June 29, 1984

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

Before The Atomic Safety And Licensing Board

In the Matter of	)	
	)	
METROPOLITAN EDISON COMPANY, ET AL.	)	Docket No. 50-289-OLA
	)	ASLBP 83-491-04-OLA
(Three Mile Island Nuclear Station, Unit No. 1)	)	(Steam Generator Repair)
	)	

LICENSEE'S TESTIMONY OF DR. DAVID H. PAI
ON ISSUE 4 (CONTENTION 1.a)

Q1. Please state your name and address, and describe your involvement with the TMI-1 steam generator tube repair program.

A1. My name is Dr. David H. Pai. I am employed by Foster Wheeler Development Corporation, 12 Peach Tree Hill Road, Livingston, New Jersey 07039. As Senior Vice President of the Engineering and Services division of Foster Wheeler Energy Applications, Inc., the business unit responsible for nuclear energy related activities at Foster Wheeler, I had overall responsibility for the kinetic expansion process qualification and on-site application of the kinetic expansion process utilized in the TMI-1 steam generator repair program.

A statement of my professional qualifications is attached.

Q2. What is the purpose of your testimony?

A2. My testimony is intended to address Issue 4 of Contention 1.a as enumerated at page 23 of the Board's Memorandum and Order (Rulings on Motions for Summary Disposition, dated June 1, 1984), in which the Licensing Board stated:

> 4. Recalling Licensee's statement in ¶ 6-8 that the use of kinetic expansions to seal heat exchanger tubes within tubesheets has a broad base of successful experience, information is requested about whether tube integrity during subsequent operation depends on whether the process is a repair, or a manufacturing process using new materials.

Q3. Does the integrity of tubes sealed with the kinetic expansion repair process depend on whether the process is a repair, or a manufacturing process using new materials?

A3. No. The seal is effective for kinetic expansions, whether performed as a field repair or as part of the original fabrication. The industry, and Foster Wheeler in particular, have considerable experience with this process in both situations.

The kinetic expansion process used for the TMI-1 OTSG repair was developed by Foster Wheeler over 20 years ago. Foster Wheeler is aware of the employment of similar processes in the manufacture of steam generators by Combustion Engineering, and in selective field applications by Westinghouse and Babcock & Wilcox. The Foster Wheeler process utilizes a controlled amount of explosive, generally a primacord containing the explosive PETN (pentaerythritoltetranitrate) to impart the necessary energy to expand tubes. A plastic insert encapsulating the primacord is used to transmit this energy and attenuate the shock waves. The use of this plastic material also enhances our ability to accommodate dimensional tolerance between the tube and the tube hole.

For a power station (nuclear or fossil), there are different kinds of heat exchangers (e.g., feedwater heaters, moisture separator reheaters, etc.), most of which are of the shell and tube type. The TMI-I once-through steam generators (OTSG) is but one type of shell and tube heat exchanger and it shares all the relevant common characteristics with other heat exchangers, e.g., small diameter, thin-walled tubes attached to tubesheets and containment of the tube bundle in a shell which forms the component pressure boundary. Heat transfer takes place between the shell side and tube side fluids through the tubewalls, generally at certain pressure and temperature differentials between the two fluids, depending on the functional requirements of the system.

Initially, the kinetic expansion process was used to support our shop fabrication. We have expanded some 5,000,000 tubes to date. In fact, since 1967, we have adopted the kinetic expansion process as the primary means of the tube expansion for high pressure feedwater heaters.

Since the mid-seventies, the kinetic expansion process also has been applied routinely to field repairs. The various repair methods include:

1) Expansion of tubes below the tube-to-tubesheet weld region to effect a new joint similar to what was done on the TMI-1 OTSGs.

2) Expansion of new tubes into an existing tubesheet as part of a tube bundle replacement.

3) Expansion of sleeves into existing heat exchanger tubes to prevent erosion-corrosion of the tubeside inlet regions.

4) Tube plugging using the Detnaplug™ process. This process kinetically expands a serrated plug into the inside diameter to form a mechanical seal.

All of the above methods of repair utilize the kinetic forming principle. A partial listing of the various Foster Wheeler field repair jobs is attached (Table 1). The tubing sizes, as well as most of the tubing and tubesheet materials, are similar to those in the OTSGs. In addition, the operating temperatures and pressures of repaired equipment bracket the OTSG conditions. Table 2 is a partial listing of field sleeving programs, mostly for high pressure feedwater heaters. The sleeves are made of austenitic material. These high pressure feedwater heaters operate in the range of 3,000 to 5,000 psi. Table 3 is a partial listing of facilities where we have applied our Detnaplug™ process to heat exchangers of various kinds. Again, the tubing sizes are similar to those in the OTSG and the pressures involved range from about 1,000 to over 5,000 psi.

When the TMI-1 OTSG tubing problem surfaced, it was readily apparent that our experience base in kinetic expansion brackets the material and geometry parameters of TMI-1 units and the process would be uniquely suited to solve the problem.

The integrity of kinetically expanded joints depends primarily on key material and geometric parameters in the kinetic expansion process, irrespective of whether the process is applied to new equipment during fabrication or to the repair of existing equipment. These key parameters are:

1) The tube-to-tubesheet material properties (yield strength, ductility) should be checked to assure that their relative values are in a range consistent with Foster Wheeler's experience, i.e., the tube material yield strength should be less than that of the tubesheet material to assure proper tube-to-tubesheet interference and the tube material should be sufficiently ductile to accommodate the kinetic expansion strains without tube damage.

2) The annular gap between the tube and the tubesheet should be free of condensates since the incompressibility of any significant amount of liquid substance may hinder the kinetic expansion process.

In kinetically expanding tubes in standard heat exchanger equipment, for new construction or repair, Foster Wheeler follows the above guidelines in a routine manner. The excellent service record for these units confirms the long-term reliability of the process. To date, we have enjoyed overwhelming success in that the only feedback we have received from the utilities and chemical process plants where we have applied these methods has been favorable. No organization has come back to us with any complaints on the reliability of the process.

In some situations, such as the TMI-1 tube repair program, more stringent and exacting requirements are imposed. In the TMI-1 OTSG, the tube and tubesheet geometries and materials were within the range of geometries and materials we dealt with in the past. However, because of the very high reliability goals specified, the following steps were taken to ensure that the kinetically expanded tubes and tube joints satisfy the design requirement in as-built and in-service conditions:

1) A qualification program was performed using tubes obtained from the manufacturer's (Babcock & Wilcox) archives. The yield strengths of the tubes used in the program covered the entire range of tube yield strengths in the TMI-1 Steam Generators. The test tubesheets in the qualification program were fabricated from tubesheet material for which the material properties, fabrication methods and heat treatment were identical to those used for the TMI-1 OTSG.

2) The original TMI-1 construction included a transition between the roller expanded and unexpanded portions of the tubes about 1-1/4 inch below the upper tubesheet. The ends of the kinetic expansion inserts used in the repair were optimized such that the new kinetic expansion transition below is more gradual in order to minimize residual stresses.

3) Tube samples removed from TMI-1 steam generators showed that only a very thin oxide layer was present on the tube outer surface and tubesheet hole. The tubes and tubesheets used in the qualification program duplicated this oxide film. To assure that no moisture existed between the tube and tubesheet, the on-site repair procedure provided for drying of the crevice and introduction of a dry nitrogen blanket to assure a continued moisture-free crevice.

The repair of the TMI-1 OTSG tubes was accomplished with more than the usual care. Stringent nuclear quality assurance procedures were followed, both with respect to the qualification program, as well as the procurement and use of the explosive inserts on-site. Important issues, such as pull-out load and qualification program leak rate measurement accuracy and reliability, chemical composition of insert material and the traceability of all components going into the making of the insert assembly, were fully documented. The excellent results of the pull-out and leak rate tests conducted after simulated service conditions, further verified the soundness of the process application. The extrapolation of this data to actual service gives us high confidence in the operating reliability of the repaired tubes.

TABLE 1

PARTIAL LISTING OF TUBE BUNDLE
REPAIRS USING DETNAFORM™

Date	Customer	Number of Tube Ends	Tube Size	Tube Material	Tube Sheet Material
1967	PSE&G	2,200	3/4"	304 SS	Carbon Steel
1976	Detroit Edison	542	5/8"	304 SS	Carbon Steel
1977	Montana Power	2,380	3/4"	70/30 CuNi	Carbon Steel
1977	Montana Power	3,644	5/8"	70/30 CuNi	Carbon Steel
1979	PSE&G	8,832	3/4"	90/10 CuNi	Carbon Steel
1980	TVA	2,124	5/8"	304 SS	Carbon Steel
1980	TVA	2,124	5/8"	304 SS	Carbon Steel
1981	TVA	1,892	5/8"	304 SS	Carbon Steel
1981	TVA	1,598	5/8"	304 SS	Carbon Steel
1981	Detroit Edison	2,280	3/4"	304 SS	Carbon Steel
1981	TVA	4,248	5/8"	304 SS	Carbon Steel
1981	TVA	1,600	5/8"	304 SS	Carbon Steel
1981	TVA	3,200	5/8"	304 SS	Carbon Steel
1982	Dairyland	2,510	5/8"	Carbon Steel	Carbon Steel
1982	TVA	12,344	5/8"	304 SS	Carbon Steel
1984	TVA	3,086	5/8"	304 SS	Carbon Steel

TABLE 2

FIELD INSTALLATION EXPERIENCE
STAINLESS STEEL SLEEVES

Client	Station	No. of Sleeves
Detroit Edison Company	Connors Creek P.P.	1,064
Detroit Edison Company	Connors Creek P.P.	635
Pennsylvania Electric Company	Keystone Station	10,740
Pennsylvania Electric Company	Conemaugh Station	7,482
Detroit Edison Company	Monroe Power Plant	1,100
Detroit Edison Company	Monroe Power Plant	1,100
Detroit Edison Company	Monroe Power Plant	1,100
Detroit Edison Company	Monroe Power Plant	1,100
Detroit Edison Company	Monroe Power Plant	1,100
Houston Lighting & Power Company	P.H. Robinson Station	3,000
Houston Lighting & Power Company	Cedar Bayou Station	3,800
Lower Colorado River Authority	Thomas C. Ferguson Plant	1,050
Foster Wheeler Limited	Saskatchewan Power Corp.	440
Houston Lighting & Power Company	W.A. Parish Station	2,963
Nova Scotia Power Corporation	Point Tupper Plant	400

TABLE 3

DETNAPLUG USERS LIST

Customer	Station
Georgia Power Company	Plant Harlee Branch
Cleveland Electric Illuminating Co.	Avon Lake Station
Public Service Co. of New Hampshire	Merrimack Station
Oklahoma Cas & Electric Company	Muskogee Station
Kansas City Power & Light Co.	Itan Station
Pacific Power & Light Co.	Centralia Station
Boston Edison Company	New Station 400
Lower Colorado River Authority	Fayette Power Project
Cincinnati Gas & Electric Co.	East Bend Station
Central Louisiana Electric Co.	Rodemacher Station
Pittsburgh Plate Glass Industries	Lake Charles, LA
Mississippi Power & Light Co.	Baxter Wilson SES
GECB England	Tilbury Plant

PROFESSIONAL QUALIFICATIONS

DR. DAVID H. PAI

Senior Vice President, Foster Wheeler
Development Corporation

Education

B.S. in C.E.	Virginia Military Institute - 1958
M.S. in C.E.	Lehigh University - 1960
Sc.D.	New York University - 1965

Experience

1984 -	Senior Vice President responsible for the R&D and Contract Operations Divisions and for the Core Research Group.
1980 - 1984	Vice President and Director of Engineering, FW Energy Applications, Inc. Responsible for all proposal, project, and development engineering. Major programs included: design and analysis of components and systems for Liquid-Metal Fast Breeder Reactor (LMFBR) and Light Water Reactor plants and design and development of advanced energy systems, including solar steam generators, ocean thermal-energy conversion, and coal gasification.
1973 - 1980	Chief Engineer, Nuclear and Special Products Department, Equipment Division. Responsible for thermal, structural, mechanical design, and materials aspects of engineering of Nuclear and Special Products.
1968 - 1973	Senior Research Associate and Assistant Head, Solid Mechanics Department, Research Division. Structural consultant advising commercial divisions on thermal shock, thermal stress, creep, and fatigue. Specific assignments included lead responsibility in structural analysis and development for the Fast Flux Text Facility (FFTF) Intermediate Heat Exchanger (IHX); LMFBR Low-Capacity IHX Conceptual Design Studies supporting FFTF development; and LMFBR IHX Research and Development, Program Definition Phase.

	Also consultant to Equipment Division on structural problems involved in the design of a sodium-heated steam generator for a breeder reactor program.
1965 - 1967	Research Associate and Head, Analysis Section, Solid Mechanics Department. Responsible for supervising a number of engineers and technicians in carrying out basic studies in thermal stresses, creep, plasticity, stress concentration, low-cycle fatigue, and high-pressure forming. Also advised other departments in the Corporation on structural mechanics problems.
1964 - 1965	Senior Engineer, Research Division. Performed basic studies in creep, creep rupture, and plasticity, including analyses of various structural components.
1960 - 1964	Development Engineer, Research Division. Performed analytical and experimental stress analysis of steam-generating equipment, including pressure vessels, naval nuclear steam generators, and other power and chemical plant equipment. Experimental methods included strain gages, brittle coating, and photo-stress techniques. Analytical tools included the use of digital computers. Also performed experiments on low-cycle fatigue on full-size vessels.
1958 - 1960	Lehigh University. Research and Teaching Assistant, Fritz Laboratory, Department of Civil Engineering. Tested structural components for industry-supported projects. Taught freshman engineering.

Other

Author or coauthor of 25 papers. Holds four patents. Member, ASME, American Society of Civil Engineering, and Fritz Engineering and Research Society, Chairman (1970-1973), Design and Analysis Committee and Member (1973-1978), Executive Committee of Pressure Vessels and Piping Division of ASME. Member, Executive Committee of Chinese Institute of Engineers Vice President (1972-1973).

PROFESSIONAL SUMMARY

Dr. Pai joined Foster Wheeler's Research Division in 1960 as leader of the Methods Development Group supporting the Corporation's entry into the advanced nuclear reactor component market. In 1973 he was appointed Chief Engineer of Foster Wheeler's Nuclear Department which later became FW Energy Applications, Inc. He held increasingly important positions in that organization and was responsible for the engineering of the major components designed and fabricated by Foster Wheeler for the U.S. Liquid Metal Fast Breeder Reactor and High Temperature Gas-Cooled Reactor Programs. More recently, he headed the successful effort in applying the Foster Wheeler Detnaform TM process to the repair of steam generator tubes at the Three Mile Island Unit #1.

A 1958 graduate of Virginia Military Institute, Dr. Pai received an M.S. degree from Lehigh University in 1960 and his Doctorate in 1965 from New York University. He is active in the American Society of Mechanical Engineers, having served as Chairman of the ASME Pressure Vessels and Piping Division. He was elected a Fellow of the ASME in 1980 and has served as a Vice President (Materials & Structures) of the ASME.

Dr. Pai is a member of the Engineering Technology Advisory Committee to the Board of Trustees of the New Jersey Institute of Technology, as well as a member of the University of Chicago/Argonne National Laboratory Review Committee on Experimental Breeder Reactor II. He also serves as a consultant to the U.S. Department of Energy on the Steering Committee for the Liquid Metal Fast Breeder Reactor Structural Design Technology Program at the Oak Ridge National Laboratory. He is a member of the American Society of Civil Engineers and the Chinese Institute of Engineers. He has written over 30 technical articles, edited two books, and holds several domestic patents.

Foster Wheeler Corporation is an international engineering, manufacturing and construction organization with 26 subsidiaries operating worldwide. Its major U. S. operating subsidiary, Foster Wheeler Energy Corporation, designs, fabricates and constructs steam generating equipment, process plants and fired heaters for electric utilities, shipbuilders, petroleum refiners and chemical producers. Foster Wheeler Development Corporation provides research services for both the parent organization and outside clients. The corporations are headquartered in Livingston, N. J.