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 M. J. WOOTTEN CONCERNING STEAM GENERATOR TUBE INTEGRITY (WATER CHEMISTRY)

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 Dr. Michael J. Wootten addresses the water chemistry measures used to minimize tube degradation on the secondary side of Westinghouse pressurized water reactors. Dr. Wootten provides his educational and professional credentials qualifying him as an expert and explains the history and development of the Westinghouse water chemistry guidelines.

Dr. Wootten's testimony demonstrates that the Westinghouse water chemistry guidelines are the result of a dynamic process that incorporates the latest knowledge in the industry learned through reactor operating experience and laboratory research. For example, the initial recommendation to use phosphate as the steam generator chemistry control agent was revised to recommend the all volatile treatment (AVT) when the latest information at the time warranted such action. The AVT water chemistry guidelines have continued to evolve since the mid-1970's, and Dr. Wootten concludes that they have been successful in minimizing the potential for tube corrosion.

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TESTIMONY OF M.J. WOOTTEN
CONCERNING STEAM GENERATOR
TUBE INTEGRITY
(WATER CHEMISTRY)

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

A.1. My name is Michael John Wootten. I am Manager of Chemistry Field Development, Westinghouse Electric Corporation, Avenue A & West Street, Pittsburgh, Pennsylvania.

Q.2. Please state your educational background.

A.2. I graduated from Leicester University, England in 1966 with a B.Sc. Degree (Honours) in Chemistry. From 1966 to 1969, I continued attending Leicester University and received a Ph.D. degree in Physical Chemistry. From September 1969 to July 1971, I was employed by Mellon Institute, Pittsburgh, Pennsylvania as a postdoctoral research fellow and from August 1971 until December 1972 as a senior research

fellow at the University of Southampton, England. The three years of post-doctoral work was spent in understanding the properties of aqueous solutions under various conditions of temperature and pressure using spectrophotometric and conductance measurements.

I have published over 20 articles in various technical periodicals related to water chemistry and corrosion of nuclear plant materials. In addition to these technical publications, I have authored or co-authored over 60 Westinghouse reports. I have lectured, presented talks and seminars at meetings of the National Association of Corrosion Engineers, Universities, National Laboratories and at International Conferences. I have been active in the Electrochemical Society and have served as chairman of the Local Chapter. I have been active in the National Association of Corrosion Engineers committees and have served as Symposium Chairman at their International Meetings.

Q.3. Please state your work experience.

A.3. From January 1973 until June 1975, I was employed as a Senior Engineer by Westinghouse Electric Corporation in their European Research Laboratory in

Brussels, Belgium where I worked in high temperature electrochemistry and solution chemistry related to Nuclear Power Plants. In June 1975, I was transferred to the Corporate Research and Development Laboratories in Pittsburgh where I continued my work in the area of high temperature aqueous corrosion of nuclear power plant materials.

From November 1977 through March 1980, I was employed as Manager of Corrosion and Solution Chemistry at the Westinghouse R&D Laboratories where I was responsible for the R&D Laboratory effort on Steam Generator Chemistry Programs.

In April 1980, I was employed by Westinghouse Water Reactor Divisions as Manager of Chemistry Operations and Field Development. I was responsible for the chemistry follow of all operating Westinghouse PWR's and several field development programs such as oxygen-hydrazine studies, hydrogen monitoring and the addition of boric acid as an inhibitor to denting in steam generators.

In March 1981, I was appointed Manager of Chemistry Technology in which I had total responsibility for

all Westinghouse Chemistry Laboratory and Technology programs.

In December 1981, I assumed my present position as Manager of Chemistry Field Development. My responsibilities in this position include the application and qualification of new field techniques, implementation of data management system for chemistry of nuclear plants and coordination of joint Westinghouse - Utility Working Groups. One such group has been established with Commonwealth Edison Company.

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

A.4. My testimony addresses Rockford League of Women Voters Contention 22 and DAARE/SAFE Contention 9(c). In particular, my testimony explains the history and development of the water chemistry guidelines recommended by Westinghouse to utilities for control of the water chemistry of the secondary side of operating Pressurized Water Reactors.

Q.5. Please explain the need for water chemistry controls in the secondary side of PWR nuclear power plants.

A.5. Water Chemistry controls are aimed at minimizing the input of impurities into the secondary system. These impurities include dissolved and suspended

solids, which can lead to corrosion of the secondary side materials. A simple schematic of the steam side of a typical Westinghouse PWR is shown in Attachment A. This identifies the interrelationship of the secondary side system (commonly called the "Balance of Plant") to the turbine and steam generator.

Q.6. What are these controls?

A.6. Water chemistry control of the steam side of Pressurized Water Reactor (PWR) Nuclear Power Plants has been developed based on the large data bank and experience accumulated from operation of industrial fossil-fueled boilers. The two traditional methods for chemistry control of the steam side of power plants are:

1. Sodium phosphate treatment.
2. All Volatile Treatment

Q.7. What is the difference between the two controls?

A.7. The sodium phosphate treatment essentially uses dissolved solids which act as a buffer to the concentrated contaminant species and has traditionally been used in recirculating boilers; whereas AVT, as the name implies, utilizes only all volatile chemicals and has been used in once through boilers.

Q.8. What advice was provided to the operators of Westinghouse nuclear steam generators to control the secondary side water chemistry?

A.8. The operation of the secondary side of a PWR and its associated water chemistry control program is the responsibility of the utility. Westinghouse has traditionally consulted with utilities on its chemistry control programs and has provided to each utility guidelines for secondary side chemistry control. The objectives of the Westinghouse PWR secondary water chemistry guidelines are:

1. To minimize metal corrosion.
2. To control the extent of sludge accumulation in the steam generator.
3. To minimize scale formation on heat transfer surfaces.
4. To minimize the potential for the formation and accumulation of corrosive species (such as free caustic or acid).
5. To minimize the level of dissolved oxygen and carbon dioxide.

Q.9. What was the initial recommendation for secondary side water chemistry control?

A.9. Westinghouse steam generators are of the recirculating type. The initial recommendation in the early

1960's was to use phosphate as the steam generator chemistry control agent. The phosphate is maintained at a desired concentration to provide the pH buffering action against excursions in alkalinity or acidity due to ingress of contaminants.

The initial guidelines stipulated a phosphate concentration of up to 10 ppm phosphate with a sodium to phosphate molar ratio of less than 2.6. The ratio was chosen because earlier work had shown that higher ratios led to formation of sodium hydroxide, a caustic, which is detrimental to the Inconel 600 steam generator tubing.

Q.10. Were any tube degradation problems experienced during the use of the initial water chemistry guidelines?

A.10. Some instances of stress corrosion cracking were observed in plants that operated with excessive condenser inleakage and little or inadequate phosphate control.

Q.11. Were the initial guidelines revised to address this concern?

A.11. Yes. Ranges of phosphate concentration with minimum

levels of phosphate were recommended because the initial guidelines allowed the utility, should it so desire, to operate with no added phosphate. The sodium to phosphate ratio remained at less than 2.6.

Q.12. Was this change successful in limiting the occurrence of stress corrosion cracking?

A.12. The recommended treatment (i.e., sodium and phosphate ratio less than 2.6 and higher phosphate concentrations) were successful in mitigating the incidence of caustic stress corrosion cracking of the steam generator tubing which had resulted from condenser inleakage and no phosphate control. However, after approximately two years, another corrosion phenomenon called "thinning" was observed in some plants.

Q.13. What actions were taken to address tube wall thinning?

A.13. Laboratory experimentation was performed using high temperature autoclaves and model boilers to understand the thinning phenomenon. The results of these studies together with field experience showed that the thinning was caused by low sodium to phosphate ratio solutions. This led to a further adjustment

in the guideline of a sodium to phosphate ratio between 2.3 and 2.6.

Q.14. Was the adjustment of the sodium to phosphate ratio between 2.3 and 2.6 successful in minimizing tube wall thinning?

A.14 . No. Results from the lead plants using this guideline showed that the thinning was not abated, and, therefore, the all volatile treatment (AVT) was recommended in lieu of the phosphate control in the latter part of 1974.

Q.15. What is AVT?

A.15. As the name implies, the basis for the All Volatile Treatment is that only volatile chemicals are intentionally added as control agents. These agents do not concentrate in the steam generator but are removed via the steam to the rest of the secondary system.

In general, two chemicals are added, a volatile amine (usually ammonium hydroxide) for pH control of the feedwater and an oxygen scavenger (hydrazine). Hydrazine scavenges oxygen according to the following simple equation:

$$O_2 + N_2H_4 - N_2 + 2H_2O$$

producing innocuous byproducts such as nitrogen and water. As the hydrazine moves through the feedwater system and is subjected to higher temperatures, any unreacted hydrazine can decompose to form such compounds as ammonia, nitrogen and hydrogen. These by-products are volatile compounds. As observed, ammonia can be produced by thermal decomposition of hydrazine; therefore, the addition of ammonium hydroxide for pH control is adjusted to compensate for that produced from the excess hydrazine thermal decomposition.

Q.16. Did the use of AVT water chemistry controls reduce the incidence of tube wall thinning?

A.16. The change to AVT mitigated the thinning of the steam generator tubing caused by acidic phosphate species. However, in the immediate years following the conversion to AVT, another form of corrosion called "denting" was observed.

Q.17. What is denting?

A.17. Denting is a localized radial reduction in the diameter of steam generator tubes, resulting from corrosion of the carbon steel tube support plates in the tube - tube support plate annulus. Initially, it was thought to be associated only with plants

with prior extended phosphate treatment. However, laboratory and field data indicated that corrosion which can produce denting has occurred in chemistry environments where no phosphate was present. The data showed that copper and chloride are active in the denting process. Plants with copper alloys in their balance of plant and situated on the sea coast or utilizing brackish water as a cooling water were observed to be more prone to this form of corrosion because of the high concentrations of acid-chloride forming constituents in this cooling water.

Ongoing laboratory programs and specific field tests have established that the denting corrosion process is multivariable with an interrelationship between chlorides, copper compounds and oxygen. It has also been shown from the field tests that the steam generator corrosion can be initiated by contaminant ingress from many locations in the secondary system. Contaminants introduced into the steam generator bulk water can be also carried to the turbine and to the rest of the equipment in the secondary plant cycle by either carryover or by the volatility of the particular chemical compound.

Q.18. What measures were taken to address denting?

A.18. Two changes were recommended to address the denting phenomenon. One was to reduce the input of oxidizing agents such as copper and/or oxygen and the other was to restrict further the input of chloride ions into the system.

In 1976, Westinghouse recommended that the balance of plant materials be considered relative to reduction of sludge generation and corrosion product transport into the steam generators. It was stressed that (1) the presence of copper alloys in the system precludes the optimum chemistry control for carbon steel protection and (2) copper corrosion products entering the steam generators appear to remain in the sludge rather than be removed by blowdown. As indicated above, these copper compounds together with chloride ions from condenser inleakage play a major role in the initiation of the corrosion leading to denting.

In 1977, interim AVT guidelines were established with the following operating practices for restricting chloride ion and oxygen input:

1. Operate to the normal power operation AVT specifications only.

2. Implement rigorous control of the condensate and feedwater chemistries during both shutdowns and power operation to minimize secondary system corrosion and transport of the corrosion products into the steam generators.

3. Sources of contaminant ingress must be identified and eliminated immediately upon detection.

These changes were recommended mainly because data collected from operating plants, field programs, and laboratory experiments indicated that a coordinated systems design approach is desirable. The steam generator is only one component of a complex secondary system that integrates system design and operational considerations. A joint effort by the nuclear equipment supplier, the utility, and the architect-engineer is essential to produce a coordinated systems approach.

Q.19. Have these measures been effective in mitigating the denting concern?

A.19. Yes. Plants that have only operated on AVT

chemistry have had less severe denting and in some cases where these changes have been adopted vigorously, the progression of denting has been arrested.

Q.20. Have any other corrosion mechanisms been observed in plants where AVT has been the exclusive water chemistry control?

A.20. Yes. However, these have been limited occurrences. For example, one plant experienced pitting of the inconel tubing which is believed to be due to an acidic chloride condition involving copper and chloride ions. Plants using AVT since initial startup have experienced only an insignificant number of stress corrosion cracking incidents. A form of tube thinning has been observed at lower tube support plate elevations around the periphery of the bundle at two all AVT plants. At the present time, no corrosion mechanism has been identified for this phenomenon.

Q.21. Are the interim guidelines established by Westinghouse in 1977 still in effect?

A.21. The principles of the guidelines have been maintained while certain modifications to the guidelines have evolved since 1979. These include

expected parameter levels considerably lower than the previous normal operation limits and increased attention on the control of air ingress to the subatmospheric sections of the condensate system.

The revised guidelines recommend that:

- The guideline chemistry conditions should be achieved prior to unit loading and maintained during power changes.
- Any source of contamination should be identified and the source corrected. No operation is allowed with locatable contaminant ingress.
- Dissolved oxygen at the condensate pump discharge should be less than 10 ppb, this minimizes the inventory of corrosion product transported to the steam generator.
- Continuous monitoring of the chemistry of the steam generator blowdown is essential. Measured values should be compared to theoretical values in order to identify whether or not excess alkalinity or acidity is present.
- Copper bearing alloys be eliminated from the secondary system to permit greater flexibility and optimization in chemistry control.
- Main condenser integrity be upgraded to minimize the ingress of impurities in the

condensate in order to improve the reliability of the steam generators and turbine.

- If a full-flow condensate polishing system is installed, it must be carefully controlled and properly operated in order to optimize the quality of the treated condensate.

Q.22. Do you have an opinion with respect to the success of the water chemistry guidelines as recommended by Westinghouse to either eliminate or mitigate the occurrence of corrosion in steam generators?

A.22. Yes.

Q.23. Please state that opinion.

A.23. The original conversion from a phosphate treatment to the All Volatile Treatment recommended by Westinghouse guidelines has eliminated the steam generator tube corrosion ascribed to the presence of phosphate. Over the last eight years, the utility industry has come to understand more fully the importance of good secondary side water chemistry control. Experience has shown that with diligent operation of the plant by the utility the Westinghouse guidelines can be achieved and in my opinion, will minimize the potential for corrosion.

In addition, I should emphasize that these measures are under continual review by the nuclear industry. Westinghouse, with other nuclear power system vendors, is involved in a joint endeavor with utilities to emphasize the importance of maintaining appropriate water chemistry conditions in the secondary systems of PWR nuclear power plants. Initiated by the Electric Power Research Institute (EPRI), a special committee was formed consisting of members from the utilities, vendors, consultants, and EPRI. This committee authored a document designed to provide guidance to the electric utility industry with respect to PWR secondary water chemistry to minimize localized corrosion in steam generators. The recommendations of the committee were formulated in a document entitled, "PWR Secondary Water Chemistry Guidelines." This document has been issued by EPRI to all members of the EPRI Steam Generator Owners' Group, and it is under review by that group as well as by Westinghouse.

Attachment A