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SUBJECT: Forwards PVNGS Unit 3 steam generator insp results which include occurrences of mechanical fetting wear in Baltwing Stay Cylinder Region.

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April 18, 1997

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Dear Sirs:

**Subject: Palo Verde Nuclear Generating Station (PVNGS)**
**Unit 3 Steam Generator Inspection Results**

In response to a request for information from Mr. James W. Clifford of your staff on April 8, 1997, APS is providing steam generator inspection results from Unit 3. These inspection results are enclosed and include occurrences of mechanical fretting wear in the Batwing Stay Cylinder Region.

Should you have any questions, please contact Scott A. Bauer at (602) 393-5978.

Sincerely,

James M. Levine

JML/AKK/JRP/rlh

Enclosure

cc: E. W. Merschoff
K. E. Perkins
J. W. Clifford
K. E. Johnston

A001

# ENCLOSURE

## UNIT 3 STEAM GENERATOR
## INSPECTION RESULTS

At the conclusion of the sixth refueling outage of Unit 3 (U3R6) of the Palo Verde Nuclear Generating Station, 199 steam generator tubes were removed from service following eddy current testing.

**Steam Generator 31**

In steam generator 31, a total of 93 tubes were removed from service. Seven (7) tubes were found to have single and/or multiple axial indications. Ten (10) tubes were found to have single volumetric indications. One (1) tube had circumferential indications in the vicinity of the secondary face of the tubesheet and was plugged and staked. Thirteen (13) other tubes were removed from service due to wear indications in excess of administrative plugging limits. Two (2) tubes were plugged and staked in the batwing stay cylinder area due to wear indications in excess of administrative limits. Sixty (60) additional tubes in the batwing stay cylinder region were preventatively plugged (see "Support Wear Evaluation" for further explanation of this condition).

**Steam Generator 32**

In steam generator 32, a total of 106 tubes were removed from service. Nine (9) tubes were found to have single and/or multiple axial indications. Six (6) tubes were found to have single volumetric indications. Seventeen (17) tubes had circumferential indications in the vicinity of the secondary face of the tubesheet and were plugged and staked. Six (6) other tubes were removed from service due to wear indications in excess of administrative plugging limits. Seventeen (17) tubes were plugged and staked in the batwing stay cylinder area due to wear indications in excess of administrative limits. Fifty-one (51) additional tubes in the batwing stay cylinder region were preventatively plugged (see "Support Wear Evaluation" for further explanation of this condition).

**Support Wear Evaluation**

During U3R6, a number of steam generator tube indications were identified which were considered to have higher than expected growth rates for Cycle 6. These indications were due to mechanical fretting tube-tube support wear in the Batwing Stay Cylinder Region. The increase in wear was observed in SG 32 only, and is believed to be a result of cutting shroud holes in SG 32 during U3R5 to increase bundle recirculation flow to improve thermal hydraulic conditions. An evaluation of this phenomenon as well as transportability issues to Units 1 and 2 is currently in progress.

Since high defect growth rates can require reduced operating periods in order to comply with Regulatory Guide 1.121 structural integrity criteria for steam generator tubing, preventative plugging of tubes in the affected region was conducted in SG 31 and SG 32. A total of 60 tubes were preventatively plugged in SG 31 and 51 tubes in SG 32. The plugging pattern employed was recommended by ABB-CE and is based on report CEN 328 Appendix 7.3 "Wear Progression Analysis Results for Palo Verde 1, 2 and 3." With the preventative plugging, no operability issues exist for Unit 3 Cycle 7. Data tables for SG 31 and 32 are attached which provide wear indication data for batwing stay cylinder tubes for U3R6 and U3R5.

**U3R6 Tube Plugging Projections**

The table below provides a comparison between the actual number of tubes plugged in Unit 3 and the pre-outage engineering projection for identified degradation mechanisms. An additional 111 tubes were preventatively plugged, as previously discussed, to bound a potential area of increased wear.

| Damage Mechanism | Upperbound Plug Projection | Actual Plugs |
|---|---|---|
| Arc Region | 55 | 9 (note 2) |
| Circumferential Cracks (TTS) | 12 | 17 (note 1) |
| Axial Cracks (lower bundle) | 7 | 7 |
| Other (wear, loose parts) | 53 | 55 |
| Total | 127 | 88 (note 3) |

Note 1 - One circumferential tube crack 8 inches below the top of tubesheet was counted as "other"
Note 2 - Excludes upper bundle SVIs (volumetric indications)
Note 3 - Excludes preventative plugging

**Condition Monitoring Assessment**

The NRC Draft Regulatory Guide on Steam Generator Tube Integrity, Section C.3.0, states that the as-found condition of tubing should be monitored during each inspection to confirm that structural and leakage performance criteria have been satisfied. This evaluation process is referred to as Condition Monitoring. Since there was no evidence of tube leakage prior to shutdown, as well as no indication of 100% through-wall penetration during ECT, this evaluation compares ECT results with the structural integrity design basis for PVNGS. The safety margins for structural integrity of steam generator tubing are defined in Regulatory Guide 1.121. Allowable flaw size criteria has been established via calculation and/or qualification burst testing.

Circumferential Defects

The number of circumferential defects (OD and ID) found in Unit 3, slightly exceeded the pre-outage estimates. With one exception, all circumferential defects were located in the expansion transition at the top of the hot leg tubesheet. The additional defect was found within the tubesheet at an expansion anomaly.

In previous inspections, circumferential cracks were typically clustered in the historical kidney bean sludge pile location (Reference 1). Sludge piles formed as a result of chemical cleaning appear to have created a new cluster site. Sludge lancing activities during U3R6 were concentrated in this region. While the actual number of circumferential defects is a small deviation from engineering projections, and is not considered to be a safety issue, long term strategic models may require adjustment based on the U3R6 inspection. In U3R6, the plus point probe was used for tubesheet inspections. This probe is industry recognized as providing the best detection capability. At PVNGS, all detected circumferential cracks are removed from service by plugging and staking.

Based on NDE results, all circumferential defects identified in U3R6 are within the structural limits specified in RG 1.121. Engineering reviewed the two largest defects found in SG 32 at R67C82 and R69C82. Based on the criteria applied by PVNGS in U1R4, these tubes would have been candidates for in-situ pressure testing since their crack angles were measured at >270 degrees. NDE capability in 1993, however, did not include the ability to depth size a circumferential crack. Consequently all defects in U1R4 were assumed to be 100% through-wall for the entire length. New ECT software provides the ability to estimate the depth profile of the flaw, and to assess the need for further testing. Application of this software led to the determination that further testing was not necessary.

APS utilized EPRI developed selection criteria for in-situ test candidates for circumferential cracks (Reference 2). The criteria accounts for NDE uncertainties with respect to the structural limits. The EPRI criteria is based on tube pull data from hard rolled plants which conservatively bound CE explanded transitions, as the ECT uncertainties for hard roll plants are significantly greater than explanded plants. The sequential criteria contained in the EPRI guideline is:

Crack angle > 220 °
Voltage integral > 0.3 volt
Percent Degraded Area (PDA) > 45%

For both R67C82 and R69C82, only the crack angle criteria is exceeded. The voltage integral for R67C82 value was computed as 0.18 and the PDA was calculated to be 41.83%. For R69C82 the voltage integral was computed as 0.17 and the PDA was determined to be 11.87%. The RG 1.121 allowable PDA is >69%. For an additional comparison, the maximum voltage indication for these defects was reviewed. Voltage amplitude is an additional ECT parameter for assessing relative flaw severity. For example, in U1R6, tube R25C50 was successfully in-situ tested. The RPC presentation of the Unit 1 defect was more severe than any of the U3R6 defects. The maximum voltage for R25C50 was 2.38 volts (U1R6). By comparison, the maximum voltage for R67C82 was measured at 0.93 volts.

It was, therefore, concluded that there was no technical basis requiring RG 1.121 verification in-situ testing of tubes R67C82 or R69C82, that all the circumferential cracks detected were bounded by previous in-situ testing, and that the structural integrity performance criteria has been satisfied with respect to circumferential flaws observed in U3R6.

<u>Axial Cracks</u>

The number of axial SCC defects (OD and ID) found in Unit 3 are within pre-outage estimates. In U3R6, the plus point probe was used for the detection of axial flaws at the tubesheet, in previous wear indications > 20%, all bobbin I-codes, the ARC region and Row 1 and 2 U-bend inspections. At PVNGS, all detected cracks are removed from service.

Based on review of the inspection results, no defects were observed to exceed the structural integrity limits for PVNGS. Based on previous tube pull evaluations, a length and voltage based screening criteria is used for verification of structural integrity (Reference 3). All axial SCC indications found during U3R6 were less than one (1) volt as measured by the pancake coil. Currently, only tubes which exceed 2 volts are candidates for in-situ testing. A RG 1.121 screening criteria of 2.25 volts is also used to assess the tubing condition. Therefore, the U3R6 indications are bounded by existing analyses that were benchmarked by previous ECT and tube pull examinations.

<u>Other Indications</u>

No mechanical fretting wear indications were found to be in excess of the minimum structural limit of 60% through-wall. The deepest wear indication, not associated with Batwing Stay Cylinder wear, was observed at 46% through-wall.

As indicated previously, a number of steam generator tube indications were observed which were considered to have higher than expected growth rates for Cycle 6. These indications were due to mechanical fretting tube-tube support wear in the Batwing Stay Cylinder Region. The increase in wear was observed in SG 32 only. The deepest indication observed was 56% through-wall by MRPC. Batwing Stay Cylinder wear has an unique wear pattern. Unlike flat bar wear, material is removed at an angle instead of uniform wall thinning. This wear angle produces a sharp point of wall penetration with substantial remaining wall thickness throughout most of the wear scar. Consequently, burst tests indicate that structural integrity is maintained within RG 1.121 limits (three times normal operating delta-pressure) for > 75% through-wall penetration. Based on the ECT results, no structural integrity limits were violated for Cycle 6. Since additional modifications were performed in U3R6 which would increase the flow field velocities during Cycle 7 in SG 31 and SG 32 further than occurred in SG 32 during Cycle 6, additional preventative plugging was performed to avoid high defect growth rates in active tubes.

<u>Conclusion</u>

Based on the engineering review of the U3R6 ECT results, it is concluded that all defects are within the structural and leakage design basis as defined in Regulatory Guide 1.121 and the PVNGS Steam Generator Degradation Management Program.

## References


1. *Status of PVNGS Steam Generator Activities*, August 1994, submitted to the USNRC by Letter 102-03083-WLS/AKK/JRP dated August 11, 1994.

2. Report, *Depth Based Structural Analysis Methods for SG Circumferential Defects,* EPRI TR-107198 (Draft).

3. *Unit 2 Cycle 7 Steam Generator Evaluation,* January 1997, submitted to the USNRC by Letter 102-03849-JML/AKK/JRP dated January 19, 1997.