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June 23, 1995

U. S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, DC 20555-0001

**Subject: Beaver Valley Power Station, Unit No. 1 and No. 2**
**BV-1 Docket No. 50-334, License No. DPR-66**
**BV-2 Docket No. 50-412, License No. NPF-73**
**Generic Letter 95-03 Response**
**Circumferential Cracking of Steam Generator Tubes**

The enclosed information is provided in response to Generic Letter 95-03, "Circumferential Cracking of Steam Generator Tubes." The generic letter specifies three items for licensee action and response. The enclosure provides a safety assessment (Section 3) justifying continued operation based on the evaluations performed in accordance with generic letter Requested Actions (1) and (2) along with a summary of the inspection plans developed in accordance with Requested Action (3) and a schedule for the next planned inspection (Section 4).

If you have any questions regarding the attached information, please contact Mr. G. A. Kammerdeiner, Nuclear Engineering Department, at (412) 393-5677.

Sincerely,

T. P. Noonan

Enclosure

c: Mr. L. W. Rossbach, Sr. Resident Inspector
Mr. T. T. Martin, NRC Region I Administrator
Mr. D. S. Brinkman, Sr. Project Manager





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AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA)
) SS:
COUNTY OF BEAVER )

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Before me, the undersigned notary public, in and for the County and Commonwealth aforesaid, this day personally appeared Thomas P. Noonan, to me known, who being duly sworn according to law, deposes and says that he is Division Vice President, Nuclear Operations of the Nuclear Power Division, Duquesne Light Company, he is duly authorized to execute and file the foregoing submittal on behalf of said Company, and the statements set forth in the submittal are true and correct to the best of his knowledge, information and belief.

Thomas P. Noonan

Thomas P. Noonan

Subscribed and sworn to before me

on this 23rd day of June, 1995

Tracey A. Baczek

Notary Public

Notarial Seal
Tracey A. Baczek, Notary Public
Shippingport Boro, Beaver County
My Commission Expires Aug. 16, 1997
Member, Pennsylvania Association of Notaries

**Enclosure**

Beaver Valley Power Station
Unit No. 1 and No. 2

Response to Generic Letter 95-03

## 1.0 INTRODUCTION

Recent examination of steam generator tubing at Maine Yankee has identified a large number of circumferential indications at the top of the tubesheet region. These most recent inspection findings coupled with previously documented inspection results regarding circumferential cracking resulted in the issuance of Generic Letter 95-03, "Circumferential Cracking of Steam Generator Tubes." The information detailed herein, will address the requested actions of GL 95-03 as they pertain to Westinghouse designed steam generators in general and specifically to Beaver Valley (BV) Units 1 and 2.

The most recent inspection findings concerning steam generator expansion regions (Maine Yankee and Arkansas Nuclear One Unit 2) appear to have impacted those steam generators utilizing the Combustion Engineering (CE) EXPLANSION process more than steam generators utilizing other expansion processes. While there are similarities between the C-E EXPLANSION process and the Westinghouse Explosive Tube Expansion (WEXTEX) process, the degree to which all Westinghouse units, regardless of tube expansion process, have been affected by circumferential cracking is significantly less than the most recent experience of the C-E units. Furthermore, the sludge pile height at Maine Yankee, which may have influenced detectability of circumferential indications, is not representative of sludge pile thicknesses of currently operating Westinghouse units.

Available historical information shows that for some Westinghouse plants, circumferential indications have been detected in the tube expansion transitions located in the tubesheet region, at the small radius (rows 1 and 2) U-bend tangent points, in the parent tube of sleeved joints and at one plant site (two units) at dented tube support plate intersections. Additionally, high cycle fatigue failures of tubes at dented upper tube support plates combined with an unsupported condition (no Anti-Vibration Bar (AVB) contact) are locations of concern for circumferential cracking in Westinghouse designed steam generators.

Many of the Westinghouse units, including the Beaver Valley units, have implemented measures to mitigate the recognized susceptibility of certain regions of steam generator tube bundles to the potential for circumferential cracking. These measures include the following:

1. In- situ stress relief heat treatment of small radius U-bends
2. Shot or Roto peening of expansion transitions
3. Preventative plugging of tubes potentially susceptible to high cycle fatigue
4. Routine augmented inspection of susceptible regions of the tube bundles

At least due in part to the ameliorative measures implemented at many of the units, successive inspection results using Rotating Pancake Coil (RPC) probes for Westinghouse plants with hardrolled or explosively expanded tubes have indicated steadily declining numbers of new indications, declining angular extent and to the degree determinant, very low growth rates.

Collectively, the items discussed above and further detailed on successive pages combined with the use of qualified eddy current inspection techniques and properly implemented analysis criteria provide for the safe continued operation of Westinghouse designed steam generators in general and more specifically Beaver Valley Units 1 and 2.

## 2.0 OPERATING EXPERIENCE FOR THE U.S. POPULATION OF WESTINGHOUSE STEAM GENERATORS SIMILAR TO THE BV 1 & 2 DESIGN

Beaver Valley Unit 1 utilizes Westinghouse Model 51 steam generators with explosively expanded (WEXTEX) transitions while Beaver Valley Unit 2 utilizes Westinghouse Model 51M steam generators with full depth mechanically rolled transitions. The listing of other plants with the steam generators using a similar expansion process are provided in the tables below. The steam generators at both Beaver Valley Units 1 and 2 utilize Alloy 600 Mill Annealed (MA) tubing. The nominal diameter of the tubing at both units is 0.875 inches with a 0.050 inch nominal wall thickness.

| WEXTEX Explosive Expansion Plants<br>Alloy 600 Mill Annealed (MA) Tubing | | | | |
|---|---|---|---|---|
| Plant | Startup | First Time Circ. Cracking | Location | Tube Pull and Results |
| Beaver Valley Unit 1/ 51 | 1976 | 1/95 | Exp. Transition | No |
| Diablo Canyon Unit 1/ 51 | 1984 | 10/92 | Row 1 U-Bend | No |
| | | 3/94 | Exp. Transition | No |
| Diablo Canyon Unit 2/ 51 | 1985 | 3/93 | Exp. Transition | No |
| Farley Unit 1/ 51 | 1977 | 3/91 | Exp. Transition | No |
| | | 3/91 | Row 1 U-Bend | No |
| Salem Unit 1/ 51 | 1976 | 3/91 | Exp. Transition | No |
| Salem Unit 2/ 51 | 1980 | 4/93 | Exp. Transition | No |
| Sequoyah Unit 1/ 51 | 1980 | 3/90 | Exp. Transition | No |
| Sequoyah Unit 2/ 51 | 1981 | 4/88 | Row 1 U-Bend | No |
| | | 8/90 | Exp. Transition | No |
| Comanche Peak Unit 1[a]/ D4 | 1990 | None | N/A | N/A |
| North Anna Unit 1 [b]/ 51 | 1978 | 1987 | Exp. Transition | Yes, segmented Circ. PWSCC |
| | | 1991 | Dented TSPs | Yes, circ. axial ODSCC |
| North Anna Unit 2 [b]/ 51 | 1980 | 1988? | Exp. Transition | No |
| | | 1991? | Dented TSPs | No |

(a): A total of 3839 tubes were removed in the shop to facilitate a stayrod modification. When the tubing was replaced, WEXTEX expansion was used.

(b): Original steam generators

| Full Depth Hardroll Expansion Plants<br>Alloy 600 Mill Annealed (MA) Tubing | | | | |
|---|---|---|---|---|
| Plant/ Steam Generator Model | Startup | First Time Circ. Cracking | Location | Tube Pull and Results |
| Beaver Valley Unit 2/ 51M | 1987 | None | N/A | N/A |
| Braidwood Unit 1/ D4 | 1987 | 2/95 | Roll Transition | No |
| Byron Unit 1/ D4 | 1985 | 9/94 | Roll Transition | Yes, circ. ODSCC |
| Catawba Unit 1/ D3 | 1985 | 3/91 | Roll Transition | Yes, circ. ODSCC |
| Comanche Peak Unit 1[a]/ D4 | 1990 | None | N/A | N/A |
| Farley Unit 2/ 51 | 1981 | 3/89 | Roll Transition | Yes, shallow circ. ODSCC plus axial SCC |
| McGuire Unit 1/ D2 | 1981 | 1/90 | Roll Transition | Yes, circ. plus axial ODSCC |
| McGuire Unit 2/ D3 | 1983 | 7/93 | Roll Transition | No |
| Shearon Harris/ D4 | 1986 | None | N/A | N/A |
| South Texas Unit 1/ E2 | 1988 | 2/93 | Roll Transition | Yes, circ. plus axial |
| Watts Bar Unit 1/ D3 | late 1995? | N/A | N/A | N/A |

(a): A total of 14473 tubes among the 4 steam generators use full depth hardroll tube expansion. A total of 3839 tubes were removed in the shop to facilitate a stay rod modification. WEXTEX expansion was used for the replacement tubing.

## 2.1 WEXTEX Tube Expansion Transitions

The WEXTEX tube expansion process uses an explosive charge to produce tube to tubesheet contact throughout the tubesheet region. WEXTEX tube expansion generally produces lower residual stresses within the expanded to unexpanded tube transition region than mechanical rolling processes. The WEXTEX process has only been implemented on Alloy 600 MA tubing.

Circumferential cracking in WEXTEX transitions was first experienced at North Anna Unit 1 in 1987. Tube pull results from two tubes removed from North Anna revealed primary water circumferential stress corrosion cracking with an angular extent of $128^{O}$ & $176^{O}$ and maximum throughwall depths of 100% and 90% respectively. Numerous uncorroded ligaments were detected in the burst macrocracks of both specimens. Measured burst pressures for these tubes were 9,250 and 10,700 psi, well in excess of Regulatory Guide (RG) 1.121 minimum requirements for demonstrating structural integrity.

Other pulled tube specimens, including tubes pulled at Beaver Valley Unit 1 to support implementation of Interim Plugging Criteria (IPC), provide evidence that the more likely region for stress corrosion cracking to appear is at the Tube Support Plate (TSP) intersection where in the absence of dents, the cracking is axial in orientation. Laboratory Nondestructive Examination (NDE) and destructive examination of the Beaver Valley Unit 1 pulled tubes has not revealed any incidence of WEXTEX circumferential cracking.

A development program was conducted by the Westinghouse Owner's Group (WOG) during the time period (1987-1992) when circumferentially oriented degradation began to appear in WEXTEX expanded tubes. To permit a rapid scoping assessment for tube burst capability of circumferential indications, a burst correlation was developed for throughwall circumferential crack extents. The burst correlation was then applied to define the structural limit on throughwall crack extents (angles) that satisfy the RG 1.121 burst margin for 3 times normal operating pressure differential. Utilizing the burst correlations developed from Electron Discharge Machining (EDM) data and analytical models, the structural limits for throughwall indications were developed as given for the crack models in the following table.

| 7/8 Inch Tubing<br>EOC Structural Limits for Circumferentially Oriented Degradation | | | |
|---|---|---|---|
| | Single Throughwall Crack Model | Single TW Crack with 50% Degraded Ligament | Segmented Throughwall Crack Model |
| $3\Delta P$ = 4500 psi | 210° | 210° | 264° |
| $3\Delta P$ = 4300 psi | 226° | 226° | 269° |
| SLB$\Delta P$ = 2650 psi | 321° | 283° | 318° |

As can be seen from the above table, circumferential cracks with significant angular extent are needed to encroach upon RG 1.121 limits. It can be concluded from the industry data that all circumferential indications found in WEXTEX transitions to date have had burst capability exceeding RG 1.121 requirements. Since continued inspections have not identified large crack angles or growth rates and operating experience shows no WEXTEX region primary to secondary leakage since the North Anna experience in 1987, it is unlikely that large indications are being missed with Motorized Rotating Pancake Coil (MRPC) technology.

### 2.2 Full Depth Mechanical Expansions

Farley Unit 2 and Beaver Valley Unit 2 are the only two plants which utilize 0.875 inch Outside Diameter (O.D.) tubing with full depth mechanical expansion. Although the available data base for circumferential indications in these types of tube expansions is limited, the data indicates a low rate of occurrence of circumferential cracking at these units. Beaver Valley Unit 2 has not identified any circumferential cracking to date even though MRPC sampling of the expansion transition region has been performed since the first refueling outage. Farley Unit 2 has reported only one circumferential indication. Both of these units have performed shot peening of the expansion transition region (Beaver Valley's being performed prior to commercial operation) to mitigate the consequences of both circumferential and axial cracking. Recognizing the remedial measures taken and the results of augmented inspections performed to date, the incidence of circumferential cracking at Beaver Valley Unit 2 is expected to be low and that if it should occur, the corresponding growth rates are likewise expected to be low.

Westinghouse has not performed any plant specific tube integrity evaluations for 0.875 inch OD full depth mechanical expansions due mainly to the lack of field indications. However, based on inspection findings to date, the assessments performed for the WEXTEX process would be considered applicable to 0.875 inch OD tubing expanded using full depth mechanical expansion. Based on the negligible incidence rate of circumferential indications in 0.875 OD full depth mechanically expanded tubes, there is no apparent reason to suggest that either large circumferential crack angles or large numbers of circumferentially oriented degradation would be present during the next scheduled inspection of Beaver Valley Unit 2.

### 2.3 Circumferential Cracking at U-bends, Dented TSP Intersections & High Cycle Fatigue

As mentioned previously, there have been incidences of circumferential cracking associated with small radius (rows 1 and 2) U-bends, dented tube support plate intersections and circumferential failures associated with high cycle fatigue in steam generators of similar design to the Beaver Valley units. While each of these regions will be addressed later as they potentially impact Beaver Valley, further discussion of industry experience is not warranted.

### 2.4 Sleeved Joints

Circumferential indications have been identified in the parent tube of sleeved joints at several operating Westinghouse units. Although the Beaver Valley units are licensed to install sleeves, no sleeves have been installed at either unit. Therefore, this concern is not applicable to either Beaver Valley 1 or 2.

## 3.0 SAFETY ASSESSMENT SUPPORT

The operating experience of similarly designed steam generators to those installed at the Beaver Valley units as well as other designs has been reviewed in regards to the incidence of circumferential cracking. The regions of the Beaver Valley tube bundles that are potentially susceptible to circumferential cracking along with the measures that have been implemented at Beaver Valley to ameliorate and/or adequately assess their condition will be discussed in the following paragraphs.

### 3.1 Beaver Valley Steam Generator NDE Program

Beaver Valley has implemented the Electric Power Research Institute (EPRI) Steam Generator Inservice Inspection Guidelines at both Units 1 and 2 and the WOG WEXTEX Inspection Guidelines at Unit 1. Eddy current techniques and personnel qualified to Appendices G and H of the EPRI Guidelines are utilized for steam generator inspections. Site specific examinations are administered to eddy current data analysts prior to the start of inspection activities. The use of qualified techniques and personnel (Qualified Data Analysts) ensures that an adequate assessment of steam generator structural integrity is being provided at each inspection.

### 3.2 WEXTEX Region - Beaver Valley Unit 1

As part of the WOG subgroup efforts, WEXTEX owners developed a top of tubesheet region inspection plan. This inspection plan divides the tubesheet into 4 distinct zones. Zone 4 represents the central region of the tubesheet and is coincident with the low cross flow velocity region where most sludge accumulation has occurred. Additionally, about 95% of all industry WEXTEX cracking has been identified in Zone 4. The WOG WEXTEX inspection plan utilizes an initial sample size of 50% of the Zone 4 active tubes (700 tubes minimum, ≈ 20% of the total number of S/G tubes) utilizing the MRPC probe for detection of circumferential indications at the top of the tubesheet. All steam generators are inspected with this minimum sample size each refueling outage. This inspection focuses on the region with the largest potential for finding indications and thus results in the highest likelihood for requiring an expansion of sample size.

At the eighth refueling outage in 1991, a 20% random MRPC inspection was performed in the WEXTEX region of each steam generator in accordance with EPRI Inservice Inspection Guidelines (ISI) at BV 1. No circumferential indications were identified. Beaver Valley Unit 1 implemented the WOG WEXTEX inspection guidelines upon their issuance in 1992. At the ninth refueling outage in 1993, a 50% sample of Zone 4 of each steam generator was inspected utilizing MRPC probes. No circumferential cracking was

identified. At the tenth refueling outage in 1995, the initial sample was again 50% of Zone 4 with MRPC. Identification of one circumferential indication in the WEXTEX region prompted Duquesne Light Company (DLC) to expand the sample to 100% of Zone 4 (≈ 50% of the total number of SG tubes) in all steam generators utilizing MRPC. No additional circumferential cracking was identified. The circumferential indication identified had an angular extent of only $60^{o}$, well within the structural integrity requirements of RG 1.121.

The augmented MRPC examinations performed at Beaver Valley Unit 1 to date utilizing qualified MRPC probes and Qualified Data Analysts have not identified significant circumferential cracking, nor do they suggest that widespread circumferential cracking should be postulated in the future. The reaffirmation of the detection capabilities of conventional MRPC probes by the EPRI NDE Center further supports the conclusion that the inspections performed to date have provided an adequate assessment of the structural integrity of the steam generator tube bundles. Additionally, as a conservative measure the primary to secondary leakage threshold was administratively lowered to 150 gpd in 1993 to provide defense-in-depth in addressing the potential for WEXTEX cracking. This threshold was formalized in a Technical Specification change in 1995 to support implementation of IPC and continues to provide an early warning of primary to secondary leakage from potential circumferential cracks. The leakage monitoring capabilities are further enhanced by installed N-16 monitors on the main steam lines.

### 3.3 Full Depth Mechanical Expansion - Beaver Valley Unit 2

The full depth mechanical expansions at Unit 2 were shot peened prior to commercial operation in 1987. This remedial measure significantly lowers the propensity for circumferential or axial cracking in this region of the tube bundle. Nonetheless, at the fifth refueling outage at Unit 2 in 1995, a 20% random MRPC sample of the expansion transition region of all three steam generators was performed in accordance with the recommendations of the EPRI ISI Guidelines. No circumferential indications were identified. At each scheduled inspection prior to the fifth refueling outage, a random 150 tube sample of each steam generator inspected that outage was MRPC inspected at the expansion transition region. No circumferential indications were identified during these inspections.

Considering the remedial measure already implemented at Unit 2 for the expansion transition region and the results of MRPC inspections performed to date, circumferential cracking at the full depth mechanical expansions is not postulated to be an impact to the present or future structural integrity of the steam generators.

### 3.4 U-bend Cracking - Units 1 and 2

All active tubes in rows 1 and 2 at both Beaver Valley Units have been inspected by MRPC probes since the sixth refueling outage at Unit 1 and the third refueling outage at Unit 2. While, U-bend indications have been identified by these examinations at both units, none of the indications have been circumferentially oriented and all tubes exhibiting axial indications have been removed from service.

The row 1 and 2 U-bends at Unit 2 were subjected to an in-situ stress relief heat treatment prior to commercial operation in 1987. Likewise, the row 1 and 2 U-bends at Unit 1 have received an in-situ U-bend stress relieving operation which was completed at the tenth refueling outage in 1995. This heat treatment process significantly lowered the potential for circumferential or axial cracking in this region of the bundle at both units. Since its potential for occurrence is considered negligible, U-bend circumferential cracking at Units 1 or 2 is not postulated to have any adverse affect on steam generator structural integrity.

### 3.5 Dented TSP Intersections

Dented tube support plate intersections are not prevalent at either of the Beaver Valley units. Control of secondary water chemistry has prevented significant denting. Both units operate with boric acid addition to the secondary water primarily for the mitigation of TSP ODSCC, however, with a potential side benefit of controlling denting.

At Unit 1, the implementation of IPC required the MRPC examination of all dents greater than 5 volts. Although the population of dents this size in the Unit 1 steam generators is very small, those that did exceed 5 volts did not reveal any evidence of circumferential cracking upon MRPC interrogation.

The potential for circumferential cracking associated with dented tube support plate intersections is considered remote considering the history of secondary water chemistry control and the use of boric acid addition. Therefore, this degradation mechanism is not postulated to have any impact on steam generator structural integrity.

### 3.6 High Cycle Fatigue

The concerns for high cycle fatigue and sudden tube failure are documented in detail in NRC Bulletin 88-02. Both Beaver Valley units have been analyzed for this condition using NRC accepted methodology. Those tubes that are susceptible to this mechanism have been identified and preventatively plugged with sentinel plugs. Therefore, this potential mechanism of initiating circumferential cracking has been adequately mitigated and will not impact steam generator structural integrity.

### 3.7 Sleeved Joints

Neither Beaver Valley unit has installed sleeves, therefore, the concerns of parent tube circumferential cracking associated with various sleeving processes are not applicable.

## 4.0 Future Inspection Plans

The next steam generator eddy current examinations are scheduled to occur in March 1996 at Unit 1 and September-October 1996 at Unit 2. Duquesne Light Company plans to continue with the implementation of the EPRI Steam Generator ISI Guidelines and the WOG WEXTEX Inspection Guidelines and potential revisions thereto. Initial sample sizes established and justified by these documents will form the bases for the Beaver Valley inspection sampling. Qualified augmented inspection techniques will continue to be employed to interrogate regions of the tube

bundle where bobbin coil eddy current techniques have limited capability to assess tube condition and/or to resolve anomalous or unexpected ISI results. The augmented techniques used will be consistent with the recommendations detailed in the EPRI and WEXTEX inspection guidelines as supported by Appendix H qualification. Sample expansion will be in accordance with the more conservative of the above mentioned guidelines or plant Technical Specifications. Data analyst qualification to Appendix G of the EPRI Guidelines will continue to be required for lead analysts, along with the continued administration of site specific testing.

Duquesne Light personnel will maintain an awareness of industry operating experience and evolving technologies and adjust future inspection plans and programs as deemed appropriate and necessary to ensure the continued structural integrity of the Beaver Valley steam generators.

## 5.0 Summary

Duquesne Light has reviewed the applicable industry operating experience regarding circumferential cracking of steam generator tubes and has assessed the potential impact of such degradation on the Beaver Valley Power Station Units 1 and 2.

The past inspection scope and results of each susceptible region of the tube bundle have been reviewed in regards to susceptibility to circumferential cracking, threshold of detection, expected or inferred crack growth rates and other relevant factors. Those susceptible regions of the steam generator tube bundles at both units 1 and 2 have been inspected utilizing sampling plans and qualified augmented techniques in accordance with EPRI Steam Generator Inservice Inspection and WOG WEXTEX Inspection Guidelines. The capabilities of these augmented inspection techniques (MRPC) to adequately assess steam generator tube condition and thus ensure structural integrity have been demonstrated and recently reaffirmed to be qualified for the detection of Inside Diameter (ID) primary water stress corrosion cracking (PWSCC) and OD stress corrosion cracking (ODSCC) irrespective of orientation-circumferential or axial. These past inspections and their associated results provide evidence that circumferential cracking of the susceptible regions of the Beaver Valley steam generator tube bundles do not present a concern in regards to tube structural integrity and that the Beaver Valley Units are safe to operate until their next scheduled inspections. This conclusion is further supported by the following facts:

1. The angular extent for circumferential WEXTEX cracks to encroach upon RG 1.121 burst requirements is quite large. The industry experience with identified WEXTEX circumferential cracks indicates that none would have violated RG 1.121 burst requirements. It is unlikely that the qualified MRPC inspections being performed at the WEXTEX transitions are missing structurally significant circumferential indications. These assessments are considered to be applicable to full depth mechanically expanded transitions, also.

2. In-situ stress relief heat treatment has significantly reduced if not eliminated the propensity for initiation of circumferential cracking at small radius U-bends at both Units 1 and 2.

3. Shot-peening of the Unit 2 full depth mechanical expansions prior to commercial operation has significantly reduced the potential for axial or circumferentially oriented primary water stress corrosion cracking.

4. Control of secondary water chemistry and the use of boric acid additions have prevented denting at TSP intersections at both Units 1 and 2.

5. Sludge lancing has been performed at both Units 1 and 2 and, along with secondary water chemistry control used to minimize corrosion product transport, will continue to be employed to control sludge pile deposits that could interfere with eddy current results.

6. Tubes with the potential for high cycle fatigue failure have been identified and preventatively plugged.

Future inspection plans include the continued implementation of the EPRI Steam Generator ISI and WOG WEXTEX Inspection Guidelines and their associated requirements for sample sizes and expansion criteria, including recommended augmented inspection techniques and associated qualification requirements for said techniques and personnel. These comprehensive inspection plans, combined with the focused remedial measures employed at susceptible tube bundle regions, will ensure the continued safe operation of the Beaver Valley steam generators.