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EPRI

April 15, 2004

Mr. Gene Carpenter
Document Control Desk
U.S. Nuclear Regulatory Commission
Washington DC, 20555

Subject: ARC Guidelines for Prevention Repair of Large +Point Indications and Noise Requirements for Voltage-Based ARC

Gentlemen:

This is a request under 10CFR2.790(a)(4) that the NRC withhold from public disclosure the information identified in the enclosed affidavit consisting of EPRI-owned proprietary information as identified above (the "Information"). A copy of the Information and the affidavit in support of this request are enclosed.

EPRI desires to disclose the Information in confidence to the NRC for informational purposes to assist the NRC. EPRI would welcome any discussions with the NRC related to the Information that the NRC desires to conduct.

The Information is for the NRC's internal use and may be used only for the purposes for which it is disclosed by EPRI. The information should not be otherwise used or disclosed to any person outside the NRC without prior written permission from EPRI.

If you have any questions about the legal aspects of this request for withholding, please do not hesitate to contact me at (650) 855-2340. Technical questions on the contents of the Information should be directed to Mr. Edward Blandford at (650) 855-8783.

Sincerely,

Warren J. Bilanin

Warren J. Bilanin
Director, Nuclear Power Sector

Enclosures

c: Edward Blandford, EPRI
Nichole Edraos, EPRI

YG01
D046

EPRI

AFFIDAVIT

RE: ARC Guidelines for Prevention Repair of Large +Point Indications and Noise Requirements for Voltage-Based ARC

I, WARREN J. BILANIN, being duly sworn, depose and state as follows:

I am a Director at the Electric Power Research Institute ("EPRI") and I have been specifically delegated responsibility for the Documentation listed above that is sought under this affidavit to be withheld (the "Documentation") and authorized to apply for their withholding on behalf of EPRI. This affidavit is submitted to the Nuclear Regulatory Commission ("NRC") pursuant to 10 CFR 2.790 (a)(4) based on the fact that the Documentation consists of trade secrets of EPRI and that the NRC will receive the Documentation from EPRI under privilege and in confidence.

The basis for withholding such Documentation from the public is set forth below:

(i) The Documentation has been held in confidence by EPRI, its owner. All those accepting copies of the Documentation must agree to preserve the confidentiality of the Documentation.

(ii) The Documentation is a type customarily held in confidence by EPRI and there is a rational basis thereof. The Documentation is a type, which EPRI considers as a trade secret(s) and is held in confidence by EPRI because to disclose it would prevent EPRI from licensing the Documentation at fees, which would allow EPRI to recover its investment. If consultants and/or other businesses providing services in the electric/nuclear power industry were able to publicly obtain the Documentation, they would be able to use it commercially for profit and avoid spending the large amount of money that EPRI was required to spend in preparation of the Documentation. The rational basis that EPRI has for classifying this/these Documentation(s) as a trade secrets is justified by the Uniform Trade Secrets Act, which California adopted in 1984 and which has been adopted by over twenty states. The Uniform Trade Secrets Act defines a "trade secret" as follows:

> "Trade secret" means information, including a formula, pattern, compilation, program, device, method, technique, or process, that:
>
> (1) Derives independent economic value, actual or potential, from not being generally known to the public or to other persons who can obtain economic value from its disclosure or use; and
>
> (2) Is the subject of efforts that are reasonable under the circumstances to maintain its secrecy.

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(iii) The Documentation will be transmitted to the NRC in confidence.

(iv) The Documentation is not available in public sources. EPRI developed the Documentation only after making a determination that the Documentation was not available from public sources. It required a large expenditure of dollars for EPRI to develop the Documentation. In addition, EPRI was required to use a large amount of time of EPRI employees. The money spent, plus the value of EPRI's staff time in preparing the Documentation, show that the Documentation is highly valuable to EPRI. Finally, the Documentation was developed only after a long period of effort of several years.

(v) A public disclosure of the Documentation would be highly likely to cause substantial harm to EPRI's competitive position and the ability of EPRI to license the Documentation both domestically and internationally. The Documentation can only be acquired and/or duplicated by others using an equivalent investment of time and effort.

I have read the foregoing and the matters stated therein are true and correct to the best of my knowledge, information and belief. I make this affidavit under penalty of perjury under the laws of the United States of America and under the laws of the State of California.

Executed at 3412 Hillview Avenue, Palo Alto, being the premises and place of business of the Electric Power Research Institute:

April 15, 2004

Warren J. Bilanin

Subscribed and sworn before me this day: April 15, 2004

Nichole Alexandra Edraos, Notary Public

NICHOLE ALEXANDRA EDRAOS
Comm. # 1295461
NOTARY PUBLIC - CALIFORNIA
Santa Clara County
My Comm. Expires Feb. 26, 2005

SUBSCRIBING WITNESS JURAT

State of California
County of Santa Clara } SS.

On 4/15/04 (DATE), before me, the undersigned, a notary public for the state, personally appeared Barbara Jeanne Ryan (SUBSCRIBING WITNESS'S NAME), personally known to me (or proved to me on the oath of ________________ (CREDIBLE WITNESS'S NAME), who is personally known to me) to be the person whose name is subscribed to the within instrument, as a witness there to, who, being by me duly sworn, deposed and said that he/she was present and saw Warren Balanon (NAME(S) OF PRINCIPAL(S)) the same person(s) described in and whose name(s) is/are subscribed to the within and annexed instrument in his/her/their authorized capacity(ies) as (a) party(ies) thereto, execute the same, and that said affiant subscribed his/her name to the within instrument as a witness at the request of Warren Balanon (NAME(S) OF PRINCIPAL(S)).

NICHOLE ALEXANDRA EDRAOS
Comm. # 1295461
NOTARY PUBLIC-CALIFORNIA
Santa Clara County
My Comm. Expires Feb. 26, 2005

ALEXANDRA EDRAOS
Comm. # 1295461
NOTARY PUBLIC-CALIFORNIA
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My Comm. Expires Feb. 26, 2005

WITNESS my hand and official seal.

Nichole Alexandra Edraos
NOTARY'S SIGNATURE

OPTIONAL INFORMATION

The information below is optional. However, it may prove valuable and could prevent fraudulent attachment of this form to an unauthorized document.

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- ☐ TRUSTEE(S)
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NUCLEAR ENERGY INSTITUTE

Alexander Marion
SENIOR DIRECTOR, ENGINEERING
NUCLEAR GENERATION DIVISION

April 13, 2004

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

SUBJECT: ARC Guidelines for Preventive Repair of Large +Point Indications and Noise Requirements for Voltage Based ARC

PROJECT NUMBER: 689

NRC Generic Letter 95-05 provides guidance for implementation of alternate repair criteria (ARC) for steam generator tubes with outside diameter stress corrosion cracking (ODSCC) at tube support plate (TSP) locations. In response to this generic letter, industry developed a database for use when inspecting tubing with this degradation mode, and has periodically submitted addenda to update the database with current information. The last addendum (5) was submitted to you in February 2003. Addendum 6 should be completed this summer. The purpose of this letter is to submit, in advance of addendum 6, new methods for preventive tube plugging and for dealing with eddy current signal noise during tube inspections. Your approval of the enclosed noise requirements is requested in time to allow use of the method during this fall's steam generator inspections.

Enclosure 1 (ARC Guidelines for Preventive Repair of Large +Point Indications) provides guidelines for preventive tube repair (i.e., repair at less than the licensed voltage based repair limits) to reduce the potential for finding large voltage growth rates for indications left in service. Since the guidelines apply to preventive repair, implementation of these guidelines is optional on a plant specific basis, and NRC approval is not necessary.

Enclosure 2 (Noise Requirements for Voltage Based ARC) provides new recommendations on noise inspection, analysis and repair for application to the ARC. Tube noise considerations for indications at TSP intersections for the voltage based ARC are currently based on measurements of the mix residual signal. The mix residual was applied in the early development of the ARC as a measure of noise prior to more recent efforts in the industry to assess the effects of noise on detection. The mix residual is a measure of the noise across the entire TSP length and is not an appropriate quantity for assessing the effects of noise on detection since most TSP indications develop at the TSP center where noise influence is minimal. Since these recommendations represent a change to GL 95-05, NRC approval is required prior to implementation under the ODSCC ARC.

The proprietary information in Enclosures 1 and 2 is supported by the signed affidavits in Enclosure 3. The affidavits set forth the basis on which the information may be withheld from public disclosure by the Commission and addresses with specificity, the consideration

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listed in paragraph (b)(4) of Section 2.790 of the Commission's regulations. Accordingly, we respectfully request that the information, which is proprietary to EPRI, be withheld from public disclosure in accordance with 10 CFR 2.790. A non-proprietary version of this information is provided in Enclosure 4 and 5.

As has been the past practice, we believe any NRC staff review of the enclosed information is exempt from the fee recovery provision contained in 10 CFR Part 170. This submittal provides information that might be helpful to NRC staff when evaluating licensee submittals provided in response to Generic Letter 95-05. Such reviews are exempted under §170.21, Schedule of Facility Fees. Footnote 4 to the Special Projects provision of §170.21 states, "Fees will not be assessed for requests/reports submitted to the NRC...as means of exchanging information between industry organizations and the NRC for the purpose of supporting generic regulatory improvements or efforts."

We would be pleased to meet with you or provide any support necessary to expedite acceptance of the outstanding issues regarding the database.

If you have any questions, please contact me at 202-739-8080; am@nei.org or Jim Riley, 202-739-8137; jhr@nei.org.

Sincerely,

Alex Marion

Alex Marion

Enclosures

c: Richard Barrett, U. S. Nuclear Regulatory Commission
Louise Lund, U. S. Nuclear Regulatory Commission
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Emmett Murphy, U. S. Nuclear Regulatory Commission
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Bob Keating, Westinghouse
Edward Blandford, EPRI
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Enclosure 4

ARC Guidelines for Preventive Repair of Large +Point Indications

Non-Proprietary Version

ARC Guidelines for Preventive Repair of Large +Point Indications

1.0 Introduction

This note provides guidelines for preventive tube repair (i.e., repair at less than the licensed voltage based repair limits) to reduce the potential for finding large voltage growth rates for indications left in service under the ARC for axial ODSCC at TSP intersections. Since the guidelines apply to preventive repair, implementation of these guidelines is optional on a plant specific basis.

ARC inspections periodically find large voltage indications (such as > 8 volts) that are not predicted to occur and generally do not occur in successive inspections. These indications with unusually large voltage growth have been shown, where successive RPC inspection data are available, to occur with normal growth in depth. Voltage increases exponentially with depth and again approximately exponentially with increasing throughwall length. Consequently, an indication that is near throughwall over a significant length at the BOC can grow with normal depth growth to a significant throughwall length over one operating cycle with an associated large voltage growth rate. Most of the large voltage growth indications found in ARC inspections have been pulled and found to satisfy burst margins at the EOC conditions. However, the ARC burst versus voltage correlation will predict burst probabilities near the ARC reporting threshold of 0.01 due to the large uncertainties in the correlation.

The likelihood of finding a large voltage indication can be reduced by preventive plugging at less than the ARC repair limit. The best currently available methods for depth sizing of axial ODSCC are based on correlations of depth with +Point voltage when developed to provide a good estimate of the voltage at initial throughwall penetration. The latter is a principal factor in the development of sizing correlations under the EPRI Tools for Tube Integrity Program and associated correlations are applied in this report to provide a recommended +Point voltage for preventive tube repair for axial ODSCC at TSP intersections.

Section 2 provides additional background information and Section 3 provides guidelines for preventive repair. Section 4 provides guidelines for supplemental inspections to further inspect for indications potentially desirable for preventive repair. Section 5 summarizes the conclusions of this report.

2.0 Background Information

The largest voltage indication found during ARC inspections was a 21.5 volt bobbin indication (12.2 volt by +Point) at Plant Y-2. Fortunately, for providing a good database for evaluation, this indication had been +Point inspected at the prior outage. At the prior inspection, this indication was found to measure 2.0 volt by bobbin and 2.97 volt by +Point (maximum volts from profile analysis). The occurrence of +Point amplitudes greater than the bobbin voltage is infrequent for ODSCC partially due to the bobbin coil integrating degradation around the circumference of the tube while RPC measures a single crack location. The two voltages tend to be closer in magnitude when there is a single dominant crack at the TSP intersection.

The range of +Point amplitudes for a short throughwall axial ODSCC indication is about 2.0 to 3.0 volts. The lowest throughwall +Point amplitude in the ARC database is 1.89 volts. This indication had two interacting axial cracks, which tends to result in a +Point voltage reduction due to cancellation between the two coils. It can be expected that the Plant Y-2 indication was near or just throughwall at

the BOC condition. The growth rate in average depth for this indication was about 12% per EFPY which is in the range of the upper 90% to 95% probability for normal growth rates and considerably smaller than ODSCC indications found to have large growth rates. The Plant Y-2 indication grew from imminent throughwall at BOC to the throughwall length of 0.42 inch found by destructive examination. The large voltage growth resulted from throughwall penetration and growth in throughwall length.

Plants P-1, Y-1 and Y-2 have performed significant +Point inspections below the 2.0 volt repair level that include some indications with data from two or three +Point inspections over the last three cycles. These data permit an assessment of the larger +Point voltage and +Point to bobbin voltage ratio indications retained in service. The last three cycles of data were reviewed to identify the largest +Point volts left in service, the largest ratio of +Point to bobbin voltage and the largest bobbin indications. The resulting data for Plant P-1 cycles 1R13 to 1R15 are given in Table 1 and for Plants Y-1 and Y-2 cycles 9 to 11 are given in Tables 2 and 3. For Plant P-1, the largest +Point volts returned to service that can be assessed at the subsequent cycle are 1.65 volts at 1R13 and 1.71 volts at 1R14. None of the indications with +Point volts up to 1.71 had a large bobbin or +Point voltage growth in the subsequent cycle. The largest bobbin indication of 4.57 volts, which would not be considered an outlier indication, for tube R11C77 had a prior cycle +Point 0.61 volt indication. Similarly, indications with +Point to bobbin voltage ratios up to 2.0 showed no significant bobbin voltage growth in the subsequent cycle. The Plant Y-1 data of Table 2 show that there have been no high +Point volts or +Point to bobbin voltage ratios for data with successive +Point inspections. Thus, these data do not provide any additional insight on potentially limiting +Point voltages. The Plant Y-2 data of Table 3 show the 2.97 +Point volt indication left in service that led to the 21.5 bobbin volt outlier indication. Indications with +Point volts as high as 1.6 volts and +Point to bobbin voltage ratios up to 2.07 did not show any significant bobbin voltage growth in the subsequent cycle. The higher ratios of +Point to bobbin voltage, such as > 1.4, are generally associated with dominant single indications with relatively small bobbin voltages (i.e., < 0.7 volt) such that the effect of increasing bobbin voltage with increasing cracking around the tube circumference is not present. There is no technical reason to expect that single indications have a higher potential for large voltage growth in the next cycle since voltage growth rates are highest for crack depths near 100% and for increases in throughwall length rather than multiple indication effects. The Tables 1 to 3 results indicate that the +Point to bobbin voltage ratio is not a meaningful predictor for large bobbin voltage growth and is, therefore, not recommended for considerations of preventive plugging.

The Table 1 results also indicate that +Point voltages up to about 1.71 do not appear to be a meaningful predictor of large bobbin voltage growth. As discussed in Section 3 below, the crack depth for a 1.71 +Point voltage indication would be expected to be too shallow to grow to a significant throughwall length with normal growth rates over one cycle of operation. The threshold for considering preventive plugging should be greater than about 1.71 volts.

3.0 Guidelines for Preventive Repair

Based on the discussion of Section 2, only +Point indications greater than about 1.71 volt appear to be candidates for preventive repair considerations and the use of +Point to bobbin voltage ratios for preventive repair considerations is not recommended. The objective for preventive repair considerations is to prevent significantly large throughwall lengths, but to not exclude the potential for any throughwall cracks which would too conservative for a repair guideline. Growth in average depth is applied to estimate a reasonable depth for preventive repair as growth over a significant length rather than local crack penetration is of interest. A growth rate of about 10% in average depth per EFPY is a reasonable estimate for normal growth at about the 90% confidence level. Thus, for preventive repair based on

+Point amplitude sizing considerations, the amplitude should be based on average crack depths in the range of 85% over the deepest segment of about 0.1 to 0.2 inch. Since the amplitude sizing correlations are based on maximum crack depth, the 85% segment average depth must be adjusted upward to define a preventive repair guideline. Since the ratio of maximum depth to average depth over the burst effective crack length for a crack is typically about 1.25, it is reasonable to assume that the maximum depth for a deep crack segment would be at least 10% greater than the average depth. Thus, the maximum depth for preventive repair should be about 95% with a lower bound of about 90%. The +Point amplitude for these depths can be estimated from a correlation of maximum depth to +Point amplitude as described below.

Sizing correlations based on +Point amplitudes are being developed under the EPRI Tools for Tube Integrity Program but these correlations have not been finalized at this time. The sizing developments show that the expected exponential dependence of voltage with depth is consistent with pulled tube data and should be the basis for amplitude based sizing correlations. Given the exponential behavior, only two data points are needed to define a sizing correlation, one of which should be tied to providing good estimates of throughwall crack lengths. The development efforts show that +Point amplitudes in the range of 2.25 to 2.75 volt provide good estimates of initial throughwall penetration and throughwall lengths for ODSCC at TSP intersections. The second point for a sizing correlation can be tied to an amplitude at a given depth such as about 40%. A mean estimate for depths near 35% to 40% for ODSCC at TSP intersections is about 0.1 +Point volt. To avoid being overly conservative for preventive plugging, an estimate for depths near 95% can be based on amplitude sizing fit to 2.5 volts for throughwall and 0.1 volt at 35% depth. Since depth is being inferred from volts, depth has a logarithmic dependence on volts.

Figure 1 shows a sizing correlation fit to 0.1 volt at 35% depth and 2.5 volts at 100% depth. For a 95% maximum depth repair guideline, the +Point indication would be about 1.9 volts. At a maximum depth of about 90%, the +Point indication would be about 1.55 volts, which is too conservative for a preventive repair guideline based on the plant experience described in Section 3.0. It is suggested that consideration be given to preventive repair of ODSCC indications found to have a +Point maximum voltage of 1.9 volts.

Although the data of Tables 1 to 3 were obtained for plants with 7/8 inch tubing, +Point amplitudes for deep indications are not significantly different for 3/4 inch tubing since voltages are calibrated for all tube sizes to 20 volts for a throughwall notch. For +Point amplitude sizing of axial ODSCC, the same correlation is applied to both 3/4 and 7/8 inch tubing. Consequently, the suggested preventive repair limit of 1.9 volts would be applicable to both 3/4 and 7/8 inch tubing. Since the GL 95-05 repair limit for 3/4 inch tubing is >1.0 bobbin volts and +Point volts are less than bobbin volts for the dominant population of indications, the suggested preventive repair limit of 1.9 +Point volts is not likely to impact plants with 3/4 inch tubing. Figure 2 shows the trend of +Point volts versus bobbin volts for an inspection in a plant with 3/4 inch tubing. For this inspection, essentially all +Point volts are less than the bobbin volts and no preventive repair would need to be considered.

The preventive repair guideline is developed based on considerations of normal growth in depth. Most plants found with large growth rates as a function of depth have had outlier bobbin voltage indications that initiated from bobbin voltages less than one volt. These plants generally had high operating temperatures which may have contributed to larger growth rates in depth. It would be excessively conservative for currently operating SGs to consider preventive repair limits low enough to encompass large growth in depth considerations.

4.0 Guidelines for Supplemental RPC Inspection

Figures 3 and 4 show +Point versus bobbin voltage trends for two plants with 7/8 inch tubing. Some tubes are found to have +Point volts comparable to or slightly exceeding the bobbin voltages. Thus, +Point voltages of about 1.9 volts may be found below the GL 95-05 repair limit for 7/8 inch tubing. A +Point to bobbin voltage ratio of about 1.1 envelopes nearly all bobbin indications. Thus, there is a high probability that bobbin indications less than 1.7 bobbin volts would have less than 1.9 +Point volts.

To increase the likelihood of identifying ODSCC indications with >1.9 +Point volts for plants with 7/8 inch tubing, a 20% sample inspection of bobbin indications between 1.7 volts and the GL 95-05 repair limit of > 2.0 volts should be considered for preventive repair applications. If a +Point indication >1.9 volts is found in the sample inspection, expansion of the inspection to include all bobbin indications >1.7 volts should be considered for preventive repair applications. Indications greater than the GL 95-05 repair limit of >2.0 volts are required to be inspected and are repaired so that preventive repair considerations are not applicable. If a plant applies locked TSPs to prevent burst and has a repair limit greater than the GL 95-05 limits, there is no need to apply preventive repair unless leakage from a single large voltage indication would potentially cause leakage limits to be exceeded. There is no identified basis to suggest expansion of +Point inspections for plants with 3/4 inch tubing.

5.0 Conclusions

ARC inspections periodically find large voltage indications (such as > 8 volts) that are not predicted to occur and generally do not occur in successive inspections. Since voltage increases exponentially with depth and again approximately exponentially with increasing throughwall length, an indication that is near throughwall over a significant length at the BOC can grow with normal depth growth to a significant throughwall length over one operating cycle with an associated large voltage growth rate. The likelihood of finding a large voltage indication can be reduced by preventive plugging at less than the ARC repair limit. Plant experience indicates that +Point volts up to about 1.71 volts and +Point to bobbin volt ratios as high as 2.07 have not resulted in large +Point indications in subsequent cycles. Since a +Point to bobbin ratio of about 2.0 bounds essentially all bobbin indications, this ratio does not provide a meaningful indicator for considerations of preventive tube repair. The data indicate that +Point amplitudes should exceed 1.7 volts for preventive repair considerations. The most appropriate measure for preventive repair considerations would be near throughwall depths that can grow to large throughwall lengths for which 95% maximum depth is shown to be a reasonable depth for preventive repair considerations. The best current methods for depth sizing of axial ODSCC are based on correlations of depth with +Point volts.

Based on applying a typical amplitude sizing correlation, a preventive tube repair at 1.9 +Point volts is suggested corresponding to about 95% maximum ODSCC depth. Since a +Point to bobbin voltage ratio of about 1.1 bounds most ODSCC indications, it is suggested that a 20% sample inspection be performed for indications >1.7 bobbin volts. If this sample inspection of bobbin indications between 1.7 volts and the 7/8 inch GL 95-05 repair limit of 2.0 volts identifies +Point indications >1.9 volts, the inspection should be expanded to include all bobbin indications between 1.7 and 2.0 volts. Since the GL 95-05 repair limit for 3/4 inch tubing is 1.0 bobbin volt and +Point volts are less than bobbin volts for the dominant population of indications, the suggested preventive repair limit of 1.9 +Point volts is not likely to impact plants with 3/4 inch tubing. Given the lower repair limit, no supplemental inspection for preventive repair considerations is recommended for plants with 3/4 inch tubing.

Table 1. Plant P-1: Successive Cycle +Point Data for Highest Bobbin Volts, +Point Volts and Ratio of +Point to Bobbin Volts

Table 2. Plant Y-1: Successive Cycle +Point Data for Highest Bobbin Volts, +Point Volts and Ratio of +Point to Bobbin Volts

Table 3. Plant Y-2: Successive Cycle +Point Data for Highest Bobbin Volts, +Point Volts and Ratio of +Point to Bobbin Volts

Tube			Bobbin Volts			+Point Volts			Ratio +Point to Bobbin Volts		
SG	Row	Col	2R9	2R10	2R11	2R9	2R10	2R11	2R9	2R10	2R11

Figure 1

+Point Amplitude Sizing Correlation for Estimating Depths Based on Amplitude
Logarithmic Fit to 2.5 Volts at 100% Depth and 0.1 Volt at 40% Depth

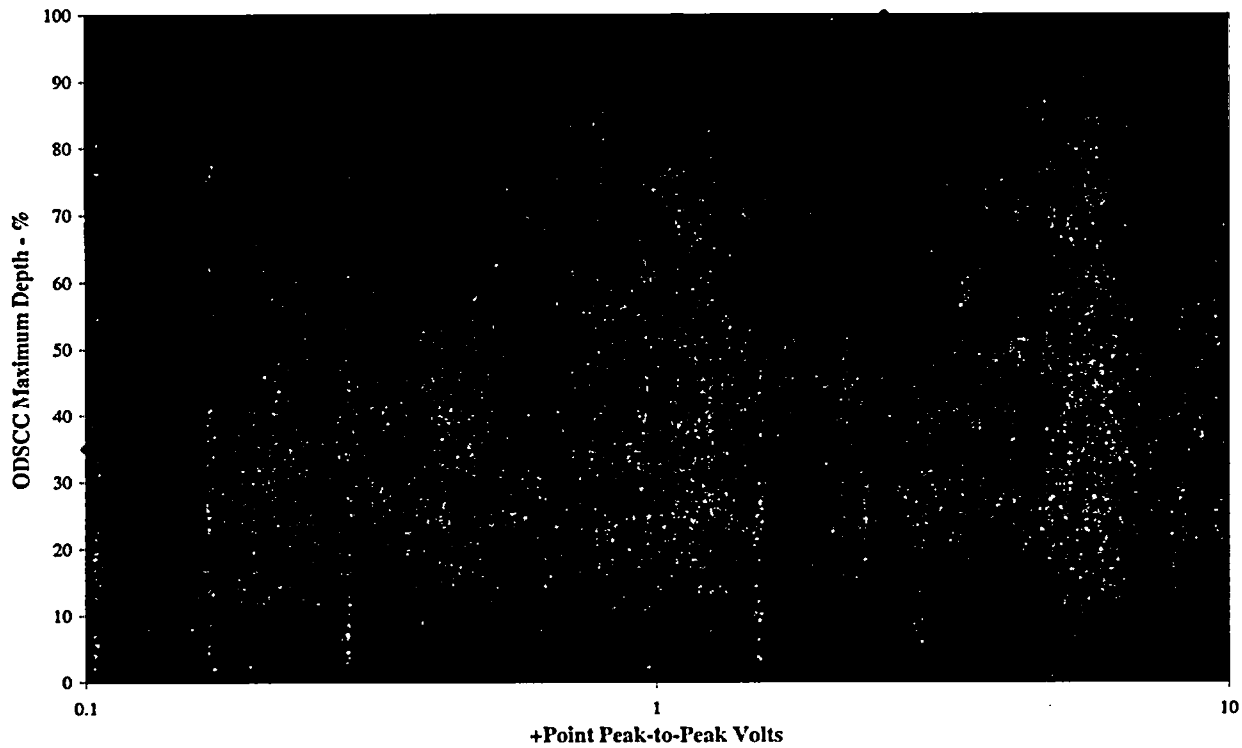


Figure 2

Plant DW +Point Volts versus Bobbin Coil Volts

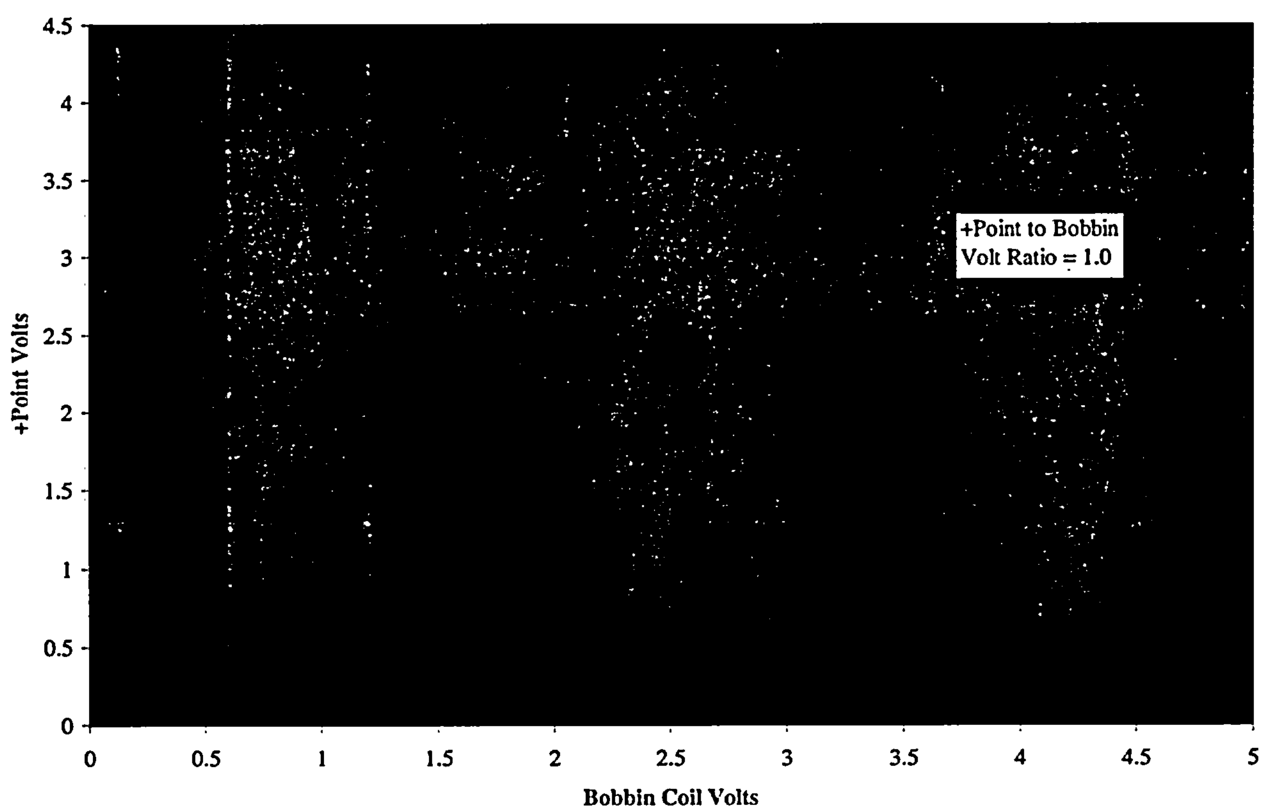


Figure 3

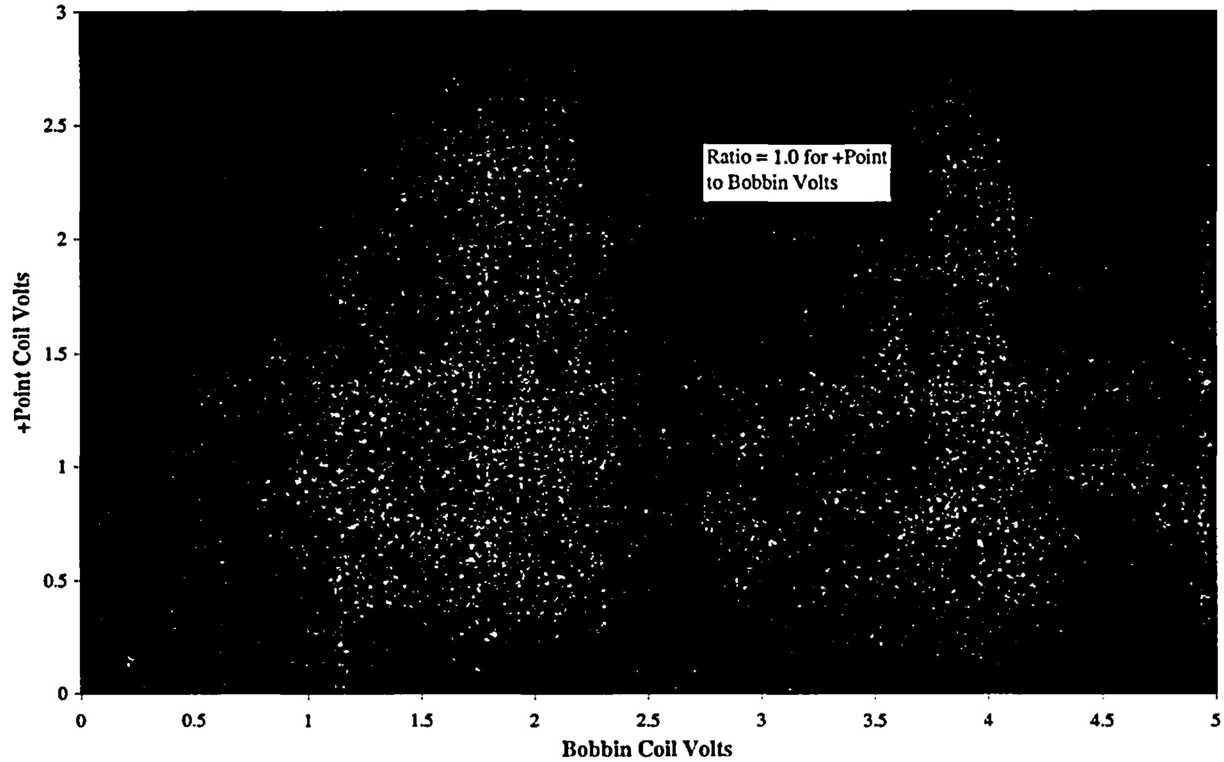
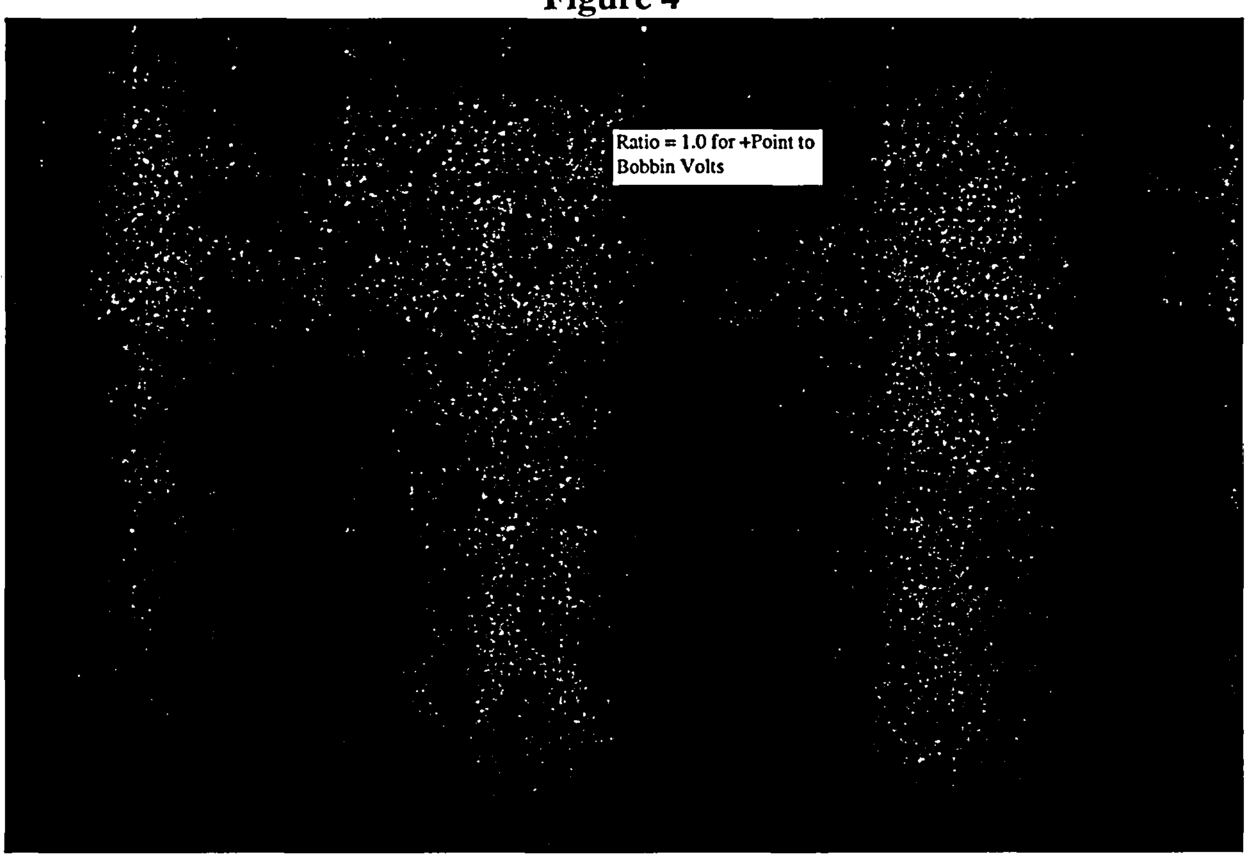


Figure 4



ARC Guidelines for Preventive Repair of Large +Point Indications

1.0 Introduction

This note provides guidelines for preventive tube repair (i.e., repair at less than the licensed voltage based repair limits) to reduce the potential for finding large voltage growth rates for indications left in service under the ARC for axial ODSCC at TSP intersections. Since the guidelines apply to preventive repair, implementation of these guidelines is optional on a plant specific basis.

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The likelihood of finding a large voltage indication can be reduced by preventive plugging at less than the ARC repair limit. The best currently available methods for depth sizing of axial ODSCC are based on correlations of depth with +Point voltage when developed to provide a good estimate of the voltage at initial throughwall penetration. The latter is a principal factor in the development of sizing correlations under the EPRI Tools for Tube Integrity Program and associated correlations are applied in this report to provide a recommended +Point voltage for preventive tube repair for axial ODSCC at TSP intersections.

Section 2 provides additional background information and Section 3 provides guidelines for preventive repair. Section 4 provides guidelines for supplemental inspections to further inspect for indications potentially desirable for preventive repair. Section 5 summarizes the conclusions of this report.

2.0 Background Information

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The range of +Point amplitudes for a short throughwall axial ODSCC indication is about 2.0 to 3.0 volts. The lowest throughwall +Point amplitude in the ARC database is 1.89 volts. This indication had two interacting axial cracks, which tends to result in a +Point voltage reduction due to cancellation between the two coils. It can be expected that the Plant Y-2 indication was near or just throughwall at

the BOC condition. The growth rate in average depth for this indication was about 12% per EFPY which is in the range of the upper 90% to 95% probability for normal growth rates and considerably smaller than ODSCC indications found to have large growth rates. The Plant Y-2 indication grew from imminent throughwall at BOC to the throughwall length of 0.42 inch found by destructive examination. The large voltage growth resulted from throughwall penetration and growth in throughwall length.

Plants P-1, Y-1 and Y-2 have performed significant +Point inspections below the 2.0 volt repair level that include some indications with data from two or three +Point inspections over the last three cycles. These data permit an assessment of the larger +Point voltage and +Point to bobbin voltage ratio indications retained in service. The last three cycles of data were reviewed to identify the largest +Point volts left in service, the largest ratio of +Point to bobbin voltage and the largest bobbin indications. The resulting data for Plant P-1 cycles 1R13 to 1R15 are given in Table 1 and for Plants Y-1 and Y-2 cycles 9 to 11 are given in Tables 2 and 3. For Plant P-1, the largest +Point volts returned to service that can be assessed at the subsequent cycle are 1.65 volts at 1R13 and 1.71 volts at 1R14. None of the indications with +Point volts up to 1.71 had a large bobbin or +Point voltage growth in the subsequent cycle. The largest bobbin indication of 4.57 volts, which would not be considered an outlier indication, for tube R11C77 had a prior cycle +Point 0.61 volt indication. Similarly, indications with +Point to bobbin voltage ratios up to 2.0 showed no significant bobbin voltage growth in the subsequent cycle. The Plant Y-1 data of Table 2 show that there have been no high +Point volts or +Point to bobbin voltage ratios for data with successive +Point inspections. Thus, these data do not provide any additional insight on potentially limiting +Point voltages. The Plant Y-2 data of Table 3 show the 2.97 +Point volt indication left in service that led to the 21.5 bobbin volt outlier indication. Indications with +Point volts as high as 1.6 volts and +Point to bobbin voltage ratios up to 2.07 did not show any significant bobbin voltage growth in the subsequent cycle. The higher ratios of +Point to bobbin voltage, such as > 1.4, are generally associated with dominant single indications with relatively small bobbin voltages (i.e., < 0.7 volt) such that the effect of increasing bobbin voltage with increasing cracking around the tube circumference is not present. There is no technical reason to expect that single indications have a higher potential for large voltage growth in the next cycle since voltage growth rates are highest for crack depths near 100% and for increases in throughwall length rather than multiple indication effects. The Tables 1 to 3 results indicate that the +Point to bobbin voltage ratio is not a meaningful predictor for large bobbin voltage growth and is, therefore, not recommended for considerations of preventive plugging.

The Table 1 results also indicate that +Point voltages up to about 1.71 do not appear to be a meaningful predictor of large bobbin voltage growth. As discussed in Section 3 below, the crack depth for a 1.71 +Point voltage indication would be expected to be too shallow to grow to a significant throughwall length with normal growth rates over one cycle of operation. The threshold for considering preventive plugging should be greater than about 1.71 volts.

3.0 Guidelines for Preventive Repair

Based on the discussion of Section 2, only +Point indications greater than about 1.71 volt appear to be candidates for preventive repair considerations and the use of +Point to bobbin voltage ratios for preventive repair considerations is not recommended. The objective for preventive repair considerations is to prevent significantly large throughwall lengths, but to not exclude the potential for any throughwall cracks which would too conservative for a repair guideline. Growth in average depth is applied to estimate a reasonable depth for preventive repair as growth over a significant length rather than local crack penetration is of interest. A growth rate of about 10% in average depth per EFPY is a reasonable estimate for normal growth at about the 90% confidence level. Thus, for preventive repair based on

+Point amplitude sizing considerations, the amplitude should be based on average crack depths in the range of 85% over the deepest segment of about 0.1 to 0.2 inch. Since the amplitude sizing correlations are based on maximum crack depth, the 85% segment average depth must be adjusted upward to define a preventive repair guideline. Since the ratio of maximum depth to average depth over the burst effective crack length for a crack is typically about 1.25, it is reasonable to assume that the maximum depth for a deep crack segment would be at least 10% greater than the average depth. Thus, the maximum depth for preventive repair should be about 95% with a lower bound of about 90%. The +Point amplitude for these depths can be estimated from a correlation of maximum depth to +Point amplitude as described below.

Sizing correlations based on +Point amplitudes are being developed under the EPRI Tools for Tube Integrity Program but these correlations have not been finalized at this time. The sizing developments show that the expected exponential dependence of voltage with depth is consistent with pulled tube data and should be the basis for amplitude based sizing correlations. Given the exponential behavior, only two data points are needed to define a sizing correlation, one of which should be tied to providing good estimates of throughwall crack lengths. The development efforts show that +Point amplitudes in the range of 2.25 to 2.75 volt provide good estimates of initial throughwall penetration and throughwall lengths for ODSCC at TSP intersections. The second point for a sizing correlation can be tied to an amplitude at a given depth such as about 40%. A mean estimate for depths near 35% to 40% for ODSCC at TSP intersections is about 0.1 +Point volt. To avoid being overly conservative for preventive plugging, an estimate for depths near 95% can be based on amplitude sizing fit to 2.5 volts for throughwall and 0.1 volt at 35% depth. Since depth is being inferred from volts, depth has a logarithmic dependence on volts.

Figure 1 shows a sizing correlation fit to 0.1 volt at 35% depth and 2.5 volts at 100% depth. For a 95% maximum depth repair guideline, the +Point indication would be about 1.9 volts. At a maximum depth of about 90%, the +Point indication would be about 1.55 volts, which is too conservative for a preventive repair guideline based on the plant experience described in Section 3.0. It is suggested that consideration be given to preventive repair of ODSCC indications found to have a +Point maximum voltage of 1.9 volts.

Although the data of Tables 1 to 3 were obtained for plants with 7/8 inch tubing, +Point amplitudes for deep indications are not significantly different for 3/4 inch tubing since voltages are calibrated for all tube sizes to 20 volts for a throughwall notch. For +Point amplitude sizing of axial ODSCC, the same correlation is applied to both 3/4 and 7/8 inch tubing. Consequently, the suggested preventive repair limit of 1.9 volts would be applicable to both 3/4 and 7/8 inch tubing. Since the GL 95-05 repair limit for 3/4 inch tubing is >1.0 bobbin volts and +Point volts are less than bobbin volts for the dominant population of indications, the suggested preventive repair limit of 1.9 +Point volts is not likely to impact plants with 3/4 inch tubing. Figure 2 shows the trend of +Point volts versus bobbin volts for an inspection in a plant with 3/4 inch tubing. For this inspection, essentially all +Point volts are less than the bobbin volts and no preventive repair would need to be considered.

The preventive repair guideline is developed based on considerations of normal growth in depth. Most plants found with large growth rates as a function of depth have had outlier bobbin voltage indications that initiated from bobbin voltages less than one volt. These plants generally had high operating temperatures which may have contributed to larger growth rates in depth. It would be excessively conservative for currently operating SGs to consider preventive repair limits low enough to encompass large growth in depth considerations.

4.0 Guidelines for Supplemental RPC Inspection

Figures 3 and 4 show +Point versus bobbin voltage trends for two plants with 7/8 inch tubing. Some tubes are found to have +Point volts comparable to or slightly exceeding the bobbin voltages. Thus, +Point voltages of about 1.9 volts may be found below the GL 95-05 repair limit for 7/8 inch tubing. A +Point to bobbin voltage ratio of about 1.1 envelopes nearly all bobbin indications. Thus, there is a high probability that bobbin indications less than 1.7 bobbin volts would have less than 1.9 +Point volts.

To increase the likelihood of identifying ODSCC indications with >1.9 +Point volts for plants with 7/8 inch tubing, a 20% sample inspection of bobbin indications between 1.7 volts and the GL 95-05 repair limit of > 2.0 volts should be considered for preventive repair applications. If a +Point indication >1.9 volts is found in the sample inspection, expansion of the inspection to include all bobbin indications >1.7 volts should be considered for preventive repair applications. Indications greater than the GL 95-05 repair limit of >2.0 volts are required to be inspected and are repaired so that preventive repair considerations are not applicable. If a plant applies locked TSPs to prevent burst and has a repair limit greater than the GL 95-05 limits, there is no need to apply preventive repair unless leakage from a single large voltage indication would potentially cause leakage limits to be exceeded. There is no identified basis to suggest expansion of +Point inspections for plants with 3/4 inch tubing.

5.0 Conclusions

ARC inspections periodically find large voltage indications (such as > 8 volts) that are not predicted to occur and generally do not occur in successive inspections. Since voltage increases exponentially with depth and again approximately exponentially with increasing throughwall length, an indication that is near throughwall over a significant length at the BOC can grow with normal depth growth to a significant throughwall length over one operating cycle with an associated large voltage growth rate. The likelihood of finding a large voltage indication can be reduced by preventive plugging at less than the ARC repair limit. Plant experience indicates that +Point volts up to about 1.71 volts and +Point to bobbin volt ratios as high as 2.07 have not resulted in large +Point indications in subsequent cycles. Since a +Point to bobbin ratio of about 2.0 bounds essentially all bobbin indications, this ratio does not provide a meaningful indicator for considerations of preventive tube repair. The data indicate that +Point amplitudes should exceed 1.7 volts for preventive repair considerations. The most appropriate measure for preventive repair considerations would be near throughwall depths that can grow to large throughwall lengths for which 95% maximum depth is shown to be a reasonable depth for preventive repair considerations. The best current methods for depth sizing of axial ODSCC are based on correlations of depth with +Point volts.

Based on applying a typical amplitude sizing correlation, a preventive tube repair at 1.9 +Point volts is suggested corresponding to about 95% maximum ODSCC depth. Since a +Point to bobbin voltage ratio of about 1.1 bounds most ODSCC indications, it is suggested that a 20% sample inspection be performed for indications >1.7 bobbin volts. If this sample inspection of bobbin indications between 1.7 volts and the 7/8 inch GL 95-05 repair limit of 2.0 volts identifies +Point indications >1.9 volts, the inspection should be expanded to include all bobbin indications between 1.7 and 2.0 volts. Since the GL 95-05 repair limit for 3/4 inch tubing is 1.0 bobbin volt and +Point volts are less than bobbin volts for the dominant population of indications, the suggested preventive repair limit of 1.9 +Point volts is not likely to impact plants with 3/4 inch tubing. Given the lower repair limit, no supplemental inspection for preventive repair considerations is recommended for plants with 3/4 inch tubing.

Table 1. Plant P-1: Successive Cycle +Point Data for Highest Bobbin Volts, +Point Volts and Ratio of +Point to Bobbin Volts

Table 2. Plant Y-1: Successive Cycle +Point Data for Highest Bobbin Volts, +Point Volts and Ratio of +Point to Bobbin Volts

Table 3. Plant Y-2: Successive Cycle +Point Data for Highest Bobbin Volts, +Point Volts and Ratio of +Point to Bobbin Volts

Tube			Bobbin Volts			+Point Volts			Ratio +Point to Bobbin Volts		
SG	Row	Col	2R9	2R10	2R11	2R9	2R10	2R11	2R9	2R10	2R11

Figure 1

+Point Amplitude Sizing Correlation for Estimating Depths Based on Amplitude
Logarithmic Fit to 2.5 Volts at 100% Depth and 0.1 Volt at 40% Depth

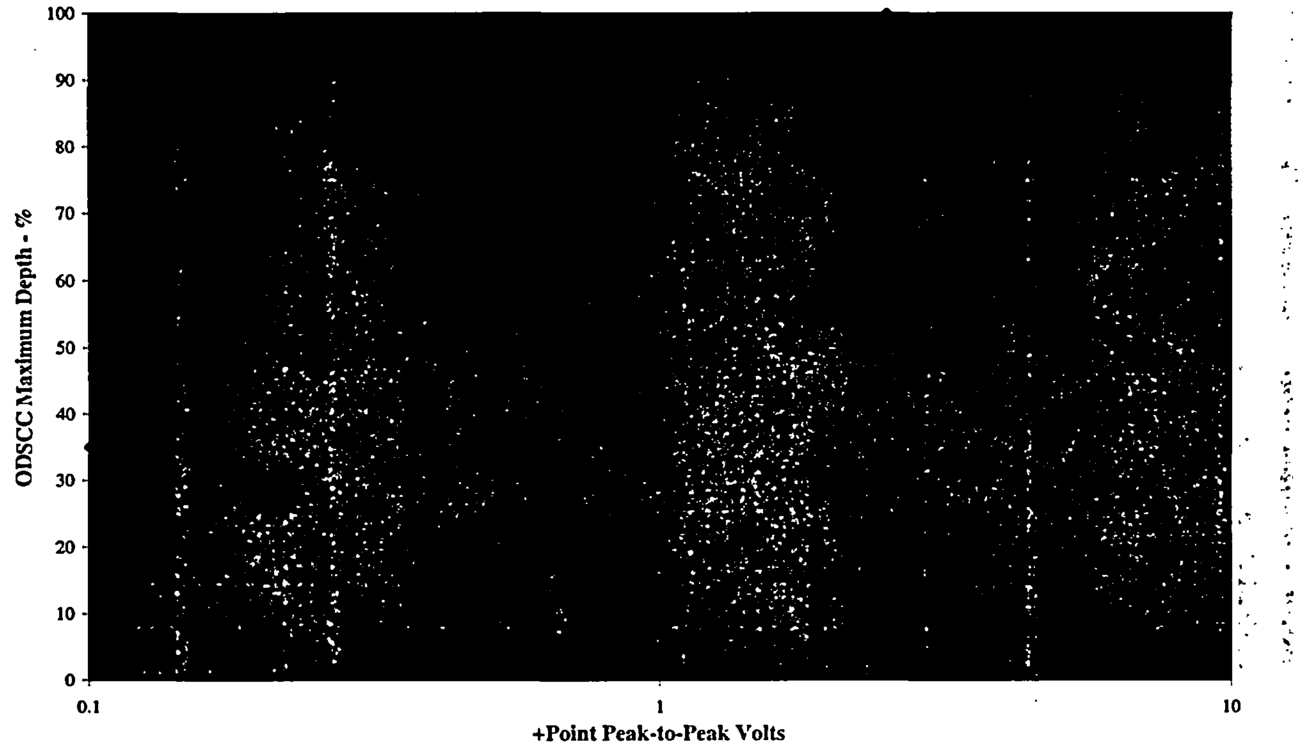


Figure 2

Plant DW +Point Volts versus Bobbin Coil Volts

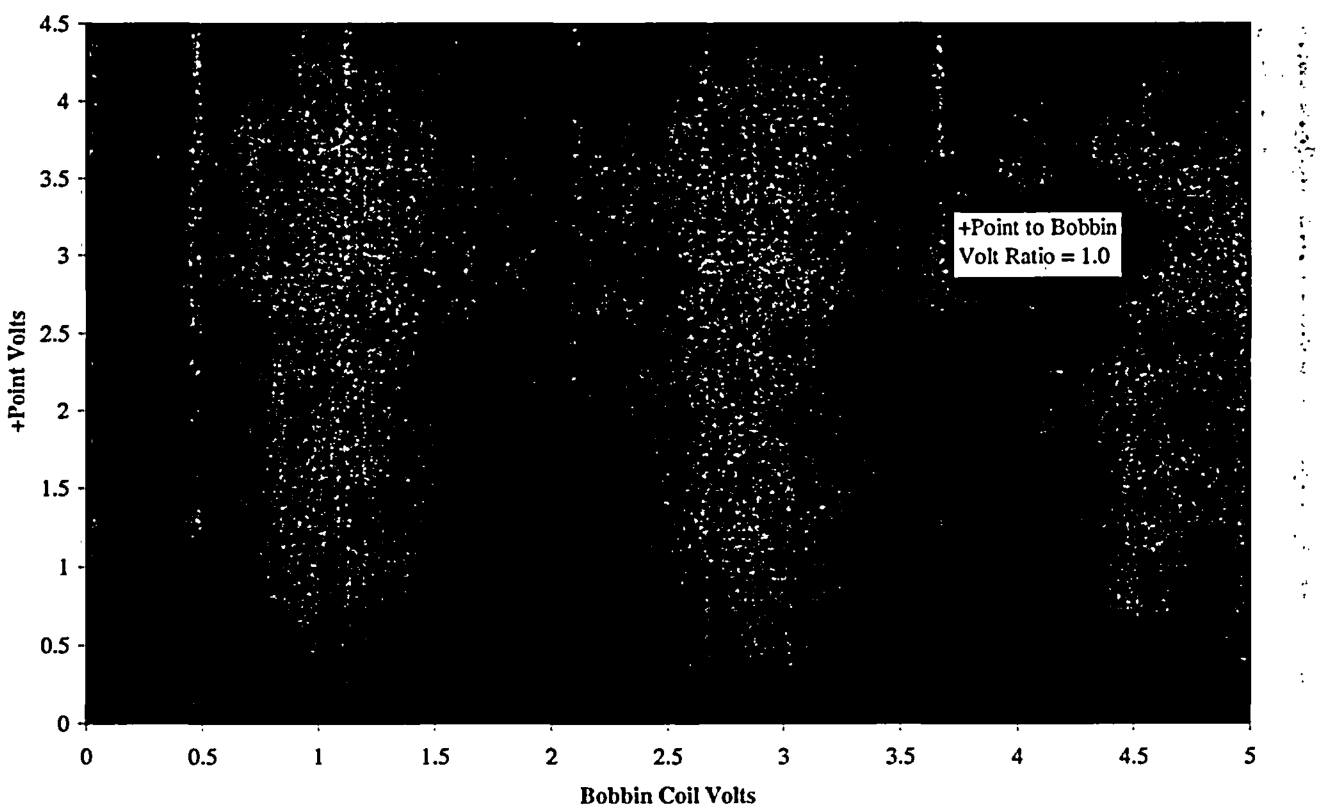


Figure 3

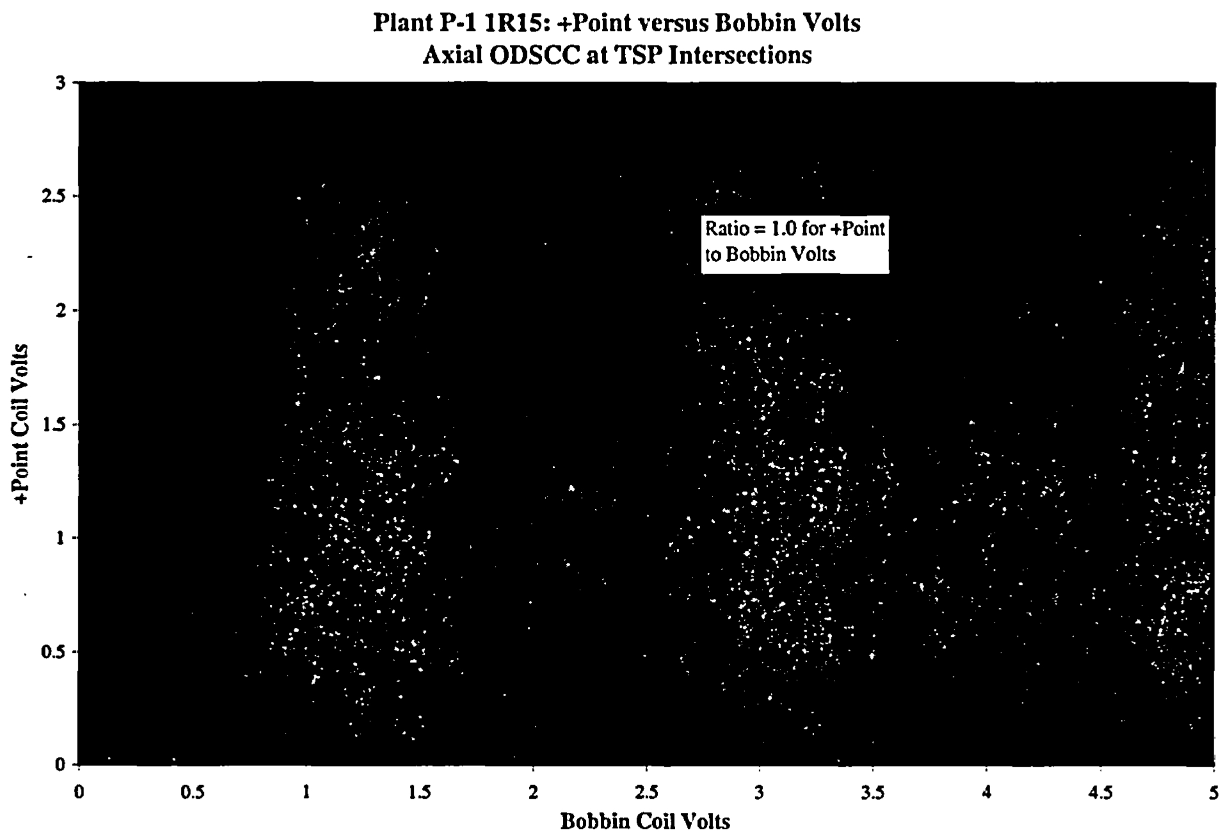
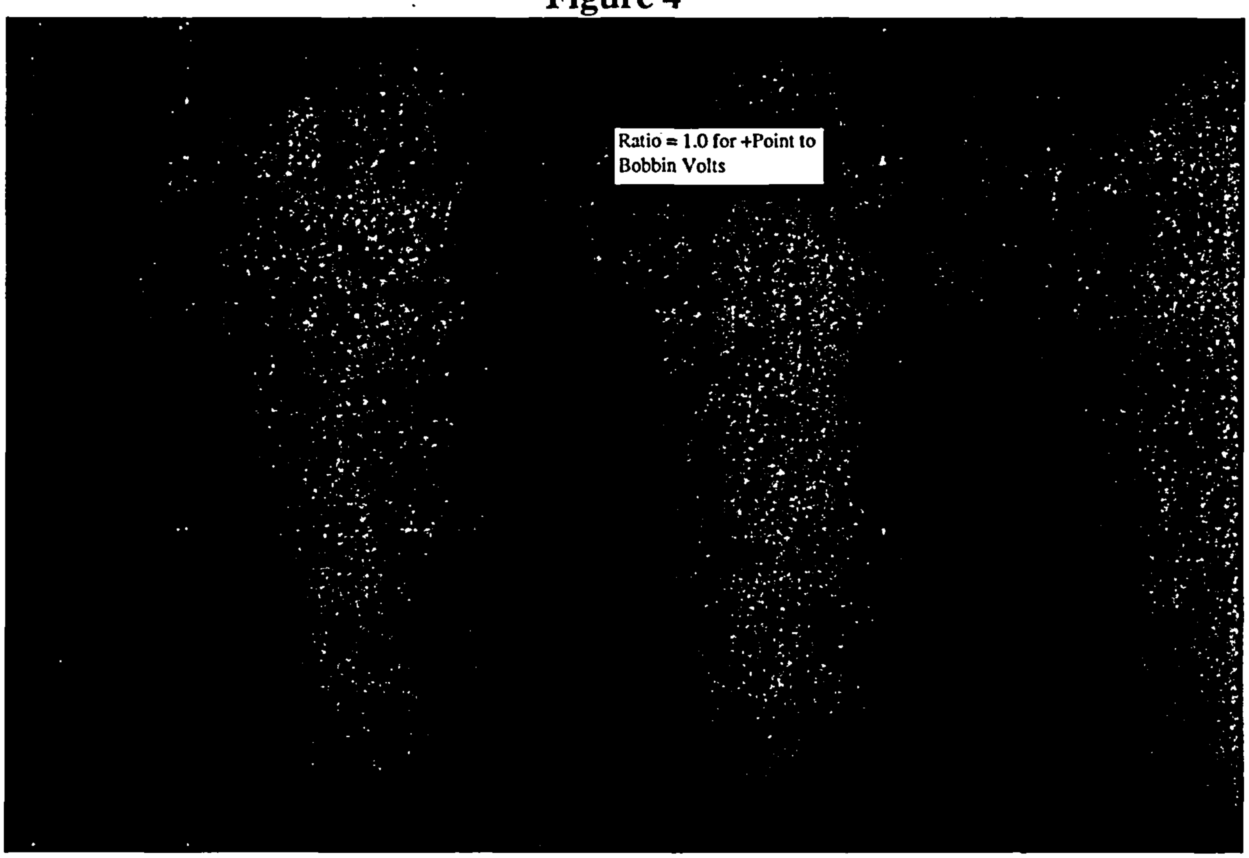


Figure 4



ARC Guidelines for Preventive Repair of Large +Point Indications

1.0 Introduction

This note provides guidelines for preventive tube repair (i.e., repair at less than the licensed voltage based repair limits) to reduce the potential for finding large voltage growth rates for indications left in service under the ARC for axial ODSCC at TSP intersections. Since the guidelines apply to preventive repair, implementation of these guidelines is optional on a plant specific basis.

ARC inspections periodically find large voltage indications (such as > 8 volts) that are not predicted to occur and generally do not occur in successive inspections. These indications with unusually large voltage growth have been shown, where successive RPC inspection data are available, to occur with normal growth in depth. Voltage increases exponentially with depth and again approximately exponentially with increasing throughwall length. Consequently, an indication that is near throughwall over a significant length at the BOC can grow with normal depth growth to a significant throughwall length over one operating cycle with an associated large voltage growth rate. Most of the large voltage growth indications found in ARC inspections have been pulled and found to satisfy burst margins at the EOC conditions. However, the ARC burst versus voltage correlation will predict burst probabilities near the ARC reporting threshold of 0.01 due to the large uncertainties in the correlation.

The likelihood of finding a large voltage indication can be reduced by preventive plugging at less than the ARC repair limit. The best currently available methods for depth sizing of axial ODSCC are based on correlations of depth with +Point voltage when developed to provide a good estimate of the voltage at initial throughwall penetration. The latter is a principal factor in the development of sizing correlations under the EPRI Tools for Tube Integrity Program and associated correlations are applied in this report to provide a recommended +Point voltage for preventive tube repair for axial ODSCC at TSP intersections.

Section 2 provides additional background information and Section 3 provides guidelines for preventive repair. Section 4 provides guidelines for supplemental inspections to further inspect for indications potentially desirable for preventive repair. Section 5 summarizes the conclusions of this report.

2.0 Background Information

The largest voltage indication found during ARC inspections was a 21.5 volt bobbin indication (12.2 volt by +Point) at Plant Y-2. Fortunately, for providing a good database for evaluation, this indication had been +Point inspected at the prior outage. At the prior inspection, this indication was found to measure 2.0 volt by bobbin and 2.97 volt by +Point (maximum volts from profile analysis). The occurrence of +Point amplitudes greater than the bobbin voltage is infrequent for ODSCC partially due to the bobbin coil integrating degradation around the circumference of the tube while RPC measures a single crack location. The two voltages tend to be closer in magnitude when there is a single dominant crack at the TSP intersection.

The range of +Point amplitudes for a short throughwall axial ODSCC indication is about 2.0 to 3.0 volts. The lowest throughwall +Point amplitude in the ARC database is 1.89 volts. This indication had two interacting axial cracks, which tends to result in a +Point voltage reduction due to cancellation between the two coils. It can be expected that the Plant Y-2 indication was near or just throughwall at

the BOC condition. The growth rate in average depth for this indication was about 12% per EFPY which is in the range of the upper 90% to 95% probability for normal growth rates and considerably smaller than ODSCC indications found to have large growth rates. The Plant Y-2 indication grew from imminent throughwall at BOC to the throughwall length of 0.42 inch found by destructive examination. The large voltage growth resulted from throughwall penetration and growth in throughwall length.

Plants P-1, Y-1 and Y-2 have performed significant +Point inspections below the 2.0 volt repair level that include some indications with data from two or three +Point inspections over the last three cycles. These data permit an assessment of the larger +Point voltage and +Point to bobbin voltage ratio indications retained in service. The last three cycles of data were reviewed to identify the largest +Point volts left in service, the largest ratio of +Point to bobbin voltage and the largest bobbin indications. The resulting data for Plant P-1 cycles 1R13 to 1R15 are given in Table 1 and for Plants Y-1 and Y-2 cycles 9 to 11 are given in Tables 2 and 3. For Plant P-1, the largest +Point volts returned to service that can be assessed at the subsequent cycle are 1.65 volts at 1R13 and 1.71 volts at 1R14. None of the indications with +Point volts up to 1.71 had a large bobbin or +Point voltage growth in the subsequent cycle. The largest bobbin indication of 4.57 volts, which would not be considered an outlier indication, for tube R11C77 had a prior cycle +Point 0.61 volt indication. Similarly, indications with +Point to bobbin voltage ratios up to 2.0 showed no significant bobbin voltage growth in the subsequent cycle. The Plant Y-1 data of Table 2 show that there have been no high +Point volts or +Point to bobbin voltage ratios for data with successive +Point inspections. Thus, these data do not provide any additional insight on potentially limiting +Point voltages. The Plant Y-2 data of Table 3 show the 2.97 +Point volt indication left in service that led to the 21.5 bobbin volt outlier indication. Indications with +Point volts as high as 1.6 volts and +Point to bobbin voltage ratios up to 2.07 did not show any significant bobbin voltage growth in the subsequent cycle. The higher ratios of +Point to bobbin voltage, such as > 1.4, are generally associated with dominant single indications with relatively small bobbin voltages (i.e., < 0.7 volt) such that the effect of increasing bobbin voltage with increasing cracking around the tube circumference is not present. There is no technical reason to expect that single indications have a higher potential for large voltage growth in the next cycle since voltage growth rates are highest for crack depths near 100% and for increases in throughwall length rather than multiple indication effects. The Tables 1 to 3 results indicate that the +Point to bobbin voltage ratio is not a meaningful predictor for large bobbin voltage growth and is, therefore, not recommended for considerations of preventive plugging.

The Table 1 results also indicate that +Point voltages up to about 1.71 do not appear to be a meaningful predictor of large bobbin voltage growth. As discussed in Section 3 below, the crack depth for a 1.71 +Point voltage indication would be expected to be too shallow to grow to a significant throughwall length with normal growth rates over one cycle of operation. The threshold for considering preventive plugging should be greater than about 1.71 volts.

3.0 Guidelines for Preventive Repair

Based on the discussion of Section 2, only +Point indications greater than about 1.71 volt appear to be candidates for preventive repair considerations and the use of +Point to bobbin voltage ratios for preventive repair considerations is not recommended. The objective for preventive repair considerations is to prevent significantly large throughwall lengths, but to not exclude the potential for any throughwall cracks which would too conservative for a repair guideline. Growth in average depth is applied to estimate a reasonable depth for preventive repair as growth over a significant length rather than local crack penetration is of interest. A growth rate of about 10% in average depth per EFPY is a reasonable estimate for normal growth at about the 90% confidence level. Thus, for preventive repair based on

+Point amplitude sizing considerations, the amplitude should be based on average crack depths in the range of 85% over the deepest segment of about 0.1 to 0.2 inch. Since the amplitude sizing correlations are based on maximum crack depth, the 85% segment average depth must be adjusted upward to define a preventive repair guideline. Since the ratio of maximum depth to average depth over the burst effective crack length for a crack is typically about 1.25, it is reasonable to assume that the maximum depth for a deep crack segment would be at least 10% greater than the average depth. Thus, the maximum depth for preventive repair should be about 95% with a lower bound of about 90%. The +Point amplitude for these depths can be estimated from a correlation of maximum depth to +Point amplitude as described below.

Sizing correlations based on +Point amplitudes are being developed under the EPRI Tools for Tube Integrity Program but these correlations have not been finalized at this time. The sizing developments show that the expected exponential dependence of voltage with depth is consistent with pulled tube data and should be the basis for amplitude based sizing correlations. Given the exponential behavior, only two data points are needed to define a sizing correlation, one of which should be tied to providing good estimates of throughwall crack lengths. The development efforts show that +Point amplitudes in the range of 2.25 to 2.75 volt provide good estimates of initial throughwall penetration and throughwall lengths for ODSCC at TSP intersections. The second point for a sizing correlation can be tied to an amplitude at a given depth such as about 40%. A mean estimate for depths near 35% to 40% for ODSCC at TSP intersections is about 0.1 +Point volt. To avoid being overly conservative for preventive plugging, an estimate for depths near 95% can be based on amplitude sizing fit to 2.5 volts for throughwall and 0.1 volt at 35% depth. Since depth is being inferred from volts, depth has a logarithmic dependence on volts.

Figure 1 shows a sizing correlation fit to 0.1 volt at 35% depth and 2.5 volts at 100% depth. For a 95% maximum depth repair guideline, the +Point indication would be about 1.9 volts. At a maximum depth of about 90%, the +Point indication would be about 1.55 volts, which is too conservative for a preventive repair guideline based on the plant experience described in Section 3.0. It is suggested that consideration be given to preventive repair of ODSCC indications found to have a +Point maximum voltage of 1.9 volts.

Although the data of Tables 1 to 3 were obtained for plants with 7/8 inch tubing, +Point amplitudes for deep indications are not significantly different for 3/4 inch tubing since voltages are calibrated for all tube sizes to 20 volts for a throughwall notch. For +Point amplitude sizing of axial ODSCC, the same correlation is applied to both 3/4 and 7/8 inch tubing. Consequently, the suggested preventive repair limit of 1.9 volts would be applicable to both 3/4 and 7/8 inch tubing. Since the GL 95-05 repair limit for 3/4 inch tubing is >1.0 bobbin volts and +Point volts are less than bobbin volts for the dominant population of indications, the suggested preventive repair limit of 1.9 +Point volts is not likely to impact plants with 3/4 inch tubing. Figure 2 shows the trend of +Point volts versus bobbin volts for an inspection in a plant with 3/4 inch tubing. For this inspection, essentially all +Point volts are less than the bobbin volts and no preventive repair would need to be considered.

The preventive repair guideline is developed based on considerations of normal growth in depth. Most plants found with large growth rates as a function of depth have had outlier bobbin voltage indications that initiated from bobbin voltages less than one volt. These plants generally had high operating temperatures which may have contributed to larger growth rates in depth. It would be excessively conservative for currently operating SGs to consider preventive repair limits low enough to encompass large growth in depth considerations.

4.0 Guidelines for Supplemental RPC Inspection

Figures 3 and 4 show +Point versus bobbin voltage trends for two plants with 7/8 inch tubing. Some tubes are found to have +Point volts comparable to or slightly exceeding the bobbin voltages. Thus, +Point voltages of about 1.9 volts may be found below the GL 95-05 repair limit for 7/8 inch tubing. A +Point to bobbin voltage ratio of about 1.1 envelopes nearly all bobbin indications. Thus, there is a high probability that bobbin indications less than 1.7 bobbin volts would have less than 1.9 +Point volts.

To increase the likelihood of identifying ODSCC indications with >1.9 +Point volts for plants with 7/8 inch tubing, a 20% sample inspection of bobbin indications between 1.7 volts and the GL 95-05 repair limit of > 2.0 volts should be considered for preventive repair applications. If a +Point indication >1.9 volts is found in the sample inspection, expansion of the inspection to include all bobbin indications >1.7 volts should be considered for preventive repair applications. Indications greater than the GL 95-05 repair limit of >2.0 volts are required to be inspected and are repaired so that preventive repair considerations are not applicable. If a plant applies locked TSPs to prevent burst and has a repair limit greater than the GL 95-05 limits, there is no need to apply preventive repair unless leakage from a single large voltage indication would potentially cause leakage limits to be exceeded. There is no identified basis to suggest expansion of +Point inspections for plants with 3/4 inch tubing.

5.0 Conclusions

ARC inspections periodically find large voltage indications (such as > 8 volts) that are not predicted to occur and generally do not occur in successive inspections. Since voltage increases exponentially with depth and again approximately exponentially with increasing throughwall length, an indication that is near throughwall over a significant length at the BOC can grow with normal depth growth to a significant throughwall length over one operating cycle with an associated large voltage growth rate. The likelihood of finding a large voltage indication can be reduced by preventive plugging at less than the ARC repair limit. Plant experience indicates that +Point volts up to about 1.71 volts and +Point to bobbin volt ratios as high as 2.07 have not resulted in large +Point indications in subsequent cycles. Since a +Point to bobbin ratio of about 2.0 bounds essentially all bobbin indications, this ratio does not provide a meaningful indicator for considerations of preventive tube repair. The data indicate that +Point amplitudes should exceed 1.7 volts for preventive repair considerations. The most appropriate measure for preventive repair considerations would be near throughwall depths that can grow to large throughwall lengths for which 95% maximum depth is shown to be a reasonable depth for preventive repair considerations. The best current methods for depth sizing of axial ODSCC are based on correlations of depth with +Point volts.

Based on applying a typical amplitude sizing correlation, a preventive tube repair at 1.9 +Point volts is suggested corresponding to about 95% maximum ODSCC depth. Since a +Point to bobbin voltage ratio of about 1.1 bounds most ODSCC indications, it is suggested that a 20% sample inspection be performed for indications >1.7 bobbin volts. If this sample inspection of bobbin indications between 1.7 volts and the 7/8 inch GL 95-05 repair limit of 2.0 volts identifies +Point indications >1.9 volts, the inspection should be expanded to include all bobbin indications between 1.7 and 2.0 volts. Since the GL 95-05 repair limit for 3/4 inch tubing is 1.0 bobbin volt and +Point volts are less than bobbin volts for the dominant population of indications, the suggested preventive repair limit of 1.9 +Point volts is not likely to impact plants with 3/4 inch tubing. Given the lower repair limit, no supplemental inspection for preventive repair considerations is recommended for plants with 3/4 inch tubing.

Table 1. Plant P-1: Successive Cycle +Point Data for Highest Bobbin Volts, +Point Volts and Ratio of +Point to Bobbin Volts

Table 2. Plant Y-1: Successive Cycle +Point Data for Highest Bobbin Volts, +Point Volts and Ratio of +Point to Bobbin Volts

Table 3. Plant Y-2: Successive Cycle +Point Data for Highest Bobbin Volts, +Point Volts and Ratio of +Point to Bobbin Volts											
Tube			Bobbin Volts			+Point Volts			Ratio +Point to Bobbin Volts		
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Figure 1

+Point Amplitude Sizing Correlation for Estimating Depths Based on Amplitude
Logarithmic Fit to 2.5 Volts at 100% Depth and 0.1 Volt at 40% Depth

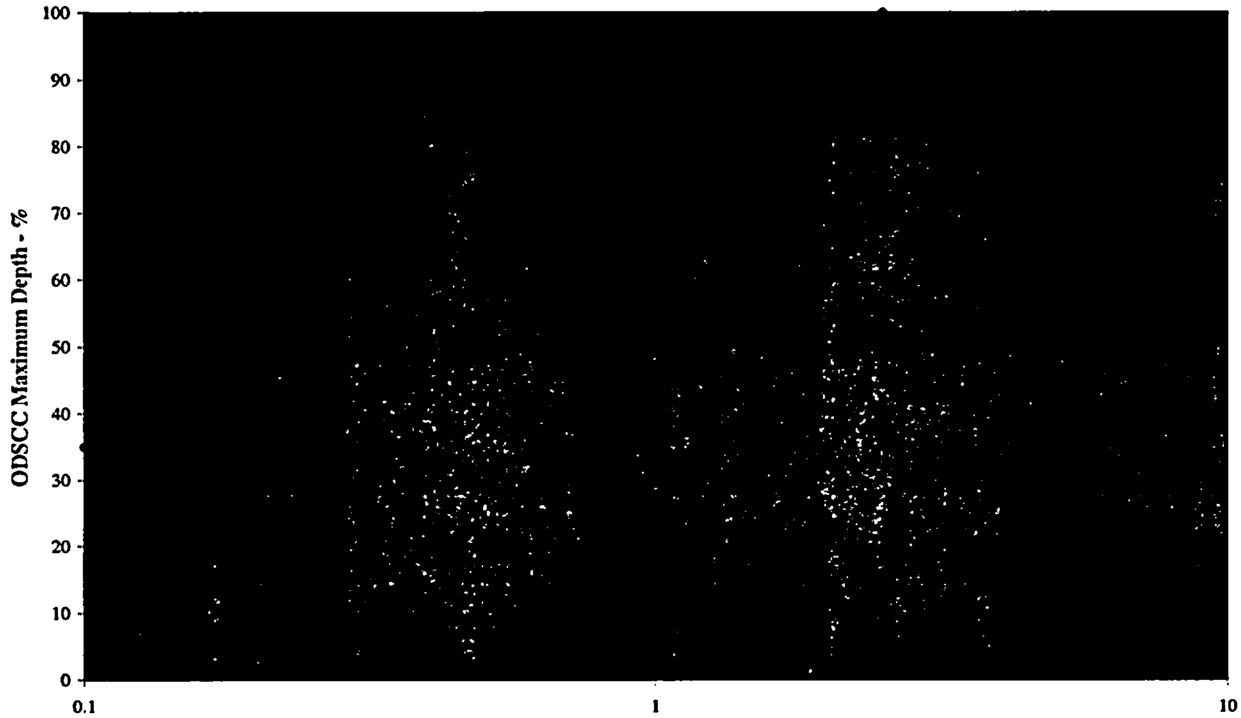


Figure 2

Plant DW +Point Volts versus Bobbin Coil Volts

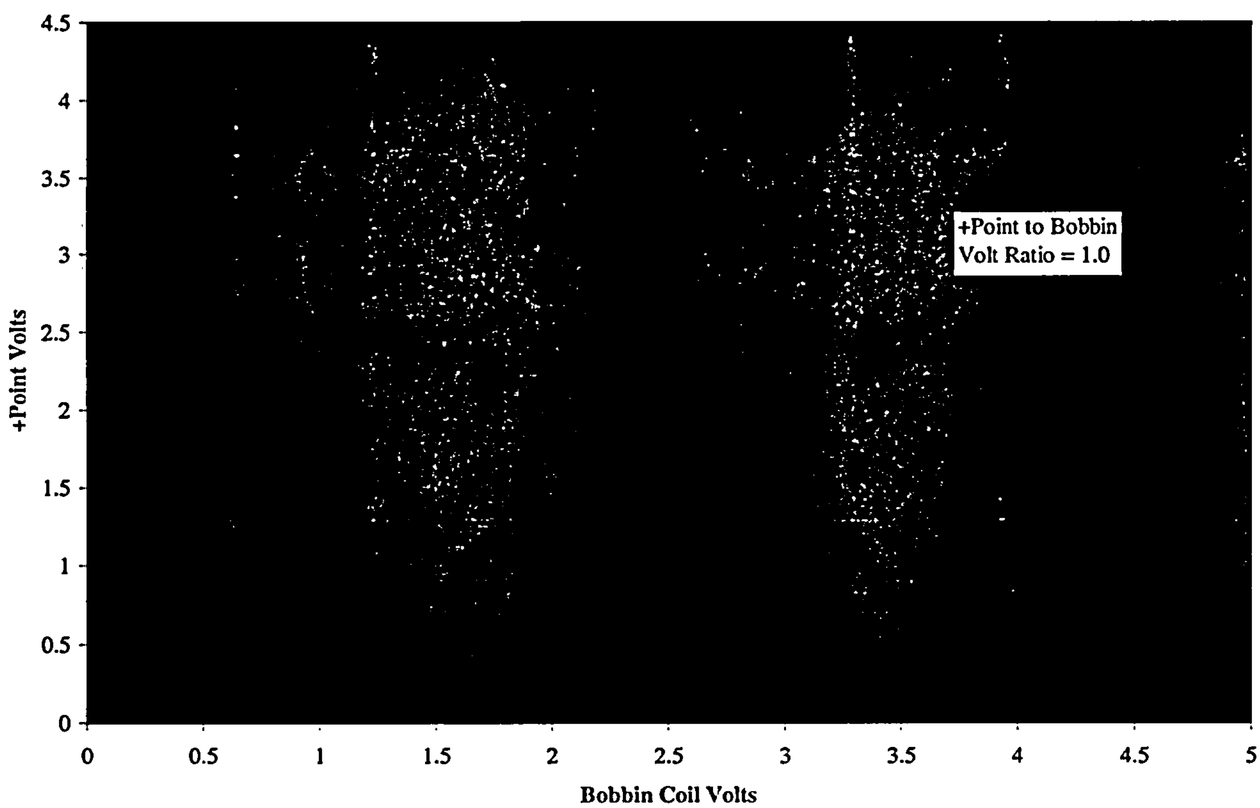


Figure 3

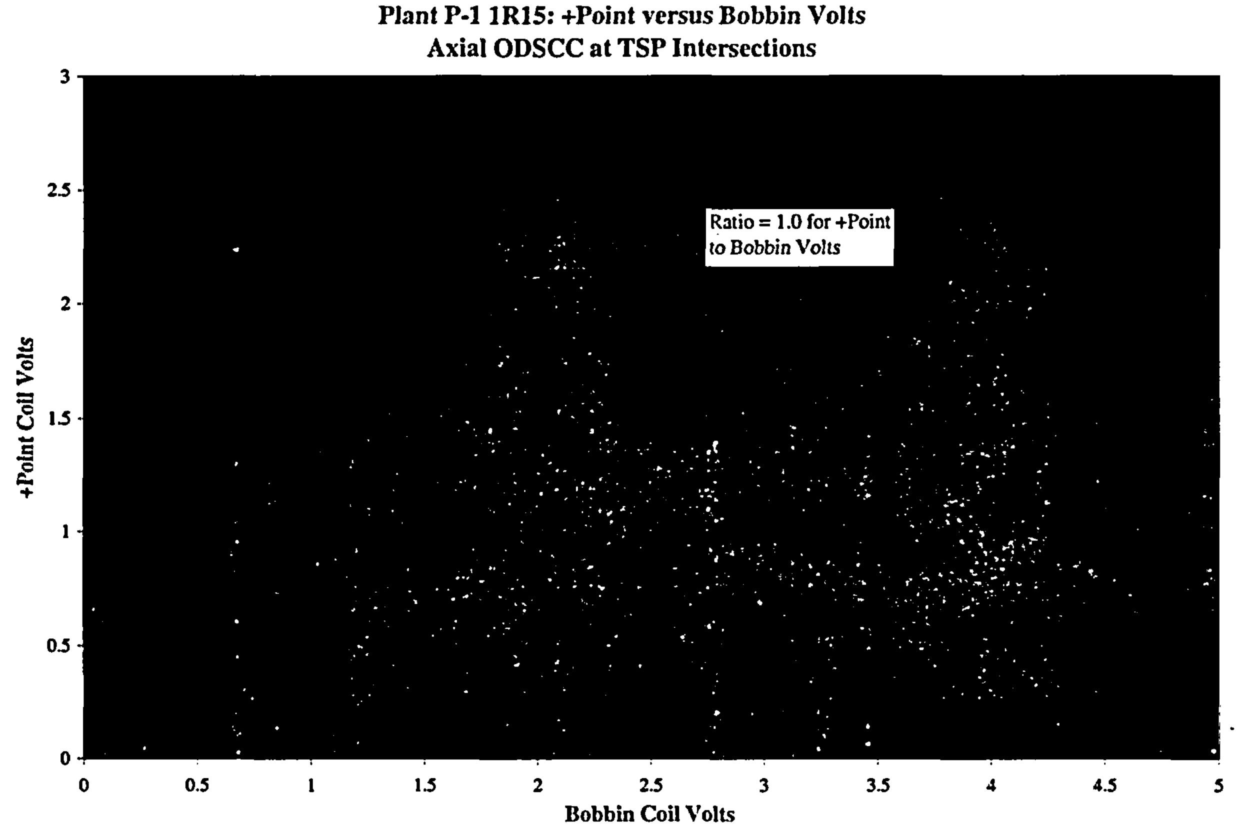
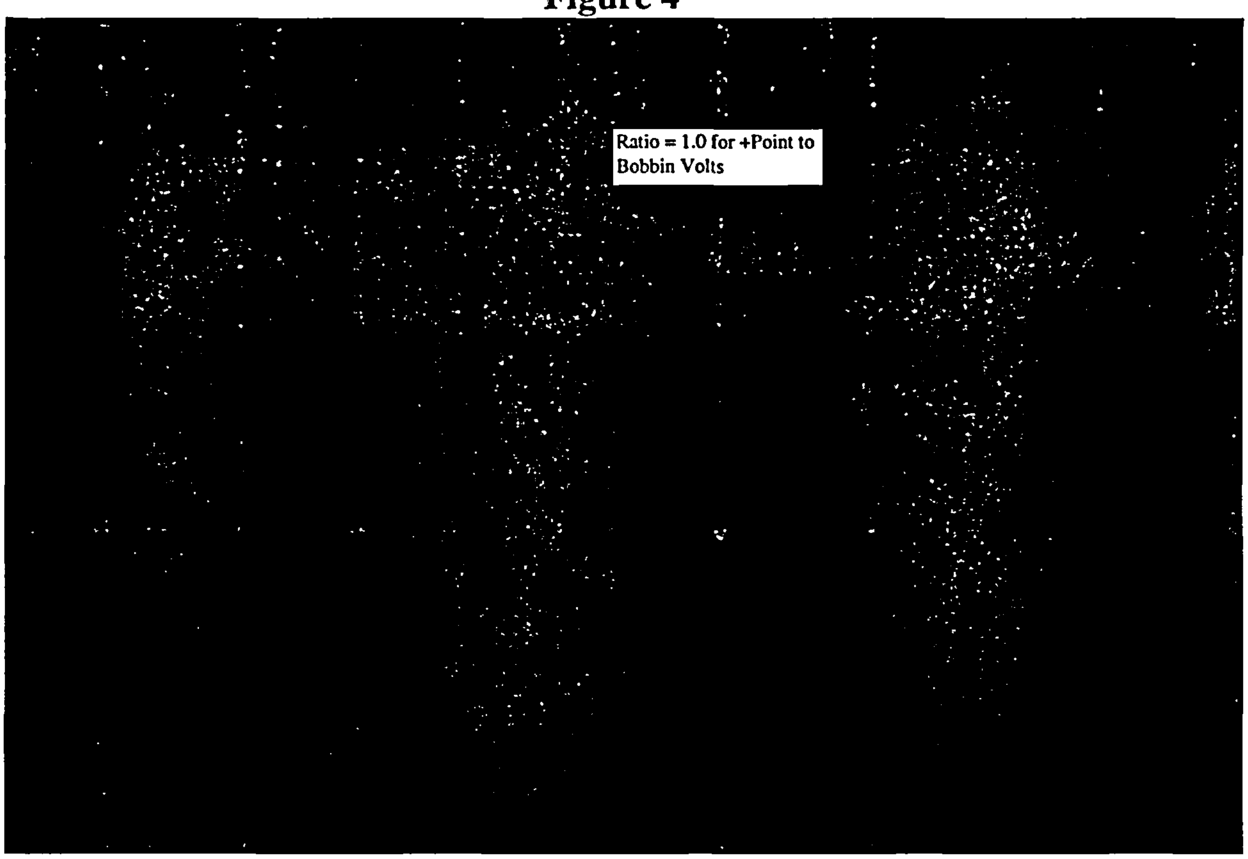


Figure 4



ARC Guidelines for Preventive Repair of Large +Point Indications

1.0 Introduction

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The largest voltage indication found during ARC inspections was a 21.5 volt bobbin indication (12.2 volt by +Point) at Plant Y-2. Fortunately, for providing a good database for evaluation, this indication had been +Point inspected at the prior outage. At the prior inspection, this indication was found to measure 2.0 volt by bobbin and 2.97 volt by +Point (maximum volts from profile analysis). The occurrence of +Point amplitudes greater than the bobbin voltage is infrequent for ODSCC partially due to the bobbin coil integrating degradation around the circumference of the tube while RPC measures a single crack location. The two voltages tend to be closer in magnitude when there is a single dominant crack at the TSP intersection.

The range of +Point amplitudes for a short throughwall axial ODSCC indication is about 2.0 to 3.0 volts. The lowest throughwall +Point amplitude in the ARC database is 1.89 volts. This indication had two interacting axial cracks, which tends to result in a +Point voltage reduction due to cancellation between the two coils. It can be expected that the Plant Y-2 indication was near or just throughwall at

the BOC condition. The growth rate in average depth for this indication was about 12% per EFPY which is in the range of the upper 90% to 95% probability for normal growth rates and considerably smaller than ODSCC indications found to have large growth rates. The Plant Y-2 indication grew from imminent throughwall at BOC to the throughwall length of 0.42 inch found by destructive examination. The large voltage growth resulted from throughwall penetration and growth in throughwall length.

Plants P-1, Y-1 and Y-2 have performed significant +Point inspections below the 2.0 volt repair level that include some indications with data from two or three +Point inspections over the last three cycles. These data permit an assessment of the larger +Point voltage and +Point to bobbin voltage ratio indications retained in service. The last three cycles of data were reviewed to identify the largest +Point volts left in service, the largest ratio of +Point to bobbin voltage and the largest bobbin indications. The resulting data for Plant P-1 cycles 1R13 to 1R15 are given in Table 1 and for Plants Y-1 and Y-2 cycles 9 to 11 are given in Tables 2 and 3. For Plant P-1, the largest +Point volts returned to service that can be assessed at the subsequent cycle are 1.65 volts at 1R13 and 1.71 volts at 1R14. None of the indications with +Point volts up to 1.71 had a large bobbin or +Point voltage growth in the subsequent cycle. The largest bobbin indication of 4.57 volts, which would not be considered an outlier indication, for tube R11C77 had a prior cycle +Point 0.61 volt indication. Similarly, indications with +Point to bobbin voltage ratios up to 2.0 showed no significant bobbin voltage growth in the subsequent cycle. The Plant Y-1 data of Table 2 show that there have been no high +Point volts or +Point to bobbin voltage ratios for data with successive +Point inspections. Thus, these data do not provide any additional insight on potentially limiting +Point voltages. The Plant Y-2 data of Table 3 show the 2.97 +Point volt indication left in service that led to the 21.5 bobbin volt outlier indication. Indications with +Point volts as high as 1.6 volts and +Point to bobbin voltage ratios up to 2.07 did not show any significant bobbin voltage growth in the subsequent cycle. The higher ratios of +Point to bobbin voltage, such as > 1.4, are generally associated with dominant single indications with relatively small bobbin voltages (i.e., < 0.7 volt) such that the effect of increasing bobbin voltage with increasing cracking around the tube circumference is not present. There is no technical reason to expect that single indications have a higher potential for large voltage growth in the next cycle since voltage growth rates are highest for crack depths near 100% and for increases in throughwall length rather than multiple indication effects. The Tables 1 to 3 results indicate that the +Point to bobbin voltage ratio is not a meaningful predictor for large bobbin voltage growth and is, therefore, not recommended for considerations of preventive plugging.

The Table 1 results also indicate that +Point voltages up to about 1.71 do not appear to be a meaningful predictor of large bobbin voltage growth. As discussed in Section 3 below, the crack depth for a 1.71 +Point voltage indication would be expected to be too shallow to grow to a significant throughwall length with normal growth rates over one cycle of operation. The threshold for considering preventive plugging should be greater than about 1.71 volts.

3.0 Guidelines for Preventive Repair

Based on the discussion of Section 2, only +Point indications greater than about 1.71 volt appear to be candidates for preventive repair considerations and the use of +Point to bobbin voltage ratios for preventive repair considerations is not recommended. The objective for preventive repair considerations is to prevent significantly large throughwall lengths, but to not exclude the potential for any throughwall cracks which would too conservative for a repair guideline. Growth in average depth is applied to estimate a reasonable depth for preventive repair as growth over a significant length rather than local crack penetration is of interest. A growth rate of about 10% in average depth per EFPY is a reasonable estimate for normal growth at about the 90% confidence level. Thus, for preventive repair based on

+Point amplitude sizing considerations, the amplitude should be based on average crack depths in the range of 85% over the deepest segment of about 0.1 to 0.2 inch. Since the amplitude sizing correlations are based on maximum crack depth, the 85% segment average depth must be adjusted upward to define a preventive repair guideline. Since the ratio of maximum depth to average depth over the burst effective crack length for a crack is typically about 1.25, it is reasonable to assume that the maximum depth for a deep crack segment would be at least 10% greater than the average depth. Thus, the maximum depth for preventive repair should be about 95% with a lower bound of about 90%. The +Point amplitude for these depths can be estimated from a correlation of maximum depth to +Point amplitude as described below.

Sizing correlations based on +Point amplitudes are being developed under the EPRI Tools for Tube Integrity Program but these correlations have not been finalized at this time. The sizing developments show that the expected exponential dependence of voltage with depth is consistent with pulled tube data and should be the basis for amplitude based sizing correlations. Given the exponential behavior, only two data points are needed to define a sizing correlation, one of which should be tied to providing good estimates of throughwall crack lengths. The development efforts show that +Point amplitudes in the range of 2.25 to 2.75 volt provide good estimates of initial throughwall penetration and throughwall lengths for ODSCC at TSP intersections. The second point for a sizing correlation can be tied to an amplitude at a given depth such as about 40%. A mean estimate for depths near 35% to 40% for ODSCC at TSP intersections is about 0.1 +Point volt. To avoid being overly conservative for preventive plugging, an estimate for depths near 95% can be based on amplitude sizing fit to 2.5 volts for throughwall and 0.1 volt at 35% depth. Since depth is being inferred from volts, depth has a logarithmic dependence on volts.

Figure 1 shows a sizing correlation fit to 0.1 volt at 35% depth and 2.5 volts at 100% depth. For a 95% maximum depth repair guideline, the +Point indication would be about 1.9 volts. At a maximum depth of about 90%, the +Point indication would be about 1.55 volts, which is too conservative for a preventive repair guideline based on the plant experience described in Section 3.0. It is suggested that consideration be given to preventive repair of ODSCC indications found to have a +Point maximum voltage of 1.9 volts.

Although the data of Tables 1 to 3 were obtained for plants with 7/8 inch tubing, +Point amplitudes for deep indications are not significantly different for 3/4 inch tubing since voltages are calibrated for all tube sizes to 20 volts for a throughwall notch. For +Point amplitude sizing of axial ODSCC, the same correlation is applied to both 3/4 and 7/8 inch tubing. Consequently, the suggested preventive repair limit of 1.9 volts would be applicable to both 3/4 and 7/8 inch tubing. Since the GL 95-05 repair limit for 3/4 inch tubing is >1.0 bobbin volts and +Point volts are less than bobbin volts for the dominant population of indications, the suggested preventive repair limit of 1.9 +Point volts is not likely to impact plants with 3/4 inch tubing. Figure 2 shows the trend of +Point volts versus bobbin volts for an inspection in a plant with 3/4 inch tubing. For this inspection, essentially all +Point volts are less than the bobbin volts and no preventive repair would need to be considered.

The preventive repair guideline is developed based on considerations of normal growth in depth. Most plants found with large growth rates as a function of depth have had outlier bobbin voltage indications that initiated from bobbin voltages less than one volt. These plants generally had high operating temperatures which may have contributed to larger growth rates in depth. It would be excessively conservative for currently operating SGs to consider preventive repair limits low enough to encompass large growth in depth considerations.

4.0 Guidelines for Supplemental RPC Inspection

Figures 3 and 4 show +Point versus bobbin voltage trends for two plants with 7/8 inch tubing. Some tubes are found to have +Point volts comparable to or slightly exceeding the bobbin voltages. Thus, +Point voltages of about 1.9 volts may be found below the GL 95-05 repair limit for 7/8 inch tubing. A +Point to bobbin voltage ratio of about 1.1 envelopes nearly all bobbin indications. Thus, there is a high probability that bobbin indications less than 1.7 bobbin volts would have less than 1.9 +Point volts.

To increase the likelihood of identifying ODSCC indications with >1.9 +Point volts for plants with 7/8 inch tubing, a 20% sample inspection of bobbin indications between 1.7 volts and the GL 95-05 repair limit of > 2.0 volts should be considered for preventive repair applications. If a +Point indication >1.9 volts is found in the sample inspection, expansion of the inspection to include all bobbin indications >1.7 volts should be considered for preventive repair applications. Indications greater than the GL 95-05 repair limit of >2.0 volts are required to be inspected and are repaired so that preventive repair considerations are not applicable. If a plant applies locked TSPs to prevent burst and has a repair limit greater than the GL 95-05 limits, there is no need to apply preventive repair unless leakage from a single large voltage indication would potentially cause leakage limits to be exceeded. There is no identified basis to suggest expansion of +Point inspections for plants with 3/4 inch tubing.

5.0 Conclusions

ARC inspections periodically find large voltage indications (such as > 8 volts) that are not predicted to occur and generally do not occur in successive inspections. Since voltage increases exponentially with depth and again approximately exponentially with increasing throughwall length, an indication that is near throughwall over a significant length at the BOC can grow with normal depth growth to a significant throughwall length over one operating cycle with an associated large voltage growth rate. The likelihood of finding a large voltage indication can be reduced by preventive plugging at less than the ARC repair limit. Plant experience indicates that +Point volts up to about 1.71 volts and +Point to bobbin volt ratios as high as 2.07 have not resulted in large +Point indications in subsequent cycles. Since a +Point to bobbin ratio of about 2.0 bounds essentially all bobbin indications, this ratio does not provide a meaningful indicator for considerations of preventive tube repair. The data indicate that +Point amplitudes should exceed 1.7 volts for preventive repair considerations. The most appropriate measure for preventive repair considerations would be near throughwall depths that can grow to large throughwall lengths for which 95% maximum depth is shown to be a reasonable depth for preventive repair considerations. The best current methods for depth sizing of axial ODSCC are based on correlations of depth with +Point volts.

Based on applying a typical amplitude sizing correlation, a preventive tube repair at 1.9 +Point volts is suggested corresponding to about 95% maximum ODSCC depth. Since a +Point to bobbin voltage ratio of about 1.1 bounds most ODSCC indications, it is suggested that a 20% sample inspection be performed for indications >1.7 bobbin volts. If this sample inspection of bobbin indications between 1.7 volts and the 7/8 inch GL 95-05 repair limit of 2.0 volts identifies +Point indications >1.9 volts, the inspection should be expanded to include all bobbin indications between 1.7 and 2.0 volts. Since the GL 95-05 repair limit for 3/4 inch tubing is 1.0 bobbin volt and +Point volts are less than bobbin volts for the dominant population of indications, the suggested preventive repair limit of 1.9 +Point volts is not likely to impact plants with 3/4 inch tubing. Given the lower repair limit, no supplemental inspection for preventive repair considerations is recommended for plants with 3/4 inch tubing.

Table 1. Plant P-1: Successive Cycle +Point Data for Highest Bobbin Volts, +Point Volts and Ratio of +Point to Bobbin Volts

Table 2. Plant Y-1: Successive Cycle +Point Data for Highest Bobbin Volts, +Point Volts and Ratio of +Point to Bobbin Volts

Table 3. Plant Y-2: Successive Cycle +Point Data for Highest Bobbin Volts, +Point Volts and Ratio of +Point to Bobbin Volts											
Tube			Bobbin Volts			+Point Volts			Ratio +Point to Bobbin Volts		
SG	Row	Col	2R9	2R10	2R11	2R9	2R10	2R11	2R9	2R10	2R11

Figure 1

+Point Amplitude Sizing Correlation for Estimating Depths Based on Amplitude

Logarithmic Fit to 2.5 Volts at 100% Depth and 0.1 Volt at 40% Depth

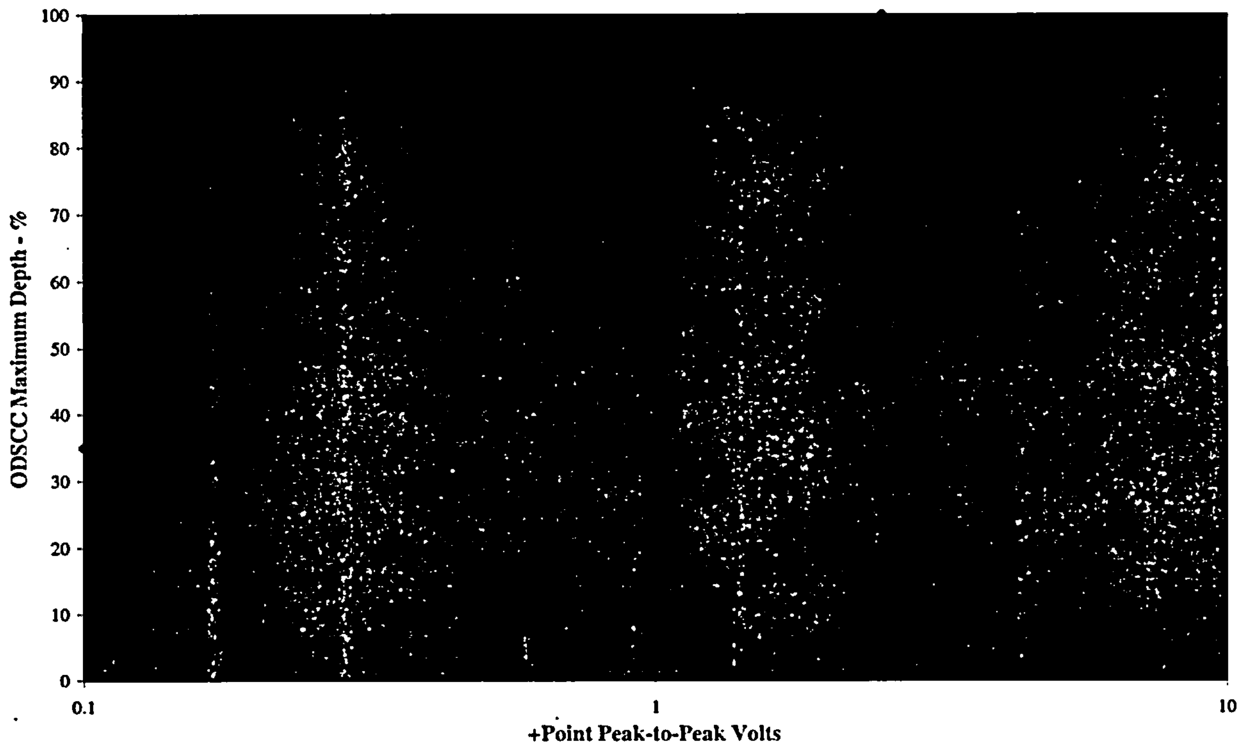


Figure 2

Plant DW +Point Volts versus Bobbin Coil Volts

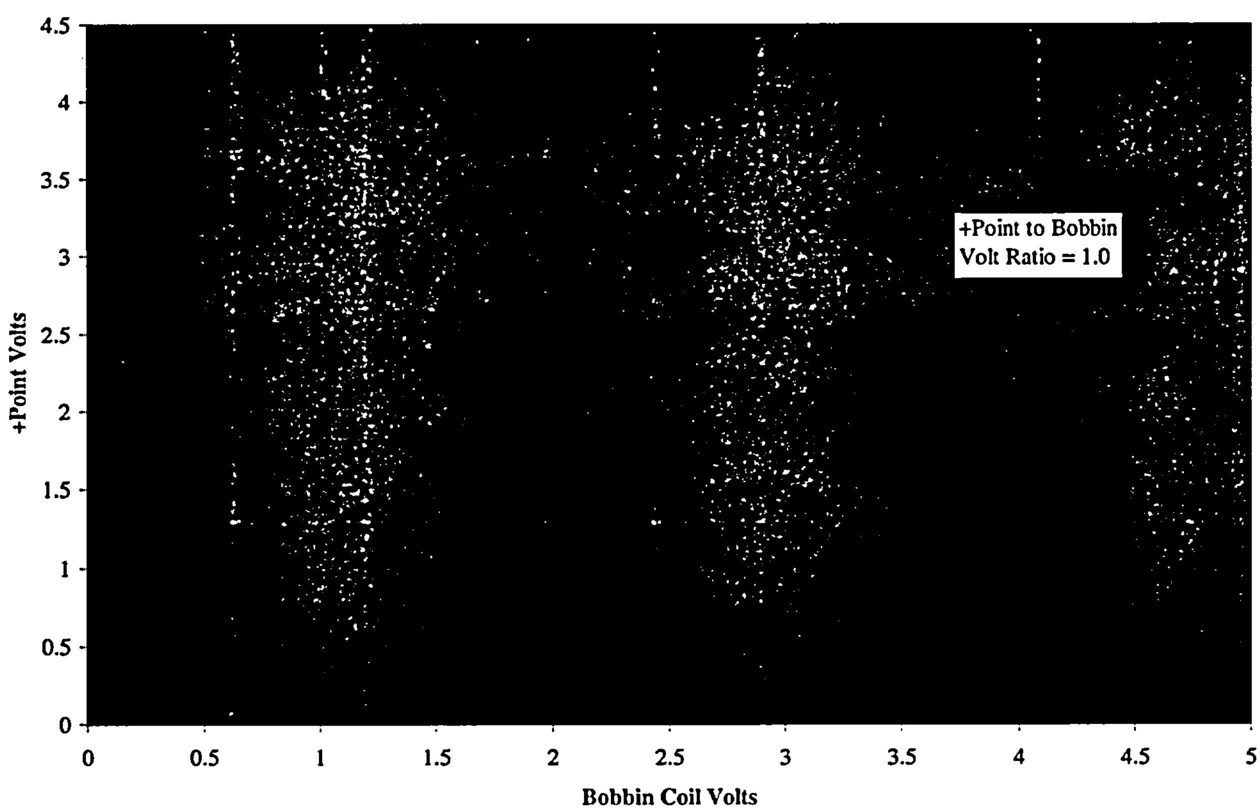


Figure 3

Plant P-1 1R15: +Point versus Bobbin Volts
Axial ODSCC at TSP Intersections

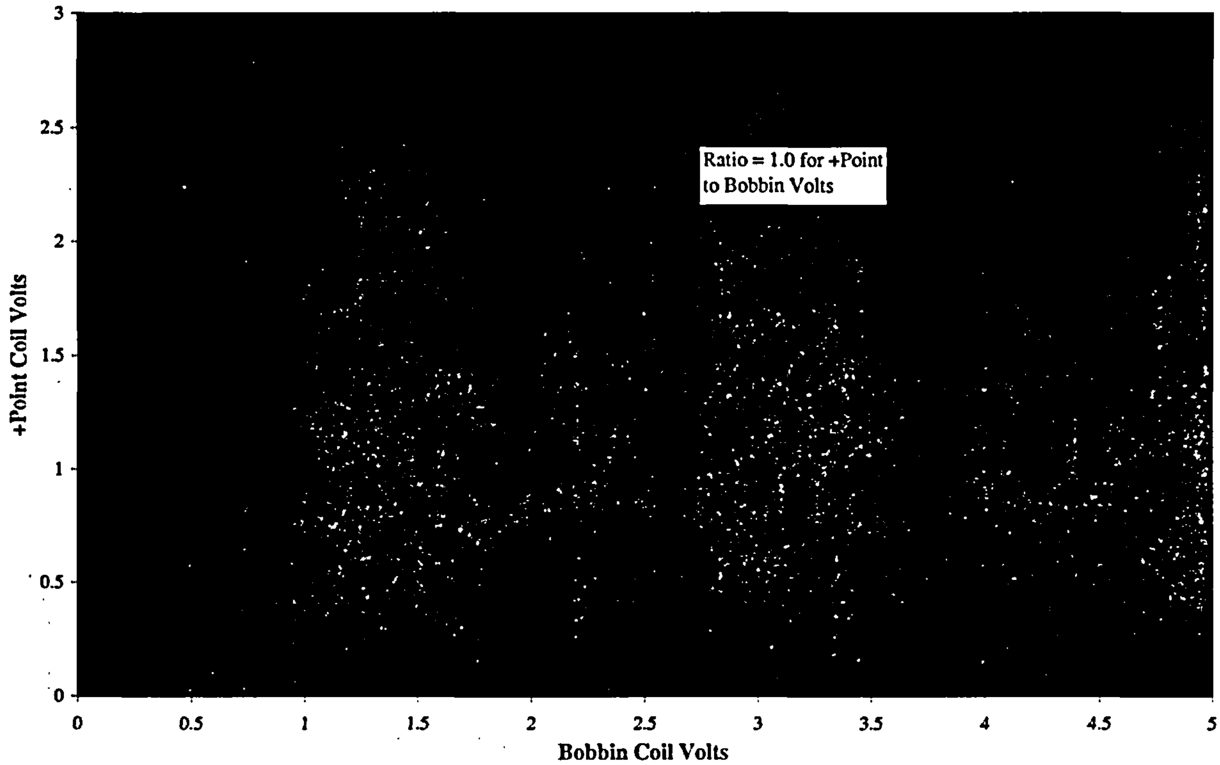
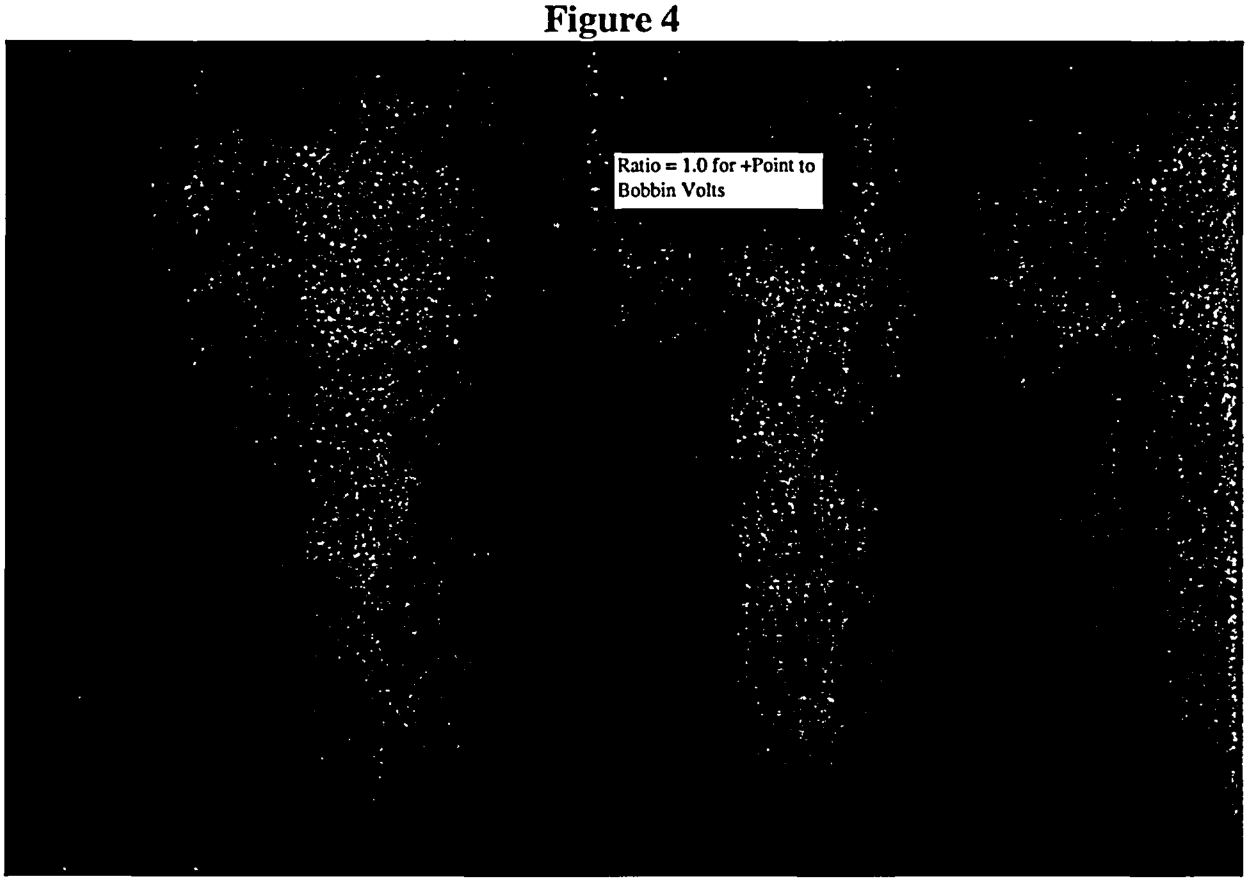


Figure 4



ARC Guidelines for Preventive Repair of Large +Point Indications

1.0 Introduction

This note provides guidelines for preventive tube repair (i.e., repair at less than the licensed voltage based repair limits) to reduce the potential for finding large voltage growth rates for indications left in service under the ARC for axial ODSCC at TSP intersections. Since the guidelines apply to preventive repair, implementation of these guidelines is optional on a plant specific basis.

ARC inspections periodically find large voltage indications (such as > 8 volts) that are not predicted to occur and generally do not occur in successive inspections. These indications with unusually large voltage growth have been shown, where successive RPC inspection data are available, to occur with normal growth in depth. Voltage increases exponentially with depth and again approximately exponentially with increasing throughwall length. Consequently, an indication that is near throughwall over a significant length at the BOC can grow with normal depth growth to a significant throughwall length over one operating cycle with an associated large voltage growth rate. Most of the large voltage growth indications found in ARC inspections have been pulled and found to satisfy burst margins at the EOC conditions. However, the ARC burst versus voltage correlation will predict burst probabilities near the ARC reporting threshold of 0.01 due to the large uncertainties in the correlation.

The likelihood of finding a large voltage indication can be reduced by preventive plugging at less than the ARC repair limit. The best currently available methods for depth sizing of axial ODSCC are based on correlations of depth with +Point voltage when developed to provide a good estimate of the voltage at initial throughwall penetration. The latter is a principal factor in the development of sizing correlations under the EPRI Tools for Tube Integrity Program and associated correlations are applied in this report to provide a recommended +Point voltage for preventive tube repair for axial ODSCC at TSP intersections.

Section 2 provides additional background information and Section 3 provides guidelines for preventive repair. Section 4 provides guidelines for supplemental inspections to further inspect for indications potentially desirable for preventive repair. Section 5 summarizes the conclusions of this report.

2.0 Background Information

The largest voltage indication found during ARC inspections was a 21.5 volt bobbin indication (12.2 volt by +Point) at Plant Y-2. Fortunately, for providing a good database for evaluation, this indication had been +Point inspected at the prior outage. At the prior inspection, this indication was found to measure 2.0 volt by bobbin and 2.97 volt by +Point (maximum volts from profile analysis). The occurrence of +Point amplitudes greater than the bobbin voltage is infrequent for ODSCC partially due to the bobbin coil integrating degradation around the circumference of the tube while RPC measures a single crack location. The two voltages tend to be closer in magnitude when there is a single dominant crack at the TSP intersection.

The range of +Point amplitudes for a short throughwall axial ODSCC indication is about 2.0 to 3.0 volts. The lowest throughwall +Point amplitude in the ARC database is 1.89 volts. This indication had two interacting axial cracks, which tends to result in a +Point voltage reduction due to cancellation between the two coils. It can be expected that the Plant Y-2 indication was near or just throughwall at

the BOC condition. The growth rate in average depth for this indication was about 12% per EFPY which is in the range of the upper 90% to 95% probability for normal growth rates and considerably smaller than ODSCC indications found to have large growth rates. The Plant Y-2 indication grew from imminent throughwall at BOC to the throughwall length of 0.42 inch found by destructive examination. The large voltage growth resulted from throughwall penetration and growth in throughwall length.

Plants P-1, Y-1 and Y-2 have performed significant +Point inspections below the 2.0 volt repair level that include some indications with data from two or three +Point inspections over the last three cycles. These data permit an assessment of the larger +Point voltage and +Point to bobbin voltage ratio indications retained in service. The last three cycles of data were reviewed to identify the largest +Point volts left in service, the largest ratio of +Point to bobbin voltage and the largest bobbin indications. The resulting data for Plant P-1 cycles 1R13 to 1R15 are given in Table 1 and for Plants Y-1 and Y-2 cycles 9 to 11 are given in Tables 2 and 3. For Plant P-1, the largest +Point volts returned to service that can be assessed at the subsequent cycle are 1.65 volts at 1R13 and 1.71 volts at 1R14. None of the indications with +Point volts up to 1.71 had a large bobbin or +Point voltage growth in the subsequent cycle. The largest bobbin indication of 4.57 volts, which would not be considered an outlier indication, for tube R11C77 had a prior cycle +Point 0.61 volt indication. Similarly, indications with +Point to bobbin voltage ratios up to 2.0 showed no significant bobbin voltage growth in the subsequent cycle. The Plant Y-1 data of Table 2 show that there have been no high +Point volts or +Point to bobbin voltage ratios for data with successive +Point inspections. Thus, these data do not provide any additional insight on potentially limiting +Point voltages. The Plant Y-2 data of Table 3 show the 2.97 +Point volt indication left in service that led to the 21.5 bobbin volt outlier indication. Indications with +Point volts as high as 1.6 volts and +Point to bobbin voltage ratios up to 2.07 did not show any significant bobbin voltage growth in the subsequent cycle. The higher ratios of +Point to bobbin voltage, such as > 1.4, are generally associated with dominant single indications with relatively small bobbin voltages (i.e., < 0.7 volt) such that the effect of increasing bobbin voltage with increasing cracking around the tube circumference is not present. There is no technical reason to expect that single indications have a higher potential for large voltage growth in the next cycle since voltage growth rates are highest for crack depths near 100% and for increases in throughwall length rather than multiple indication effects. The Tables 1 to 3 results indicate that the +Point to bobbin voltage ratio is not a meaningful predictor for large bobbin voltage growth and is, therefore, not recommended for considerations of preventive plugging.

The Table 1 results also indicate that +Point voltages up to about 1.71 do not appear to be a meaningful predictor of large bobbin voltage growth. As discussed in Section 3 below, the crack depth for a 1.71 +Point voltage indication would be expected to be too shallow to grow to a significant throughwall length with normal growth rates over one cycle of operation. The threshold for considering preventive plugging should be greater than about 1.71 volts.

3.0 Guidelines for Preventive Repair

Based on the discussion of Section 2, only +Point indications greater than about 1.71 volt appear to be candidates for preventive repair considerations and the use of +Point to bobbin voltage ratios for preventive repair considerations is not recommended. The objective for preventive repair considerations is to prevent significantly large throughwall lengths, but to not exclude the potential for any throughwall cracks which would too conservative for a repair guideline. Growth in average depth is applied to estimate a reasonable depth for preventive repair as growth over a significant length rather than local crack penetration is of interest. A growth rate of about 10% in average depth per EFPY is a reasonable estimate for normal growth at about the 90% confidence level. Thus, for preventive repair based on

+Point amplitude sizing considerations, the amplitude should be based on average crack depths in the range of 85% over the deepest segment of about 0.1 to 0.2 inch. Since the amplitude sizing correlations are based on maximum crack depth, the 85% segment average depth must be adjusted upward to define a preventive repair guideline. Since the ratio of maximum depth to average depth over the burst effective crack length for a crack is typically about 1.25, it is reasonable to assume that the maximum depth for a deep crack segment would be at least 10% greater than the average depth. Thus, the maximum depth for preventive repair should be about 95% with a lower bound of about 90%. The +Point amplitude for these depths can be estimated from a correlation of maximum depth to +Point amplitude as described below.

Sizing correlations based on +Point amplitudes are being developed under the EPRI Tools for Tube Integrity Program but these correlations have not been finalized at this time. The sizing developments show that the expected exponential dependence of voltage with depth is consistent with pulled tube data and should be the basis for amplitude based sizing correlations. Given the exponential behavior, only two data points are needed to define a sizing correlation, one of which should be tied to providing good estimates of throughwall crack lengths. The development efforts show that +Point amplitudes in the range of 2.25 to 2.75 volt provide good estimates of initial throughwall penetration and throughwall lengths for ODSCC at TSP intersections. The second point for a sizing correlation can be tied to an amplitude at a given depth such as about 40%. A mean estimate for depths near 35% to 40% for ODSCC at TSP intersections is about 0.1 +Point volt. To avoid being overly conservative for preventive plugging, an estimate for depths near 95% can be based on amplitude sizing fit to 2.5 volts for throughwall and 0.1 volt at 35% depth. Since depth is being inferred from volts, depth has a logarithmic dependence on volts.

Figure 1 shows a sizing correlation fit to 0.1 volt at 35% depth and 2.5 volts at 100% depth. For a 95% maximum depth repair guideline, the +Point indication would be about 1.9 volts. At a maximum depth of about 90%, the +Point indication would be about 1.55 volts, which is too conservative for a preventive repair guideline based on the plant experience described in Section 3.0. It is suggested that consideration be given to preventive repair of ODSCC indications found to have a +Point maximum voltage of 1.9 volts.

Although the data of Tables 1 to 3 were obtained for plants with 7/8 inch tubing, +Point amplitudes for deep indications are not significantly different for 3/4 inch tubing since voltages are calibrated for all tube sizes to 20 volts for a throughwall notch. For +Point amplitude sizing of axial ODSCC, the same correlation is applied to both 3/4 and 7/8 inch tubing. Consequently, the suggested preventive repair limit of 1.9 volts would be applicable to both 3/4 and 7/8 inch tubing. Since the GL 95-05 repair limit for 3/4 inch tubing is >1.0 bobbin volts and +Point volts are less than bobbin volts for the dominant population of indications, the suggested preventive repair limit of 1.9 +Point volts is not likely to impact plants with 3/4 inch tubing. Figure 2 shows the trend of +Point volts versus bobbin volts for an inspection in a plant with 3/4 inch tubing. For this inspection, essentially all +Point volts are less than the bobbin volts and no preventive repair would need to be considered.

The preventive repair guideline is developed based on considerations of normal growth in depth. Most plants found with large growth rates as a function of depth have had outlier bobbin voltage indications that initiated from bobbin voltages less than one volt. These plants generally had high operating temperatures which may have contributed to larger growth rates in depth. It would be excessively conservative for currently operating SGs to consider preventive repair limits low enough to encompass large growth in depth considerations.

4.0 Guidelines for Supplemental RPC Inspection

Figures 3 and 4 show +Point versus bobbin voltage trends for two plants with 7/8 inch tubing. Some tubes are found to have +Point volts comparable to or slightly exceeding the bobbin voltages. Thus, +Point voltages of about 1.9 volts may be found below the GL 95-05 repair limit for 7/8 inch tubing. A +Point to bobbin voltage ratio of about 1.1 envelopes nearly all bobbin indications. Thus, there is a high probability that bobbin indications less than 1.7 bobbin volts would have less than 1.9 +Point volts.

To increase the likelihood of identifying ODSCC indications with >1.9 +Point volts for plants with 7/8 inch tubing, a 20% sample inspection of bobbin indications between 1.7 volts and the GL 95-05 repair limit of > 2.0 volts should be considered for preventive repair applications. If a +Point indication >1.9 volts is found in the sample inspection, expansion of the inspection to include all bobbin indications >1.7 volts should be considered for preventive repair applications. Indications greater than the GL 95-05 repair limit of >2.0 volts are required to be inspected and are repaired so that preventive repair considerations are not applicable. If a plant applies locked TSPs to prevent burst and has a repair limit greater than the GL 95-05 limits, there is no need to apply preventive repair unless leakage from a single large voltage indication would potentially cause leakage limits to be exceeded. There is no identified basis to suggest expansion of +Point inspections for plants with 3/4 inch tubing.

5.0 Conclusions

ARC inspections periodically find large voltage indications (such as > 8 volts) that are not predicted to occur and generally do not occur in successive inspections. Since voltage increases exponentially with depth and again approximately exponentially with increasing throughwall length, an indication that is near throughwall over a significant length at the BOC can grow with normal depth growth to a significant throughwall length over one operating cycle with an associated large voltage growth rate. The likelihood of finding a large voltage indication can be reduced by preventive plugging at less than the ARC repair limit. Plant experience indicates that +Point volts up to about 1.71 volts and +Point to bobbin volt ratios as high as 2.07 have not resulted in large +Point indications in subsequent cycles. Since a +Point to bobbin ratio of about 2.0 bounds essentially all bobbin indications, this ratio does not provide a meaningful indicator for considerations of preventive tube repair. The data indicate that +Point amplitudes should exceed 1.7 volts for preventive repair considerations. The most appropriate measure for preventive repair considerations would be near throughwall depths that can grow to large throughwall lengths for which 95% maximum depth is shown to be a reasonable depth for preventive repair considerations. The best current methods for depth sizing of axial ODSCC are based on correlations of depth with +Point volts.

Based on applying a typical amplitude sizing correlation, a preventive tube repair at 1.9 +Point volts is suggested corresponding to about 95% maximum ODSCC depth. Since a +Point to bobbin voltage ratio of about 1.1 bounds most ODSCC indications, it is suggested that a 20% sample inspection be performed for indications >1.7 bobbin volts. If this sample inspection of bobbin indications between 1.7 volts and the 7/8 inch GL 95-05 repair limit of 2.0 volts identifies +Point indications >1.9 volts, the inspection should be expanded to include all bobbin indications between 1.7 and 2.0 volts. Since the GL 95-05 repair limit for 3/4 inch tubing is 1.0 bobbin volt and +Point volts are less than bobbin volts for the dominant population of indications, the suggested preventive repair limit of 1.9 +Point volts is not likely to impact plants with 3/4 inch tubing. Given the lower repair limit, no supplemental inspection for preventive repair considerations is recommended for plants with 3/4 inch tubing.

Table 1. Plant P-1: Successive Cycle +Point Data for Highest Bobbin Volts, +Point Volts and Ratio of +Point to Bobbin Volts

Table 2. Plant Y-1: Successive Cycle +Point Data for Highest Bobbin Volts, +Point Volts and Ratio of +Point to Bobbin Volts

Table 3. Plant Y-2: Successive Cycle +Point Data for Highest Bobbin Volts, +Point Volts and Ratio of +Point to Bobbin Volts

Tube			Bobbin Volts			+Point Volts			Ratio +Point to Bobbin Volts		
SG	Row	Col	2R9	2R10	2R11	2R9	2R10	2R11	2R9	2R10	2R11

Figure 1

+Point Amplitude Sizing Correlation for Estimating Depths Based on Amplitude
Logarithmic Fit to 2.5 Volts at 100% Depth and 0.1 Volt at 40% Depth

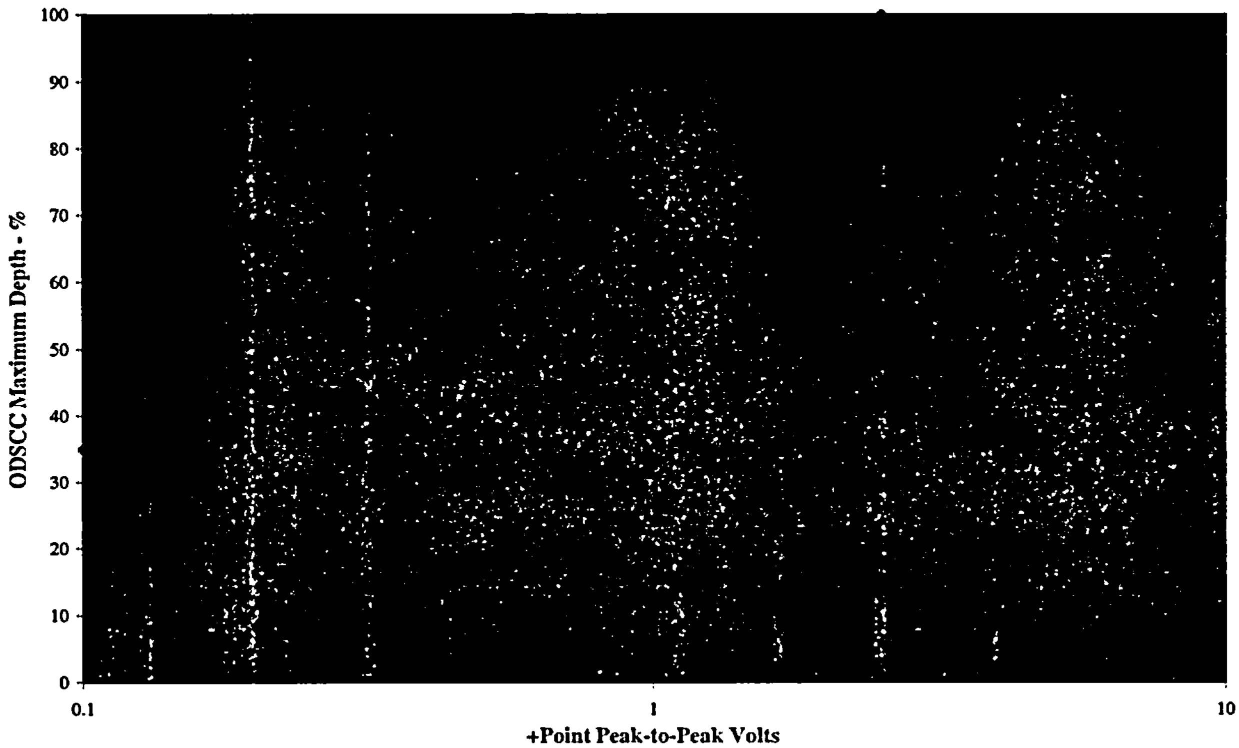


Figure 2

Plant DW +Point Volts versus Bobbin Coil Volts

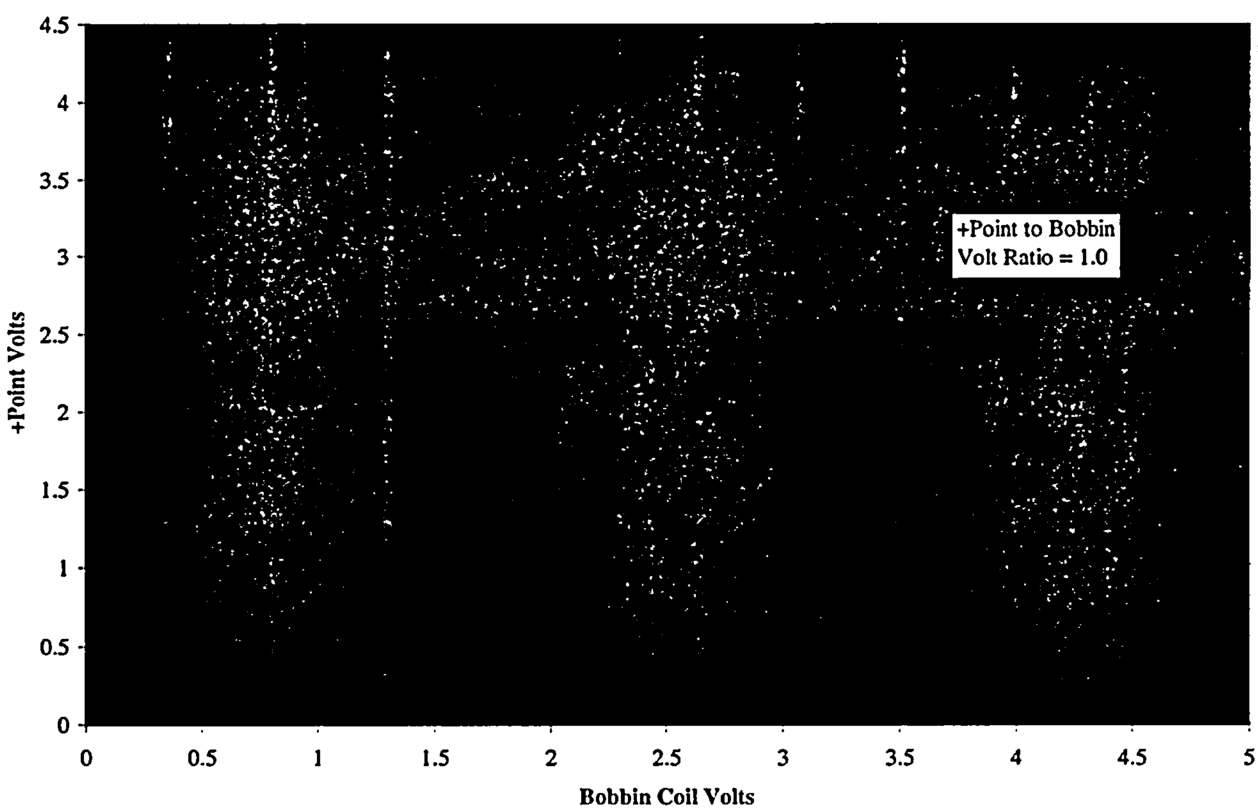


Figure 3

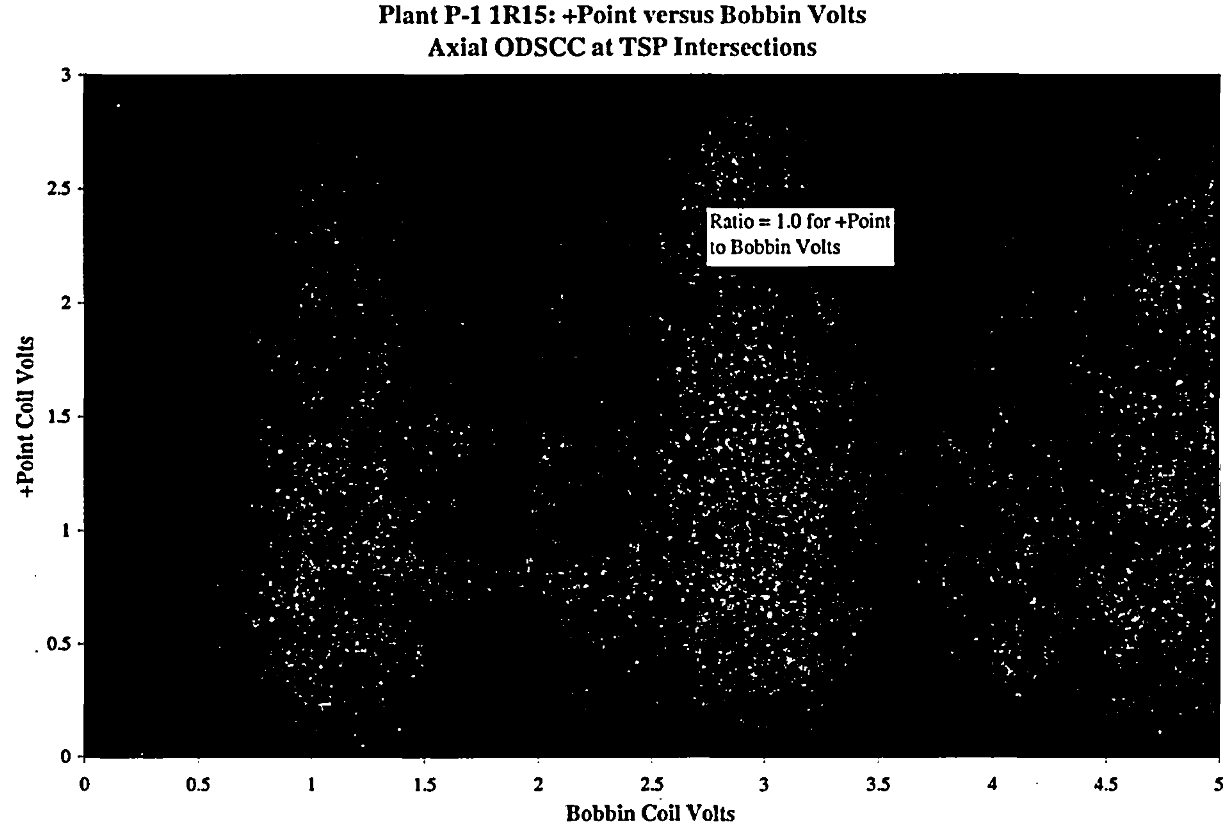
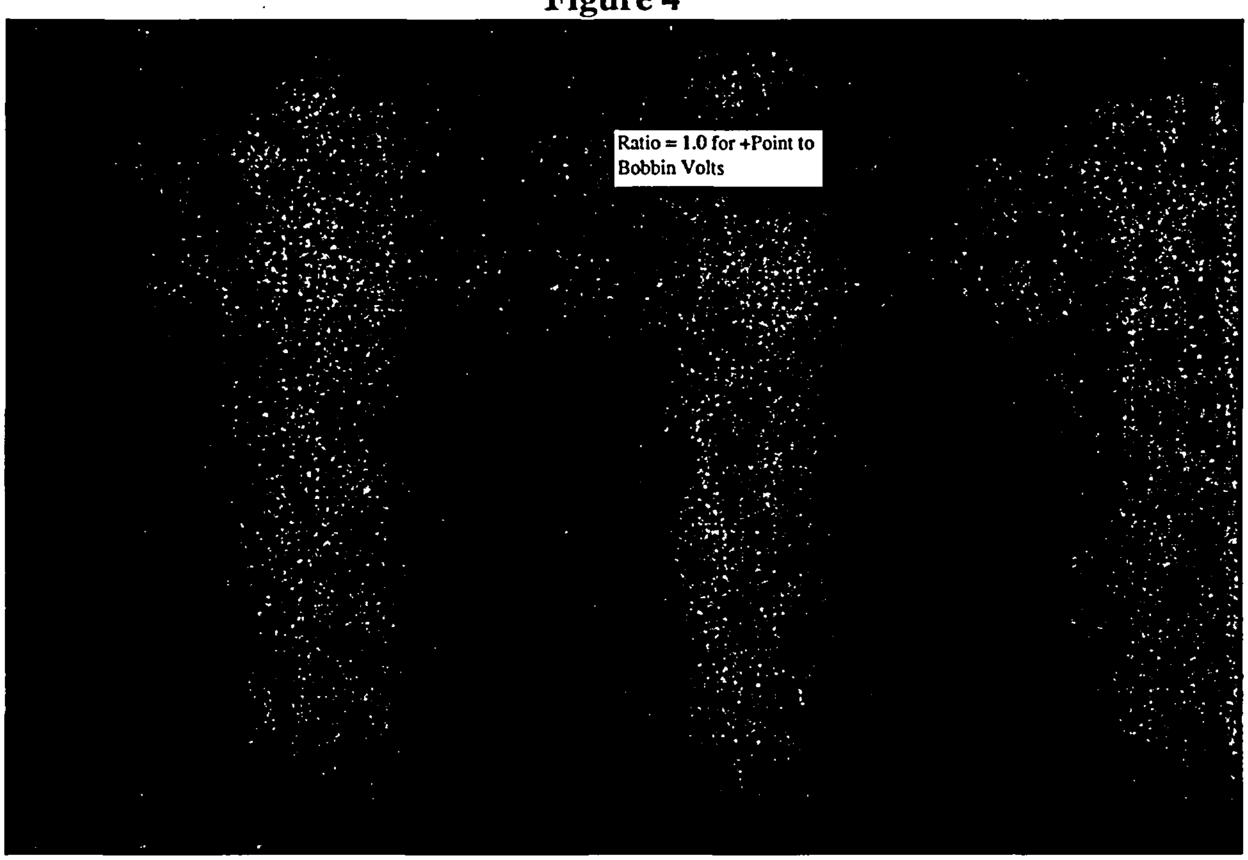


Figure 4



Enclosure 5

Noise Requirements for Voltage Based ARC

Non-Proprietary Version

Noise Requirements for Voltage Based ARC

1.0 Introduction

This note provides recommendations on noise inspection, analysis and repair for application to the ARC for ODSCC at TSP intersections. These recommendations differ from the mix residuals requirements given in GL 95-05. Since these recommendations represent a change to GL 95-05, NRC approval is required prior to implementation under the ODSCC ARC.

Tube noise considerations for indications at TSP intersections for the voltage based ARC are currently based on measurements of the mix residual signal. The mix residual was applied in the early development of the ARC as a measure of noise prior to more recent efforts in the industry to assess the effects of noise on detection. The mix residual is a measure of the noise across the entire TSP length and is not an appropriate quantity for assessing the effects of noise on detection since most TSP indications develop at the TSP center where noise influence is minimal. The noise at TSP intersections develops over the first and second cycle of operation and is not significantly sensitive to the NDE setup for the frequency mix at TSP intersections or significantly variable from cycle to cycle. To update the ARC noise inspection and repair requirements to current noise assessment methodology, revised requirements for inspection and repair at noisy TSP intersections are developed in this report.

NRC Generic Letter 95-05 (Reference 1) requires RPC inspection of intersections with large mix residuals that could cause a 1.0 volt bobbin signal to be masked or misread. The GL states that "Any indications found at such intersections with RPC should cause the tube to be repaired." The latter GL requirement has had two interpretations. The industry interpretation in Reference 2 is that repair "at such intersections" refers to repair at intersections having mix residuals that mask a 1.0 volt indication so that repair is only required when the bobbin voltage is estimated to be ≥1.0 volt. The statement has alternately been interpreted by the NRC to imply that all indications found by RPC during mix residual inspections are to be repaired independent of the estimated bobbin voltage. As discussed in Section 2.0, all TSP intersections have mix residual signals and the influence of the mix residual signals (better defined as a measure of TSP noise) on voltage measurements is built into the ARC burst and leak rate correlations. The concept of misreading a voltage due to TSP noise should not be applied for the ARC since the effects of noise on voltage measurements are already included in the ARC database and contribute to the voltage variability in the ARC burst and leakage correlations. The repair criteria for ODSCC indications found at noisy TSP intersections are redefined in this note to more closely tie the noise intersection repair limits to the plant specific voltage based repair limits. As shown in this report, bobbin voltages can be adequately assigned to indications found by RPC inspections so that the indications can be included in condition monitoring and operational assessments, thus eliminating any need for lower repair limits based on potential influence on burst and leakage.

GL 95-05 also requires 100% inspection of all dents > 5 volts and repair of any indications found in dents > 5 volts. Since these indications can be adequately sized using correlations of bobbin to RPC volts such that the indications can be included in condition monitoring and operational assessments, this report also recommends that repair for these indications be tied to the plant specific voltage based repair limits.

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to RPC indications is demonstrated by field data and recommendations for repair of the RPC indications are provided. Section 4 defines the recommended requirements for selecting samples for RPC inspection of noisy TSP intersections and for expanding the inspections if indications exceeding the GL 95-05 ARC repair limits are found in the sample inspection. Section 5 summarizes the conclusions of this report.

2.0 Considerations for Noise at TSP Intersections

With regard to the presence of mix residuals and their influence on sizing of indications, it must be emphasized that all TSP intersections have mix residuals after the first one or two cycles of operation. The mix residuals may be more easily understood as a measure of TSP noise. After about two cycles, the mix residuals generally do not change significantly with operating time. The dominant voltage for the mix residual signals is not strongly affected by the mixing used to analyze the bobbin data so the mix residual signal amplitude does not vary significantly with operating time or NDE analyst. Frequently, a significant part of the mix residual signal is present in bobbin data obtained without a TSP for pulled tubes examined in the laboratory. Some of the model boiler specimens show mix residuals although generally smaller than field data due to the shorter time at temperature. The bobbin response apparently includes an effect of the time at temperature at a TSP on the electrical and/or magnetic properties of the tube. Metallography was performed on a pulled tube to attempt to identify the cause for the signal, but was not successful in identifying any physical change to the tube or grain structure.

Many of the pulled tubes in the ARC database (and the prior cycle probability of detection or POPCD database) have mix residual signals larger than typically found in currently operating SGs. Figure 1 shows the 1.87 flaw voltage and the 3.23 mix residual voltage for pulled tube R27C54 from plant A-1 in the ARC database. This is only one example of the pulled tube data. The flaw signal is easily detectable which would imply easy detection at signal to noise (S/N) of about 0.58 for the associated flaw and mix residual peak-to-peak voltages. As shown in Section 3, a S/N of 0.58 would be expected to have a probability of detection of about 0.25. This indicates that the use of the mix residual as a measure of noise is not appropriate for assessing detection.

The mix residual voltage is not being used, nor should it be used, in current assessments of the influence of noise on detection or sizing. For signal to noise evaluations, the noise is being evaluated as the maximum voltage response over approximately one third sections of the TSP to distinguish the relatively low noise at the center of the TSP from the larger noise near the edges of the TSP. Figure 2 shows the lower and upper TSP noise amplitudes for R27C54-1H. Noise at the middle section cannot be evaluated due to the presence of the flaw. Figure 3 shows the mix residual voltage and noise levels at the center, upper and lower one-third sections of the R27C54-2H TSP, where the mix residual is the same as at 1H. The noise level affecting detection and sizing at the center of the TSP, where most of the TSP ODSCC indications are found, is 0.70 volts peak-to-peak while the edge noise amplitudes are 1.70 and 1.52 volts. These noise levels are in the upper 20% of noise amplitudes expected at TSP intersections. The noise differences between the center and edge affect detectability of short, low voltage indications located at the edges of the TSP. The short indications at the TSP edges must grow to the center of the TSP to become structurally significant and the lower noise levels at the TSP center provide for detection of even low voltage indications. The noise levels in these figures are peak-to-peak amplitudes although the vertical amplitudes are more appropriate for assessing signal to noise for flaw detection. However, the applications of this report are related to amplitude sizing for which peak-to-peak flaw and noise amplitudes are the recommended quantities. Applying the peak-to-peak amplitudes of 1.87 volts for the flaw from Figure 1 and 0.70 volt for the noise at the TSP center from Figure 3, the

S/N for the flaw would be about 2.7 (expected POD about 0.96 from Section 3), which supports the ease of detection found for the flaw. This result is consistent with the recommended use of the flaw and noise evaluated at the TSP center.

The above noise and mix residual discussion demonstrates that it is neither feasible nor necessary to attempt to define bobbin flaw voltages that are not affected by the TSP noise or mix residuals. All indications have negligibly small to a range of noise influence on voltage sizing, and the ARC database includes many indications with larger noise levels than most currently active SGs. Whatever influence the mix residuals may have on voltage sizing for TSP indications is built into the ARC database by the pulled tubes and the concept of misreading voltages is irrelevant to the ARC.

Since nearly all TSP indications are located near the center of the TSP or span the center of the TSP, the appropriate quantity for assessing the influence of noise is the amplitude over approximately the center 1/3 of the TSP between the peaks associated with TSP edge effects. Short indications at the edges of the TSP would not have a significant influence on tube integrity. Amplitude measurements at the area of interest are being applied for tube integrity applications under the EPRI Tools for Tube Integrity Program. These measurements are being utilized to develop ETSSs and PODs based on performance testing of multiple analyst teams. The use of amplitude noise measurements are recommended for ARC noise assessments for consistency with the EPRI methodology for tube integrity applications. The following sections apply the amplitude noise measurements at the center of the TSP to develop RPC repair and inspection requirements for ARC applications.

3.0 Tube Repair Requirements for Indications Found by RPC at Noisy TSP Intersections

3.1 Bobbin Voltage Sizing for Indications Found by RPC

Axial ODSCC indications found only by RPC inspection can be sized for bobbin voltages by the methods described in Section 10.1 of Reference 2. Methods are described based on obtaining voltages from detection at the half-prime frequency and from correlations of bobbin to RPC voltages, which may be pancake or +Point coils. When detection can be adequately obtained at the half-prime frequency, this method is preferred over the bobbin/RPC voltage correlation since the method is closely related to the normal inspection process for detecting and sizing indications. However, it is shown below that both methods yield essentially the same bobbin voltages and that the inferred bobbin voltages are consistent with voltages obtained from the normal primary/secondary/resolution detection and sizing process.

The most extensive inspection of TSP intersections with significant mix residual noise signals was performed at Plant P-1 in 2003. The results of these inspections can be used to demonstrate the adequacy of the bobbin voltage sizing methods. Figure 4 compares the ratio of bobbin voltages in the 400/100 kHz mix to the 200 kHz volts for indications reported in the normal primary/secondary/ resolution analysis process to the ratios obtained from detecting the flaw (identified by the RPC) on the 200 kHz channel and using the inferred mix signal measurement with no additional adjustments. It is seen that the distributions obtained from both sizing methods are equivalent, which supports the adequacy of sizing by identifying the flaw in the half-prime frequency signal and obtaining voltages from the mix signal. Figure 5 compares the regression correlations of bobbin to +Point volts obtained using the normal inspection process with that obtained from the half-prime frequency analyses. The bobbin to RPC voltage correlations are essentially the same for both analysis methods. Since Figure 4 shows the adequacy of sizing from detection in the half-prime frequency and Figure 5 shows that correlations of bobbin to RPC volts are the same between the normal ODSCC sizing and half-prime

frequency analyses, it can be concluded that both of the methods for bobbin voltage sizing of RPC indications yield essentially the same bobbin voltages and both methods are acceptable for ARC applications.

3.2 Tube Repair Requirements for Indications Found by RPC at Noisy TSP Intersections

As noted in Section 1, the industry interpretation of GL 95-05 is that indications associated with large mix residuals and found only by RPC should be repaired if the inferred bobbin voltage is ≥1.0 volt. This repair limit is inconsistent with the differences in repair limits between 3/4" and 7/8" tubing. Since a bobbin voltage is assigned to the indications found only by RPC and the indications are included in the condition monitoring and operational assessments, there is no need to apply repair limits more conservative than the licensed repair limits.

For consistency in ARC repair limits, it is recommended that the following tube repair limits be applied for indications found only by RPC:

- Based on bobbin voltages determined by the methods of Reference 2 from indications found only by RPC inspection, indications with inferred bobbin voltages exceeding the licensed plant specific bobbin voltage repair limit are to be repaired. The GL 95-05 repair limits are > 1.0 volt for 3/4" tubing and > 2.0 volts for 7/8" tubing. Some plants may have larger repair limits such as obtained from locked TSP intersections.

- This repair limit applies for RPC indications found at noisy TSP intersections and at dented TSP intersections for dents of any voltage. For indications found at TSP intersections with both ODSCC and PWSCC indications for plants having a licensed PWSCC ARC, the above repair limit can be applied only if consistent with the licensed requirements.

- The bobbin voltages obtained by the Reference 1 methods from RPC testing of noisy TSP and dented TSP intersections are to be included in the ARC condition monitoring and operational assessments.

4.0 RPC Inspection Requirements for Noise at TSP Intersections

The selection of noisy TSP intersections for potential RPC inspection is to be based on POD versus signal/noise (S/N) correlations for axial ODSCC at TSP intersections. When available, the POD vs. S/N correlations for noise levels at the center of the TSP as obtained from ETSSs based on multiple analyst testing should be applied. Until these ETSS POD correlations are available, the POD vs. S/N correlation from SSPD testing of multiple analysts described in Reference 3, as shown in Figure 6, is to be applied. Figure 6 is based on flaw and noise peak-to-peak amplitudes to permit application of peak-to-peak voltage repair limits in defining S/N. For more general applications of S/N for detection, the vertical max voltages would be used as this quantity is more closely tied to NDE detection methods.

The GL 95-05 repair limits are the appropriate limits for detection of indications found at noisy TSP intersections based on burst and leakage considerations. The lowest voltages found for leaking indications in the ARC database (Reference 2) is 1.13 volts for 3/4" tubing and 2.81 volts for 7/8" tubing. The leak rates for these two indications were very small at 0.000088 and 0.00035 gpm, respectively. Thus, indications below the GL 95-05 repair limits would not be expected to leak and, if they do leak, would have a negligible leak rate. The probability of burst for indications at the GL 95-05

repair limits are less than about $5x10^{-6}$ for both 3/4" and 7/8" tubing, and thus undetected indications below the repair limits would have a negligible contribution to the burst probability. The GL 95-05 repair limits are to be applied to develop the inspection requirements of this section even for plants with higher licensed repair limits in order to assure that indications with potential significant leakage are included in the ARC analyses.

A S/N value for a nominal POD of 0.9 is to be obtained from the POD versus S/N correlation for axial ODSCC peak-to-peak amplitudes at the center of the TSP. For plants licensed to apply the Probability of Prior Cycle Detection (POPCD) for operational assessments, the POD value to be applied to obtain S/N values is the nominal POPCD POD at the appropriate GL 95-05 repair limit. The use of POPCD distributions at 1.0 and 2.0 volt repair limits would likely lead to POD values within about ± 0.05 of 0.9. The use of a POD on the order of 0.9 to define a S/N value at the ARC repair limit assures that the detection for ODSCC at noisy intersections is consistent with or conservative relative to the POD used in ARC operational assessments. From Figure 6, the associated S/N value for a POD of 0.9 is 1.9. To obtain a noise threshold for potential RPC inspections, detection at a POD of 0.9 (or that from POPCD at the repair limit when POPCD is licensed) is applied to obtain the S/N value and the signal, S, is applied at the ARC repair limit. The noise threshold value for the mix at the center of the TSP is then 0.53 volt for a repair limit of 1.0 volt and 1.05 volt for a repair limit of 2.0 volt. As noted, these values are to be updated when the EPRI ETSS POD versus S/N correlations from multiple analyst testing are available.

Noise evaluations should be performed for a minimum of 100 hot leg TSP intersections per SG to . identify noisy TSP intersections. Since the TSP noise levels do not change significantly from cycle to cycle, the noise analyses may be performed on the bobbin data from the last inspection or the current inspection. RPC inspection shall be performed for a minimum of 25 intersections (total summed over all SGs) exceeding the noise threshold values. The noise measurements shall be made at the TSP intersections where most of the ODSCC indications are found, which are typically the lower three hot leg TSPs. If this sample does not identify at least 25 intersections with noise levels exceeding the noise threshold values, the noise evaluation sample size shall be increased to include an additional 100 TSP intersections per SG to obtain a total noise sample population of 200 TSP intersections per SG to identify intersections for RPC inspection. The RPC inspection shall then be performed at the 25 TSP intersections with the highest noise levels in the noise analysis population evaluated.

If axial ODSCC indications are found in the sample RPC inspection, the following guidelines are to be applied to determine whether an expansion of the inspection is required:

- If the inferred bobbin voltage of any indication found in the RPC inspection of noisy TSP intersections (sample with noise exceeding threshold values) is found to exceed the GL 95-05 repair limits of 1.0 and 2.0 volts for 3/4" and 7/8" tubing respectively, the noisy TSP intersection RPC inspection shall be expanded to include an additional 100 TSP intersections with the next highest noise levels in the noise sample population. If this inspection expansion identifies a flaw with a bobbin voltage exceeding the GL 95-05 repair limit, the inspection should be expanded in 100 sample increments until one of the samples is found with no indications exceeding the GL repair limit.

- The fraction of TSP intersections inspected that are found to have axial ODSCC indications defines an average undetected fraction, or 1-POD, for the base inspection since the RPC inspection is a supplemental sample inspection applied to assess the adequacy of the base inspection. If the operational assessment applies the GL 95-05 POD of 0.6, the associated undetected fraction is 0.4.

If POPCD is applied for the operational assessment, the average bobbin voltage for the ODSCC indications should be used to determine an average or expected POD for the indications by application of the latest licensed nominal industry or plant specific POPCD distribution (Figure 7 provides the industry POPCD distribution although an updated industry POPCD is under preparation). The expected POD is defined as the POPCD value at the average bobbin voltage for the ODSCC indications found by RPC inspection. If the sample fraction of intersections with detected flaws in the RPC inspection (undetected in base inspection) is greater than the expected 1-POD (0.4 if POPCD is not licensed) by more than a 0.1 difference, the inspection should be expanded in 50 sample increments (applying next highest noise levels in the noise sample population) until one of the samples is found with an average POD equal to or greater than the expected POD. This requirement is applied to provide reasonable confidence that the detection capability in noisy tubes is comparable to that used in the operational assessments for the overall population of indications.

The required expansion sample size of 50 samples for the POD comparison is smaller than the 100 samples required if an indication is found to exceed the repair limits. This difference is applied to reflect the significance on the operational assessment between the two conditions. Undetected indications left in service below the GL 95-05 repair limits are expected to have a negligible impact on leakage or burst as described above.

Examples of peak-to-peak amplitude noise distributions are shown in Figure 8 for a plant with 3/4" tubing and for a preliminary version (dataset currently being finalized) of the noise distribution for indications planned for performance testing to development ETSSs under the EPRI Tools for Tube Integrity Program. The preliminary ETSS and plant noise distributions are very similar. For a plant with 3/4" inch tubing and a 0.53 volt noise threshold for potential RPC inspection, about 40% of the intersections exceed this level. The sample inspection would start at the highest noise levels in the distribution. Due to the low 1.0 volt repair criterion, the noise threshold for RPC inspection is very conservative. The noise distributions for plants with 7/8" tubing are expected to be similar to those in Figure 8. For the associated 1.05 volt noise threshold with 7/8" tubing, less than 5% of the TSP intersections would be expected to exceed this threshold. The sample size applied to develop the noise distribution for 7/8" tubing may have to be expanded to 200 TSP intersections per SG in order to identify the 25 intersections with the highest noise levels for RPC inspection. It can be noted that the POD versus S/N curves, such as Figure 6, are used to assess differences in noise levels and a plant specific noise distribution does not have to be bounded by the noise distribution used in developing the POD correlation.

5.0 Conclusions

The use of mix residuals to characterize noise at TSP intersections was initiated in the early 1990s and is shown in this report to be a poor measure of the influence of noise on detection. The noise at TSP intersections for bobbin probes varies significantly between the center and edges of the TSP whereas the mix residual is a single measure of noise across the entire TSP. Since nearly all ODSCC indications at TSP intersections extend through the center of the TSP, the noise levels at the TSP center provide the best measure of noise for the influence on detection and amplitude sizing. The few indications found only at the edges of the TSP that could be masked by the higher noise levels are very short and would have negligible impact on burst and leakage. Therefore, it is recommended that the ARC noise methods be based on evaluations of the noise amplitude at the center of the TSP.

The EPRI Tools for Tube Integrity Program is developing ETSSs based on performance testing of multiple analysts. Noise analyses are an integral part of this program with noise analyses for tube integrity applications based on measurements of the noise amplitudes at the regions of interest. As part of this program, PODs as a function of S/N are being developed. These correlations permit identification of the noise level that supports a specified POD level at the ARC voltage based repair limits. The recommended threshold noise value for RPC sampling of noisy intersections is based on obtaining a POD of 0.9 at the ARC repair limits of 1.0 and 2.0 for 3/4" and 7/8" tubing, respectively. Plant noise analyses for a minimum of 100 TSP intersections per SG are recommended to characterize the plant specific noise levels. If this sample does not identify at least 25 intersections with noise levels exceeding the noise threshold values, the noise evaluation sample size shall be increased to include an additional 100 TSP intersections per SG to obtain a total noise sample population of 200 intersections per SG to identify intersections for RPC inspection. The 25 TSP intersections with the largest noise levels are recommended for RPC inspection. If an axial ODSCC indication exceeding the ARC repair limit of GL 95-05 is found in the noise sample inspection, the inspection would be expanded by steps of 100 TSP intersections until no ODSCC indication exceeding the repair limits is found in the 100 intersection sample. The inspection would also be expanded in steps of 50 TSP intersections if the fraction of indications found in the RPC inspection, which represents the fraction undetected in the base inspection, exceeds the undetected fraction expected from the POD used for operational assessment by more than 0.1. Bobbin flaw amplitudes for the RPC indications can be obtained either by identification of the flaw in the half-prime frequency response or by correlations of bobbin to RPC voltage. It is shown by plant data that these two methods yield very similar bobbin voltages and voltages consistent with the normal primary/secondary/resolution analysis.

It is recommended that indications found by the RPC inspection be repaired if they exceed the licensed plant specific repair limit based on bobbin voltages assigned to the RPC indications. This provides a consistent ARC repair limit independent of how the indication was found in the inspection. Based on the bobbin voltages assigned to the indications, all indications found in the RPC inspection are to be included in the ARC condition monitoring and operational assessments. The bobbin voltages for the RPC indications are adequately defined to obtain tube integrity margins consistent with all bobbin indications, and there is no need to define different repair limits for the indications found by RPC. Since indications found by RPC inspection in dents > 5 volts can be adequately sized using correlations of bobbin to RPC volts, it is also recommended that repair for these indications be based on the plant specific voltage based repair limits. Since GL 95-05 requires 100% inspection of all dents > 5 volts, no additional inspection or expansion requirements are necessary for the dented TSP intersections.

6.0 References

1. Generic Letter 95-05, "Voltage-Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking," dated August 3, 1995
2. EPRI Topical Report NP 7480-L, Addendum 5, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits, Update 2002," dated January 2003.
3. EPRI Report, unpublished, "Assessment of Bobbin Coil Noise Analysis Methods for Tube Integrity Applications," July 2003

Figure 1. Flaw and Mix Residual (400/100 Mix) for Plant A-1 Pulled Tube R27C54-1H

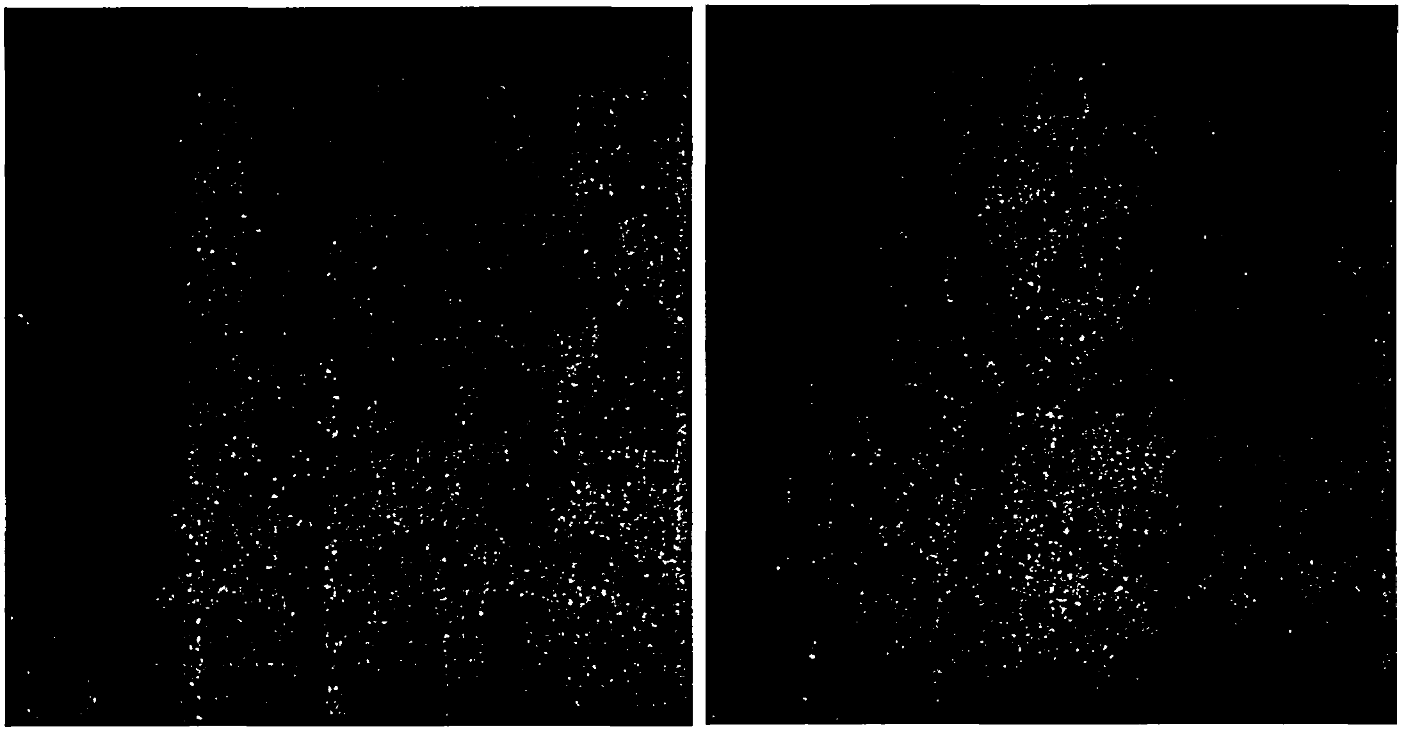


Figure 2. Upper and Lower TSP Noise Signals for Plant A-1 R27C54-1H (Center 1/3 of TSP Cannot be Evaluated Due to Flaw Signal)

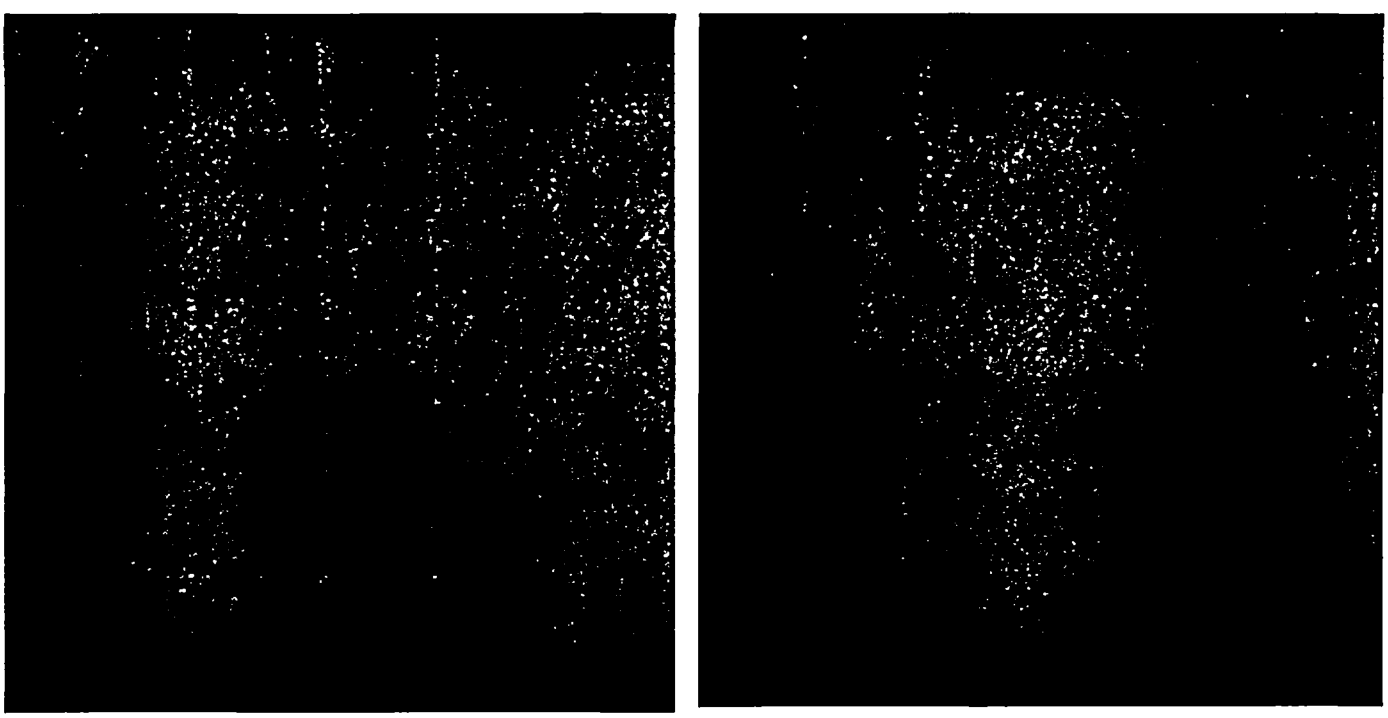


Figure 3. Mix Residual and Center, Upper and Lower 1/3 TSP Noise Signals (400/100 kHz Mix) for Plant A-1 R27C54 at 2H

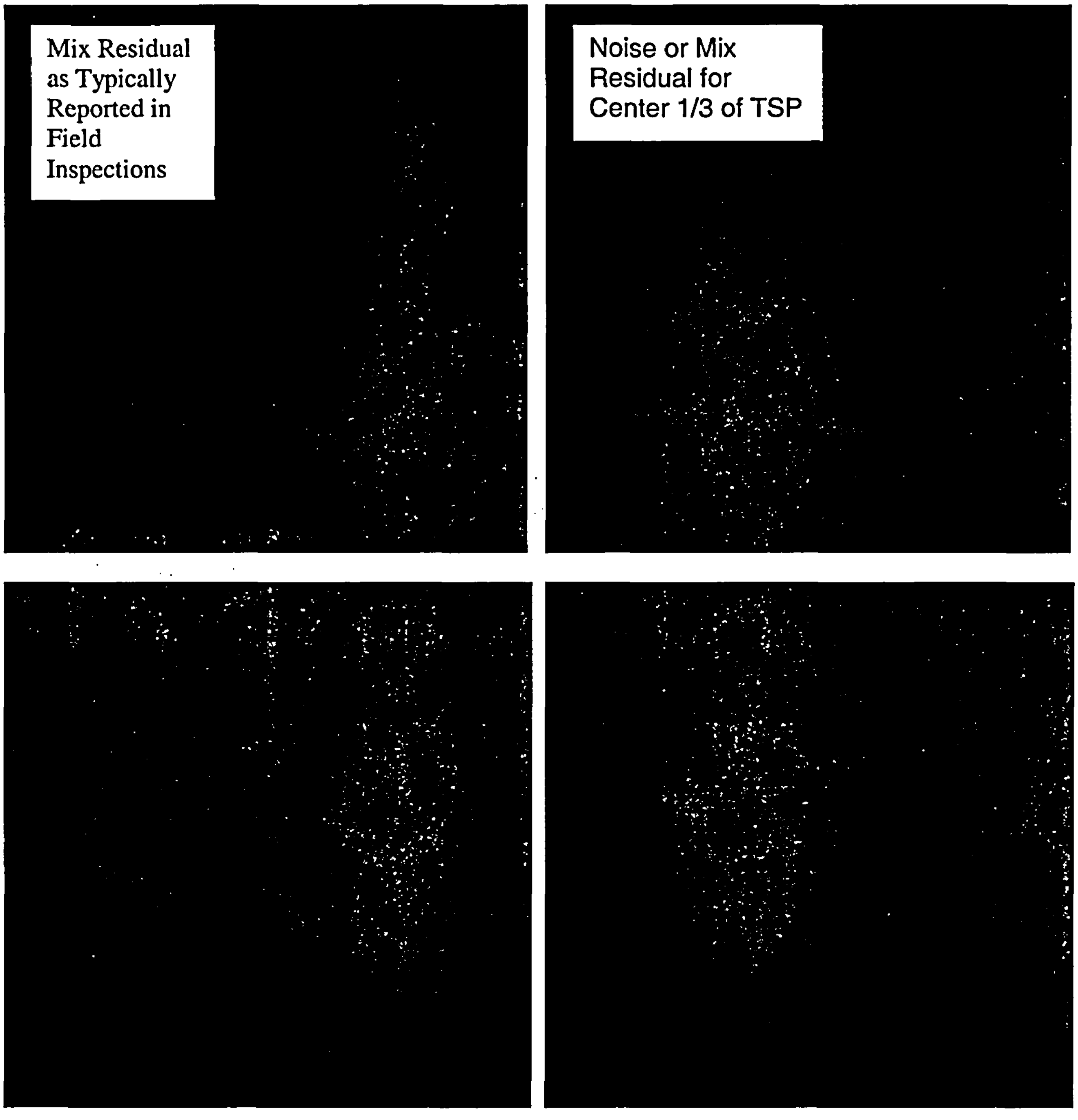


Figure 4

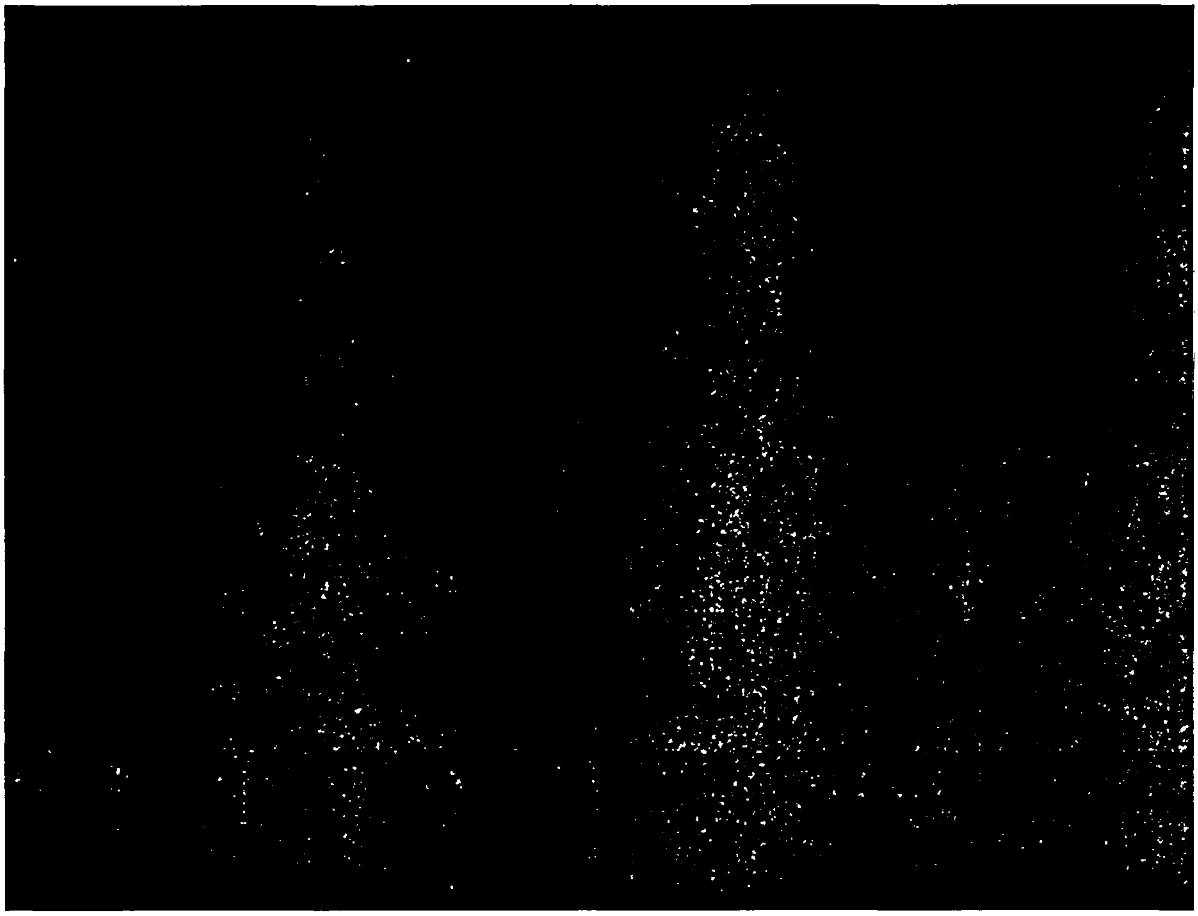


Figure 5

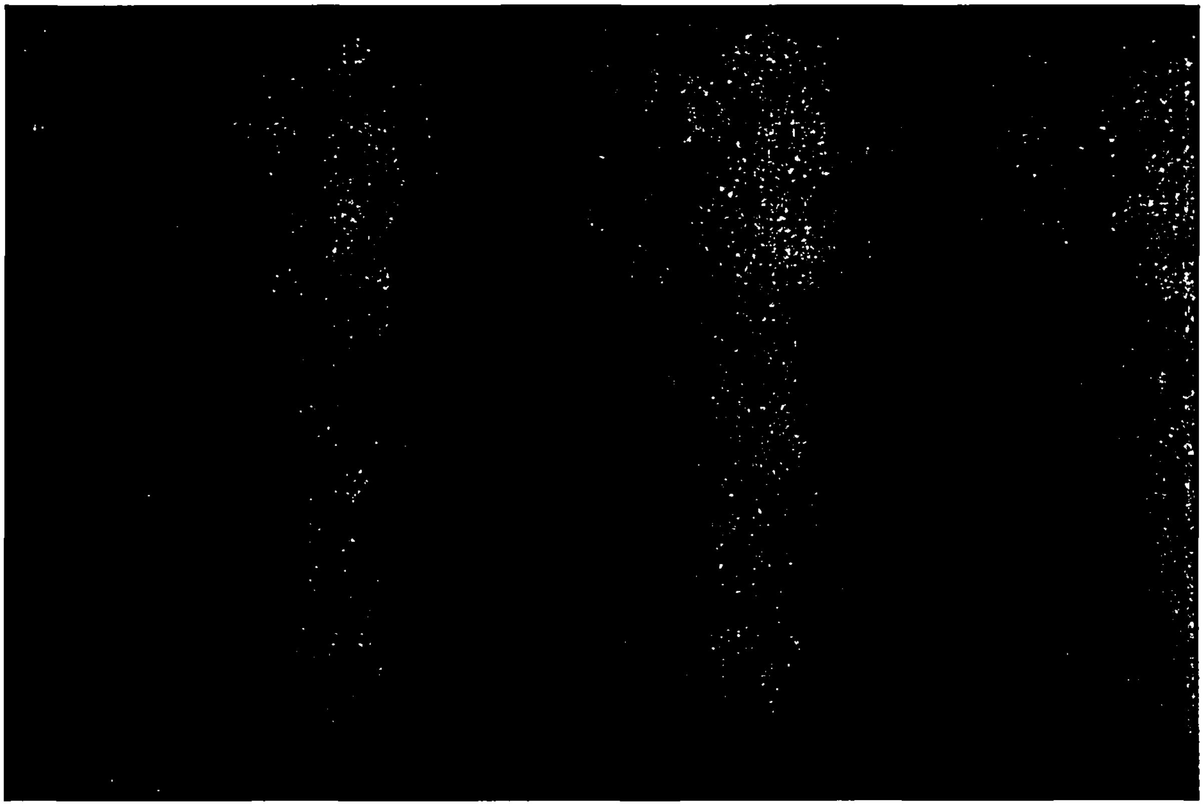


Figure 6

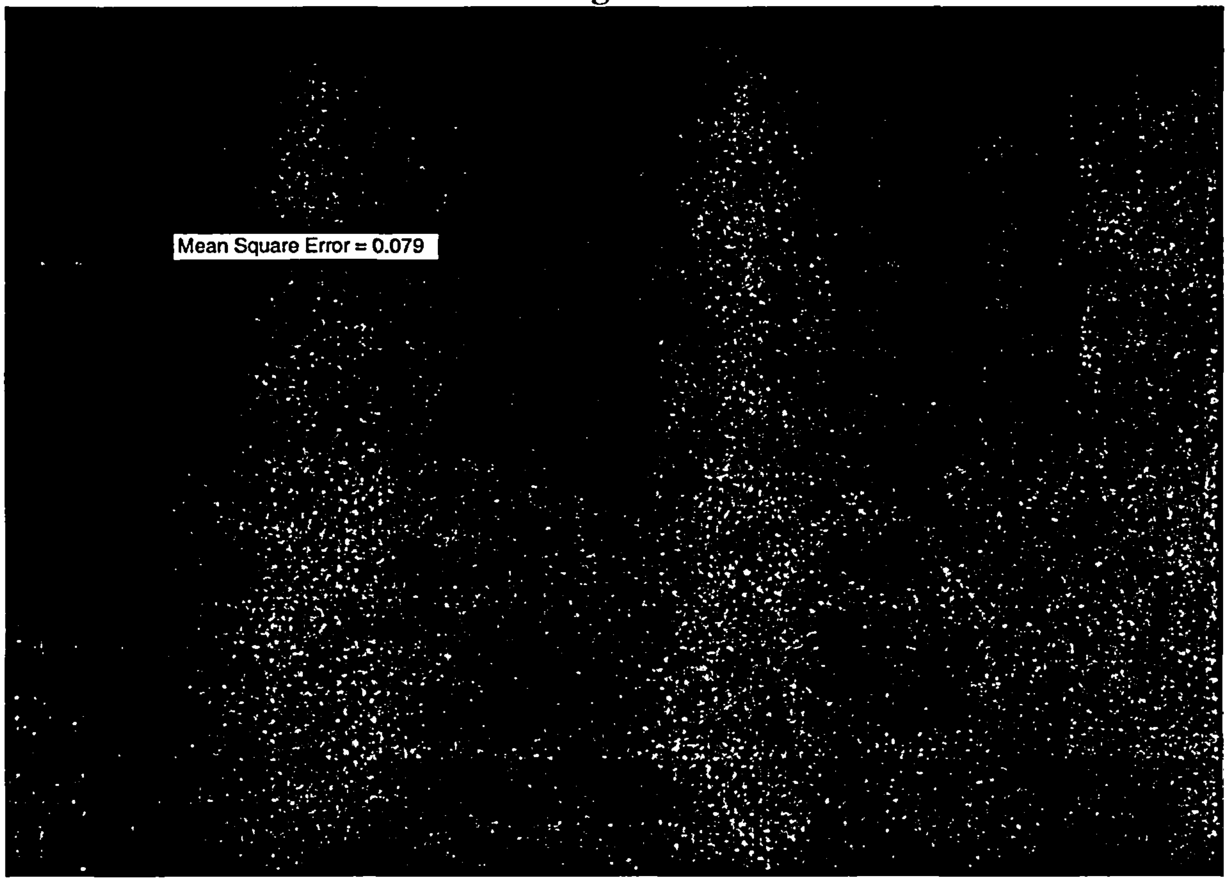


Figure 7 (update in process)

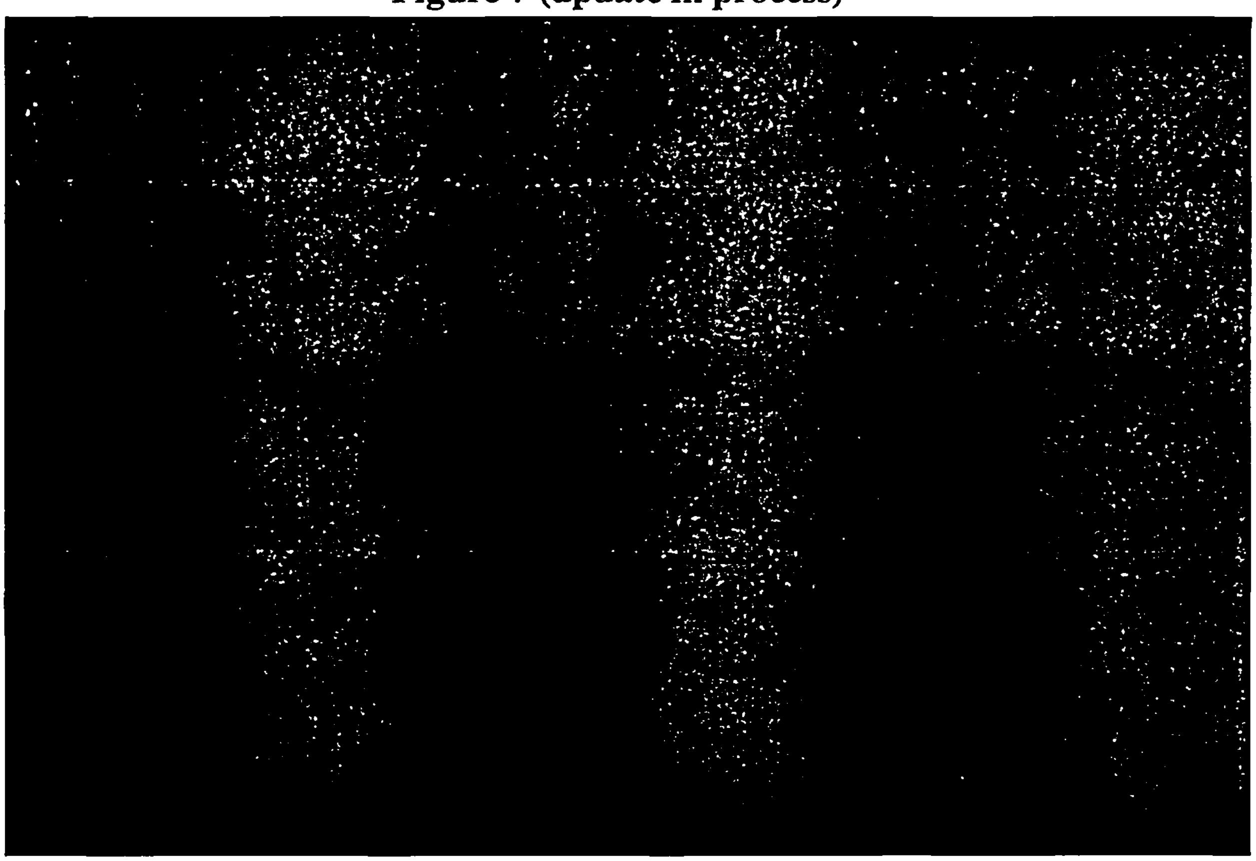
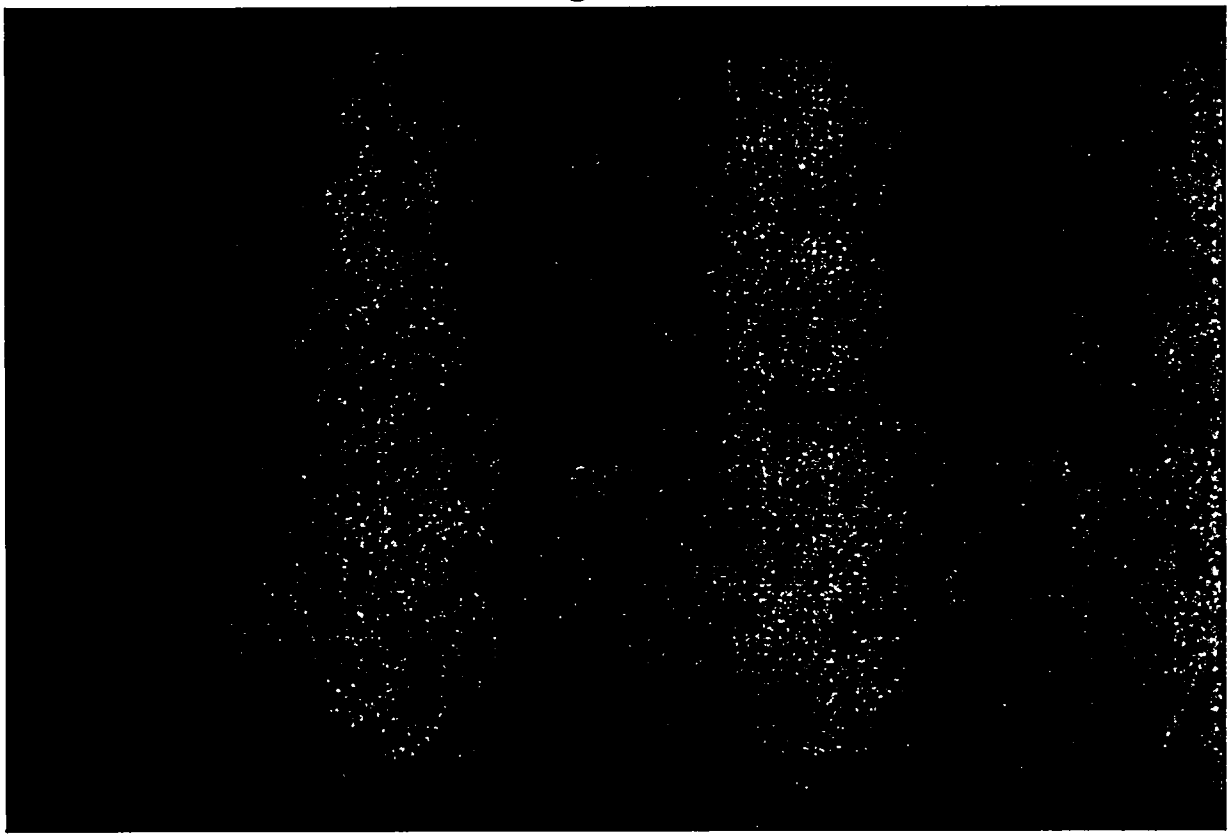


Figure 8



Noise Requirements for Voltage Based ARC

1.0 Introduction

This note provides recommendations on noise inspection, analysis and repair for application to the ARC for ODSCC at TSP intersections. These recommendations differ from the mix residuals requirements given in GL 95-05. Since these recommendations represent a change to GL 95-05, NRC approval is required prior to implementation under the ODSCC ARC.

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NRC Generic Letter 95-05 (Reference 1) requires RPC inspection of intersections with large mix residuals that could cause a 1.0 volt bobbin signal to be masked or misread. The GL states that "Any indications found at such intersections with RPC should cause the tube to be repaired." The latter GL requirement has had two interpretations. The industry interpretation in Reference 2 is that repair "at such intersections" refers to repair at intersections having mix residuals that mask a 1.0 volt indication so that repair is only required when the bobbin voltage is estimated to be ≥1.0 volt. The statement has alternately been interpreted by the NRC to imply that all indications found by RPC during mix residual inspections are to be repaired independent of the estimated bobbin voltage. As discussed in Section 2.0, all TSP intersections have mix residual signals and the influence of the mix residual signals (better defined as a measure of TSP noise) on voltage measurements is built into the ARC burst and leak rate correlations. The concept of misreading a voltage due to TSP noise should not be applied for the ARC since the effects of noise on voltage measurements are already included in the ARC database and contribute to the voltage variability in the ARC burst and leakage correlations. The repair criteria for ODSCC indications found at noisy TSP intersections are redefined in this note to more closely tie the noise intersection repair limits to the plant specific voltage based repair limits. As shown in this report, bobbin voltages can be adequately assigned to indications found by RPC inspections so that the indications can be included in condition monitoring and operational assessments, thus eliminating any need for lower repair limits based on potential influence on burst and leakage.

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With regard to the presence of mix residuals and their influence on sizing of indications, it must be emphasized that all TSP intersections have mix residuals after the first one or two cycles of operation. The mix residuals may be more easily understood as a measure of TSP noise. After about two cycles, the mix residuals generally do not change significantly with operating time. The dominant voltage for the mix residual signals is not strongly affected by the mixing used to analyze the bobbin data so the mix residual signal amplitude does not vary significantly with operating time or NDE analyst. Frequently, a significant part of the mix residual signal is present in bobbin data obtained without a TSP for pulled tubes examined in the laboratory. Some of the model boiler specimens show mix residuals although generally smaller than field data due to the shorter time at temperature. The bobbin response apparently includes an effect of the time at temperature at a TSP on the electrical and/or magnetic properties of the tube. Metallography was performed on a pulled tube to attempt to identify the cause for the signal, but was not successful in identifying any physical change to the tube or grain structure.

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The mix residual voltage is not being used, nor should it be used, in current assessments of the influence of noise on detection or sizing. For signal to noise evaluations, the noise is being evaluated as the maximum voltage response over approximately one third sections of the TSP to distinguish the relatively low noise at the center of the TSP from the larger noise near the edges of the TSP. Figure 2 shows the lower and upper TSP noise amplitudes for R27C54-1H. Noise at the middle section cannot be evaluated due to the presence of the flaw. Figure 3 shows the mix residual voltage and noise levels at the center, upper and lower one-third sections of the R27C54-2H TSP, where the mix residual is the same as at 1H. The noise level affecting detection and sizing at the center of the TSP, where most of the TSP ODSCC indications are found, is 0.70 volts peak-to-peak while the edge noise amplitudes are 1.70 and 1.52 volts. These noise levels are in the upper 20% of noise amplitudes expected at TSP intersections. The noise differences between the center and edge affect detectability of short, low voltage indications located at the edges of the TSP. The short indications at the TSP edges must grow to the center of the TSP to become structurally significant and the lower noise levels at the TSP center provide for detection of even low voltage indications. The noise levels in these figures are peak-to-peak amplitudes although the vertical amplitudes are more appropriate for assessing signal to noise for flaw detection. However, the applications of this report are related to amplitude sizing for which peak-to-peak flaw and noise amplitudes are the recommended quantities. Applying the peak-to-peak amplitudes of 1.87 volts for the flaw from Figure 1 and 0.70 volt for the noise at the TSP center from Figure 3, the

S/N for the flaw would be about 2.7 (expected POD about 0.96 from Section 3), which supports the ease of detection found for the flaw. This result is consistent with the recommended use of the flaw and noise evaluated at the TSP center.

The above noise and mix residual discussion demonstrates that it is neither feasible nor necessary to attempt to define bobbin flaw voltages that are not affected by the TSP noise or mix residuals. All indications have negligibly small to a range of noise influence on voltage sizing, and the ARC database includes many indications with larger noise levels than most currently active SGs. Whatever influence the mix residuals may have on voltage sizing for TSP indications is built into the ARC database by the pulled tubes and the concept of misreading voltages is irrelevant to the ARC.

Since nearly all TSP indications are located near the center of the TSP or span the center of the TSP, the appropriate quantity for assessing the influence of noise is the amplitude over approximately the center 1/3 of the TSP between the peaks associated with TSP edge effects. Short indications at the edges of the TSP would not have a significant influence on tube integrity. Amplitude measurements at the area of interest are being applied for tube integrity applications under the EPRI Tools for Tube Integrity Program. These measurements are being utilized to develop ETSSs and PODs based on performance testing of multiple analyst teams. The use of amplitude noise measurements are recommended for ARC noise assessments for consistency with the EPRI methodology for tube integrity applications. The following sections apply the amplitude noise measurements at the center of the TSP to develop RPC repair and inspection requirements for ARC applications.

3.0 Tube Repair Requirements for Indications Found by RPC at Noisy TSP Intersections

3.1 Bobbin Voltage Sizing for Indications Found by RPC

Axial ODSCC indications found only by RPC inspection can be sized for bobbin voltages by the methods described in Section 10.1 of Reference 2. Methods are described based on obtaining voltages from detection at the half-prime frequency and from correlations of bobbin to RPC voltages, which may be pancake or +Point coils. When detection can be adequately obtained at the half-prime frequency, this method is preferred over the bobbin/RPC voltage correlation since the method is closely related to the normal inspection process for detecting and sizing indications. However, it is shown below that both methods yield essentially the same bobbin voltages and that the inferred bobbin voltages are consistent with voltages obtained from the normal primary/secondary/resolution detection and sizing process.

The most extensive inspection of TSP intersections with significant mix residual noise signals was performed at Plant P-1 in 2003. The results of these inspections can be used to demonstrate the adequacy of the bobbin voltage sizing methods. Figure 4 compares the ratio of bobbin voltages in the 400/100 kHz mix to the 200 kHz volts for indications reported in the normal primary/secondary/ resolution analysis process to the ratios obtained from detecting the flaw (identified by the RPC) on the 200 kHz channel and using the inferred mix signal measurement with no additional adjustments. It is seen that the distributions obtained from both sizing methods are equivalent, which supports the adequacy of sizing by identifying the flaw in the half-prime frequency signal and obtaining voltages from the mix signal. Figure 5 compares the regression correlations of bobbin to +Point volts obtained using the normal inspection process with that obtained from the half-prime frequency analyses. The bobbin to RPC voltage correlations are essentially the same for both analysis methods. Since Figure 4 shows the adequacy of sizing from detection in the half-prime frequency and Figure 5 shows that correlations of bobbin to RPC volts are the same between the normal ODSCC sizing and half-prime

frequency analyses, it can be concluded that both of the methods for bobbin voltage sizing of RPC indications yield essentially the same bobbin voltages and both methods are acceptable for ARC applications.

3.2 Tube Repair Requirements for Indications Found by RPC at Noisy TSP Intersections

As noted in Section 1, the industry interpretation of GL 95-05 is that indications associated with large mix residuals and found only by RPC should be repaired if the inferred bobbin voltage is ≥1.0 volt. This repair limit is inconsistent with the differences in repair limits between 3/4" and 7/8" tubing. Since a bobbin voltage is assigned to the indications found only by RPC and the indications are included in the condition monitoring and operational assessments, there is no need to apply repair limits more conservative than the licensed repair limits.

For consistency in ARC repair limits, it is recommended that the following tube repair limits be applied for indications found only by RPC:

- Based on bobbin voltages determined by the methods of Reference 2 from indications found only by RPC inspection, indications with inferred bobbin voltages exceeding the licensed plant specific bobbin voltage repair limit are to be repaired. The GL 95-05 repair limits are > 1.0 volt for 3/4" tubing and > 2.0 volts for 7/8" tubing. Some plants may have larger repair limits such as obtained from locked TSP intersections.

- This repair limit applies for RPC indications found at noisy TSP intersections and at dented TSP intersections for dents of any voltage. For indications found at TSP intersections with both ODSCC and PWSCC indications for plants having a licensed PWSCC ARC, the above repair limit can be applied only if consistent with the licensed requirements.

- The bobbin voltages obtained by the Reference 1 methods from RPC testing of noisy TSP and dented TSP intersections are to be included in the ARC condition monitoring and operational assessments.

4.0 RPC Inspection Requirements for Noise at TSP Intersections

The selection of noisy TSP intersections for potential RPC inspection is to be based on POD versus signal/noise (S/N) correlations for axial ODSCC at TSP intersections. When available, the POD vs. S/N correlations for noise levels at the center of the TSP as obtained from ETSSs based on multiple analyst testing should be applied. Until these ETSS POD correlations are available, the POD vs. S/N correlation from SSPD testing of multiple analysts described in Reference 3, as shown in Figure 6, is to be applied. Figure 6 is based on flaw and noise peak-to-peak amplitudes to permit application of peak-to-peak voltage repair limits in defining S/N. For more general applications of S/N for detection, the vertical max voltages would be used as this quantity is more closely tied to NDE detection methods.

The GL 95-05 repair limits are the appropriate limits for detection of indications found at noisy TSP intersections based on burst and leakage considerations. The lowest voltages found for leaking indications in the ARC database (Reference 2) is 1.13 volts for 3/4" tubing and 2.81 volts for 7/8" tubing. The leak rates for these two indications were very small at 0.000088 and 0.00035 gpm, respectively. Thus, indications below the GL 95-05 repair limits would not be expected to leak and, if they do leak, would have a negligible leak rate. The probability of burst for indications at the GL 95-05

repair limits are less than about $5x10^{-6}$ for both 3/4" and 7/8" tubing, and thus undetected indications below the repair limits would have a negligible contribution to the burst probability. The GL 95-05 repair limits are to be applied to develop the inspection requirements of this section even for plants with higher licensed repair limits in order to assure that indications with potential significant leakage are included in the ARC analyses.

A S/N value for a nominal POD of 0.9 is to be obtained from the POD versus S/N correlation for axial ODSCC peak-to-peak amplitudes at the center of the TSP. For plants licensed to apply the Probability of Prior Cycle Detection (POPCD) for operational assessments, the POD value to be applied to obtain S/N values is the nominal POPCD POD at the appropriate GL 95-05 repair limit. The use of POPCD distributions at 1.0 and 2.0 volt repair limits would likely lead to POD values within about ± 0.05 of 0.9. The use of a POD on the order of 0.9 to define a S/N value at the ARC repair limit assures that the detection for ODSCC at noisy intersections is consistent with or conservative relative to the POD used in ARC operational assessments. From Figure 6, the associated S/N value for a POD of 0.9 is 1.9. To obtain a noise threshold for potential RPC inspections, detection at a POD of 0.9 (or that from POPCD at the repair limit when POPCD is licensed) is applied to obtain the S/N value and the signal, S, is applied at the ARC repair limit. The noise threshold value for the mix at the center of the TSP is then 0.53 volt for a repair limit of 1.0 volt and 1.05 volt for a repair limit of 2.0 volt. As noted, these values are to be updated when the EPRI ETSS POD versus S/N correlations from multiple analyst testing are available.

Noise evaluations should be performed for a minimum of 100 hot leg TSP intersections per SG to identify noisy TSP intersections. Since the TSP noise levels do not change significantly from cycle to cycle, the noise analyses may be performed on the bobbin data from the last inspection or the current inspection. RPC inspection shall be performed for a minimum of 25 intersections (total summed over all SGs) exceeding the noise threshold values. The noise measurements shall be made at the TSP intersections where most of the ODSCC indications are found, which are typically the lower three hot leg TSPs. If this sample does not identify at least 25 intersections with noise levels exceeding the noise threshold values, the noise evaluation sample size shall be increased to include an additional 100 TSP intersections per SG to obtain a total noise sample population of 200 TSP intersections per SG to identify intersections for RPC inspection. The RPC inspection shall then be performed at the 25 TSP intersections with the highest noise levels in the noise analysis population evaluated.

If axial ODSCC indications are found in the sample RPC inspection, the following guidelines are to be applied to determine whether an expansion of the inspection is required:

- If the inferred bobbin voltage of any indication found in the RPC inspection of noisy TSP intersections (sample with noise exceeding threshold values) is found to exceed the GL 95-05 repair limits of 1.0 and 2.0 volts for 3/4" and 7/8" tubing respectively, the noisy TSP intersection RPC inspection shall be expanded to include an additional 100 TSP intersections with the next highest noise levels in the noise sample population. If this inspection expansion identifies a flaw with a bobbin voltage exceeding the GL 95-05 repair limit, the inspection should be expanded in 100 sample increments until one of the samples is found with no indications exceeding the GL repair limit.

- The fraction of TSP intersections inspected that are found to have axial ODSCC indications defines an average undetected fraction, or 1-POD, for the base inspection since the RPC inspection is a supplemental sample inspection applied to assess the adequacy of the base inspection. If the operational assessment applies the GL 95-05 POD of 0.6, the associated undetected fraction is 0.4.

If POPCD is applied for the operational assessment, the average bobbin voltage for the ODSCC indications should be used to determine an average or expected POD for the indications by application of the latest licensed nominal industry or plant specific POPCD distribution (Figure 7 provides the industry POPCD distribution although an updated industry POPCD is under preparation). The expected POD is defined as the POPCD value at the average bobbin voltage for the ODSCC indications found by RPC inspection. If the sample fraction of intersections with detected flaws in the RPC inspection (undetected in base inspection) is greater than the expected 1-POD (0.4 if POPCD is not licensed) by more than a 0.1 difference, the inspection should be expanded in 50 sample increments (applying next highest noise levels in the noise sample population) until one of the samples is found with an average POD equal to or greater than the expected POD. This requirement is applied to provide reasonable confidence that the detection capability in noisy tubes is comparable to that used in the operational assessments for the overall population of indications.

The required expansion sample size of 50 samples for the POD comparison is smaller than the 100 samples required if an indication is found to exceed the repair limits. This difference is applied to reflect the significance on the operational assessment between the two conditions. Undetected indications left in service below the GL 95-05 repair limits are expected to have a negligible impact on leakage or burst as described above.

Examples of peak-to-peak amplitude noise distributions are shown in Figure 8 for a plant with 3/4" tubing and for a preliminary version (dataset currently being finalized) of the noise distribution for indications planned for performance testing to development ETSSs under the EPRI Tools for Tube Integrity Program. The preliminary ETSS and plant noise distributions are very similar. For a plant with 3/4" inch tubing and a 0.53 volt noise threshold for potential RPC inspection, about 40% of the intersections exceed this level. The sample inspection would start at the highest noise levels in the distribution. Due to the low 1.0 volt repair criterion, the noise threshold for RPC inspection is very conservative. The noise distributions for plants with 7/8" tubing are expected to be similar to those in Figure 8. For the associated 1.05 volt noise threshold with 7/8" tubing, less than 5% of the TSP intersections would be expected to exceed this threshold. The sample size applied to develop the noise distribution for 7/8" tubing may have to be expanded to 200 TSP intersections per SG in order to identify the 25 intersections with the highest noise levels for RPC inspection. It can be noted that the POD versus S/N curves, such as Figure 6, are used to assess differences in noise levels and a plant specific noise distribution does not have to be bounded by the noise distribution used in developing the POD correlation.

5.0 Conclusions

The use of mix residuals to characterize noise at TSP intersections was initiated in the early 1990s and is shown in this report to be a poor measure of the influence of noise on detection. The noise at TSP intersections for bobbin probes varies significantly between the center and edges of the TSP whereas the mix residual is a single measure of noise across the entire TSP. Since nearly all ODSCC indications at TSP intersections extend through the center of the TSP, the noise levels at the TSP center provide the best measure of noise for the influence on detection and amplitude sizing. The few indications found only at the edges of the TSP that could be masked by the higher noise levels are very short and would have negligible impact on burst and leakage. Therefore, it is recommended that the ARC noise methods be based on evaluations of the noise amplitude at the center of the TSP.

The EPRI Tools for Tube Integrity Program is developing ETSSs based on performance testing of multiple analysts. Noise analyses are an integral part of this program with noise analyses for tube integrity applications based on measurements of the noise amplitudes at the regions of interest. As part of this program, PODs as a function of S/N are being developed. These correlations permit identification of the noise level that supports a specified POD level at the ARC voltage based repair limits. The recommended threshold noise value for RPC sampling of noisy intersections is based on obtaining a POD of 0.9 at the ARC repair limits of 1.0 and 2.0 for 3/4" and 7/8" tubing, respectively. Plant noise analyses for a minimum of 100 TSP intersections per SG are recommended to characterize the plant specific noise levels. If this sample does not identify at least 25 intersections with noise levels exceeding the noise threshold values, the noise evaluation sample size shall be increased to include an additional 100 TSP intersections per SG to obtain a total noise sample population of 200 intersections per SG to identify intersections for RPC inspection. The 25 TSP intersections with the largest noise levels are recommended for RPC inspection. If an axial ODSCC indication exceeding the ARC repair limit of GL 95-05 is found in the noise sample inspection, the inspection would be expanded by steps of 100 TSP intersections until no ODSCC indication exceeding the repair limits is found in the 100 intersection sample. The inspection would also be expanded in steps of 50 TSP intersections if the fraction of indications found in the RPC inspection, which represents the fraction undetected in the base inspection, exceeds the undetected fraction expected from the POD used for operational assessment by more than 0.1. Bobbin flaw amplitudes for the RPC indications can be obtained either by identification of the flaw in the half-prime frequency response or by correlations of bobbin to RPC voltage. It is shown by plant data that these two methods yield very similar bobbin voltages and voltages consistent with the normal primary/secondary/resolution analysis.

It is recommended that indications found by the RPC inspection be repaired if they exceed the licensed plant specific repair limit based on bobbin voltages assigned to the RPC indications. This provides a consistent ARC repair limit independent of how the indication was found in the inspection. Based on the bobbin voltages assigned to the indications, all indications found in the RPC inspection are to be included in the ARC condition monitoring and operational assessments. The bobbin voltages for the RPC indications are adequately defined to obtain tube integrity margins consistent with all bobbin indications, and there is no need to define different repair limits for the indications found by RPC. Since indications found by RPC inspection in dents > 5 volts can be adequately sized using correlations of bobbin to RPC volts, it is also recommended that repair for these indications be based on the plant specific voltage based repair limits. Since GL 95-05 requires 100% inspection of all dents > 5 volts, no additional inspection or expansion requirements are necessary for the dented TSP intersections.

6.0 References

1. Generic Letter 95-05, "Voltage-Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking," dated August 3, 1995
2. EPRI Topical Report NP 7480-L, Addendum 5, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits, Update 2002," dated January 2003.
3. EPRI Report, unpublished, "Assessment of Bobbin Coil Noise Analysis Methods for Tube Integrity Applications," July 2003

Figure 1. Flaw and Mix Residual (400/100 Mix) for Plant A-1 Pulled Tube R27C54-1H

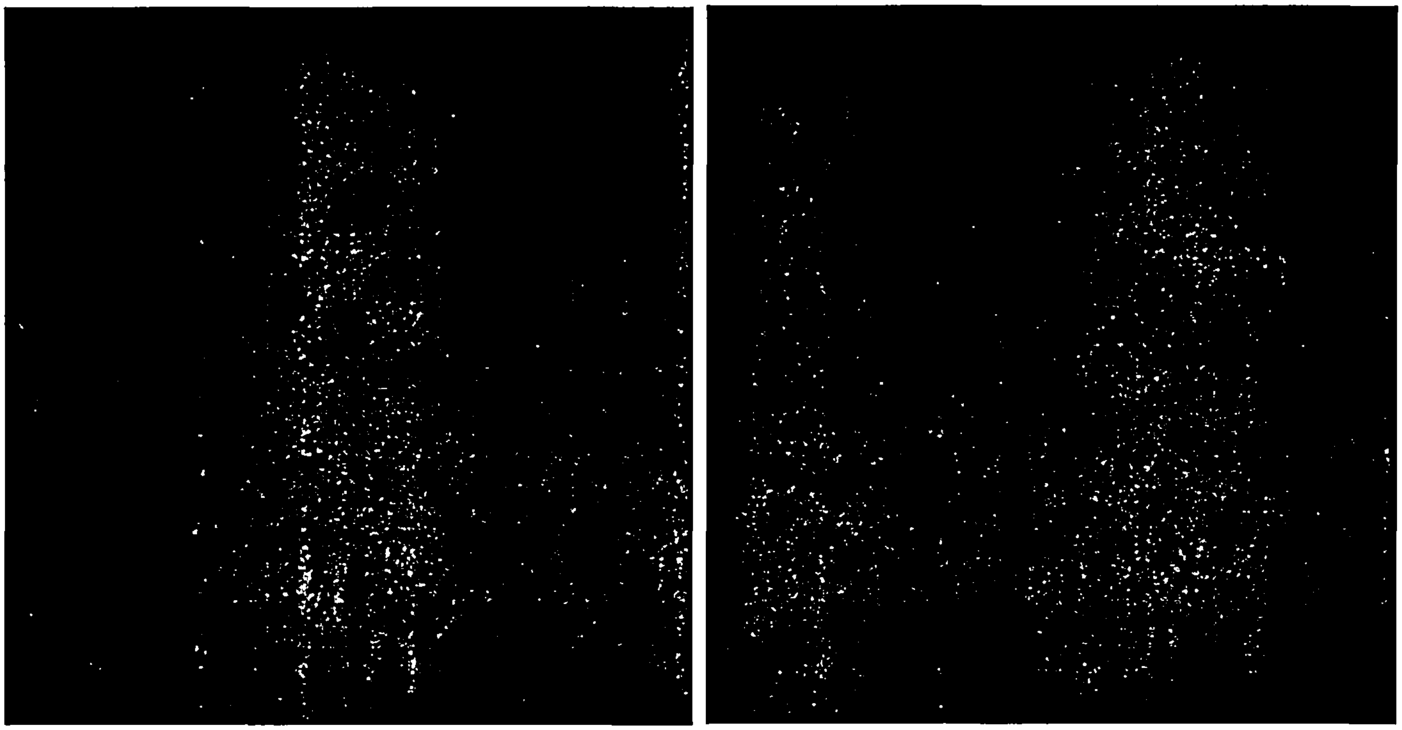


Figure 2. Upper and Lower TSP Noise Signals for Plant A-1 R27C54-1H
(Center 1/3 of TSP Cannot be Evaluated Due to Flaw Signal)

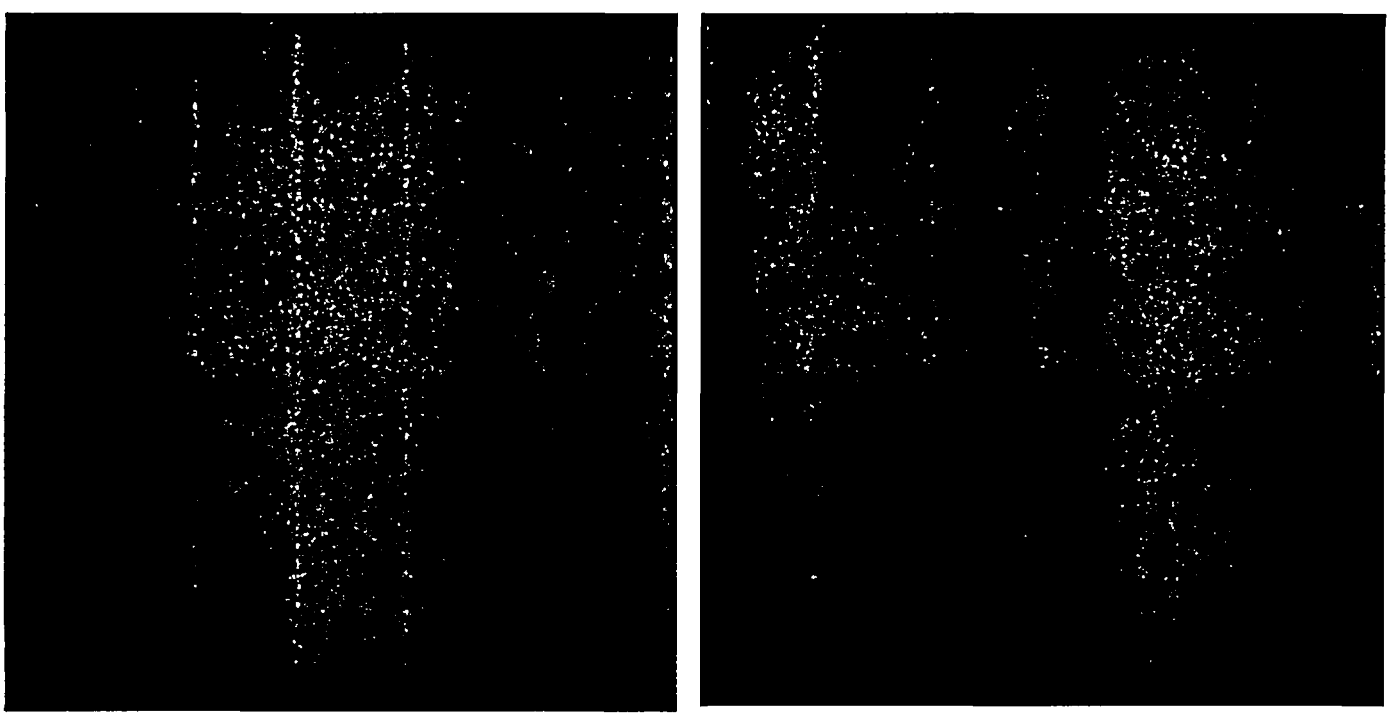


Figure 3. Mix Residual and Center, Upper and Lower 1/3 TSP Noise Signals (400/100 kHz Mix) for Plant A-1 R27C54 at 2H

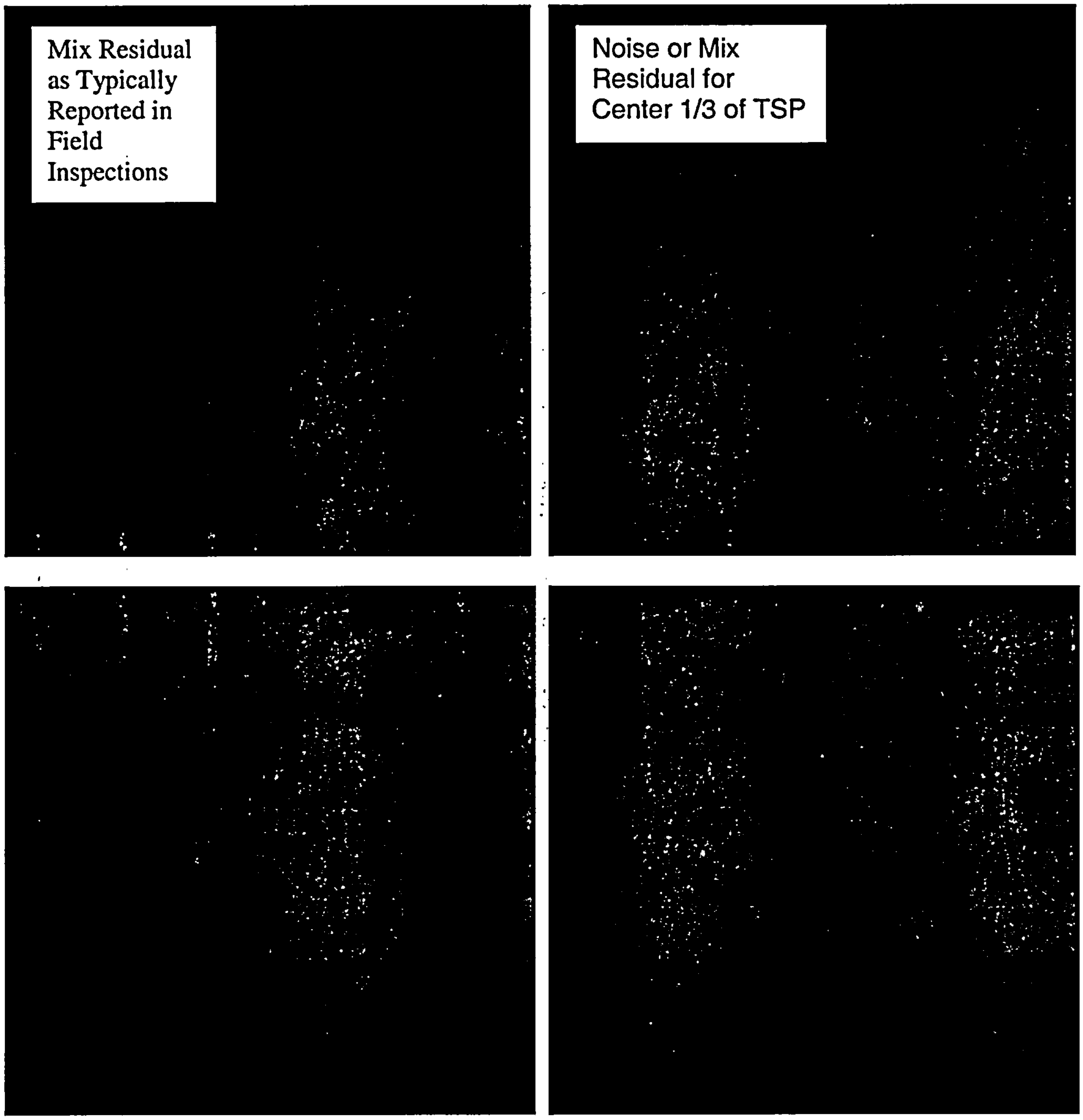


Figure 4

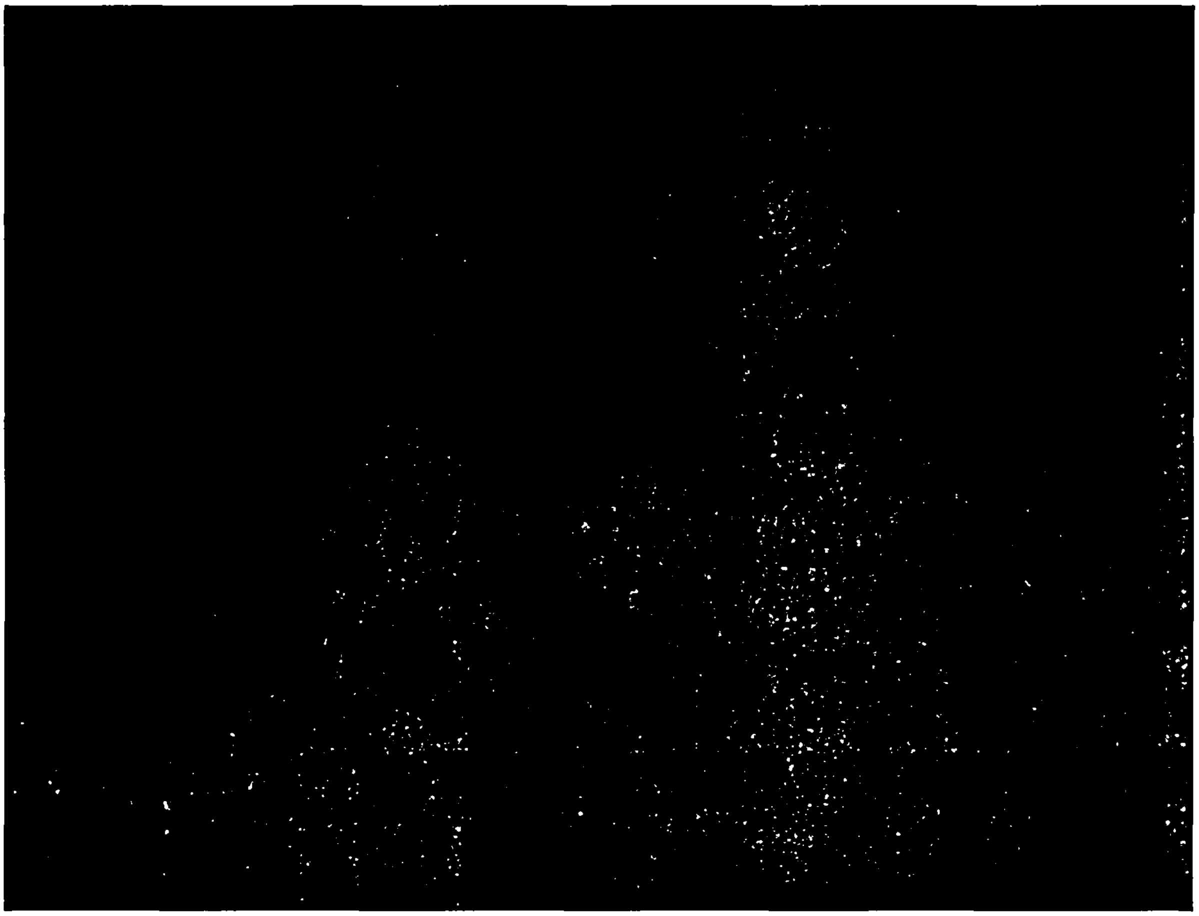


Figure 5

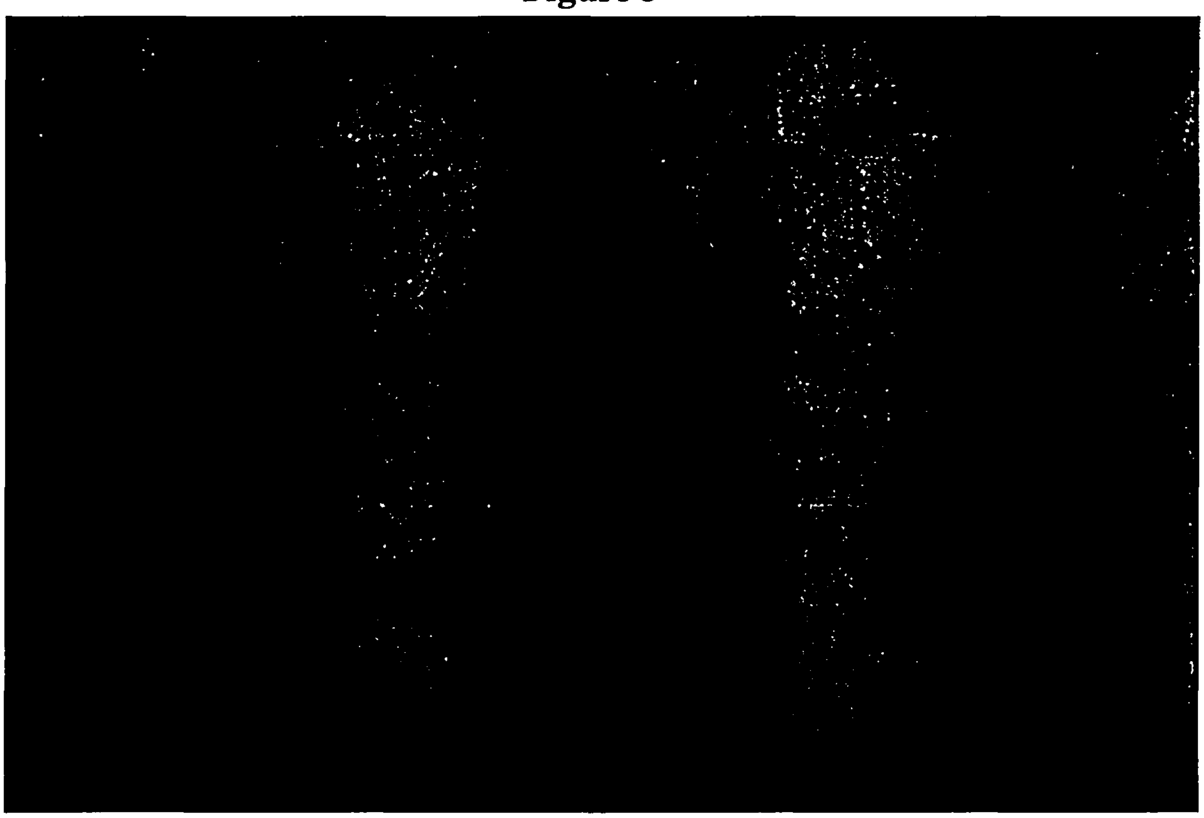


Figure 6

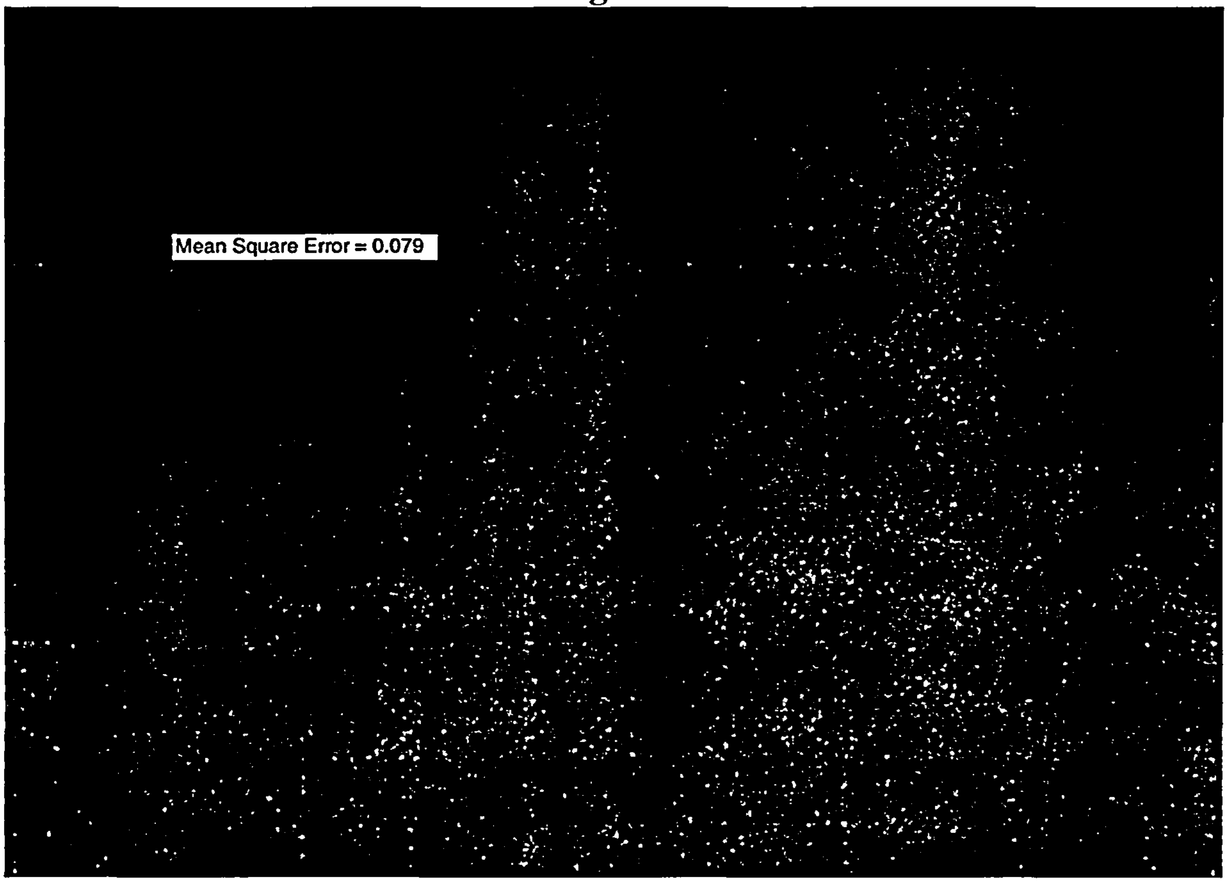


Figure 7 (update in process)

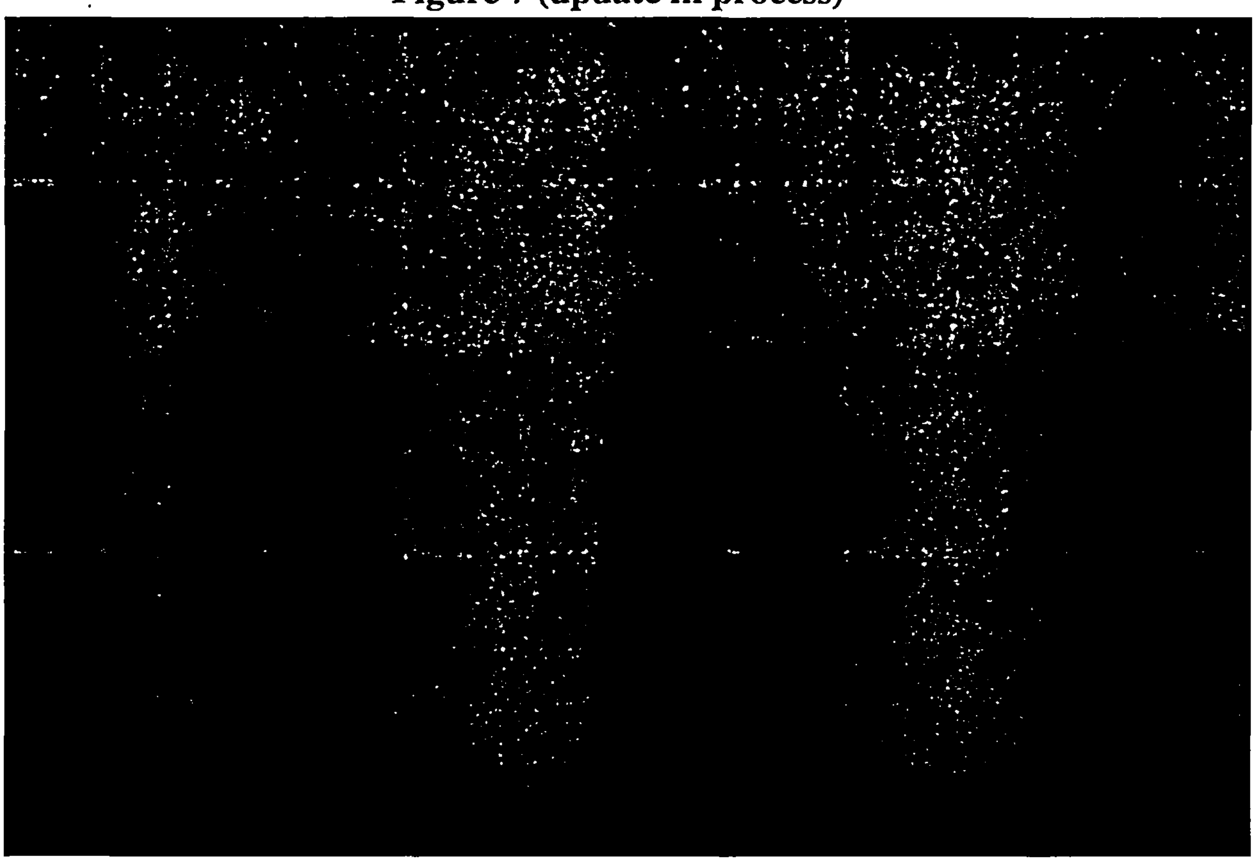
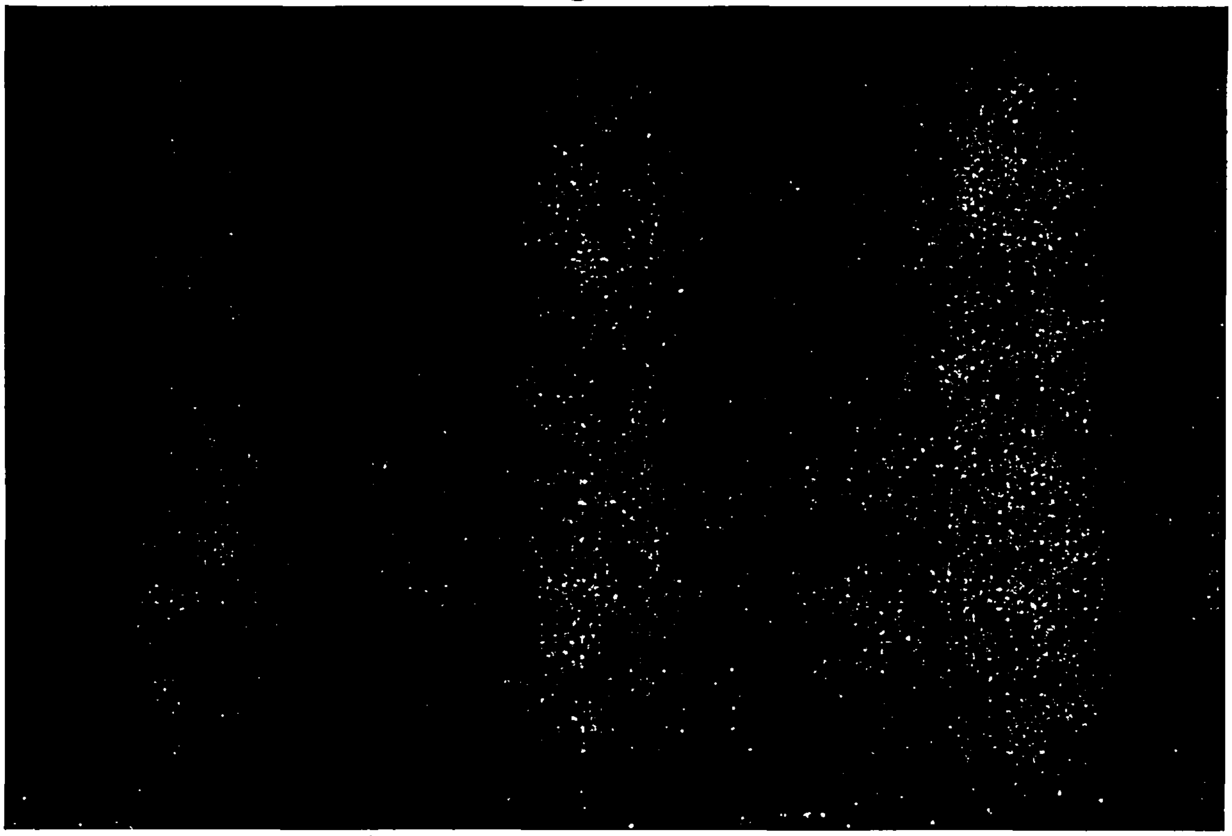


Figure 8



Noise Requirements for Voltage Based ARC

1.0 Introduction

This note provides recommendations on noise inspection, analysis and repair for application to the ARC for ODSCC at TSP intersections. These recommendations differ from the mix residuals requirements given in GL 95-05. Since these recommendations represent a change to GL 95-05, NRC approval is required prior to implementation under the ODSCC ARC.

Tube noise considerations for indications at TSP intersections for the voltage based ARC are currently based on measurements of the mix residual signal. The mix residual was applied in the early development of the ARC as a measure of noise prior to more recent efforts in the industry to assess the effects of noise on detection. The mix residual is a measure of the noise across the entire TSP length and is not an appropriate quantity for assessing the effects of noise on detection since most TSP indications develop at the TSP center where noise influence is minimal. The noise at TSP intersections develops over the first and second cycle of operation and is not significantly sensitive to the NDE setup for the frequency mix at TSP intersections or significantly variable from cycle to cycle. To update the ARC noise inspection and repair requirements to current noise assessment methodology, revised requirements for inspection and repair at noisy TSP intersections are developed in this report.

NRC Generic Letter 95-05 (Reference 1) requires RPC inspection of intersections with large mix residuals that could cause a 1.0 volt bobbin signal to be masked or misread. The GL states that "Any indications found at such intersections with RPC should cause the tube to be repaired." The latter GL requirement has had two interpretations. The industry interpretation in Reference 2 is that repair "at such intersections" refers to repair at intersections having mix residuals that mask a 1.0 volt indication so that repair is only required when the bobbin voltage is estimated to be ≥1.0 volt. The statement has alternately been interpreted by the NRC to imply that all indications found by RPC during mix residual inspections are to be repaired independent of the estimated bobbin voltage. As discussed in Section 2.0, all TSP intersections have mix residual signals and the influence of the mix residual signals (better defined as a measure of TSP noise) on voltage measurements is built into the ARC burst and leak rate correlations. The concept of misreading a voltage due to TSP noise should not be applied for the ARC since the effects of noise on voltage measurements are already included in the ARC database and contribute to the voltage variability in the ARC burst and leakage correlations. The repair criteria for ODSCC indications found at noisy TSP intersections are redefined in this note to more closely tie the noise intersection repair limits to the plant specific voltage based repair limits. As shown in this report, bobbin voltages can be adequately assigned to indications found by RPC inspections so that the indications can be included in condition monitoring and operational assessments, thus eliminating any need for lower repair limits based on potential influence on burst and leakage.

GL 95-05 also requires 100% inspection of all dents > 5 volts and repair of any indications found in dents > 5 volts. Since these indications can be adequately sized using correlations of bobbin to RPC volts such that the indications can be included in condition monitoring and operational assessments, this report also recommends that repair for these indications be tied to the plant specific voltage based repair limits.

Section 2 discusses noise considerations at TSP intersections to demonstrate the importance of applying noise measurements specific to the center of the TSP rather than the mix residual signal, which measures noise across the entire TSP resulting in an overestimate of noise at the location of the cracks near the center of the TSP. In Section 3, the adequacy of the Reference 2 methods for assigning bobbin voltages

to RPC indications is demonstrated by field data and recommendations for repair of the RPC indications are provided. Section 4 defines the recommended requirements for selecting samples for RPC inspection of noisy TSP intersections and for expanding the inspections if indications exceeding the GL 95-05 ARC repair limits are found in the sample inspection. Section 5 summarizes the conclusions of this report.

2.0 Considerations for Noise at TSP Intersections

With regard to the presence of mix residuals and their influence on sizing of indications, it must be emphasized that all TSP intersections have mix residuals after the first one or two cycles of operation. The mix residuals may be more easily understood as a measure of TSP noise. After about two cycles, the mix residuals generally do not change significantly with operating time. The dominant voltage for the mix residual signals is not strongly affected by the mixing used to analyze the bobbin data so the mix residual signal amplitude does not vary significantly with operating time or NDE analyst. Frequently, a significant part of the mix residual signal is present in bobbin data obtained without a TSP for pulled tubes examined in the laboratory. Some of the model boiler specimens show mix residuals although generally smaller than field data due to the shorter time at temperature. The bobbin response apparently includes an effect of the time at temperature at a TSP on the electrical and/or magnetic properties of the tube. Metallography was performed on a pulled tube to attempt to identify the cause for the signal, but was not successful in identifying any physical change to the tube or grain structure.

Many of the pulled tubes in the ARC database (and the prior cycle probability of detection or POPCD database) have mix residual signals larger than typically found in currently operating SGs. Figure 1 shows the 1.87 flaw voltage and the 3.23 mix residual voltage for pulled tube R27C54 from plant A-1 in the ARC database. This is only one example of the pulled tube data. The flaw signal is easily detectable which would imply easy detection at signal to noise (S/N) of about 0.58 for the associated flaw and mix residual peak-to-peak voltages. As shown in Section 3, a S/N of 0.58 would be expected to have a probability of detection of about 0.25. This indicates that the use of the mix residual as a measure of noise is not appropriate for assessing detection.

The mix residual voltage is not being used, nor should it be used, in current assessments of the influence of noise on detection or sizing. For signal to noise evaluations, the noise is being evaluated as the maximum voltage response over approximately one third sections of the TSP to distinguish the relatively low noise at the center of the TSP from the larger noise near the edges of the TSP. Figure 2 shows the lower and upper TSP noise amplitudes for R27C54-1H. Noise at the middle section cannot be evaluated due to the presence of the flaw. Figure 3 shows the mix residual voltage and noise levels at the center, upper and lower one-third sections of the R27C54-2H TSP, where the mix residual is the same as at 1H. The noise level affecting detection and sizing at the center of the TSP, where most of the TSP ODSCC indications are found, is 0.70 volts peak-to-peak while the edge noise amplitudes are 1.70 and 1.52 volts. These noise levels are in the upper 20% of noise amplitudes expected at TSP intersections. The noise differences between the center and edge affect detectability of short, low voltage indications located at the edges of the TSP. The short indications at the TSP edges must grow to the center of the TSP to become structurally significant and the lower noise levels at the TSP center provide for detection of even low voltage indications. The noise levels in these figures are peak-to-peak amplitudes although the vertical amplitudes are more appropriate for assessing signal to noise for flaw detection. However, the applications of this report are related to amplitude sizing for which peak-to-peak flaw and noise amplitudes are the recommended quantities. Applying the peak-to-peak amplitudes of 1.87 volts for the flaw from Figure 1 and 0.70 volt for the noise at the TSP center from Figure 3, the

S/N for the flaw would be about 2.7 (expected POD about 0.96 from Section 3), which supports the ease of detection found for the flaw. This result is consistent with the recommended use of the flaw and noise evaluated at the TSP center.

The above noise and mix residual discussion demonstrates that it is neither feasible nor necessary to attempt to define bobbin flaw voltages that are not affected by the TSP noise or mix residuals. All indications have negligibly small to a range of noise influence on voltage sizing, and the ARC database includes many indications with larger noise levels than most currently active SGs. Whatever influence the mix residuals may have on voltage sizing for TSP indications is built into the ARC database by the pulled tubes and the concept of misreading voltages is irrelevant to the ARC.

Since nearly all TSP indications are located near the center of the TSP or span the center of the TSP, the appropriate quantity for assessing the influence of noise is the amplitude over approximately the center 1/3 of the TSP between the peaks associated with TSP edge effects. Short indications at the edges of the TSP would not have a significant influence on tube integrity. Amplitude measurements at the area of interest are being applied for tube integrity applications under the EPRI Tools for Tube Integrity Program. These measurements are being utilized to develop ETSSs and PODs based on performance testing of multiple analyst teams. The use of amplitude noise measurements are recommended for ARC noise assessments for consistency with the EPRI methodology for tube integrity applications. The following sections apply the amplitude noise measurements at the center of the TSP to develop RPC repair and inspection requirements for ARC applications.

3.0 Tube Repair Requirements for Indications Found by RPC at Noisy TSP Intersections

3.1 Bobbin Voltage Sizing for Indications Found by RPC

Axial ODSCC indications found only by RPC inspection can be sized for bobbin voltages by the methods described in Section 10.1 of Reference 2. Methods are described based on obtaining voltages from detection at the half-prime frequency and from correlations of bobbin to RPC voltages, which may be pancake or +Point coils. When detection can be adequately obtained at the half-prime frequency, this method is preferred over the bobbin/RPC voltage correlation since the method is closely related to the normal inspection process for detecting and sizing indications. However, it is shown below that both methods yield essentially the same bobbin voltages and that the inferred bobbin voltages are consistent with voltages obtained from the normal primary/secondary/resolution detection and sizing process.

The most extensive inspection of TSP intersections with significant mix residual noise signals was performed at Plant P-1 in 2003. The results of these inspections can be used to demonstrate the adequacy of the bobbin voltage sizing methods. Figure 4 compares the ratio of bobbin voltages in the 400/100 kHz mix to the 200 kHz volts for indications reported in the normal primary/secondary/ resolution analysis process to the ratios obtained from detecting the flaw (identified by the RPC) on the 200 kHz channel and using the inferred mix signal measurement with no additional adjustments. It is seen that the distributions obtained from both sizing methods are equivalent, which supports the adequacy of sizing by identifying the flaw in the half-prime frequency signal and obtaining voltages from the mix signal. Figure 5 compares the regression correlations of bobbin to +Point volts obtained using the normal inspection process with that obtained from the half-prime frequency analyses. The bobbin to RPC voltage correlations are essentially the same for both analysis methods. Since Figure 4 shows the adequacy of sizing from detection in the half-prime frequency and Figure 5 shows that correlations of bobbin to RPC volts are the same between the normal ODSCC sizing and half-prime

frequency analyses, it can be concluded that both of the methods for bobbin voltage sizing of RPC indications yield essentially the same bobbin voltages and both methods are acceptable for ARC applications.

3.2 Tube Repair Requirements for Indications Found by RPC at Noisy TSP Intersections

As noted in Section 1, the industry interpretation of GL 95-05 is that indications associated with large mix residuals and found only by RPC should be repaired if the inferred bobbin voltage is ≥1.0 volt. This repair limit is inconsistent with the differences in repair limits between 3/4" and 7/8" tubing. Since a bobbin voltage is assigned to the indications found only by RPC and the indications are included in the condition monitoring and operational assessments, there is no need to apply repair limits more conservative than the licensed repair limits.

For consistency in ARC repair limits, it is recommended that the following tube repair limits be applied for indications found only by RPC:

- Based on bobbin voltages determined by the methods of Reference 2 from indications found only by RPC inspection, indications with inferred bobbin voltages exceeding the licensed plant specific bobbin voltage repair limit are to be repaired. The GL 95-05 repair limits are > 1.0 volt for 3/4" tubing and > 2.0 volts for 7/8" tubing. Some plants may have larger repair limits such as obtained from locked TSP intersections.

- This repair limit applies for RPC indications found at noisy TSP intersections and at dented TSP intersections for dents of any voltage. For indications found at TSP intersections with both ODSCC and PWSCC indications for plants having a licensed PWSCC ARC, the above repair limit can be applied only if consistent with the licensed requirements.

- The bobbin voltages obtained by the Reference 1 methods from RPC testing of noisy TSP and dented TSP intersections are to be included in the ARC condition monitoring and operational assessments.

4.0 RPC Inspection Requirements for Noise at TSP Intersections

The selection of noisy TSP intersections for potential RPC inspection is to be based on POD versus signal/noise (S/N) correlations for axial ODSCC at TSP intersections. When available, the POD vs. S/N correlations for noise levels at the center of the TSP as obtained from ETSSs based on multiple analyst testing should be applied. Until these ETSS POD correlations are available, the POD vs. S/N correlation from SSPD testing of multiple analysts described in Reference 3, as shown in Figure 6, is to be applied. Figure 6 is based on flaw and noise peak-to-peak amplitudes to permit application of peak-to-peak voltage repair limits in defining S/N. For more general applications of S/N for detection, the vertical max voltages would be used as this quantity is more closely tied to NDE detection methods.

The GL 95-05 repair limits are the appropriate limits for detection of indications found at noisy TSP intersections based on burst and leakage considerations. The lowest voltages found for leaking indications in the ARC database (Reference 2) is 1.13 volts for 3/4" tubing and 2.81 volts for 7/8" tubing. The leak rates for these two indications were very small at 0.000088 and 0.00035 gpm, respectively. Thus, indications below the GL 95-05 repair limits would not be expected to leak and, if they do leak, would have a negligible leak rate. The probability of burst for indications at the GL 95-05

repair limits are less than about $5x10^{-6}$ for both 3/4" and 7/8" tubing, and thus undetected indications below the repair limits would have a negligible contribution to the burst probability. The GL 95-05 repair limits are to be applied to develop the inspection requirements of this section even for plants with higher licensed repair limits in order to assure that indications with potential significant leakage are included in the ARC analyses.

A S/N value for a nominal POD of 0.9 is to be obtained from the POD versus S/N correlation for axial ODSCC peak-to-peak amplitudes at the center of the TSP. For plants licensed to apply the Probability of Prior Cycle Detection (POPCD) for operational assessments, the POD value to be applied to obtain S/N values is the nominal POPCD POD at the appropriate GL 95-05 repair limit. The use of POPCD distributions at 1.0 and 2.0 volt repair limits would likely lead to POD values within about ± 0.05 of 0.9. The use of a POD on the order of 0.9 to define a S/N value at the ARC repair limit assures that the detection for ODSCC at noisy intersections is consistent with or conservative relative to the POD used in ARC operational assessments. From Figure 6, the associated S/N value for a POD of 0.9 is 1.9. To obtain a noise threshold for potential RPC inspections, detection at a POD of 0.9 (or that from POPCD at the repair limit when POPCD is licensed) is applied to obtain the S/N value and the signal, S, is applied at the ARC repair limit. The noise threshold value for the mix at the center of the TSP is then 0.53 volt for a repair limit of 1.0 volt and 1.05 volt for a repair limit of 2.0 volt. As noted, these values are to be updated when the EPRI ETSS POD versus S/N correlations from multiple analyst testing are available.

Noise evaluations should be performed for a minimum of 100 hot leg TSP intersections per SG to identify noisy TSP intersections. Since the TSP noise levels do not change significantly from cycle to cycle, the noise analyses may be performed on the bobbin data from the last inspection or the current inspection. RPC inspection shall be performed for a minimum of 25 intersections (total summed over all SGs) exceeding the noise threshold values. The noise measurements shall be made at the TSP intersections where most of the ODSCC indications are found, which are typically the lower three hot leg TSPs. If this sample does not identify at least 25 intersections with noise levels exceeding the noise threshold values, the noise evaluation sample size shall be increased to include an additional 100 TSP intersections per SG to obtain a total noise sample population of 200 TSP intersections per SG to identify intersections for RPC inspection. The RPC inspection shall then be performed at the 25 TSP intersections with the highest noise levels in the noise analysis population evaluated.

If axial ODSCC indications are found in the sample RPC inspection, the following guidelines are to be applied to determine whether an expansion of the inspection is required:

- If the inferred bobbin voltage of any indication found in the RPC inspection of noisy TSP intersections (sample with noise exceeding threshold values) is found to exceed the GL 95-05 repair limits of 1.0 and 2.0 volts for 3/4" and 7/8" tubing respectively, the noisy TSP intersection RPC inspection shall be expanded to include an additional 100 TSP intersections with the next highest noise levels in the noise sample population. If this inspection expansion identifies a flaw with a bobbin voltage exceeding the GL 95-05 repair limit, the inspection should be expanded in 100 sample increments until one of the samples is found with no indications exceeding the GL repair limit.

- The fraction of TSP intersections inspected that are found to have axial ODSCC indications defines an average undetected fraction, or 1-POD, for the base inspection since the RPC inspection is a supplemental sample inspection applied to assess the adequacy of the base inspection. If the operational assessment applies the GL 95-05 POD of 0.6, the associated undetected fraction is 0.4.

If POPCD is applied for the operational assessment, the average bobbin voltage for the ODSCC indications should be used to determine an average or expected POD for the indications by application of the latest licensed nominal industry or plant specific POPCD distribution (Figure 7 provides the industry POPCD distribution although an updated industry POPCD is under preparation). The expected POD is defined as the POPCD value at the average bobbin voltage for the ODSCC indications found by RPC inspection. If the sample fraction of intersections with detected flaws in the RPC inspection (undetected in base inspection) is greater than the expected 1-POD (0.4 if POPCD is not licensed) by more than a 0.1 difference, the inspection should be expanded in 50 sample increments (applying next highest noise levels in the noise sample population) until one of the samples is found with an average POD equal to or greater than the expected POD. This requirement is applied to provide reasonable confidence that the detection capability in noisy tubes is comparable to that used in the operational assessments for the overall population of indications.

The required expansion sample size of 50 samples for the POD comparison is smaller than the 100 samples required if an indication is found to exceed the repair limits. This difference is applied to reflect the significance on the operational assessment between the two conditions. Undetected indications left in service below the GL 95-05 repair limits are expected to have a negligible impact on leakage or burst as described above.

Examples of peak-to-peak amplitude noise distributions are shown in Figure 8 for a plant with 3/4" tubing and for a preliminary version (dataset currently being finalized) of the noise distribution for indications planned for performance testing to development ETSSs under the EPRI Tools for Tube Integrity Program. The preliminary ETSS and plant noise distributions are very similar. For a plant with 3/4" inch tubing and a 0.53 volt noise threshold for potential RPC inspection, about 40% of the intersections exceed this level. The sample inspection would start at the highest noise levels in the distribution. Due to the low 1.0 volt repair criterion, the noise threshold for RPC inspection is very conservative. The noise distributions for plants with 7/8" tubing are expected to be similar to those in Figure 8. For the associated 1.05 volt noise threshold with 7/8" tubing, less than 5% of the TSP intersections would be expected to exceed this threshold. The sample size applied to develop the noise distribution for 7/8" tubing may have to be expanded to 200 TSP intersections per SG in order to identify the 25 intersections with the highest noise levels for RPC inspection. It can be noted that the POD versus S/N curves, such as Figure 6, are used to assess differences in noise levels and a plant specific noise distribution does not have to be bounded by the noise distribution used in developing the POD correlation.

5.0 Conclusions

The use of mix residuals to characterize noise at TSP intersections was initiated in the early 1990s and is shown in this report to be a poor measure of the influence of noise on detection. The noise at TSP intersections for bobbin probes varies significantly between the center and edges of the TSP whereas the mix residual is a single measure of noise across the entire TSP. Since nearly all ODSCC indications at TSP intersections extend through the center of the TSP, the noise levels at the TSP center provide the best measure of noise for the influence on detection and amplitude sizing. The few indications found only at the edges of the TSP that could be masked by the higher noise levels are very short and would have negligible impact on burst and leakage. Therefore, it is recommended that the ARC noise methods be based on evaluations of the noise amplitude at the center of the TSP.

The EPRI Tools for Tube Integrity Program is developing ETSSs based on performance testing of multiple analysts. Noise analyses are an integral part of this program with noise analyses for tube integrity applications based on measurements of the noise amplitudes at the regions of interest. As part of this program, PODs as a function of S/N are being developed. These correlations permit identification of the noise level that supports a specified POD level at the ARC voltage based repair limits. The recommended threshold noise value for RPC sampling of noisy intersections is based on obtaining a POD of 0.9 at the ARC repair limits of 1.0 and 2.0 for 3/4" and 7/8" tubing, respectively. Plant noise analyses for a minimum of 100 TSP intersections per SG are recommended to characterize the plant specific noise levels. If this sample does not identify at least 25 intersections with noise levels exceeding the noise threshold values, the noise evaluation sample size shall be increased to include an additional 100 TSP intersections per SG to obtain a total noise sample population of 200 intersections per SG to identify intersections for RPC inspection. The 25 TSP intersections with the largest noise levels are recommended for RPC inspection. If an axial ODSCC indication exceeding the ARC repair limit of GL 95-05 is found in the noise sample inspection, the inspection would be expanded by steps of 100 TSP intersections until no ODSCC indication exceeding the repair limits is found in the 100 intersection sample. The inspection would also be expanded in steps of 50 TSP intersections if the fraction of indications found in the RPC inspection, which represents the fraction undetected in the base inspection, exceeds the undetected fraction expected from the POD used for operational assessment by more than 0.1. Bobbin flaw amplitudes for the RPC indications can be obtained either by identification of the flaw in the half-prime frequency response or by correlations of bobbin to RPC voltage. It is shown by plant data that these two methods yield very similar bobbin voltages and voltages consistent with the normal primary/secondary/resolution analysis.

It is recommended that indications found by the RPC inspection be repaired if they exceed the licensed plant specific repair limit based on bobbin voltages assigned to the RPC indications. This provides a consistent ARC repair limit independent of how the indication was found in the inspection. Based on the bobbin voltages assigned to the indications, all indications found in the RPC inspection are to be included in the ARC condition monitoring and operational assessments. The bobbin voltages for the RPC indications are adequately defined to obtain tube integrity margins consistent with all bobbin indications, and there is no need to define different repair limits for the indications found by RPC. Since indications found by RPC inspection in dents > 5 volts can be adequately sized using correlations of bobbin to RPC volts, it is also recommended that repair for these indications be based on the plant specific voltage based repair limits. Since GL 95-05 requires 100% inspection of all dents > 5 volts, no additional inspection or expansion requirements are necessary for the dented TSP intersections.

6.0 References

1. Generic Letter 95-05, "Voltage-Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking," dated August 3, 1995
2. EPRI Topical Report NP 7480-L, Addendum 5, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits, Update 2002," dated January 2003.
3. EPRI Report, unpublished, "Assessment of Bobbin Coil Noise Analysis Methods for Tube Integrity Applications," July 2003

Figure 1. Flaw and Mix Residual (400/100 Mix) for Plant A-1 Pulled Tube R27C54-1H

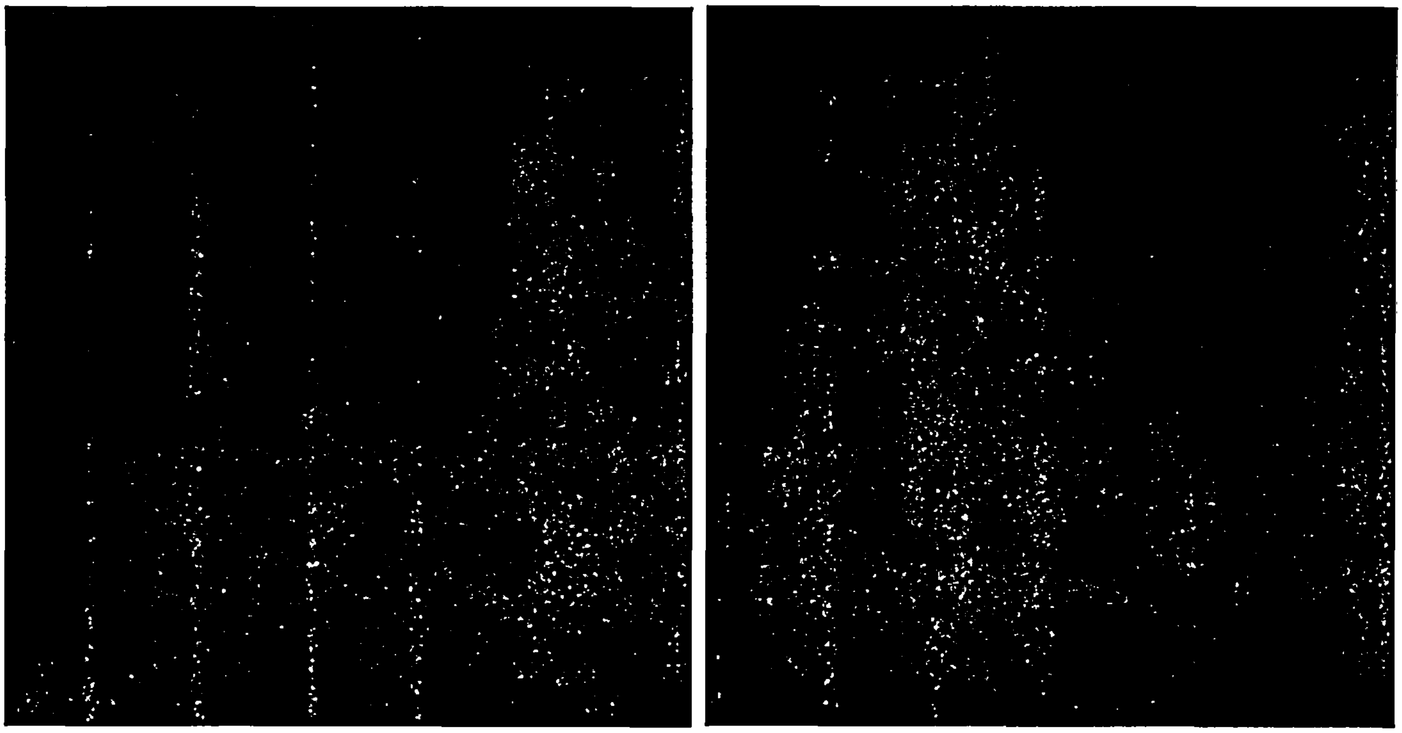


Figure 2. Upper and Lower TSP Noise Signals for Plant A-1 R27C54-1H (Center 1/3 of TSP Cannot be Evaluated Due to Flaw Signal)

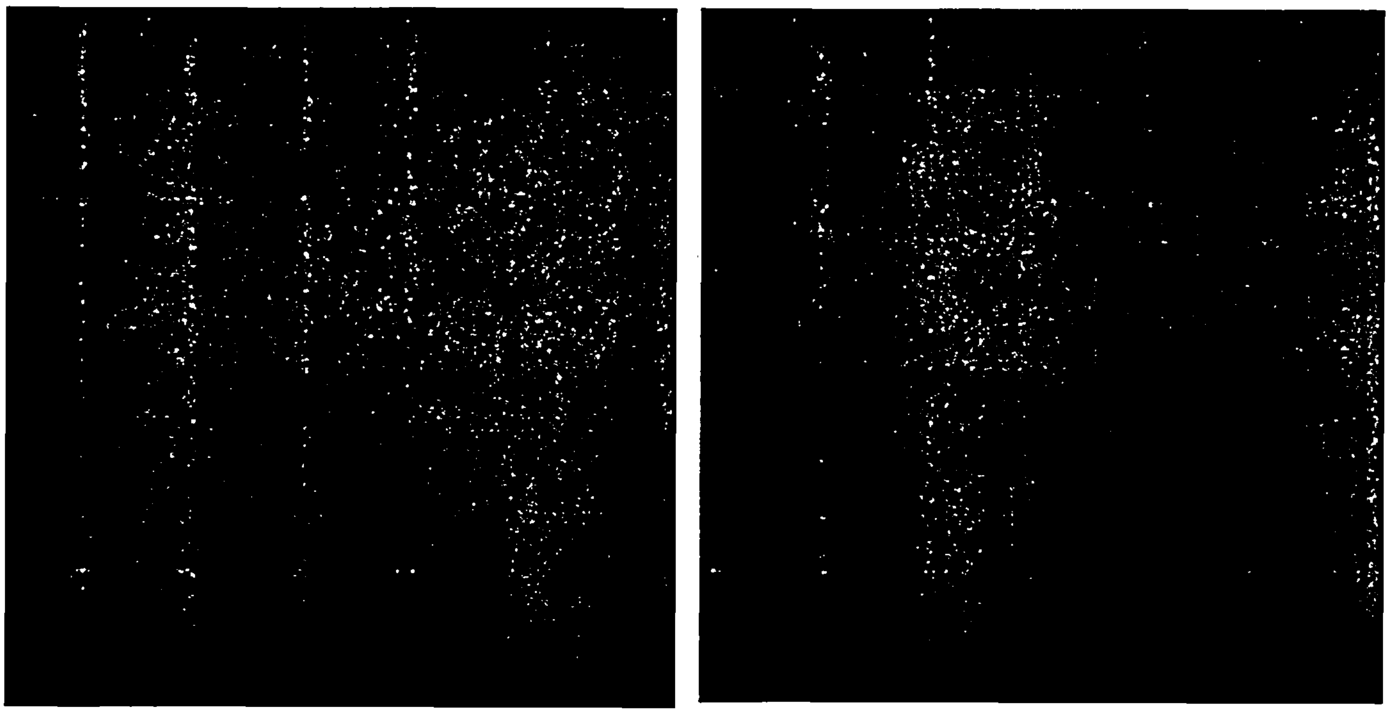


Figure 3. Mix Residual and Center, Upper and Lower 1/3 TSP Noise Signals (400/100 kHz Mix) for Plant A-1 R27C54 at 2H

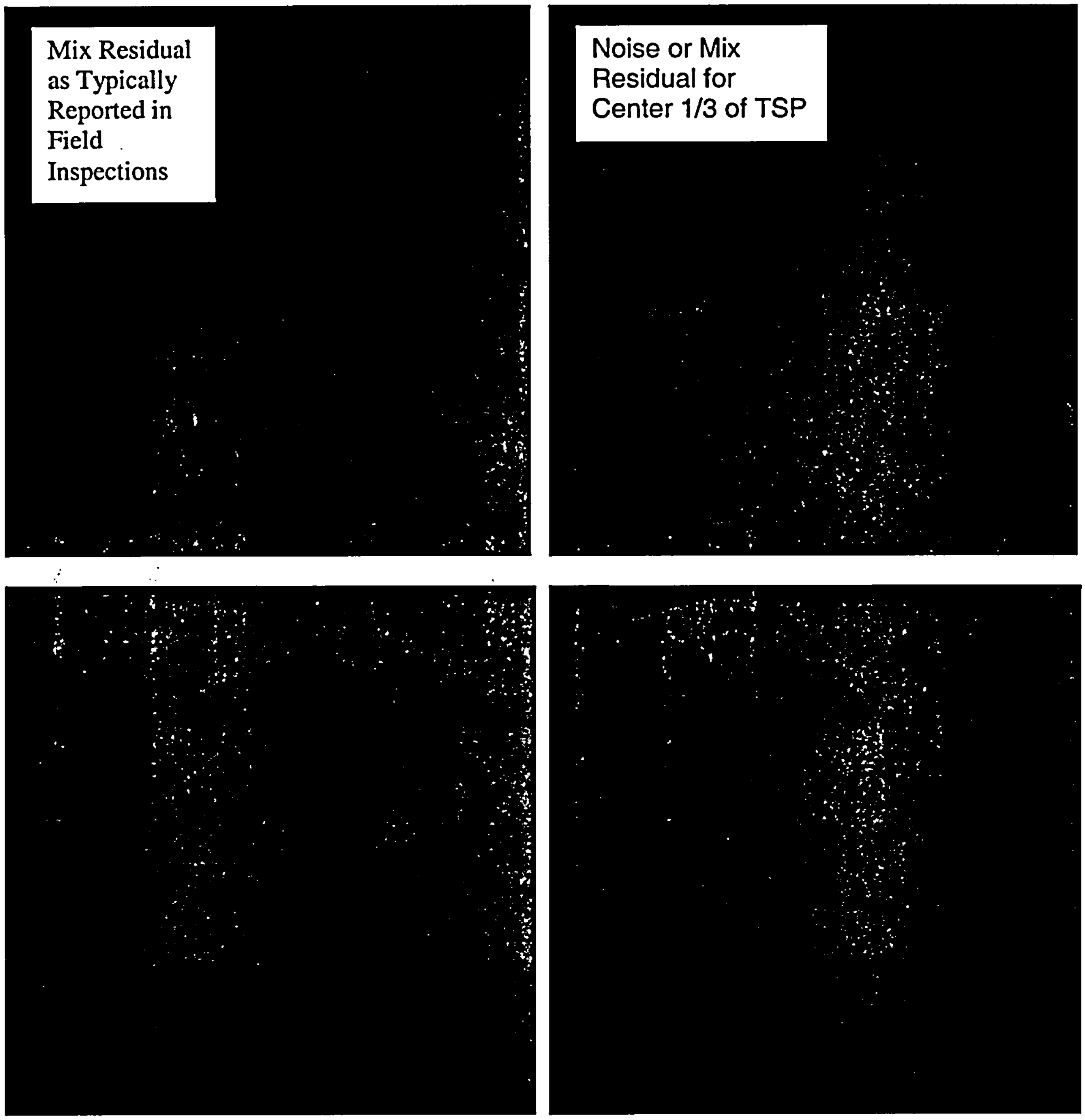


Figure 4

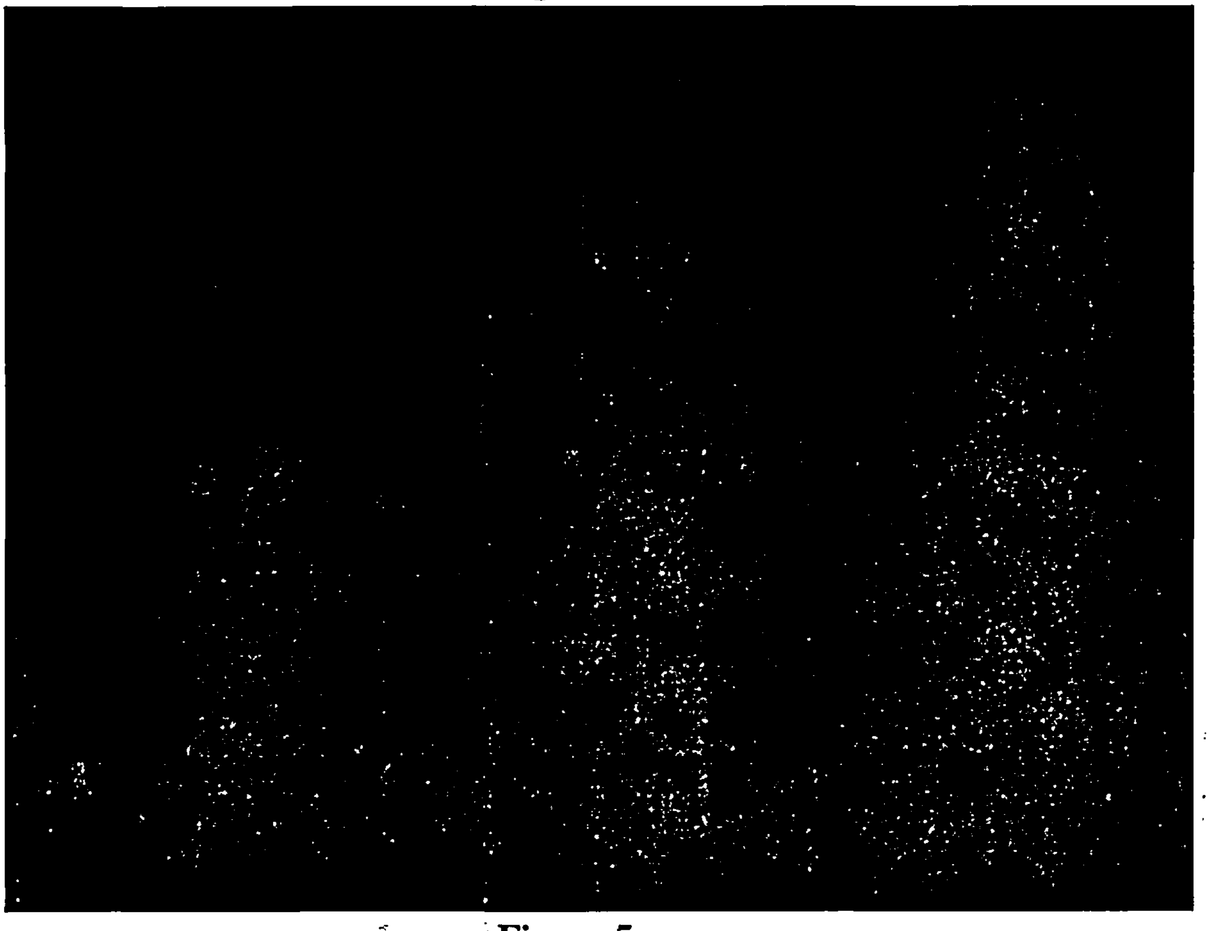


Figure 5

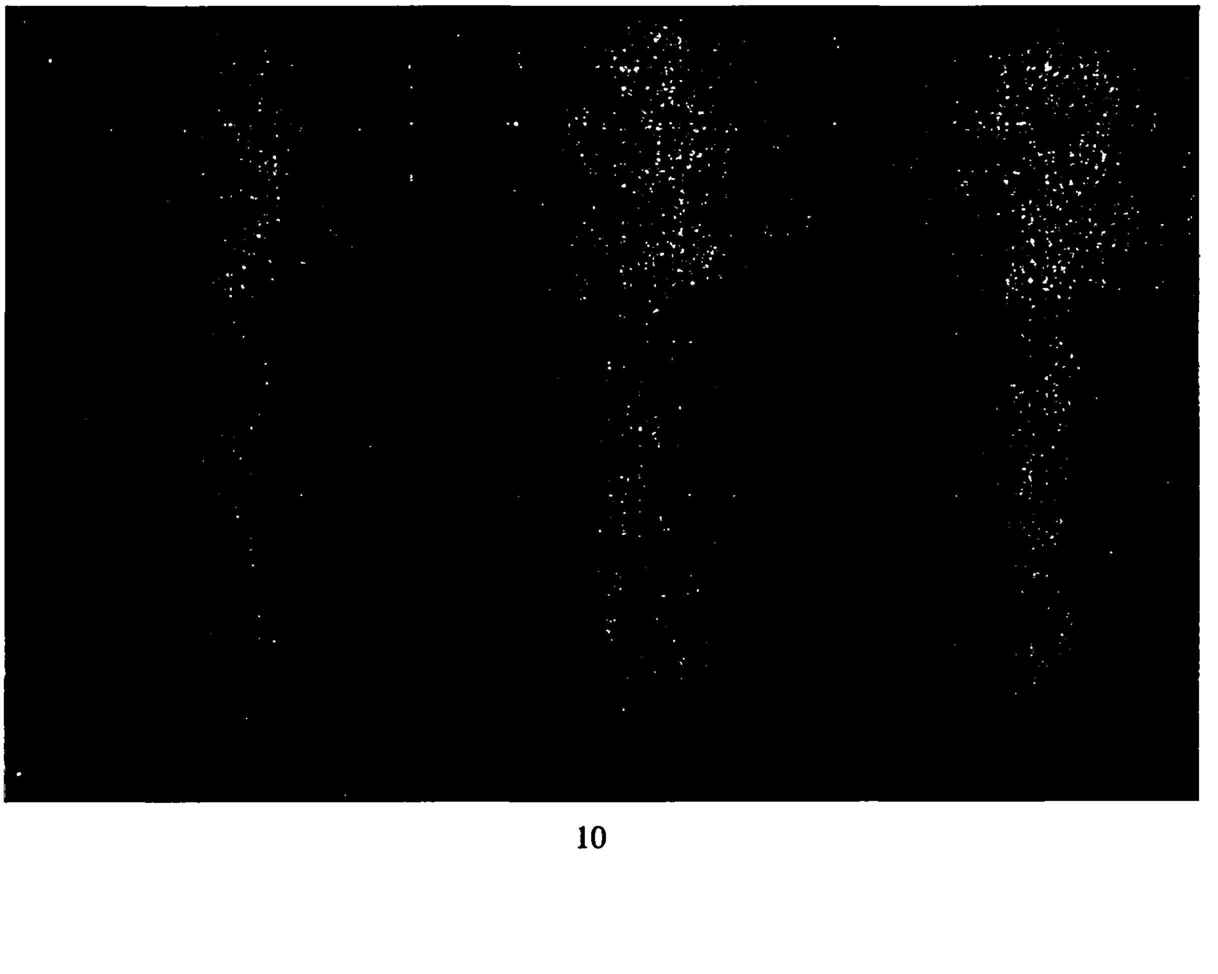


Figure 6

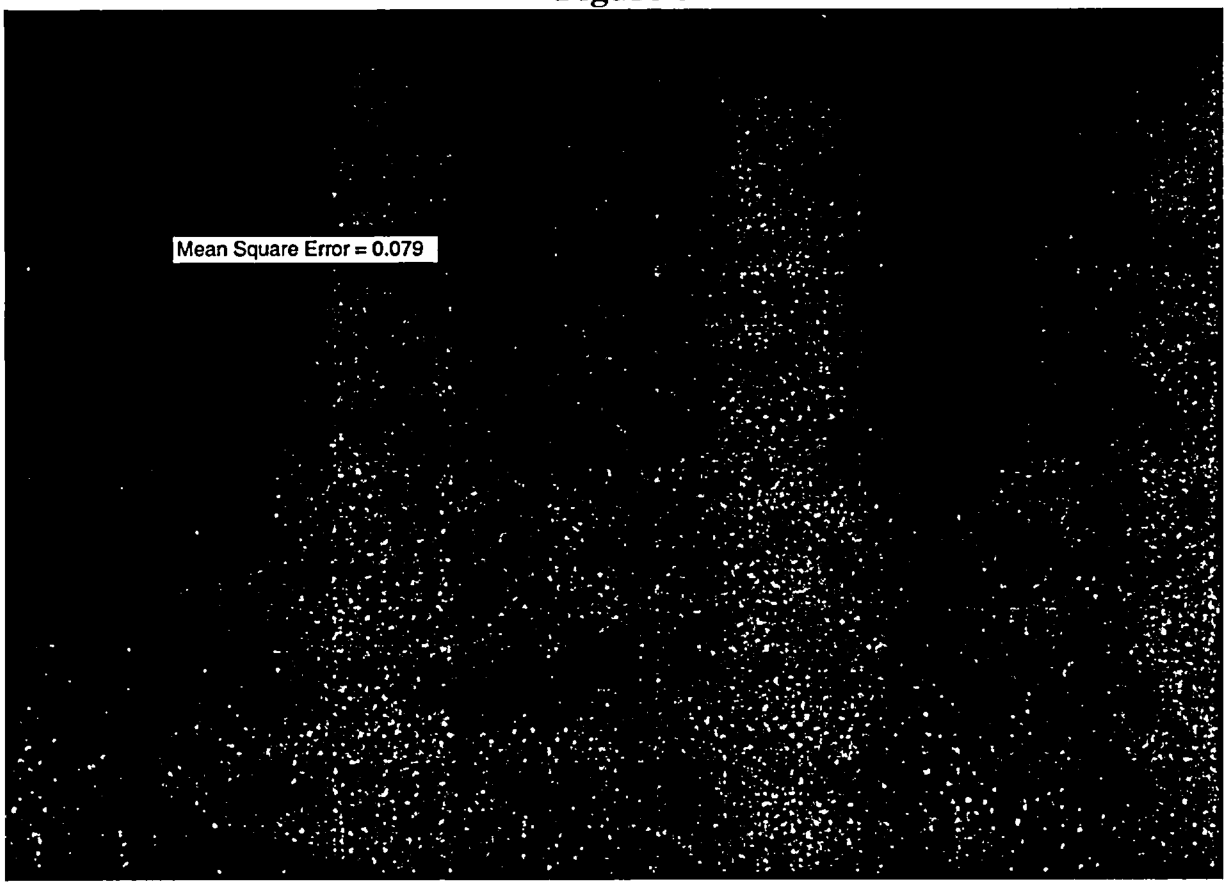


Figure 7 (update in process)

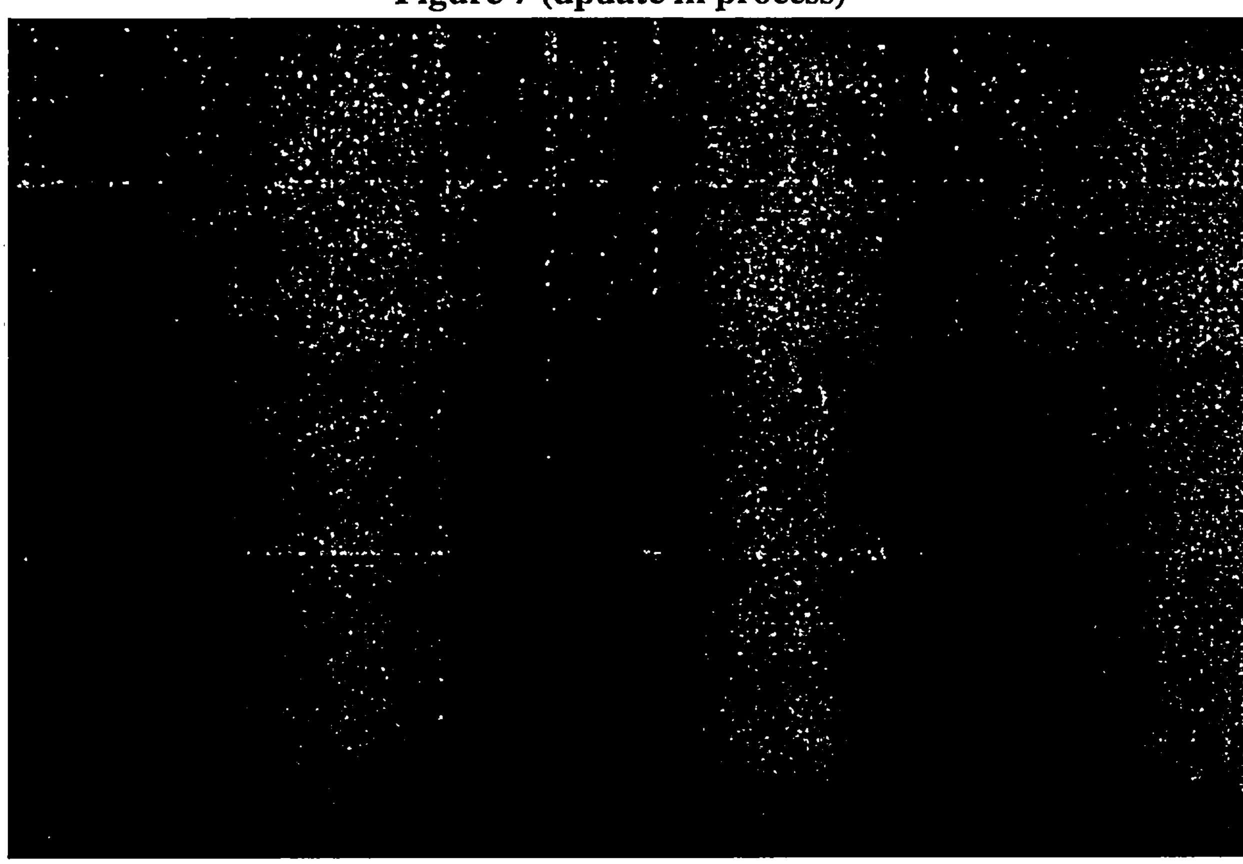
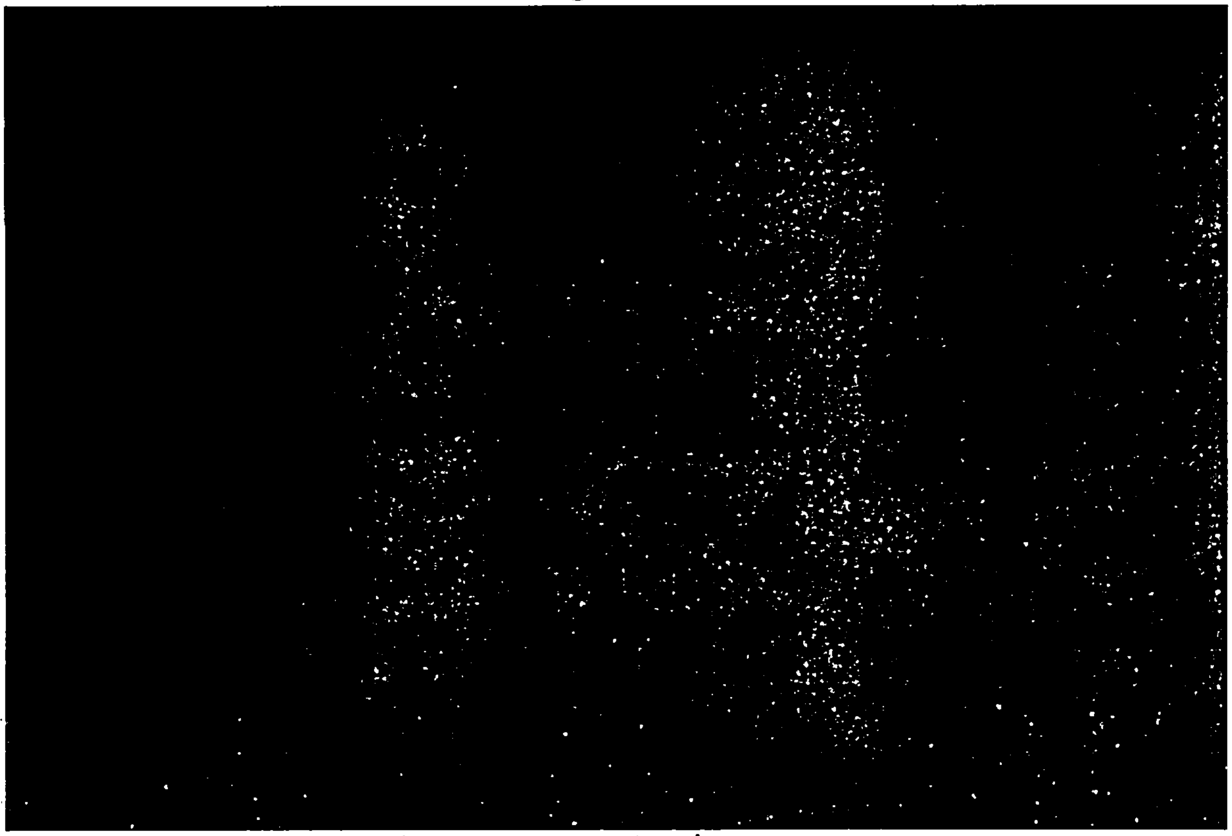


Figure 8



Noise Requirements for Voltage Based ARC

1.0 Introduction

This note provides recommendations on noise inspection, analysis and repair for application to the ARC for ODSCC at TSP intersections. These recommendations differ from the mix residuals requirements given in GL 95-05. Since these recommendations represent a change to GL 95-05, NRC approval is required prior to implementation under the ODSCC ARC.

Tube noise considerations for indications at TSP intersections for the voltage based ARC are currently based on measurements of the mix residual signal. The mix residual was applied in the early development of the ARC as a measure of noise prior to more recent efforts in the industry to assess the effects of noise on detection. The mix residual is a measure of the noise across the entire TSP length and is not an appropriate quantity for assessing the effects of noise on detection since most TSP indications develop at the TSP center where noise influence is minimal. The noise at TSP intersections develops over the first and second cycle of operation and is not significantly sensitive to the NDE setup for the frequency mix at TSP intersections or significantly variable from cycle to cycle. To update the ARC noise inspection and repair requirements to current noise assessment methodology, revised requirements for inspection and repair at noisy TSP intersections are developed in this report.

NRC Generic Letter 95-05 (Reference 1) requires RPC inspection of intersections with large mix residuals that could cause a 1.0 volt bobbin signal to be masked or misread. The GL states that "Any indications found at such intersections with RPC should cause the tube to be repaired." The latter GL requirement has had two interpretations. The industry interpretation in Reference 2 is that repair "at such intersections" refers to repair at intersections having mix residuals that mask a 1.0 volt indication so that repair is only required when the bobbin voltage is estimated to be ≥1.0 volt. The statement has alternately been interpreted by the NRC to imply that all indications found by RPC during mix residual inspections are to be repaired independent of the estimated bobbin voltage. As discussed in Section 2.0, all TSP intersections have mix residual signals and the influence of the mix residual signals (better defined as a measure of TSP noise) on voltage measurements is built into the ARC burst and leak rate correlations. The concept of misreading a voltage due to TSP noise should not be applied for the ARC since the effects of noise on voltage measurements are already included in the ARC database and contribute to the voltage variability in the ARC burst and leakage correlations. The repair criteria for ODSCC indications found at noisy TSP intersections are redefined in this note to more closely tie the noise intersection repair limits to the plant specific voltage based repair limits. As shown in this report, bobbin voltages can be adequately assigned to indications found by RPC inspections so that the indications can be included in condition monitoring and operational assessments, thus eliminating any need for lower repair limits based on potential influence on burst and leakage.

GL 95-05 also requires 100% inspection of all dents > 5 volts and repair of any indications found in dents > 5 volts. Since these indications can be adequately sized using correlations of bobbin to RPC volts such that the indications can be included in condition monitoring and operational assessments, this report also recommends that repair for these indications be tied to the plant specific voltage based repair limits.

Section 2 discusses noise considerations at TSP intersections to demonstrate the importance of applying noise measurements specific to the center of the TSP rather than the mix residual signal, which measures noise across the entire TSP resulting in an overestimate of noise at the location of the cracks near the center of the TSP. In Section 3, the adequacy of the Reference 2 methods for assigning bobbin voltages

to RPC indications is demonstrated by field data and recommendations for repair of the RPC indications are provided. Section 4 defines the recommended requirements for selecting samples for RPC inspection of noisy TSP intersections and for expanding the inspections if indications exceeding the GL 95-05 ARC repair limits are found in the sample inspection. Section 5 summarizes the conclusions of this report.

2.0 Considerations for Noise at TSP Intersections

With regard to the presence of mix residuals and their influence on sizing of indications, it must be emphasized that all TSP intersections have mix residuals after the first one or two cycles of operation. The mix residuals may be more easily understood as a measure of TSP noise. After about two cycles, the mix residuals generally do not change significantly with operating time. The dominant voltage for the mix residual signals is not strongly affected by the mixing used to analyze the bobbin data so the mix residual signal amplitude does not vary significantly with operating time or NDE analyst. Frequently, a significant part of the mix residual signal is present in bobbin data obtained without a TSP for pulled tubes examined in the laboratory. Some of the model boiler specimens show mix residuals although generally smaller than field data due to the shorter time at temperature. The bobbin response apparently includes an effect of the time at temperature at a TSP on the electrical and/or magnetic properties of the tube. Metallography was performed on a pulled tube to attempt to identify the cause for the signal, but was not successful in identifying any physical change to the tube or grain structure.

Many of the pulled tubes in the ARC database (and the prior cycle probability of detection or POPCD database) have mix residual signals larger than typically found in currently operating SGs. Figure 1 shows the 1.87 flaw voltage and the 3.23 mix residual voltage for pulled tube R27C54 from plant A-1 in the ARC database. This is only one example of the pulled tube data. The flaw signal is easily detectable which would imply easy detection at signal to noise (S/N) of about 0.58 for the associated flaw and mix residual peak-to-peak voltages. As shown in Section 3, a S/N of 0.58 would be expected to have a probability of detection of about 0.25. This indicates that the use of the mix residual as a measure of noise is not appropriate for assessing detection.

The mix residual voltage is not being used, nor should it be used, in current assessments of the influence of noise on detection or sizing. For signal to noise evaluations, the noise is being evaluated as the maximum voltage response over approximately one third sections of the TSP to distinguish the relatively low noise at the center of the TSP from the larger noise near the edges of the TSP. Figure 2 shows the lower and upper TSP noise amplitudes for R27C54-1H. Noise at the middle section cannot be evaluated due to the presence of the flaw. Figure 3 shows the mix residual voltage and noise levels at the center, upper and lower one-third sections of the R27C54-2H TSP, where the mix residual is the same as at 1H. The noise level affecting detection and sizing at the center of the TSP, where most of the TSP ODSCC indications are found, is 0.70 volts peak-to-peak while the edge noise amplitudes are 1.70 and 1.52 volts. These noise levels are in the upper 20% of noise amplitudes expected at TSP intersections. The noise differences between the center and edge affect detectability of short, low voltage indications located at the edges of the TSP. The short indications at the TSP edges must grow to the center of the TSP to become structurally significant and the lower noise levels at the TSP center provide for detection of even low voltage indications. The noise levels in these figures are peak-to-peak amplitudes although the vertical amplitudes are more appropriate for assessing signal to noise for flaw detection. However, the applications of this report are related to amplitude sizing for which peak-to-peak flaw and noise amplitudes are the recommended quantities. Applying the peak-to-peak amplitudes of 1.87 volts for the flaw from Figure 1 and 0.70 volt for the noise at the TSP center from Figure 3, the

S/N for the flaw would be about 2.7 (expected POD about 0.96 from Section 3), which supports the ease of detection found for the flaw. This result is consistent with the recommended use of the flaw and noise evaluated at the TSP center.

The above noise and mix residual discussion demonstrates that it is neither feasible nor necessary to attempt to define bobbin flaw voltages that are not affected by the TSP noise or mix residuals. All indications have negligibly small to a range of noise influence on voltage sizing, and the ARC database includes many indications with larger noise levels than most currently active SGs. Whatever influence the mix residuals may have on voltage sizing for TSP indications is built into the ARC database by the pulled tubes and the concept of misreading voltages is irrelevant to the ARC.

Since nearly all TSP indications are located near the center of the TSP or span the center of the TSP, the appropriate quantity for assessing the influence of noise is the amplitude over approximately the center 1/3 of the TSP between the peaks associated with TSP edge effects. Short indications at the edges of the TSP would not have a significant influence on tube integrity. Amplitude measurements at the area of interest are being applied for tube integrity applications under the EPRI Tools for Tube Integrity Program. These measurements are being utilized to develop ETSSs and PODs based on performance testing of multiple analyst teams. The use of amplitude noise measurements are recommended for ARC noise assessments for consistency with the EPRI methodology for tube integrity applications. The following sections apply the amplitude noise measurements at the center of the TSP to develop RPC repair and inspection requirements for ARC applications.

3.0 Tube Repair Requirements for Indications Found by RPC at Noisy TSP Intersections

3.1 Bobbin Voltage Sizing for Indications Found by RPC

Axial ODSCC indications found only by RPC inspection can be sized for bobbin voltages by the methods described in Section 10.1 of Reference 2. Methods are described based on obtaining voltages from detection at the half-prime frequency and from correlations of bobbin to RPC voltages, which may be pancake or +Point coils. When detection can be adequately obtained at the half-prime frequency, this method is preferred over the bobbin/RPC voltage correlation since the method is closely related to the normal inspection process for detecting and sizing indications. However, it is shown below that both methods yield essentially the same bobbin voltages and that the inferred bobbin voltages are consistent with voltages obtained from the normal primary/secondary/resolution detection and sizing process.

The most extensive inspection of TSP intersections with significant mix residual noise signals was performed at Plant P-1 in 2003. The results of these inspections can be used to demonstrate the adequacy of the bobbin voltage sizing methods. Figure 4 compares the ratio of bobbin voltages in the 400/100 kHz mix to the 200 kHz volts for indications reported in the normal primary/secondary/resolution analysis process to the ratios obtained from detecting the flaw (identified by the RPC) on the 200 kHz channel and using the inferred mix signal measurement with no additional adjustments. It is seen that the distributions obtained from both sizing methods are equivalent, which supports the adequacy of sizing by identifying the flaw in the half-prime frequency signal and obtaining voltages from the mix signal. Figure 5 compares the regression correlations of bobbin to +Point volts obtained using the normal inspection process with that obtained from the half-prime frequency analyses. The bobbin to RPC voltage correlations are essentially the same for both analysis methods. Since Figure 4 shows the adequacy of sizing from detection in the half-prime frequency and Figure 5 shows that correlations of bobbin to RPC volts are the same between the normal ODSCC sizing and half-prime

frequency analyses, it can be concluded that both of the methods for bobbin voltage sizing of RPC indications yield essentially the same bobbin voltages and both methods are acceptable for ARC applications.

3.2 Tube Repair Requirements for Indications Found by RPC at Noisy TSP Intersections

As noted in Section 1, the industry interpretation of GL 95-05 is that indications associated with large mix residuals and found only by RPC should be repaired if the inferred bobbin voltage is ≥1.0 volt. This repair limit is inconsistent with the differences in repair limits between 3/4" and 7/8" tubing. Since a bobbin voltage is assigned to the indications found only by RPC and the indications are included in the condition monitoring and operational assessments, there is no need to apply repair limits more conservative than the licensed repair limits.

For consistency in ARC repair limits, it is recommended that the following tube repair limits be applied for indications found only by RPC:

- Based on bobbin voltages determined by the methods of Reference 2 from indications found only by RPC inspection, indications with inferred bobbin voltages exceeding the licensed plant specific bobbin voltage repair limit are to be repaired. The GL 95-05 repair limits are > 1.0 volt for 3/4" tubing and > 2.0 volts for 7/8" tubing. Some plants may have larger repair limits such as obtained from locked TSP intersections.

- This repair limit applies for RPC indications found at noisy TSP intersections and at dented TSP intersections for dents of any voltage. For indications found at TSP intersections with both ODSCC and PWSCC indications for plants having a licensed PWSCC ARC, the above repair limit can be applied only if consistent with the licensed requirements.

- The bobbin voltages obtained by the Reference 1 methods from RPC testing of noisy TSP and dented TSP intersections are to be included in the ARC condition monitoring and operational assessments.

4.0 RPC Inspection Requirements for Noise at TSP Intersections

The selection of noisy TSP intersections for potential RPC inspection is to be based on POD versus signal/noise (S/N) correlations for axial ODSCC at TSP intersections. When available, the POD vs. S/N correlations for noise levels at the center of the TSP as obtained from ETSSs based on multiple analyst testing should be applied. Until these ETSS POD correlations are available, the POD vs. S/N correlation from SSPD testing of multiple analysts described in Reference 3, as shown in Figure 6, is to be applied. Figure 6 is based on flaw and noise peak-to-peak amplitudes to permit application of peak-to-peak voltage repair limits in defining S/N. For more general applications of S/N for detection, the vertical max voltages would be used as this quantity is more closely tied to NDE detection methods.

The GL 95-05 repair limits are the appropriate limits for detection of indications found at noisy TSP intersections based on burst and leakage considerations. The lowest voltages found for leaking indications in the ARC database (Reference 2) is 1.13 volts for 3/4" tubing and 2.81 volts for 7/8" tubing. The leak rates for these two indications were very small at 0.000088 and 0.00035 gpm, respectively. Thus, indications below the GL 95-05 repair limits would not be expected to leak and, if they do leak, would have a negligible leak rate. The probability of burst for indications at the GL 95-05

repair limits are less than about $5x10^{-6}$ for both 3/4" and 7/8" tubing, and thus undetected indications below the repair limits would have a negligible contribution to the burst probability. The GL 95-05 repair limits are to be applied to develop the inspection requirements of this section even for plants with higher licensed repair limits in order to assure that indications with potential significant leakage are included in the ARC analyses.

A S/N value for a nominal POD of 0.9 is to be obtained from the POD versus S/N correlation for axial ODSCC peak-to-peak amplitudes at the center of the TSP. For plants licensed to apply the Probability of Prior Cycle Detection (POPCD) for operational assessments, the POD value to be applied to obtain S/N values is the nominal POPCD POD at the appropriate GL 95-05 repair limit. The use of POPCD distributions at 1.0 and 2.0 volt repair limits would likely lead to POD values within about ± 0.05 of 0.9. The use of a POD on the order of 0.9 to define a S/N value at the ARC repair limit assures that the detection for ODSCC at noisy intersections is consistent with or conservative relative to the POD used in ARC operational assessments. From Figure 6, the associated S/N value for a POD of 0.9 is 1.9. To obtain a noise threshold for potential RPC inspections, detection at a POD of 0.9 (or that from POPCD at the repair limit when POPCD is licensed) is applied to obtain the S/N value and the signal, S, is applied at the ARC repair limit. The noise threshold value for the mix at the center of the TSP is then 0.53 volt for a repair limit of 1.0 volt and 1.05 volt for a repair limit of 2.0 volt. As noted, these values are to be updated when the EPRI ETSS POD versus S/N correlations from multiple analyst testing are available.

Noise evaluations should be performed for a minimum of 100 hot leg TSP intersections per SG to identify noisy TSP intersections. Since the TSP noise levels do not change significantly from cycle to cycle, the noise analyses may be performed on the bobbin data from the last inspection or the current inspection. RPC inspection shall be performed for a minimum of 25 intersections (total summed over all SGs) exceeding the noise threshold values. The noise measurements shall be made at the TSP intersections where most of the ODSCC indications are found, which are typically the lower three hot leg TSPs. If this sample does not identify at least 25 intersections with noise levels exceeding the noise threshold values, the noise evaluation sample size shall be increased to include an additional 100 TSP intersections per SG to obtain a total noise sample population of 200 TSP intersections per SG to identify intersections for RPC inspection. The RPC inspection shall then be performed at the 25 TSP intersections with the highest noise levels in the noise analysis population evaluated.

If axial ODSCC indications are found in the sample RPC inspection, the following guidelines are to be applied to determine whether an expansion of the inspection is required:

- If the inferred bobbin voltage of any indication found in the RPC inspection of noisy TSP intersections (sample with noise exceeding threshold values) is found to exceed the GL 95-05 repair limits of 1.0 and 2.0 volts for 3/4" and 7/8" tubing respectively, the noisy TSP intersection RPC inspection shall be expanded to include an additional 100 TSP intersections with the next highest noise levels in the noise sample population. If this inspection expansion identifies a flaw with a bobbin voltage exceeding the GL 95-05 repair limit, the inspection should be expanded in 100 sample increments until one of the samples is found with no indications exceeding the GL repair limit.

- The fraction of TSP intersections inspected that are found to have axial ODSCC indications defines an average undetected fraction, or 1-POD, for the base inspection since the RPC inspection is a supplemental sample inspection applied to assess the adequacy of the base inspection. If the operational assessment applies the GL 95-05 POD of 0.6, the associated undetected fraction is 0.4.

If POPCD is applied for the operational assessment, the average bobbin voltage for the ODSCC indications should be used to determine an average or expected POD for the indications by application of the latest licensed nominal industry or plant specific POPCD distribution (Figure 7 provides the industry POPCD distribution although an updated industry POPCD is under preparation). The expected POD is defined as the POPCD value at the average bobbin voltage for the ODSCC indications found by RPC inspection. If the sample fraction of intersections with detected flaws in the RPC inspection (undetected in base inspection) is greater than the expected 1-POD (0.4 if POPCD is not licensed) by more than a 0.1 difference, the inspection should be expanded in 50 sample increments (applying next highest noise levels in the noise sample population) until one of the samples is found with an average POD equal to or greater than the expected POD. This requirement is applied to provide reasonable confidence that the detection capability in noisy tubes is comparable to that used in the operational assessments for the overall population of indications.

The required expansion sample size of 50 samples for the POD comparison is smaller than the 100 samples required if an indication is found to exceed the repair limits. This difference is applied to reflect the significance on the operational assessment between the two conditions. Undetected indications left in service below the GL 95-05 repair limits are expected to have a negligible impact on leakage or burst as described above.

Examples of peak-to-peak amplitude noise distributions are shown in Figure 8 for a plant with 3/4" tubing and for a preliminary version (dataset currently being finalized) of the noise distribution for indications planned for performance testing to development ETSSs under the EPRI Tools for Tube Integrity Program. The preliminary ETSS and plant noise distributions are very similar. For a plant with 3/4" inch tubing and a 0.53 volt noise threshold for potential RPC inspection, about 40% of the intersections exceed this level. The sample inspection would start at the highest noise levels in the distribution. Due to the low 1.0 volt repair criterion, the noise threshold for RPC inspection is very conservative. The noise distributions for plants with 7/8" tubing are expected to be similar to those in Figure 8. For the associated 1.05 volt noise threshold with 7/8" tubing, less than 5% of the TSP intersections would be expected to exceed this threshold. The sample size applied to develop the noise distribution for 7/8" tubing may have to be expanded to 200 TSP intersections per SG in order to identify the 25 intersections with the highest noise levels for RPC inspection. It can be noted that the POD versus S/N curves, such as Figure 6, are used to assess differences in noise levels and a plant specific noise distribution does not have to be bounded by the noise distribution used in developing the POD correlation.

5.0 Conclusions

The use of mix residuals to characterize noise at TSP intersections was initiated in the early 1990s and is shown in this report to be a poor measure of the influence of noise on detection. The noise at TSP intersections for bobbin probes varies significantly between the center and edges of the TSP whereas the mix residual is a single measure of noise across the entire TSP. Since nearly all ODSCC indications at TSP intersections extend through the center of the TSP, the noise levels at the TSP center provide the best measure of noise for the influence on detection and amplitude sizing. The few indications found only at the edges of the TSP that could be masked by the higher noise levels are very short and would have negligible impact on burst and leakage. Therefore, it is recommended that the ARC noise methods be based on evaluations of the noise amplitude at the center of the TSP.

The EPRI Tools for Tube Integrity Program is developing ETSSs based on performance testing of multiple analysts. Noise analyses are an integral part of this program with noise analyses for tube integrity applications based on measurements of the noise amplitudes at the regions of interest. As part of this program, PODs as a function of S/N are being developed. These correlations permit identification of the noise level that supports a specified POD level at the ARC voltage based repair limits. The recommended threshold noise value for RPC sampling of noisy intersections is based on obtaining a POD of 0.9 at the ARC repair limits of 1.0 and 2.0 for 3/4" and 7/8" tubing, respectively. Plant noise analyses for a minimum of 100 TSP intersections per SG are recommended to characterize the plant specific noise levels. If this sample does not identify at least 25 intersections with noise levels exceeding the noise threshold values, the noise evaluation sample size shall be increased to include an additional 100 TSP intersections per SG to obtain a total noise sample population of 200 intersections per SG to identify intersections for RPC inspection. The 25 TSP intersections with the largest noise levels are recommended for RPC inspection. If an axial ODSCC indication exceeding the ARC repair limit of GL 95-05 is found in the noise sample inspection, the inspection would be expanded by steps of 100 TSP intersections until no ODSCC indication exceeding the repair limits is found in the 100 intersection sample. The inspection would also be expanded in steps of 50 TSP intersections if the fraction of indications found in the RPC inspection, which represents the fraction undetected in the base inspection, exceeds the undetected fraction expected from the POD used for operational assessment by more than 0.1. Bobbin flaw amplitudes for the RPC indications can be obtained either by identification of the flaw in the half-prime frequency response or by correlations of bobbin to RPC voltage. It is shown by plant data that these two methods yield very similar bobbin voltages and voltages consistent with the normal primary/secondary/resolution analysis.

It is recommended that indications found by the RPC inspection be repaired if they exceed the licensed plant specific repair limit based on bobbin voltages assigned to the RPC indications. This provides a consistent ARC repair limit independent of how the indication was found in the inspection. Based on the bobbin voltages assigned to the indications, all indications found in the RPC inspection are to be included in the ARC condition monitoring and operational assessments. The bobbin voltages for the RPC indications are adequately defined to obtain tube integrity margins consistent with all bobbin indications, and there is no need to define different repair limits for the indications found by RPC. Since indications found by RPC inspection in dents > 5 volts can be adequately sized using correlations of bobbin to RPC volts, it is also recommended that repair for these indications be based on the plant specific voltage based repair limits. Since GL 95-05 requires 100% inspection of all dents > 5 volts, no additional inspection or expansion requirements are necessary for the dented TSP intersections.

6.0 References

1. Generic Letter 95-05, "Voltage-Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking," dated August 3, 1995
2. EPRI Topical Report NP 7480-L, Addendum 5, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits, Update 2002," dated January 2003.
3. EPRI Report, unpublished, "Assessment of Bobbin Coil Noise Analysis Methods for Tube Integrity Applications," July 2003

Figure 1. Flaw and Mix Residual (400/100 Mix) for Plant A-1 Pulled Tube R27C54-1H

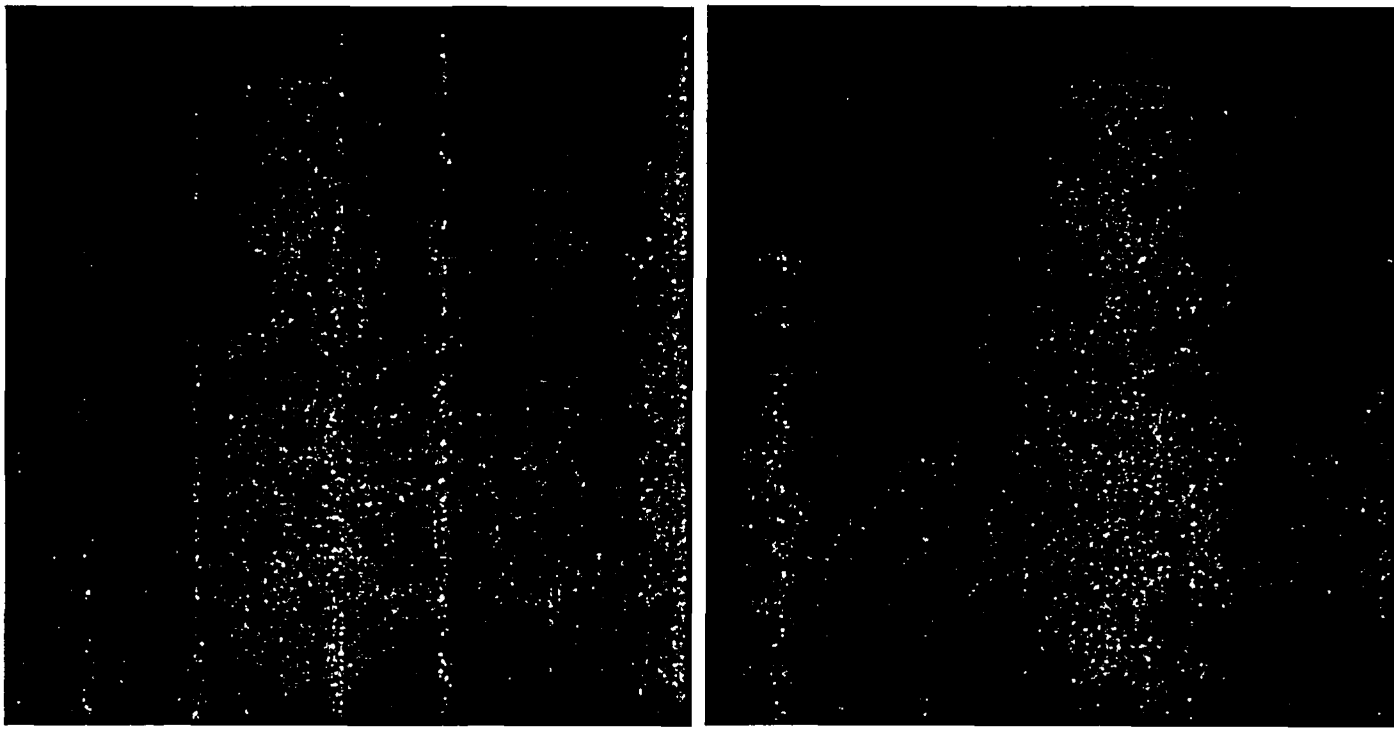


Figure 2. Upper and Lower TSP Noise Signals for Plant A-1 R27C54-1H
(Center 1/3 of TSP Cannot be Evaluated Due to Flaw Signal)

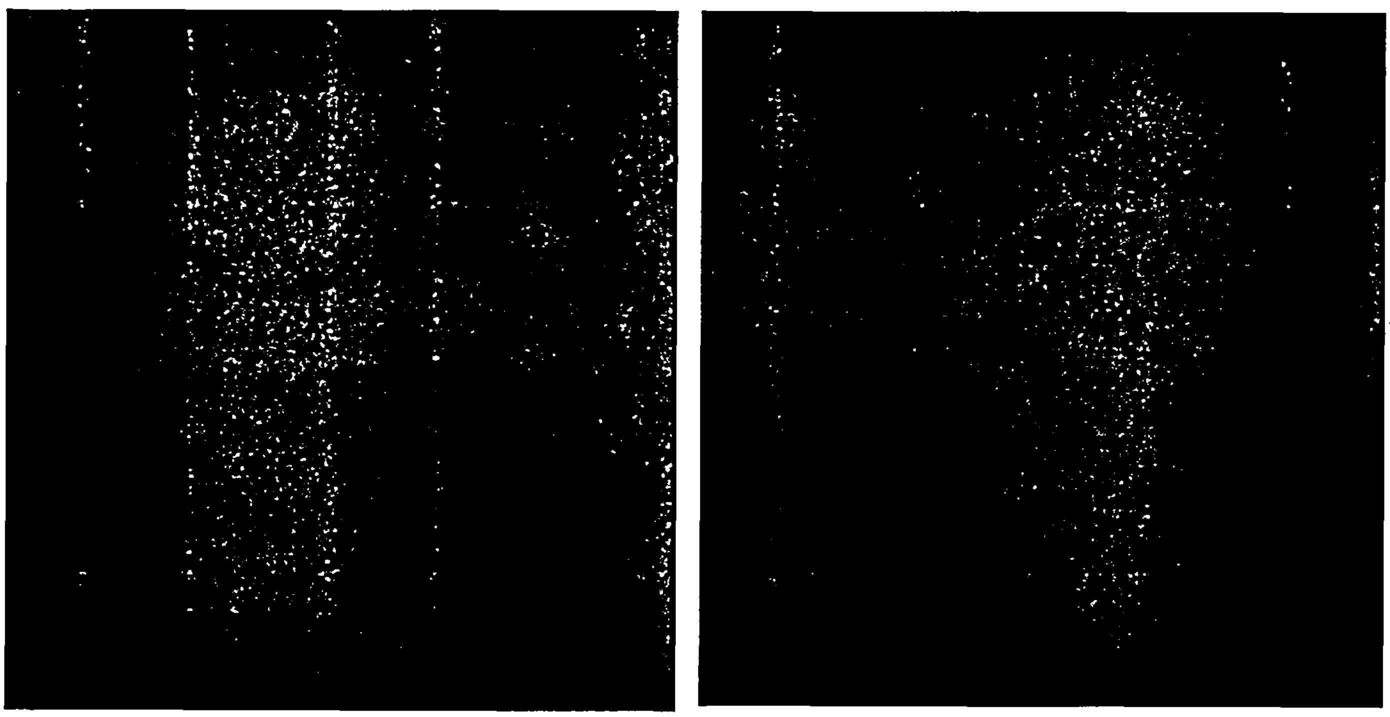


Figure 3. Mix Residual and Center, Upper and Lower 1/3 TSP Noise Signals (400/100 kHz Mix) for Plant A-1 R27C54 at 2H

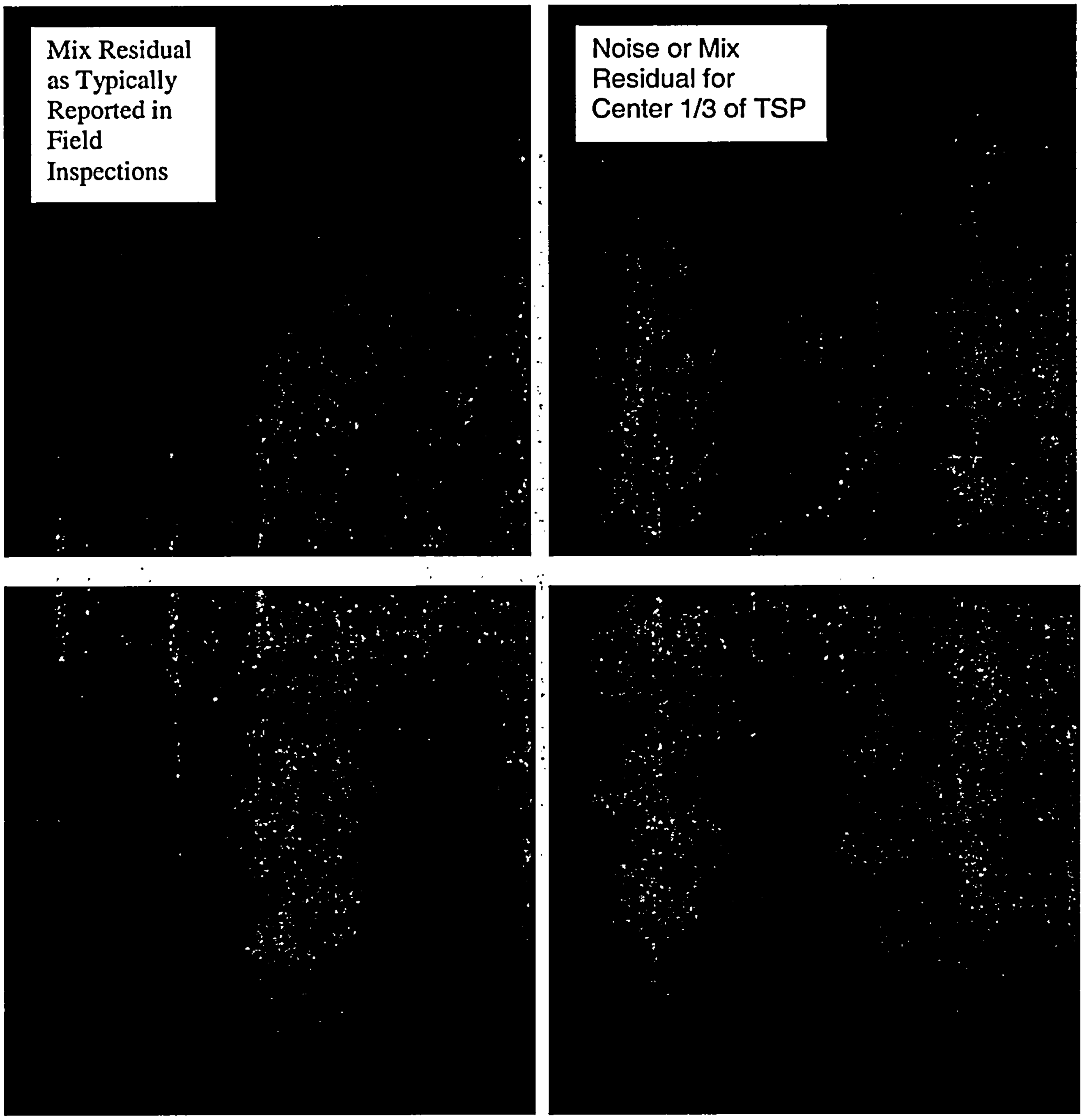


Figure 3. Mix Residual and Center, Upper and Lower 1/3 TSP Noise Signals (400/100 kHz Mix) for Plant A-1 R27C54 at 2H

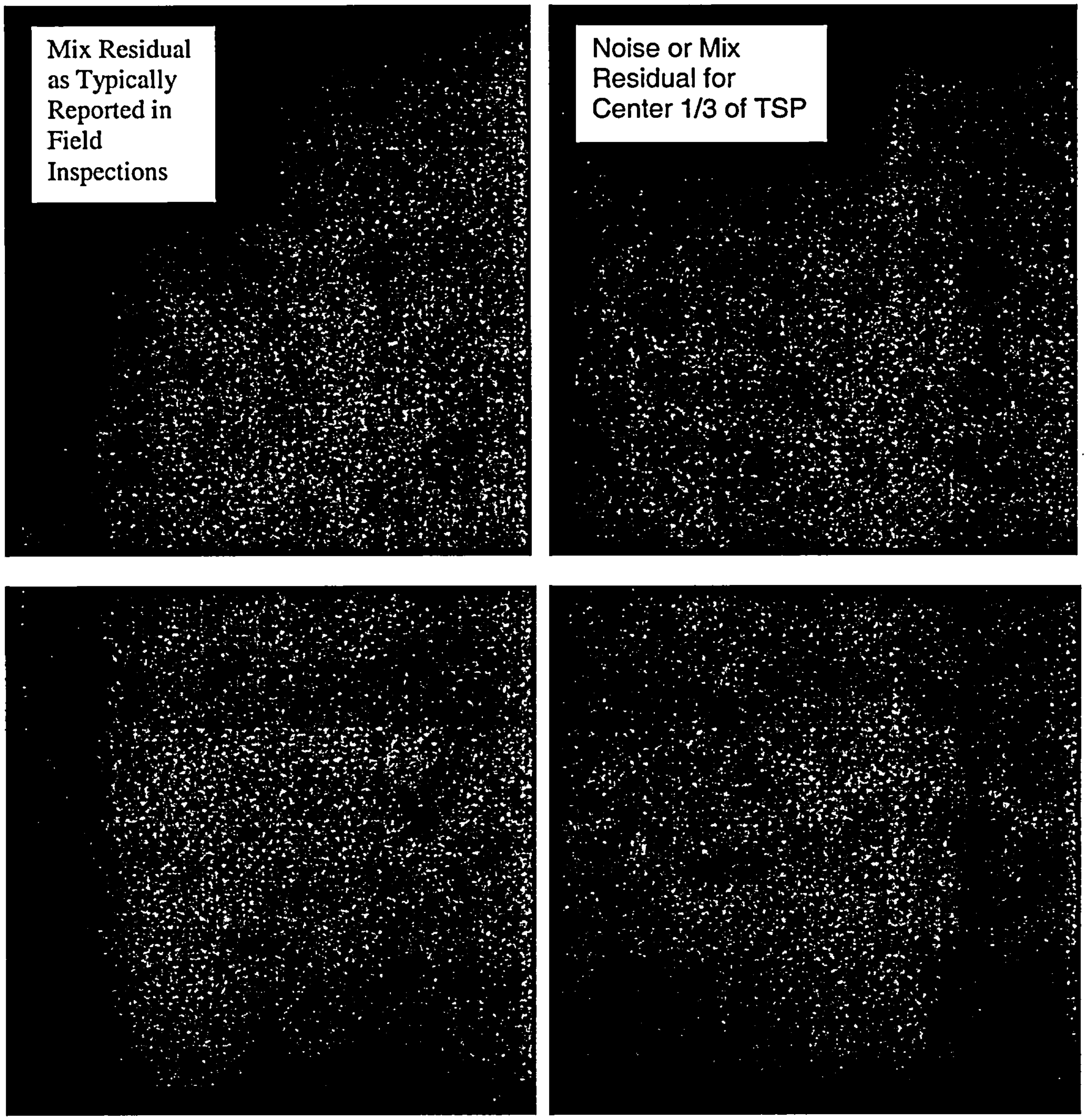


Figure 4

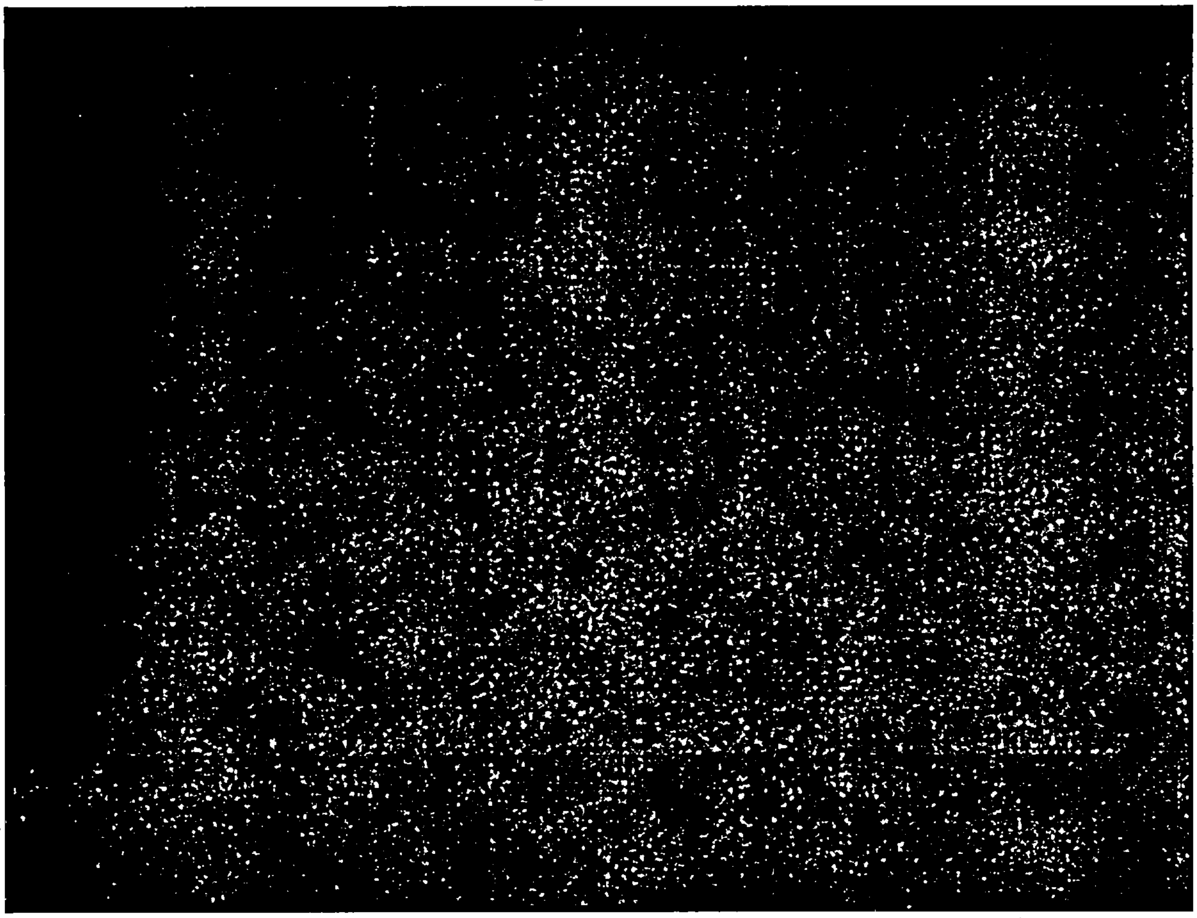


Figure 5

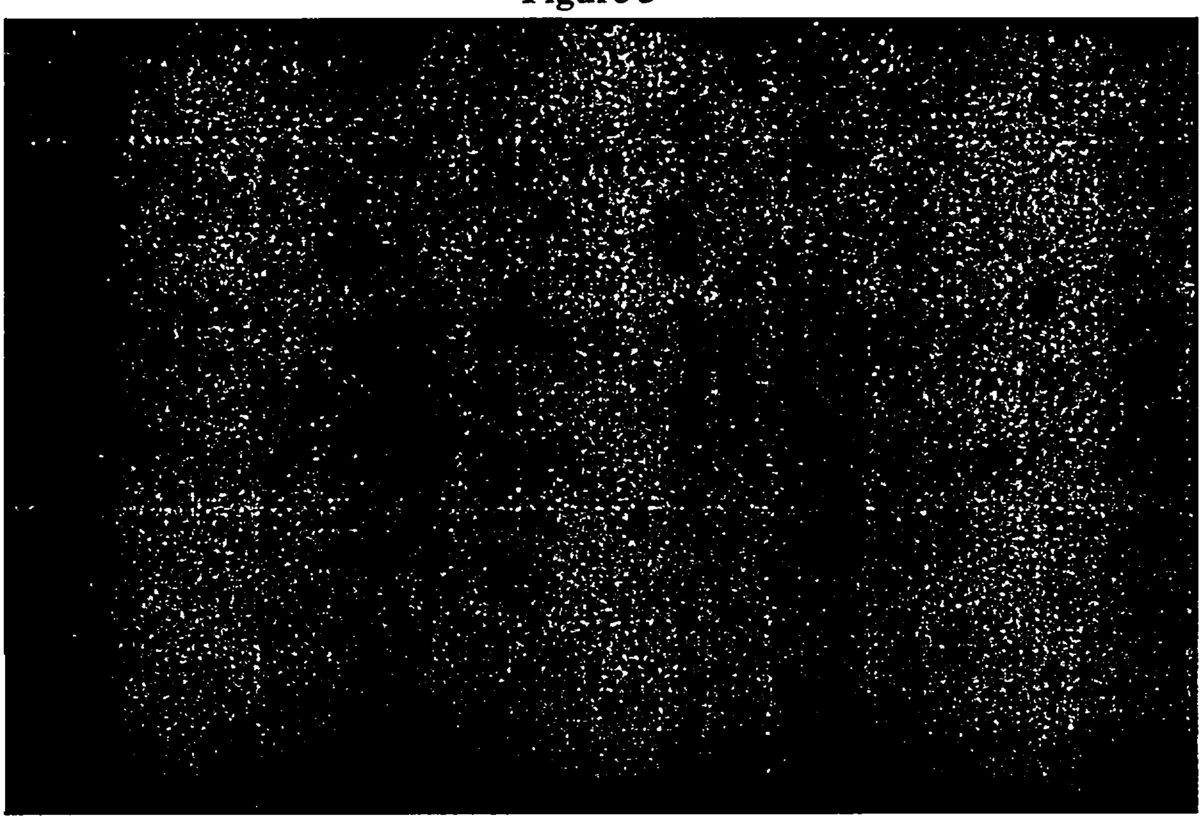


Figure 6

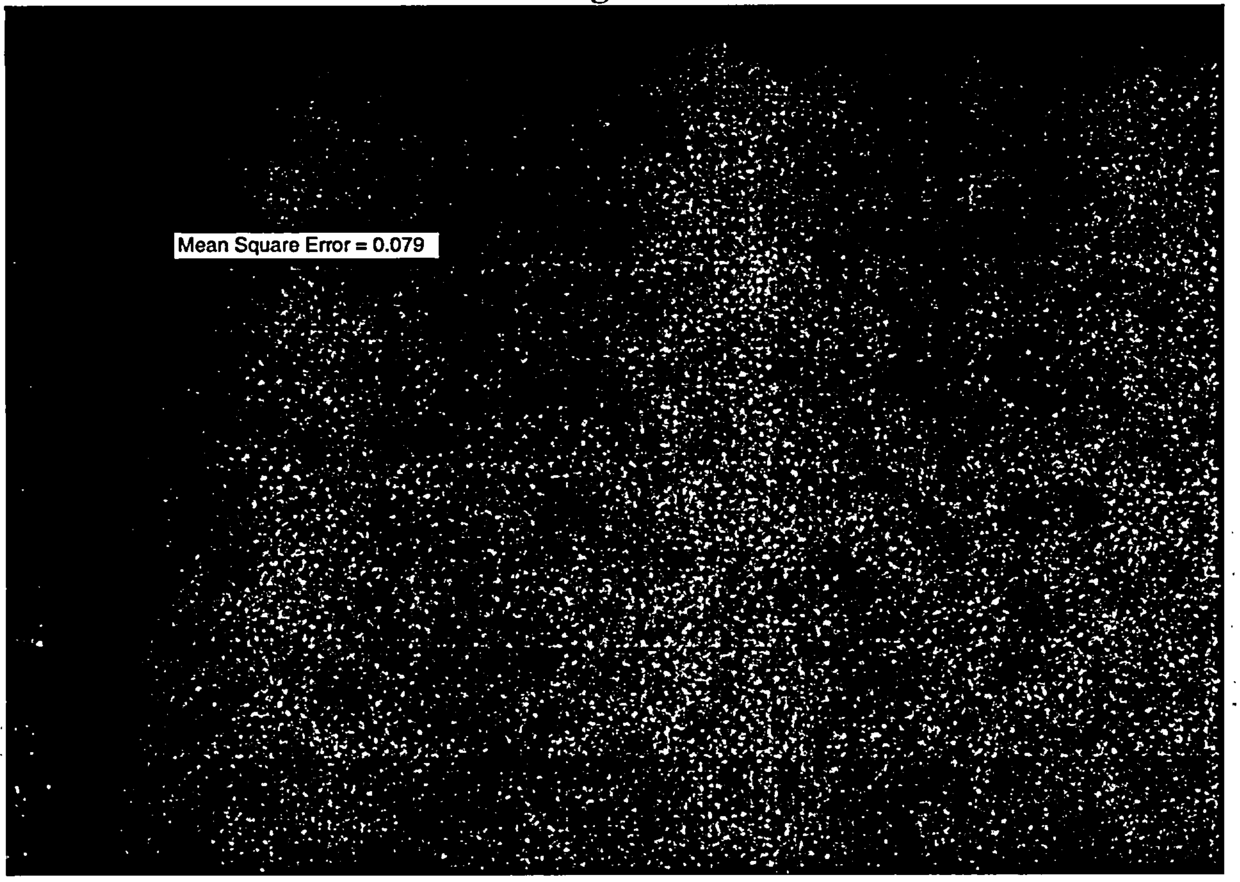


Figure 7 (update in process)

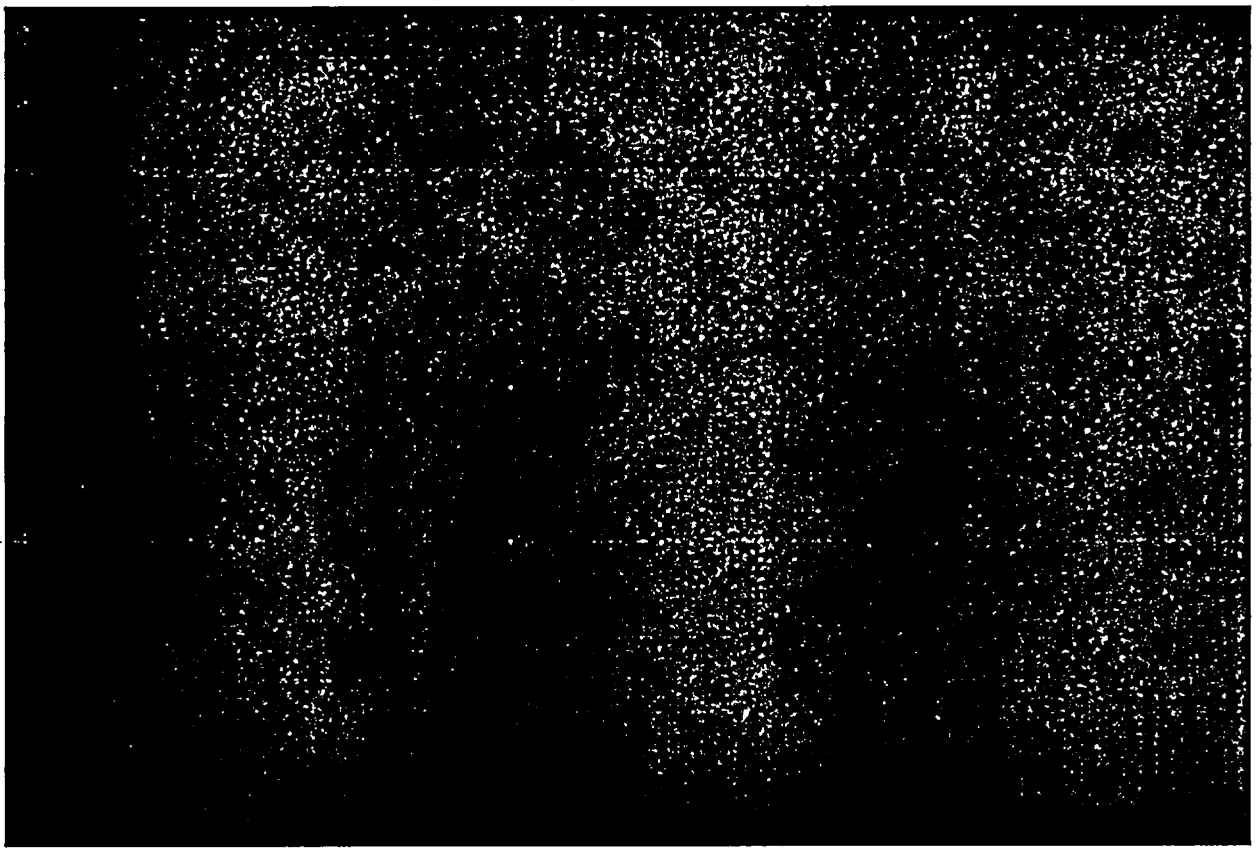
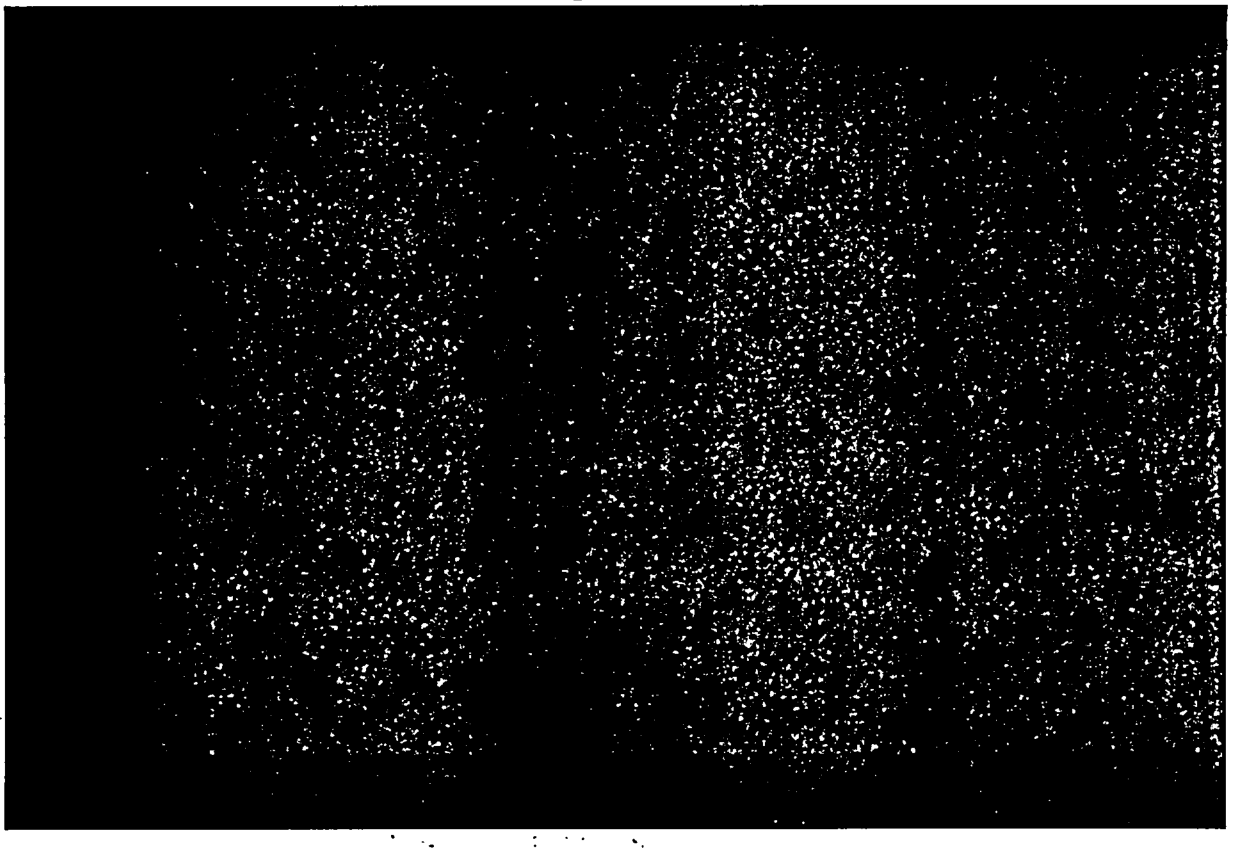


Figure 8



Noise Requirements for Voltage Based ARC

1.0 Introduction

This note provides recommendations on noise inspection, analysis and repair for application to the ARC for ODSCC at TSP intersections. These recommendations differ from the mix residuals requirements given in GL 95-05. Since these recommendations represent a change to GL 95-05, NRC approval is required prior to implementation under the ODSCC ARC.

Tube noise considerations for indications at TSP intersections for the voltage based ARC are currently based on measurements of the mix residual signal. The mix residual was applied in the early development of the ARC as a measure of noise prior to more recent efforts in the industry to assess the effects of noise on detection. The mix residual is a measure of the noise across the entire TSP length and is not an appropriate quantity for assessing the effects of noise on detection since most TSP indications develop at the TSP center where noise influence is minimal. The noise at TSP intersections develops over the first and second cycle of operation and is not significantly sensitive to the NDE setup for the frequency mix at TSP intersections or significantly variable from cycle to cycle. To update the ARC noise inspection and repair requirements to current noise assessment methodology, revised requirements for inspection and repair at noisy TSP intersections are developed in this report.

NRC Generic Letter 95-05 (Reference 1) requires RPC inspection of intersections with large mix residuals that could cause a 1.0 volt bobbin signal to be masked or misread. The GL states that "Any indications found at such intersections with RPC should cause the tube to be repaired." The latter GL requirement has had two interpretations. The industry interpretation in Reference 2 is that repair "at such intersections" refers to repair at intersections having mix residuals that mask a 1.0 volt indication so that repair is only required when the bobbin voltage is estimated to be ≥1.0 volt. The statement has alternately been interpreted by the NRC to imply that all indications found by RPC during mix residual inspections are to be repaired independent of the estimated bobbin voltage. As discussed in Section 2.0, all TSP intersections have mix residual signals and the influence of the mix residual signals (better defined as a measure of TSP noise) on voltage measurements is built into the ARC burst and leak rate correlations. The concept of misreading a voltage due to TSP noise should not be applied for the ARC since the effects of noise on voltage measurements are already included in the ARC database and contribute to the voltage variability in the ARC burst and leakage correlations. The repair criteria for ODSCC indications found at noisy TSP intersections are redefined in this note to more closely tie the noise intersection repair limits to the plant specific voltage based repair limits. As shown in this report, bobbin voltages can be adequately assigned to indications found by RPC inspections so that the indications can be included in condition monitoring and operational assessments, thus eliminating any need for lower repair limits based on potential influence on burst and leakage.

GL 95-05 also requires 100% inspection of all dents > 5 volts and repair of any indications found in dents > 5 volts. Since these indications can be adequately sized using correlations of bobbin to RPC volts such that the indications can be included in condition monitoring and operational assessments, this report also recommends that repair for these indications be tied to the plant specific voltage based repair limits.

Section 2 discusses noise considerations at TSP intersections to demonstrate the importance of applying noise measurements specific to the center of the TSP rather than the mix residual signal, which measures noise across the entire TSP resulting in an overestimate of noise at the location of the cracks near the center of the TSP. In Section 3, the adequacy of the Reference 2 methods for assigning bobbin voltages

to RPC indications is demonstrated by field data and recommendations for repair of the RPC indications are provided. Section 4 defines the recommended requirements for selecting samples for RPC inspection of noisy TSP intersections and for expanding the inspections if indications exceeding the GL 95-05 ARC repair limits are found in the sample inspection. Section 5 summarizes the conclusions of this report.

2.0 Considerations for Noise at TSP Intersections

With regard to the presence of mix residuals and their influence on sizing of indications, it must be emphasized that all TSP intersections have mix residuals after the first one or two cycles of operation. The mix residuals may be more easily understood as a measure of TSP noise. After about two cycles, the mix residuals generally do not change significantly with operating time. The dominant voltage for the mix residual signals is not strongly affected by the mixing used to analyze the bobbin data so the mix residual signal amplitude does not vary significantly with operating time or NDE analyst. Frequently, a significant part of the mix residual signal is present in bobbin data obtained without a TSP for pulled tubes examined in the laboratory. Some of the model boiler specimens show mix residuals although generally smaller than field data due to the shorter time at temperature. The bobbin response apparently includes an effect of the time at temperature at a TSP on the electrical and/or magnetic properties of the tube. Metallography was performed on a pulled tube to attempt to identify the cause for the signal, but was not successful in identifying any physical change to the tube or grain structure.

Many of the pulled tubes in the ARC database (and the prior cycle probability of detection or POPCD database) have mix residual signals larger than typically found in currently operating SGs. Figure 1 shows the 1.87 flaw voltage and the 3.23 mix residual voltage for pulled tube R27C54 from plant A-1 in the ARC database. This is only one example of the pulled tube data. The flaw signal is easily detectable which would imply easy detection at signal to noise (S/N) of about 0.58 for the associated flaw and mix residual peak-to-peak voltages. As shown in Section 3, a S/N of 0.58 would be expected to have a probability of detection of about 0.25. This indicates that the use of the mix residual as a measure of noise is not appropriate for assessing detection.

The mix residual voltage is not being used, nor should it be used, in current assessments of the influence of noise on detection or sizing. For signal to noise evaluations, the noise is being evaluated as the maximum voltage response over approximately one third sections of the TSP to distinguish the relatively low noise at the center of the TSP from the larger noise near the edges of the TSP. Figure 2 shows the lower and upper TSP noise amplitudes for R27C54-1H. Noise at the middle section cannot be evaluated due to the presence of the flaw. Figure 3 shows the mix residual voltage and noise levels at the center, upper and lower one-third sections of the R27C54-2H TSP, where the mix residual is the same as at 1H. The noise level affecting detection and sizing at the center of the TSP, where most of the TSP ODSCC indications are found, is 0.70 volts peak-to-peak while the edge noise amplitudes are 1.70 and 1.52 volts. These noise levels are in the upper 20% of noise amplitudes expected at TSP intersections. The noise differences between the center and edge affect detectability of short, low voltage indications located at the edges of the TSP. The short indications at the TSP edges must grow to the center of the TSP to become structurally significant and the lower noise levels at the TSP center provide for detection of even low voltage indications. The noise levels in these figures are peak-to-peak amplitudes although the vertical amplitudes are more appropriate for assessing signal to noise for flaw detection. However, the applications of this report are related to amplitude sizing for which peak-to-peak flaw and noise amplitudes are the recommended quantities. Applying the peak-to-peak amplitudes of 1.87 volts for the flaw from Figure 1 and 0.70 volt for the noise at the TSP center from Figure 3, the

S/N for the flaw would be about 2.7 (expected POD about 0.96 from Section 3), which supports the ease of detection found for the flaw. This result is consistent with the recommended use of the flaw and noise evaluated at the TSP center.

The above noise and mix residual discussion demonstrates that it is neither feasible nor necessary to attempt to define bobbin flaw voltages that are not affected by the TSP noise or mix residuals. All indications have negligibly small to a range of noise influence on voltage sizing, and the ARC database includes many indications with larger noise levels than most currently active SGs. Whatever influence the mix residuals may have on voltage sizing for TSP indications is built into the ARC database by the pulled tubes and the concept of misreading voltages is irrelevant to the ARC.

Since nearly all TSP indications are located near the center of the TSP or span the center of the TSP, the appropriate quantity for assessing the influence of noise is the amplitude over approximately the center 1/3 of the TSP between the peaks associated with TSP edge effects. Short indications at the edges of the TSP would not have a significant influence on tube integrity. Amplitude measurements at the area of interest are being applied for tube integrity applications under the EPRI Tools for Tube Integrity Program. These measurements are being utilized to develop ETSSs and PODs based on performance testing of multiple analyst teams. The use of amplitude noise measurements are recommended for ARC noise assessments for consistency with the EPRI methodology for tube integrity applications. The following sections apply the amplitude noise measurements at the center of the TSP to develop RPC repair and inspection requirements for ARC applications.

3.0 Tube Repair Requirements for Indications Found by RPC at Noisy TSP Intersections

3.1 Bobbin Voltage Sizing for Indications Found by RPC

Axial ODSCC indications found only by RPC inspection can be sized for bobbin voltages by the methods described in Section 10.1 of Reference 2. Methods are described based on obtaining voltages from detection at the half-prime frequency and from correlations of bobbin to RPC voltages, which may be pancake or +Point coils. When detection can be adequately obtained at the half-prime frequency, this method is preferred over the bobbin/RPC voltage correlation since the method is closely related to the normal inspection process for detecting and sizing indications. However, it is shown below that both methods yield essentially the same bobbin voltages and that the inferred bobbin voltages are consistent with voltages obtained from the normal primary/secondary/resolution detection and sizing process.

The most extensive inspection of TSP intersections with significant mix residual noise signals was performed at Plant P-1 in 2003. The results of these inspections can be used to demonstrate the adequacy of the bobbin voltage sizing methods. Figure 4 compares the ratio of bobbin voltages in the 400/100 kHz mix to the 200 kHz volts for indications reported in the normal primary/secondary/ resolution analysis process to the ratios obtained from detecting the flaw (identified by the RPC) on the 200 kHz channel and using the inferred mix signal measurement with no additional adjustments. It is seen that the distributions obtained from both sizing methods are equivalent, which supports the adequacy of sizing by identifying the flaw in the half-prime frequency signal and obtaining voltages from the mix signal. Figure 5 compares the regression correlations of bobbin to +Point volts obtained using the normal inspection process with that obtained from the half-prime frequency analyses. The bobbin to RPC voltage correlations are essentially the same for both analysis methods. Since Figure 4 shows the adequacy of sizing from detection in the half-prime frequency and Figure 5 shows that correlations of bobbin to RPC volts are the same between the normal ODSCC sizing and half-prime

frequency analyses, it can be concluded that both of the methods for bobbin voltage sizing of RPC indications yield essentially the same bobbin voltages and both methods are acceptable for ARC applications.

3.2 Tube Repair Requirements for Indications Found by RPC at Noisy TSP Intersections

As noted in Section 1, the industry interpretation of GL 95-05 is that indications associated with large mix residuals and found only by RPC should be repaired if the inferred bobbin voltage is ≥1.0 volt. This repair limit is inconsistent with the differences in repair limits between 3/4" and 7/8" tubing. Since a bobbin voltage is assigned to the indications found only by RPC and the indications are included in the condition monitoring and operational assessments, there is no need to apply repair limits more conservative than the licensed repair limits.

For consistency in ARC repair limits, it is recommended that the following tube repair limits be applied for indications found only by RPC:

- Based on bobbin voltages determined by the methods of Reference 2 from indications found only by RPC inspection, indications with inferred bobbin voltages exceeding the licensed plant specific bobbin voltage repair limit are to be repaired. The GL 95-05 repair limits are > 1.0 volt for 3/4" tubing and > 2.0 volts for 7/8" tubing. Some plants may have larger repair limits such as obtained from locked TSP intersections.

- This repair limit applies for RPC indications found at noisy TSP intersections and at dented TSP intersections for dents of any voltage. For indications found at TSP intersections with both ODSCC and PWSCC indications for plants having a licensed PWSCC ARC, the above repair limit can be applied only if consistent with the licensed requirements.

- The bobbin voltages obtained by the Reference 1 methods from RPC testing of noisy TSP and dented TSP intersections are to be included in the ARC condition monitoring and operational assessments.

4.0 RPC Inspection Requirements for Noise at TSP Intersections

The selection of noisy TSP intersections for potential RPC inspection is to be based on POD versus signal/noise (S/N) correlations for axial ODSCC at TSP intersections. When available, the POD vs. S/N correlations for noise levels at the center of the TSP as obtained from ETSSs based on multiple analyst testing should be applied. Until these ETSS POD correlations are available, the POD vs. S/N correlation from SSPD testing of multiple analysts described in Reference 3, as shown in Figure 6, is to be applied. Figure 6 is based on flaw and noise peak-to-peak amplitudes to permit application of peak-to-peak voltage repair limits in defining S/N. For more general applications of S/N for detection, the vertical max voltages would be used as this quantity is more closely tied to NDE detection methods.

The GL 95-05 repair limits are the appropriate limits for detection of indications found at noisy TSP intersections based on burst and leakage considerations. The lowest voltages found for leaking indications in the ARC database (Reference 2) is 1.13 volts for 3/4" tubing and 2.81 volts for 7/8" tubing. The leak rates for these two indications were very small at 0.000088 and 0.00035 gpm, respectively. Thus, indications below the GL 95-05 repair limits would not be expected to leak and, if they do leak, would have a negligible leak rate. The probability of burst for indications at the GL 95-05

repair limits are less than about 5×10^{-6} for both 3/4" and 7/8" tubing, and thus undetected indications below the repair limits would have a negligible contribution to the burst probability. The GL 95-05 repair limits are to be applied to develop the inspection requirements of this section even for plants with higher licensed repair limits in order to assure that indications with potential significant leakage are included in the ARC analyses.

A S/N value for a nominal POD of 0.9 is to be obtained from the POD versus S/N correlation for axial ODSCC peak-to-peak amplitudes at the center of the TSP. For plants licensed to apply the Probability of Prior Cycle Detection (POPCD) for operational assessments, the POD value to be applied to obtain S/N values is the nominal POPCD POD at the appropriate GL 95-05 repair limit. The use of POPCD distributions at 1.0 and 2.0 volt repair limits would likely lead to POD values within about ± 0.05 of 0.9. The use of a POD on the order of 0.9 to define a S/N value at the ARC repair limit assures that the detection for ODSCC at noisy intersections is consistent with or conservative relative to the POD used in ARC operational assessments. From Figure 6, the associated S/N value for a POD of 0.9 is 1.9. To obtain a noise threshold for potential RPC inspections, detection at a POD of 0.9 (or that from POPCD at the repair limit when POPCD is licensed) is applied to obtain the S/N value and the signal, S, is applied at the ARC repair limit. The noise threshold value for the mix at the center of the TSP is then 0.53 volt for a repair limit of 1.0 volt and 1.05 volt for a repair limit of 2.0 volt. As noted, these values are to be updated when the EPRI ETSS POD versus S/N correlations from multiple analyst testing are available.

Noise evaluations should be performed for a minimum of 100 hot leg TSP intersections per SG to identify noisy TSP intersections. Since the TSP noise levels do not change significantly from cycle to cycle, the noise analyses may be performed on the bobbin data from the last inspection or the current inspection. RPC inspection shall be performed for a minimum of 25 intersections (total summed over all SGs) exceeding the noise threshold values. The noise measurements shall be made at the TSP intersections where most of the ODSCC indications are found, which are typically the lower three hot leg TSPs. If this sample does not identify at least 25 intersections with noise levels exceeding the noise threshold values, the noise evaluation sample size shall be increased to include an additional 100 TSP intersections per SG to obtain a total noise sample population of 200 TSP intersections per SG to identify intersections for RPC inspection. The RPC inspection shall then be performed at the 25 TSP intersections with the highest noise levels in the noise analysis population evaluated.

If axial ODSCC indications are found in the sample RPC inspection, the following guidelines are to be applied to determine whether an expansion of the inspection is required:

- If the inferred bobbin voltage of any indication found in the RPC inspection of noisy TSP intersections (sample with noise exceeding threshold values) is found to exceed the GL 95-05 repair limits of 1.0 and 2.0 volts for 3/4" and 7/8" tubing respectively, the noisy TSP intersection RPC inspection shall be expanded to include an additional 100 TSP intersections with the next highest noise levels in the noise sample population. If this inspection expansion identifies a flaw with a bobbin voltage exceeding the GL 95-05 repair limit, the inspection should be expanded in 100 sample increments until one of the samples is found with no indications exceeding the GL repair limit.

- The fraction of TSP intersections inspected that are found to have axial ODSCC indications defines an average undetected fraction, or 1-POD, for the base inspection since the RPC inspection is a supplemental sample inspection applied to assess the adequacy of the base inspection. If the operational assessment applies the GL 95-05 POD of 0.6, the associated undetected fraction is 0.4.

If POPCD is applied for the operational assessment, the average bobbin voltage for the ODSCC indications should be used to determine an average or expected POD for the indications by application of the latest licensed nominal industry or plant specific POPCD distribution (Figure 7 provides the industry POPCD distribution although an updated industry POPCD is under preparation). The expected POD is defined as the POPCD value at the average bobbin voltage for the ODSCC indications found by RPC inspection. If the sample fraction of intersections with detected flaws in the RPC inspection (undetected in base inspection) is greater than the expected 1-POD (0.4 if POPCD is not licensed) by more than a 0.1 difference, the inspection should be expanded in 50 sample increments (applying next highest noise levels in the noise sample population) until one of the samples is found with an average POD equal to or greater than the expected POD. This requirement is applied to provide reasonable confidence that the detection capability in noisy tubes is comparable to that used in the operational assessments for the overall population of indications.

The required expansion sample size of 50 samples for the POD comparison is smaller than the 100 samples required if an indication is found to exceed the repair limits. This difference is applied to reflect the significance on the operational assessment between the two conditions. Undetected indications left in service below the GL 95-05 repair limits are expected to have a negligible impact on leakage or burst as described above.

Examples of peak-to-peak amplitude noise distributions are shown in Figure 8 for a plant with 3/4" tubing and for a preliminary version (dataset currently being finalized) of the noise distribution for indications planned for performance testing to development ETSSs under the EPRI Tools for Tube Integrity Program. The preliminary ETSS and plant noise distributions are very similar. For a plant with 3/4" inch tubing and a 0.53 volt noise threshold for potential RPC inspection, about 40% of the intersections exceed this level. The sample inspection would start at the highest noise levels in the distribution. Due to the low 1.0 volt repair criterion, the noise threshold for RPC inspection is very conservative. The noise distributions for plants with 7/8" tubing are expected to be similar to those in Figure 8. For the associated 1.05 volt noise threshold with 7/8" tubing, less than 5% of the TSP intersections would be expected to exceed this threshold. The sample size applied to develop the noise distribution for 7/8" tubing may have to be expanded to 200 TSP intersections per SG in order to identify the 25 intersections with the highest noise levels for RPC inspection. It can be noted that the POD versus S/N curves, such as Figure 6, are used to assess differences in noise levels and a plant specific noise distribution does not have to be bounded by the noise distribution used in developing the POD correlation.

5.0 Conclusions

The use of mix residuals to characterize noise at TSP intersections was initiated in the early 1990s and is shown in this report to be a poor measure of the influence of noise on detection. The noise at TSP intersections for bobbin probes varies significantly between the center and edges of the TSP whereas the mix residual is a single measure of noise across the entire TSP. Since nearly all ODSCC indications at TSP intersections extend through the center of the TSP, the noise levels at the TSP center provide the best measure of noise for the influence on detection and amplitude sizing. The few indications found only at the edges of the TSP that could be masked by the higher noise levels are very short and would have negligible impact on burst and leakage. Therefore, it is recommended that the ARC noise methods be based on evaluations of the noise amplitude at the center of the TSP.

The EPRI Tools for Tube Integrity Program is developing ETSSs based on performance testing of multiple analysts. Noise analyses are an integral part of this program with noise analyses for tube integrity applications based on measurements of the noise amplitudes at the regions of interest. As part of this program, PODs as a function of S/N are being developed. These correlations permit identification of the noise level that supports a specified POD level at the ARC voltage based repair limits. The recommended threshold noise value for RPC sampling of noisy intersections is based on obtaining a POD of 0.9 at the ARC repair limits of 1.0 and 2.0 for 3/4" and 7/8" tubing, respectively. Plant noise analyses for a minimum of 100 TSP intersections per SG are recommended to characterize the plant specific noise levels. If this sample does not identify at least 25 intersections with noise levels exceeding the noise threshold values, the noise evaluation sample size shall be increased to include an additional 100 TSP intersections per SG to obtain a total noise sample population of 200 intersections per SG to identify intersections for RPC inspection. The 25 TSP intersections with the largest noise levels are recommended for RPC inspection. If an axial ODSCC indication exceeding the ARC repair limit of GL 95-05 is found in the noise sample inspection, the inspection would be expanded by steps of 100 TSP intersections until no ODSCC indication exceeding the repair limits is found in the 100 intersection sample. The inspection would also be expanded in steps of 50 TSP intersections if the fraction of indications found in the RPC inspection, which represents the fraction undetected in the base inspection, exceeds the undetected fraction expected from the POD used for operational assessment by more than 0.1. Bobbin flaw amplitudes for the RPC indications can be obtained either by identification of the flaw in the half-prime frequency response or by correlations of bobbin to RPC voltage. It is shown by plant data that these two methods yield very similar bobbin voltages and voltages consistent with the normal primary/secondary/resolution analysis.

It is recommended that indications found by the RPC inspection be repaired if they exceed the licensed plant specific repair limit based on bobbin voltages assigned to the RPC indications. This provides a consistent ARC repair limit independent of how the indication was found in the inspection. Based on the bobbin voltages assigned to the indications, all indications found in the RPC inspection are to be included in the ARC condition monitoring and operational assessments. The bobbin voltages for the RPC indications are adequately defined to obtain tube integrity margins consistent with all bobbin indications, and there is no need to define different repair limits for the indications found by RPC. Since indications found by RPC inspection in dents > 5 volts can be adequately sized using correlations of bobbin to RPC volts, it is also recommended that repair for these indications be based on the plant specific voltage based repair limits. Since GL 95-05 requires 100% inspection of all dents > 5 volts, no additional inspection or expansion requirements are necessary for the dented TSP intersections.

6.0 References

1. Generic Letter 95-05, "Voltage-Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking," dated August 3, 1995
2. EPRI Topical Report NP 7480-L, Addendum 5, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits, Update 2002," dated January 2003.
3. EPRI Report, unpublished, "Assessment of Bobbin Coil Noise Analysis Methods for Tube Integrity Applications," July 2003

Figure 1. Flaw and Mix Residual (400/100 Mix) for Plant A-1 Pulled Tube R27C54-1H

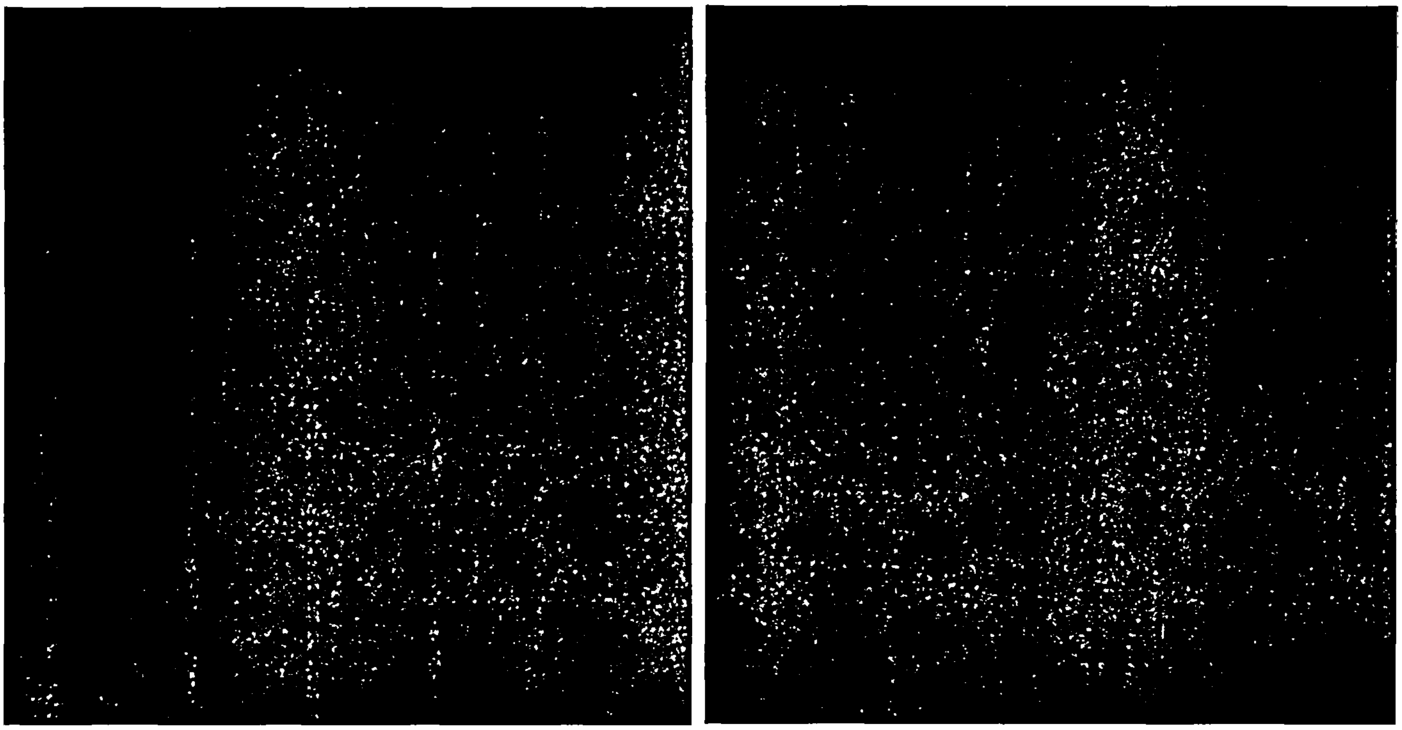


Figure 2. Upper and Lower TSP Noise Signals for Plant A-1 R27C54-1H
(Center 1/3 of TSP Cannot be Evaluated Due to Flaw Signal)

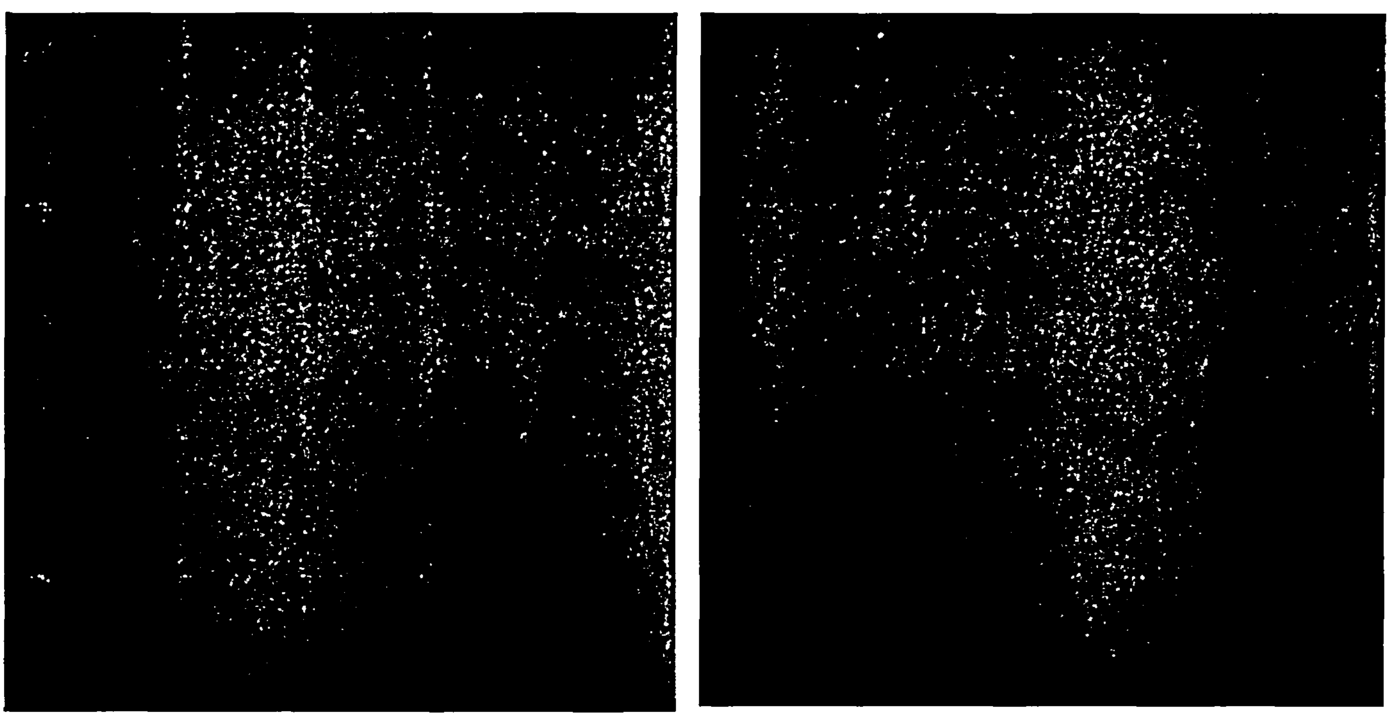


Figure 3. Mix Residual and Center, Upper and Lower 1/3 TSP Noise Signals (400/100 kHz Mix) for Plant A-1 R27C54 at 2H

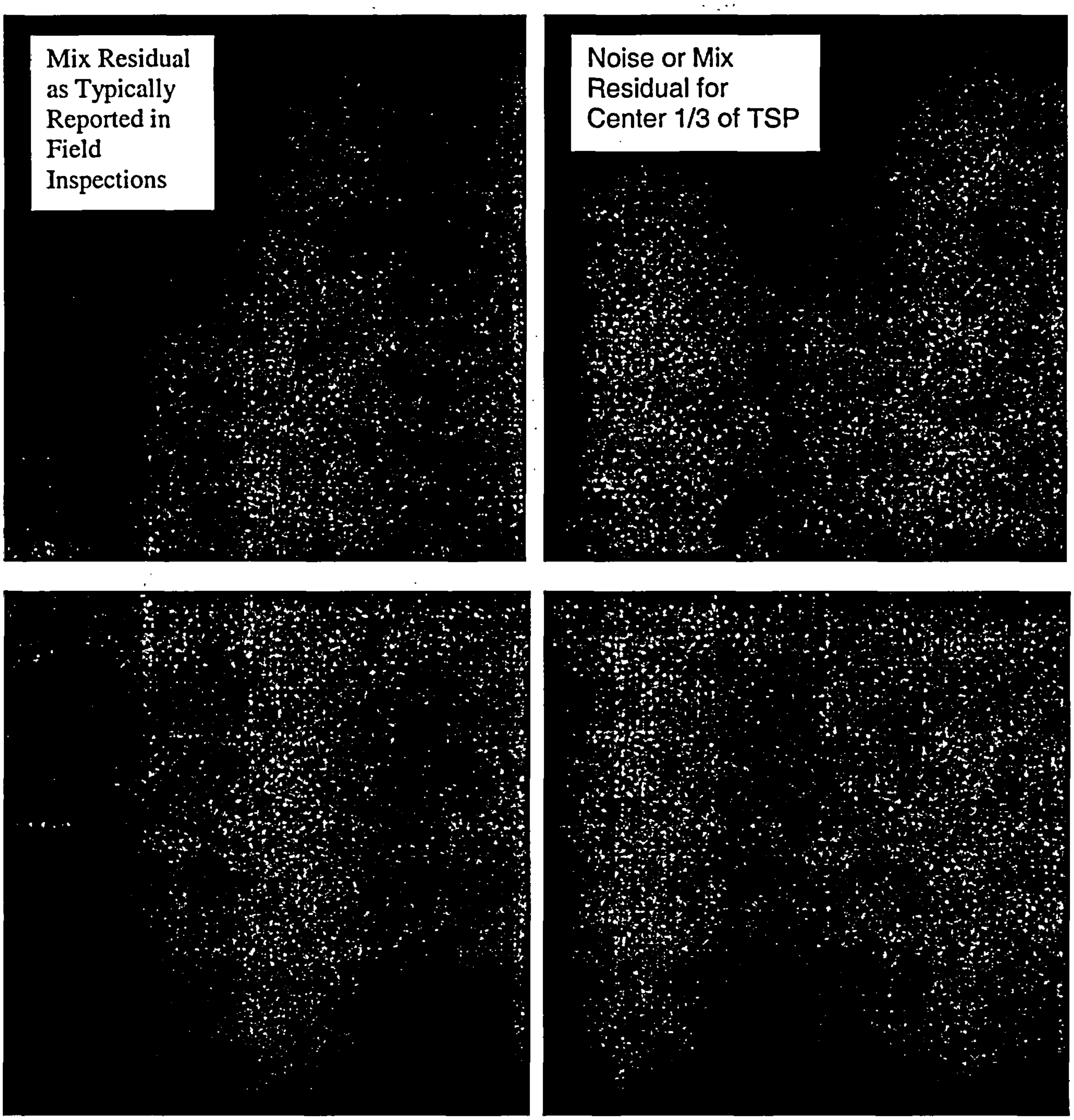


Figure 4

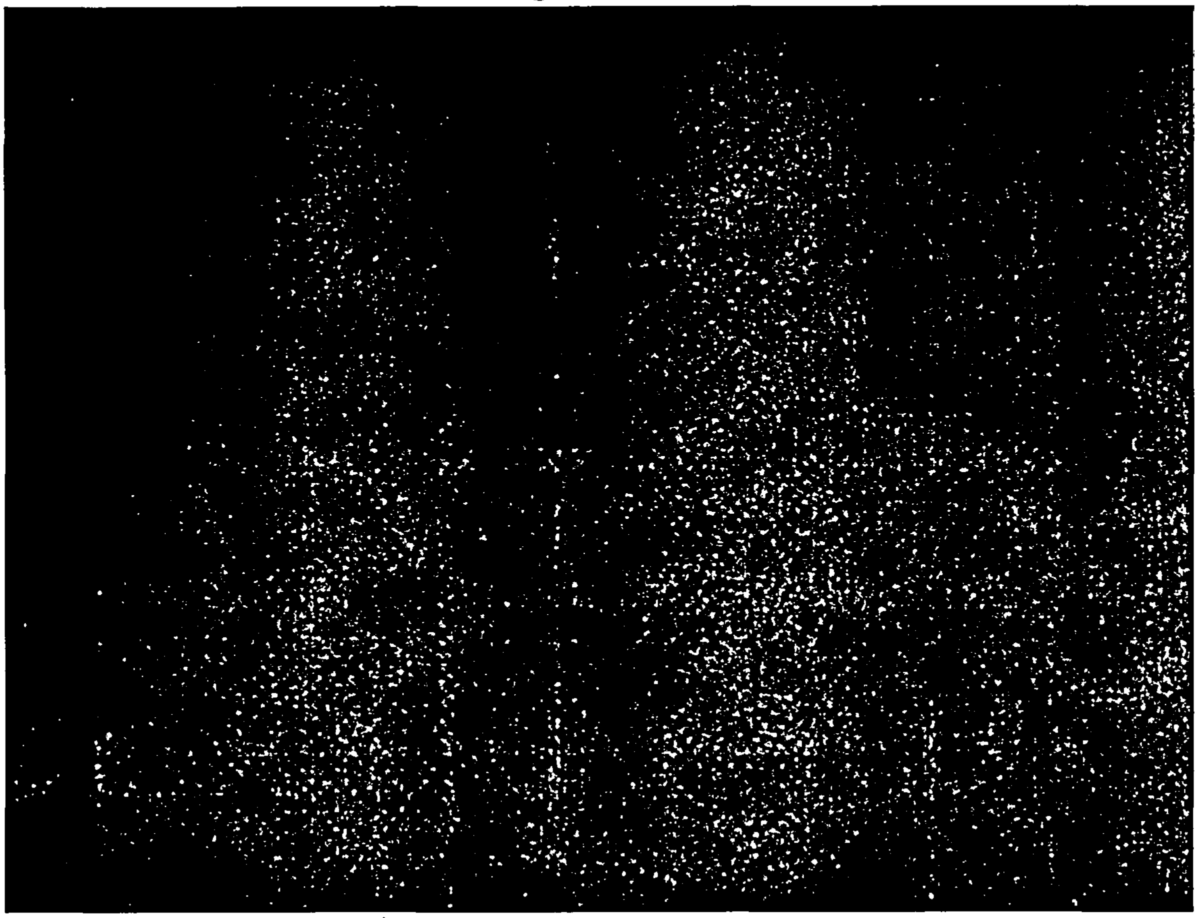


Figure 5

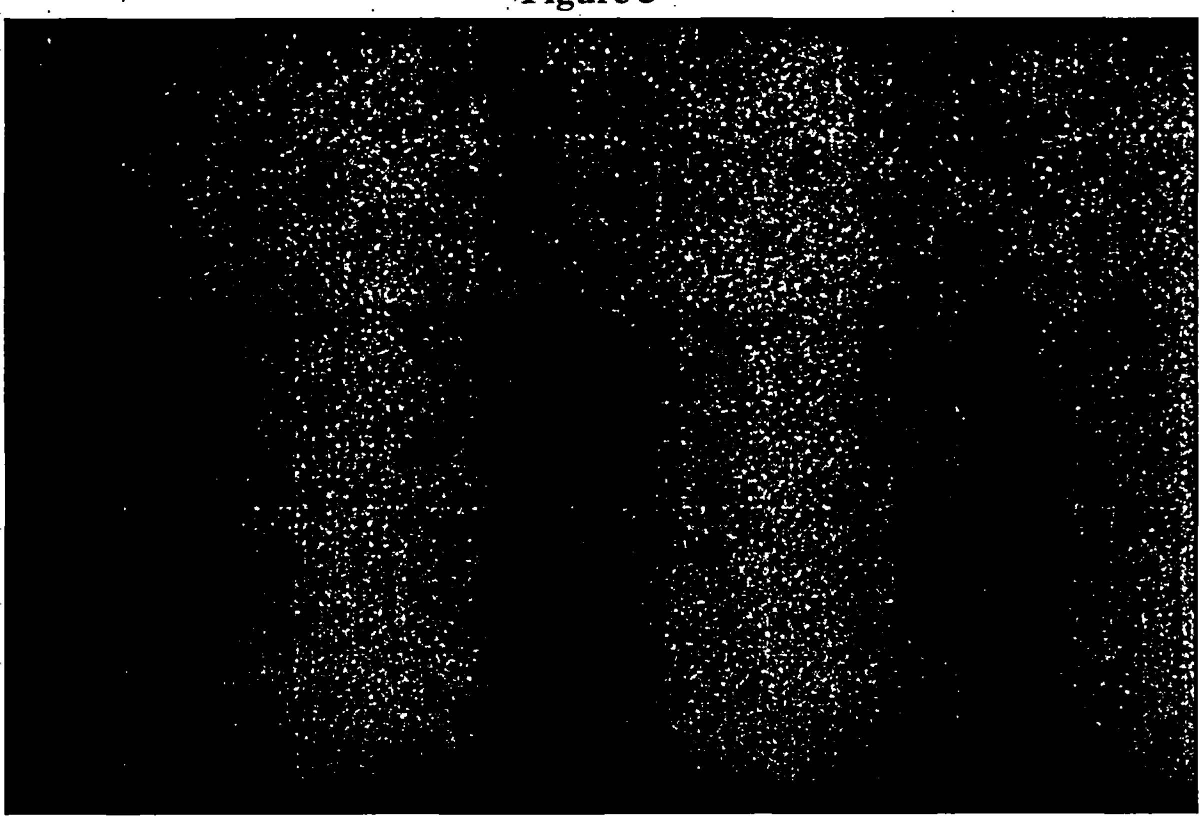


Figure 6

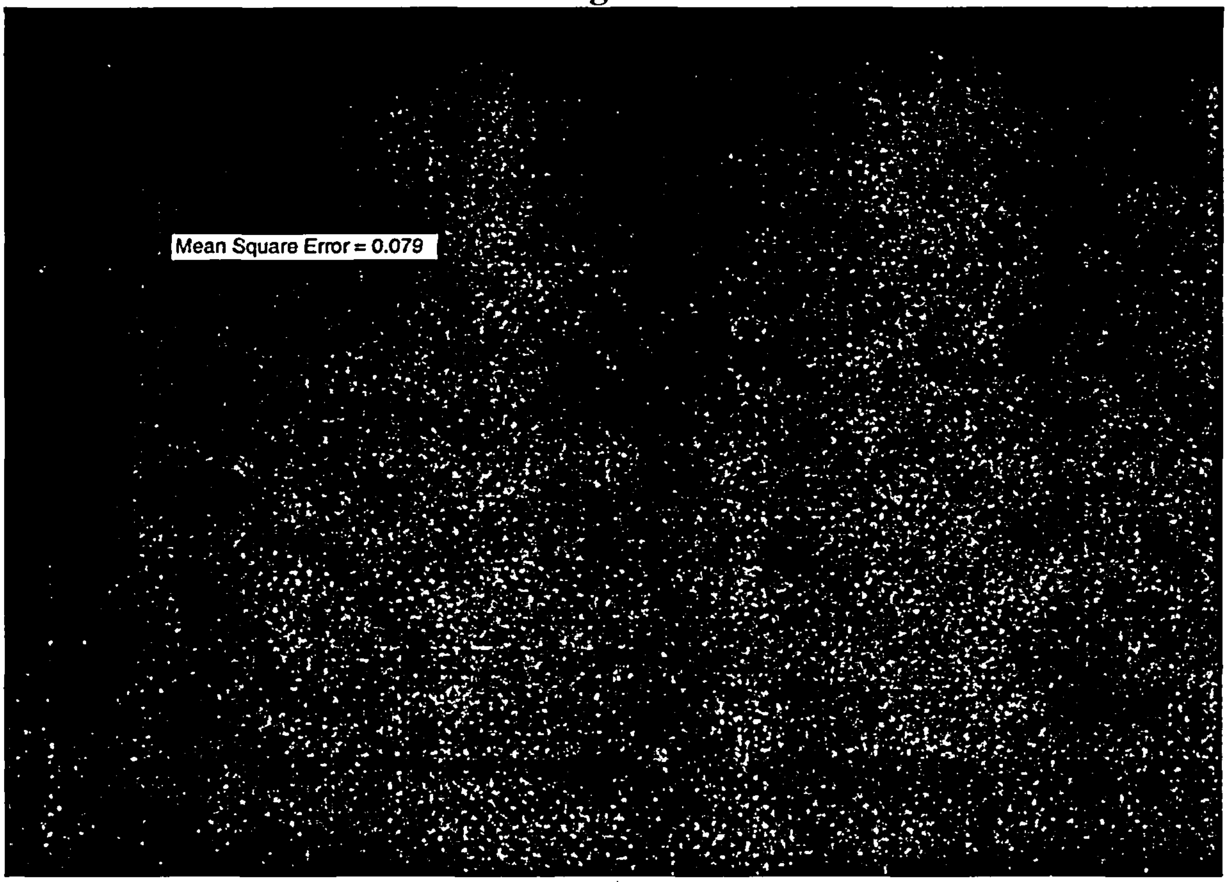


Figure 7 (update in process)

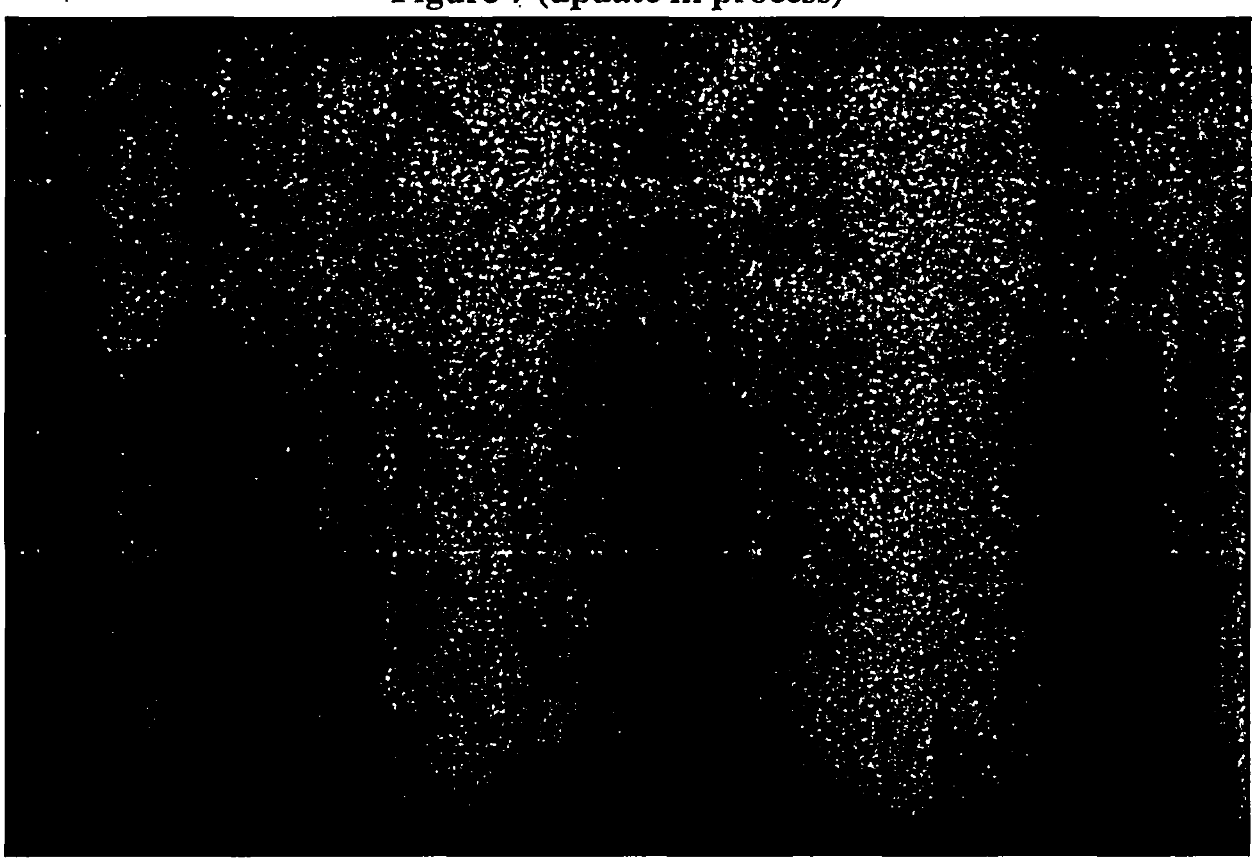


Figure 8