UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
COMMONWEALTH EDISON COMPANY	)	Docket No. 50-454-OLA
	)	50-455-OLA
(Byron Station, Units 1 and 2)	)	

TESTIMONY OF DANIEL D. MALINOWSKI CONCERNING STEAM GENERATOR TUBE INTEGRITY (INSPECTION AND EDDY CURRENT TESTING)

Submitted on behalf of
the Applicant, Commonwealth Edison
Company in Response to DAARE/SAFE
Contention 9c and League Contention 22

February 25, 1983

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SUMMARY

The testimony of Daniel D. Malinowski addresses the inspection aspects of the steam generator tube degradation issue. Mr. Malinowski sets forth his credentials qualifying him as an expert witness and describes the inspection program and techniques used for the detection of steam generator tube degradation. Specifically, NRC Regulatory Guide 1.83 provides a basis for determining inspection intervals and selecting the appropriate sample of tubes for inspection; and eddy current testing serves as the primary tool for detecting tube degradation.

Mr. Malinowski describes the capability and sensitivity of eddy current testing to detect the various forms of tube degradation. The sensitivity of eddy current testing varies from 20% (e.g., tube wall thinning) to 40% (e.g., tube wall cracking) of the depth of the tube wall. The uncertainties associated with eddy current testing are accommodated by an allowance, i.e., a percentage of tube wall thickness that is included as a part of the tube plugging criterion. The combined allowance for eddy current measurement uncertainties and the rate of continued tube degradation is 10% of the tube wall thickness.

Mr. Malinowski concludes that eddy current testing, given the 10% allowance described above, is adequate to detect tube degradation at or below the 40% tube plugging criterion. Thus, tube degradation of significance is expected to be detected by eddy current testing.

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TESTIMONY OF DANIEL D. MALINOWSKI CONCERNING STEAM GENERATOR TUBE INTEGRITY (INSPECTION AND EDDY CURRENT TESTING)

Q.1. State your name, address and present occupation.

A.1. My name is Daniel D. Malinowski. My business address is P.O. Box 855, Pittsburgh, Pennsylvania 15230. I am employed by Westinghouse Electric Corporation as a Manager of Field Data Analysis in Steam Generator Programs of the Water Reactors Division.

Q.2. State your educational background and professional work experience.

A.2. I graduated from Duquesne University in 1959 with a B.S. Degree in Chemistry. In 1963, I received an M.S. in Chemistry from the Massachusetts Institute of Technology, where my area of specialization was Nuclear Chemistry. I received a Juris Doctorate

degree from the Duquesne University law school in 1976.

From February 1963 until March 1967, I was employed by Westinghouse Electric Corporation at the Bettis Atomic Power Laboratory. I worked as a Scientist in the Radiochemistry Section where my activities included radiochemical assay, computer analysis of plant follow data, and supervision of radiochemical evaluation of naval reactor cores at initial criticality testing.

From March 1967 to June 1968, I was employed by the Tracerlab Division of Laboratory for Electronics (LFE, Inc.) in Waltham, Massachusetts as a Staff Chemist in the Technical Services Department. My duties included supervision of Radiochemical Laboratory activities, development of radioassay procedures, and direction of subcontract work in radiochemical evaluation of naval nuclear cores.

I resumed my employment with Westinghouse in July 1968 when I accepted a position as Senior Engineer with Westinghouse Nuclear Energy Systems in the Chemistry and Chemistry Operations Groups located at Forest Hills, Pennsylvania.

In December 1973, I began working on analyses of steam generator in-service experience and inspection trends evaluation. In October 1975, after my appointment as a Principal Engineer, I organized and directed a task force whose goals were to assemble and evaluate design, inspection, and operational data from Westinghouse-designed steam generators. I was promoted t· my present position, Manager of Field Data Analysis, in June 1977.

Q.3. Please describe your work responsibilities as they concern steam generator tube integrity matters in more detail.

A.3. Since December 1973 to the present time, my work assignments at Westinghouse have related directly to programs addressing steam generator tube integrity matters. I have assisted in the overall coordination of laboratory and in-plant activities relating to corrosion studies, steam generator tube inspections, and water chemistry specifications. I have also participated in the assembly and evaluation of operating plant data from steam generators, including the development of expedited and automated methods of data evaluation, processing and transmission. My duties included presenting Westinghouse water chemistry recommendations to present and

future nuclear power plant operators, and monitoring the development of nondestructive testing methods for steam generator tubes, especially eddy current testing.

In June 1977, a Steam Generator Data Analysis Group was formed as part of the Nuclear Steam Generation Division. I was appointed manager of this Group. This responsibility encompasses diagnostic reevaluation of eddy current inspection tapes, development of improved eddy current techniques, and evaluation of inspection results from operating plants.

Q.4. What is the purpose of your testimony?

A.4. My testimony addresses several of the mechanisms used to preserve the integrity of the steam generator tubes. Specifically, my testimony explains (i) the inspection program and techniques for the detection and evaluation of steam generator tube degradation, and (ii) the bases for determining the allowances for eddy current testing uncertainties and corrosion rates which are incorporated into the tube plugging criteria.

Q.5. Why is there a need for the inspection of steam generator tubes?

Q.5. Why is there a need for the inspection of steam generator tubes?

A.5. It was recognized early in the operating experience of the first PWR's that steam generator tube leaks might occur as a result of service-induced wall degradation. To minimize the potential for such leakage events, it is prudent to identify tubes which are or likely may become degraded sufficiently during the subsequent period of operation to cause excessive leakage. This is accomplished by a program of inspection which will give confidence that all such tubes have been found and repaired. Indeed since steam generator tubing is a part of the reactor coolant pressure boundary, periodic inspection must be provided for General Design Criterion 32 of 10 C.F.R. Part 50 Appendix A.

Regulatory Guide 1.83 "Inservice Inspection of Pressurized Water Reactor Steam Generator Tubes" Rev. 1 July 1975 represents the NRC Staff's guidance to PWR operators on the approach to be taken to satisfy the requirements of the General Design Criteria.

Q.6. What does the Staff's guidance in Reg. Guide 1.83

recommend with respect to the inspection interval for steam generators?

A.6. NRC Regulatory Guide 1.83 provides a basis for monitoring steam generator tube integrity beginning with a 100% pre-service inspection. Thereafter, the first in-service inspection may be performed during the plant's first refueling outage, but in any event, within 24 months of startup. The interval between inspections may be lengthened to 40 months if two consecutive in-service inspections reveal insignificant evidence of tube degradation.

I would stress that steam generator tube inspections are both prudent and required by technical specifications and their frequency depends on relevant experience either in the particular plant or in similar plants. More frequent inspections may be recommended if experience from similar operating steam generators indicates the possible existence of tube degradation phenomena not previously identified in a given plant.

Q.7. Are 100% of the tubes inspected in the first in-service inspection?

A.7. Generally no. The usual approach laid out in the

plant's Technical Specifications calls for sampling 3% of all the tubes in the plant. This sample is selected on a random basis unless experience from similar steam generators indicates specific problem areas in the tube bundle. In this event, the sample distribution is focused on the problem areas to enhance the probability of detecting tube degradation in the problem areas.

The scope of the inspection may be expanded to cover 100% of the tubes in circumstances where either (i) greater than 10% of the tubes inspected have eddy current indications greater than 20%, or (ii) greater than 1% of the tubes inspected exceed the plugging criterion. This procedure applies to each of the steam generators inspected, e.g., at least two in a four-loop plant; the other steam generators will be inspected if either of the first two steam generators require the expanded inspections described above.

With respect to inspections subsequent to the first in-service inspection, all unplugged tubes previously identified to have eddy current indications greater than 20% must be inspected in addition to the 3% sample provided by the Technical

Specifications. So long as significant new tube degradation is observed during the in-service inspections, two or more steam generators (out of four) must be inspected. If two consecutive in-service inspections indicate only insignificant progression of tube degradation, subsequent inspections may be performed in only one steam generator on a 40-month rotating basis.

Q.8. Can steps be taken to insure that the next in-service inspection will be conducted before tube degradation has progressed to the point where a tube might fail?

A.8. Yes. If a significant rate of tube degradation is determined as a result of an in-service inspection, measures are available to reduce the probability that tube leakage will occur before the next scheduled inspection. These measures include alterations of the steam generator environment to reduce the degradation rate such as temperature changes, water lancing, flushing and chemical cleaning; mechanical or design modifications; fore-shortening the interval between inspections; and increasing the allowance for corrosion by lowering the tube plugging limit.

Q.9. How is the rate of degradation determined?

A.9. The rate of tube degradation experienced during a specific interval of operation is determined by comparing the current inspection results for specific locations with prior results for the same locations. These changes, or deltas, may range from small negative values (arising from measurement uncertainties) to positive values which combine true increases with measurement errors. All deltas appropriate to the specific tube degradation phenomenon are analyzed to yield the average rate of change. This figure is then divided by an expression representing the time of operation e.g., calendar time, operating time, effective full power time; the result is the rate per unit time applicable to the tube degradation observed.

Q.10. Is the tube degradation rate taken into account in establishing the tube plugging criterion?

A.10. Yes. As explained in the testimony of Dr. Patel, a tube plugging criterion is obtained by determining the structural limit for tube degradation in faulted conditions, reducing that value to account for measurement uncertainty and to provide allowance for finite tube degradation during the anticipated operation interval preceding the next inspection.

In practice, this means that a value for a potential corrosion rate is preset by reference to industry and/or laboratory experience for the particular material and environment applicable to the steam generator tubing. If no specific form of tube degradation is foreseen, a combined allowance of 10% for corrosion and measurement error is used. Upon observation of tube degradation in an in-service inspection, the actual degradation rate calculated as indicated above is employed to justify the interval of operation before the next in-service inspection; it may also be used to calculate a revised tube plugging criterion.

Q.11. Is a degradation rate allowance established for a new plant like the Byron Station?

A.11. A new steam generator goes into service with a considerable reserve against tube degradation, i.e., nominally all tubes start with a 50% margin for degradation based on the ASME Code-established structural limit. Since no systematic tube degradation is expected, the 10% combined allowance for tube degradation and measurement error is assigned by the ASME Code, resulting in a tube plugging criterion of 40%.

Q.12. What inspection technique is used to detect steam generator tube degradation?

A.12. Steam generator tube degradation inspection is accomplished with eddy current testing, as recommended by U.S. NRC Regulatory Guide 1.83, and in accordance with Appendix IV "Eddy Current Examination Method of Nonferromagnetic Steam Generator Heat Exchanger Tubing" of the ASME Boiler and Pressure Vessel Code, Section XI "Inservice Inspection of Pressurized Water Reactor Steam Generator Tubes."

Q. 13. How does the eddy current system for inspecting steam generator tubes work?

A. 13. An internal sensing probe, upon which electrical coils are mounted, is inserted into a steam generator tube. The probe is attached to a conduit which houses electrical cables. It is then pushed through the tube for the length desired to be inspected. The coils are excited electrically by an alternating current, creating a magnetic field around the coils and inducing eddy currents in the tube wall. The probe is pulled at constant speed back to the tube entrance. Wherever the tube wall contains a discontinuity, the eddy currents will be disturbed, causing a change in the electrical

impedance as measured at the terminals of the test coils. These changes are observed as output voltages and read out onto a strip chart recorder and a magnetic tape recorder. They are then viewed as Lissajous figures on an oscilloscope display. By comparing these figures, resembling figure "8's" in the differential form, with the corresponding figures generated from an ASME drilled hole calibration standard with known simulated defects, it is possible to determine the depth, length and volume of material affected on the sample tube.

Eddy current testing is usually performed using an instrument which impresses four different test frequencies on the coil simultaneously. The frequencies are selected on the basis of providing definitive information on tube degradation, support plates, and external deposits. Since the responses for external discontinuities vary according to the test frequency, it is possible by linear combinations of the responses at different frequencies to reduce unwanted signals from a composite response. The most common use of mixing is to eliminate expected, normal signals from tube support plates to enhance detection of tube degradation at the edge of the support plates. It

can also be used to reduce signals from magnetic deposits like magnetite and conductive deposits like copper. Reduction in signals from tube deformation may also be accomplished by mixing to enhance the eddy current sensitivity for tube degradation in deformed tube regions.

Q. 14. What can eddy current testing detect?

A. 14. Eddy current testing of tubes will detect discontinuities in conductivity and magnetic permeability resulting from tube wall degradation, tube deformation, magnetic and conductive deposits, external structures and changes in these features from prior inspection results. Such discontinuities can be caused by denting, tube wall thinning, tube wear, pitting, cracking, and intergranular attack.

Q.15. What is the capability of eddy current testing to identify the type of steam generator tube degradation, e.g., thinning vs. cracking?

A. 15. By itself, an eddy current signal does not give a clear indication of its cause. Certain signals may be characterized in conjunction with their location and orientation, e.g., denting signals. However, denting is not a form of tube degradation but rather a form of tube deformation that is readily detected

by eddy current testing. Signals produced by tube wall penetration may appear similar whether caused by cracking, thinning, or other forms of degradation. To help identify the type of degradation, inferences may be drawn from related information; e.g., statistical distribution of all similar observations, location with respect to steam generator design features, plant operating experience, prior inspection results from similar steam generators and the chemical environment. However, the only absolute means of confirming the form of tube degradation found is by direct observation, including the removal of the tube and by metallographic examination.

Q. 16. Is eddy current testing an adequate means for detecting tube degradation?

A. 16. Eddy current testing is considered to be adequate if its sensitivity to detect tube degradation is at or below the plugging criterion, generally 40%.

Q. 17. Does eddy current testing meet this objective?

A. 17. Generally speaking, yes. However, the sensitivity of an eddy current system to tube wall degradation varies depending on the size, shape and nature of the degradation. The sensitivity of the system to

any particular type of discontinuity further depends on its location relative to such items as the tubesheet or the tube support edge, the regions with tube deformation, such as tangent points of U-bends, denting-related deformation and roll transitions, sludge, copper plated tube regions, and the tubesheet region. To account for such factors, a combined allowance of 10% for eddy current measurement uncertainty and tube degradation is incorporated in the derivation of the tube plugging criterion established by the ASME Code.

Q.18. What is the sensitivity of eddy current testing?

A.18. The sensitivity of the eddy current systems presently in use for steam generator inspections is in the range of 20 percent to 40 percent depth of the tube wall. This figure varies depending on the type of degradation, its extent and location. These types of degradation have been previously described in my testimony as tube wall thinning, pitting, cracking, intergranular attack, and tube wear as forms of steam generator tube degradation.

Q.19. What is tube wall thinning?

A.19. Tube wall thinning is a localized reduction in the

tube thickness resulting from corrosion by phosphates in high concentrations. It has been observed within sludge piles at the top of the tubesheet and at tube support plate elevations, where lower flow velocities allowed concentration of phosphates to saturation levels.

Q.20. What is the sensitivity of eddy current testing for detecting tube wall thinning?

A.20. The sensitivity of eddy current testing for tube wall thinning is reliable at 20 percent depth of the tube wall based on laboratory simulations of this condition. In fact, indications in the field data from penetrations less than 20 percent (in the range of 10 percent or lower) can often be observed. The detectability of shallow thinning by eddy current testing has been confirmed by tube pulls from operating plants. The data on pulled tubes further show that eddy current testing overestimates the depth of discontinuities resulting from tube wall thinning, an inherent conservatism.

Q.21. What is pitting?

A.21. Pitting is a form of tube degradation that involves small discrete roughly circular regions of tube penetration typically less than 100 mils in

diameter. Pits may occur separately or in bands wherein each pit acts independently of others within the band. Pits resemble the drilled holes utilized as the ASME calibration standards.

Q.22. What is the sensitivity of eddy current testing for detecting pitting?

A.22. The eddy current sensitivity for pitting is reliable at 20 percent depth of the tube wall. In the one case where significant pitting has been observed in Westinghouse steam generators, it was strongly associated with deposits of copper on the tubes affected. Because of the high conductivity of copper metal, interference signals coincident with pitting signals degraded the sensitivity of the eddy current testing. By simulating the pitting in laboratory samples and by modifying the eddy current probe, the test frequencies and the mixing technique, it was possible to restore sensitivity at approximately 30 percent depth.

Q.23. What is tube wall cracking?

A.23. Tube wall cracking is a linear degradation phenomenon that occurs in discrete or network configurations, leaving the bulk of the tube material intact with its original properties undiminished. The

degraded local region or crack face may extend through the entire wall thickness.

Depending upon the orientation of tube wall stresses, cracks may initiate from the outside diameter or the inside diameter of the tube. Cracks may be axially oriented or circumferential in nature. All tube wall stress corrosion cracks detected in Westinghouse designed steam generators have been intergranular in nature, i.e., there has been no observation of transgranular cracking.

Q.24. What is the sensitivity of eddy current testing to detect the various forms of cracking discussed in your previous answer?

A.24. The eddy current sensitivity for outside diameter axial cracking is reliable at 40 percent depth of the tube wall. This level is confirmed by work performed by Westinghouse and others using machined slots and laboratory-induced cracks.

The eddy current sensitivity for outside diameter cracking which is circumferentially-oriented is 40 percent. This type of discontinuity is likely to occur in regions of tube deformation. The eddy current signal resulting from the deformation can

interfere with detection of cracks when the bobbin-type probe is used during general inspections. If such interference causes inconclusive eddy current results, probes with surface-riding capabilities are employed on a sample of tubes. The surface-riding probes reduce the effect of the interfering signal sufficiently to restore the 40 percent sensitivity level. Improvements can also be realized by mixing two or more frequency data with the bobbin probe calibrated specifically to eliminate the interference. The 40 percent sensitivity level has been verified by laboratory testing with machined slots and by metallurgical examination of tubes with field-detected circumferential cracking.

Eddy current sensitivity to inside diameter cracking is generally 40 percent. Inside diameter cracking is usually detected in regions of tube deformation with a resulting potential for interference. Again, if the inspection data obtained from the bobbin type probe in the general inspection is inconclusive, a sample of tubes is inspected using probes with surface-riding properties. In the case of small radius U-bend tangents, the usual modes of inspection with surface-riding probes must be

modified due to the tube curvature. Development programs are in progress to optimize the detectability of inside diameter cracking in small radius U-bend tangents.

In deformed tube regions which are by design symmetric around the tube circumference, e.g., expansion transitions, the "cross-wound" probe has been found to provide 40 percent sensitivity in the presence of the transition signal. This probe minimizes the signal from the expansion transition because it is relatively insensitive to discontinuities which possess 360° symmetry, but retains sensitivity comparable to the normal bobbin for inside diameter cracking.

Q.25. What is intergranular attack?

A.25. Intergranular attack (IGA) is a form of tube degradation usually characterized by general grain boundary dissolution. IGA occurs in conjunction with stress corrosion cracking on the outside diameter of the tube; it usually occurs within crevices between the tube and the tubesheet. IGA is believed to be only slightly dependent on the stress state of the tube and occurs in concentrated free caustic solutions.

Q.26. What is the sensitivity of eddy current testing for detecting IGA?

A.26. The sensitivity of eddy current testing for detecting IGA is 40 percent of tube wall thickness. Eddy current testing of laboratory-induced IGA points to a lower sensitivity, near 20 percent, but some reduction in visibility for IGA in field data is anticipated due to interference factors. For conservatism, it is prudent for the present time to rely on the 40 percent threshold.

Q.27. What does the term "tube wear" mean?

A.27. Tube wear is a form of tube degradation that results from a mechanical abrasion of the tube surface. Such wear progressively reduces the thickness of the tube area effected. Wear results from the impact of adjacent structures or loose objects on the tubing; it has been observed at anti-vibration bar intersections, the baffle plates in preheat sections and locations in contact with foreign objects.

Q.28. What is the sensitivity of eddy current testing to detect tube wear?

A.28. The sensitivity for tube wear is reliable at 20

percent but a visible response can be obtained at 10 percent. These values have been confirmed by laboratory simulations and tube pulls.

Q.29. What are your conclusions regarding the adequacy of eddy current testing to detect significant tube degradation and to prevent excessive tube leakage?

A.29. A review of the sensitivity of the eddy current method for detecting the degradation phenomena encountered in steam generator operating experience has shown that for each case tube wall penetrations at or above the plugging limit (usually 40 percent) are detectable. Thus, tube degradation of significance is expected to be detected by eddy current testing, thereby increasing the probability that tube integrity will be maintained prior to the next inspection. Eddy current development now in progress in the industry is expected to further improve detection limits and characterization of possible tube degradation.