the primary or secondary pressure boundary; there is no austenitic stainless steel used for the primary and secondary side pressure boundary of the APR1400 steam generators. The low alloy steel components which comprise the primary side primary boundary are covered with austenitic stainless steel or nickel base alloy.

For the primary side, a corrosion allowance of 2 mils or 0.03 mpy (0.053 mm or 0.0008 mm/year) for austenitic stainless steel and nickel base alloy cladding is used. This value is considered conservative since the reported maximum corrosion rate of austenitic stainless steel is 0.00175 mpy ($4.45x10^{-5}$ mm/year), which is measured in primary water environment without zinc addition (See Table 1).

For carbon steels and low alloy steels of secondary side of steam generator, the corrosion allowance of 1.0 mpy (0.025 mm/year) is reasonable because the highest corrosion rate is 0.524 mpy (0.01 mm/year) in the secondary-side low level faulted condition. Thus, an overall corrosion allowance of 1/16 inch (62.5 mils or 1.6 mm) will be sufficient for the 60 year design life of the APR1400 steam generator.

Note: 1. J.J. Krupowicz, "Corrosion of Support Materials", paper presented to the EPRI proceedings (EPRI NP-2791, Proceedings: Support-Structure Corrosion in Steam Generator)," Jan. 1983, page 2-7.

2. J.N. Esposito, et al., "The Addition of Zinc to Primary Reactor Coolant for Enhanced PWSCC Resistance," paper presented at the symposium (International Symposium on Environmental Degradation of Materials in Nuclear Power Systems- Water Reactors)," 1991, page 497.

Based on the above evaluation, FSAR 5.4.2.1.2 will be revised as follows:

"<u>Corrosion Allowance</u>

Carbon or low allow steel materials, which compose the pressure boundary of the secondary side, have a corrosion allowance of 1.6 mm (1/16 in). For the primary side pressure boundary materials which are low alloy steel, they are protected against general corrosion with austenitic stainless steel or Ni-base alloy deposited cladding which has a corrosion allowance of 0.053 mm (0.002 in). These corrosion allowances for the primary and secondary side pressure boundary materials are selected based on test data. Therefore, there is no expectation of a general corrosion problem in the APR1400 steam generators."

Non-Proprietary

Response to Action Item 5-6 Section 5.4.2.1

Impact on DCD
DCD 5.4.2.1.2.2 will be revised as indicated in the attached markup.

Impact on PRA
There is no impact on the PRA.

Impact on Technical Specifications
There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports
There is no impact on any Technical, Topical or Environmental Reports.

tubesheet by the use of hydraulic expansion. For hydraulic expansion, the expansion mandrel length is set to provide full-depth expansion, and hydraulic pressure is accurately applied, measured, reapplied, and controlled inside the tube so that the crevice between the tube and tubesheet is as small as possible. Expansion of tubes creates residual stresses in the transition zone between the expanded and the unexpanded regions of the tube. Residual stress measurements have been taken on the transition zone. The residual stress measurements verify the absence of any high residual tensile stress in the transition zone. Material specifications such as the use of TT tubing, welding procedures and fabrication procedures preclude the need for complete-bundle stress relief after assembly.

Corrosion Allowance

Carbon or low alloy steel materials, which compose the pressure boundary of secondary side, have the corrosion allowance of 1.5875 mm (1/16 in). Other secondary side materials and primary side materials are Ni-based alloys or austenitic stainless steels or clad with these materials, which have sufficiently high corrosion resistance.

Bolting Materials

Primary studs and nuts of the APR1400 steam generators are SB-637 N07718, and secondary studs and nuts are SA-540 Grade B24, or SA-193 Grade B7. These studs and nuts have performed adequately under service conditions and have not shown stress-corrosion cracking. The yield strength of ferritic fastener materials is limited to a maximum of 10,546 kg/cm^2 (150 ksi).

5.4.2.1.3 Fabrication and Processing of Ferritic Materials

Fracture Toughness

The Class 1 components of the steam generator meet the fracture toughness requirements of the ASME Code. Fracture toughness testing is described further in Subsection 5.2.3.3.

Revise. "Carbon or low allow steel materials, which comprise the pressure boundary of the secondary side, have the corrosion allowance of 1.6 mm (1/16 in). For the primary side pressure boundary materials which are low alloy steel, they are protected against general corrosion with austenitic stainless steel or Ni-base alloy deposited cladding which has a corrosion allowance of 0.053 mm (0.002 in). These corrosion allowances for the primary and secondary side pressure boundary materials are selected based on test data. Therefore, there is no expectation of a general corrosion problem in the APR1400 steam generators."

Response to Action Item 5-6 Section 5.4.2.1

MCB Issue List Regarding APR-1400, FSAR Section 5.4.2.1

Issue #12 (AI 5-6.12)

The paragraph on "Tube Supports" in FSAR Subsection 5.4.2.1.2.2 states that the tube supports contact the tubes with a flat surface except for the flow distribution plate above the economizer section entrance. The method of contact with the tubes is important with respect to 10 CFR Part 50, Appendix A, GDC 14, 15, and 31 because of the potential for mechanical and chemical effects on tube integrity.

Revise FSAR Subsection 5.4.2.1.2.2 to describe how the flow distribution plate contacts the tubes.

Response

The following statement will be added in Subsection 5.4.2.1.2.2 "Tube Supports":

"The flow distribution plate is a stainless steel perforated plate with circular flow holes, where the tube and secondary side fluid pass. The diameter of a flow hole is 19.685 mm (0.775 in)."

Impact on DCD

DCD 5.4.2.1.2.2 will be revised as indicated in the attached markup.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical or Environmental Reports.

Tube Supports

Add. "The flow distribution plate is a stainless steel perforated plate with circular flow holes, where the tube and secondary side fluid pass. The diameter of a flow hole is 19.685 mm (0.775 in)."

The three types of structures in the APR1400 steam generators that support the tubes are horizontal grid or eggcrate, vertical, and diagonal. All three types are fabricated from Stainless Steel Type 409. A design consideration for the supports is the prevention of dryout at support locations. With one exception, all tube supports in the APR1400 steam generator are constructed of flat strips that present a flat surface to the tube. The exception is the flow distribution plate just above the entrance to the economizer section of the tube bundle. At this location, secondary water is subcooled, and dryout will therefore not occur.

The eggcrates have three configurations depending on their location in the evaporator: a full circular structure, a half circular structure, and a structure bounded by the circumference and a chord. An eggcrate is composed of strips intersecting at an angle of 60 degrees and joined at the outer and inner perimeters with a pair of square bars on top and bottom. The strips alternate between a 50.8 mm (2 in) slotted type and a 25.4 mm (1 in) unslotted type; both are 2.286 mm (0.090 in) thick (refer to Figure 5.4.2-4). The eggcrates themselves are supported and spaced by tie rods located throughout the tube bundle and by the weldment to the tube bundle shroud.

The eggcrates form an open lattice and thus minimize the potential for local dryout conditions. The number of eggcrates is selected to maintain the natural frequency of the tubes that is significantly higher than the exciting frequencies induced by cross flow at the fluid entrances to the bundle. Both analysis and test results have been applied to define spacing that precludes vibration-induced damage (fretting and wear). In addition, careful attention is paid to localized flow path details where velocities may be higher than nominal. The vertical supports, shown in Figure 5.4.2-5, are assembled concurrently with tube installation and are composed of vertical, slotted 50.8 mm (2 in) strips intersecting with horizontal 12.7 mm (0.5 in) strips; both 2.286 mm (0.090 in) thick. The assembly is bounded about the periphery by either square bars or custom-shaped plates depending on the location. The vertical supports in the bend region are made of perforated strips to enhance their free-flowing nature. As shown on Figure 5.4.2-5, the vertical supports are also integrated with perforated diagonal strips, which provide thorough vibration support of the bend region without compromising the free-flowing character of the supports.

Non-Proprietary

Response to Action Item 5-6 Section 5.4.2.1

MCB Issue List Regarding APR-1400, FSAR Section 5.4.2.1

Issue #13 (AI 5-6.13)

To meet the requirements of 10 CFR Part 50, Appendix A, GDC 14, 15, and 31, the ferritic materials used to form the primary and secondary pressure boundaries must: (1) comply with Appendix G to 10 CFR Part 50, 10 CFR 50.55a(c), (d), and (e), and (2) follow the provisions of Appendix G to Section III of the ASME Code. For Class 1 and Class 2 steam generator components, the regulations cited above require the use of Section III of the ASME Code. Article NB-2300, Article NC-2300, and Appendix G of Section III of the ASME Code address fracture toughness requirements for Class 1 and Class 2 components. FSAR Subsection 5.4.2.1.3 states that Class 1 components meet the fracture toughness requirements of the ASME Code but does not address Class 2 components.

Revise FSAR Subsection 5.4.2.1.3 to state the requirements for both Class 1 and Class 2 components. This can be accomplished with a reference to FSAR Subsection 5.2.3.3 with additional information to address the requirements for the Class 2 steam generator components.

Response

Tier 1, page 2.4-6 defines the ASME Section III Class used for designing APR1400 RCS Components. The Safety Class in Table 3.2-1 in Tier 2 shows the Safety Class that ASME requires in designing Nuclear Power Plants.

The pressure boundary components of the APR1400 steam generators are entirely ASME Section III Class 1 components even though the secondary side of the steam generator is classified as Safety Class 2 (See Tier 1, Page 2.4-6 and Tier 2, Table 3.2-1). Therefore, for clarification, the first sentence of Subsection “Fracture Toughness” of FSAR Section 5.4.2.1.3 will be revised as follows:

> “The primary and secondary side pressure boundary components of the steam generator meet the fracture toughness requirements of the ASME Code, Section III NB.”

Impact on DCD

DCD 5.4.2.1.3 will be revised as indicated in the attached markup.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical or Environmental Reports.

tubesheet by the use of hydraulic expansion. For hydraulic expansion, the expansion mandrel length is set to provide full-depth expansion, and hydraulic pressure is accurately applied, measured, reapplied, and controlled inside the tube so that the crevice between the tube and tubesheet is as small as possible. Expansion of tubes creates residual stresses in the transition zone between the expanded and the unexpanded regions of the tube. Residual stress measurements have been taken on the transition zone. The residual stress measurements verify the absence of any high residual tensile stress in the transition zone. Material specifications such as the use of TT tubing, welding procedures and fabrication procedures preclude the need for complete-bundle stress relief after assembly.

Corrosion Allowance

Carbon or low alloy steel materials, which compose the pressure boundary of secondary side, have the corrosion allowance of 1.5875 mm (1/16 in). Other secondary side materials and primary side materials are Ni-based alloys or austenitic stainless steels or clad with these materials, which have sufficiently high corrosion resistance.

Bolting Materials

Primary studs and nuts of the APR1400 steam generators are SB-637 N07718, and secondary studs and nuts are SA-540 Grade B24, or SA-193 Grade B7. These studs and nuts have performed adequately under service conditions and have not shown stress-corrosion cracking. The yield strength of ferritic fastener materials is limited to a maximum of 10,546 kg/cm^2 (150 ksi).

5.4.2.1.3 Fabrication and Processing of Ferritic Materials

Fracture Toughness

~~The Class 1 components of the steam generator meet the fracture toughness requirements of the ASME Code.~~ Fracture toughness testing is described further in Subsection 5.2.3.3.

Revise. “The primary and secondary side pressure boundary components of the steam generator meet the fracture toughness requirements of the ASME Code Section III NB.”

Non-Proprietary

Response to Action Item 5-6 Section 5.4.2.1

MCB Issue List Regarding APR-1400, FSAR Section 5.4.2.1

Issue #14 (AI 5-6.14)

To meet the requirements of 10 CFR Part 50, Appendix A, GDC 1, welding of ferritic Class 1 and Class 2 pressure-boundary steam generator components must comply with 10 CFR 50.55a(c), (d), and (e). FSAR Subsection 5.4.2.1.3 lists appropriate Regulatory Guides (RGs) and refers to Subsection 5.2.3.3 for welding controls; however, Subsection 5.2.3.3 states that the requirements are for reactor coolant pressure boundary components (Class 1) only.

Revise FSAR Subsection 5.4.2.1 to state that the welding requirements for ferritic Class 1 components described in Subsection 5.2.3 also apply to Class 2 steam generator components or revise FSAR Subsection 5.4.2.1 to identify specific welding requirements for ferritic Class 2 components.

FSAR Subsection 5.4.2.1 does not list conformance with RG 1.34, “Control of Electroslag Weld Properties,” nor does this subsection state that electroslag welding is not used for the steam generator Class 2 components. Revise Subsection 5.4.2.1 to, (a) state that electroslag welding is not used for steam generator components, or, (b) state that electroslag welding conforms to the guidance in RG 1.34.

Response

Regarding welding requirements, there is no difference in the application of the ASME Code and/or regulatory requirements between the primary and secondary side pressure boundary components of the APR1400 steam generator. Therefore, the following sentence will be added in front of the first sentence of Subsection “Welding” of FSAR Section 5.4.2.1.3:

> “The primary and secondary side pressure boundary components of the steam generator meet the welding requirements as described in Subsection 5.2.3.3.”
>
> “Electroslag welding (ESW) is not used in the primary or secondary side pressure boundary components of the steam generator”

Impact on DCD

DCD 5.4.2.1.3 will be revised as indicated in the attached markup.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical or Environmental Reports.

Add. "The primary and secondary side pressure boundary components of the steam generator meet the welding requirements as described in Subsection 5.2.3.3."

Welding

Subsection 5.2.3.3 describes the controls for welding ferritic steels. Conformance to the applicable NRC RGs for steam generators is summarized as follows:

a. NRC RG 1.50, "Control of Preheat Temperature for Welding of Low-Alloy Steel," is addressed in Subsection 5.2.3.3.

b. NRC RG 1.71, "Welder Qualification for Areas of Limited Accessibility," is addressed in Subsection 5.2.3.3.

c. NRC RG 1.43, "Control of Stainless Steel Weld Cladding of Low-Alloy Steel Components," is addressed in Subsection 5.2.3.3.

5.4.2.1.4 Fabrication and Processing of Austenitic Stainless Steel

Limiting Susceptibility to Cracking

Add. "Electroslag welding (ESW) is not used in primary and secondary side pressure boundary components of the steam generator."

Cold-worked austenitic stainless steel is not used for steam generator RCPB materials.

Fabrication of the steam generator is consistent with the recommendations of NRC RG 1.44, except for the criterion used to demonstrate freedom from sensitization. ASTM A 262 Practice A or E is used to demonstrate freedom from sensitization in fabricated and unstabilized stainless steel. Stabilized stainless steels are not subject to sensitization. Stress corrosion cracking of unstabilized austenitic stainless steels in the pressure boundary of the APR1400 steam generators is prevented through the following:

a. Solution heat treatment

b. Implementation of the procedures and/or practices demonstrated not to produce a sensitized structure for the fabrication of RCPB components

c. Delta ferrite control of weld filler metal, which is controlled to 8FN-15FN (8FN-16FN for Type 309 (L)) with no reading below 5FN as deposited

Response to Action Item 5-6 Section 5.4.2.1

MCB Issue List Regarding APR-1400, FSAR Section 5.4.2.1

Issue #15 (AI 5-6.15)

Controls are needed in the fabrication and processing of austenitic stainless steel Class 1 and Class 2 pressure boundary components in order to meet 10 CFR Part 50, Appendix A, GDC 14, GDC 15, and GDC 31. FSAR Subsection 5.4.2.1.4 provides these requirements. However, the staff notes that since this topic is complex and addressed elsewhere in the FSAR, it would be appropriate to remove the details from FSAR Subsection 5.4.2.1.4 and refer to Subsection 5.2.3.4. The staff will address the documentation of controls on the fabrication and processing of austenitic stainless steel materials further in its Issue List for FSAR Section 5.2.3.

Revise FSAR Section 5.4.2.1.4 to delete statements regarding controls on the fabrication and processing of austenitic stainless steel materials and instead insert a reference to FSAR Section 5.2.3.4.

Response

The fabrication and processing requirements for austenitic stainless steel materials described in FSAR Section 5.4.2.1.4 are the same as those of FSAR Section 5.2.3.4. However, there is no austenitic stainless steel used for the primary and secondary side pressure boundary of steam generator in APR 1400. To be consistent with the answer to Issue #5, FSAR 5.4.2.1.4 will be replaced with the following sentence:

> "There is no austenitic stainless steel that is used for the primary and secondary side pressure boundary of steam generators of APR1400."

Impact on DCD

DCD 5.4.2.1.4 will be revised as indicated in the attached markup.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical or Environmental Reports.

Welding

Subsection 5.2.3.3 describes the controls for welding ferritic steels. Conformance to the applicable NRC RGs for steam generators is summarized as follows:

a. NRC RG 1.50, "Control of Preheat Ter[...] is addressed in Subsection 5.2.3.3.

Replace.
"There is no austenitic stainless steel that is used for the primary and secondary side pressure boundary of the APR1400 steam generators."

b. NRC RG 1.71, "Welder Qualification for Areas of Limited Accessibility," is addressed in Subsection 5.2.3.3.

c. NRC RG 1.43, "Control of Stainless Steel Weld Cladding of Low-Alloy Steel Components," is addressed in Subsection 5.2.3.3.

5.4.2.1.4 Fabrication and Processing of Austenitic Stainless Steel

~~Limiting Susceptibility to Cracking~~

~~Cold-worked austenitic stainless steel is not used for steam generator RCPB materials.~~

~~Fabrication of the steam generator is consistent with the recommendations of NRC RG 1.44, except for the criterion used to demonstrate freedom from sensitization. ASTM A 262 Practice A or E is used to demonstrate freedom from sensitization in fabricated and unstabilized stainless steel. Stabilized stainless steels are not subject to sensitization. Stress corrosion cracking of unstabilized austenitic stainless steels in the pressure boundary of the APR1400 steam generators is prevented through the following:~~

~~a. Solution heat treatment~~

~~b. Implementation of the procedures and/or practices demonstrated not to produce a sensitized structure for the fabrication of RCPB components~~

~~c. Delta ferrite control of weld filler metal, which is controlled to 8FN-15FN (8FN-16FN for Type 309 (L)) with no reading below 5FN as deposited~~

d. Prohibition of exposure of unstabilized austenitic Type 300 series stainless steels to temperatures ranging from 427 to 816 °C (800 to 1,500 °F)

e. Limit of carbon content of unstabilized austenitic Type 300 series stainless steels to a maximum of 0.065 percent

f. Control of welding parameters:

1) Weld heat input to less than 23.6 kJ/cm (60 kJ/in)

2) Interpass temperature to a maximum of 176.7 °C (350 °F)

Avoidance of stress corrosion cracking is described further in Subsection 5.2.3.4.

Requirements for cleanliness and contamination protection are included in the equipment specification for the steam generator fabricated with austenitic stainless steel. Procedures for contamination control during fabrication, shipment, and storage of the steam generator meet the requirements of NRC RG 1.28. Avoidance of contamination causing stress corrosion cracking is described further in Subsection 5.2.3.4.

Tools used in abrasive work operations on austenitic stainless steel such as grinding or wire brushing do not contain and are not contaminated with ferritic carbon steel or other materials that could contribute to intergranular cracking or stress corrosion cracking.

The thermal insulation that is used for the steam generator is either reflective metal insulation or nonmetallic insulation that meets the criteria of NRC RG 1.36.

Welding

Subsection 5.2.3 describes the controls for welding austenitic stainless steels. Conformance to the applicable NRC RGs for the steam generator is summarized as follows:

a. NRC RG 1.31, "Control of Ferrite Content in Stainless Steel Weld Metal," is addressed in Subsection 5.2.3.4.

b. ~~NRC RG 1.34, "Control of Electroslag Weld Properties," is addressed in Subsection 5.2.3.3.~~

c. ~~NRC RG 1.71, "Welder Qualification for Areas of Limited Accessibility," is addressed in Subsection 5.2.3.3.~~

5.4.2.1.5 Compatibility of Materials with the Primary and Secondary Coolant and Cleanliness Control

Localized corrosion of tubing material has led to steam generator tube leakage in some operating reactor plants. Examinations of tube defects that have resulted in leakage have shown that two mechanisms are primarily responsible. Localized corrosion mechanisms are referred to as stress assisted caustic cracking and wastage or tube wall thinning. Both types of corrosion have been related to steam generators that have operated on phosphate chemistry. The caustic stress-corrosion type of failure is precluded by controlling bulk water chemistry to the specification limits shown in Subsection 10.3.5.

Operating steam generators have experienced the following corrosion degradation mechanisms: phosphate wastage, sulfate wastage, intergranular attack, secondary side stress corrosion cracking, and pitting and denting resulting from tube support corrosion. With respect to these phenomena, the most important design feature of the APR1400 steam generators is the selection of tubing and tubing support materials. NiCrFe Alloy 690 TT is specified for the APR1400 steam generator tubes. Stainless Steel Type 409 material is specified for the tube supports (see Table 5.2-2).

Volatile chemistry has been successfully used to minimize corrosion in many of the steam generators that have gone into operation since 1972. Secondary water chemistry and operating chemistry limits for secondary water and feedwater are addressed in Subsection 10.3.5. Removal of solids from the secondary side of the steam generator is addressed in Subsection 10.4.8.

The onsite cleaning and cleanliness of the steam generator are controlled according to NRC RG 1.28.

Response to Action Item 5-6 Section 5.4.2.1

MCB Issue List Regarding APR-1400, FSAR Section 5.4.2.1

Issue #16 (AI 5-6.16)

The steam generator components that form the reactor coolant pressure boundary (RCPB) and the supporting structural components must be compatible with the reactor coolant and secondary coolant in order to meet the requirements of 10 CFR Part 50, Appendix A, GDC 4. However, FSAR Subsection 5.4.2.1.5 addresses only the secondary water chemistry.

Revise FSAR Subsection 5.4.2.1.5 to include a description of primary water chemistry and compatibility with the steam generator materials, or include a reference to a section in which this is addressed.

Response

For the description of the primary water chemistry of the steam generator, the following sentence will be incorporated into the FSAR 5.4.2.1.5 “Compatibility of Materials with the Primary and Secondary Coolant and Cleanliness Control:”

> “The primary water chemistry is controlled at a level comparable to the EPRI guidelines as stated in FSAR Section 5.2.3.2.1 to minimize corrosion in the steam generators. The materials of the primary side steam generators are selected to minimize corrosion and have demonstrated satisfactory performance in existing operating reactor plants. A detailed description is provided in FSAR Section 5.2.3.2.2.”

Impact on DCD

DCD 5.4.2.1.5 will be revised as indicated in the attached markup.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical or Environmental Reports.

b. NRC RG 1.34, "Cont... Subsection 5.2.3.3.

Add. "The primary water chemistry is controlled at a level comparable to the guidelines in the EPRI as stated in FSAR Section 5.2.3.2.1 to minimize corrosion in the steam generator. The materials of the primary side steam generator are selected to minimize corrosion and have demonstrated satisfactory performance in existing operating reactor plants. A detailed description is shown in FSAR Section 5.2.3.2.2."

c. NRC RG 1.71, "Welde... addressed in Subsection

5.4.2.1.5 Compatibility of Materials with the Primary and Secondary Coolant and Cleanliness Control

Localized corrosion of tubing material has led to steam generator tube leakage in some operating reactor plants. Examinations of tube defects that have resulted in leakage have shown that two mechanisms are primarily responsible. Localized corrosion mechanisms are referred to as stress assisted caustic cracking and wastage or tube wall thinning. Both types of corrosion have been related to steam generators that have operated on phosphate chemistry. The caustic stress-corrosion type of failure is precluded by controlling bulk water chemistry to the specification limits shown in Subsection 10.3.5.

Operating steam generators have experienced the following corrosion degradation mechanisms: phosphate wastage, sulfate wastage, intergranular attack, secondary side stress corrosion cracking, and pitting and denting resulting from tube support corrosion. With respect to these phenomena, the most important design feature of the APR1400 steam generators is the selection of tubing and tubing support materials. NiCrFe Alloy 690 TT is specified for the APR1400 steam generator tubes. Stainless Steel Type 409 material is specified for the tube supports (see Table 5.2-2).

Volatile chemistry has been successfully used to minimize corrosion in many of the steam generators that have gone into operation since 1972. Secondary water chemistry and operating chemistry limits for secondary water and feedwater are addressed in Subsection 10.3.5. Removal of solids from the secondary side of the steam generator is addressed in Subsection 10.4.8.

The onsite cleaning and cleanliness of the steam generator are controlled according to NRC RG 1.28.

Non-Proprietary

Response to Action Item 5-6 Section 5.4.2.1

MCB Issue List Regarding APR-1400, FSAR Section 5.4.2.1

Issue #17 (AI 5-6.17)

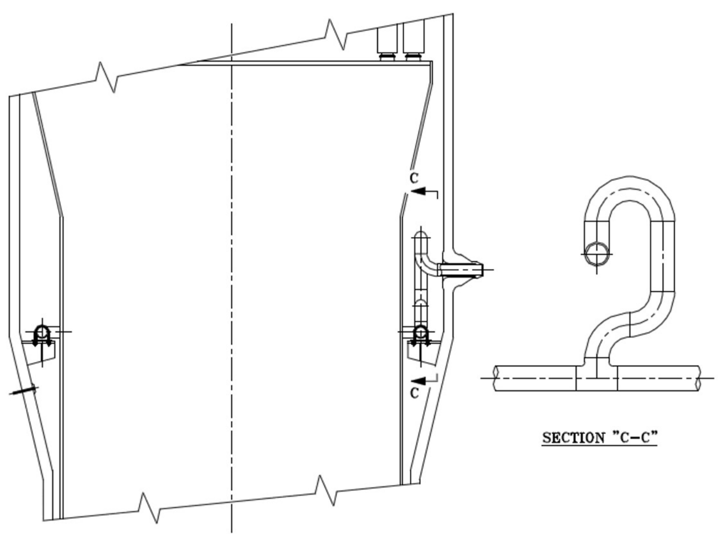
Providing adequate access for corrosion product and foreign object detection and removal is necessary to meet the requirements of 10 CFR Part 50, Appendix A, GDC 14 and GDC 15. Among the sources of loose parts are the feedwater components.

Revise FSAR Subsection 5.4.2.1.6 to explain the difference between downcomer feedwater and recirculation feedwater rings, and provide the location of the feedwater box.

Response

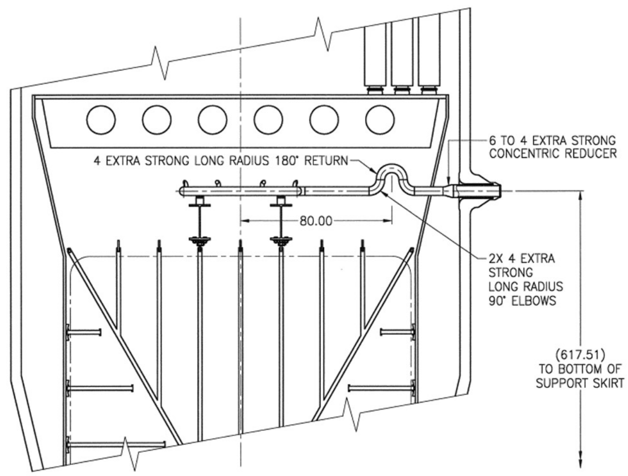
The downcomer feedwater ring inside the steam generator applies the upward bend using a goose-neck design and I-type spray nozzles having small holes (hole diameter is 0.23 inch) and are installed to prevent the foreign object inclusion. Two I-type spray nozzles at each end of the piping is threaded into the piping, thus the two I-type spray nozzles can be detached from the piping to remove any foreign objects.

The recirculation feedwater ring provides the circulation of water through the steam generator during wet lay-up and the addition of chemical cleaning agents. There are J-type discharge nozzles on the recirculation piping.

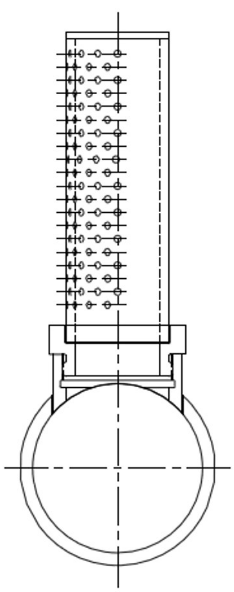


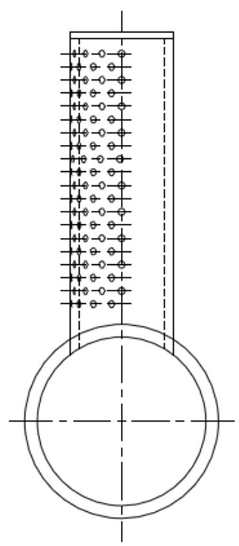
[Downcomer Feedwater Ring]

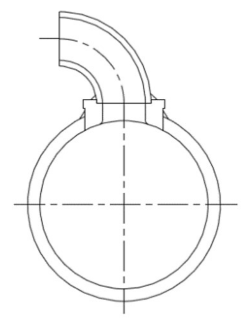
Response to Action Item 5-6 Section 5.4.2.1



[Recirculation Feedwater Ring]







[Detachable I-Type Spray Nozzle] [I-Type Spray Nozzle] [J-Type Discharge Nozzle]

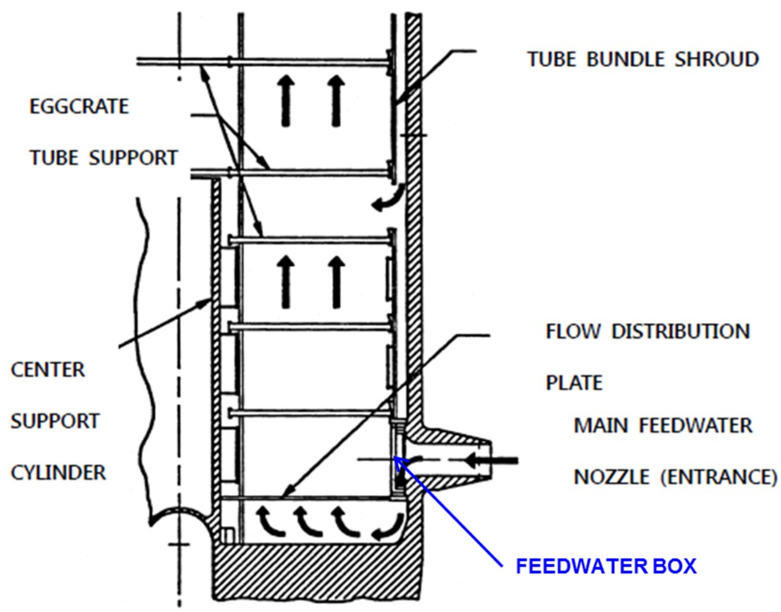
The feedwater box is installed in the pathway of economizer feedwater nozzle flow as shown in Figure 5.4.2-2.

Non-Proprietary

Response to Action Item 5-6 Section 5.4.2.1

In the feedwater box bottom plate where all the economizer feedwater inflows, there are clusters of small holes (hole diameter is 0.23 inch) to prevent any foreign objects through the economizer feedwater line. Two 5 inch inspection holes provide access to remove any foreign objects trapped in the feedwater box bottom plate. The hole clusters in the feedwater box bottom plate and two I-type spray nozzles in the downcomer feedwater piping prevent the foreign object inclusion from the feedwater line to the steam generator secondary side.

Figure 5.4.2-2 Steam Generator Economizer and Lower Tube Bundle Region



[Location of Feedwater Box at the Lower Tube Bundle Region]

Impact on DCD
There is no impact on the DCD.

Impact on PRA
There is no impact on the PRA.

Impact on Technical Specifications
There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports
There is no impact on any Technical, Topical or Environmental Reports.

Non-Proprietary

Response to Action Item 5-6 Section 5.4.2.1

MCB Issue List Regarding APR-1400, FSAR Section 5.4.2.1

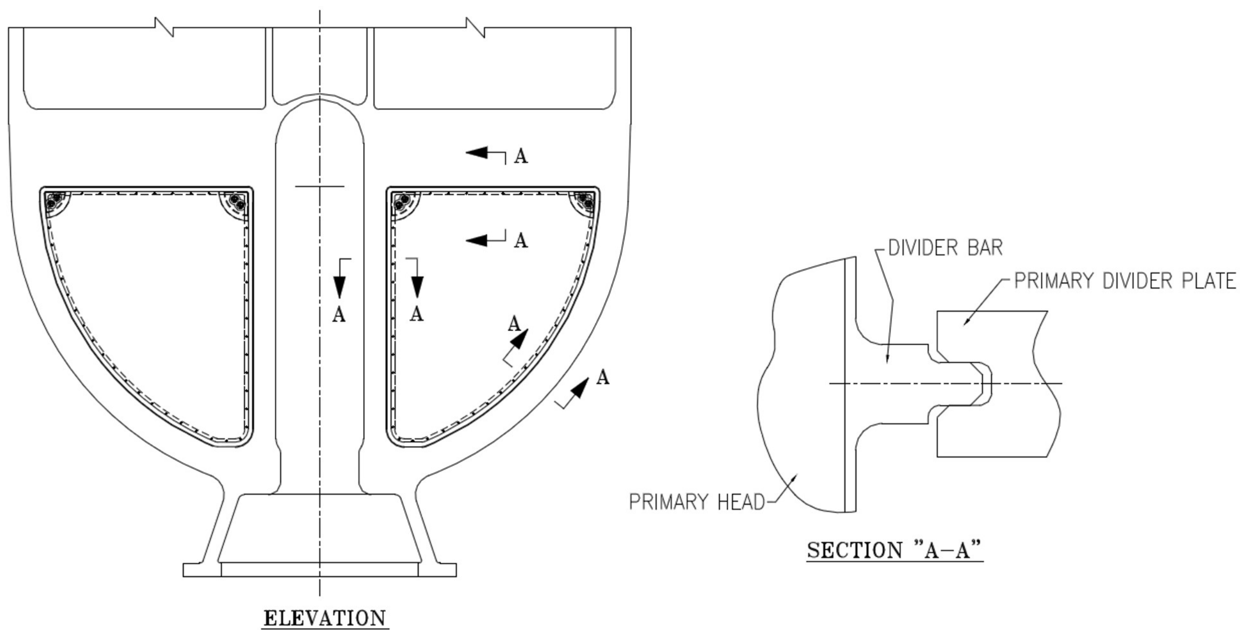
Issue #18 (AI 5-6.18)

FSAR Table 5.4.2-2 identifies SA240, Type 410S martensitic stainless steel as the divider plate material for the steam generators. If the divider plate provides structural support to pressure boundary components (e.g., tubesheet), then the FSAR needs to provide the fabrication and processing requirements.

If the divider plate provides structural support, revise FSAR Table 5.4.2-2 to include fabrication and processing requirements for SA240, Type 410S martensitic stainless steel, or include a reference to a section in which such requirements are addressed.

Response

The divider plate in the steam generator primary head applies the tongue-and-groove joint instead of welding to the primary head and tubesheet as shown below. The divider plate is not the structural support to the pressure boundary components.



Impact on DCD

There is no impact on the DCD.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Non-Proprietary

Response to Action Item 5-6 Section 5.4.2.1

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical or Environmental Reports.