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B&W Replacement RSG
Internals Degradation Assessment
Re NRC GL 97-06

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B&W Replacement RSG
INTERNALS DEGRADATION ASSESSMENT
Re NRC GL 97-06

SUMMARY

NRC Generic Letter GL 97-06 identifies six degradation mechanisms which have been observed on various European and domestic PWR steam generators. The potential for these mechanisms to occur in B&W steam generators provided as replacements for the original equipment and any confirmatory inspections recommended as a result are assessed as follows.

The design configuration and materials of internal components of B&W Canada Replacement Recirculating Steam Generators for PWR plants are different in most respects than the cited units. The tube supports are of a 410S stainless steel lattice bar configuration as compared to drilled-plates (or eggcrate supports) of carbon steel for the units cited with degradation. U-bend supports are of a 410S material flat bar construction. The bundle wrapper is supported to the main shell by robust lugs with full penetration welds at the lower end and by radial pins at various tube support elevations along the wrapper height. These, along with the tube supports, are arranged (and analyzed) to accommodate thermal motions during operation as well as accident related loads. No manufacturing thermal loads apply since all relevant (lower vessel) post weld heat treatment is performed before installation of internals. No full vessel post weld heat treatment is performed.

In total, 30 RSG units are in-service or under construction for nine reactor units operated by six different utilities. These replace O.E.M. SG's of System 67 and Model D, 44 and 51 designs. Of these, 22 are in-service and 8 SG's at 3 plants have completed inspection after first fuel cycle operation.

The effect/relevance of the individual mechanisms are addressed as follows:

i) Support Plate Wastage Due to Chemical Cleaning - is not currently relevant as none of these units have been chemically cleaned. In addition the materials and designs have generally been pre-qualified for multiple application of a chemical cleaning process at some time in the future.

ii) Broken Tube Support Ligaments - is not directly relevant because tube supports are lattice bar type rather than drilled plates. Damage to tube supports during manufacturing thermal cycles (as suggested re the cited degradation) is avoided by installation of internals after heat treatment of the lower vessel so that the tube bundle; tube supports, wrapper and related structures are not exposed to thermal effects. The shell closure weld, which is performed after tubing, is located at the conical shell and is carefully isolated from the tube bundle, tube

supports and wrapper. The closure weld is also carefully monitored/controlled during post weld heat treatment activities.

During operating transients such as heatup, the tubing, tube supports, wrapper and particularly the shell may respond thermally at different rates. In such a case, the shell temperature lag will resist free radial and axial expansions of the wrapper, tube supports, etc. Such conditions are accommodated by local flexibilities within the wrapper design which provide for the necessary differential expansion motions.

iii) Support Plate Wastage in Operation - due to corrosion conditions is addressed by material selection of the lattice bar and U-bend support bar material. The 410S stainless steel material chosen is conditioned to provide the necessary corrosion resistance as well as structural strength.

iv) Wrapper Drop - due to failure of wrapper support lugs during vessel manufacturing is avoided by installing the wrapper after vessel thermal treatment as noted above. Failure during operation is addressed by providing robust shell lugs with full penetration welds to support the lower edge of the wrapper and by accommodating radial/vertical wrapper vs shell growth during operation by providing the necessary wrapper flexibility.

v) Wrapper Cracking - due to possible wrapper vibratory motion is avoided by effectively providing anti-vibration support at numerous points including each of the fixed lower shroud lugs and by the many levels of wrapper (to shell) lateral support pins. In addition, each of the lattice grid support ring to wrapper wedge points provides additional restraint for this type of condition.

vi) Degradation of Eggcrate Supports - due to flow/corrosion effects is addressed by selection of 410S stainless steel for the lattice bars. 410S is a material with corrosion resistance and strength suitable for the operating conditions.

Beyond the six mechanisms cited it was observed during manufacture of these RSG's, that positioning of the U-bend support components could result in contact between peripheral tubes. The U-bend support structure, which is free to move with the U-bend during operating transients, is supported by the peripheral tubes by "L" or "J" shaped elements called J-tabs. It was determined that the positioning of some of the J-tabs during manufacture may cause contact between certain pairs of vertically adjacent peripheral tube U-bends. The potential for and effect of this condition has been assessed in detail and documented. The assessment has confirmed that while some fretting may occur at such contact locations it will be less than that predicted at the tube support locations and will not be sufficient to limit safe operation of the tubing. In-situ inspections of the equipment have indicated that tube proximity (less than desired clearance or possible contact) is indicated for a small number of tubes on a number of

the RSG's. The routine ongoing outage cycle inspections (by Eddy Current Test (ECT) and/or secondary side visual) will monitor the condition over time.

During the three inspections mentioned above which were made after first fuel cycle operation, the steam drum, upper bundle (U-bend) and tubesheet regions were inspected by direct visual and/or video techniques. Visual inspections included samples of steam separators, feedwater header, upper wrapper, wrapper support pins, U-bends, U-bend support structure, visible ends of U-bend support bars and lattice support bars, lattice support peripheral ring and positioning blocks/wedges, shell lugs supporting wrapper lower edge, shroud position (vertically) at inspection port, tubesheet secondary side annulus and tube-free-lane regions. Also the tubes received their full bundle inspection by ECT. This is additional to inspections performed during/after manufacture and installation. These inspections addressed all of the above mechanisms - albeit after a relatively brief (but significant) period of operation and with coverage of a somewhat variable portion of all possible sample sites. No evidence of degradation was observed. Visual/feeler gauge inspection was performed on several tubes for which tube proximity was indicated by ECT. Inspection confirmed that proximity existed where indicated by ECT and (at least in the instance of the small number of tubes thus inspected) did not exist where not detected by ECT. No related degradation was observed by ECT or visual.

Based on the above, it is recommended that further immediate inspections to assess the identified degradation mechanisms in these replacement steam generators is not necessary nor recommended. Ongoing operation of these units is supported by design provisions for avoidance of the identified mechanisms and by inspections to date.

Over time, visual inspections similar to those already completed (as well as ECT inspection) should be performed to confirm the continued health of the equipment. Such inspections should address one SG per unit at the first fuel cycle outage and periodically thereafter. Each of these inspections should address;

- steam line flow restrictors, secondary and primary separators, separator support decks/lugs, feedwater header/J-tubes/impingement areas, upper wrapper/cone/separator deck region, U-bend tube surface, U-bend support structure, tube/U-bend support bar contact areas, tube/U-bend support J-tab areas, peripheral inter-tube clearance, uppermost lattice support periphery including peripheral ring, positioning blocks/wedges, lattice bars (ends), downcomer annulus region including separator deck lugs and wrapper lateral support pins, tubesheet region including lower shell/wrapper lugs, annulus region, tube-free-lane area, lower lattice support structure, tubesheet inter-tube areas, lattice support inter-tube areas and support bars.

SECONDARY SIDE DEGRADATION
Assessment Report
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1.0 INTRODUCTION

NRC Generic Letter GL 97-06 (Ref. 1) identified certain degradation mechanisms which have affected steam generators in PWR plants. It also requires that each addressee provide a written report that includes;

1. Discussion of any program in place to detect degradation of steam generator internals.

2. If.no program....include a discussion and justification of plans....or why no program is needed.

This report is prepared for and in cooperation with certain owners of B&W (BWC) Replacement Recirculating Steam Generator units (BRSG's). It is intended as a response to the above summarized requirements and for inclusion in the submissions of the individual participating utility owners. The report provides assessment of the cited degradation mechanisms as they may relate to the BRSG equipment. It discusses inspections performed during the brief but significant operating history of these units. It indicates that immediate inspection is not required nor recommended but it also identifies inspections, similar to the above, which should be peformed over time to monitor the ongoing health of the equipment.

B&W Replacement Recirculating Steam Generators are in operation, installation or manufacturing as follows;

Utility	Plant	In-Service	First Outage
Northeast Utilities	Millstone 2	01/93	10/94Ref. 3
Rochester G&E	Ginna	06/96	09/97 Ref. 4
Duke Power	Catawba 1 McGuire 1 McGuire 2	10/96 05/97 12/97	11/97 Ref. 5
Florida P&L	St. Lucie 1	01/98	
Commonwealth Edison	Byron 1 Braidwood 1	02/98 12/98 est.	
AEP	D. C. Cook 1	03/00 est.	

Inspection of units now in service was performed at various points during manufacture and installation including after final positioning. In addition the SG's at three reactor units have completed their first fuel cycle of operation and have

received inspections of tubing (ECT), and of upper bundle and tubesheet regions. The pre-operational inspections are relevant to manufacturing issues related to the cited degradation issues. These inspections including the brief but significant initial period of operation address essentially all cited degradation issues.

Discussion of design features, operating conditions, etc. within this report generally relate to the Duke Power Catawba1/McGuire 1&2 steam generators as being representative of the group. Differences between the BRSG's and any unique observations are addressed in the appendices. The original equipment manufacture (OEM) model designation of the various BRSG's are as follows.

Plant	MP2	Ginna	Duke	PSL 1	ComEd	DCC1
OEM Model	67	44	D2, D3, D5	67	D4, D5	51

In general, the BRSG's differ in size from one-another since they are replacements for units of different O.E.M. origins as noted above but they are identical to one-another in concept and in almost all materials of construction including the critically important tubing and the tube support materials.

2.0 SUMMARY OF CITED DEGRADATION MECHANISMS

The GL-97-06 described six degradation mechanisms which have been observed on PWR steam generators in European or domestic sites. In brief these mechanisms relate to;

i) Support Plate Wastage Due to Chemical Cleaning

ii) Broken Tube Support Ligaments

iii) Support Plate Wastage in Operation

iv) Wrapper Drop

v) Wrapper Cracking

vi) Degradation of Eggcrate Supports.

The potential for such degradation mechanisms occurring in the BRSG's is assessed in this report. In order to realistically consider these mechanisms for these units, an effort is made to translate the potential mechanisms to allow for the major design differences between the cited units and these BRSG units, i.e. this will then address the question as to whether a similar condition could occur even though the exact condition may not be relevant.

In addition to the cited mechanisms, discussion is included regarding a condition discovered during recent tube bundle assembly inspections. This condition relates to U-bend support positioning and the resultant effect on the inter-tube spacing between certain peripheral, vertically adjacent tubes. This condition is reviewed herein - an extensive review has previously been prepared and documented which confirmed acceptability of the condition for extended unrestricted SG operation.

Detailed discussion of potential for such degradation mechanisms is given in Section 5 below.

3.0 DESCRIPTION OF DESIGN

The B&W Replacement Recirculating Steam Generators presently in service have replaced three models of Original Equipment Steam Generators (OESG's) and correspondingly have three different general designs: Millstone and St. Lucie BRSG's replaced System 67 OESG's, Ginna BRSG's replaced Series 44 OESG's and Catawba, McGuire and Byron BRSG's replaced Model D OESG's. Figure 1 illustrates the general arrangements for these three BRSG designs while Figures 2 thru 4 provide details of typical internal features.

The six degradation circumstances described in NRC Generic Letter 97-06 are all related to tube support structures or wrapper degradation. Consequently these features of the BRSG designs are described in detail. The BRSG designs all use wrappers with lower restraint lugs, radial shroud pins and upper slip joint rings. Also common to all BRSG designs are lattice grid tube support structures and a flatbar U-bend restraint system. These tube support structures restrict flow induced vibration of tubing and provide structural support for lateral tube bundle loads such as those originating during seismic events.

The following describes typical design features and design requirements for the BRSG wrapper, lattice grid and U-bend support components.

3.1 BRSG Wrapper (Shroud) Design

The primary function of a wrapper (shroud) in a recirculating steam generator is to separate the downward flowing recirculating liquid from the rising two phase mixture within the tube bundle. The B&W wrapper design (Figure 2) has two sections; a lower cylindrical section rigidly supported by shell/shroud lugs near the tubesheet and an upper section semi-rigidly supported by the primary separator deck and deck lugs at the upper end. The lower shroud lugs are welded to the pressure shell and the shroud by robust structural lugs. The primary separator deck lugs allow free radial differential thermal expansion of the primary separator deck and pressure shell. The mating ends of the two wrapper sections have machined rings forming an overlapping slip joint which provides restraint in only the lateral direction and allows free axial differential thermal expansion between the upper and lower wrapper section and the lower cylindrical wrapper also has radial "shroud pins" between the wrapper and shell at several elevations providing additional lateral support to the tube bundle.

Lattice grid tube support assemblies are laterally positioned within the cylindrical wrapper by radial wedges between the lattice rings and wrapper and are vertically restrained by blocks above and below the lattice rings. Both the lattice wedges and support blocks are welded only to the wrapper. No welded connections exist between the lattice assemblies and the wrapper.

The wrapper configuration is designed to withstand structural loads during normal, upset, emergency and faulted conditions as well as manufacturing, handling and transportation loads. The most severe loads result from combined seismic and burst pipe events which generate both lateral and vertical loads. The wrapper also accommodates thermally induced relative motions between internal components and the pressure boundary. Relative thermal motions in both vertical and radial directions occur during transient heating or cooling cycles. Both the upper and lower sections of the wrapper have only one vertical restraint connection thereby allowing relative vertical growth between the wrapper and shell. Relative sliding motions occur at the slip joint, between the shroud pins and shell and between the tube bundle and lattice grids.

Relative radial motions during transient operation is analyzed for the lower wrapper lugs, shroud pins, lattice wedge and lattice ring components. The wrapper slip joint is not subjected to relative radial motions since the upper and lower wrapper thickness and radial thermal responses are identical. The primary separator support deck is stiff in its in-plane direction and consequently is radially disconnected from the shell. This is typically accomplished by allowing radial shell lugs to slide within pockets below the primary deck while maintaining vertical and lateral support.

The analysis of the radial thermal interference at the shroud pins, wrapper, lattice wedges and lattice ring considers a shell that is colder than internal components which are all assumed to be at a uniform temperature corresponding to the secondary side fluid temperature. The radial forces and corresponding thermal stresses are reduced by designing a flexible load path. By positioning shroud pins at points between lattice wedges, thermal displacements are absorbed by local bending of the wrapper plate between wedges and shroud pins. This spring like interaction reduces thermal loads to acceptable values.

In addition to design considerations related to in-service conditions, the wrapper design must consider loading during fabrication and transportation. The BRSG lower wrapper is installed into the lower shell sub-assembly only after completion of the vessel Post Weld Heat Treatment (PWHT). After attachment of the wrapper to the shroud lugs and the installation of shroud pins, the tube bundle support system and tubes are installed. Since the primary head is part of the initial lower shell sub-assembly no effect of local PWHT near the wrapper occurs.

The wrapper is potentially exposed to thermal effects only during the final PWHT of the shell transition cone closing seam - a process which is carefully isolated from the wrapper and tube bundle. By careful analysis of wrapper and shell components, strict monitoring of temperature gradients and the use of carefully engineered PWHT procedures which include placing insulation between the shell and wrapper and drawing an internal vacuum, the possibility of wrapper or tube support damage is avoided.

3.2 Lattice Grid Tube Supports

The design of the tube support system is critical to the reliability of the tube bundle and the steam generator. The design requirements for reliable, effective tube supports must: a) preclude excessive Flow-Induced Vibration (FIV), b) minimize pressure loss in order to promote a high circulation ratio, c) provide line support contact to reduce the potential for deposition of corrosion-causing impurities and localized dryout, d) provide sufficient tube contact length to lower contact stress and hence minimize fretting wear of tubes, e) provide a strong tube support design to withstand lateral seismic loads, loads caused by LOCA and burst pipe events, and handling and shipping loads, f) accommodate tube-support motions during heatup/startup operation without risk of lockup or large thermally induced stresses, g) resist corrosion, denting and stress corrosion cracking due to normal operation and chemical cleaning.

BWC has fabricated a considerable number of steam generators using both lattice grids and broached plates and is the only supplier with operating experience with both designs. As a result of many years of design and operating experience BWC has concluded that the lattice grid tube support system was the best choice for reliable operation of replacement recirculating steam generators and best satisfies the design requirements.

Figures 2 and 4 show the details of a typical lattice grid arrangement. The lattice grid is made up of two intersecting arrays of 410S stainless steel high bars (approximately 3 inches in width) oriented at 30 ° and 150° to the tube free lane and located every four to eight pitches, depending on the size of the bundle and the particular steam generator loading conditions. 410S stainless steel low bars (approximately 1 inch wide) are located at every pitch location between the high bars. All low bars flush to the top of the high bars are oriented at 30° to the tube free lane and all low bars flush to the bottom plane of the high bars are oriented at 150° to the tube free lane. The bar ends are fitted into precise slots of a specially designed peripheral support ring, which is then clamped by two outer retainer rings. These tube support assemblies are positioned within the tube bundle by wedges and blocks both of which are welded to the wrapper only.

All of the lattice supports are similar except that the lowermost lattice incorporates a differential resistance feature which is used to encourage bundle flow penetration above the tubesheet. The construction of the differential resistance lattice grid resembles that of a regular grid, however, the low bars located towards the bundle periphery are replaced by medium bars. Because of the increased width of the medium bars (approximately 2½ inches wide) all crossing bars in the outer regions intersect at each pitch location. As a result, the flow passages through these regions offer more resistance to flow and the fluid is preferentially directed to penetrate into the central region of the tube bundle.

3.3 Flatbar U-Bend Restraints

The primary objective of U-bend supports is to effectively restrain the tubing such that Flow Induced Vibration (FIV) and fretting wear is minimized. In addition, the U-bend support configuration must provide lateral structural support to U-tubes during fabrication, transportation and service conditions such as seismic events.

The BRSG Flatbar U-bend Restraint (FUR) system consists of 410S stainless steel flatbar fan assemblies supported by 316L stainless steel J-tabs, carbon steel archbars, clamping bars and tie tubes as illustrated in Figure 3. Fan assemblies, which incorporate a number of flatbar "fingers", are positioned between each layer of tubes. The fan assemblies stagger in and out from tube layer to tube layer so that tubes are not contacted on directly opposite sides by a flatbar. Depending on the radius of the tube bundle, the largest fan assemblies can have up to five fingers all connected at their lower ends to a "connector bar". The connection to the connector bar is an autogenous full penetration weld which is post weld heat treated.

The flatbars in a fan assembly are positioned so that U-bend tubes are supported at quite close intervals - typically 19" to 22". The actual span length and the number of support locations depends on the bundle size, tube size and flow loadings. All tubes in the U-bend bundle assembly are supported by at least two flatbar positions on each side of the tube. Wide, tangent contact regions and small nominal gaps between tubes and flatbars minimize tube wall thinning due to fretting.

Free expansion of the U-bend during operation is essential in order to avoid tube stress or damage. The FUR system allows free expansion of the U-bend tubes without the need for sliding between tubes and bars. This is achieved by supporting the FUR assembly by the outermost layer of tubes and by avoiding other restraint points. In this way the FUR assembly and U-tubes move up and down together on heatup and cooldown and also during operation at power when tube hot legs and cold legs have slightly unequal leg temperatures.

The weight of the U-bend assembly is transferred to the outer U-bend tubes by J-tabs which are individually positioned to distribute the load onto the supporting tubes (Figure 2). In the event of a supporting tube being taken out of service, its load is simply redistributed to the remaining tubes with no significant increase in deflection of the FUR assembly.

Qualification of the FUR assembly includes FIV analysis, wear assessment, structural analysis, and material qualification such as autoclave and corrosion testing in aggressive secondary side environments.

3.4 Material Qualification

Material qualification includes identifying corrosion allowances for structural analysis including the effects of general corrosion, flow assisted corrosion and chemical cleaning allowance. Autoclave fretting wear behaviour of 410S stainless steel supports and Alloy 690 tubing has been quantified at typical PWR temperatures, pressures and chemistries. The wear behaviour was confirmed by testing to be equivalent or better than other typical material combinations used for U-bend support applications.

Constant-extension-rate (CERT) tests were performed on 410S material in various environments as part of an environmental screening program. To reduce the overall size of the test matrix, 410S was processed to exhibit the most Stress Corrosion Cracking (SCC) susceptible (i.e., hardened) condition. This material, exhibiting a hardness of ~110 HRB, is consistent with a fully martensitic microstructure and not representative of the material utilized in production.

CERT tests were performed in typical steam generator environments (i and iv) and environments that simulate extreme pH excursions (ii and iii), as follows;

i) AVT
ii) AVT adjusted to pH 3 with HCl
iii) AVT adjusted to pH 11 with Na0H
iv) AVT + 5 ppm H_3B0_3

This program revealed that hardened 410S stainless steel is susceptible to SCC in an environment consistent with an acidic excursion (i.e., AVT + HCl). This environment resulted in material failure in the shortest time period, at the lowest maximum load and generated the greatest amount of intergranular fracture face area. On the basis of this observation, the acidic environment was then chosen to assess the SCC susceptibility of production processed, welded and stress relieved 410S specimens. The results of the second phase of testing (CERT and 2000 hour immersion U-bend tests) confirmed that stress relieved autogenous welded Type 410S material is not susceptible to SCC. In the case of the CERT test program where the specimens were stressed to overload, failure was by ductile mode, indicating resistance to the corrosive test environment. In both test phases, surface attack was limited to general oxidation; no features consistent with localized corrosion (pitting or intergranular attack) were observed.

Additional denting tests were performed on 410S material to investigate the corrosion product characteristics, especially the growth of the oxide film. It was shown that the 410S material oxide will not cause denting and that the material would not experience catastrophic oxidation even in the extreme test environment. The oxide layer was observed to be tightly adherent and non-voluminous. B&W has also performed chemical cleaning qualification tests for

40 hours in the EPRI/SGOG magnetite dissolution solvent in the presence of actual steam generator deposits. The 410S material experienced negligible free and galvanic corrosion during these tests.

4.0 SUMMARY OF RELEVANT INSPECTIONS

Inspections relevant to the identified degradation mechanisms include; i) inspections performed during/post manufacture, ii) inspection of the equipment in situ prior to operation (typically U-bend region inspections at time of temporary restraint removal and foreign object inspection) and iii) inspections performed after a period of operation.

Discussion of inspections is limited to items relevant to the cited degradation mechanisms. The significance of some of the observations below may be best understood by first reviewing Sections 3 and 5.

Throughout the course of manufacture, quality control inspections are performed to ensure compliance of the fabricated components to design requirements, as defined by drawings and shop specifications. Ordered material is also similarly confirmed to comply with all ordering requirements. These confirmations are performed by both manufacturer personnel as well as resident customer representatives.

4.1 Inspection - During and Post Manufacture

Very extensive inspections of numerous components are performed during and after manufacture. Those relevant to the cited degradation mechanisms include the following.

4.1.1 Tube Support Degradation

The first, second, third and sixth degradation items (see Sections 5.1, 5.2 5.3 and 5.6 respectively) relate to support degradation in most cases including the periphery of the uppermost tube support. As noted elsewhere, the upper tube support lattice is heavily loaded in handling (includes rotation) and shipping but is not subjected to manufacturing thermal treatment conditions. Distress in the upper lattice support would be most likely to occur at the ends of the bars where they enter the peripheral ring of the support. This peripheral region is readily visible after assembly of the SG.

Visual inspections of this region are performed at a number of points during the manufacturing program. No observation of distress or degradation has been observed.

4.1.2 Wrapper Drop

The fourth and fifth mechanisms relate to wrapper drop and cracking. In the BRSG design this would relate to problems with the shroud lugs and

shroud pins. These (particularly the upper shroud pins) are also heavily loaded during handling and shipping but are not exposed to manufacturing heat treatment thermal effects.
Visual inspection of this region performed during and after completion of manufacture showed no degradation in this area.

4.1.3 Tube Proximity

Proximity of peripheral tubes due to positioning of the U-bend supports during manufacture is an additional item discussed in Section 5.7. This relates to the possibility that certain peripheral tubes (those with J-tabs) may be close to their (vertically adjacent) neighbours or even in contact. Tube proximity was deemed to be a condition of tube contact if the tube-to-tube clearance was less than 0.040" after the vessel was settled in its vertical orientation in the plant. Somewhat larger clearances were required in the horizontal to allow for settling of the U-bend support assembly on uprighting.

Many measurements of inter tube gaps were made on SG's in manufacture, in the field (horizontal) and in situ. Measurements were made by ECT and by physical measurement. Typical findings were that proximity was observed to exist on a small number of tubes on most steam generators. The effect of this condition (which was determined to be acceptable) is discussed further in Section 5.7 and Reference 6.

4.2 Inspection - Post Installation

Inspections performed after installation of the steam generators in the vertical position in the plant included i) inspection of the U-bend region upon removal of the temporary U-bend restraints, ii) inspection of the tubesheet annulus region for foreign objects, etc. In some cases, in situ pre-service ECT provided information regarding tube proximity. This inspection stage is after uprighting and therefore includes any effects of all manufacturing, handling and transportation.

Observations from these inspections are generally the same as those of Section 4.1.

4.3 Inspections After Operation

Three units have operated through their first fuel cycles and undergone first outage inspections including; i) ECT inspections, ii) tubesheet secondary side visual inspections and iii) U-bend/steam drum region inspections. These latter inspections as documented in Reference 3, 4 and 5 were performed at the Millstone 2 (10/94), Ginna (10/97) and Catawba 1 (12/97) plants respectively.

All three upper vessel inspections were similar and incorporated the same approach and most of the detailed inspection points as those identified in the plan/recommendations of Section 6. Allowing for a few items added incrementally over time, these plans typically called for inspections of;

- steam line flow restrictors, secondary and primary separators, separator support decks/lugs, feedwater header/J-tubes/impingement areas, upper wrapper/cone/separator deck region, U-bend tube surface, U-bend support structure, tube/U-bend support bar contact areas, tube/U-bend support J-tab areas, peripheral inter-tube clearance, uppermost lattice support periphery including peripheral ring, positioning blocks/wedges, lattice bars (ends), downcomer annulus region including separator deck lugs and wrapper lateral support pins, tubesheet region including lower shell/wrapper lugs, annulus region, tube-free-lane area, lower lattice support structure, tubesheet inter-tube areas, lattice support inter-tube areas and support bars.

These inspections were quite comprehensive. However, for the purpose of this report, rather than reviewing these results systematically, specific observations which relate to the specific degradation mechanisms will be cited.

Inspections were visual, by direct access, by video camera or by flexible video probe.

4.3.1 Tube Support Degradation

The first, second, third and sixth degradation items (see Sections 5.1, 5.2, 5.3 and 5.6 respectively) relate to the support degradation - in most cases including at the periphery of the uppermost tube support. The periphery of the uppermost lattice bar tube support, including the peripheral ring, the ends of the lattice bars and the wedges/blocking which position the ring to the shroud, are visible during the upper bundle inspection (flexible video equipment may be required). Support degradation, similar to that cited, should be expected to appear in this visible region of the upper support - if it has occurred.

In all cases (but one), this area appears to have been inspected - although perhaps with difficulty or from a distance. No indication of degradation or concern is reported. Reports included the following.

Ref. 3 - "Top Tube Support Lattice" listed in procedure inspection matrix.

Ref. 4 - "...inspection....aborted....camera..." (access problem).

Ref. 5 - "A video probe was then used to view the periphery of lattice at the 9th TSP elevation. This was followed by inspections of the shroud pins at the 9th and 8th TSP elevations..."

While it is not as heavily loaded or susceptible to damage, inspection of the lowermost support provides additional confirmation of tube support integrity. The periphery and tube-free lane regions of the lower support are typically accessible during tubesheet annulus inspections and was done in two of these three cases. No indication of degradation or concern is reported. Reports include the following.

Ref. 3 - Tubesheet inspection (reported elsewhere - not in same scope as upper bundle inspection covered by Ref. 3).

Ref. 4 - "The FOSAR tool also provided good views of the bottom of the lower lattice grid, shroud support lugs and shroud pins... The lower lattice grid bars were not fouled."

Ref. 5 - "Tubesheet, tube crevices inspected by access from above but lattice not observed."

4.3.2 Wrapper Drop

The fourth and fifth mechanisms (see Section 5.4 and 5.5 respectively) relate to wrapper (or shroud) drop and cracking i.e. problems relating to support lugs, shroud pins and the shroud area near those locations - all of which serve to support the shroud and the tube bundle during various operating and safety related load conditions.

The shroud support lugs and nearby shroud pins are accessible during tubesheet annulus inspection. The shroud pins at/near the upper tube support elevation (which are much more heavily loaded during manufacture, handling and accident conditions) are accessible during steam drum/U-bend inspections. Distress in this area would manifest itself as a buckling of the shroud pin/socket and/or rupture of the socket to shroud weld.

Inspection reports regarding the upper shroud pins has been performed in several cases. No indications of degradation or concern is reported. Reports indicate;

Ref. 5 - "A video probe was then used...inspection of the shroud pins at the 9th and 8th TSP elevations..."

- "Figure 5.32 TSP #9 Shroud Pin". View of shroud pin threaded against shell, shroud pin socket and socket to shroud weld. All in good condition.

Inspections relating to the shroud lugs (and/or lower shroud pins) were performed in several cases. No indication of degradation or concern was reported. Reports indicated;

Ref. 4 - "The FOSAR provided very good views of the bottom of the lower lattice grid, the shroud support lugs, and shroud pins. No problems were observed with the full penetration shroud (to shell) support lug welds. Several shroud pins were observed and were not degraded."

Ref. 5 - "... a 6 mm video probe was deployed through the (transition cone) handhole... to the secondary face of the tubesheet...Also...one of the shroud support structures was viewed....where the support attached to the shell was seen fairly well....however, the weld attaching the shroud to the support is on the shroud ID and could not be viewed from outside the shroud."

4.3.3 Tube Proximity

Inspections relating to the additional item regarding tube proximity were made by ECT and visually. One post fuel cycle visual inspection was performed to confirm the ECT results which were much more comprehensive. The inspection (visual and feeler gauge) in effect indicated that where tube proximity (tube-to-tube gaps less than .050" between certain peripheral tubes) was indicated by ECT, it did physically exist. Also that for the few "control" tubes checked (proximity not indicated by ECT), proximity was not found where it was not indicated by ECT. The report indicates;

Ref. 4 - "U-bend gap measurements were completed in both RSG's as indicated in Table 2. Four of five U-bend gaps identified by ECT were measured in SGB. One of five U-bend proximity indications was measured in SGA. ...The nominal tube-to-tube gap in the Ginna RSG's is 0.369", although tube bending tolerances can reduce this to a design minimum of 0.269". All of the proximity indications that were found by ECT and subsequently inspected were less than 0.100", indicating that the ECT upper detection limit is between 0.050" and 0.100". Several "control" gaps were checked in the U-bend and were found to be greater than

> 0.200" (the largest gauge available). This control group was not comprehensive, and it is likely that there are tube gaps between the ECT upper detection limit and the nominal minimum of 0.269" that ECT was not able to locate. This is an acceptable condition, based on the Babcock & Wilcox technical report disposition."

The above confirmed that the tube proximity condition did exist for a small number of tubes as indicated by ECT i.e. existence of the proximity condition was observed by ECT and confirmed by visual inspection/feeler gauge check.

5.0 ASSESSMENT OF DEGRADATION MECHANISMS

5.1 Support Plate Wastage Due to Chemical Cleaning

The first degradation mechanism described in Ref. 1 refers to "... wastage of the uppermost support plate caused by misapplication of a chemical cleaning process.". In Ref. 2, this was described as "... missing TSP ligaments at the top TSP (TSP8), ... attributed to placement of discharge hoses too close to the TSP's during the chemical cleaning performed during 1992...".

This is not directly applicable to the RSG units since none have been chemically cleaned. Pre-qualification of these RSG's has however been provided for multiple chemical cleanings. Such qualification is incorporated in design reports provided as part of the project deliverables. These prequalification documents support design and execution of a chemical cleaning process at some future date.

For RSG's, the equipment specifications require provision for six or seven cleans using the EPRI-SGOG (low temperature) process. The qualification provided may be applicable to other processes (including high temperature processes) subject to confirmation that such a process is bounded by EPRI-SGOG conditions.

The qualification process included review of materials of construction and assessment of material susceptibility to corrosion during cleaning against the EPRI-SGOG database. Testing was performed where the database did not contain information. Corrosion allowance values, inclusive of chemical cleaning and operation corrosion, were determined for all exposed surfaces and incorporated in the design analysis of the components.

Additionally, the vessel designs make provision for connections for execution of cleaning including; ports for fill/drain/instrument connections, blowdown ports for drainage, recirc connections, taps for level measurement, steam nozzle for venting. The design is also compatible with cleaning in that no trapped spaces exist which will either trap concentrated solvent or prevent solvent access for cleaning.

The materials of construction of the tubing and tube support bars are Alloy 690 and 410S respectively - both are resistant to chemical cleaning conditions as confirmed by the above mentioned qualification testing.

In summary, degradation due to chemical cleaning has not occurred since chemical cleaning has not been performed. Additionally, the equipment prequalification provides that a cleaning process may be applied if and when required in future.

5.2 Broken Tube Support Ligaments

A damage mechanism referenced to in Ref. 1 describes "...broken tube support plate ligaments at the uppermost, and sometimes at the next lower tube support plates.... damage apparently dates back to initial startup....ligaments may have broken because of excessive stress during the final thermal treatment...".

The tube supports in the BRSG design is of a lattice bar type in which tube support is provided by a multiplicity of bars rather than by drilled or broached plates as in some other types of steam generators. Therefore plate cracking as cited above is not directly relevant. The support situation does however see loads during handling and operation which may be evaluated.

Ref. 1 cites the possible effect of final thermal treatment. In the BRSG's manufacturing process, the tube bundle is not exposed to thermal treatment. The entire lower vessel including primary (channel) head, tubesheet, main shell and cone section are welded and post weld heat treated (PWHT) prior to installation of the shroud (wrapper), tube supports and tubing.

After completion of tubing and insertion of the steam drum internals, the steam drum to main shell closure weld (at the top of the transition cone section) is completed. A local PWHT of the steam drum to transition cone weld is then performed. Care is taken to isolate any PWHT or related effects from the internals by insulating and evacuating the inside of the steam generator and by adherence to temperature and temperature differential limits during the PWHT process. Vessel thermal treatment is thereby removed as a possible concern regarding integrity of the tubing, tube supports or shroud structures.

In normal operation, the lattice bar supports are relatively lightly loaded. The supports are exposed to heatup and cooldown effects and modest flow loads. The supports are designed to sustain accident loads due to seismic, LOCA or steam/feed line break. Since no incidents relating to such accident conditions have occurred, degradation related to these events may be eliminated as a possibility.

During manufacturing, handling and shipping, the vessel is horizontal and the most highly loaded (by approximately a factor of two) lattice support is the upper support adjacent to the U-bends. Even though the U-bends are supported by temporary U-bend supports at all times during such handling, substantial loads still transfer to the uppermost tube support structure. The most highly stressed areas tend to be the lattice bars themselves at the periphery of the bundle near the peripheral ring.

The tube bundle and its supports (including the uppermost) are analyzed in detail for handling and shipping conditions. The strength of these structures is

established to accommodate these loads during the design phase of the component. The materials and the basic lattice design configuration have been selected, analyzed and tested to deliver the needed strength.

Any loss of integrity of the lattice structures related to shipping, handling or manufacture would exist prior to inspections at final manufacturing stages and after installation. The highly loaded peripheral region of the upper lattice support is accessible to direct visual inspection. The pre-operational inspection in this area is that related to removal of the temporary supports which restrain the U-bends during handling and shipping. These inspections include a general visual survey of all visible components in the U-bend area. Such inspections have not identified any sign of pre-operational damage or degradation relating to the upper tube support. Confirmation that the critical regions of these highly loaded upper supports are in good condition is a sound basis for confidence that other lower supports are in good condition since it is the most highly loaded during handling, shipping and installation events. Reference Section 4 - re pre-operation inspection.

During normal operation, loads on the lattice tube support structures are relatively low. During heatup, the lattice structures and shroud heat more quickly than the shell causing some radial load on the lattice rings at the lattice ring/shroud wedge supports. In the vertical direction, the tubes, which expand more than the vessel and shroud, expand vertically relative to the lattice support locations (typically about 3/16"). During operation, the lattice supports see some flow loading (typically 1.0 to 1.5 psi per support).

Stresses and displacements are calculated for the lattice grids, shroud and related support components resulting from thermal interaction and flow loading and are shown to be safely below design allowable stresses. The basic design of the lattice supports, lattice to shroud attachments, shroud and shroud support is such that the normal operation thermal interactions are readily accommodated.

In the event of damage due to such operational loads, one of the areas most likely to see distress would be the ends of the lattice bars of the uppermost support. These areas are accessible by video during secondary side upper bundle inspections. A limited amount of such inspection has been performed at a first fuel cycle outage and no sign of degradation was reported (Ref. 5).

Based on the above design considerations, post manufacture/ installation inspection and post operation inspection, degradation related to tube support structure integrity is not anticipated.

5.3 Tube Support Wastage in Operation

In Ref. 1, a "...damage mechanism involved wastage not associated with chemical cleaning and affected tube support plates at various elevations...apparently involves a corrosion or erosion-corrosion mechanism of undetermined origin.".

Ref. 2 describes "...Broached TSP ligaments...much of it was FAC thinning of ligaments that was evolving from year to year...only confirmed at...units with carbon steel TSP's that have operated for many years with ammonia water chemistry...mechanism is considered to be FAC/erosion-corrosion ...thinning is believed to increase as the local pH decreases...material...equivalent to ASTM A285C steel...believed that susceptibility to FAC is related to the low chromium level in this type of steel....".

Discussion of such degradation is deferred to Section 5.6 which relates to an apparently similar mechanism seen in a steam generator with eggcrate (lattice bar) type supports. That discussion is intended to address both sets of symptoms equally.

5.4 Wrapper Drop

A wrapper drop phenomena is described in Ref. 1 in which the tube bundle wrapper was observed to have shifted vertically downward. It was "... postulated that an interference fit developed between the wrapper and the seismic restraints (mounted to the shell) as a result of differential thermal expansion associated with the cooling transients..." "...cooling transients are believed to have been particularly severe for two units as the result of the use of a special operating procedure..." "Poor quality wrapper support welds may also have contributed to this failure".

The wrapper (or shroud) design for the RSG's is as follows;

- the shroud is a steel cylinder (typically ½" thick) extending from just below the lowermost lattice grid tube support up to a slip joint in the region of the upper U-bend.
- the shroud is supported at its lower edge by (typically) 12 support blocks (2" x 4½", stiff axis vertical) which are full penetration welded to the lower pressure shell.
- the shroud in turn is welded to these lugs by full penetration welds.
- with this support arrangement, the shroud, tubes and main shell all thermally expand in the same direction from the tubesheet upward with

the magnitude of expansion being determined by the temperature and expansion properties of the parts involved.

- above the shroud support blocks, the shroud is laterally supported at various tube support elevations by shroud pins. Typically, there may be 16 shroud pins at each support elevation. The top two support grids have corresponding shroud pin supports and shroud pins are included at least at every other support grid elevation down to the shroud support blocks.

- shroud pins are robust (typically 2" diameter) threaded pins which screw (outward) through threaded sockets which are welded to the shroud. The pins, which contact the main shell, position the shroud within the shell and they also support lateral tube bundle loads to the shell during handling, shipping and seismic loading conditions.

- axial differential expansion is accommodated by sliding of the shroud pin ends along the shell inner surface. The shroud pins are designed to accommodate the frictional loads involved. Radial differential expansions between the tube support peripheral rings, the shroud and the shell are accommodated by local flexing of the shroud. The shroud pins are offset from tube support grid wedges so that shroud flexing can accommodate the necessary differential radial motion. The tube support rings are wedged (lateral loads)/blocked (vertical loads) to the shroud inside diameter and move with the shroud in the longitudinal direction. There are no welds between the lattice grids and wedges/blocks.

Differential thermal motion between shroud and shell may occur on vessel heatup or cooldown. In the cited case, damage was attributed to aggressive cooldown procedures using cold feed injection. In this RSG design, such cooling (or any rapid cooldown) would tend to cause the shroud to shrink axially and radially relative to the shell. Since the shroud is thinner and wetted on both sides it will follow the thermal fluid conditions much more closely than the thicker shell which is cooled on one surface only. In this case the shroud will shrink back from the shell, the shroud pin/shell load will be relaxed and the differential expansion will occur more easily.

In the heatup case, the shell temperature may lag the shroud and tube support temperatures. In this case, the shroud pins will see increased radial load simultaneous with pin end sliding over the shell surface. Such radial motion is accommodated by local shroud flexure at the pin locations as noted above. Sliding drag force is readily accommodated by the strength of the shroud pin/socket.

The above conditions are addressed in the design analysis documentation for the equipment.

A condition which could also be implicated in the cited failure is vessel post weld heat treatment (PWHT) relating to the tubesheet/primary head closure. The manufacturing sequence of the RSG's involves performing all such thermal treatment prior to installation of internals including shroud, tubing and tube supports. It is therefore not possible for this to cause any degradation relating to shroud support.

The steam drum to transition cone closure weld is performed after the tubes and internals are in place. This local PWHT process is however, carefully isolated and monitored to confirm no effect on the tubing, tube supports or any other internal components by insulating and evacuating the inside of the steam generator and by adherence to temperature and temperature differential limits during the PWHT process.

5.5 Wrapper Cracking

Reference 1 describes a condition - "In addition to the wrapper dropping problem cracking of the wrapper above the original support was discovered at the same foreign unit....cause....not yet known.". Reference 2 describes "Fatigue cracks in the wrapper emanating from the corners of the support blocks have been detected at many of the support blocks in the two wrappers that dropped in Blayais 3.... showed signs of wear between the lug welded to the shell and the support blocks.. Vibration monitoring...has confirmed that significant vibration is occurring... The available evidence rather conclusively indicates that flow induced vibration are the main cause of wrapper cracks...".

The potential for vibration induced fatigue is discussed below. Fatigue could also be caused by differential thermal motion and will also be discussed.

As indicated in the previous section, the wrapper extends from below the lower support to a point above the uppermost tube support and is ½" thick. It is supported at its lower edge by 12 heavy lugs welded to the shell and at higher levels by shroud pins at multiple support elevations. It is also stiffened by the tube supports through the multiple wedges between the lateral support rings and the shroud.

The wrapper is supported and restrained as follows;

-	shroud lugs at lower edge	12
-	shroud pins (16 at each of 5 levels)	80
-	tube support wedges (16 at each of 9 levels)	<u>144</u>
		236

Of the above support points;

- the shroud lugs are rigidly (welded) to the shell
- the shroud pin and support wedge points are in hard contact
- all of the above are without clearance

Given the above support conditions (multiple, zero clearance support points), vibration of the entire wrapper in a beam mode or ovalizing mode does not appear possible. Vibratory modes would have to be limited to motion within the spans (typically 41") between the vibration nodes established by shroud pins and tube support wedges at tube support elevations. This also does not appear very likely.

Fatigue due to thermal motions is a further possibility even though not identified for the cited cases. Distress due to manufacturing thermal (PWHT) effects is not a possibility since the internals, including the shroud, are installed after completion of all lower vessel welding and PWHT activity. During operation thermal stresses will exist during heatup and cooldown as follows. On heatup, the shell temperature lags the shroud and other internals due to its thickness and the inefficiency of single surface heat transfer. Such a lag will cause force which is radially inward and longitudinal (to the vessel) on the ends of the shroud pins (and on the lugs). The shroud around the shroud pin sockets and shroud lugs will as a result be somewhat stressed but to and acceptable level.

On cooldown, the shell also lags the thermal response of the shroud and other internals resulting in a relaxation of load on the shroud pins.

The analysis indicates that the shroud and related components will sustain operation throughout the life of the plant without damage relating to these loading mechanisms.

5.6 Degradation of EggCrate Supports

Reference 1 describes a condition - "At a U.S. PWR facility, degradation of steam generator tube egg-crate supports was discovered through secondary side visual inspections performed during the spring 1997 refueling outage. The licensee identified erosion-corrosion as the damage mechanism; the cause is not yet known. The damage appears to be confined to the periphery and the untubed staywell region of the tube bundle. The eggcrate degradation at the periphery extends inward to the first one or two rows of tubes. The degradation at the staywell region primarily affects the support structures within the untubed section. Damage to the eggcrate supports was found in both steam generators on the hot and cold leg sides although the damage was more extensive on the hot leg side. No degradation of the eggcrate supports was identified within the tube bundle."

The reported degradation occurred on a tube support structure similar to the B&W lattice grid tube support, constructed of intersecting lattice bars. The primary difference between the B&W tube support design and the unit which experienced the degradation is that the B&W lattice bars are ferritic stainless steel Type 410S (11.5 - 13.5 % Cr) as opposed to carbon steel in the degraded unit. Studies have shown that material containing more than 5% chromium are not susceptible to Flow-Assisted Corrosion.

A secondary contributing factor to the degradation may have been due to deposit buildup on the egg-crate support structure which would obstruct the flow passages within the tube bundle. The tube bundle region blockage could cause increased by-pass flow streaming around the periphery of the bundle and through the center un-tubed region and the resultant higher velocities would aggravate FAC on a susceptible carbon steel material. The B&W lattice grid design differs from the subject unit in that the lattice grids for the second through top tube supports are of a more open flow design which promotes higher circulation and the bundle is therefore less prone to regions of higher vapor quality. Correlation between field deposition and 3-dimensional thermal hydraulic analytical simulations has shown a strong correlation between deposition sites and regions of high vapor quality. This is supported by the evidence that the degradation was more severe on the hot leg side of the subject unit, where higher heat fluxes would cause regions of higher quality and promote deposition.

The lower-most lattice grid tube support in the BRSG's incorporates intersecting medium bars to increase the axial flow resistance around the periphery of the bundle thus promoting flow penetration across the tubesheet. The differential resistance lattice grid approaches the flow resistance of the egg-crates in the subject unit, however sealing strips are incorporated on this tube support to prevent by-pass flow around the bundle. The lower tube support can be inspected periodically to verify that the flow passages within the bundle are not becoming plugged. The lowest tube support with the differential resistance construction experiences the highest heat fluxes on the hot leg side just above the tubesheet and thus inspection of this tube support, should provide good indication of the condition of the remaining tube support grids.

The BRSG's are operated in general compliance with the latest EPRI secondary side water chemistry guidelines and thus it is anticipated that the net deposit loadings entering the steam generator through the feed train would be less than that experienced at the subject unit.

Lattice bar and U-bend bar material qualifications performed are described in Section 3.4. The material qualifications include CERT and immersion testing to demonstrate that the material is not susceptible to SCC even in faulted secondary side environment, denting tests which demonstrate that the material

oxide does not increase in volume and thus the support structure is not susceptible to denting and chemical cleaning qualification to the EPRI/SGOG process. The chemical cleaning qualification demonstrated that there is negligible free and galvanic corrosion of the material during the chemical cleaning process.

5.7 U-Bend Support Positioning

During recent inspections of Steam Generators being fabricated for a replacement SG application it was determined there was less than optimum radial spacing between the outermost tubes and the adjacent inner tubes in the U-bend region. This condition is limited to only those tubes at the periphery of the bundle which are in contact with J-tabs. These J-tabs transfer the weight of the U-bend support assembly to the peripheral tubes. The potential for this condition applies to RSG's which utilize Flatbar U-bend Restraint Supports. The existence of any tube-to-tube contact relates to the potential for increased wear and for increased corrosion due to deposit build up. Documented studies summarized here confirm that the situation of tube to tube proximity or contact does not result in a condition which adversely affects the integrity of the operating RSG's, and confirms that this close proximity condition is bounded by configurations normally present in the as-designed generators.

Engineering analysis of an assumed tubes touching condition for the Byron and Braidwood RSG's was performed to assess the potential of increased fretting-wear damage. The Byron and Braidwood wear assessment is shown to bound the other BRSG's. The relative potential of tube degradation due to deposition in the U-bend region as compared to the tube to tubesheet joint is also addressed.

The fretting-wear damage assessment, which is based on conservative estimates of wear coefficients and work-rates at the tube to tube contact, shows that the maximum tube wall loss after 60 years of continuous full power operation is 40% of the nominal thickness. It is also concluded that similar results can be expected for normal tube to flat bar contacts in the same area of the tube bundle. The potential for tube degradation as a consequence of excessive fouling is addressed by confirming that the U-bend condition is bounded by fouling at the tube to tubesheet joint region which has been previously qualified by extensive testing. This comparative assessment includes consideration of heat flux, margin to critical heat flux, residual stresses, local environment, and material corrosion resistance.

Potential tube touching, wall degradation and deposition can be effectively monitored using normal Eddy Current Inspection techniques carried out by Plant Owners during routine inspection outages. No additional inspection is required to monitor this condition. The condition does not affect the normal performance

of the steam generator nor does it compromise its ability to withstand upset, emergency or faulted conditions such as seismic, LOCA or pipe rupture events.

5.7.1 U-Bend Support Function and Design

The primary considerations in establishing a tube bundle arrangement is achievement of thermal performance while accommodating the effects of thermal conditions, velocity and quality distributions, FIV and tube bundle deposition. The U-bend assembly consists of Alloy 690 tubes, 410S stainless steel flat bars, 316L stainless steel J-tabs and carbon steel structural support components such as arch bars, clamping bars and tie tubes. Tube anti-vibration support is provided by the 410S flat bars. The U-bend assembly is in turn supported by the peripheral tubes via 316L J-tabs which span between the arch bars and outer tube rows.

5.7.2 Justification of Condition

In the event that close U-bend tube-to-tube proximity or contact exists in operation, those tubes will perform normally in most respects however assessment of several aspects is required to determine the ongoing reliability of these tubes relating to fretting wear at the tube-to-tube contact location (between peripheral tubes with J-tabs and their interior neighbour) and/or deposition, bridging and tube corrosion in the region of contact.

Fretting Wear

Peripheral tubes in contact during SG operation may be subject to Flow Induced Vibration (FIV) fretting wear at the point of contact between the respective tubes, i.e. the outer tube as positioned by the J-tabs and its interior neighbour in the second last tube location (to be referred to as "peripheral" and "2nd" tubes respectively). At a region of tube-to-tube contact;

- The peripheral tubes are under J-tabs and bear the distributed load of the U-bend support structure. These curved tubes are stiffly supported by the normal flat bar restraints and by the loaded J-tabs - in effect a four way restraint. These tubes will have much less than normal motion at or between supports.

- 2nd row tubes will be supported normally by the flat bars. At any point of contact with a peripheral tube, the 2nd row tube will have an additional support point. That location will provide additional tube support against FIV but it also needs to be assessed for fretting.

Analysis has been performed for tubes/conditions representative of BRSG peripheral U-bend locations - both without and with tube-to-tube contact conditions. The analysis determines fretting rates at tube/support and tube/tube contact locations based on flow velocity/density distribution, turbulent excitation, work rate at the contact point and material fretting characteristics to determine wear rate. From this wear (volume) rate, the wear penetration vs time was determined. Conclusions based on these analyses are;

- tube wear for a tube or location with an "upper bound" work rate is projected to have a wall loss of about 33% over 40 years of operation and 40% over 60 years.

- wear depth may progress noticeably in the first few years, i.e. after one fuel cycle the depth may be 5% for upper bound locations. This penetration rate will drop off rapidly as the contact area broadens.

- projected rates of growth are sufficiently low to allow monitoring by routine/normal inspection programs - even allowing for a large margin of uncertainty in the prediction parameters.

- the through-wall wear rates for the tubes touching condition is approximately equal to the wall loss expectations for the nominal tube to flatbar support condition.

Based on the above assessments, steam generators may enter and continue in operation with tube-to-tube contact. Fretting wear will not result in unacceptable tube wall reduction over a normal 40 or 60 year operating life. Tube condition may be monitored during routine inspection programs.

Deposition Bridging

Tube bundle deposition and the potential of bridging is assessed for tubes in close proximity by using local thermal and fluid conditions determined from 3-D thermal hydraulic simulations. Deposition rates determined from two different methods resulted in a similar rate of deposition. Assuming a minimum gap and no vibratory tube contact, bridging could result in approximately 10 years. Also for the tubes touching condition analysis indicates that a 50% margin to CHF exists.

Thermally treated (TT) Alloy 690 tubing is the preferred material for replacement steam generators (RSGs) around the world. Corrosion studies have been conducted at B&W's Alliance Research Centre to

determine the effects of environment and residual stress on the corrosion performance of Alloy 690 TT RSG tubes. Based on the results of these studies, the corrosion properties of Alloy 690 TT tubes in the U-bend and tube-to-tubesheet (T/TS) expansion locations (and in particular crevice or under-deposit corrosion resistance) indicate that the performance of Alloy 690 tubes in the T/TS expansion transition region was found to bound the performance of other tube areas, including the U-bend region. It is therefore concluded that there is not an additional tube degradation risk as a result of tube bridging in the U-bends.

6.0 INSPECTION RECOMMENDATIONS

The following are inspection recommendations made pursuant to the above assessment of the degradation mechanisms cited by the Generic Letter (Ref. 1).

6.1 Inspection - Short Term

Immediate inspections to assess the identified degradation mechanisms in these replacement steam generators is not necessary nor is such recommended.

Ongoing operation of these units is supported by design provisions for avoidance of the identified mechanisms and by inspections to date.

No immediate inspections are recommended.

6.2 Inspections - Over Time

Inspections over time are recommended to monitor the continued health of the equipment. These relate to ongoing monitoring and not to concern regarding specific degradation mechanisms. This inspection program is not considered mandatory. Rather it is a recommendation based on current experience.

Inspection at the first outage and from time to time thereafter is suggested.

After the first outage inspection, the need, frequency, timing, focus and extent of individual inspections shall be redetermined from time to time by the station based on;

- experience and confidence level over time.
- experience and supporting operational feedback from other BRSG plants.
- the need to focus inspection effort should a condition of special interest or concern develop at this or another BRSG plant.
- the need/value of reasonably current inspection results in support of equipment condition reporting.

An inspection matrix is listed. Table 1 provides a recommended plan of ongoing inspection in support of ongoing monitoring of the equipment. This inspection matrix is essentially the same as inspections already successfully performed including those reported in Reference 3, 4 and 5.

7.0 REFERENCES

1. NRC Generic Letter 97-06, "Degradation of Steam Generator Internals", US NRC Office of Nuclear Reactor Regulation, Washington, D.C. 25000, December 30,1997.

2. Steam Generator Internals Degradation, "Modes of Degradation Detected in EDF Units", EPRI Topical Report, GC-109558, December, 1997.

3. Millstone 2, "Steam Generator Secondary Side Inspection", October 1994, BWC Report BWI-TR-95-01, January 10, 1995.

4. Rochester Gas and Electric Corporation Ginna Station, "1997 Refueling Outage Replacement Steam Generator Secondary Internals Inspection Report", RGE Report issued February 20, 1998.

5. Duke Energy Corp. Catawba Unit 1, "Steam Generators Secondary Side Inspection Report", December 1997, FTI Report No. 1272555A Rev. 0, January 5, 1998.

Table 1
Steam Generator Internals Inspection Program

The following is a program of recommended inspections of tubing and secondary side internal components. The objective is to monitor conditions and integrity of components over time.

- Inspection scope is intended to be comprehensive, covering most internal components.
- Visual inspections are recommended for one SG of the two to four in the reactor unit - unless otherwise noted.
- Inspection at the first outage and from time to time thereafter is suggested.
- Inspection in rotation over time is suggested.
- All Visual is Inspection of a Number of Sample Points or a Sample Region (i.e. Normally a small percentage of the population).
- After the first outage inspection, the need frequency, focus and extent of individual inspections may be reassessed by the station based on i) experience, ii) experience at other BRSG plants, iii) need to focus on items of special interest or concerns and iv) need for condition reporting records. The objective is awareness of condition rather than process completion

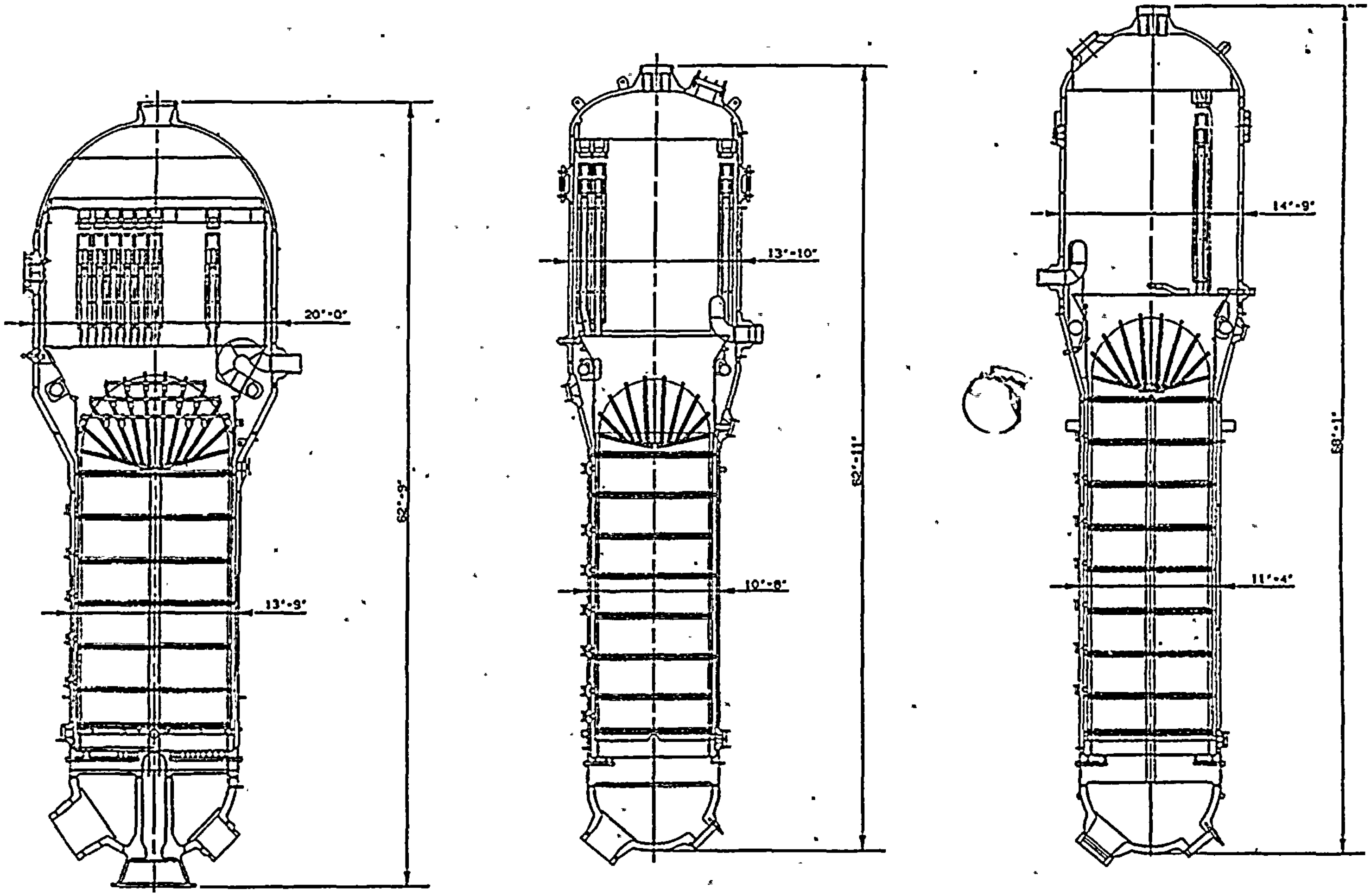
Region (Access)	Feature	Inspection
Primary Side (via manways)	Tubes Incl. For Defects (Cracking, Pitting, Wastage, Fretting) Incl. Secondary Expansion Transition Incl. Support Confirmation, Locations Incl. Sludge Pile Depth Incl. Support Deposition Indication Incl. Peripheral Tube Proximity	ECT/UT Per Site Program
Secondary Side Tubesheet Region	Tubes Within Bundle Incl. Surface Deposits	Visual and Swab Sampling
(via Tubesheet Insp. Ports)	Tubesheet Within Bundle Incl. Sludge Pile Zone	Visual (Fibreoptic)
	Incl. Sludge Deposits Incl. Tube/TS Crevice Region	Visual <u>and</u> Sampling

Region (Access)	Feature	Inspection
	Lattice Grid (Underside of #1) Incl. Tube Contacts, Flow Passages Incl. Sludge Deposits	Visual
	Lattice Grid Rim Incl. Support Blocks Incl. Span Breaker Ends	Visual
	Lattice Grid NTL	Visual
	Tubesheet Periphery Incl. NTL Incl. Drain Channel Incl. Blowdown Entrance Ports	Visual
	Shroud Lower End Incl. Support Blocks	Visual
Secondary Side (via Steam Drum Manway)	Steam Drum Head Incl. Venturi Fixity, Flow Effects	Visual
	Secondary Separators (from above) Incl. Seal Skirt Integrity Incl. Outlet Ports Incl. Vent Holes Incl. Skimmer Vanes, Gaps Incl. Inlet Vanes Incl. Drain Tubes (from bet'n Pri. & Sec.) Incl. Internal Manway/ Cover/ Fastener(s)	Visual
	Primary Separators Incl. Upper Can Vent Holes and Rim Incl. Flow Arms Incl. Secondary Drain Tubes (lower end) Incl. Riser Tube to Deck Joint Area	Visual
	Primary Separator Deck Incl. Deposition on Upper Surface Incl. Internal Manway/Cover/Fasteners	Visual

.Region (Access)	Feature	Inspection
	Incl. Structural Members Incl. Deck/Shell Lugs Incl. Aux. FW Header (as applicable)	
Secondary Side (via Steam Drum Manway) (cont'd)	Riser Cone Incl. Cone/Deck Joint Incl. Slip Ring Joint Incl. Recirc. Nozzle Exit	Visual
	FW Header Incl. Gooseneck Incl. Header Pipe Incl. Header Support Brackets Incl. J-Tubes Incl. J-Tube/Header Welds Incl. J-Tube Entrance (Header I.D.) Incl. Flow Impingement Locations Incl. Shroud Slip Joint Incl. Downcomer Entrance Incl. Shroud Pin Assy./Weld	Visual
Secondary Side U-Bend Region(via Drum)	U-Bend Support (Exoskeletal) Structure	
	Tube Surface Condition	Visual
	Tube Deposition	Visual, Swab Sample
	J-Tab Condition	Visual
	Tube/J-Tab Contact Locations	Visual
	Flat Bar U-Bend Support Bars	Visual
	Flat Bar/Tube Contact Locations	Visual
	Upper Lattice Rim	Visual
	Upper Lattice - Visible Ends of Bars	Visual
Secondary Side(via Cone Access Port)	FW Header O.D.	Visual
	J-Tubes	Visual
	J-Tube/Header Weld	Visual

Region (Access)	Feature	Inspection
	Impingement Zones	Visual
	FW Header I.D. (Videoprobe)	Visual
Secondary Side (Via Inspection Ports)	Lattice Grid NTL Structure	Visual
	Lattice Grid Rim Structure	Visual
	Lattice Bar Ends At Rim	Visual
	Tubes Within Bundle	Visual
	Lattice Bars Tube Contacts (from above)	Visual
	Lattice Bars Tube Contacts (from below) (Special Tooling)	Visual

1 - Arrangements of B&W Replacement Steam Generator



MILLSTONE UNIT 2
ST.LUCIE UNIT 1
(APPROX.540 TON DRY WEIGHT)

GINNA
(315 TON DRY WEIGHT)

CATAWBA UNIT 1, McGUIRE UNITS 1 & 2
BYRON UNIT 1, & BRAIDWOOD UNIT 1
(APPROX.400 TON DRY WEIGHT)

FIGURE 1
RSG GENERAL ARRANGEMENTS

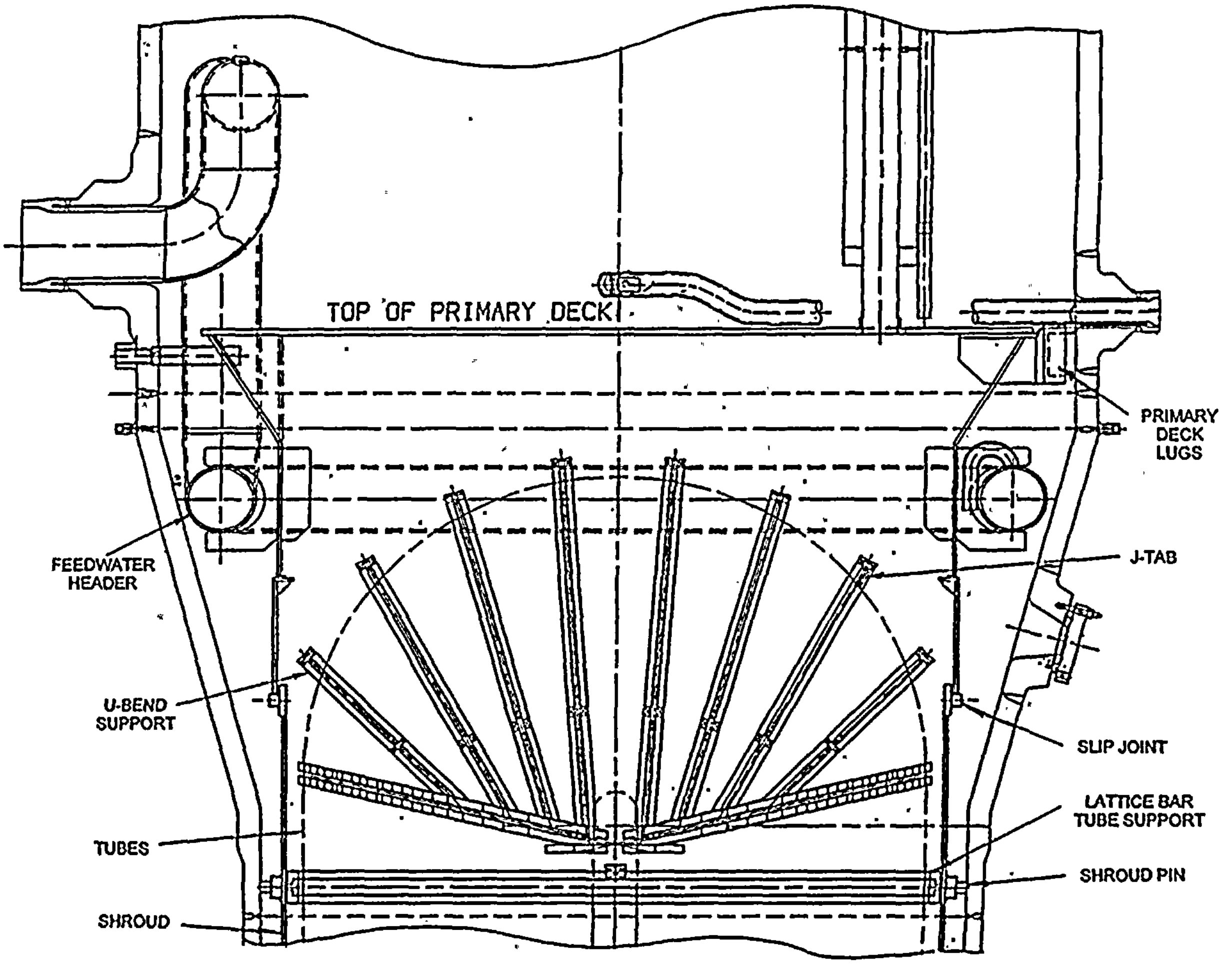


Figure 2 - Steam Generator Upper Tube Bundle

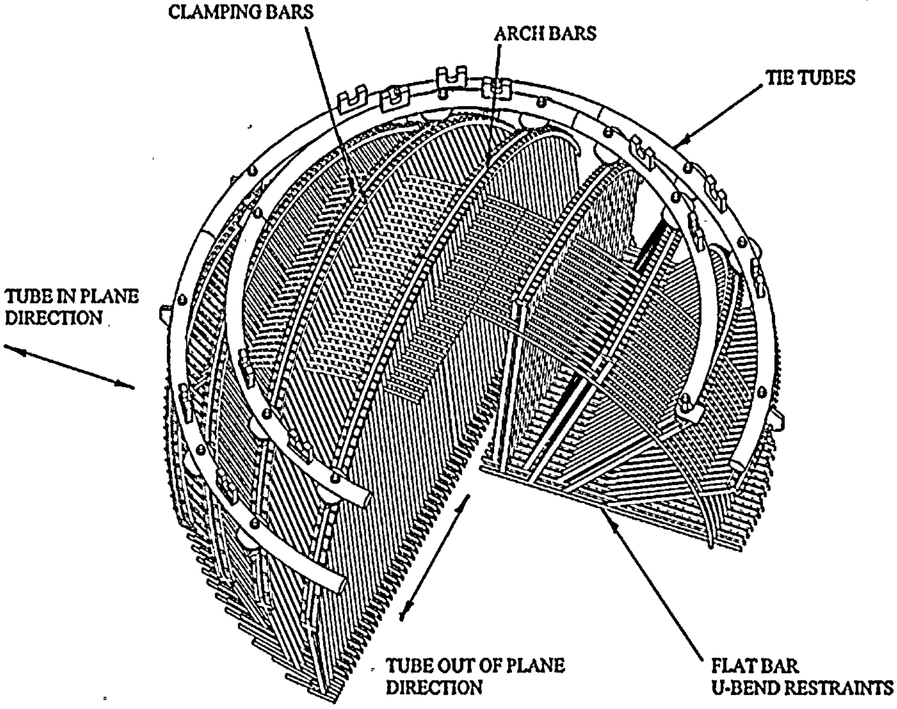


Figure 3 - Flatbar U-bend Restraint System Arrangement

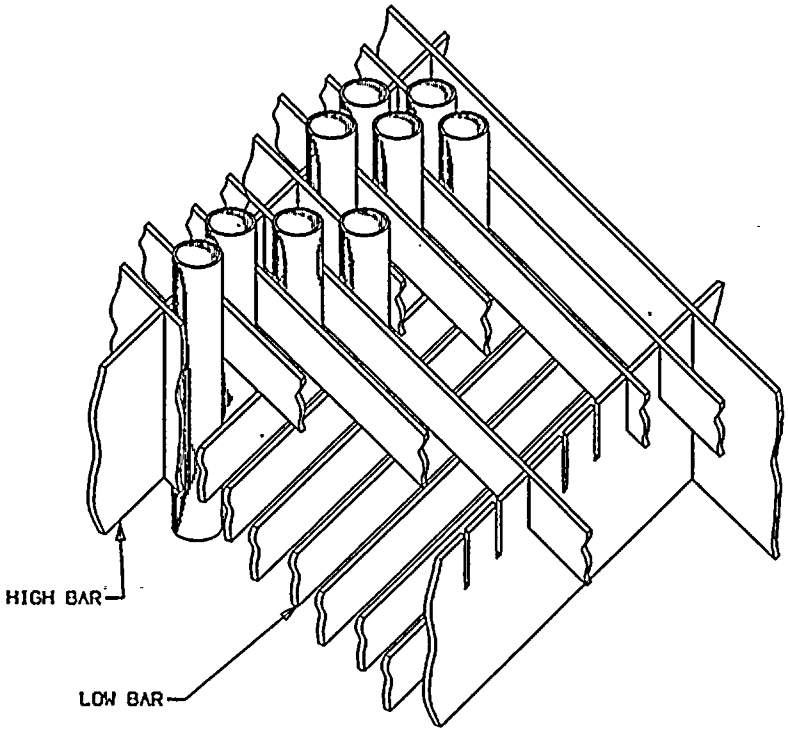


Figure 4 - Lattice Grid High Bar/Low Bar Detail

APPENDIX 1

Site Specific Design Detail - Catawba 1, McGuire 1&2

Discussion regarding BRSG design configuration and operation in the body of the report relates primarily to the replacement SG's provided for the Duke Power sites at Catawba 1 and McGuire 1 and 2. Like all BRSG's they are steam generators designed to replace existing units. The design envelope of the original OESG's is duplicated including pressure vessel dimensions and key performance parameters. They are tubed with Alloy 690TT tubing with lattice bar tube support structures (410S stainless bar), B&W CAP primary/cyclone secondary drum internals, no preheaters and no drilled/broached tube supports.

These BRSG's are replacement for Model D2, D3 and D5 OESG's. Differences respectively between the BRSG's vs OEMSG's include; Alloy 690TT vs Alloy 600MA tubing, 11/16" vs 3/4" tubing diameter, lattice bar supports vs broached plates, no preheater vs baffled preheater, CAP/cyclone steam separators vs cyclone/corrugated dryer type, heat transfer surface of 79,800 ft^2/SG vs 48,300 ft^2/SG.

A unique feature of the Duke BRSG's is the specified service life of 60 years vs 40 years for other units.

The assessments, conclusions and inspection recommendations of the base report apply without change.

APPENDIX 2

Site Specific Design Detail - Byron 1, Braidwood 1

The ComEd BRSG's are essentially identical in all respects to the Duke Power units. Also comparisons between the BRSG and OESG units at the two plants are very similar. Design service life for these and all units other than the Duke Power units is 40 years.

The assessments, conclusions and inspection recommendations of the base report apply without change.

APPENDIX 3

Site Specific Design Detail - Ginna

The RG&E Ginna BRSG's are replacements for Model 44 OESG's. They are the same in concept and materials of construction to the other BRSG's. They are smaller in size so as to duplicate the dimensions and performance of the replaced units.

Comparisons between the BRSG's and the OESG's include; Alloy 690TT tubing vs Alloy 600MA, 3/4" tubing diameter vs 7/8", 410S lattice bar vs C.S. drilled plate supports, B&W CAP/cyclone steam separators vs cyclone/corrugated dryer type, heat transfer surface of 54,000ft^2/SG vs 44,000ft^2/SG.

The assessments, conclusions and inspection recommendations of the base report apply without change.