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 WILSON D. FLETCHER CONCERNING STEAM GENERATOR TUBE INTEGRITY (AN OVERVIEW OF THE SAFETY SIGNIFICANCE OF THE ISSUE)

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

February 25, 1983

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SUMMARY

The testimony of Mr. Wilson D. Fletcher provides an overview of the safety significance of the steam generator tube integrity issue. Mr. Fletcher is Manager of Westinghouse's Division of Steam Generator Materials and Chemistry, and for the past 12 years he has held various positions of responsibility at Westinghouse involving various aspects of steam generator design and operation with particular emphasis on tube degradation matters. This work experience together with his educational background provide Mr. Fletcher with impeccable credentials as an expert.

Mr. Fletcher concludes that tube rupture should not occur even under conditions of postulated loss-of-coolant accidents and main steam line accidents, and therefore that steam generator tube degradation is not a cause for a safety concern as suggested by intervenors' contentions. This opinion is based upon Mr. Fletcher's extensive personal knowledge and experience in the field and on the testimony of other witnesses appearing on behalf of Commonwealth Edison Company. With respect to the other witnesses' testimony, Mr. Fletcher relies upon (i) the conservatism of the 40% tube plugging criterion as detailed by Dr. Patel, (ii) the capability of eddy current testing to detect tube degradation at or above the tube plugging criterion as articulated by Mr. Malinowski, (iii) the success of AVT water chemistry to minimize tube corrosion as discussed by Dr. Wootten, (iv) the continual design evolution of Westinghouse steam generators that resulted in the Byron Station steam generators embodying the very best design features from the perspective of reducing tube degradation as described by Dr. Conway, and (v) the assurance, as demonstrated by Mr. Timmons, that the flow-induced vibration phenomenon is well-understood and that measures will be taken to render the matter of little concern. Finally, Mr. Fletcher's also relies on the various commitments testified to by Mr. Blomgren as being adopted by Commonwealth Edison Company for implementation at the Byron Station.

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

A.1. My name is Wilson Douglas Fletcher. I am Manager of Steam Generator Materials and Chemistry with the Westinghouse Electric Corporation, Forest Hills Site, Avenue A and West Street, Pittsburgh, Pennsylvania.

Q.2. Please state your educational background.

A.2. I was graduated from Hardin Simmons University in 1950 with a Bachelor's Degree in Chemistry and from Fordham University in 1960 with a Master's Degree in Chemistry. I also have taken course work at Stevens Institute of Technology in chemical thermodynamics and at Carnegie-Mellon University in radiochemistry.

I have published over 12 articles in various technical periodicals and have authored or co-authored over 12 Westinghouse reports, all of which have pertained to plant chemistry, steam generator operating experience and corrosion. I am a member of the American Chemical Society, the American Nuclear Society, the National Association of Corrosion Engineers and the American Society of Mechanical Engineers. I am also a member of the Committee on Water in Thermal Power Systems of the ASME.

Q.3. Please state your work experience.

A.3. I was employed with the Vitro Corporation from 1951 to 1955 where I performed research on organo-phosphorus compound synthesis, reaction kinetics and mechanisms of organo-phosphorus compounds, phase studies, bench scale and pilot plant production of organo-phosphites, high and low temperature kinetic studies of boron hydride synthesis, and electro-kinetic studies of electrophoretic deposition of inorganic oxides in the manufacture of reactor fuel elements.

In 1957, I began my employment with Westinghouse and have been engaged in development work on the

heterogeneous catalysis of reactions between hydrogen and oxygen produced through radiolysis of reactor coolants, reaction kinetics and mechanisms, catalyst development and evaluation in high temperature and pressure aqueous solutions; evaluation and study of reactor coolant contaminants and means of coolant purification; study of behavior of fission and corrosion products in reactor coolants; in-pile studies of reactor coolants as pertains to chemical shim technology; reactor plant chemistry control, analyses, and data collection and interpretation of all operating reactor systems designed by Westinghouse.

Since 1970, I have been directly involved in development and design activities related to Westinghouse steam generators. Under my direction, steam generator programs related to operations have been executed involving chemistry and materials as well as specific design configurations. During this period, I held management positions pertaining to chemistry, materials and steam generator operations and analysis.

Recently, and until November 1982, I was Manager of Steam Generator Development and Performance

Engineering which had responsibilities for steam generator thermal/hydraulic design and verification, advanced steam generator design and analysis and field modification designs.

Presently, as Manager of Steam Generator Materials and Chemistry, I am responsible for plant chemistry and material aspects related to steam generators and the reactor primary system. This entails operating plant follow and resolution of filed issues, research and development programs related to both the steam generator chemistry and materials and the reactor primary system.

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

A.4. The purpose of my testimony is to provide an overview summary of the other Westinghouse witnesses testimony on the panel with respect to addressing both the Rockford League of Women Voters Contention 22 and DAARE/SAFE Contention 9c. These contentions question the safety of Commonwealth Edison's Byron plant owing to the potential for steam generator tube degradation under either normal operation or accident conditions.

I do not agree with the apparent safety concerns raised by the intervenors on the basis of my own understanding of the issues and the previous witnesses' testimony having shown that the inherent features and operating measures and limitations of the Byron steam generators minimize the potential for safety-related events consistent with NRC's General Design Criterion 14; and, therefore, steam generator tube degradation should not be considered a safety issue.

Q.5. Who are the witnesses you referred to in your A.4.?

A.5. The testimony of Dr. Conway, Dr. Wootten, Dr. Patel, Mr. Malinowski, Mr. Timmons, Mr. Blomgren and Mr. Paul.

Q.6. What is the basis for your opinion that tube degradation in the Byron steam generators should not be considered a safety issue?

A.6. As I previously stated, my opinion is based on the expert opinion of the witnesses I have identified and my understanding of the commitments made by Commonwealth Edison for the Byron Station and my own experience during the past 12 years working on the steam generator tube degradation issues. If I may explain further -

The Byron steam generators are progressive evolutions in the state-of-the-art design as described by Dr. Conway. These steam generators, being the Model D4 in Byron and 1 and Model D5 in Byron 2, have features which are designed to minimize the occurrence of tube corrosion. Included among the features are a flow distribution baffle which maintains a horizontal sweep of water across the upper surface of the tubesheet so as to minimize the potential for sludge deposition. This sweeping action is directed toward the center of the hot leg tube bundle where the blowdown pipe is located. The blowdown location is another feature different from earlier feedring models, having the design objective of added efficiency for sludge removal. Another feature included in the Model D4 and D5 steam generators is that the tubes are full-depth expanded into the tubesheet to minimize accumulation of impurities in the tube-tubesheet crevice.

All steam generators for Byron 1 and 2 have Inconel 600 tubing material which is a corrosion resistant nickel alloy that has been studied and evaluated extensively by the industry during the last decade. The properties of Inconel 600 are very well known and the impurities that may affect Inconel 600 in a

manner to cause stress corrosion cracking or thinning are also quite well known.

The Byron 2 D5 steam generators also have further advanced state-of-the-art features. The Inconel 600 tubing has been thermally treated, using a well defined temperature cycle during tubing manufacture to provide a microstructural change in the material, as well as to provide for reduction in residual stresses. The thermally treated material has been demonstrated by Westinghouse and others in the industry to provide significant resistance to stress corrosion cracking. In addition, in the Model D5 steam generator for Byron 2, the tube support plate material has been changed from carbon steel to a Type 405 stainless steel which also provides corrosion resistance against impurities.

Operating plant experience has indicated the need for rigorous control of the water chemistry environment of the entire steam cycle. As described by Dr. Wootten, All Volatile Treatment (AVT) has been selected by the majority of the industry as the most suitable chemistry for the system, which includes the steam generators, AVT chemistry control is based on a philosophy of minimum

contaminant ingress through the practice of good initial design and material selection of condensers, feedwater heaters, makeup water systems and other components. Further, AVT control is maintained by appropriate inspection and maintenance practices and operator actions during plant operation. Adherence to AVT guidelines enhances the long term integrity of the steam cycle, by minimizing the corrosion of condenser and feedwater heater materials, the steam generator and the turbine. This in-turn minimizes the formation of corrosion products which are delivered to the steam generator, thus reducing the potential for tube corrosion.

AVT chemistry guidelines were first issued by Westinghouse during 1974 and they have been adopted by the majority of the utilities in the U.S. These guidelines have been reviewed by industry groups and more recently, in order to reinforce the need for rigorous chemistry control, EPRI has issued AVT guidelines as a model to be reviewed by the industry. Because of the extensive laboratory work that has been performed in evaluating the mechanisms of stress corrosion cracking, thinning and denting of the steam generator tubes, it is clear that impurities admitted to the steam cycle which

ultimately may reside in the steam generator, must be limited. Impurities such as air, which contains oxygen, condenser cooling water such as fresh water sources that contain excess alkalinity, make-up water impurities and the like must be excluded to the extent possible. It has also been demonstrated that copper bearing alloys in the feed train can participate in corrosion reactions when transported to the steam generator. There are no copper bearing alloys in the feed train at the Byron Station. The industry has progressed significantly in operating and maintenance practices by the utilities in meeting the AVT guidelines.

Mr. Malinowski has described in some detail the types of corrosion that have occurred in operating plant steam generators. Each of these types of corrosion have been examined in detail by Westinghouse and other industry groups and in conjunction with EPRI so that we believe to have a good understanding of the mechanisms and causes involved. Caustic impurities have been responsible for much of the observed tubing corrosion, which provides the basis for minimizing condenser leakage of caustic-forming natural waters and leakage of caustic from condensate polishers and makeup water

systems. Correspondly, acid chloride along with oxidizing impurities which are responsible for tube denting and pitting are to be avoided by rigorous attention to condenser leakage.

Mr. Timmons has provided a detailed description of the Model D4 and D5 steam generators along with the status of operating experience and testing applicable to these units. Tube wear due to flow induced vibration is not expected to be a continuing concern because of the lesser amount of tube vibration noted for the counterflow steam generator. Moreover, candidate modifications to the counterflow steam generators have been identified and are undergoing laboratory and in-plant testing for effectiveness in reducing vibrations. Modifications at the Byron Station are expected to be finally identified and available by the third quarter of 1983, to support the plant schedule.

At this point, I would like to briefly review the five events in operating plant steam generators that have led to large rates of primary coolant leakage through a steam generator tube.

The first event occurred in a steam generator tube at Point Beach Unit 1 in 1975 that had previously been thinned by phosphate chemistry. Subsequent conditions believed related to the conversion of steam generator chemistry from phosphate to AVT led to the accumulation of caustic around one tube and this in turn led to stress corrosion cracking within the previously thinned region. When stress corrosion cracking penetrated the tube wall at the unreinforced thinned region of the wall the tube developed an abrupt, large leak. The plant was shutdown following the normal procedures. As described by Dr. Wootten, phosphate chemistry control of the steam generator water led to tube corrosion in some plants, which included Point Beach Unit 1. With this finding, Westinghouse recommended in 1974 that phosphate control be replaced by AVT and the majority of utilities have adopted this chemistry, including Commonwealth Edison for the Byron Station. For all other plants on AVT since its introduction, there has not been a large leak event as that at Point Beach, and, therefore, such mechanism is not expected at Byron.

A second event of large tube leakage occurred at Surry Unit 2 in 1976 in a steam generator that was

experiencing extensive, active tube denting. Because of denting, the apex of a narrow radius U-bend tube was ovalized producing high stresses to such a degree that stress corrosion cracking occurred in that location of the tube. Cracking originated from the inside surface of the tube which was diagnosed to be due to the presence of high stress and active straining of the tube wall in contact with high temperature water. The cause and effect is rather clear in that secondary side tube support plate crevice corrosion led to tube denting which in turn led to closing together of the tube legs at the upper plate, causing the active straining and high stress in the tube wall. To minimize the potential for this occurrence, secondary side water chemistry control is to be maintained and thus avoid the incidence of denting. The elements of AVT chemistry control were described by Dr. Wootten. Moreover, periodic steam generator inspections as described by Mr. Malinowski will detect tube denting, if present, to allow for actions to be taken in advance of extensive straining of tubes in the U-bend. These actions may consist of more rigorous chemistry control or plugging of affected tubes, if necessary. Also, in Byron 2, the steam generator tube support plate

material in 405 stainless steel which significantly resists the corrosion mechanism which can lead to tube denting. For these reasons, therefore, tube leakage at the apex of the U-bend of the tubes is not expected to occur at the Byron Station.

The third event occurred in 1979 in a Doel Unit 2 steam generator. The Doel plant is located in Belgium. The leakage was confirmed by visual examination to have occurred at the apex of the U-bend of the small radius (innermost) tube. Investigation by gauging techniques showed the tube, at the location of leakage, had significant ovality in that it would not pass selected ball gauges. The high degree of ovality imparts high residual stresses to the tube which influences its susceptibility to stress corrosion cracking. Investigators have attributed the ovality to be the result of improper fabrication. Other tubes found to have excess ovality were plugged and there has not been a recurrence of leakage at this location. The Byron steam generator tubes are all inspected after fabrication so that the extent of ovality is measured to be within design limits. Thus, leakage from this cause is not expected in the Byron Steam generators.

The fourth large tube leakage event occurred at the Prairie Island Unit 1 plant in 1979. Following plant shutdown, inspection showed the leaking tube on the periphery of the tube bundle had undergone localized wear due to the presence of a foreign object. The object was a coil spring which remained in the steam generator following an earlier outage for steam generator maintenance. Application of rigorous inspections and inventory control of items used for steam generator maintenance is expected to minimize the potential for this type of occurrence.

A fifth large leakage of event occurred at the Ginna plant during 1982. This occurrence was also due to the presence of a foreign object which impacted against and severed a previously plugged tube. The severed tube subsequently wore against an unplugged tube providing a long wear scar which ultimately lead to tube leakage. Again, with due attention to loose parts through inventory and inspection, a repeat of this event is not expected.

As to the question of loose parts in a steam generator and the potential impact on steam generator tubes, this issue is being actively pursued by the industry. Special attention is being

applied to inspection and retrieval techniques for loose objects in the steam generator through tooling developmental efforts. Fiberoptic and television view devices are being utilized for searching annular regions of the steam generator and other confined areas. Inventory control procedures are implemented such that during maintenance operations tooling and other devices are accounted for before and after the work is completed so as to not leave any part in the steam generator. Further, loose parts monitoring systems are utilized for indications of impact signals within the steam generator that alert operators to the possible presence of metal objects. Thus, with the implementation of these controls, observations and procedures, the loose parts issue should diminish.

Mr. Malinowski further described the process of inspecting steam generator tubes in considerable detail and illustrated that tube degradation can be detected and quantified before the integrity of the tube is called into question as a safety issue. Periodic inspection by the operating plant utilities have provided the means by which tube degradation, if present, can be measured with respect to the tube plugging criteria established by the U.S.N.R.C. in

the plant technical specifications. The sensitivity of eddy current testing using multi-frequency techniques is generally expected to meet the requirement to detect 40% tube wall penetration and below. This is expected for such forms of tube degradation as cracking, thinning, or wear. Presently under refinement is the eddy current technique for detecting and measuring the existence of intergranular attack, which is another form of caustic corrosion. Continually active programs in the industry have yielded state-of-the-art improvements in eddy current testing to a high degree of reliance. These techniques are being further developed for ease of signal interpretation and efficiency of inspection.

Eddy current testing is only one means that provides surveillance against tube degradation. Eddy current testing is substantially supported by the inherent features of the steam generator tubing material. These features as described by Dr. Patel include recognition that Inconel 600 is a material with considerable toughness and ductility. This means that the tube material will behave in a fashion to first resist very high pressures and then to respond in an elastic, rather than a brittle, manner. This

behavior supports the characteristic referred to as leak-before-break which has been established through extensive testing of the Inconel 600 tube material. Should stress corrosion occur in the tube wall, the propagation of the crack will be such as to penetrate the wall before the crack extends a certain length. Inherent to operator control is the leak rate limitation placed on the plant during operation in the case of tube degradation such as to preclude a crack length in excess of the critical crack length. In other words, leakage from crack penetration of the tube wall can be detected at an early stage in crack progression allowing for appropriate action by plant operators. It further means that while meeting primary to secondary leak rate limitations, if the tube were to be subjected to high pressure such as resulting from a MSLB, the tube would not burst because the length of the crack would not have exceeded the critical crack size.

In addition to eddy current testing and leak-before-break characteristics, other operations are applicable which provide margin against safety concerns related to the tube. One is that periodic hydrostatic testing of the steam generators is performed which provides an overall measure of the

tube bundle integrity. Another feature is in the tube plugging criteria established by the U.S.N.R.C. which contains conservatisms within regard to the actual strength capabilities of the tube.

Mechanical analysis of the strength of the steam generator tube material under normal operation, LOCA and the more limiting Feedline Break/Steam Line Break conditions provides the basis for the tube plugging criterion as described by Dr. Patel. The analysis is supported by extensive burst and collapse testing and shows that there is conservatism in the U.S.N.R.C. applied tube plugging criteria. All of these features coupled with the inherent corrosion resistance of Inconel 600 provide significant margin against tube degradation becoming a safety concern.

Overall, my summary emphasizes the important considerations that have been made so that reliance can be placed on steam generator design, operation, inspection, and maintenance to conclude that tube rupture should not occur even under conditions of the postulated MSLB or LOCA accidents. The events which led to large tube leaks are well understood by the industry and considerable attention has been

devoted by the industry to substantially minimize a reoccurrence of these experiences. Therefore, I do not believe that the contentions identified by the League of Women Voters and DAARE/SAFE should remain a concern.