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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

March 17, 2000

MEMORANDUM TO: Stuart A. Richards, Director
Project Directorate IV & Decommissioning
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

FROM: Jack Cushing, Project Manager, Section 2 Steph Dembek /FOR
Project Directorate IV & Decommissioning
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

SUBJECT: SUMMARY OF PUBLIC MEETING WITH CALDON TO DISCUSS FEBRUARY 15, 2000, SUBMITTAL ON ULTRASONIC FLOW MEASUREMENT INSTRUMENTATION

On March 8, 2000, the NRC staff met with representatives of Caldon to discuss the information provided to the NRC by Caldon in their February 15, 2000 letter. Because the meeting was noticed less then 10 days prior to the meeting, the staff elected to have the meeting transcribed in order that members of the public who could not attend the meeting can have access to exactly what was discussed. Attachment 1 is a list of the meeting participants. Attachment 2 is the resumes of the Caldon participants. Attachment 3 is a copy of the meeting slides. Attachment 4 is the meeting transcript.

Mr. Richards of the NRC staff opened the meeting by stating the purpose of the meeting. By letter dated February 15, 2000, Caldon submitted to the NRC information related to the measurement of feedwater flow at commercial nuclear power plants. In this letter, Caldon specifically expressed concern that instruments measuring flow by means of cross correlating ultrasonic signals affected by eddies in the flow stream may not support a significant reduction in the 2 percent power margin of 10 CFR 50, Appendix K. Caldon further expressed a willingness to meet with the staff to discuss their submittal. Hence, this meeting was an opportunity for Caldon to present directly to the staff their concerns with cross correlation flowmeters.

Mr. Calvin Hastings, President and Chief Executive Officer of Caldon Inc., then addressed the meeting and his remarks closely followed the slides in Attachment 3 and are transcribed in Attachment 4. Mr. Hastings, in his opening remarks introduced the people attending the meeting on Caldon's behalf. He discussed his company's expertise in the area of ultrasonic flow measuring instrumentation. He went on to say that the reason for submitting the February 15, 2000, letter was that he was surprised to learn that ABB-CE anticipated that the NRC would find acceptable CROSSFLOW UFM (ultrasonic flow measurement) system measurement accuracy of less than or equal to .5 percent. He believes that cross correlation flow meters have a bounding value for uncertainty that is significantly larger.

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Ms. Jennifer Regan, of Key Technologies provided an overview of the information submitted on February 15, 2000. The presentation was then turned over to Mr. Herbert Estrada, Chief Engineer, for Caldon. Mr. Estrada discussed the technical aspects of the submittal. Dr. Thomas Maginnis, Professor, U-Mass Lowell, presented his background in ultrasonic flow measurement, and his concerns with possible uncertainties associated with this technology. Next, Dr. George Mattingly, of the National Institute of Standards and Technology, presented his insights into ultrasonic flow measurement technology.

Mr. Calvin Hastings summarized Caldon's presentation by stating that, "... you cannot conclude that this instrument can achieve an accuracy of a half percent." Mr. Hastings then thanked the staff for the opportunity to meet with them to clarify his concerns.

Mr. Richards then stated that the staff did not have any questions at this time and thanked Mr. Hastings for his presentation.

Attachments:
1. Meeting Participants
2. Resumes of Caldon Particpants
3. Meeting Slides
4. Meeting Transcript

cc w/atts:
Mr. Calvin R. Hastings, President
Caldon, Inc.
1070 Banksville Avenue
Pittsburgh, PA 15216

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MEETING WITH CALDON

MARCH 8, 2000

ATTENDANCE LIST

CALDON
C. Hastings
H. Estrada
E. Hauser

KEY TECHNOLOGIES
J. Regan

PRO DES CON
R. Horn
C. Waite

NIST
G. Mattingly

WINSTON & STRAWN
B. Horin
M. Philips

PARAMETRICS, INC.
L. Lynnworth

FISHER PRECISION SYSTEMS
S. Fisher

ABB COMBUSTION ENGINEERING
I. Rickard
C. French

AMAG
Y. Gurevich

McGRAW-HILL
C. Coe

NUSIS
M. Neal

MPR ASSOCIATES
A. Zaruhnak

PUBLIC SERVICE ELECTRIC & GAS
R. Moore
F. Todd

PRIVATE CONSULTANT
T. Maginnis

NRC
S. Dembek
J. Rutberg
C. Marco
I. Ahmed
J. Cushing
J. Donoghue
R. Caruso
J. Wermiel
J. Calvo
T. Jackson
S. Arndt
H. Garg
F. Eltawila
N. Lauben
J. Zwolinski

Attachment 1

CALVIN R. HASTINGS, President

[redacted]

Education

B.S. Mechanical Engineering, University of Maryland, 1958
Graduate Study, University of Pittsburgh, 1959
M.S. Mechanical Engineering, University of Maryland, 1968
Graduate Study, MIT, 1968 - 1969

Career History

1987-Present, President, Caldon, Inc.

Founded Caldon in 1987 with the objective to excel in bringing new high technology products to market. Developed a business plan to introduce new products quickly by building upon technology already developed by others. Introduced first product in 1988 and second in 1989. Through acquisition and collaboration with other companies, developed a technology base in acoustics/ultrasonics and a level of product support capability ordinarily available from large corporations.

1979 - 1987, Manager, Power Conversion and Control Department, Westinghouse Industry/Construction Projects Division

Member of team starting up a new large scale organization. Developed strategic plans for growing the business. Exceeded $100 million in 3-1/2 years. Developed and introduced to the marketplace ten new products in 4 years. Developed joint venture combining technology of large European company with American marketing capability.

1975 - 1979, Executive level assignments at Westinghouse Headquarters, Pittsburgh, PA

Conducted research on turnover in high level executive positions. Developed improvements to selection process. Directed activities for executive development and succession planning.

1959 - 1975, Engineering, project management, marketing assignments, various Westinghouse Divisions

Developed high technology products. Managed defense technology programs. Introduced new products into industrial/commercial markets.

January, 2000

RESUME

HERB ESTRADA

[redacted]

EDUCATION

University of Pennsylvania, B. S. in Electrical Engineering, with distinction, 1951
University of Pittsburgh, Graduate Courses in Physics and Mathematics, 1953

PROFESSIONAL HISTORY

1951-1963: Bettis Atomic Power Laboratory, Westinghouse Electric Corporation

At the Bettis Laboratory, Mr. Estrada held the following positions:

> Designer of power range nuclear instrumentation and reactor protection system for the USS NAUTILUS
>
> Lead Engineer for nuclear plant analysis of SKATE class nuclear submarines
>
> Chief Test Engineer for acceptance testing of Westinghouse designed reactor plants for nuclear submarines at Portsmouth Naval Shipyard
>
> Supervisor of Advanced Surface Ship Instrumentation and Control Engineering

1963-1964: Allison Division, General Motors Corporation

At Allison, Mr. Estrada held the position of Chief, Systems Engineering. He was responsible for engineering design and operations research on chemical systems for several advanced energy conversion projects.

1964-1994: MPR Associates, Incorporated

Mr. Estrada was a senior associate at MPR. He was responsible for coordination and technical direction of a broad range of projects including the design, analysis, testing, operation and troubleshooting of instrumentation, control, electrical and fluid systems for nuclear and fossil power plants. Some specific projects included:

> *Management of the Bellefonte Nuclear Power Plant Assessment Project*
> He provided technical and administrative direction for a team of 250 technical and

support personnel assigned to analyzing and planning the reactivation of the Bellefonte Nuclear Power Plant for the Tennessee Valley Authority.

Steam Power Plant Analysis
He formulated, supervised, and saw the following projects through to successful completion:

- Performance of computer analysis to predict temperature transients, fatigue damage and crack propagation in heavy metal parts of nuclear and fossil power plants, in response to normal operational changes and upsets

- Development of control hardware and software for fossil power plants subjected to cyclic loading

- Development of computer software for analysis of the dynamic response of key steam power plant variables (e.g., steam generator water level, steam pressure, turbine speed and torque, condenser back pressure) to upsets such as load rejection, loss of circulating water flow, loss of feedwater flow, loss of heat source, etc. This software has been used to design turbine bypass systems, to predict turbine overspeed, to size and set steam relief valves, to evaluate steam generator level response, and to design plant control systems.

- Development of heat balance software used by a major manufacturer of turbomachinery to establish power generation capability in nuclear and fossil power plants with one or more feedwater heaters out of service

Control Systems
Mr. Estrada supervised the development of simplified and decoupled control systems for reactivity, steam demand and feedwater flow of B&W nuclear power plants. He also supervised the design, installation, and testing of simplified combustion and boiler feedwater controls for TARAWA class assault ships of the US Navy. This work included a major upgrade of the maneuvering room design.

Instrumentation Systems
He was instrumental in the design development, proof testing, calibration, and application of an ultrasonic system for the precise measurement of reactor coolant flow in a nuclear power plant. This system was installed at the Prairie Island Nuclear Plant and was used by the reactor designer (Westinghouse) to verify the design of the reactor coolant system. Mr. Estrada also provided engineering support to Westinghouse in the application of this system to the measurement of feedwater flow in nuclear plants, and for leak detection on the Trans Alaska Pipeline.

Human Factors
He conducted reviews of the human factors of nuclear and fossil power plant control rooms and formulated and implemented design modifications to improve them. Work in this area included testimony before an Atomic Safety and Licensing Board for the relicensing of Three Mile Island Unit 1, as well as the development of an alarm system improvement guide under the sponsorship of the Electric Power Research Institute. Mr. Estrada was also a member of a panel of the National Academy of Sciences, to evaluate human factors research in the nuclear industry.

Problem Solving
Mr. Estrada participated in numerous task forces to determine root causes of significant technical problems in nuclear power plants and to formulate action programs to correct these problems. Some of these activities included:

(1) correction of reliability problems with the emergency feedwater system at Davis Besse Nuclear Power Plant

(2) correction of water hammer problems at Nine Mile Point Nuclear Power Plant, Unit 1

(3) determination of the root cause of a catastrophic last stage bucket failure at Maanshan (Taiwan) Nuclear Power Plant

(4) analysis of consequences and root causes of failures of type AK reactor trip circuit breakers for the B&W Owners Group, including formulation of a corrective maintenance and testing program

1994-1996: Caldon, Incorporated

Mr. Estrada was Chief Engineer for Caldon, a small company in Pittsburgh, PA. Caldon is a supplier of precision flow measurement hardware for the nuclear power, petroleum pipeline, and hydroelectric industries. Mr. Estrada was responsible for technical oversight of the development and application of Caldon products. His principal activities were in the analysis of the hydraulics, acoustics and signal processing for both externally mounted and "wetted" ultrasonic flow measurement systems and in the development of flow and temperature measurement algorithms for these systems. He also participated in the application of ultrasonic flow measurement systems to pipeline leak detection.

1997-Present: Consulting Engineer

Mr. Estrada currently provides consulting engineering services to utilities and manufacturers of the electric power industry.

This work has included continued engineering oversight, as Chief Engineer for Caldon, of instrument developments and applications. Working for Caldon, he has made significant contributions to the design and analysis for a new Caldon nuclear feedwater flow measurement initiative. This initiative is the subject of a topical report which has recently been the subject of favorable NRC action. The new Caldon measurement system will allow nuclear plant operators using the instrument to increase their licensed thermal power by 1%. The benefits to utilities of this power increase appear very favorable, relative to its cost.

Mr. Estrada's services to utilities have included problem solving and independent review work for American Electric Power, Commonwealth Edison, Illinois Power, and Cleveland Electric Illuminating. Sample activities for utility clients include:

(1) Root cause analysis of failures of intermediate voltage circuit breakers,

(2) Engineering review of systems to enhance the voltage regulation for safety related 4160V systems with degraded offsite power supplies,

(3) Root cause analysis of degraded jet pump performance in a BWR reactor recirculation system.

(4) Membership on senior independent engineering review committees for two plants that had been shut down because of continuing engineering problems. These senior review committees used a formal and rigorous methodology to define the nature and scope of significant engineering problems for a plant, and to review the effectiveness of planned corrective actions. The purpose of these independent engineering reviews was to provide credible evidence to regulators that the full scope of engineering problems had been discovered and addressed.

PUBLICATIONS AND AWARDS

Mr. Estrada is the author of numerous technical papers and reports, both in the technical literature and in proprietary publications, on the following subjects:

- Measurement of the dynamic response of power plants

- Transient response and design of controls for boilers and steam generators

- Computer codes for calculating nuclear and fossil power plant responses to normal transients and upsets

- Theory of operation and accuracy of flow measurement systems

- Theory and procedures for checking, aligning, calibrating and troubleshooting instrumentation and control systems

- Evaluation of control room human factors and design of measures for their improvement

- Analysis of operator responses to alarms

- Development of emergency operating procedures for nuclear power plants

- Procedures and practices for the control of water chemistry in power plant feedwater systems

- Chemical engineering thermodynamics for the production of hydrogen and oxygen from water

Mr. Estrada also holds numerous patents relating to electronics, power plant systems, instrumentation, and controls.

Mr. Estrada has received several awards during his career including the following:

- The Distinguished Service Award for his work at Bettis Atomic Power Laboratory (1962).
- Most Meritorious Patent Disclosure Award, Bettis Atomic Power Laboratory, for a patent on a Reactor Core Thermal Protection Device (1963)
- A Leadership Award from TVA for work on the Bellefonte project (1991)
- An Outstanding Achievement from Caldon, Inc. for work on the LEFM✓™ project (1999)
- The Reactor Technology Award from the American Nuclear Society for the development of flow measurement technology that allows an increase in reactor power while simultaneously improving reactor safety (1999)

Jennifer A. Regan, P.E.

[redacted]
jregan@keytechinc.com

Key Technologies, Inc.
Phone (610) 274-8256
Fax (610) 925-3559

PROFESSIONAL EXPERIENCE:

Ms. Regan has worked as a consulting engineer for electric generating facilities since 1984, as a principal officer for Key Technologies, Inc. and in a prior position as a senior project engineer with MPR Associates, Inc. Personal accomplishments include:

First Commercial Application of Caldon Leading Edge Flow Meter for Power Increase; Engineering and Licensing Consultant. Supported engineering and licensing management at TU Electric's Comanche Peak Steam Electric Station during first application for license amendment to increase power by 1%. Participated in Nuclear Regulatory Commission (NRC) meetings and performed analyses to develop responses to NRC technical questions. Power increased October 1999.

Licensing Approval for Power Increase Using the Caldon Leading Edge Flow Meter; Author and Project Manager. Authored Topical Report presented to the NRC justifying a 1% increase in nuclear power plant licensed power level when a highly accurate digital instrument is used for power determination. Report demonstrates improvement in plant safety margin with use of this instrument, even with a 1% increase in power. Analyzed instrument operating experience in the field, in support of reliability. Developed strategy for regulatory approval, and represented instrument manufacturer in meetings with regulators. Application approved by NRC in March 1999.

Structural Analysis of Spent Fuel Storage System; Technical Reviewer. Performed third party review of structural analysis of canister and transport system for storage and off-site transport of spent nuclear fuel rods. Comprehensive analysis included normal and accident conditions in conformance with 10CFR parts 71 and 72. Performed independent calculations for structural adequacy of package components, assessed adequacy of analysis methods and design inputs, and reviewed source codes and standards to verify accuracy and completeness of design documentation. Final report of findings presented to system manufacturer and utility customers.

Trip Hardening of Plant Protective and Control Systems, Project Manager. Compiled and categorized plant trip history by cause. Searched literature and surveyed other utilities to determine industry-generic problems. Developed logic trees of problem circuitry, initiators and actuated devices. Identified high risk circuits and recommended modifications to design, operations and maintenance as input to the utility's Reliability-Centered Maintenance Program.

Independent Reviewer, Statistical Reliability Analysis For Medical Device Testing. Prepared acceptance criteria for device reliability testing for a medical device manufacturer. The reliability testing was performed in support of an application to the Food and Drug Administration (FDA) for approval to proceed with clinical trials. The acceptance criteria provided the manufacturer with test guidance by indicating how many device failures could be tolerated while still meeting reliability goals within a specified confidence interval. Also participated in drafting the appropriate test protocol. As part of this effort, device design modifications made during the course of prior testing were assessed for impact on reliability test conclusions.

Applications of Ultrasonic Flow Meter; Program Manager. Managed team of 15 engineers performing applications engineering for flow measurements in power plants and for pipeline leak detection in the petroleum industry. Primary contact with flow measurement clients. Performed calibration, testing, troubleshooting of ultrasonic instruments. Participated in product development. Analyzed plant heat cycles and other flow and temperature measurement instrumentation as necessary.

Cost-Benefit Assessment for Resumption of Plant Construction; Site Engineering Manager. In-depth technical cost-benefit assessment for completing a partially constructed nuclear power plant. Responsible for immediate staff of 20 professionals over a two year period. Managed efforts to define work scope, cost estimate and completion schedule, stabilize licensing requirements, re-establish site information systems and procedures, identify high impact design deficiencies, and initiate critical path engineering programs. Day-to-day tasks included technical product review, task definition, staff development, coordination of NRC submittals and progress reports to utility executives.

Reactor Vessel Sample Removal; Shift Engineering Manager. Removed metallurgical samples from the Three Mile Island Unit 2 reactor vessel damaged in the 1979 accident. Samples were removed using metal disintegration machining with manually manipulated tools under 40 feet of water. Supervised sample removal as shift supervisor for on-site engineering team.

Plant Control System Design; Designer and Project Manager. Designed and patented replacement control system for primary operations of nuclear power plant. Performed conceptual and detailed design of system to control reactor power, feedwater flow, feed pump speed and main turbine control. Integrally involved from conceptual design of algorithms through full scale simulator operator response testing. Developed complete installation drawings for new system.

Plant System Root Cause Analysis and Reliability Improvement; Project Team Member. Identified equipment upgrades and control system logic and set point revisions. Reviewed design documents, identified root causes for component failures and system trips, inspected and analyzed the performance of system pumps and valves.

Control Room Alarm System Design Improvement; Project Team Member. Engineering and human factors reviews of nuclear control room alarm systems. Analyzed alarm conditions as they relate to plant systems and their limits. Applied industry guidelines to determine minimum conditions to be alarmed, and designed annunciators to present these conditions in the control room for best operator performance. Formally instructed utility engineers in the review and design method and participated during its application at a nuclear plant in Taiwan, R.O.C.

Operator Training; Designer and Trainer. Programmed real-time PC-based simulator for nuclear plant operator part-task training in steam generator level control. Authored user's manual and conducted training on the simulator with plant operators.

EDUCATION/CERTIFICATION

The Catholic University of America, B.S.E. Mechanical Engineering, 1984 (Summa Cum Laude)
Georgetown University, B.S. Physics, 1983
Registered Professional Engineer in the Commonwealth of Virginia, Number 019524

AWARDS, PUBLICATIONS, AFFILIATIONS

Recipient of Georgetown University Faculty Physics Award, 1983.

Patent Number 4,975,238, "Control System for a Nuclear Steam Power Plant."

"The Design and Development of a Coordinated Control System For Pressurized Water Reactors Employing Once Through Steam Generators," Proceedings of The International Conference on Control & Instrumentation In Nuclear Installations, Glasgow, United Kingdom, May 10, 1990.

"Topical Report; Improving Thermal Power Accuracy and Plant Safety While Increasing Operating Power Level Using the LEFM✓ System", March 1997.

"Improving the Reliability of Protective and Control Systems At Entergy's ANO Unit 1", April 1999.

Malcolm H. Philips, Jr.

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Malcolm Philips practices primarily in the area of energy law, representing foreign and U.S. utilities, design and construction organizations, government agencies and government contractors.

Mr. Philips represents these clients on a wide range of issues, including strategic restructuring, counseling, compliance with state and federal regulations, licensing, enforcement, transportation and storage of waste and spent nuclear fuel, internal investigations, and project development.

Before joining Winston & Strawn, Mr. Philips was responsible for managing energy consulting projects at NUS Corporation. As an officer in the U.S. Army, Mr. Philips was the Site Executive for the SM-1 Nuclear Power Plant, responsible for all power plant activities, including plant operations, maintenance and modifications, and ancillary activities such as transportation of high-level waste and spent nuclear fuel. He also decommissioned the SM-1 Nuclear Power Plant. Prior to this, Mr. Philips was responsible for design and construction of horizontal and vertical construction projects in the military.

Mr. Philips has received a B.S. from the United States Military Academy in 1967, an M.E. from Iowa State University in 1971, and a J.D. from the Georgetown University Law Center in 1978 where he was a member of the *American Criminal Law Review*. Mr. Philips was a registered professional engineer (Texas).

NAME: Malcolm H. Philips, Jr.

EDUCATION:

Legal:
Georgetown University Law Center,
Washington, D.C., J.D., May 1978
Law Review - American Criminal Law Review

Graduate:
Iowa State University, Ames, Iowa, Master of Engineering
(Nuclear/Energy) 1971

Undergraduate:
United States Military Academy, West Point, New York, B.S. 1967
(Focus on nuclear and civil engineering)

Training:
- U.S. Army Nuclear Plant Engineer Course, 1972
- U.S. Army Nuclear Power Plant Management (designed to produce a plant manager of a Nuclear Power Plant), 1972

PROFESSIONAL REGISTRATION: Held a Professional Engineer Registration, Texas #36461

EXPERIENCE: <u>Winston & Strawn</u>, Washington, D.C. (1978-present)

Partner (1986-present); Associate (1978-1985)
Represents primarily corporate clients before federal and state administrative agencies. Practices predominantly in the area of nuclear energy, representing nuclear utilities and contractors working in the area of nuclear energy. Specific areas of responsibility include the following:

- Represented nuclear utilities in nine nuclear power generating facility licensing proceedings before the Nuclear Regulatory Commission on numerous issues relating to compliance with state and federal requirements.

- Represented DOE contractors in work related to nuclear energy, *e.g.*, compliance with regulations, enforcement and tritium production.

- Represents major nuclear utility groups consisting of 15-44 nuclear utilities each on issues associated with compliance with state and federal requirements relating to nuclear power, *e.g.*, fire protection, seismic and environmental qualification of equipment, backfitting and enforcement of pertinent federal regulations.

- Routinely represents a number of nuclear utility retainer clients regarding issues involving strategic counseling, compliance with state and federal regulations, licensing issues, and enforcement actions including issues involving transportation and storage of high and low-level waste and spent nuclear fuel, security requirements for nuclear power facilities, "whistleblower" issues, cost reduction initiatives, and regulatory and organizational restructuring.

NUS Corporation, Rockville, Maryland (1974-1978)

Manager, Programs Development Department - 1976-1978
Responsible for management of consulting projects regarding nuclear licensing activities and technical training programs for industry. Programs included areas of nuclear and fossil energy, maintenance, environmental regulation and mining.

Senior Engineer/Project Manager - 1974-1976
Project Manager for engineering, management and training consulting projects for utility and industrial clients. Projects included organizational and staffing studies; management training; QA program/procedure and system description development; and production of videotape technical training programs.

United States Army (1967-1974)

Site Director, SM-1 Nuclear Power Plant, Fort Belvoir, Virginia - 1972-1974
Responsible for all plant operations and activities including transportation of high level waste and spent nuclear fuel. Developed, obtained state and federal concurrence with and implemented a decommissioning plan for the SM-1 nuclear power plant.

Chief Operations and Environmental Projects, Fort Belvoir, Virginia - 1971-1972
Provided operational support for nuclear and fossil plants. Project Manager for related Environmental Impact Statements. Assisted in Alternate energy source studies and selected as member of Department of the Army Inspector General inspection team on nuclear power.

Various Positions in Civil/Construction Engineering, Ames, Iowa; Fort Knox, Kentucky; Vietnam; and Fort Meade, Maryland - 1967-1970
Designed and managed construction of road networks, bridges, limited vertical construction and related projects and managed testing programs for Army equipment.

MEMBERSHIP AWARDS & HONORS

1967-1974 - Various awards and honors in the military including Airborne/Ranger designations in 1967, Bronze Star in 1968, early selection for graduate schooling in 1970 and Nuclear Plant Manager in 1972.

Member, Council of Governors - Washington, D.C. 1976-77

Member, American Criminal Law Review - Georgetown University Law Center
1976-78

Member of the American Bar Association and Maryland Bar Association and admitted to practice before the Bars of the District of Columbia and Maryland

Many presentations before legal/technical organizations regarding federal and state regulation of nuclear energy.

William A. Horin

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(202) 371-5737
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William Horin is a graduate of Northwestern University where he received his Bachelor's and Master's degrees in Chemical Engineering. He graduated in 1976 as the Harry S. McCormick Award recipient as the outstanding Chemical Engineering Student in the Chicago, Illinois region. Mr. Horin is a lifetime member of Tau Beta Pi, the National Engineering Honor Society and a member of the American Institute of Chemical Engineers. Following graduation from Northwestern, Mr. Horin attended and received his Juris Doctor degree from Georgetown University, in Washington, D.C., in 1979. He is a member of the District of Columbia Bar.

While at Georgetown Law School, Mr. Horin worked in the nuclear practice of a law firm that represented the Clinch River Breeder Reactor. Following graduation from Georgetown, he joined Debevoise & Liberman, the predecessor firm to Winston & Strawn, in their nuclear practice. He has represented numerous utilities before the Nuclear Regulatory Commission on matters ranging from licensing, enforcement, and rulemakings.

Mr. Horin has participated on behalf of nuclear utility clients before the Nuclear Regulatory Commission in administrative adjudications related to the licensing of nuclear power reactors. Mr. Horin has significant adjudicatory experience before NRC Atomic Safety and Licensing Boards in the operating license proceeding context, including the development and presentation of utility applicant evidence on contested technical, financial and environmental issues. In addition, he as served as counsel to nuclear clients with respect to NRC enforcement matters (including all aspects of plant operation and radioactive materials transportation), requests for license amendments (related to among other topics construction permit period recapture and power level upgrades) and other licensing activities.

Mr. Horin has represented utility and utility group clients with regard to significant NRC administrative rulemakings, including decommissioning (focussing on legal and financial implications of NRC regulatory scheme), license renewal, deregulation issues, equipment qualification, and power reactor nuclear insurance (liability and property).

Mr. Horin serves as counsel to a nuclear vendor related to the legal and licensing issues associated with the application of advanced technologies to nuclear power reactor operations to obtain NRC approval for the application of that technology to authorize power operation at higher power levels. He is also actively involved in nuclear industry generic efforts, including participation in Nuclear Energy Institute issue task forces on license renewal, equipment qualification, revised source term and licensing and design basis.

WILLIAM A. HORIN

Winston & Strawn
1400 L. Street, N.W.
Washington, D.C. 20005

EDUCATION

Legal

Georgetown University Law Center, Washington, D.C.
Juris Doctor, 1979

Graduate/Undergraduate

Northwestern University, Evanston, Illinois
Master of Science, Chemical Engineering (1976)

Northwestern University, Evanston, Illinois
Bachelor of Science, Chemical Engineering (1976)

Scholastic Awards

Harry S. McCormick Award (Multi-School Award, Outstanding Chemical Engineering Student in Chicago Area)

Tau Beta Pi, National Engineering Honor Society

PROFESSIONAL EXPERIENCE

Winston & Strawn - 1979 to Present
Senior Attorney, Winston & Strawn, 1992

Principal practice in the area of nuclear energy regulation, representing nuclear utility applicants and licensees, trade associations and others before the Nuclear Regulatory Commission.

- Participation on behalf of nuclear utility clients before the Nuclear Regulatory Commission in administrative adjudications related to the licensing of nuclear power reactors. Significant adjudicatory experience before NRC Atomic Safety and Licensing Boards in the operating license proceeding context, including the development and presentation of utility applicant evidence on contested technical, financial and environmental issues.

William A. Horin
Winston & Strawn

- Counsel to nuclear clients with respect to NRC enforcement matters (including all aspects of plant operation and radioactive materials transportation), requests for license amendments (related to among other topics construction permit period recapture and power level uprates) and other licensing activities.

- Representation of utility and utility group clients with regard to significant NRC administrative rulemakings, including decommissioning (focussing on legal and financial implications of NRC regulatory scheme) and license renewal.

- Significant involvement in regulatory areas concerning the implementation of NRC regulations related to equipment qualification, decommissioning of power reactors (and related IRS requirements concerning decommissioning funding), nuclear insurance (liability and property), and license renewal. In these contexts coordinate client activities with Nuclear Energy Institute generic industry initiatives.

- Represented nuclear trade association on tax and grassroot lobbying issues.

- Counsel to nuclear vendor related to the legal and licensing issues associated with the application of advanced technologies to nuclear power reactor operations to obtain economic benefits for power reactor licensees.

- Active involvement in industry generic efforts, including participation in Winston & Strawn representation of NEI on specific regulatory matters, and serving on or participating in NEI Issue Task Forces (formerly Advisory Committees) on topics including license renewal, equipment qualification and alternate source term.

- Participation in "whistleblower" proceedings before the Department of Labor.

Pro Bono Activities include representation of national non-profit secondary education association on tax and corporate matters.

ADMISSIONS/MEMBERSHIPS

- District of Columbia Bar (Administrative Law/Environment, Energy and Natural Resources Sections)
- United States District Court for the District of Columbia
- United States Court of Appeals, District of Columbia Circuit
- American Institute of Chemical Engineers

George E. Mattingly
National Institute of Standards and Technology
Gaithersburg, MD 20899
Ph: (301) 975-5939
Fax: (301) 258-9201
e-mail: gmattingly@nist.gov

EDUCATION:

PhD - Princeton University - Aerospace and Mechanical Sciences:
Major area: Fluid Mechanics; Minor area: Mathematics
MS - University of Maryland - Mechanical Engineering
Major area: Fluid Mechanics; Minor area: Mathematics
BS - University of Maryland - Mechanical Engineering

WORK EXPERIENCE:

2000-present

Deputy Chief, Process Measurements Division
Chemical Sciences and Technology Laboratory
National Institute of Standards and Technology (NIST)
Gaithersburg, MD

The Process Measurements Division develops and provides measurement standards and services, measurement techniques, recommended practices, sensing technology, instrumentation, and mathematical models required for analysis, control, and optimization of industrial processes. The Division's research seeks fundamental understanding of, and generates key data pertinent to, chemical process technology. These efforts include the development and validation of data-predictive computational tools and correlations, computer simulations of processing operations, and provision of requisite chemical, physical, and engineering data.

As the recently elected Chairman of the newly formed Working Group for Flow in the International Bureau of Weights and Measures (BIPM) I am organizing the International Key Comparison Testing programs that will quantify the equivalency of the flow standards maintained in the world's National Measurement Institutes (NMIs). This activity will remove measurement-based barriers to world trade. This activity will be done under the Consultative Committee for Mass and Related Quantities in the International Committee for Weights and Measures (CIPM).

1975 – 2000

Leader, Fluid Flow Group
National Institute of Standards and Technology
Gaithersburg, MD.

This position has responsibility for maintenance and dissemination of the national standards for fluid (liquid and gas) flow, air speed, liquid density and volume. By standards are meant the physical standards, as opposed to the paper standards, for these measurements. This position also includes leading effective research in these areas of metrology and in related areas of fluid mechanics appropriate for the advancement of flow standards and the fluid measurement needs of US industries.

1959-1975
A number of positions-academic and government-involved with fluid mechanics or flow measurement. Details available on request.

JOURNAL EDITORSHIP:
Associate Editor for the Journal: Flow Measurement and Instrumentation, Butterworth Scientific Publishers, Guildford, U.K.

PROFESSIONAL SOCIETY COMMITTEE MEMBERSHIPS:

1. ASME Main Committee on the Measurement of Fluid Flow in closed Conduits (MFFCC), and its:
    a) Sub-Committee 1-Uncertainties
    b) Sub-Committee 6-Glossary
    c) Sub-Committee14 (Chair)-Weighing & Volumetric Techniques
    d) Sub-Committee 15-Installation Effects
    e) Sub-Committee 16-Vortex Shedding Meters
    f) Sub-Committee 19-Flow Conditioning
    g) Sub-Committee 22-Critical Flow Meters
    h) Sub-Committee 23-Small Bore Orifice Meters

OTHER COMMITEES/ORGANIZATIONS:

1. International Measurement Confederation (IMEKO) Committee TC-9 Flow Measurement.
2. International District Heating and Cooling Association (IDHCA) Committee on Fluid Metering.
3. U.S. Delegation to the International Standards Organization (1SO) and Organization Internationale de Metrologia Legale (OIML) Committees on Water Metering.

AWARDS AND HONORS: (12 specific awards for a range of technical accomplishments...details available on request).

PUBLICATION AND REPORTS: Over 100 publications and reports have been authored or co-authored on a wide range of fluid mechanics and flow measurement topics.

SETH G. FISHER

PRESIDENT, CHAIRMAN OF THE BOARD

SPECIFIC EXPERIENCE

1988 to Present: President and Chairman of the Board, Fisher Precision Systems, Inc.

1980 to 1988: Program Manager, Electronic Warfare Division, Westinghouse Electronic Systems Group. Managed WEC and ITT joint venture participation in a joint services test and evaluation program for a $2 billion airborne electronics countermeasure system for U.S. Air Force, Navy and Marine fighter and surveillance aircraft. Managed 30+ professionals and managers from both joint venture partners. Negotiated and managed a joint venture support budget for prime equipment maintenance and special test equipment of $18 million. Represented joint venture in matters dealing with the joint services test program.

1976 to 1980: Field Engineering Manager, TCOM Corporation, a wholly owned subsidiary of the Westinghouse Electronic Systems Group. Built and managed a department of 100 management and professional personnel responsible for the installation, customer acceptance, operation and maintenance of aerostat-supported telecommunications sites in remote emerging countries. Managed and controlled $25 million portion of contracts as large as $120 million.

1968 to 1976: Program/Product Line Manager, Oceanic Division, Westinghouse Electronic Systems Group. Managed all departments within division with respect to sonar systems and flow measurement. Built the flow measurement business from scratch to a multi-million dollar value with a 20+% profit margin.

1963 to 1968: Sub-Division Engineering Manager, Oceanic Division, Westinghouse Electronic Systems Group. Managed 80 management and professional personnel designing and producing state-of-the-art equipment in the fields of sonar and optical instrumentation, vehicle hydrodynamics and control, data processing and communications.

1955 to 1963: Supervisory Engineer, Aerospace Division, Westinghouse Electronic Systems Group. Managed 25 engineers and 10 technicians in various aspects of radar programs including pulse doppler radar, analog computer design and special field test equipment.

1946 to 1955: Engineering Professional, Ordnance Department, Transformer Division, Westinghouse Electric Corporation. Held various positions of increasing responsibility and authority. Fields of endeavor included sonar, torpedo control and industrial instrumentation.

APPLICABLE RESULTS

- Pioneered the successful development, application and marketing of ultrasonic flowmeters yielding a 20+% profit margin.
- Formed new company that has significantly advanced the state-of-the-art in flow measurement and successfully introduced it into the marketplace.
- Designed new high resolution, one part in 10,000, instrument to measure weight, pressure or torque - a significant advance in the state-of-the-art.
- Hold four patents in the instrumentation and control field.

EDUCATION AND MEMBERSHIPS

Bachelor of Science in Electrical Engineering; University of Illinois

Registered Professional Engineer in states of Maryland and Pennsylvania

Member: American Society of Mechanical Engineers (ASME)
Institute of Electrical and Electronic Engineers (IEEE)
International Society for Measurement and Control (ISA)

LAWRENCE C. LYNNWORTH

Vice-President and General Manager, PCI Research and Development Division
Process Control Instrumentation Division

EDUCATION

B.E.E. New York University - 1958
M.S. Stanford University - 1959
Recipient of New York State, NYU, Tau Beta Pi, and Stanford University scholarships

EXPERIENCE

At Panametrics since 1962, Mr. Lynnworth is Vice-President and General Manager, PCI Research and Development Division. His early work at Panametrics was on high temperature ultrasonic measurements of elastic properties of solids, high temperature nondestructive testing, and measurement of temperature and transport properties in gases and plasmas in the 300 to 10,000 K range. Two NASA New Technology Awards were received for some of this high temperature R&D. Later on, he concentrated on engineering applications such as the development of ultrasonic sensors, transducers, and test equipment for measuring process control parameters such as flow, temperature, density, liquid level, etc. His work on a flare gas ultrasonic flowmeter in the early 1980's led to that product being awarded a Vaaler Award in 1984. One of his clamp-on transducer inventions formed the basis for a second Vaaler Award two years later. In 1992 he received notification of his third NASA New Technology Award for his 1990 work on an ultrasonic isolator. Recent patents allowed or likely to issue by Y2K are in the areas of acoustic isolation, flexural sensing of density or liquid level (HLAS), flow-sensing buffers for hot gas or hot liquid (BWT), and for shear waves (OKS for clamp-on at high temperature or cryogenic temperatures). The OKS has also been used to measure flow over quadrature paths and other paths that previously could not be reached by clamp-on transducers.

At Avco, 1959 to 1962, Mr. Lynnworth worked on the development of new dielectric and ultrasonic methods for nondestructively testing heatshield materials, and on the measurement of ablation by an ultrasonic technique (pulse-echo method) and a nucleonic technique (originator of the step-type gamma ray ablation sensor using discrete implanted sources of radiation, which became an Avco product used in re-entry vehicle heatshields). He also developed an experimental noncontact optical coating gage.

Author of some 200 publications and reports; author of invited chapters on Ultrasonic Flowmeters for the Academic Press book *Physical Acoustics*. Vol. 14 (1979), co-author of Chapter 4 in Volume 23 (1999), and on Ultrasonic Instrumentation for the Wiley *Handbook of Measurement Science*, Vol. 3 (1992); on Nonresonant Ultrasonic Sensors for the VCH book *Mechanical Sensors* (1994); invited chapter on acoustic and ultrasonic sensors for encyclopedia published by the American Physical Society [1996]; inventor (approximately 40 U.S. patents); elected to professional society posts such as founding chairman (1969-1972) of ASTM's E20.06 subcommittee on Acoustical Thermometers; past chairman (1970-1971) of ASNT's Boston Section; past chairman (1972-1973) of IEEE's Boston Section of the Sonics and Ultrasonics Group; Associate Editor, *IEEE Trans. on Ultrasonics, Ferroelectrics and Frequency Control* (1980-1992); reviewer for this journal, the Institute of Physics (UK), the *Review of Scientific Instruments,* and for one of the New England state offices that issues grants to small businesses. In 1989, his 720-page book, *Ultrasonic Measurements for Process Control,* was published by Academic Press.

MEMBER: IEEE (Fellow, 1993), Tau Beta Pi, Eta Kappa Nu

Roger D. Horn, Ph.D.

ProDesCon
Process Design Consultants, Inc.
Knoxville, TN
rhorn@ProDesCon.com

Industrial and Academic Experience

Senior Consultant

ProDesCon **1997 – present**
Data Refining, Inc.
Mount Laurel, New Jersey

Participated in Standard Review Plan compliance audits for international client constructing new nuclear reactors. Evaluated vendor programs for compliance to the NRC's Standard Review Plan (NUREG 0800) with emphasis on software development of safety-related applications (BTP-14).

Reviewed software and electronic hardware design, and developed a theory of operations manual and acceptance test criteria for a nuclear power plant turbine control subsystem.

Performed numerous evaluations of commercially available digital equipment to support EPRI/utility-sponsored generic qualification efforts. Evaluation criteria was based on Reg. Guide 1.152 endorsed IEEE 7-4.3.2, and EPRI TR-106439.

Reviewed nuclear power plant systems for Y2K issues and mitigation strategies. Systems included: emergency sirens using trunked radio, reactor vessel level, service air, main generator RF monitor, and video capture. Developed systematic Y2K tests for emergency siren system to isolate multiple commercial components.

Performed evaluation of software and electronic hardware design for networked laboratory system. Developed specification of imaging system design, evaluation, and test methods for new production method at existing pharmaceutical facility. Prepared functional specifications to support validation effort.

Research Associate

University of Tennessee **1995 - present**
Knoxville, Tennessee

Investigated rapid prototyping system for analysis of wireless (spread spectrum) communications in the 900MHz, 2.4GHz, and 5.2GHz bands used in manufacturing and process control applications. Modeled low power RF transceivers, collocated with process sensors, in geometrically complex RF-reflective environments and studied limitations regarding range, noise immunity, and data error rate.

Research and system support for West Florida Counterdrug Information Network (WFCIN), an operational ATM network test bed for new technologies with application to counterdrug operations. Participated in development of WFCIN research agenda for two year program investigating interpretive structural modeling, secure information indexing and retrieval, decision support for emergency and disaster management, and imaging and surveillance systems.

Designed and implemented a tree structured database search engine for rapid DNA profile identification for forensic applications. The search engine provides retrieval of matching DNA markers/alleles on very large (10^6-10^8) profile data sets and accommodates search targets with missing loci data.

Consultant

Data Refining Technologies, Inc. **1993 -1997**
Plaquemine, Louisiana

Review software and electronic hardware design of nuclear power plant turbine control systems, digital feedwater control systems, radiation monitoring systems, UPS, and pressure transducer.

Reviewed quality assurance and software design of digital data recorder for use in nuclear power plant application. Developed a report generator (C++), FoxPro database, and GUI for the DRT Object-Oriented Signal Processing Library. Developed software standard for nuclear power plant digital instrumentation upgrade.

Reviewed quality assurance and software design of nuclear power plant digital feedwater control and radiation monitoring systems.

Research Assistant

University of Tennessee **1988 -1992**
Knoxville, Tennessee

Designed and implemented an object-oriented (C++) GUI for a plasma physics simulation program.

Investigated the use of machine learning and advanced statistical methods (PCR and PLS) to classify process operation.

Worked on a discrete event simulation program based on Petri net modeling.

Investigated new approaches to real-time expert system design for power electronics applications. Developed new methods for inverter modulation using decision trees (Ph.D. dissertation research).

Developed methods for identification of dynamical events that induce sickness during helicopter flight simulator operation.

Conducted research on computer-assisted generation of hypothesis feedback models. Developed methods for automatic generation of discrete dynamical event filters.

Instructor (Fall 1989). Taught Linear Systems Analysis. Steady-state and transient response; log-frequency, gain-phase, and polar plots; block diagram transformations; signal flow graphs; analog systems; properties of second-order systems; introduction to feedback theory; stability criteria.

Electrical Engineer/Consultant

Varian Associates **1982 -1988**
Walnut Creek, California

Provided software development and maintenance support for continuing projects.

Designed control program for monochromator stepper motor, analog electronics and deuterium lamp for liquid chromatography detector. Developed software in C and 68000 assembly language on VAX/UNIX. Detector software ran under pSOS-68K real-time multi-tasking executive program.

Electronics Team Leader for development of Liquid Chromatography (LC) solvent delivery system. Developed finite element model of LC column. Designed CRT controller and power supply for microprocessor based (8085) instrument. Wrote product test software for manufacturing and service engineers.

Roger D. Horn, Ph.D.

Electrical Engineer

Lawrence Berkeley Laboratory **1977 -1982**
Berkeley, California

Designed instrumentation for high energy physics experiments at the Bevatron particle accelerator. Participated in development of control system for magnet power supply used in heavy ion superconducting spectrometer experiment. Designed analog and digital interfacing for microcomputer data systems.

Designed instrumentation for biomedical experiments using the Bevatron. Developed system to verify selection and operation of ion filter used in radiation treatment facility.

Designed and built signal overload protection system and computer interface for monitoring of superconducting experiments. Assisted in electronic design of experimental systems for the Bevatron.

Hewlett-Packard, H-P Labs **Summer 1979**
Palo Alto, California

Designed and built hardware for low current testing system to make DC measurements on CMOS integrated circuits. Developed controlling software for automated wafer probe station. Test system performed DC characterization of N-channel and P-channel devices in the linear and subthreshold operating regions.

Education

Ph.D.
University of Tennessee, 1992
Knoxville, Tennessee
Dissertation Title: Decision Tree Modulators for Power Electronics Applications

M.S.E.E.
University of California, 1984
Berkeley, California
Project: Design and Implementation of a State Space Controller for a High Pressure Solvent Pump

B.S.E.E.
University of California, 1978
Berkeley, California

Patent

"Method and apparatus using a decision tree in an adjunct system cooperating with another physical system."
J. D. Birdwell and R. D. Horn, U.S. Patent No. 5,481,649

Publications

1. Horn, R. D., J. D. Birdwell, and L. W. Leedy, "Link Discovery Tool", *1997 ONDCP International Symposium*, August 1997.

2. Birdwell, J. D., R. D. Horn, M. S. Rader, and A. A. Shourbaji, "Propagation Modeling in a Manufacturing Environment," *Workshop on Wireless Communications for Improved Manufacturing*, November, 1995.

3. Horn, R. D., and J. D. Birdwell, "Adaptive modulation of inverters for adjustable speed drives," *32nd IEEE Conference on Decision and Control*, December 1993.

Publications (continued)

4. Horn, S. P., R. D. Horn, and A. R. Byrne. "An automated charcoal scanner for paleoecological studies," *Palynology*, Vol. 16, pp. 7-12, 1993.

5. Horn, R. D., and J. D. Birdwell, "Real-time object oriented intelligent control environment," *31st IEEE Conference on Decision and Control*, Vol. 3, pp. 2984-2985, December 1992.

6. Birdwell, J. D., R. D. Horn, and S. Liang, "Automatic generation of signal classification algorithms using machine learning," pp. 197-219, *Recent Advances in Computer Aided Control Systems Engineering*, M. Jamshidi and C. J. Herget (Eds.), Elsevier, Amsterdam, 1992.

7. Birdwell, J. D., J. S. Lawler, G. Qiu, R. E. Uhrig, Z. Duan, R. Horn, J. Ilic, S. Liang, S. Patek, P. Shanmugam, and Y. Zhu, "New approaches to real-time expert system design for power electronics applications," Department of Electrical and Computer Engineering, University of Tennessee, final report for Electric Power Research Institute, EPRI RP8000-40, December 1992.

8. Birdwell, J. D., R. D. Horn, J. Ilic, S. D. Patek, and P. Shanmugam, "A variable-speed induction motor drive using expert system technology," *4th European Conference on Power Electronics and Applications*, Vol. 3, pp. 66-69, September 1991.

9. Horn, R. D., and J. D. Birdwell, "Variable frequency closed-loop discrete pulse modulation for induction motor control," *29th IEEE Conference on Decision and Control*, Vol. 6, pp. 3039-3044, December 1990.

10. Horn, R. D., J. D. Birdwell, and G. O. Allgood, "Prediction of helicopter simulator sickness," *29th IEEE Conference on Decision and Control*, Vol. 4, pp. 2380-2385, December 1990.

11. J. D. Birdwell, and Horn, R. D., "Optimal filters for attribute generation and machine learning," *29th IEEE Conference on Decision and Control*, Vol. 3, pp. 1537-1539, December 1990.

12. Horn, R. D., and J. D. Birdwell, "Solution of integer programs for power electronics," *SPIE Applications of Artificial Intelligence VIII*, SPIE Proceedings Series, Vol. 1293: Part 2, pp. 888-895, April 1990.

13. Horn, R. D., and J. D. Birdwell, "Digital filters for inductive inference applications," *1989 IEEE International Symposium on Circuits and Systems*, Vol. 3, pp. 1676-1679, May 1989.

Thomas O. Maginnis, Ph.D.

[redacted]

SUMMARY:

Applied physicist with more than 10 years of progressive, diversified, hands-on experience developing state-of-the-art process control instruments and sensors. Proven leadership record taking small multi-disciplinary teams from initial concept generation through design, construction, and testing of prototype instruments.

CAPABILITIES:

ELECTRONICS: Extensive background in electronic, ultrasonic, and thermal measurement instruments and techniques.

PROGRAMMING: Fortran, Basic, Pascal, Hpl

SOFTWARE: MathCad, Pro-E, Wordperfect, Mathematica, Amipro, 123, other PC programs.

MATHEMATICS: Strong mathematical/physical modeling capability including Fourier transforms, correlation and statistical analysis, partial differential equations, linear systems theory.

SPECIALIZED INSTRUMENTS: Spectral Dynamics SD 375 Dual Channel Spectrum Analyzer, Hewlett-Packard HP 5370 High Resolution Timer, Dual Track Time Delay Oscilloscopes, Fabry-Perot Interferometers, Thermal Mass Flow Controllers.

ACCOMPLISHMENTS:

THERMAL MASS FLOW CONTROLLERS:

- Invented, prototyped and patented a new family of very low noise thermal flow sensors
- Demonstrated the ability of prototype sensors to control gas flow at exceptionally low rates
- Achieved a major advance in the theory of thermal flow sensors: understood low flow noise
- Developed a general mathematical/computer model that accurately predicts sensor behavior
- Applied understanding to design of liquid thermal flow sensors
- Very rapidly(<2 mo.) developed a thermal sensor that functions at very low pressure(<10 torr)

OPTICAL SENSOR DEVELOPMENT:

- Developed low power mechanical and thermal microsensors directly coupled via optical fiber without need for electronic conversion
- Created theoretical model of optical escapement for self-oscillating mechanical micro-resonator powered by steady light supplied through an optical fiber
- Successfully modeled and understood opto-mechanical coupling, optical feedback and power budget, leading directly to the demonstration of a working self-oscillating microresonator
- Devised and implemented an optical sensor for selective detection of torsional oscillations and suppression of flexural background noise

RESONANT SENSORS:

- Developed very low power (sub-microwatt) mechanical sensors with frequency output for easy microprocessor interface and superior electrical noise suppression
- Mathematically modeled very high performance vibrating wire pressure sensors and determined factors limiting their accuracy
- Derived an equivalent circuit to accurately represent the electrical impedance of the vibrating wire as seen by the drive electronics
- Investigated other resonant systems better than vibrating wires as force sensors
- Devised naturally tracking mechanical filter to eliminate mechanical coupling of a vibrating wire to sympathetic resonances in its supporting structure

ULTRASONICS:

- Devised and completed tests & math models needed to design and build a prototype clamp-on time-of-flight ultrasonic flowmeter
- Led three-man team that designed and built a working prototype, accurate to 1% of flow rate over a 40° C. temperature range
- Investigated feasibility of clamp-on ultrasonic cross-correlation for flow measurement
- Diagnosed and solved standing wave problem, improving signal/noise ratio by a factor of 5
- Led project to measure flow by detecting vortex shedding frequency by external ultrasonics

EMPLOYMENT:

1999-present	University of Massachusetts at Lowell ADJUNCT PROFESSOR: Applied Physics
1995-1998	MKS Instruments, Methuen, MA MECHANICAL ENGINEER III, Process Control Instrumentation Group
1993-1995	Consulting and applied research
1992-1993	Mass Bay Community College, Wellesley Heights, MA ADJUNCT PROFESSOR: Environment, Pascal, Physics
1991-1992	Consulting
1978-1990	The Foxboro Company, Foxboro, MA PRINCIPAL RESEARCH SCIENTIST, Corporate Research

PROFESSIONAL AFFILIATION:

Society of Concurrent Engineering
American Physical Society
American Association for the Advancement of Science
Sigma Pi Sigma

EDUCATION:

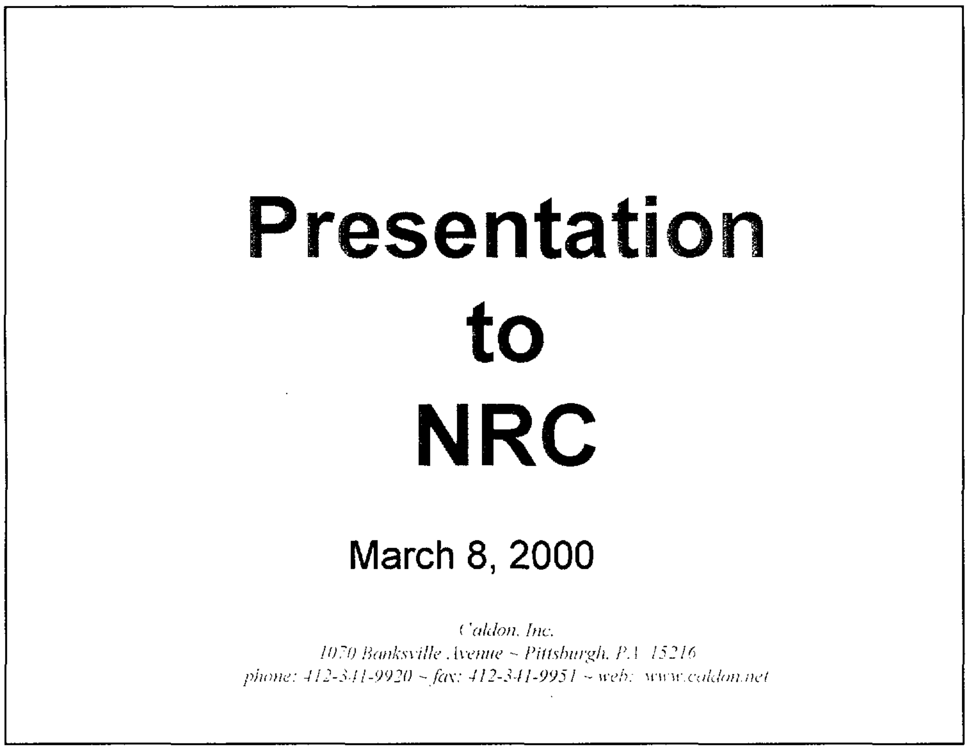
Adelphi University (NY)	Ph.D.	Physics
Columbia University (NY)	M.A.	Physics
St. Joseph's University (PA)	B.S.	Electronic Physics

Thomas O. Maginnis, Ph.D
[redacted]

ACADEMIC HONORS AND AWARDS:

Woodrow Wilson Fellowship
NSF Award to attend Brandeis Summer Institute in Theoretical Physics
Adelphi University Senior Teaching Fellowship
Teaching.Assistantships at Columbia and Adelphi
Merit Scholar Finalist

List of internal technical papers and references available on request.



Presentation to NRC

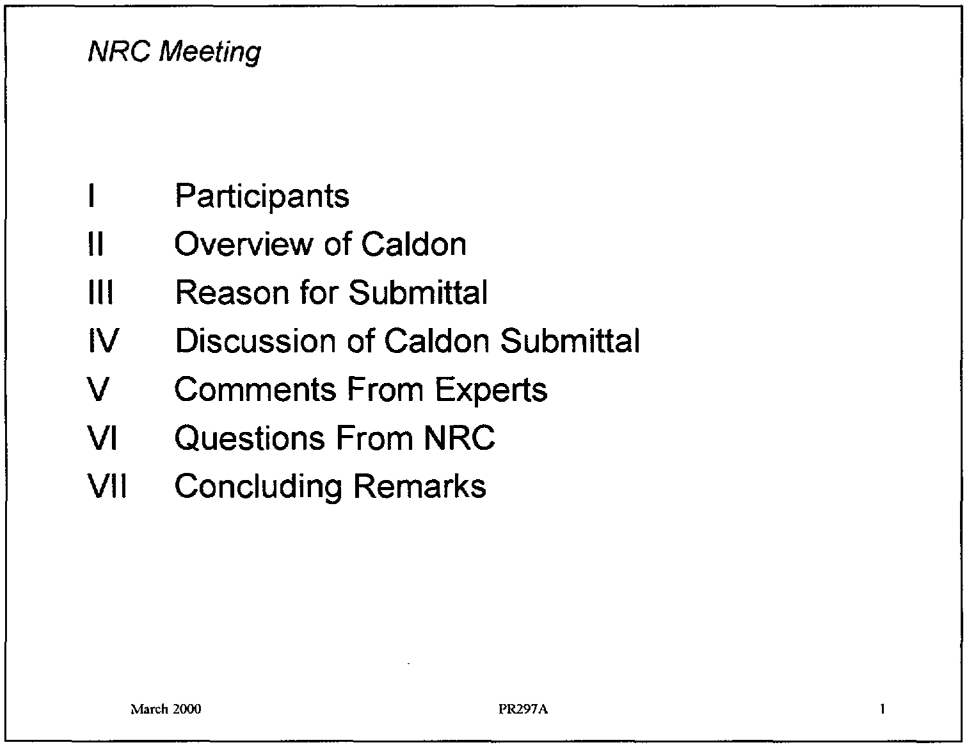
March 8, 2000

Caldon, Inc.
1070 Banksville Avenue ~ Pittsburgh, PA 15216
phone: 412-341-9920 ~ fax: 412-341-9951 ~ web: www.caldon.net

Good afternoon. I am Cal Hastings the President and CEO of Caldon. I am here to discuss a serious topic with you.

I have prepared a formal presentation for portions of this meeting, including a script. At the end of the meeting copies of the charts and the script will be available.

Attachment 3



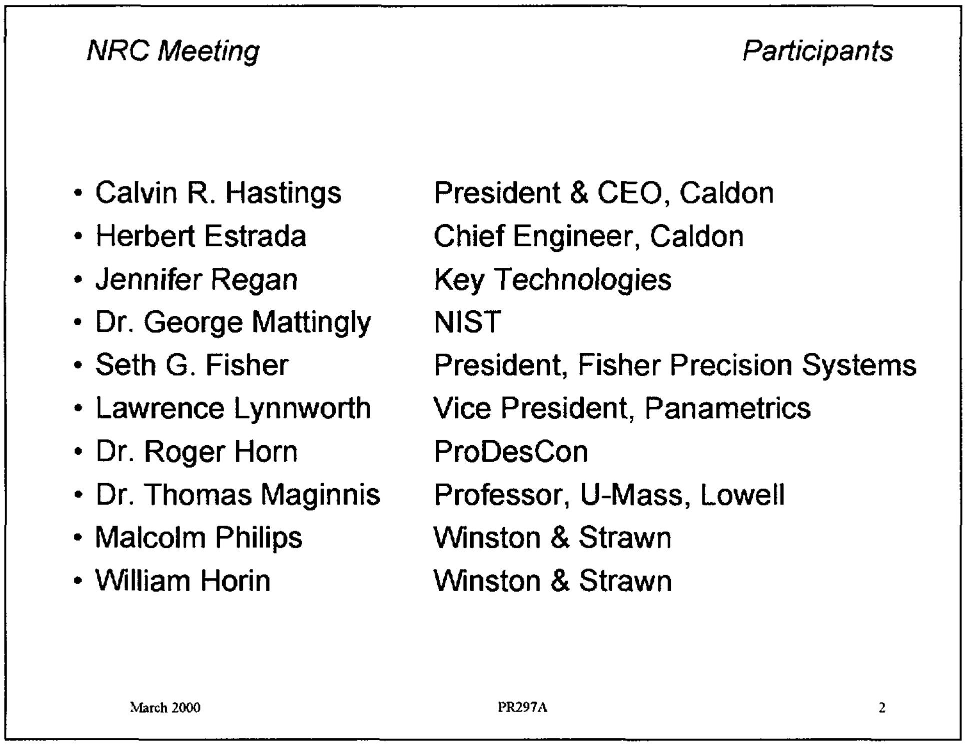
NRC Meeting

- I Participants
- II Overview of Caldon
- III Reason for Submittal
- IV Discussion of Caldon Submittal
- V Comments From Experts
- VI Questions From NRC
- VII Concluding Remarks

March 2000 PR297A 1

I plan to cover the following topics:

- The people here who I invited and want to talk on this subject have introduced themselves. I will say a few more words about them.
- I will tell you a little about Caldon
- Then explain why we submitted our February 15th information package
- Jenny Regan and Herb Estrada will discuss the technical information submitted
- The experts here will make comments and offer their opinions where they feel they can contribute to better understanding
- We would expect and welcome questions from the NRC at any time during our discussions
- I expect that both NRC and Caldon will have some concluding remarks.



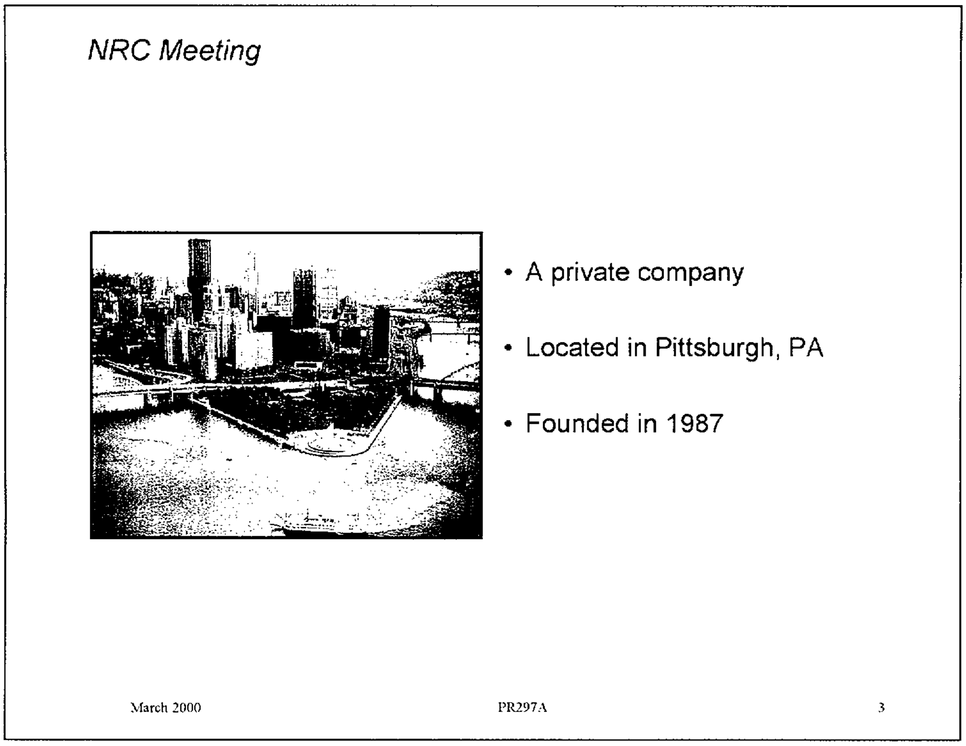
NRC Meeting *Participants*

Calvin R. Hastings	President & CEO, Caldon
Herbert Estrada	Chief Engineer, Caldon
Jennifer Regan	Key Technologies
Dr. George Mattingly	NIST
Seth G. Fisher	President, Fisher Precision Systems
Lawrence Lynnworth	Vice President, Panametrics
Dr. Roger Horn	ProDesCon
Dr. Thomas Maginnis	Professor, U-Mass, Lowell
Malcolm Philips	Winston & Strawn
William Horin	Winston & Strawn

Those attending this afternoon on behalf of Caldon include:

- myself,
- Herb Estrada - Caldon's Chief Engineer,
- Jenny Regan - a key technical consultant to Caldon,
- George Mattingly - National Institute of Standards & Technology,
- Seth Fisher and Larry Lynnworth who are competitors of Caldon and are highly regarded for their flow measurement know-how,
- Roger Horn, who accepted Caldon's assignment to study cross-correlation flowmeters and identify and bound their sensitivities
- and Tom Maginnis, formerly in research and product development at Foxboro where he worked on transit-time and cross-correlation flowmeters, and now a professor at U-Mass, Lowell.
- Malcolm Philips and Bill Horin - attorneys; they have been advising us from the beginning with respect to NRC regulations and they are also engineers

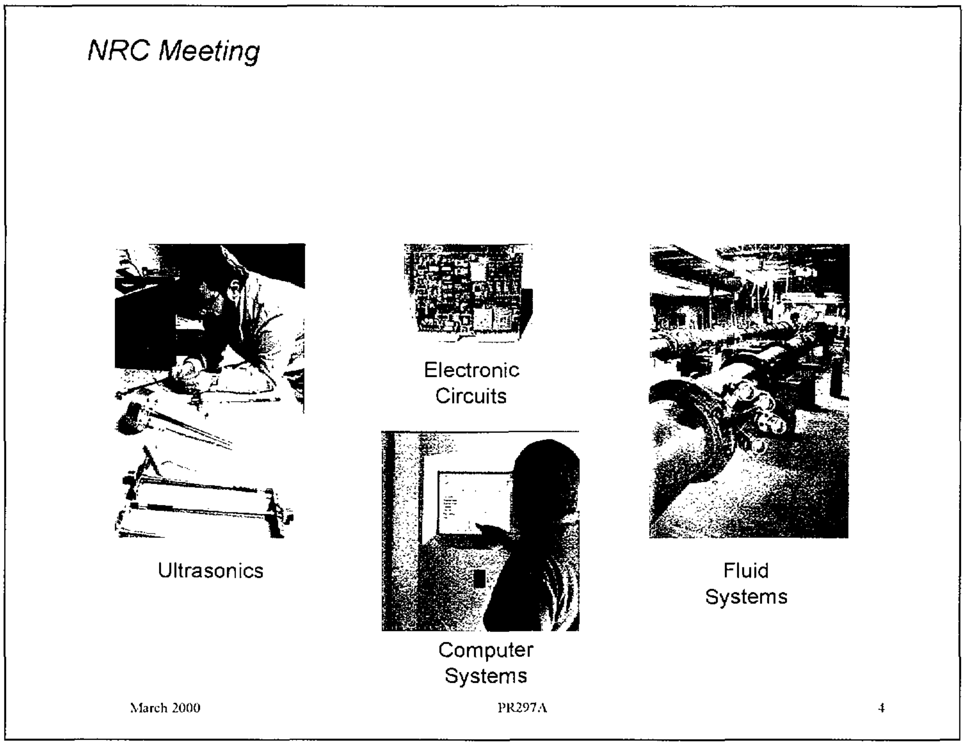
Copies of resumes of the technical experts will be provided at the end of this meeting.



NRC Meeting

- A private company
- Located in Pittsburgh, PA
- Founded in 1987

Caldon is a privately held company, located in Pittsburgh, PA. I founded the company in 1987.



NRC Meeting

Ultrasonics

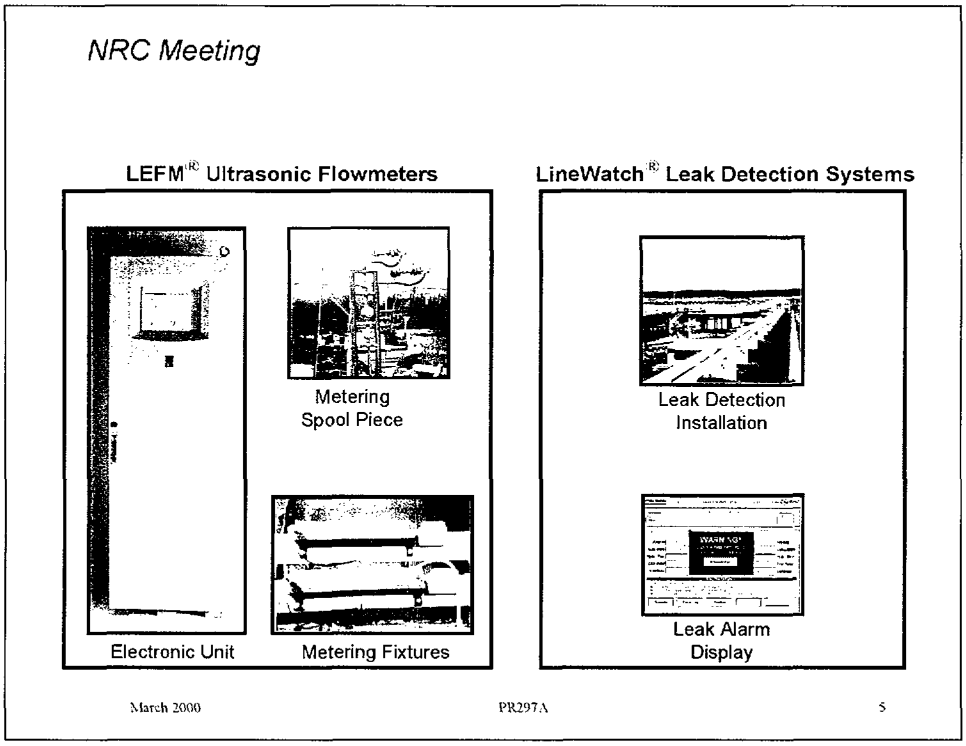
Electronic Circuits

Computer Systems

Fluid Systems

March 2000 PR297A 4

We are a high technology company with significant know-how in ultrasonics, electronic circuits, computer systems, and flow phenomena within fluid systems.



NRC Meeting

LEFM® Ultrasonic Flowmeters

Electronic Unit

Metering Spool Piece

Metering Fixtures

LineWatch® Leak Detection Systems

Leak Detection Installation

Leak Alarm Display

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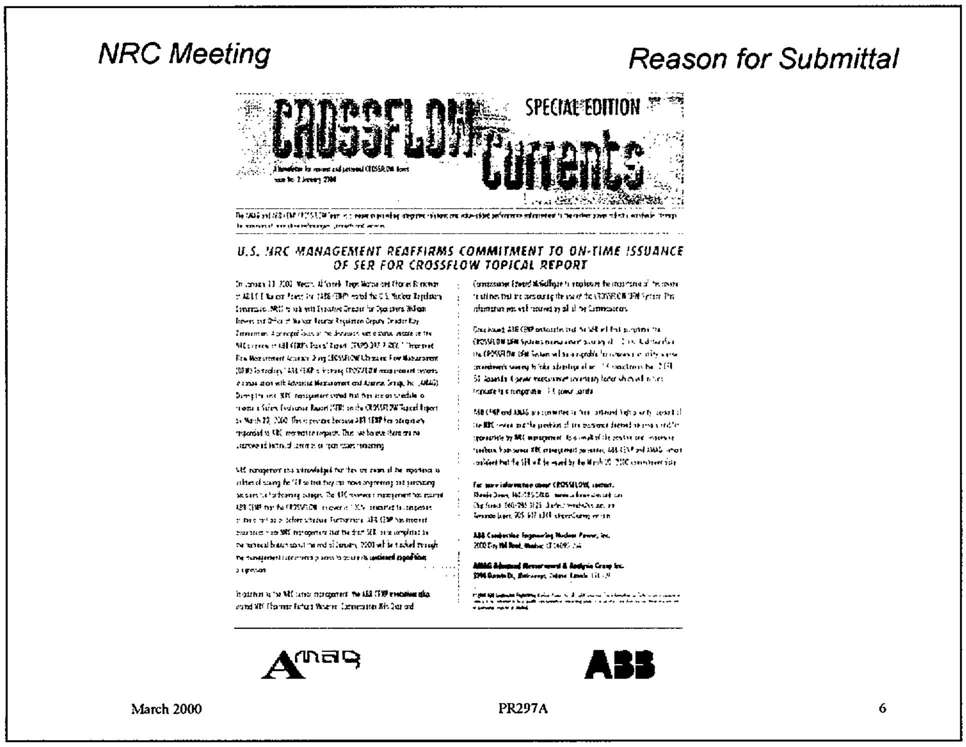
We have two principal product lines:

- LEFM® Ultrasonic Flowmeters
- LineWatch® Leak Detection Systems

These products are used in important and technically demanding applications, including:

- Ballast control on Seawolf Class Submarines
- Leak detection on the trans-Alaska Pipeline
- Turbine monitoring at New Zealand's hydro- electric stations,
- Feedwater flow measurement in 33 nuclear power plants



NRC Meeting

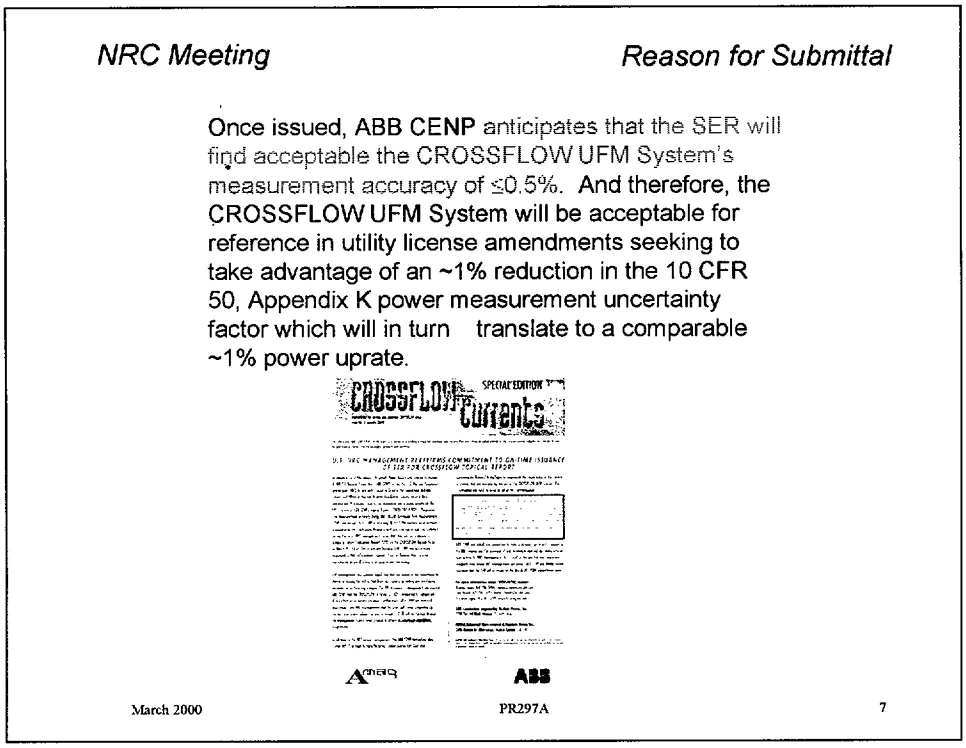
Reason for Submittal

SPECIAL EDITION

CROSSFLOW Currents

U.S. NRC MANAGEMENT REAFFIRMS COMMITMENT TO ON-TIME ISSUANCE OF SER FOR CROSSFLOW TOPICAL REPORT

Last month, I was given a copy of the Special Edition of ABB's CROSSFLOW Currents Newsletter, Issue No. 2, January 2000. This newsletter provides information on the status, at that time, of the NRC's review of ABB's Topical Report on CROSSFLOW UFM technology.



NRC Meeting *Reason for Submittal*

Once issued, ABB CENP anticipates that the SER will find acceptable the CROSSFLOW UFM System's measurement accuracy of ≤0.5%. And therefore, the CROSSFLOW UFM System will be acceptable for reference in utility license amendments seeking to take advantage of an ~1% reduction in the 10 CFR 50, Appendix K power measurement uncertainty factor which will in turn translate to a comparable ~1% power uprate.

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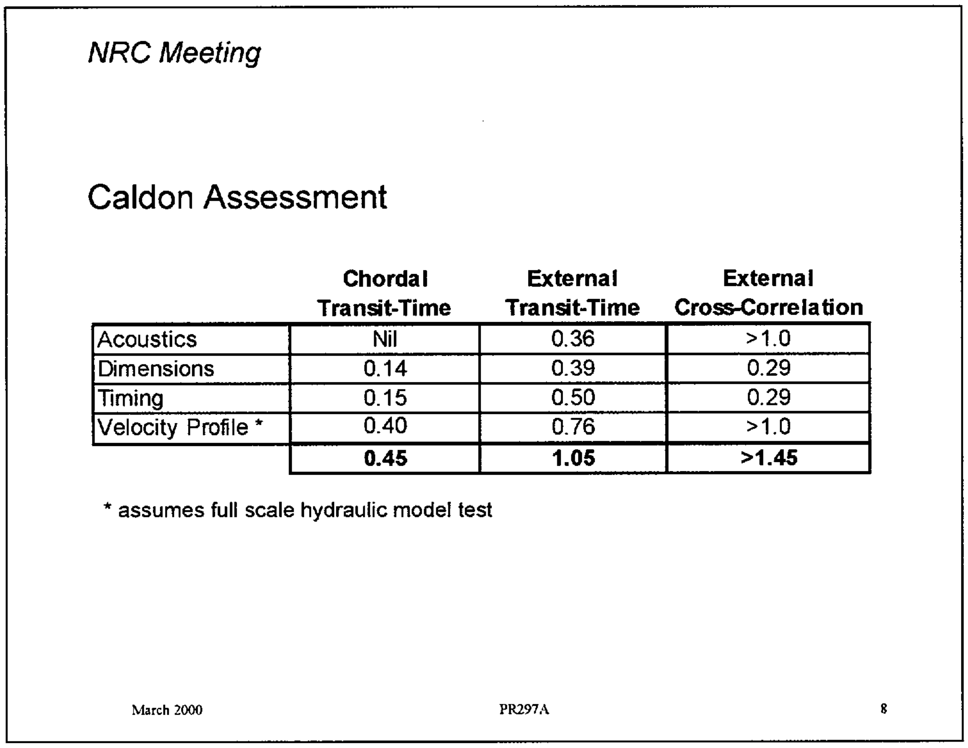
I was surprised by the statement "... the SER will find acceptable the CROSSFLOW UFM System's measurement accuracy of ≤ 0.5%."

I had fully expected that the NRC would find that a bounding value for the overall uncertainty of this instrument would be significantly larger. I have reasons to feel that way.



NRC Meeting

Caldon Assessment

	Chordal Transit-Time	**External Transit-Time**	**External Cross-Correlation**
Acoustics	Nil	0.36	>1.0
Dimensions	0.14	0.39	0.29
Timing	0.15	0.50	0.29
Velocity Profile *	0.40	0.76	>1.0
	0.45	**1.05**	**>1.45**

* assumes full scale hydraulic model test

This is our assessment of uncertainties for ultrasonic flowmeters for a typical 2-loop plant installation. One is a chordal 4-path transit time flowmeter like Caldon's LEFM(check), one is an externally mounted transit time flowmeter like Caldon's External LEFM. The third is an externally mounted cross-correlation type flowmeter.

The uncertainties are identified here by four sources:

- Those from acoustic effects, such as scattering and reverberation of sound waves
- Those from less than perfect knowledge of dimensions, such as inside pipe diameter and sensor spacing
- Those from errors in measuring transit time or cross-correlation time
- Those from flow distortions, often referred to as velocity profile effects

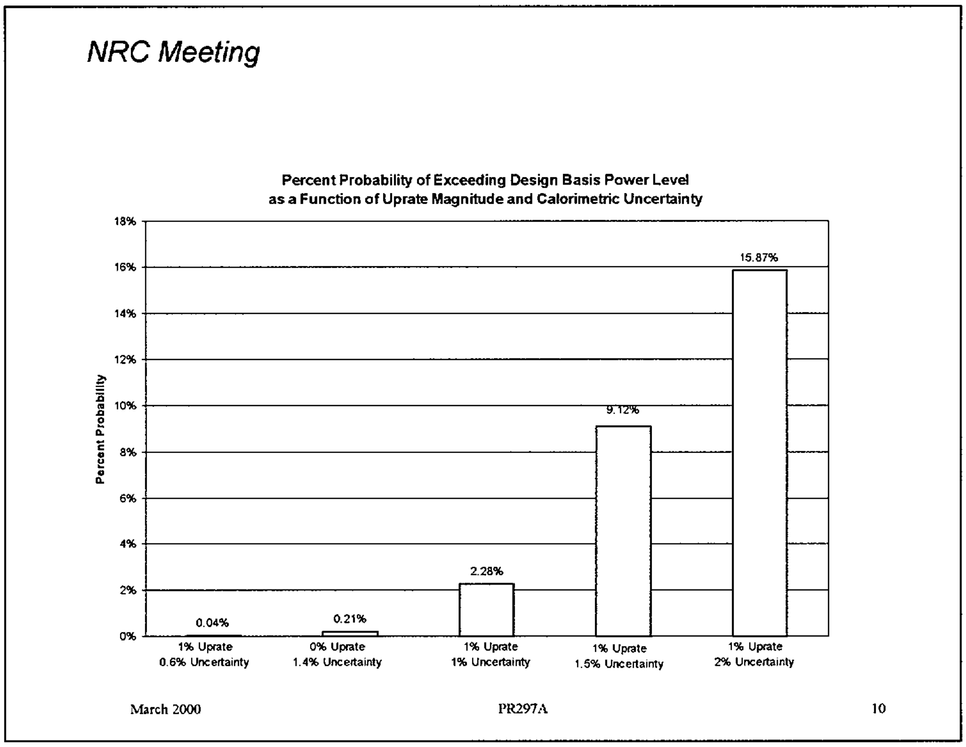
You can see why I was surprised by the newsletter. By our accounting, the overall bounding uncertainty for an external cross-correlation flowmeter (such as the one under review by the NRC) is greater than 1.4%.

NRC Meeting

- This issue is important to safety
- Everyone can lose

I believe that we all agree that this issue is important to safety. I will illustrate this point further in a moment.

Everyone can lose if an error in feedwater flow measurement causes a plant to go overpower. The good work that has gone into the Appendix K Rule Change and the intended positive outcome would surely suffer.



NRC Meeting

Percent Probability of Exceeding Design Basis Power Level as a Function of Uprate Magnitude and Calorimetric Uncertainty

March 2000 PR297A 10

I have attempted to show the safety implications by relating uncertainty in the thermal power measurement to the probability of a plant overpower incident. The case identified as #1 represents the use of the LEFM(check) for a 1% uprate in power. The measurement uncertainty is 0.6%. For this case, the probability of an overpower incident is 0.04%.

This is contrasted with Case #2 that represent the situation in most power plants today. Except for Comanche Peak, all other plants are still operating under the 2% Appendix K rule. Caldon's analysis, previously given to the NRC, concludes that the uncertainty in thermal power measurement is typically 1.4%. For these plants, the probability of exceeding their design basis power level is 0.21%.

Case #3 represents the situation in which a plant uprates its power level by 1% and that it employs a flowmeter that produces a thermal power uncertainty of 1%. For this plant, the probability of an overpower incident is 2.28%.

Cases 4 and 5 are also for situations involving 1% uprates, but in these cases, the thermal power uncertainty is even greater, that is, 1.5% and 2% respectively.

The safety penalty for being wrong on the uncertainty analyses may be exceedingly great.

- We submitted a large book containing 19 documents on ultrasonic flow measurement
- Each document in the book is relevant to Caldon's concerns
- There are three documents proprietary to Caldon and the rest are in the open literature
- We are unaware of any published documents in the open literature that refute the contents of this book

- We included entire documents to avoid citing sections out of context
- The documents are separated by tabs
- There is a summary in the front of the book that is intended as a roadmap, tying Caldon's concerns to specific references
- The documents span years of engineering research; some are as recent as this year and others go back as far as the 1970's

- Documents are included because they contain information about inherent fluid flow and acoustic effects for each of the flow measurement technologies
- For example, the hydraulic testing report by Seth Fisher and Paul Spink for chordal transit time meters is just as valid today as when it was published in 1971

There are three types of information in the book:

- Cross correlation technology research and field experience
- Transit time research and field experience (chordal and external)
- A comparative analysis of these technologies

- Cross-Correlation Technology Information
  - Tab 1 describes a system applying cross-correlation technology to N-16 for PWR primary flow measurement
  - Tabs 2, 3 and 4 contain publications supporting the designer's accuracy statements of 1% to 3% in 1992, 1996 and 1998 and describing field applications
  - Tabs 5, 6 and 17 describe experimental data that illustrates the profile sensitivities of the cross correlation technology
  - Tab 7 provides a general overview of the principals of operation of cross correlation meters

- Cross-Correlation Technology Information
  - Tab 8 describes results of Dr. Roger Horn's independent analysis of cross correlation technology uncertainties. This document is proprietary to Caldon.
  - Tab 9 is an excerpt from a textbook on cross correlation measurement technology

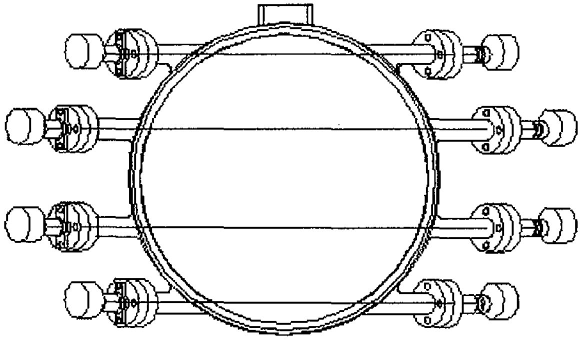
- Transit Time Technology Information
  - Tabs 10, 11, 12, 13, 14, 16, 18 and 19 support Caldon's accuracy statements about their chordal and external transit time meters, using analytical and experimental data and field experience
- Comparative Information
  - The introduction to the book and Tab 15 compare the three ultrasonic technologies in order to provide a frame of reference for the reviewer.

- Data in the open literature indicate that the hydraulic and acoustic uncertainties inherent in cross correlation technology would support an accuracy of between 1% and 3% rather than 0.5%
- These same data raise fundamental issues that cannot be addressed without extensive testing in a variety of piping configurations and wall roughnesses
- We will now address the hydraulic and acoustic uncertainties in greater detail, referring to the book of references as appropriate

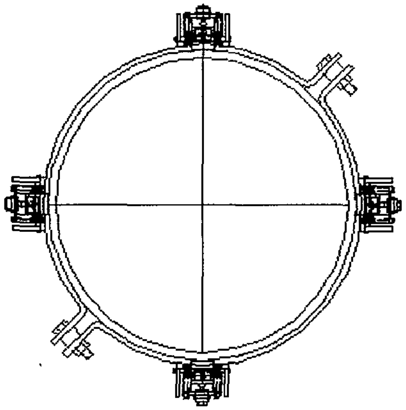
- Significant and variable sensitivities to:
  - velocity profile
  - acoustics
- No first principles theory:
  - errors may go unidentified and undetected

Compendium Tabs 8 and 9

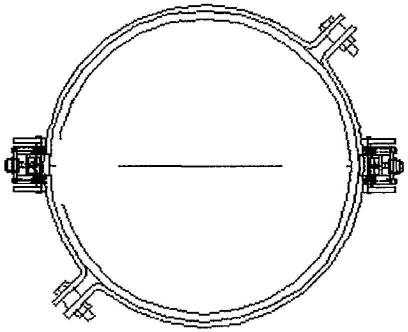
NRC Meeting Caldon Submittal - Cross Correlation Review



LEFM ✓

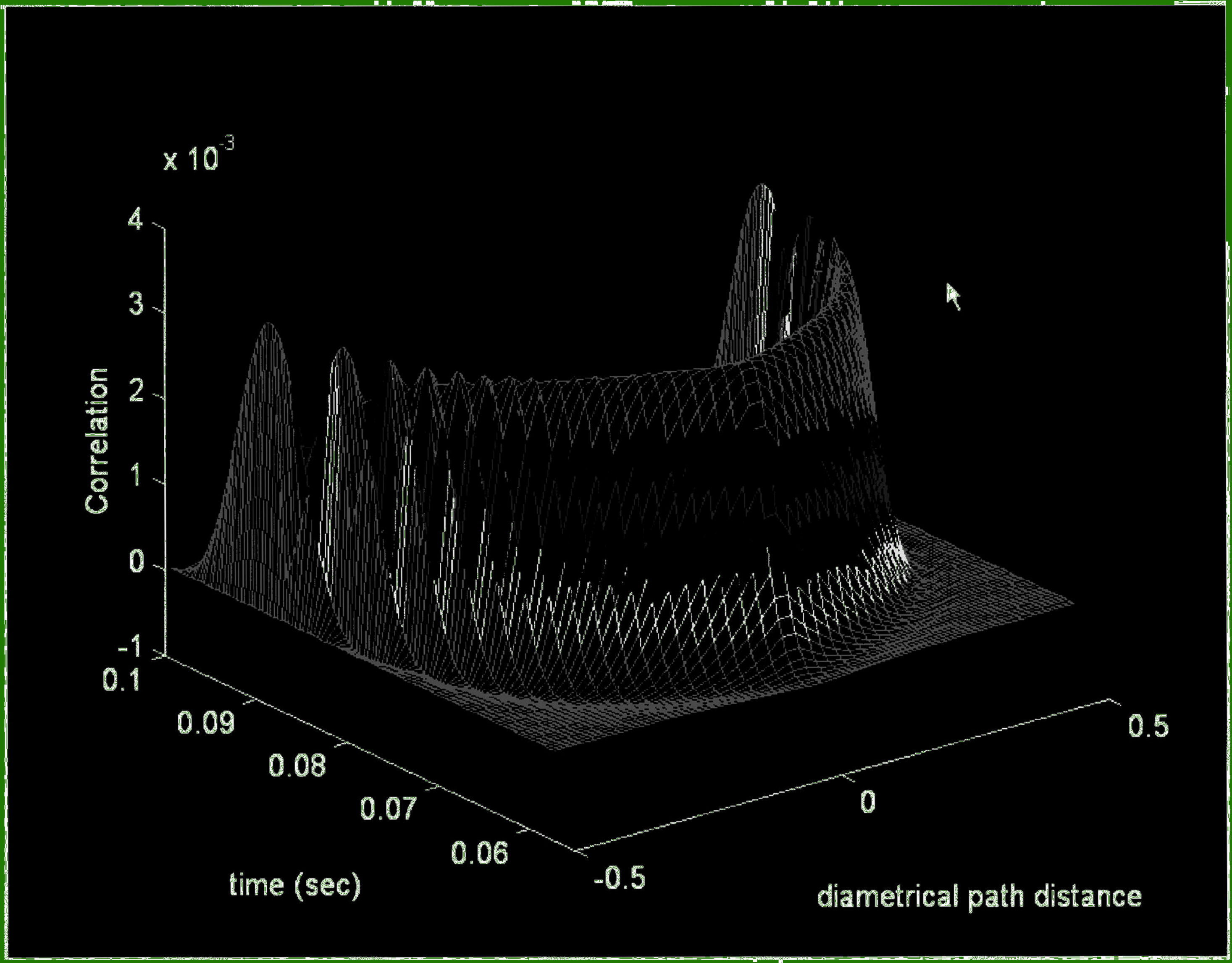


EXTERNAL LEFM

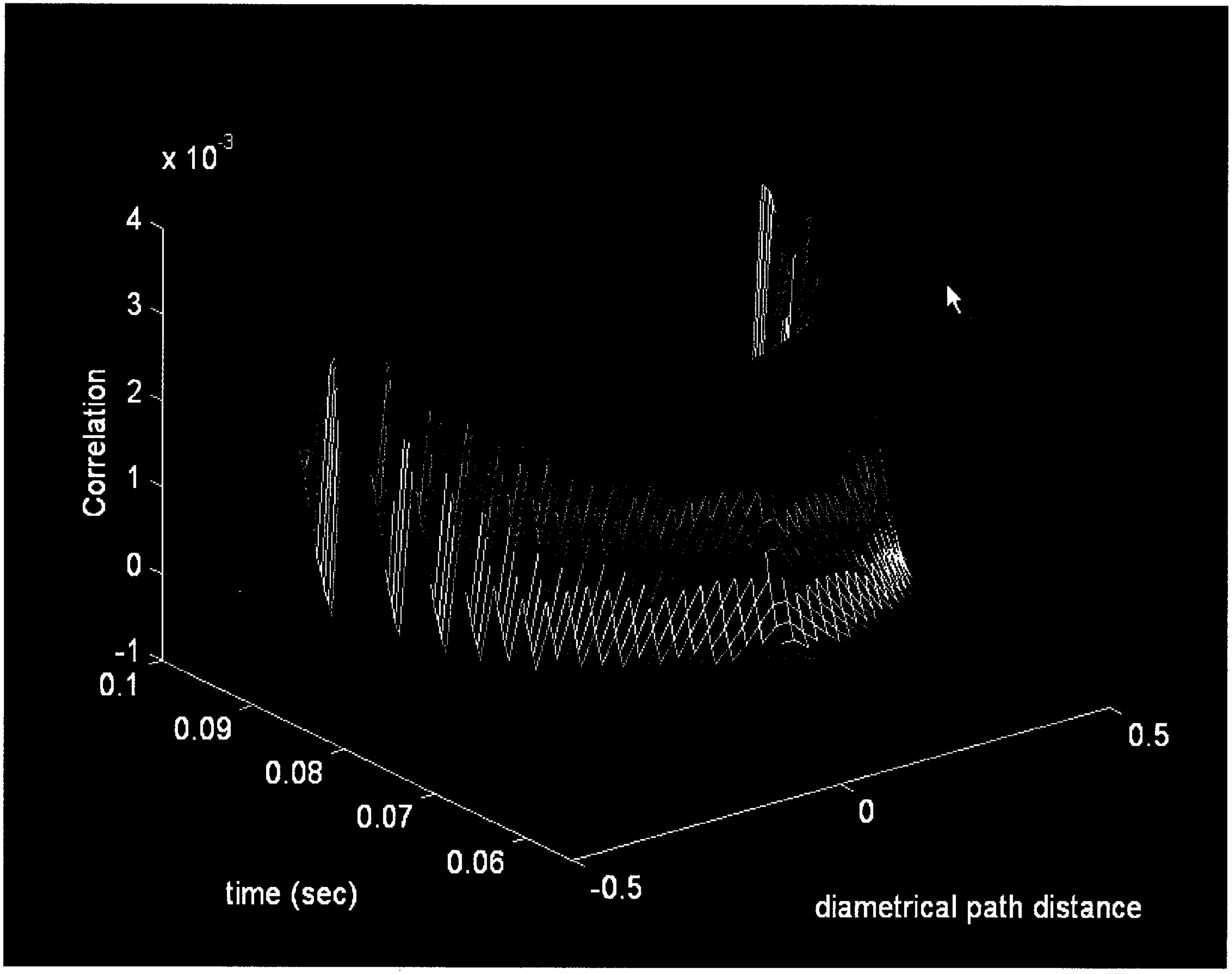


CROSS-CORRELATION FLOW METER

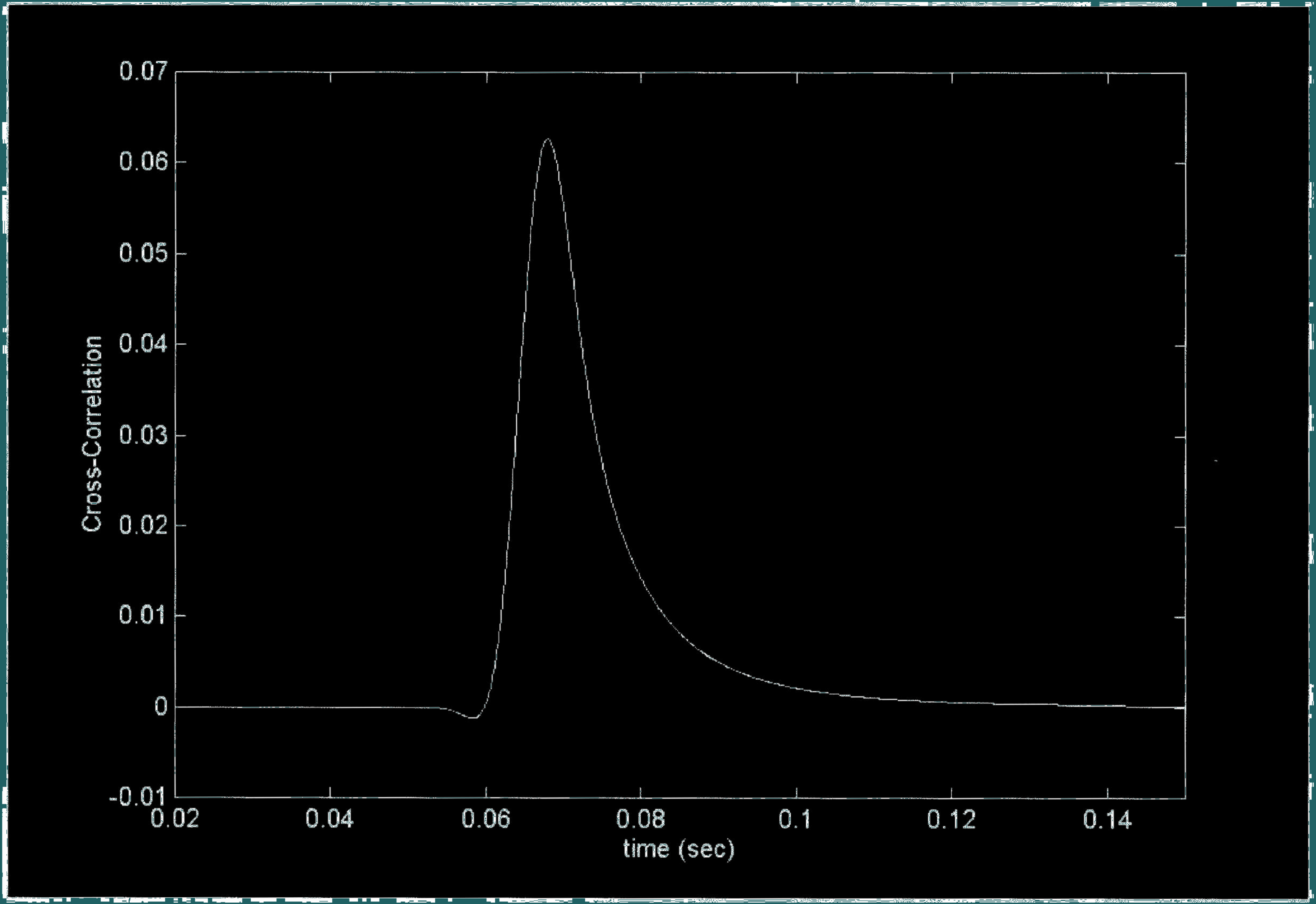
NRC Meeting Caldon Submittal - Cross Correlation Review



Caldon Submittal - Cross Correlation Review

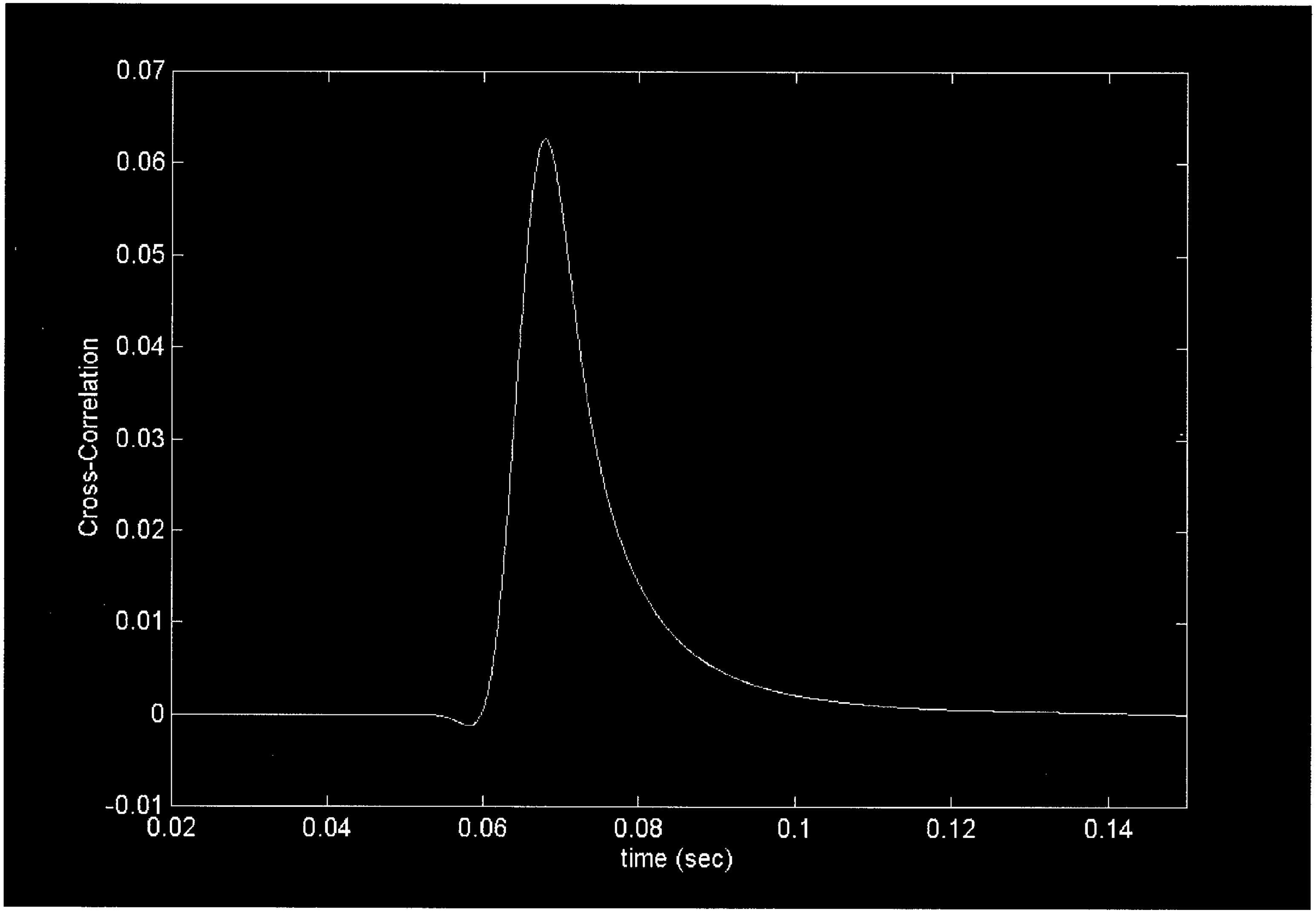


Caldon Submittal - Cross Correlation Review

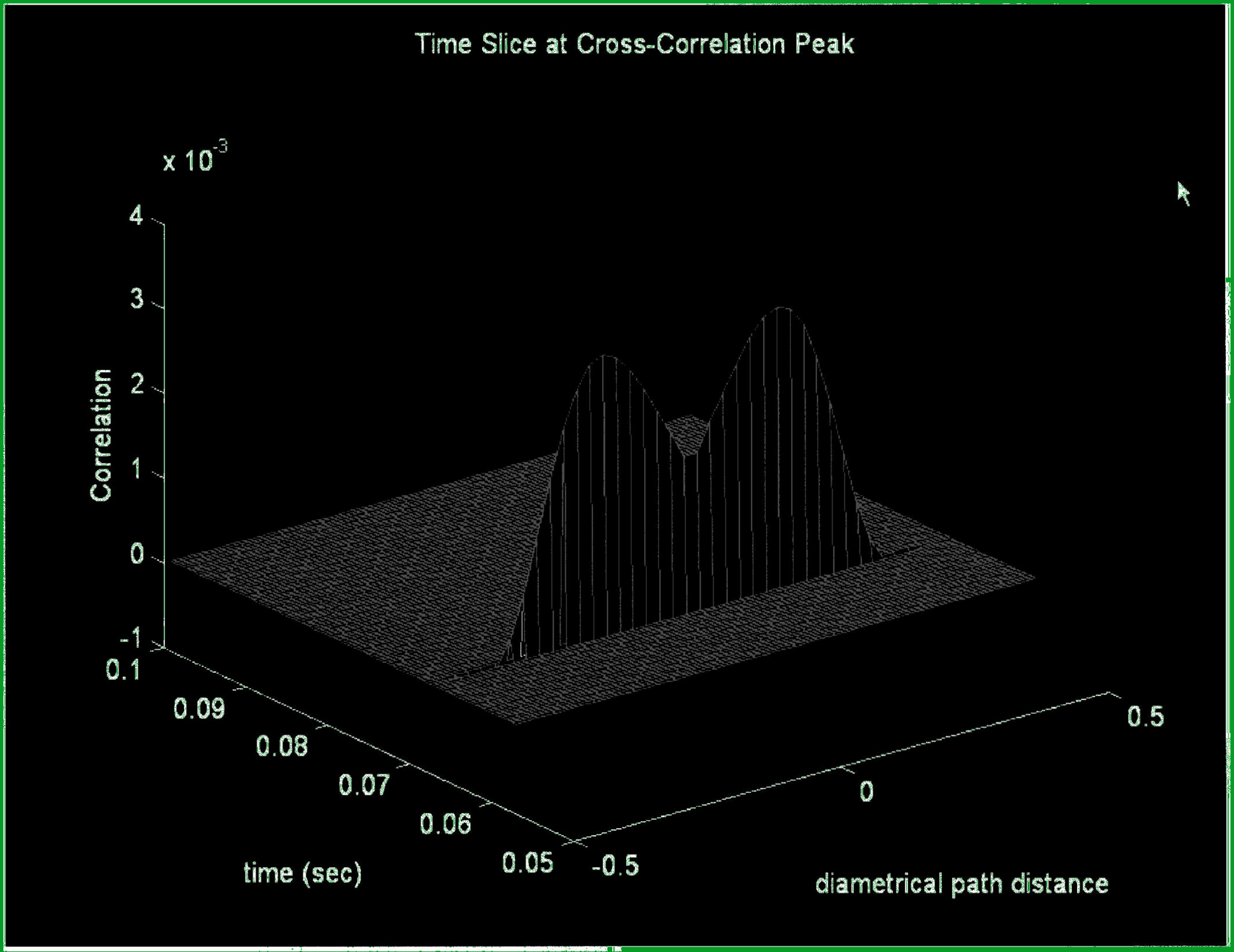


CZ

Caldon Submittal - Cross Correlation Review

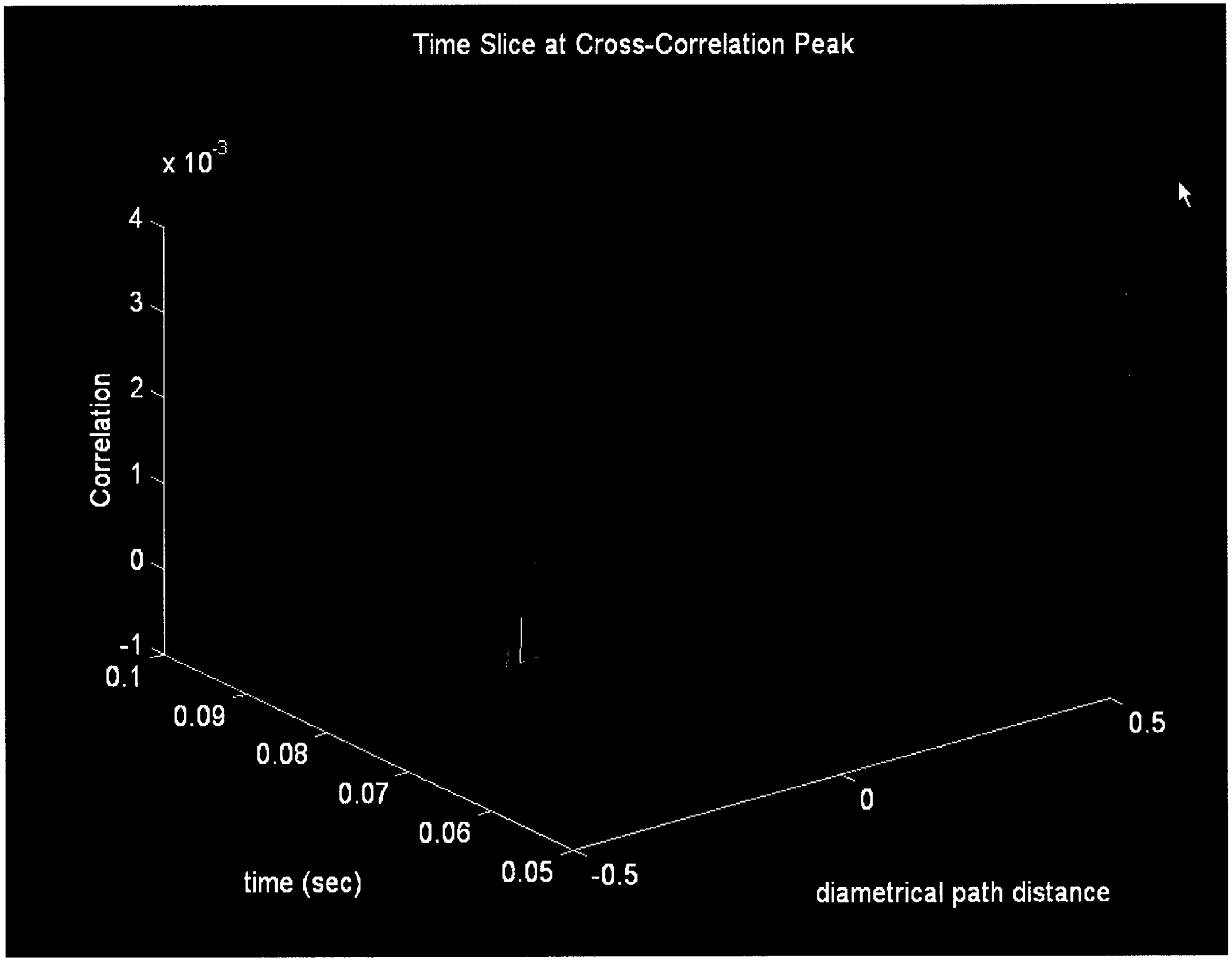


Caldon Submittal - Cross Correlation Review



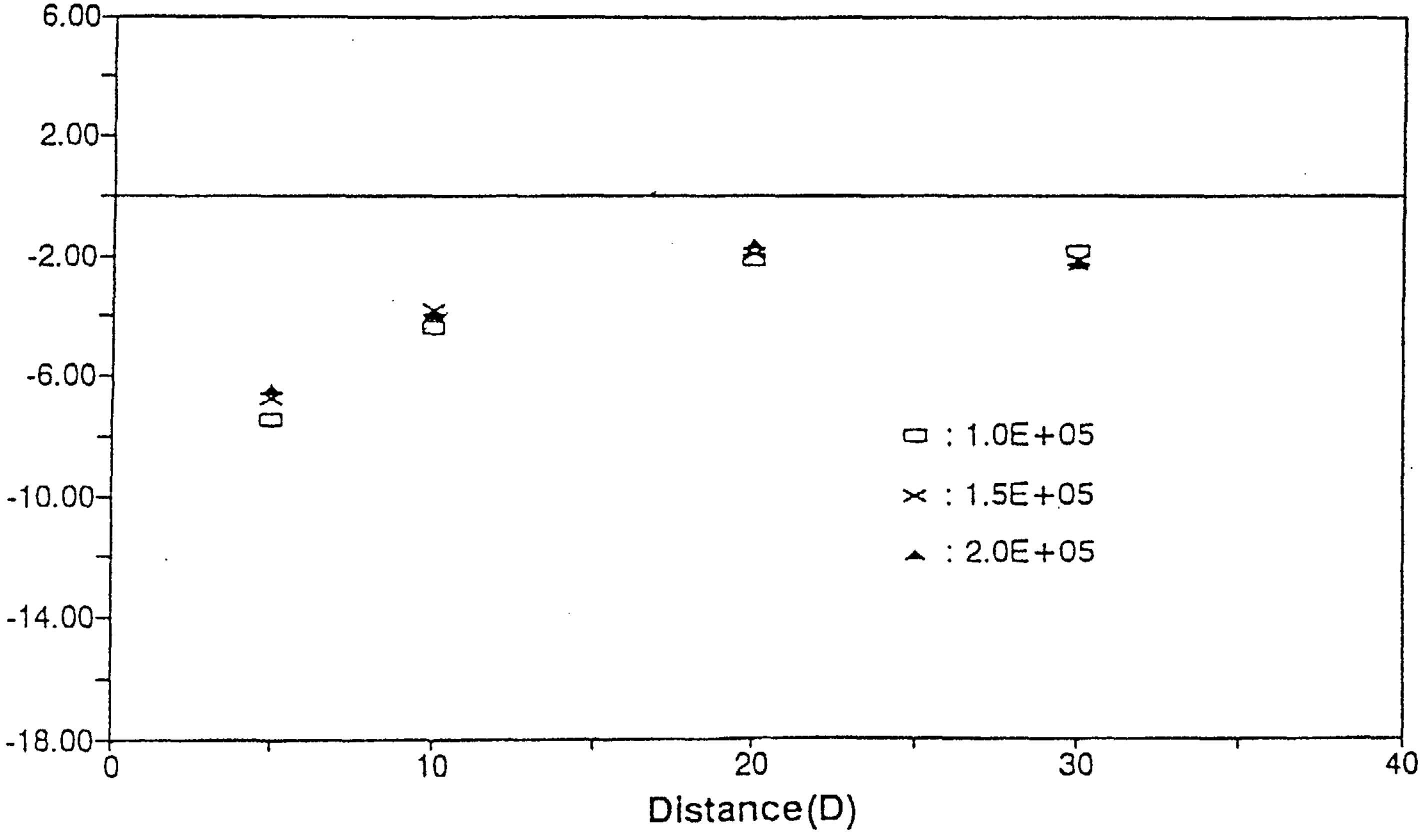
53

NRC Meeting *Caldon Submittal - Cross Correlation Review*



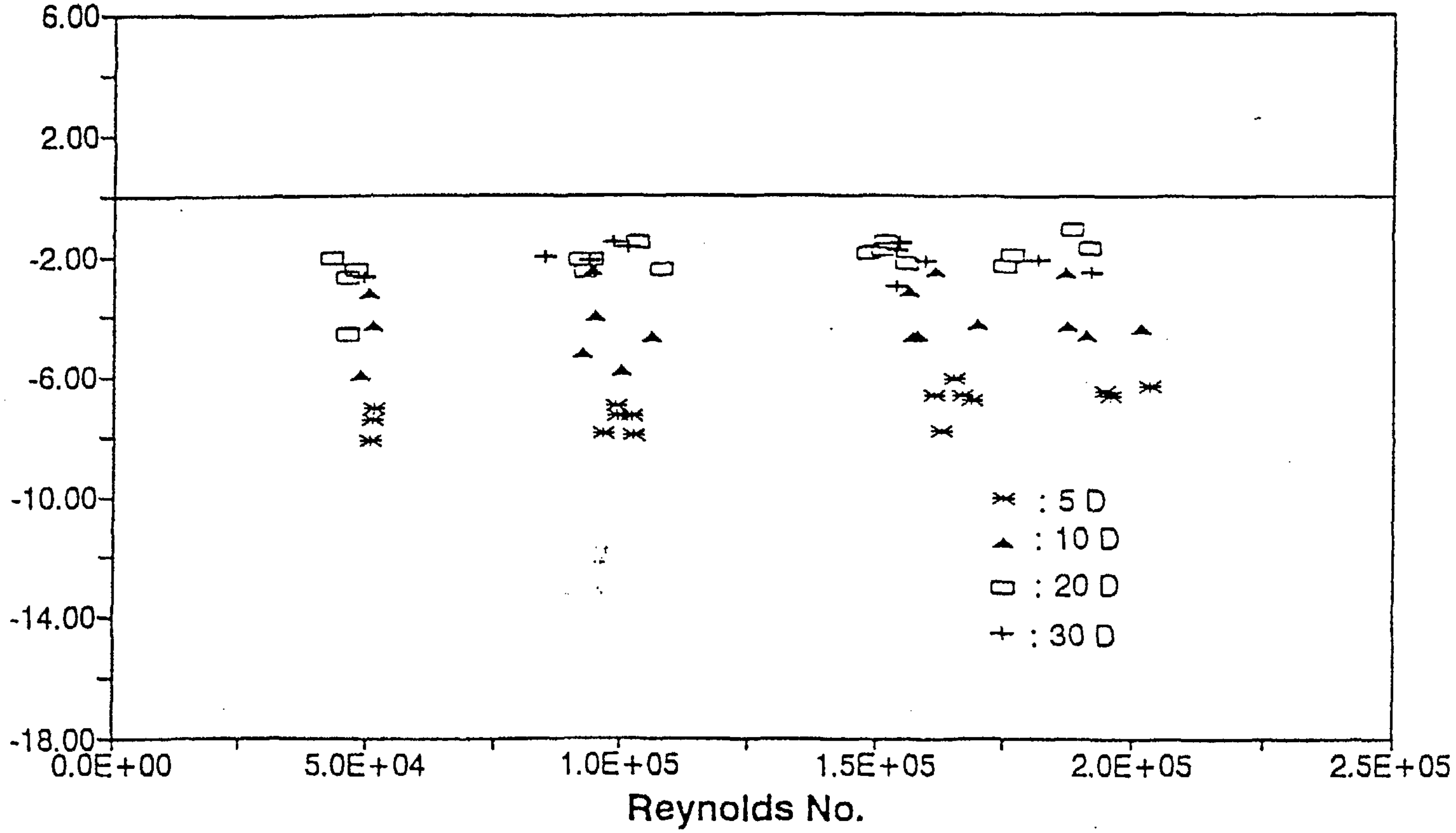
Percent Deviation From Baseline vs Distance

Compendium Tab 6



Percent Deviation From Baseline vs. Reynolds No.

Compendium Tab 6



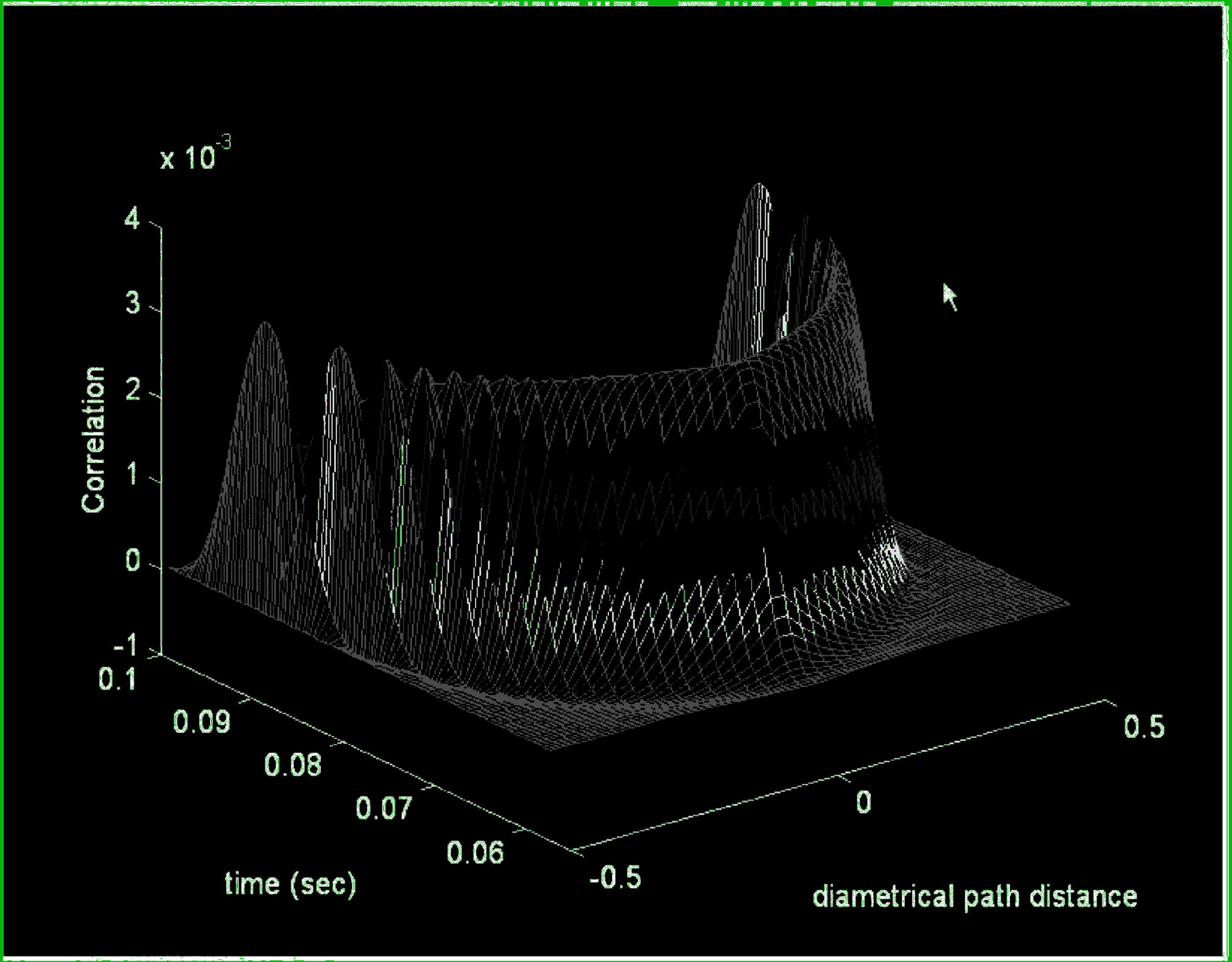
- Measurement of calibration coefficient in lab carries substantial uncertainty

- Wall roughness in the lab cannot be used to predict wall roughness in the plant
- Viscosity also changes from lab to plant. Though the change can be estimated, the effect on profile shape carries uncertainty

Compendium Tabs 8, 13, 17

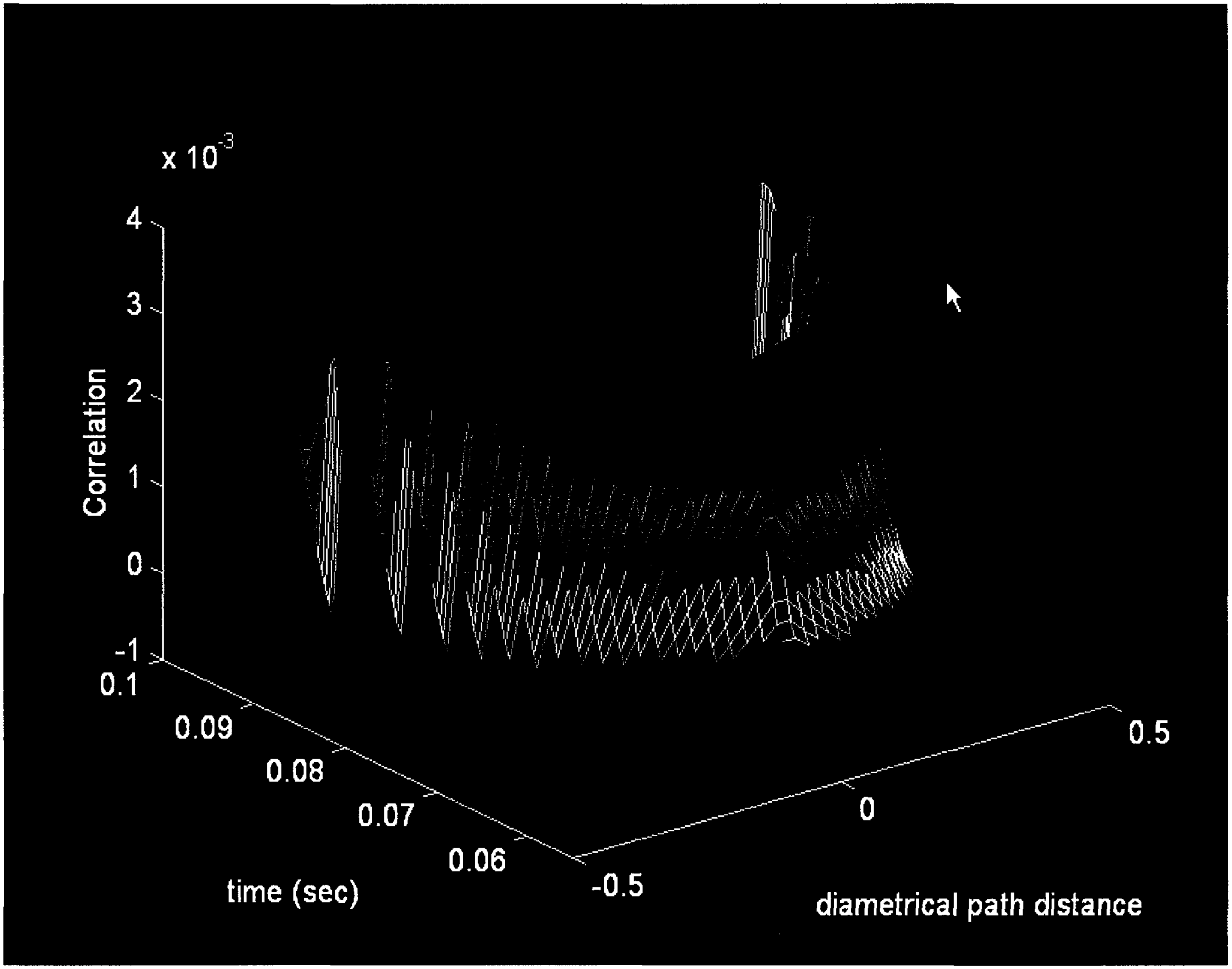
NRC Meeting

Caldon Submittal - Cross Correlation Review



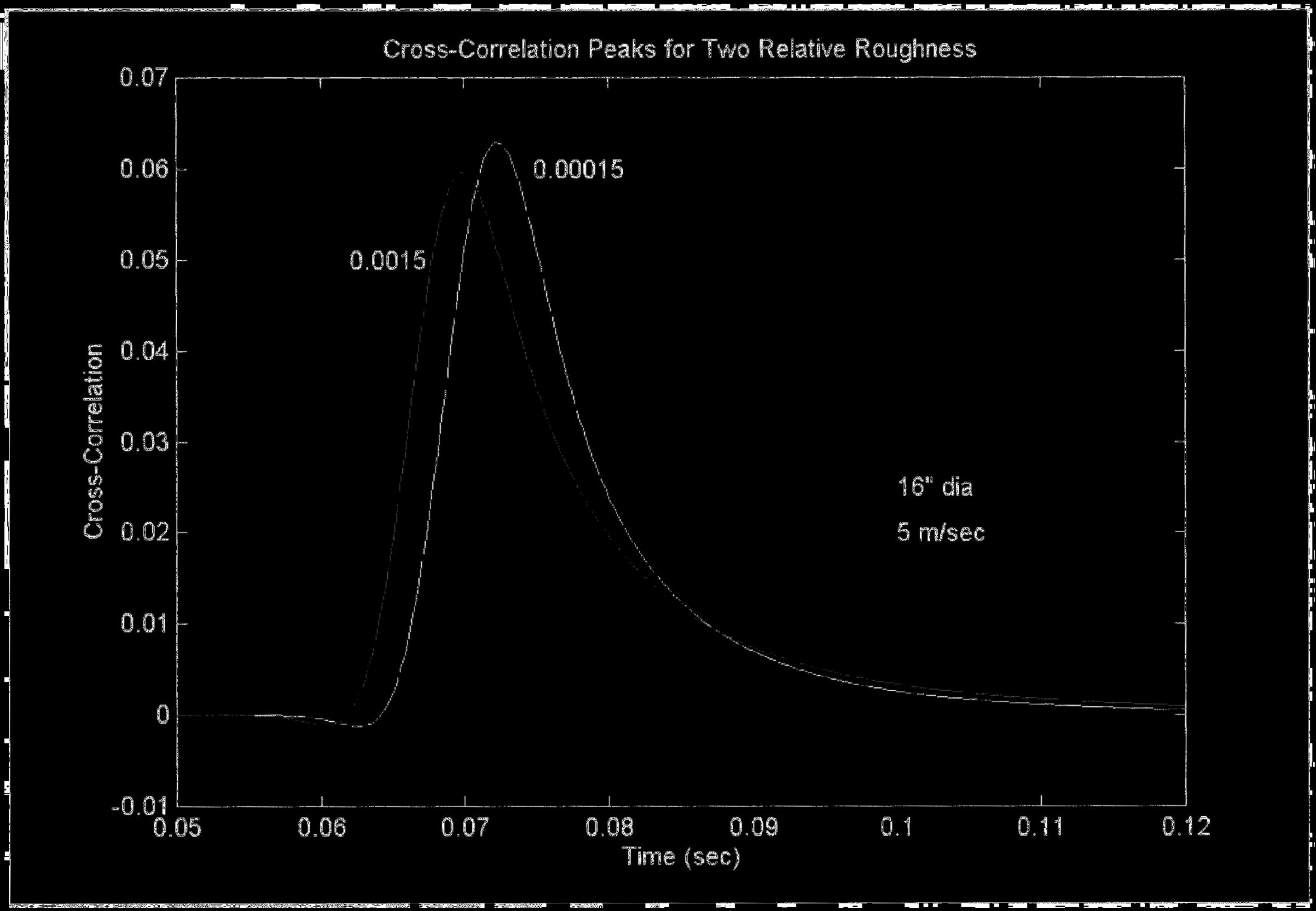
C4

NRC Meeting *Caldon Submittal - Cross Correlation Review*

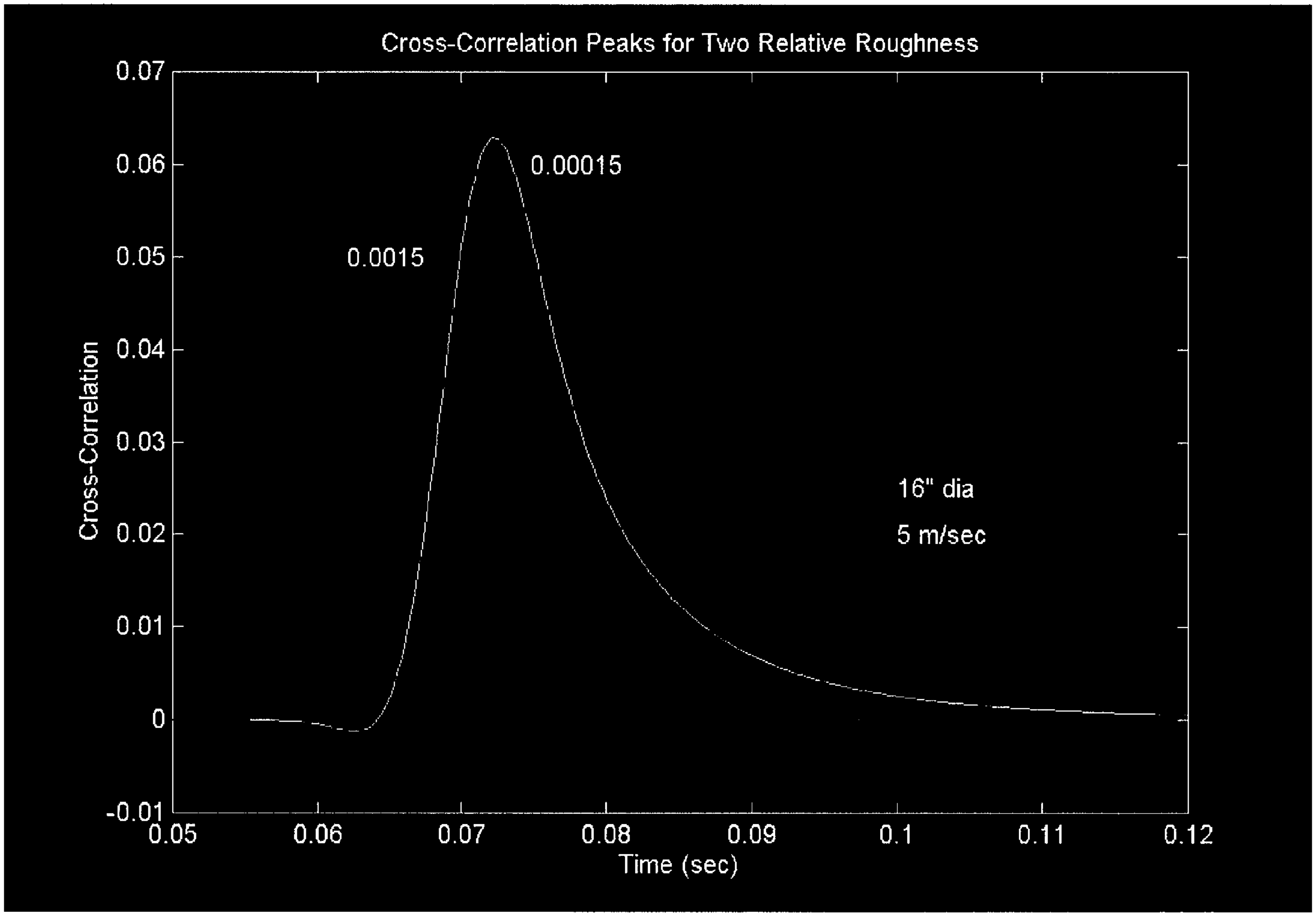


[illegible]

Indication Span is 3.2%



Indication Span is 3.2%



Caldon Submittal - Cross Correlation Review

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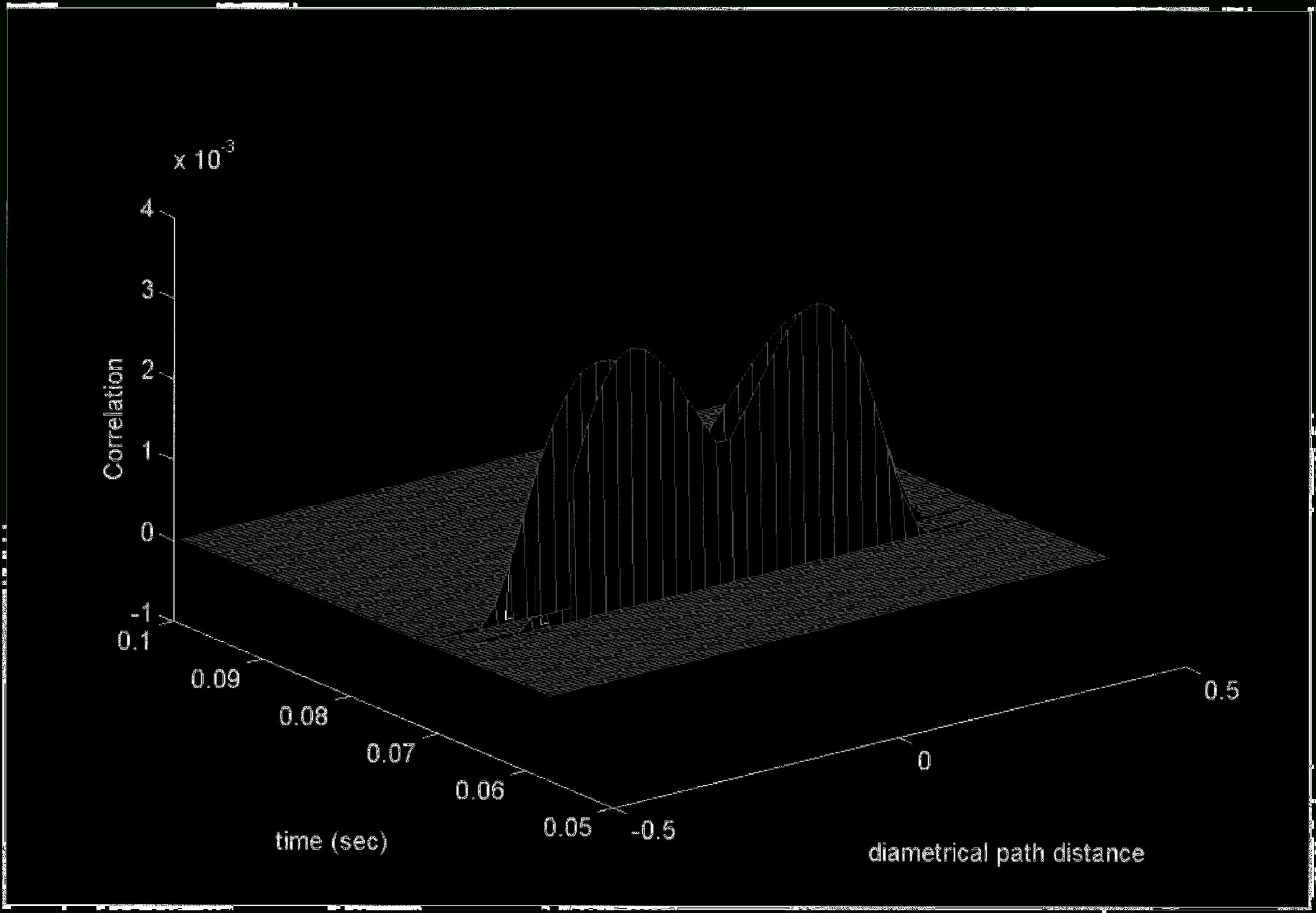
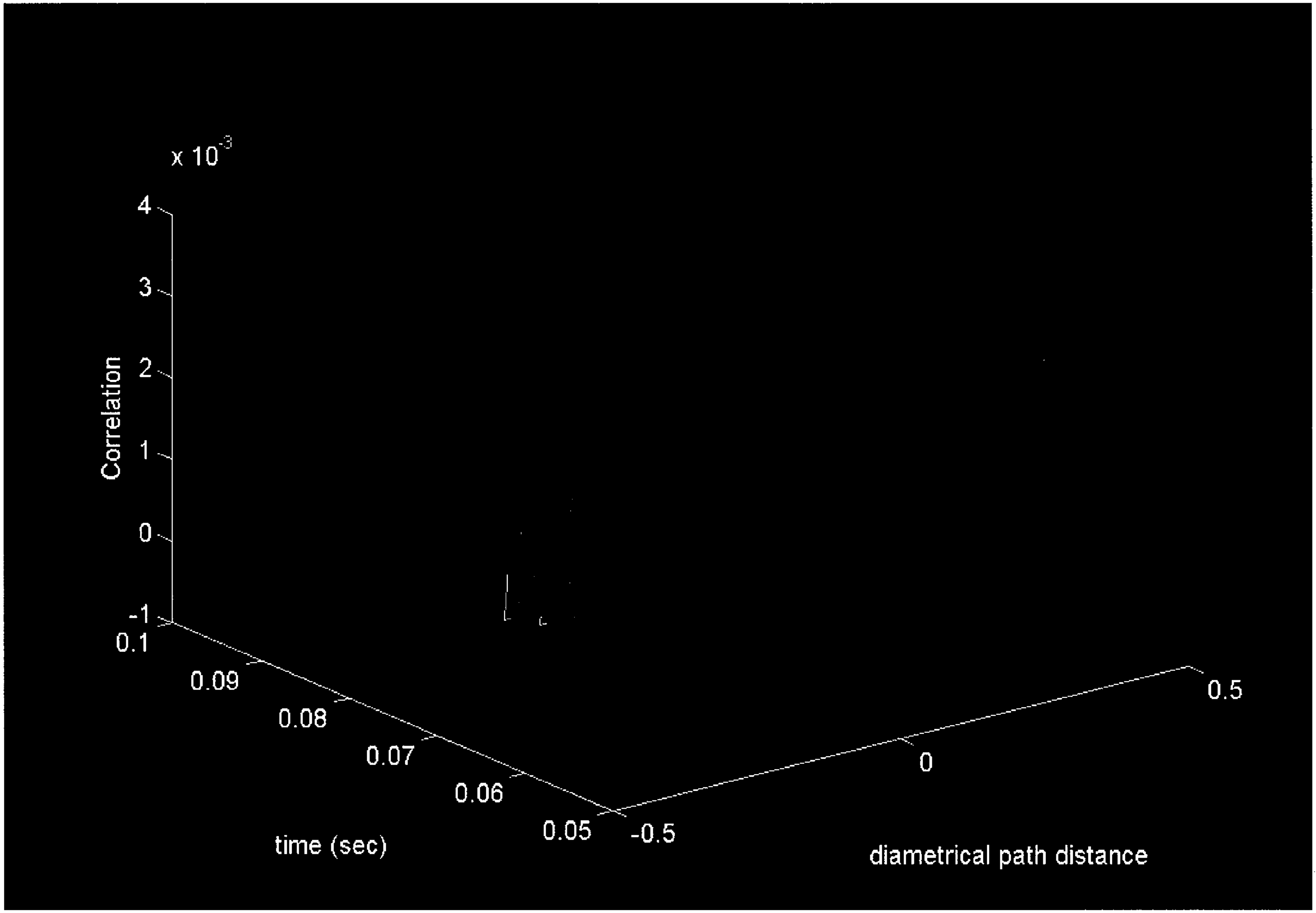


NRC Meeting *Caldon Submittal - Cross Correlation Review*



- Recent in-plant data indicate pipe wall roughness can change in service on the order of 20%
- Cross correlation meter indication would change accordingly by about 0.6%, and there is no primary standard to reveal this change.

Compendium Tab 8; in-plant data can be made available if desired

- Wavelength of ultrasound = sound velocity/frequency
- Sound velocity in the plant is 80% of the sound velocity in the lab
- Therefore, wavelength of ultrasound in the plant is 80% of the wavelength in the lab
- Correlated eddies have dimensions in the order of a wavelength of ultrasound

Compendium Tab 17

- Therefore correlated eddies in the plant will be of different dimensions than those in the lab
- Different size eddies travel at different speeds
- Therefore the calibration may change from lab to plant
- During an application of the cross correlation meter at Point LePreau, a 2% change in indication was observed on changing transmit frequency. This may be evidence of the same effect.

Compendium Tabs 4 and 17

- EPRI Report TR-112118 Nuclear Feedwater July 1999 cites designer claim of 0.5% overall uncertainty:

Correction factor	±0.25%
Density	±0.2%
Repeatability	±0.1%
Flow area	±0.3%
Transducer spacing	±0.05%

- The correction factor uncertainty of ±0.25% cannot cover all profile and acoustic uncertainties

SLIDES USED BY
Dr. George Mattingly

Ultrasonic Technology: Prospects for Improving Flow Measurements and Standards

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ABSTRACT

Ultrasonic technology is evolving rapidly. It offers prospects for improving flow measurements, for serving as transfer standards, and possibly for serving as a primary flow standard. This paper describes results from several current NIST projects that have the goal of assessing travel-time ultrasonic flow measurement techniques for their potential in improving flow measurements. These projects include a meter testing program and computer simulations of travel-time techniques in ideal conditions and in measured pipe flows for a range of metering configurations.

Meter test results show that the "as-received" performance of several commercially available, clamp-on, travel-time, ultrasonic flow meters have errors that range from 1% to 3% when measuring high Reynolds number water flows in nearly ideal installation conditions. These errors could be reduced if manufacturers better compensated for pipe flow profile effects using improved software or if they improved the measurement traceability of their meter calibration capabilities to NIST's flow standards. The reproducibilities of most of these units are 1% or better, thus producing conclusions that these meters could attain accuracy levels commensurate with these reproducibilities if these software or calibration improvements are made.

Results also show that these manufacturers have significantly improved: (1) the awkward requirement for a "zero flow" condition to attain satisfactory performance, and (2) the "remove-replace" variations which plagued these types of meters.

Additionally, test results for an in-line, 8-path, travel-time, ultrasonic meter that was set up using only length and time standards showed uncertainties of ±0.2%, or better. These results show that this kind of meter might evolve into a primary standard for flow.

The computer simulations of travel-time metering arrangements provide insight into ways that this technology can improve flow measurements. If it becomes feasible to quantitatively model all the component measurement systems that comprise the ultrasonic metering of a pipe flow using only length and time standards, this technique would be a primary standard at some specified uncertainty. This would greatly expand the capability of primary flow standards, and it would make flow measurements traceable to national standards.

INTRODUCTION

The objectives of this study are to improve our understanding of ultrasonic flow measurement, to assess its potential for improving flow measurements, and to test the performance of selected travel-time meters, [1,2][1]. We tested several meters and used computer simulations to study installation effects. This paper focuses on prospects for dual-sensor, travel-time ultrasonic techniques applied to high Reynolds number

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[1] Square bracketed integers refer to references given below.

Attachment 3

pipe flows in water. Our meter installation conditions approached "ideal" in order to assess optimal performance characteristics. In this paper, we describe results from a recent testing program for travel-time flow meters and we use computer simulations to understand the effects of pipe flows on the performance of this type of meter, [1].

TESTING PROGRAM

NIST devised a program to test the performance of a number of several commercially available, clamp-on, travel-time flow meters. Details are given in [1]. The meters were installed on pipes both with and without a "zero flow" condition. The tests also determined the effects of removing these meters from the pipes and re-installing them. The "remove-replace" tests were done when the mounting rails were left clamped to the pipe and the sensors were taken off, and when both sensors and rails were removed and replaced. To minimize the meter performance variation associated with installing these clamp-on units, the manufacturers performed these tasks. The meter manufacturers that participated are listed alphabetically in the Acknowledgment.

Tests were done using 250 mm dia., schedule 40, 304 stainless steel pipe having 150 lb flanges. The Reynolds number ranged from 4E5 to 3E6. The coordinate system used is right-handed with the origin on the pipe centerline at the entrance to the 250 mm dia. pipe section; the Z direction is axial with the flow, the Y direction is vertically upward, and the X direction is horizontal. The velocity components in these directions are W, V, and U, respectively. The pipe flow characteristics in the test pipe were measured using laser Doppler velocimetry (LDV) [5]; results are shown in Figure 1 for the highest and lowest flows tested along horizontal and vertical diameter traverses in the test pipe where the meters were installed. Figure 1 shows: (a) relatively low levels of skewness of the axial mean velocity profile, (b) small transverse velocities, and (c) the expected distributions for the axial and transverse components of the turbulent intensity. Based on these results, the test conditions were considered satisfactory approximations to ideal, fully developed pipe flows, [6,7].

The NIST flow standards were used to determine the flow rates in these tests. These standards use static gravimetric techniques that have a quoted expanded uncertainty of 0.12%, using a coverage factor of 2, [1, 3 and 4]. These standards were used to assess meter indications that were averaged during the 40 to 140 second collection intervals used for the gravimetric standards. To obtain real-time data for the pipe flow during the tests, an in-line, travel-time, ultrasonic flow meter was installed downstream of the meter test section. This unit was a Fisher Precision Systems, Inc., Model 2502[1] having 8 chordal paths. The results from this ultrasonic unit are presented below because they contribute significantly to our conclusions that ultrasonic techniques have great potential for improving flow measurements.

The time-averaged results for the clamp-on meters and the in-line ultrasonic flow meter were assessed using the NIST standards. The deviations of the rapidly recorded meter outputs from the in-line ultrasonic meter and the clamp-on meters were expressed as standard deviations and are presented graphically using error bars about their temporal mean values. Further averaging quantified the repeatability and reproducibility of both the in-line and participating meters, as described below.

Initial tests quantified clamp-on meter performance without and then with a "zero flow" condition. To quantify the repeatability of the meters without a "zero flow" set-up condition, the initial installation of each participant's meter was done with flow in the test pipe. Once the meter was installed, a three flow rate test sequence was run with nominal Reynolds numbers of 4E5, 1.6E6, and 2.6E6. Five gravimetric determinations of flow rate were done at each Reynolds number. Once the three flow rate sequence was completed, the flow was stopped. A second sequence was done without alteration of the meter.

The average of the recorded participating meter results taken during the gravimetric collection was compared to each of the five static gravimetric determinations of flow rate with NIST's standards. The difference between these results, expressed as a percent of the reference result was then averaged and the standard deviation of these five results, also expressed as a percent, was defined to be the meter

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[1] Use of commercial names is only intended to be descriptive; it should not be considered an endorsement by NIST. The product may not be the best product for the task at hand.

repeatability for the pertinent test condition. After this test was replicated, the ten results at each flow were averaged and the standard deviation of these was defined to be the meter reproducibility for the flow condition. In what follows, these tests for the "non-zero" start condition will be referred to as T1 and T2. The designations T3 and T4 will indicate the corresponding results for the "zero-flow" start condition.

To quantify the effects of removing then re-installing the meters, the sensors were removed from and replaced on their "rails" or test fixtures, which remained attached to the test pipe. These tests are designated T5. The tests designated T6 show the effects of removing and replacing both the sensors and rails. These remove-replace tests were only done for the lowest and highest flow rates; at each of these, five replications of tests were done in rapid succession using NIST's gravimetric standard. The data set for each meter tested participant includes 80 points: 30 each for the low flow (Re = 4E5) and the high flow (Re = 2.9E6) and 20 for the middle flow (Re = 1.6E6) since the middle flow was not included in the remove-replace tests.

COMPUTER SIMULATIONS OF ULTRASONIC METER PERFORMANCE IN IDEAL PIPEFLOWS

Detailed descriptions of the methods used to simulate ultrasonic metering techniques in incompressible and compressible flows are given elsewhere, [8]. Our simulation results shown in Figure 2 indicate that if travel-time ultrasonic flow meters use typical paths through the pipe center from transmitting and receiving sensors and if the pipe flow distribution is assumed to be uniform, then positive errors will occur, [8]. These errors will range from 5% to 6.5% of the true value in our flow test range, depending upon which model for the ideal flow distribution is selected. These errors depend on Reynolds number, pipe roughness, inlet flow conditions, distance from the inlet, etc. For most fully developed pipe flow distributions, these distributions decrease monotonically with Reynolds number. Note that the Gilmont distribution was developed for lower Reynolds numbers less than 1E5, [9]. We also note that meters that are properly compensated for these effects need to have the proper negative trend with increasing Reynolds number.

Meter simulations were done using the profile measurements shown in Figure 1, assuming negligible axial gradients. Results are given in Figure 2. The data denoted LDV-H and LDV-V show the errors that would occur if the meter were installed horizontally and vertically, respectively, and if its readings were interpreted using the assumption that the pipe flow profile was uniform. In spite of our extensive efforts to condition our pipe flow to attain ideal installation conditions, our test flows only approximated the Bogue & Metzner distribution, as shown in Figure 1(a). In these flows, our horizontal simulation results fall 0.5% to 1.7% below the band of errors given by the Bogue & Metzner, Reichardt, Log, and Power Law distributions, [6,9-11]. We estimate the LDV results shown in Figure 1(a) to be within 1% of the true values, and conclude, therefore, that these simulation results are due to the LDV values lying, for the most part, below counterparts in the Bogue & Metzner distributions in Figure 1(a). These simulation results also show decreasing errors with Reynolds number for both horizontal and vertical profiles. For the horizontal profile, this slope closely matches that for all the distributions, excluding the Gilmont, which, as mentioned above, is for lower Reynolds numbers.

RESULTS AND DISCUSSION OF METER TESTS

Figure 3 plots error assessment data for the clamp-on units for all flows. Most of these units were installed essentially horizontal, i.e., within small angular orientations about the horizontal plane on the test pipe. Six data sets are presented because one of the participants had to re-test. The points plotted are the participant's averages during the collection runs. The ordinate scale is the difference between each of these participant's averages and the NIST standard, expressed as a percentage of the NIST result. Error bars show one standard deviation of the mean of the five time-averaged differences at each test condition. These error bars represent the "single reading" imprecision of the meter in these conditions. Excluding the meters with the largest percentage error (D), and the largest time-averaged deviations from means (E), these results show errors that are predominately positive, ranging from approximately +1% to +3%, with most values in the range from +2% to +3%. For these meters, standard deviations of time-averaged differences ranged up to 0.5%. These manufacturers are compensating in part for profile effects. If they had assumed a uniform profile at Reynolds numbers of 4E5 and 3E6, errors of +5% and +4% would have resulted, see Figure 2. If these manufacturers had used Bogue and Metzner or Reichardt profile distributions to produce their metering results, the errors would have been –0.5% to –1.7%.

Figure 4 presents mean values and repeatability results for all 6 clamp-on meter tests. The data plotted are the means of the five successive error assessments obtained in each of the six tests, denoted T1 through T6. Most of the data range from −1% to +3%; the worst case error is −14%, but this occurred only for manufacturer D. Error bars quantify repeatability, which is defined here as one standard deviation of the mean of the five successive error values at each test condition. Repeatabilities range from ±0.1% to ±0.2% for most of these manufacturers; the worst case is ±2%, but this occurred only for meter E. Additionally, Figure 4 shows error trends that, for several of these meters, are either constant or increase with Reynolds number, namely A, F, and for some conditions, C. This contrasts with the negative trends expected from the simulation results shown in Figure 2. Therefore, we conclude that both flow profile compensation and its trend with Reynolds number need to be reconsidered by these manufacturers.

Figure 5 presents mean values and reproducibility results for all clamp-on meters for all flow rates. Reproducibilities are here defined as the standard deviations of the mean for: (1) the ten values at each flow in tests T1 and T2, where no "zero-flow" condition was allowed before testing, and in tests T3 and T4, where a zero flow condition was used, (2) the twenty values in tests T1 through T4 at each flow, and (3) in tests T1 through T6 at all flows except the middle one, which was excluded from tests T5 and T6. Figure 6 shows the results of these tests mostly range from +0.5% to +3%; the worst case is −13.5%, but this occurred only for meter D. Reproducibilities range from ±0.1 to ±3%, but three meters have reproducibilities of ±1%, or better. From these impressive results, we conclude that, if NIST calibrations were to compensate for these mean value errors, these meters could attain performance levels ±1%, or better.

Figures 6-8 present error assessment results for the in-line ultrasonic flow meter as obtained during the six tests of the clamp-on meters. Figure 6 shows mean values of this meter's output for each run of all three flows as assessed using NIST's flow standards. Error bars show one standard deviation of the time-varying meter indication about its temporal mean. This unit also assessed, in real time, the pipe flow distributions in these test flows using its four chordal planes of measurement; results are compatible with the data shown in Figures 1(a) and (b). Figure 7 shows repeatability results for the six tests with error bars showing one standard deviation of the five successive measurements about their mean. Prior to the tests of meter B a minor software change was made to enhance its noise suppression capabilities. Figure 8 gives reproducibilities, with error bars showing one standard deviation of the respective values about their mean. Figure 8 shows error levels for the medium and high flows of 0.2% or better with repeatabilities and reproducibilities of 0.2 % or better. This meter was not calibrated by its manufacturer; its results are based on length and time measurements. From this impressive performance at these higher flows, we conclude that it may be feasible to recognize this meter as a primary flow standard. If this development were to occur, it would extend the capabilities of flow laboratories for establishing and maintaining traceability to national standards.

CONCLUSIONS:

The specific results of these Phase 1 tests of these clamp-on units are:

1) Their errors, as obtained by recording and averaging meter outputs and comparing these to the results from NIST's gravimetric flow measurement standards, range from +1% to +3% except for the -14% for meter D.
2) Repeatabilities, as defined by the standard deviation of the mean of five successively determined error assessments, range from ±0.1% to ±0.2% except for the ±2% result for meter E.
3) Reproducibilities, as defined by the standard deviations of the mean of error assessments made under a variety of conditions typical of normal meter usage, range up to 3%. However, 3 of the 6 sets of results show reproducibilities bounded by 1%.
4) The low flow results are the most varied; the high flow results are least varied.
5) The different "zero flow" conditions designed into these tests did not cause different performances.
6) The remove-replace conditions designed into these tests did not cause different performances.
7) Computer simulations of the travel-time ultrasonic techniques used by these clamp-on meters show that errors in the conditions used for these tests should range from +4% to +5% if the meter operation used the assumption that the pipe flow profile being measured is uniform. If meter operation compensated for Bogue & Metzner or Reichardt type profiles, simulations in these test conditions

show that the results should be in the range –0.5% to –1.7%. Since the error assessments found lie mostly in the range from +2% to +3%, we conclude that these manufacturers do compensate for profile effects; however, the compensations could be improved.

Clamp-on type, travel time ultrasonic technology has progressed very well in improving flow measurement. Concerns regarding "zero flow" set requirements and "remove-replace" variations, dating to the early stages of ultrasonic meter development are no longer valid. If meter buyers are properly trained, they should be able to attain the same performance.

The ultrasonic reference meter used in these tests had errors and repeatabilities of 0.2% or better for the two higher flows This meter was not calibrated by the manufacturer; it was set up using only length and time standards. Its impressive performance at these higher flows indicates that it may be feasible to recognize this meter as a primary flow standard. If this development were to occur, it would extend the capabilities of flow laboratories for establishing and maintaining flow measurement traceability to national standards.

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Kimmon Mfgr. Co. Ltd.; Tokyo, Japan; Dr. Hajime Onoda,
Pacific Gas & Electric Co.; San Francisco, CA; Mr. John Stuart,
Visteon Technical Center; Dearborn, MI; Mr. Richard Caron,
Halliburton Inc.; Duncan, OK; Mr. Steve Skinner,
New York Power Authority; White Plains, NY; Mr.Peter Ludwig.

The manufacturers that participated in these tests are, alphabetically:

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Controlotron, Inc., Hauppauge, NY,
Krohne America, Inc., Peabody, MA,
Mesa Labs, Lakewood, CO,
Panametrics, Inc, Waltham, MA.

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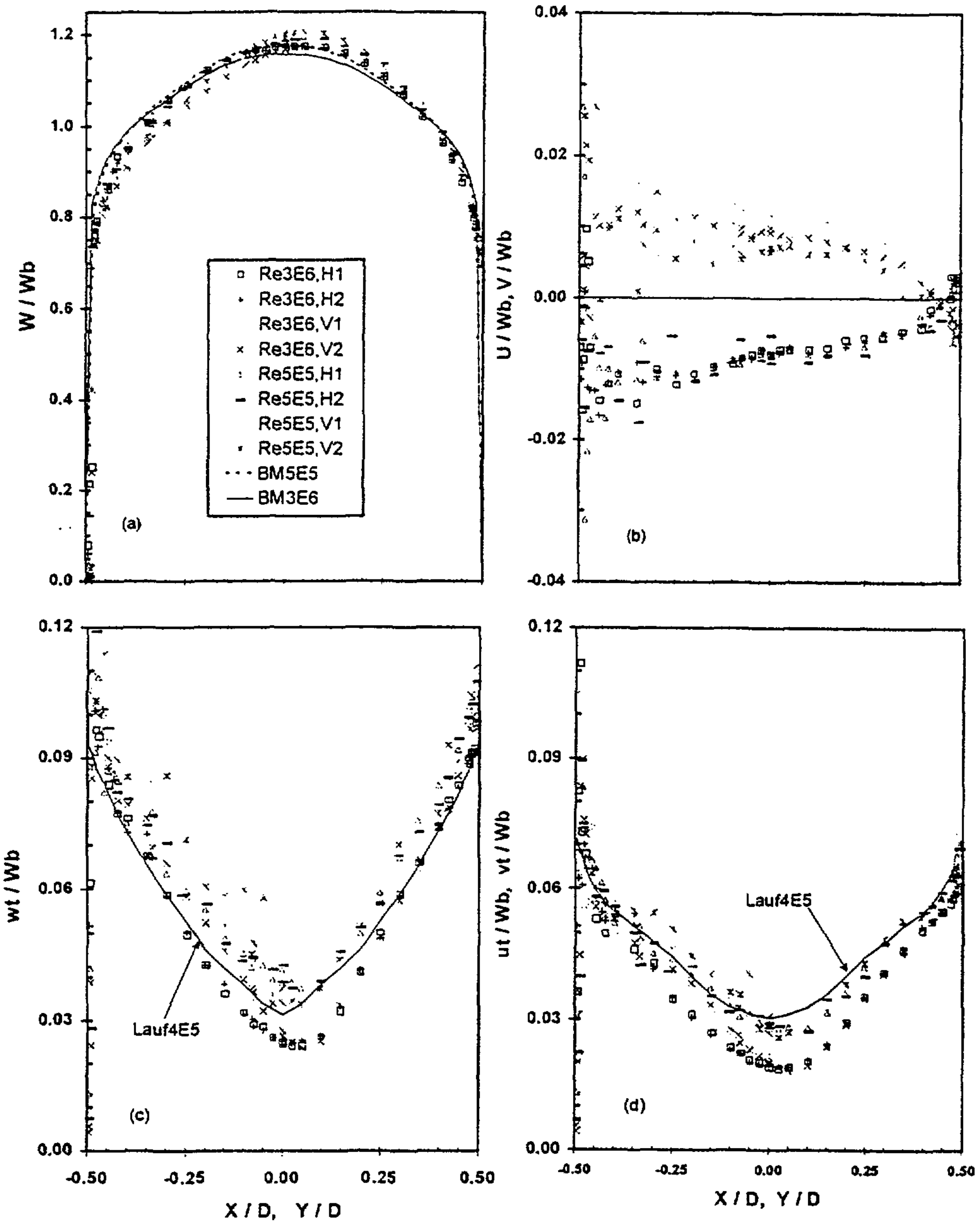


Figure 1. Pipe Flow Characteristics: These LDV results were measured over horizontal and vertical diameters for the lowest and highest flows used for testing. Notations are: W is the mean axial velocity; W_b is the bulk average velocity determined using NIST's Gravimetric Standards; X/D and Y/D are, respectively, horizontal and vertical distances in diameters from the pipe centerline; Re is the Reynolds number; H1, H2 denote, respectively, initial and repeated horizontal profile measurements; and V1, V2 denote vertical counterparts. (a) The lines show the Bogue & Metzner profiles for: Re=3E6, the solid line; Re=5E5, the dashed line. (b) Mean Transverse Velocity Profiles, U and V along the vertical and horizontal diameters, respectively. The zero ordinate denotes the ideal transverse velocity profile. (c) Axial Turbulence Intensity Profiles. wt is the rms of the axial turbulent velocity. The line shows Laufer's measured distribution for the axial component of the turbulence for Re=4.3E5, [7]. (d) Transverse Turbulent Intensity Profiles. ut and vt are the rms of the transverse turbulent velocities along the vertical and horizontal diameters, respectively.

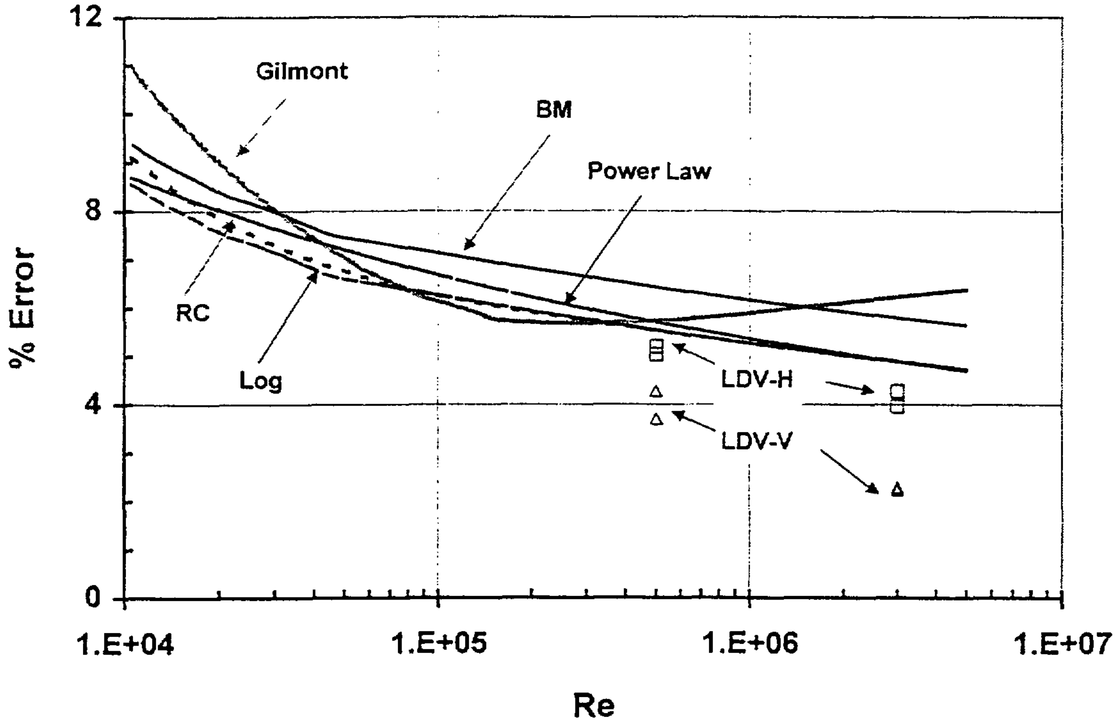


Figure 2. Meter Simulation Errors Resulting from the Assumption of Uniform Flow Profiles for Commonly Used Pipe Flow Distributions. Unnamed profiles are: BM refers to Bogue & Metzner, [6]; LOG refers to logarithmic, [11]; and RC refers to Reichardt, [10]. The designations LDV-H and LDV-V refer, respectively, to the horizontal and vertical profiles plotted in Figure 1(a).

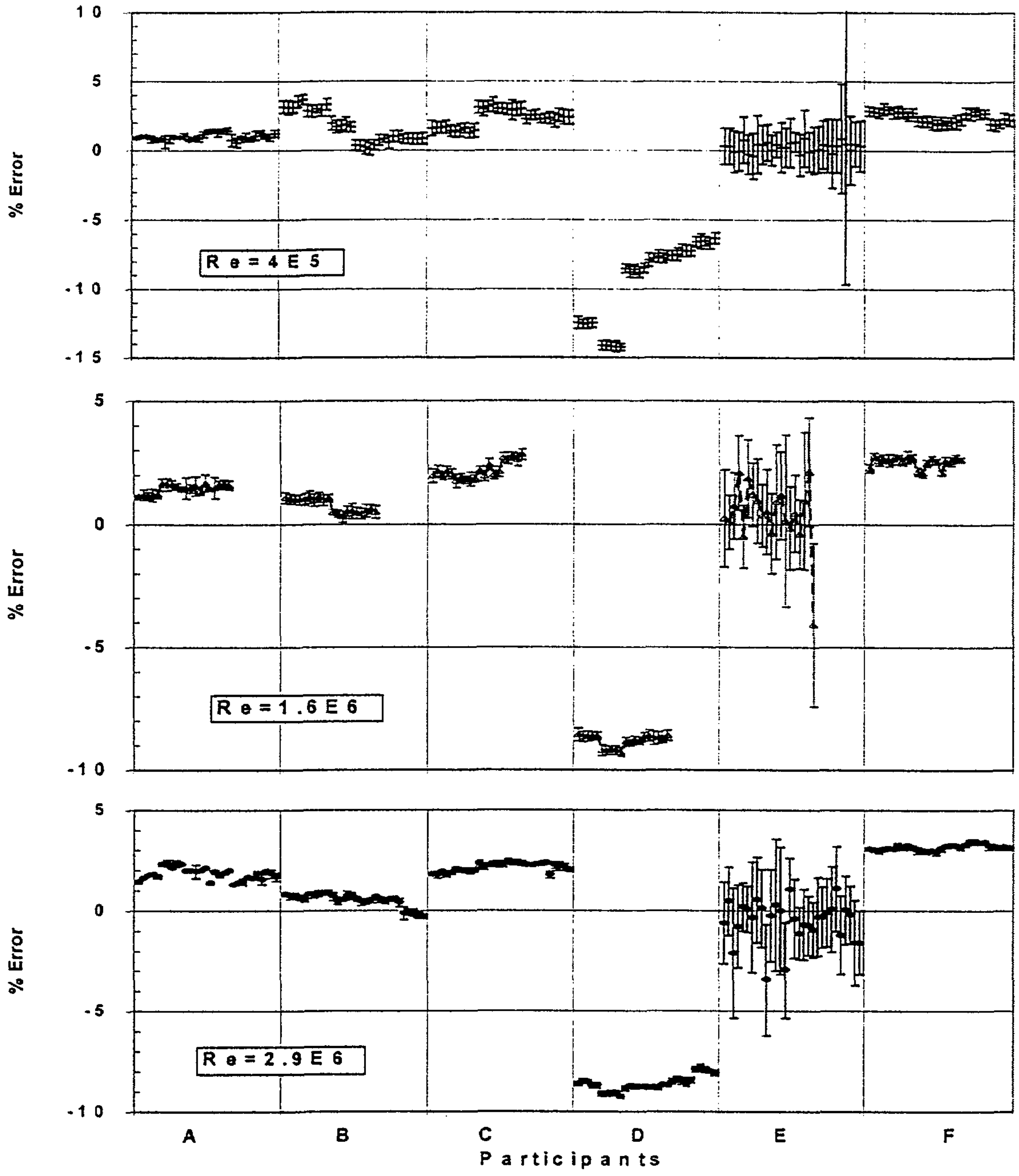


Figure 3. Error Assessment Data for the Participants for Three Flow Rates as a Percentage Difference from the NIST Gravimetric Standards Result. The data, plotted sequentially, left to right, are the results for each timed collection for the six tests, T1-T6. Error bars show one standard deviation of the time varying meter indication about its temporal mean.

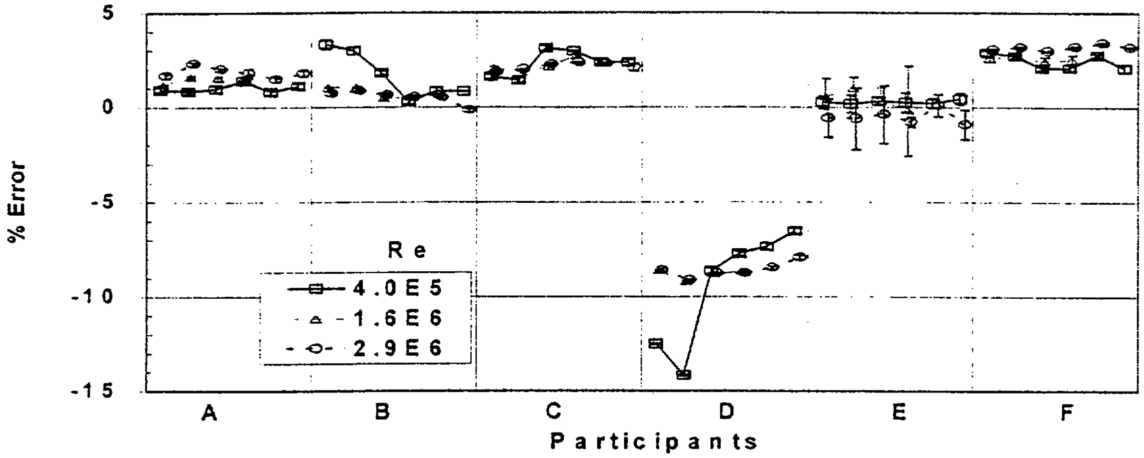


Figure 4. Mean Value and Repeatability Results for Each of the Six Tests for All Flow Rates. Values plotted are averages of the five successive error assessments in each test condition relative to the NIST gravimetric standards; error bars show repeatability as defined as one standard deviation of these five successive error assessments about their mean value. The six results sequentially plotted, left-to-right, for each participant and for each flow are, respectively, T1 to T6. It is noted that there is no T5 and T6 data for Re=1.6E6.

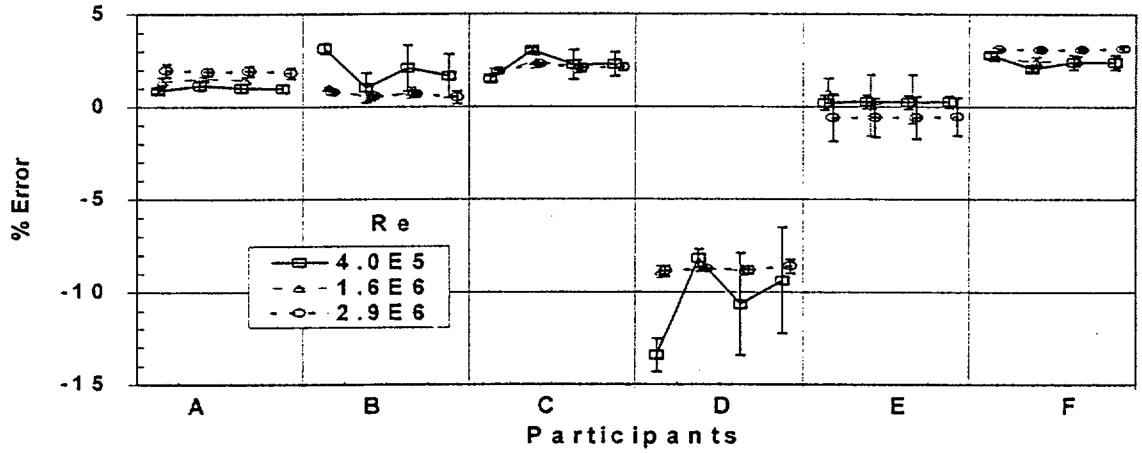


Figure 5. Mean Value and Reproducibility Results for Participants for All Flow Rates. The mean values and reproducibilities are plotted left-to-right for each participant, where: T1-2 and T3-4 are for the 10 values in Tests 1-2 and Tests 3-4; T1-4 are for the 20 values in Tests 1-4; and T1-6 are for the 30 values in Tests 1-6. These four results sequentially plotted, left-to-right, for each participant and for each flow are, respectively, T1-2, T3-4, T1-4, and T1-6. It is noted that there is no T1-6 for Re=1.6E6. Respective error bars show reproducibility as defined as one standard deviation about these averages.

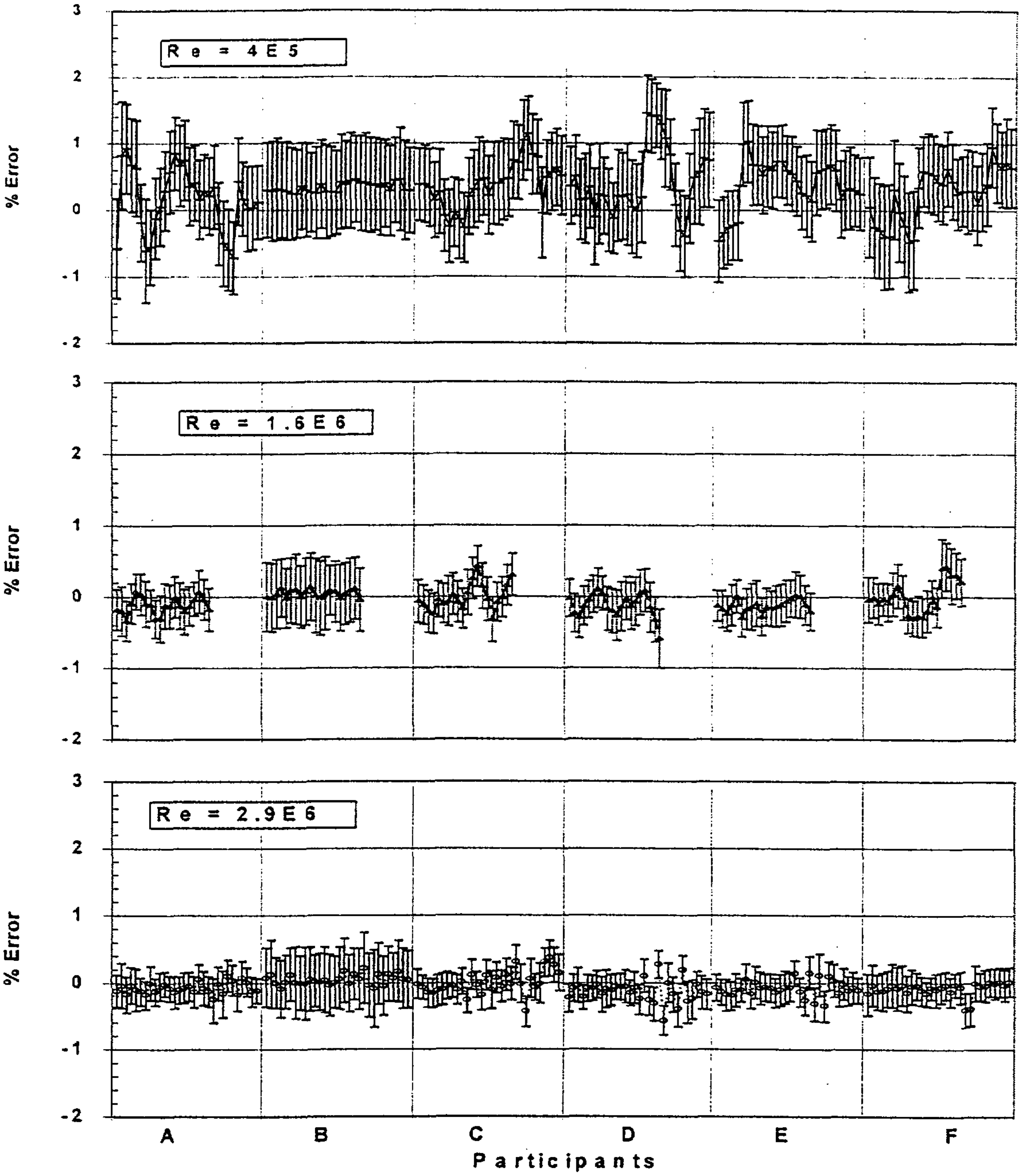


Figure 6. Mean Value Results for the In-Line Ultrasonic Flow Meter through All of the Tests of the Participating Meters Expressed as a Percentage Difference from the NIST Gravimetric Standards Result. It is noted that there is no data for T5 or T6 for Re=1.6E6. Error bars show one standard deviation of the time-varying meter indication about its temporal mean value during each timed-collection.

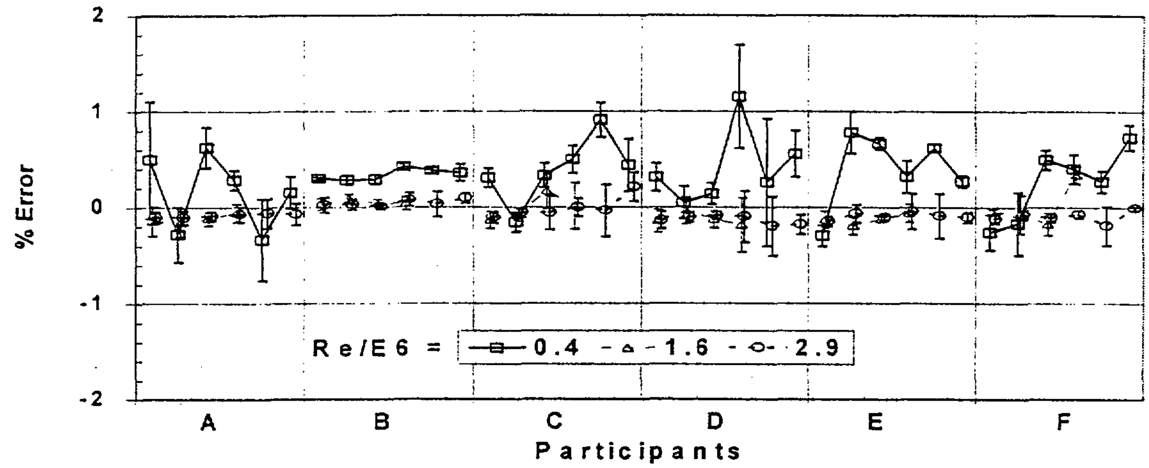


Figure 7. Mean Value and Repeatability Results for the In-Line Ultrasonic Flow Meter for All Flow Rates During the Tests of Each Participant. Error bars show repeatability as defined as one standard deviation of the five successive error assessments relative to the NIST gravimetric standards about their mean value. The six results sequentially plotted, left-to-right, during the tests of each participant for each flow are, respectively, T1 to T6. It is noted that there is no T5 and T6 data for Re=1.6E6.

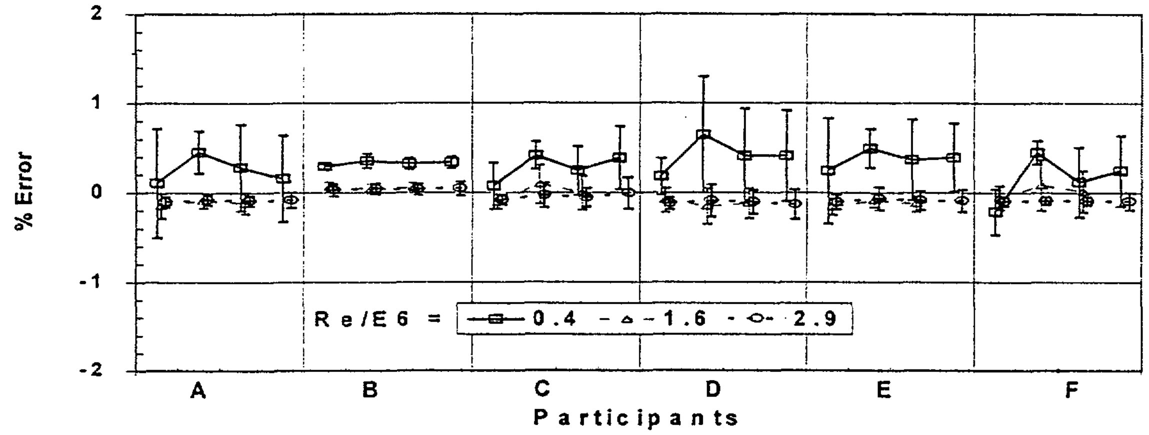
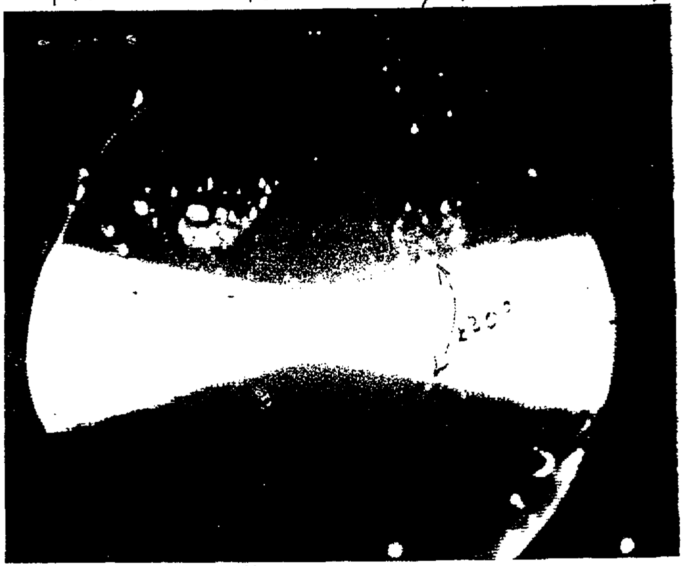
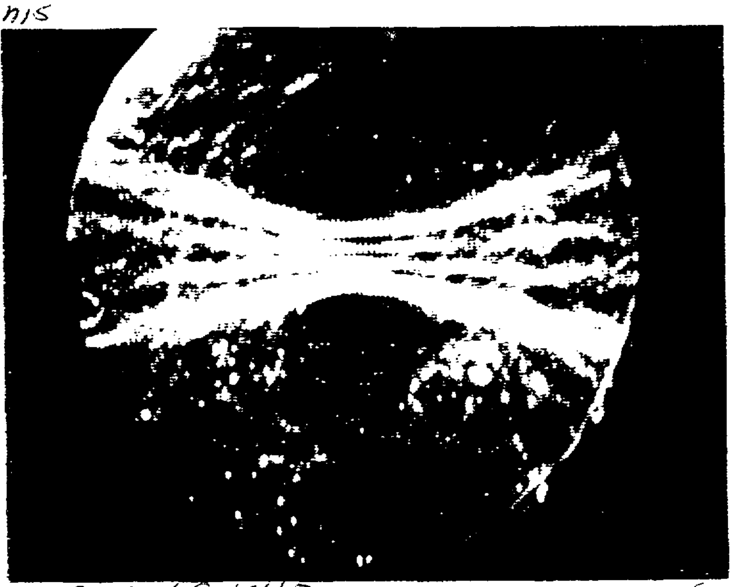


Figure 8. Mean Value and Reproducibility Results for the In-Line Ultrasonic Flow Meter for All Flow Rates During the Tests of Each Participant. The mean values and reproducibilities denoted: T1-2 and T3-4 are for the 10 values in Tests 1-2 and Tests 3-4, respectively; T1-4 are for the 20 values in Tests 1-4; and T1-6 are for the 30 values in Tests 1-6. These four results sequentially plotted, left-to-right, for each participant and for each flow are, respectively, T1-2, T3-4, T1-4, and T1-6. It is noted that there is no T1-6 for Re=1.6E6. Respective error bars show reproducibility as defined as one standard deviation about these averages.

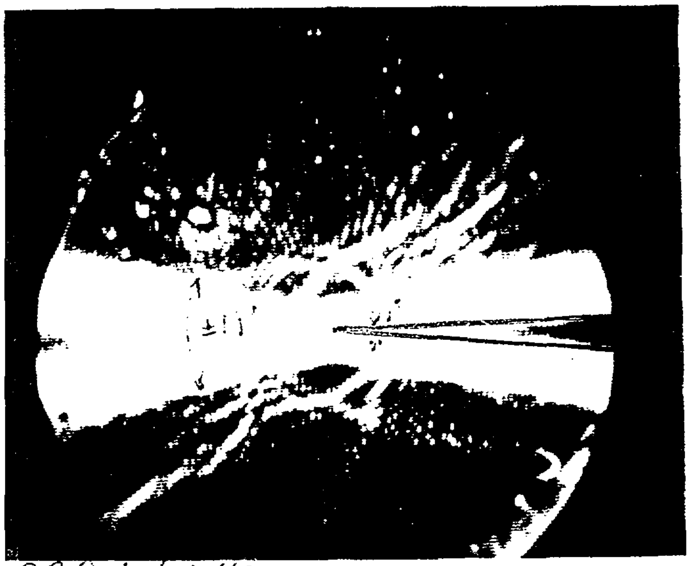
Pictures Presented by Dr Thomas Maginnis



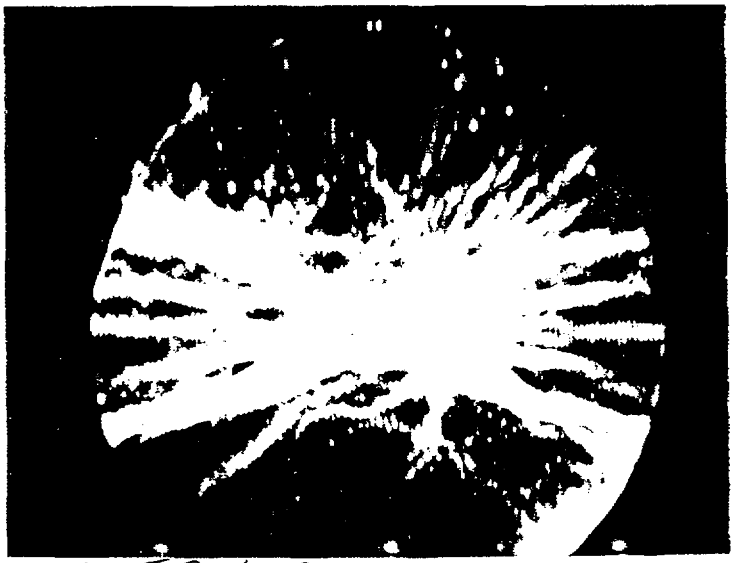
939. 38 KHZ 4.2 V_{IN}



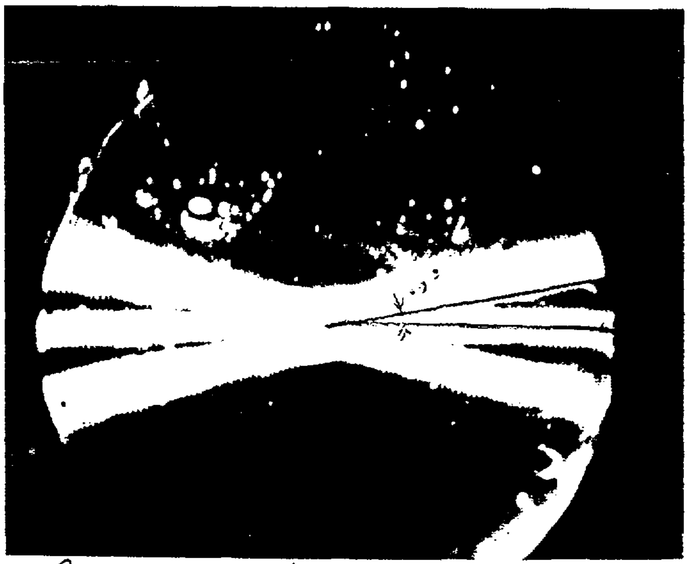
936.69 KHZ



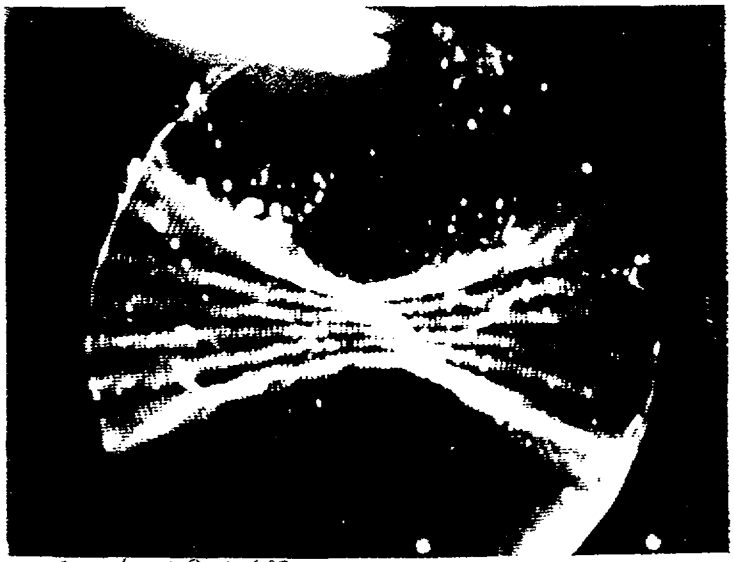
938.64 KHZ



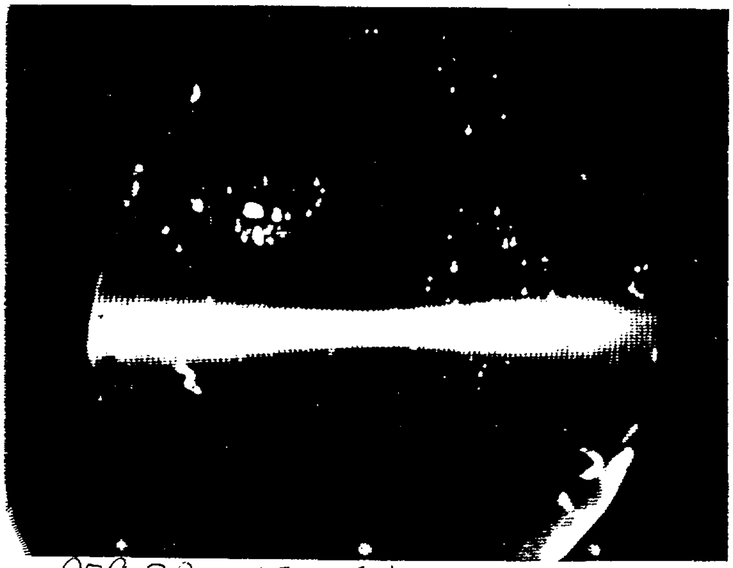
935.70 KHZ



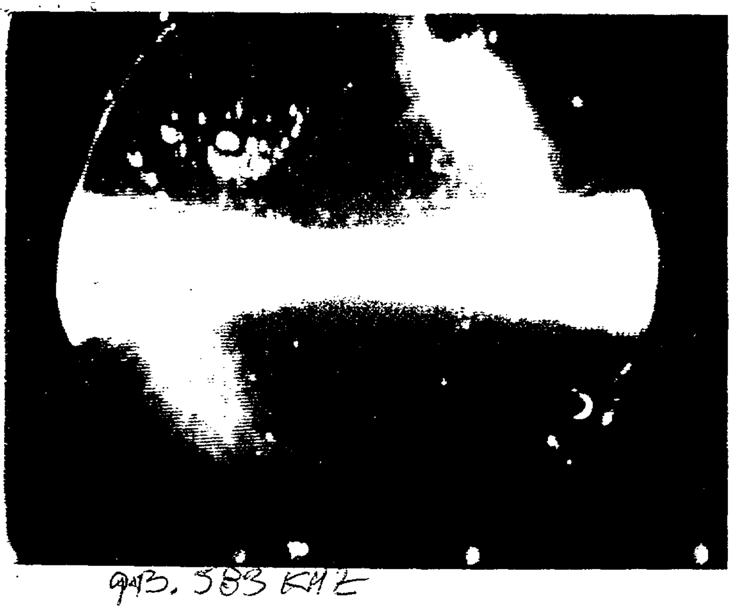
937.62 KHZ



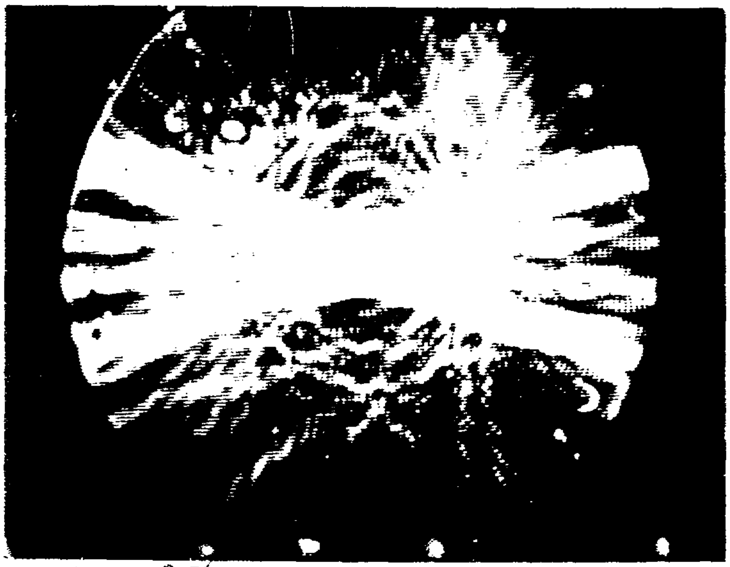
934.88 KHZ



939.38 kHz 1Vin

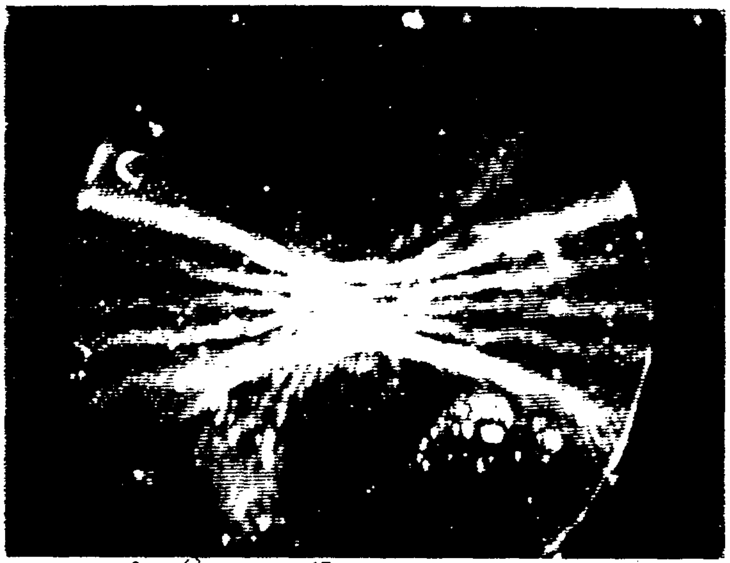


943.583 KHz

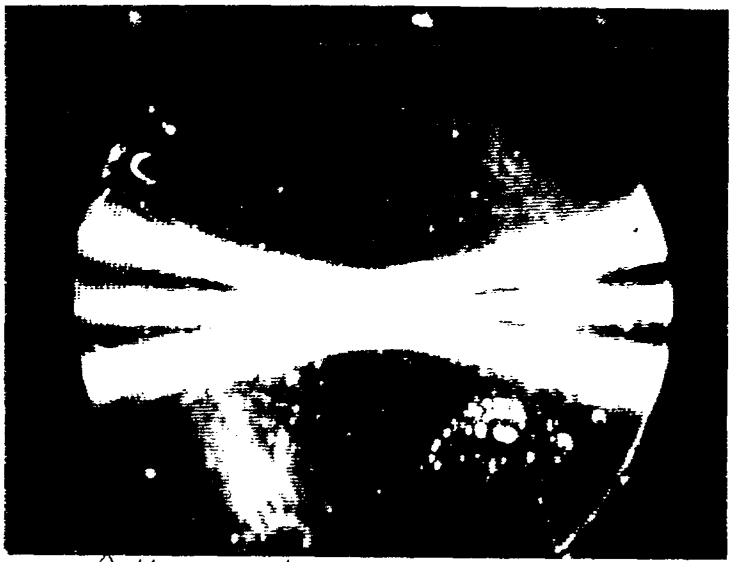


940.853

942.811 KHz

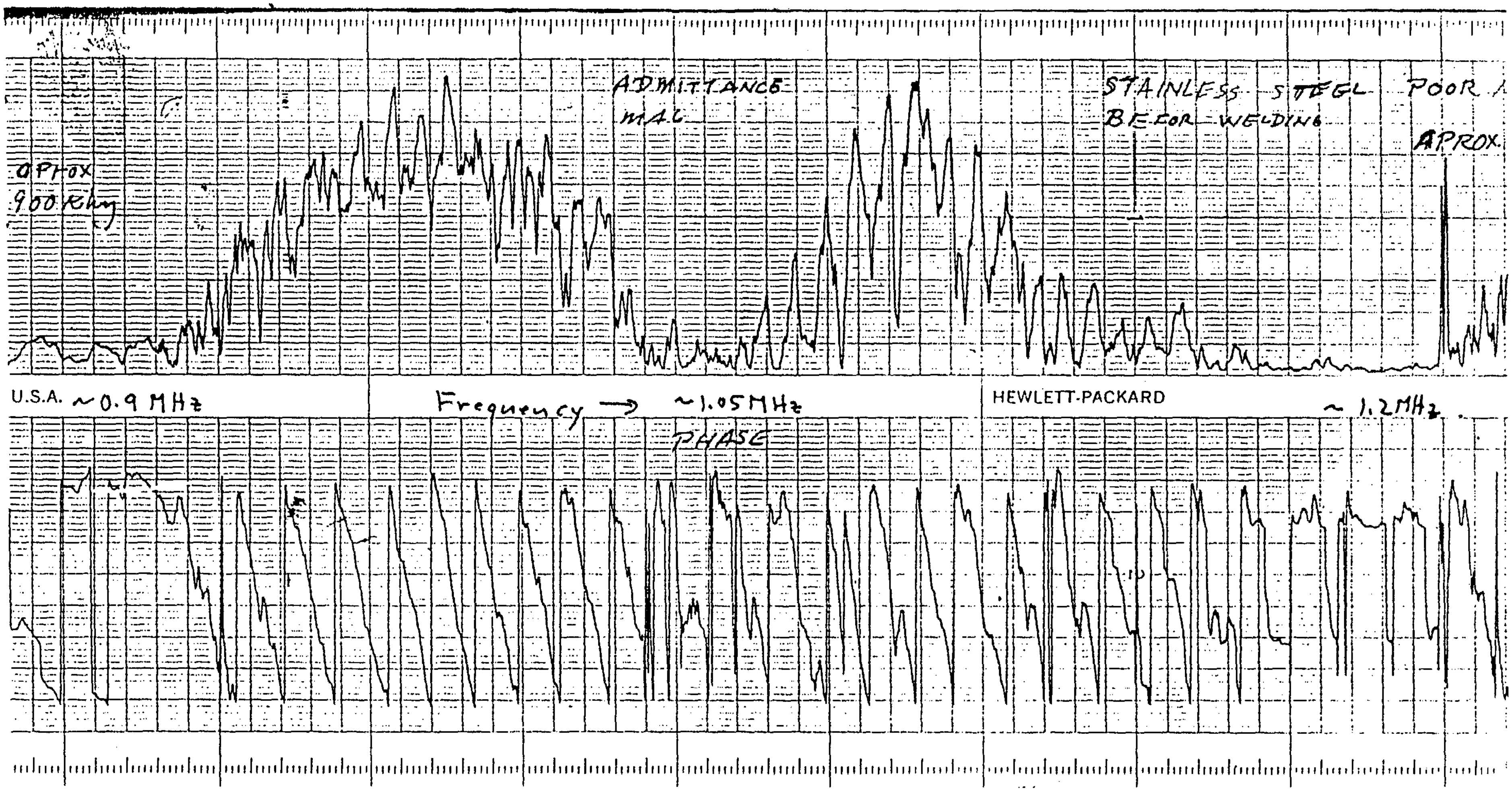


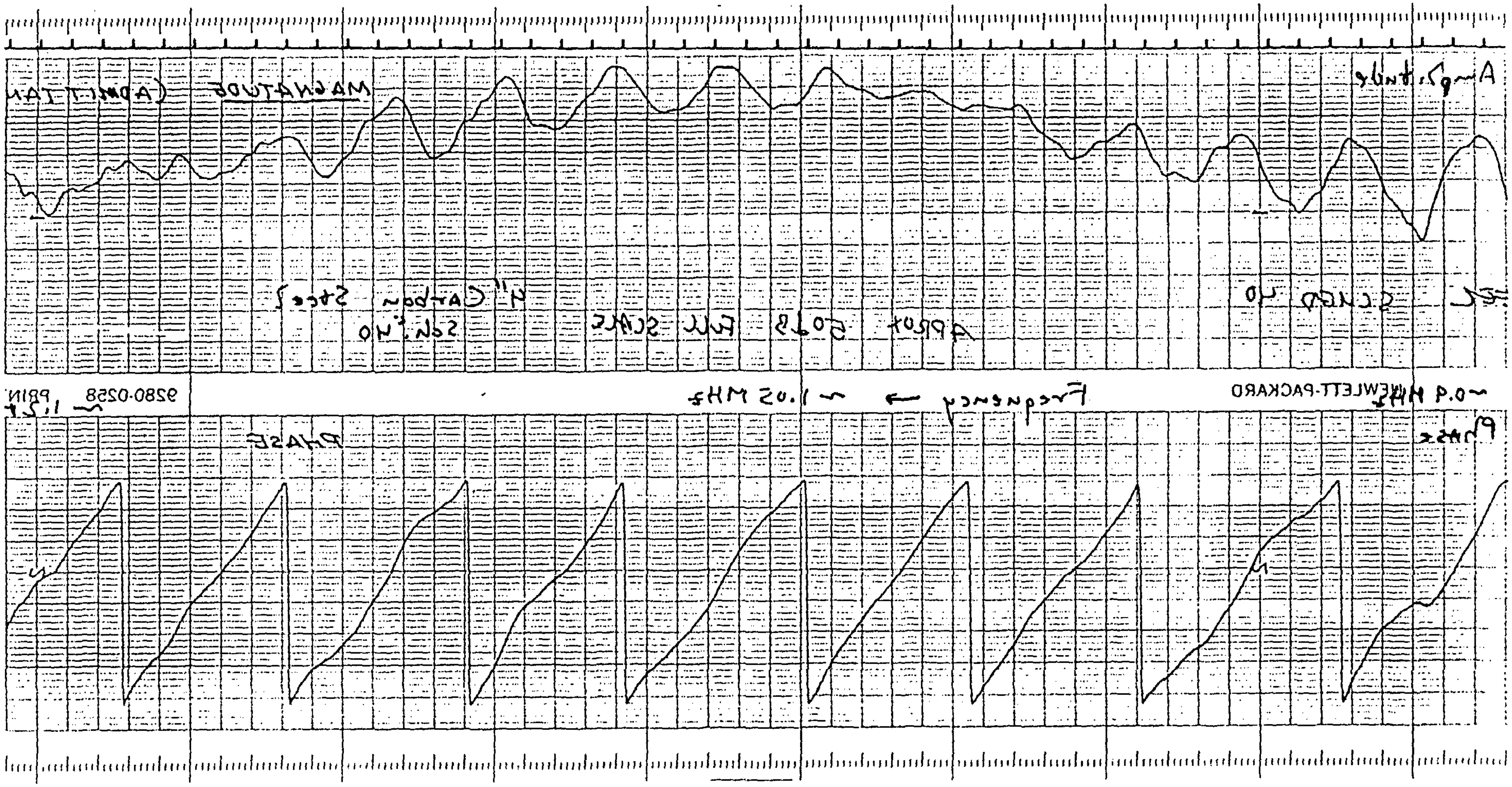
939.824 KHz



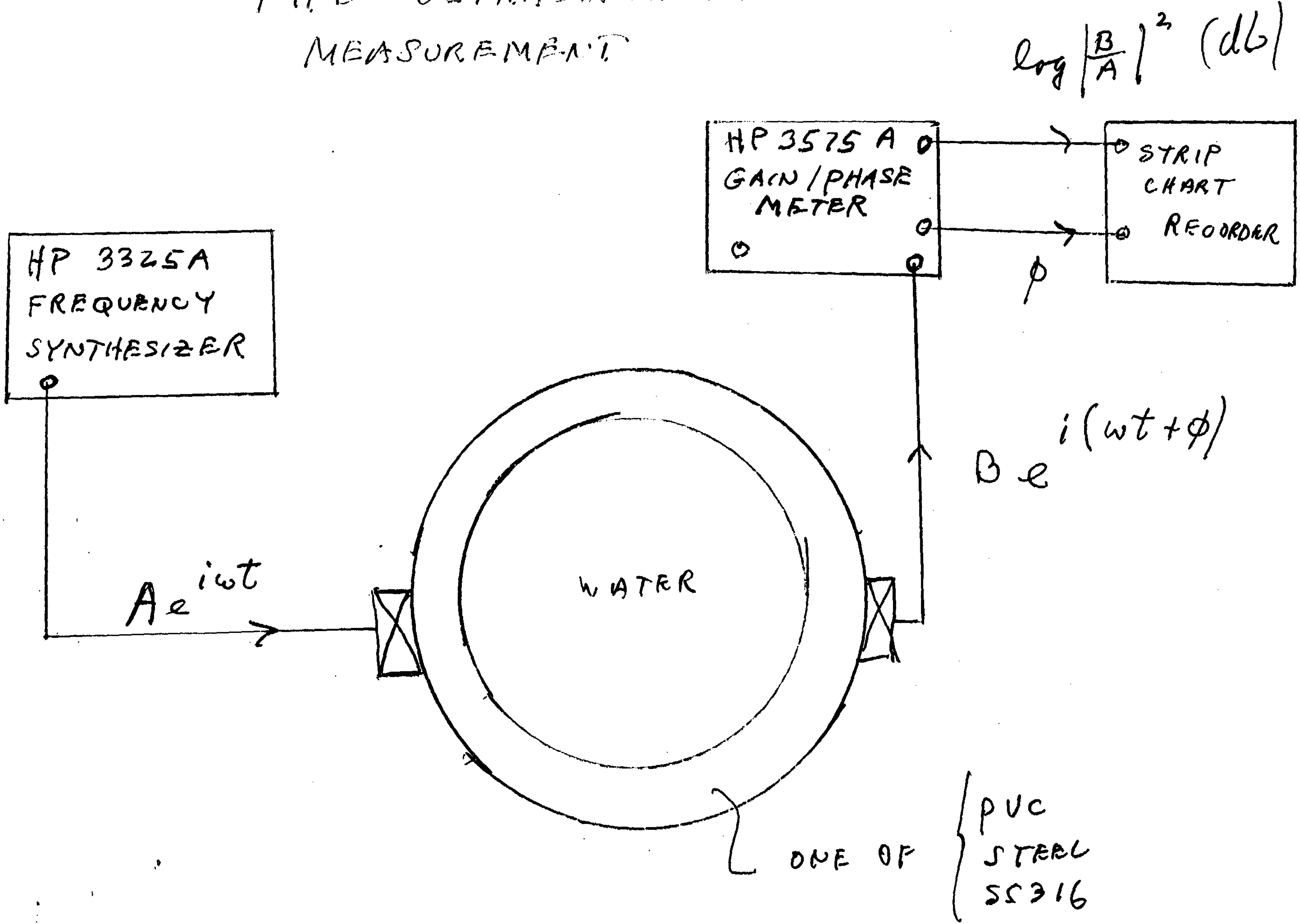
941.826 KHz

SLIDES USED BY
Dr. Tom Maginnis

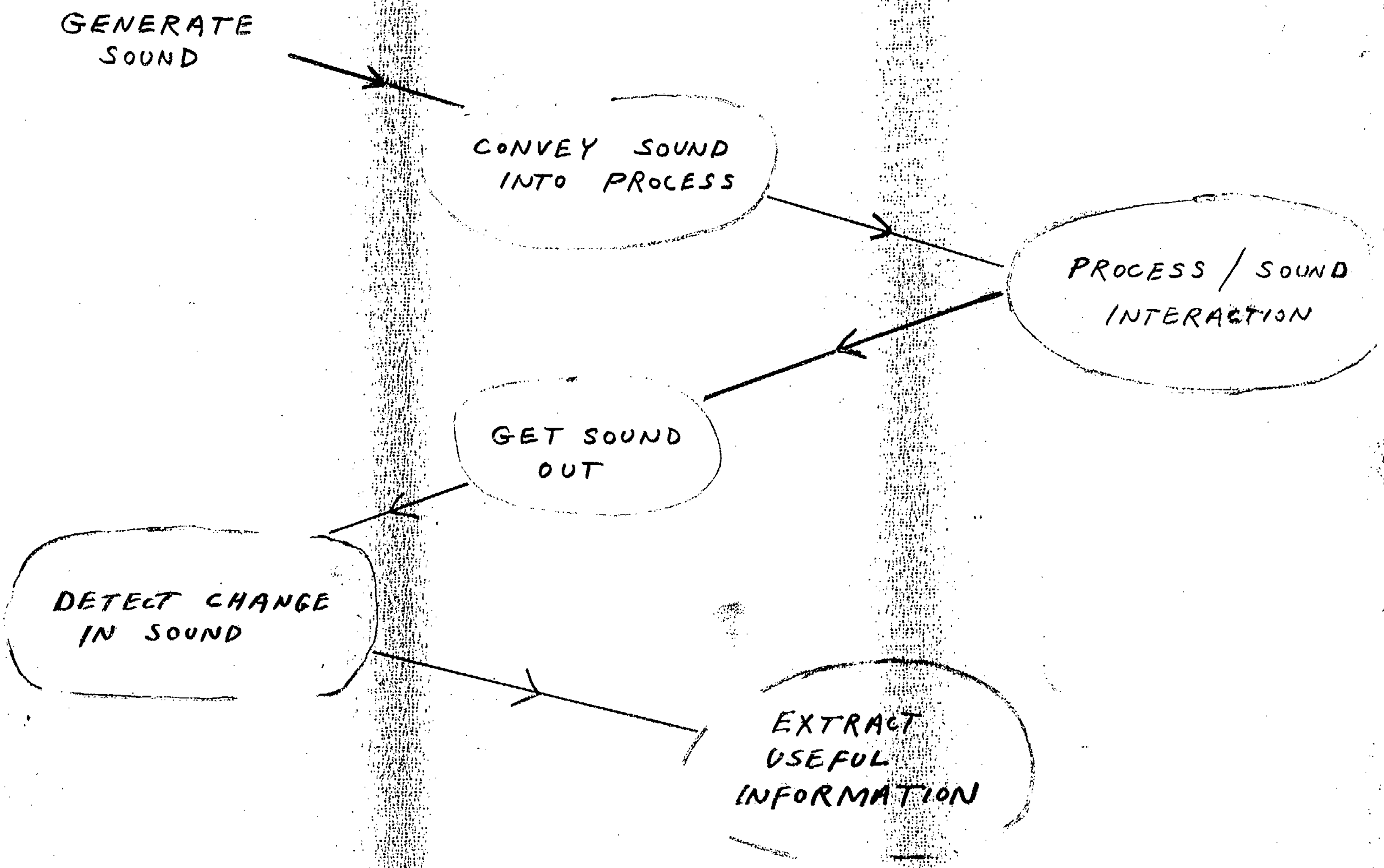


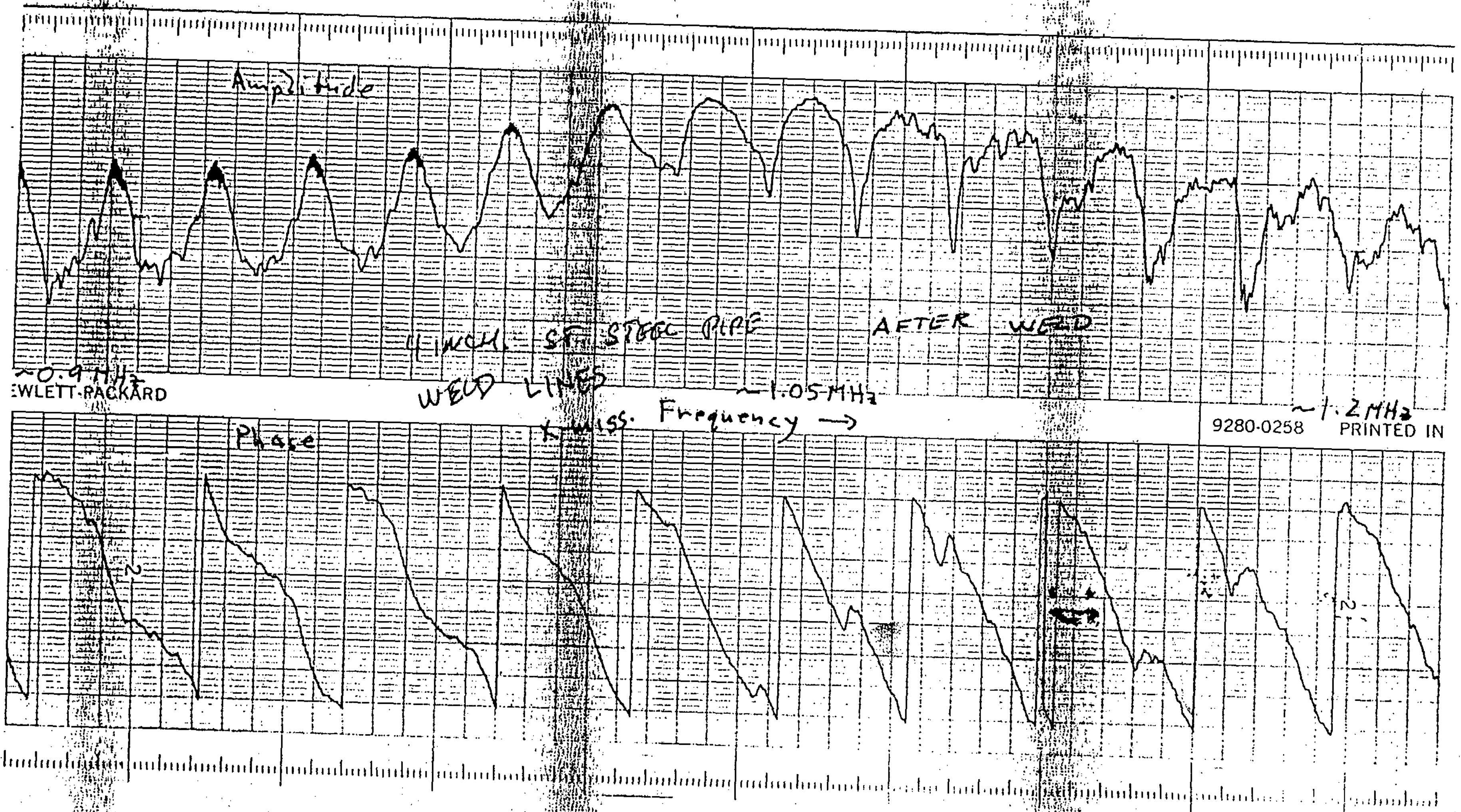
MAGNITUDE (ADMITTAN
Amplitude
4" Carbon Steel
SCH. 40
APPROX 60dB FULL SCALE
SCHED 40
HEWLETT-PACKARD
9280-0258
~0.4 MHz
Frequency → ~1.05 MHz
~1.2
PHASE
Phase

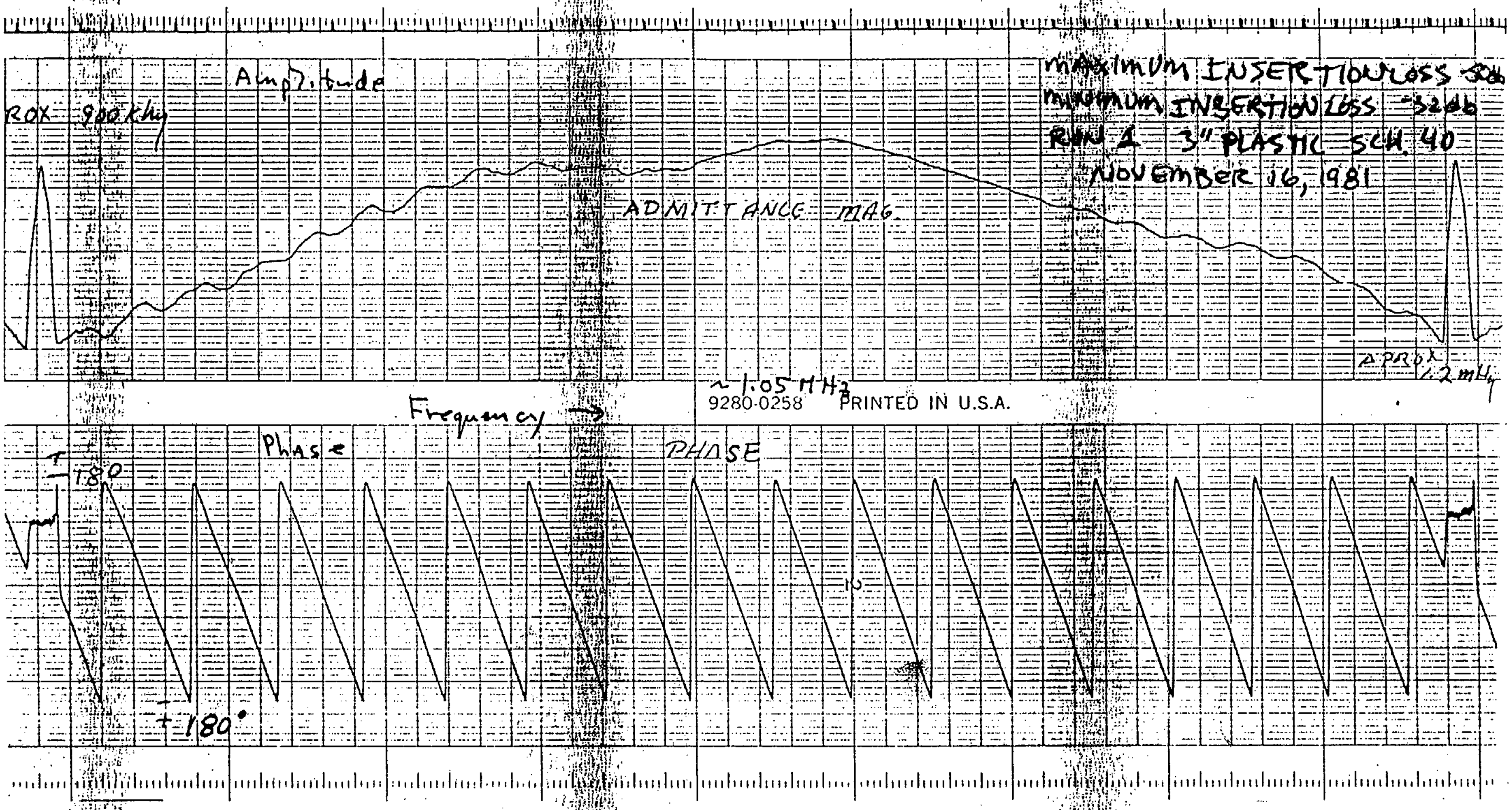
PIPE ULTRASONIC TRANSMISSION MEASUREMENT



ULTRASONIC MEASUREMENT TECHNOLOGY




Amplitude
4 INCH SS STEEL PIPE AFTER WELD
~0.9 MHz
EWLETT-PACKARD
WELD LINES
~1.05 MHz
Xmiss. Frequency →
~1.2 MHz
9280-0258 PRINTED IN
Phase



Amplitude
ROX 900 khz
ADMITTANCE MAG.
MAXIMUM INSERTION LOSS 50db
MINIMUM INSERTION LOSS -32db
RUN 1 3" PLASTIC SCH. 40
NOVEMBER 16, 1981
APPROX 1.2 mHz
~1.05 MHz
9280-0258 PRINTED IN U.S.A.
Frequency →
Phase
PHASE
-180
+180°
10

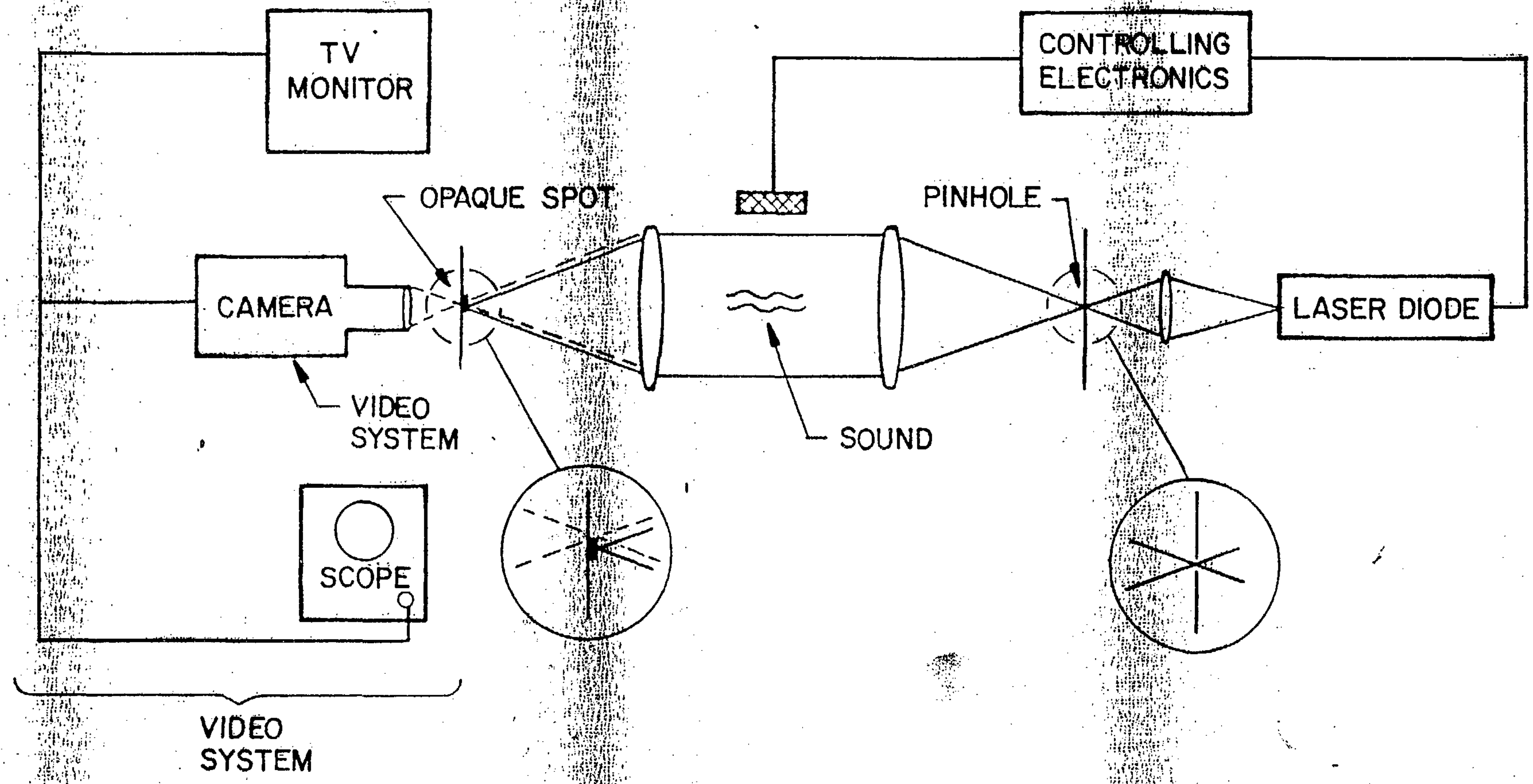
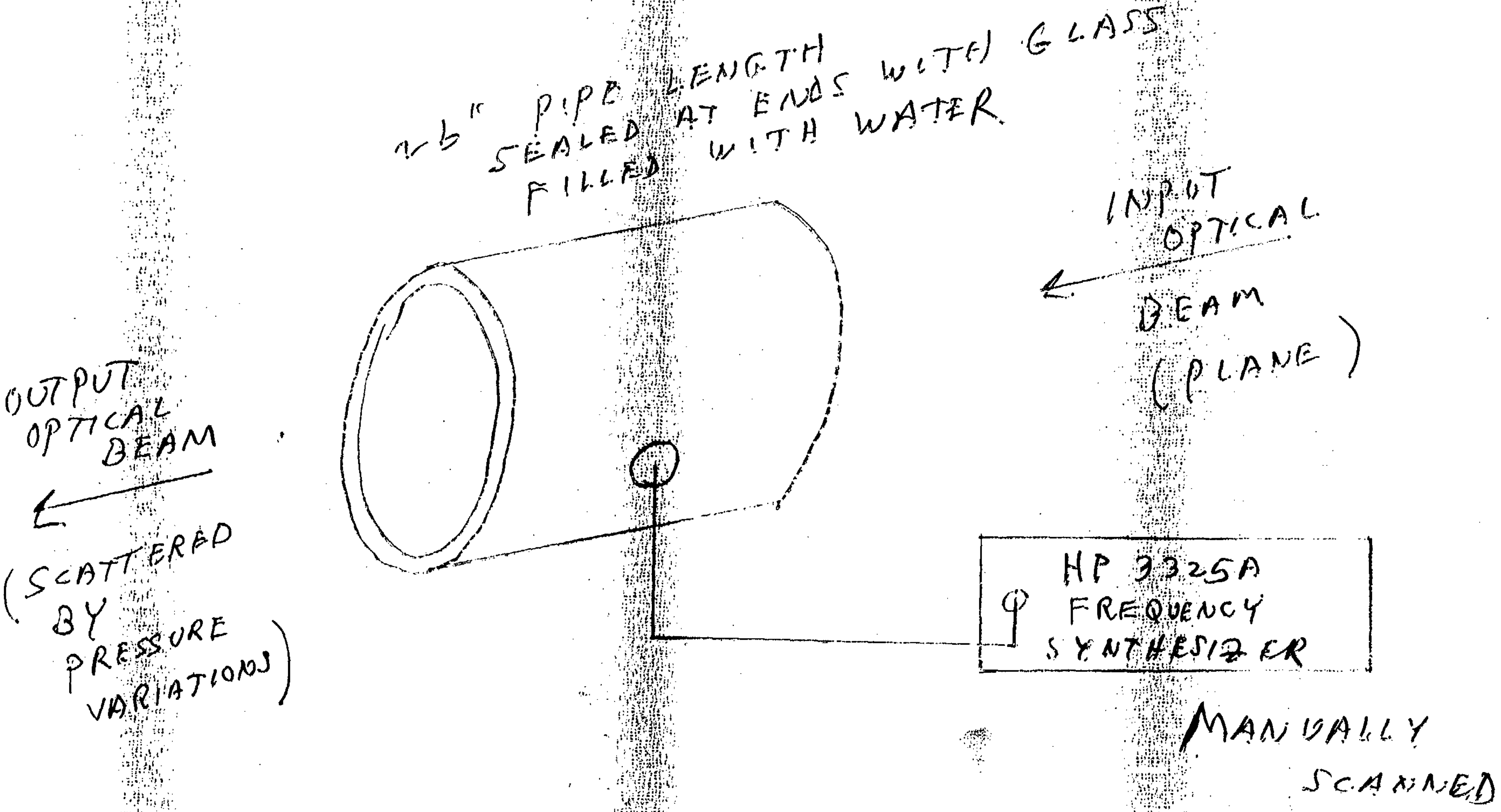


FIG.8 ULTRASOUND VISUALIZATION SYSTEM

SETUP FOR OBSERVING ULTRASONIC WAVES INSIDE A PIPE SECTION



UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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PUBLIC MEETING

Nuclear Regulatory Commission
Two White Flint North
Room T2-B1
11545 Rockville Pike
Rockville, Maryland 20852
Wednesday, March 8, 2000

The above-entitled meeting commenced, pursuant to notice, at 3:02 p.m.

PARTICIPANTS:

STUART RICHARDS
PROJECT DIRECTOR
PD4 AND DECOMMISSIONING, NRR
CAL HASTINGS
HERB ESTRADA
ERNIE HAUSER
JENNIFER REGAN, Caldon, Inc.
ROGER HORN, Key Technologies
CHARLIE WAITE, Key Technologies
GEORGE MATTINGLY

Attachment 4

PARTICIPANTS: [CONTINUED]

JACK CUSHING
BILL HORIN
MALCOLM PHILIPS
LAWRENCE C. LYNNWORTH, Panametrics, Inc.
SETH G. FISHER, Fisher Precision Systems
TOM MAGINNIS,Professor, U-Mass, Lowell
IAN RICKARD, ABB
CHIP FRENCH, ABB
YURI GUREVICH, AMAG
STEVE DEMBEK, NRR/DLPM
JOE RUTBERG
CATHY MARCO, OGC
MIKE NEAL, NUSIS
I. AHMED, NRR/DE
JOE DONOGHUE
RALPH CARUSO
JARED WERMIEL, NRR/DSSA/SRXB
JOSE CALVO
HUKAM GARG,NRR/DE/EEIB
TERRY JACKSON
STEVEN ARNDT, RES/DET/ERAB
FAROUK ELTAWILA
NORMA LAUBEN, NRC/RES

JOHN ZWOLINSKI, NRR/DLPM

PARTICIPANTS: [CONTINUED]

ALEX ZARUHNAK, MPR Associates

PROCEEDINGS

[3:02 p.m.]

RICHARDS: Good afternoon, I am Stu Richards. I am the Project Director with PD4 and Decommissioning in NRR. This is a public meeting between the Caldon company and the Nuclear Regulatory Commission.

By letter dated February 15th, 2000, Caldon submitted to the NRC information related to the measurement of feedwater flow at commercial nuclear power plants. In this letter Caldon specifically expressed concern that instruments measuring flow by means of cross-correlating ultrasonic signals affected by eddies in the flow system may not support a significant reduction in the 2 percent power margin of 10 CFR 50, Appendix K.

Caldon further expressed a willingness to meet with the staff to discuss their submittal, hence, today's meeting is an opportunity for Caldon to present directly to the staff their concerns with cross-correlation flowmeters.

Portions of Caldon's February 15th, 2000 submittal are proprietary, however, there will be no discussion of proprietary information in today's meeting. Because this meeting was noticed less than 10 days prior to the meeting, the staff has elected to have the meeting transcribed in order that members of the public who could not be here today can have access to specifically what discussed. So, please identify yourself before speaking in order to aid the transcription, and usually the transcriber will ask if, you know, we get too many people talking at one time, so help out on that.

There is a sign-up sheet going around the room. Please ensure that you sign the sheet so that we will have a record of meeting attendance.

Today's meeting is scheduled to last until 4:30. I would ask Caldon to keep this in mind in making your presentation. The staff has reviewed the material you submitted and is somewhat familiar with its content already.

Members of the public in attendance here today are here to observe only. If members of the public have questions or comments, I would ask you to hold them until the end of the meeting. The NRC staff will be available to speak with people who have questions and comments then.

Mr. Hastings, could we please start by your introducing yourself and the members of your contingent joining you today.

HASTINGS: Thanks. I am Cal Hastings, I am the President and CEO of Caldon. I have with me some people who -- some of whom are employees of Caldon, some of whom are people that I have asked to be here on our behalf. They are people who I regard highly as experts who may be able to speak more to the point on some of the issues than even we can.

I would like to introduce Herb Estrada, who is seated here at the table. Herb is our Chief Engineer and a number of you at the NRC have met him during previous meetings.

Next is Jennifer Regan. Jennifer is with a company called Key Technologies, and I will use the "key" again to say she is one of the key consultants to Caldon and has been involved for some years in our work in feedwater flow measurement.

Next is Dr. George Mattingly. George is probably well known by people here for his work at NIST in Gaithersburg.

Seated closer to me from George is Seth Fisher. Seth is President of Fisher Precision Systems, it is a company that manufactures transmit time ultrasonic flowmeters and I didn't intend to make reference to Seth's age, but Seth has got to me more familiar for more years with ultrasonic flowmeters than anyone in this room.

FISHER: Since 1960.

HASTINGS: Seated to Seth's left and George Mattingly's right is Larry Lynnworth. Larry is the Vice President of Panametrics. And both Larry and Seth are competitors of Caldon. I don't know that I have ever asked a competitor to come and speak to make a point to support my own before, but I will say that I did it in this case because of the high regard that I have for their work and for what they have published, and for what they know about flow measurement.

Next is Dr. Tom Maginnis who is seated here more closely to my left. Tom was formerly in research and product development at Foxboro, a company well known in the flow measurement field, where he worked on transit time and cross-correlation flowmeters. He is now a professor at the University of Massachusetts in Lowell.

Over here by the -- well, let's see there is Dr. Roger Horn, I am sorry I passed over Roger. Roger accepted an assignment from Caldon last year to do an in-depth study on cross-correlation flowmeters for us, to help us to identify and to bound their uncertainties.

And then last, close to the post here is Malcolm Philips and Bill Horin. They are well known here at the NRC. They are attorneys, and they have been advising us from the beginning as we have tried to do work in support of this 1 percent uprate, and they have been advising us on nuclear regulatory matters. They also are pretty good engineers.

I believe we have copies of the resumes of all of us here with us, and they will be available for anyone who wants them at the end of this meeting.

RICHARDS: Before you start, Mr. Hastings, if I could ask the rest of the audience to introduce themselves, just so we know who is here.

HASTINGS: I think I would like that very much.

RICHARDS: Jerry.

WERMIEL: My name is Jared Wermiel, I am the Chief of the Reactor Systems Branch at NRR.

CALVO: Jose Calvo, NRR.

DEMBEK: I am Steve Dembek, I am Section Chief in charge of Vendors and Owners Group, and I am going to be making -- we ran out of copies of the handout. I am going to be making more copies. Can I get a show of hands of who would like a copy? I will make about 15. A few more.

ZWOLINSKI: I am John Zwolinski, I am the Division Director, Division of Licensing and Project Management.

MARCO: Catherine Marco, OGC.

RUTBERG: Joe Rutberg, OGC.

COE: Christie Coe, McGraw-Hill.

NEAL: Mike Neal, NUSIS.

WAITE: Charles Waite, ProDesCon.

DONOGHUE: Joe Donoghue, Reactor Systems Branch, NRR.

CARUSO: Ralph Caruso, Reactor Systems Branch at NRR.

CUSHING: Jack Cushing, Project Manager, Division of Licensing and Project Management, NRR.

GARG: Hukam Garg, NRR.

GUREVICH: Yuri Gurevich, AMAG.

FRENCH: Chip French, ABB.

RICKARD: Ian Rickard, ABB.

ELTAWILA: Farouk Eltawila, NRC, Research.

LAUBEN: Norm Lauben, NRC, Research.

JACKSON: Terry Jackson, NRC, Research.

RICHARDS: All right. Mr. Hastings, with that, we will turn the floor over to you.

HASTINGS: Okay, Stu. I have prepared a list of topics. It is almost an agenda. Let me run through it and explain. We have, of course, already identified the participants.

I want to tell you a little bit about Caldon and it will be brief, it is merely to give you a feel for where we are coming from. I will then try to explain to you why we submitted the February 15th information package.

Jenny Regan and Herb Estrada will then discuss the technical information that we submitted.

I am going to look to the experts here with me to make comments, to offer clarification, offer their opinions as we go through our material. My feeling is they know what they know, and they should react accordingly. If they feel what we are presenting is inappropriate or wrong, I am sure they are going to tell me that. And if the want to raise questions of their own, we will welcome them.

We would expect and welcome questions from those of you from the NRC as well. They can be at any time during the discussion, and I think the only time you would expect me to not answer is if I felt my answer to your question was going to come along in the next point or two, or that it would be better to let me continue with my thought before we get around to it.

At the end I would expect to have some concluding remarks based upon the interaction here, and I have made the assumption that you would as well. And it seems to me we just have to wait until we get to the end to see what those will be.

Caldon is a privately held company located in Pittsburgh, Pennsylvania. I founded the company in 1987. We are a high technology company with significant know-how in ultrasonics, electronic circuits, computer systems, and flow phenomena within fluid systems.

We have two principal product lines at Caldon. One we call LEFM, these are ultrasonic flowmeters. LEFM is a trademark that stands for leading edge flowmeter. The other product line is called LineWatch. LineWatch is the trade name of a leak detection system that we apply normally to petroleum pipelines, but other pipelines as well.

These products are used in important and technically demanding applications, including ballast control on the Seawolf Class submarines; leak detection on the trans-Alaska pipeline; turbine monitoring at New Zealand's hydro-electric stations; and feedwater flow measurement in 33 nuclear power plants.

Now, I want to get at the reasons for our submittal. Last month I was given a copy of the Special Edition of ABB's CROSSFLOW Currents, the one that you see projected on the screen. This newsletter provides information on the status of, at that time, the NRC's review of ABB's Topical Report on CROSSFLOW UFM technology.

I was surprised by this statement, and I just extracted it, I didn't change any of the words here, and highlighted what surprised me, that "the SER will find acceptable the CROSSFLOW UFM System's measurement accuracy less than or equal to a half a percent."

I had fully expected the NRC would find that a bounding vale for the overall uncertainty of this instrument would be significantly larger than that, and I have my reasons for feeling that way. I am going to attempt to let you understand what they are.

I was accused, I guess, of cutting to the chase by letting you see some numbers which quickly give you a feel for why I was surprised. This is our assessment of uncertainties for ultrasonic flowmeters for a typical 2-loop nuclear plant installation.

On the left, the left column represents uncertainties, under the heading of chordal transit-time I list uncertainties that are associated with a 4-path transit time like Caldon's LEFM(check). In the middle column I list uncertainties that we find apply to an externally mounted transit-time system like the one manufactured by Caldon. In the righthand column we list our assessment of the uncertainties for a cross-correlation type flowmeter externally mounted to hot pipes on feedwater lines.

At the extreme left I listed the method I have used for categorizing these uncertainties. What I mean by the top one are those uncertainties that are from acoustical effects like scattering, like reverberation of sound waves. What I mean is the errors that can be induced in any of these instruments by such acoustical phenomena.

Next, it is our assessment of those uncertainties are associated with less than perfect knowledge of dimensions. In this case, dimensions, I mean inside pipe diameter, how well do we know that? The pipe wall thickness, the spacing between ultrasonic sensors.

The next category of uncertainties are those from errors in measuring transmit time or cross-correlation time.

At the bottom I used the term "velocity profile." One more appropriately might have been flow distortions. And what I mean is the uncertainties in flow reading from an ultrasonic instrument that derive from the distortions inside -- the distortions of the flow field inside the pipe, and these are often referred to as velocity profile, and I used that shorthand notation here.

You can see why I was surprised, given my beliefs about the uncertainties, and our own assessment, supported by a fair amount of literature and analysis, which we will discuss here momentarily, but we believe that the uncertainties of that device for this application -- we are speaking now of one in particular, feedwater lines in a nuclear power plant -- we believe that is more like 1.45 or 1-1/2 percent.

I felt I had, feeling this way, and I hope I don't come across as too fanatical about it, but believe that, I felt I had to do something, and I didn't know exactly what to do in a situation like this, and I felt I had to come to the NRC, because you have reviewed our work, and I knew you were reviewing ABB's work, and the ABB Newsletter told me that I should expect an SER to soon hit the street, and that SER would -- they already changed the slide -- but that SER would state that you agreed that the accuracy of their instrument was about three times better than I thought it was.

I think all of us in this room agree that this is an issue that is important to safety. I will illustrate that point a little bit more clearly in a moment. But I also think that everyone can lose if an error in feedwater flow measurement causes a plant to go overpower. The good work that has gone into the Appendix K Rule Change and the intended positive outcome would surely suffer. And I guess I have to tell you that after putting an awful lot of good work into this thing on our part, if the industry would stop buying ultrasonic flowmeters because of an overpower incident, my company is going to lose enormously. And as the CEO of the company, again, I can't sit idly and not try to bring to you my concern before it leads to a significant problem for me.

I said I would come back to the issue of safety. It is not the easiest thing to deal with, so I tried here in my own way. I have attempted to show the safety implications by relating uncertainty in the thermal power measurement to the probability of a plant overpower incident. The case identified as #1, and I can see it is very small, on the left, unfortunately, but this case represents the use of the LEFM(check) for a 1 percent uprate in power. In this case the thermal power measurement uncertainty is six-tenths of a percent. Also, for this case, the probability of an overpower incident in a plant using that device with a 1 percent uprate is .04 percent.

That number has been discussed with you all previously, it ties directly to information that was in our Topical Report.

This is contrasted with Case #2 that represents the situation in most power plants today. Except for Comanche Peak, all other plants are still operating under the 2 percent Appendix rule. Caldon's analysis, previously given to the NRC, concludes that the uncertainty in thermal power measurements is typically 1.4 percent. And I might say that some of the staff felt that it is greater than that and expressed that in our SER. For these plants, the probability of exceeding their design basis power level is .21 percent. And, so, you can see that under Case #1, we have actually made an improvement in safety through the LEFM(check), and that is appreciated by those of you here at the NRC who were involved in reviewing our Topical Report.

Case #3 represents a situation in which a plant uprates its power level by 1 percent and that it employs a flowmeter that produces a thermal power uncertainty of

1 percent. For this plant, the probability of an overpower incident is 2.28 percent. And, likewise, the next case is very similar except the measurement uncertainty is 2 percent.

And one way to look at this is if you assume that an instrument has an uncertainty as low as, and this is on a thermal power basis, I think the SER, and I mention one-half a percent, that refers to, I believe, mass flow measurement. So there is some slight difference. But if you make this assumption, or I make the assumption and I am wrong, if I am wrong a little bit, or if I am wrong a little bit more, or if I am wrong a lot, it can have significant safety consequences.

At this time I am going to ask Jennifer Regan to go through the materials. And what Jennifer will try to do first is acquaint you with the book and, apparently, since you have looked at it, she won't have to spend too much time at that. But if you have questions about the book itself, I would say now would be the time to raise them.

REGAN: I am Jenny Regan, and this is the book. I wanted to say a few words about myself so you become familiar with who I am. I am the President of Key Technologies, that is an engineering company in Baltimore. I have been an engineering consultant in the nuclear industry serving electric utility clients for about 17 years. I have been working generally in the area of instrumentations and controls for this time.

I have been working in particular with Caldon, as Cal mentioned, on feedwater flow measurement and ultrasonic technology since 1991.

Back to the book, we submitted a large book to the NRC on the 15th of February. This book contains 19 documents on ultrasonic flow measurement. Each document in the book is relevant to Caldon's concerns. There are three documents proprietary to Caldon and the rest are available in the open literature.

We are unaware of any published documents in the open literature, any outside these, that refute the contents of this book. This represents a selected set that we have chosen to help with the review.

We included entire documents in this book rather that sections of those documents in order to avoid citing sections out of context. The documents are separated by tabs. Some of you are probably familiar with this. And there is a summary in the front of the book that is intended as a road map, tying Caldon's concerns to specific references within the book.

These documents span years of engineering research. Some are as recent as this year, while others go back as far as the 1970s. We included documents because they contain information about inherent fluid flow and acoustic effects for each of the flow measurement technologies.

For example,, the hydraulic testing report in this book, by Seth Fisher, who is here today, and Paul Spink, for chordal transit time meters is just as valid today as when it was published in 1971.

There are three types of information in this book. There is cross-correlation technical research and field experience. There is transit time research and field experience for both chordal and external mount meters. And then there is a comparative analysis of these technologies.

In the first category there are quite a few documents on cross-correlation technology. I am just going to choose a couple of particularly pertinent examples of this type of information. For example, Tabs 2, 3 and 4 in this book contain publications supporting the designer's accuracy statements of between 1 percent and 3 percent for the cross-correlation meter, published in 1992, 1996 and 1998. These papers also describe field applications of these meters.

Another example, Tabs 5, 6 and 17 describe experimental data that illustrates the profile sensitivities of the cross-correlation technology. Here I am speaking about hydraulic profile.

Next slide. Another pertinent example is Tab 8. This is Dr. Roger Horn's independent analysis of the cross-correlation technology uncertainties. This document is proprietary to Caldon.

The next category of information in the book is transit time technology information. This transit time technology information is provided as a perspective. Tabs 10, 11, 12, 13, 14, 16, 18 and 19 support Caldon's accuracy statements about Caldon's chordal and external mount transit time flowmeters, using analytical and experimental data, and referring to field experience with these meters.

Finally, there is comparative information in this book. The introduction to the book, which I mentioned earlier, the summary this is in the front, and Tab 15 compare the three ultrasonic technologies in order to provide a frame of reference for the reviewer of the material in this book.

Looking at this information in this book, we can conclude that data in the open literature indicate that the hydraulic and acoustic uncertainties inherent in the cross-correlation technology would support an accuracy of between 1 and 3 percent rather than the half percent that we have seen published. In fact, the 1 to 3 percent numbers are nowhere near the half percent number we have seen published.

These same data in this book raise fundamental issues that cannot be addressed without extensive testing in a variety of piping configurations and wall roughnesses.

We will now address the hydraulic and acoustic uncertainties in greater detail, referring to the book of references as appropriate as we go along. Herb Estrada is going to be doing that for you.

I am going to put the book over here, Herb.

ESTRADA: Okay. And I will need the viewgraphs.

I should mention before I start that a number of the pictorials in this part of the presentation are excerpted from Tab 8 of the compendium, which is a proprietary document, however, the pictorials that are included in this presentation should not be treated as proprietary.

As Jenny mentioned, our own investigations of the cross-correlation flow measurement system indicated to us that there are significant and variable sensitivities of such technology to both the shape of the velocity profile within the tank and to the acoustics of the installation, that is to say, the installation -- the interaction between the ultrasound and the hydraulics themselves, as well as the piping environment in which the flow is being measured.

RICHARDS: Could I ask you to face this way because the acoustics of this room aren't very good.

ESTRADA: Very good.

RICHARDS: I have been back there before and it is hard to hear in that end of the room. So we apologize for that.

ESTRADA: Part of the reason for being concerned about the sensitivity to velocity profile is that the relationship between what a cross-correlation instrument measures and the bulk average flow in a duct is not obvious. There is no first principles theory that provides that relationship.

Now, we have, in fact, in the book, provided you with two references.

One, a reference that is roughly 15 years old, Beck, which is a good text and describes approximately what the cross-correlation meter is reading. That doesn't constitute a first principles analysis, it provides an explanation of what it is you correlate when you do cross-correlation the two ultrasonic beams.

Tab 8, I guess it is, is Roger Horn's analysis. That also endeavors to describe analytically and mathematically what it is the cross-correlation flow measurement system reads. Neither of those, however, constitutes anything approaching a first principles type of instrument. Let me illustrate.

A Venturi nozzle fundamentally changes the momentum flux between two adjacent areas of a pipe, and one can relate the differential pressure that a Venturi measures to the mass flow rate, providing you make some estimate of the density of the flow rate. You can relate those using first principles, you can derive what the meaning of that relationship is.

If he does this, without ever calibrating the Venturi nozzle, the chances are he will be within 1 or 2 percent of the true answer. The reason is that the Venturi behaves, in the absence of fouling, and if its configuration doesn't include bypass flow, it behaves like the physics that you use to describe it. One can analyze then the Venturi, one can describe the errors in the Venturi by methodically looking at the mathematics that describe it and assessing what the uncertainties are in each of those elements. That is, in fact, what the ASME did 30 years ago when they developed flow measurement standards for the Venturi.

Likewise for chordal ultrasonic meters, the principles of a chordal ultrasonic meter are clear. The transit times of the pulses can be related directly by first principles to the sound velocity and the fluid velocity along a line of the acoustic path. It is a clear, unequivocal type of relationship and the uncertainty in relating those velocities to the volumetric flow, because the chordal paths are spaced such as to perform a numerical integration, again, are typically within a few tenths of a percent of what a strictly analytical approach would tell you that the volumetric flow is.

So, again, one can make a rigorous mathematical analysis and bound the uncertainties associated by a flow measurement using a chordal ultrasonic system by simply writing the algorithm and then quizzically and rigorously, and skeptically analyzing each of the elements in that analysis. No such rigor exists, to our knowledge, in the open literature on cross-correlation flow measurements.

Now, absent that, absent the underlying theory, the danger that you miss something, that there is an error that you simply haven't thought about, that later comes back to bite you, that is the key. It is the nasty surprise that the absence of underlying theory makes you vulnerable to.

Let me amplify a little bit. As I mentioned, a chordal ultrasonic flowmeter makes measurements along each of four acoustic paths, in effect, determining what the axial velocity is on each of these four chords. And because of the placement of the chords and the weighting functions that are applied to them, in effect, it integrates the velocity profile across this area. And one can calculate, as I mentioned, the flow from the velocities, from the numerical integration rules that you get out of a handbook, and you can calculate the volumetric flow, and, typically, with this instrument, you will be between one-tenth of a percent to four-tenths of a percent of the true answer, depending on whose numerical integration rules you use.

The situation is a little bit different with an externally mounted time of flight instrument. And I bring this up because it is our experience with such instruments that led us first to question the fundamental accuracy being claimed for the cross-correlation flow measurement.

Externally mounted time of flight measurements typically measure the velocity along one or, in our case, two diametral paths, as is shown in the middle circle here. Now you can make, if you are very careful about your acoustic uncertainties and your time measurements, and your geometry, you can make a pretty precise measurement of the velocities, the axial velocities that intersect those paths. But that doesn't tell you what the volumetric flow is, and, typically, in one of these instruments, we find that the relationship between the velocity that we measure along these paths, and the true volumetric flow velocity, may range from anything from .94 to 1. That is to say the calibration coefficient typically ranges from .94 for this instrument, where I take the velocity of that measure and multiply it by .94, or, in another hydraulic installation, it might be as high as 1.

Fairly heavy sensitivity, one can -- that doesn't mean that the answer is uncertain over that range, but it does mean you are sensitive to hydraulic geometry, and you have got to work like hell to get accuracy out of that instrument. And, as Cal showed you in his earlier chart, our claim is that such instruments can be made to read within about a percent but no better, and we would not propose to use such an instrument for a thermal power uprate.

Now, as we will discuss later, a cross-correlation flow measurement system, if it uses two stations separated from each other by, say, one or to three diameters on a pipe, and measures the -- and correlates the turbulent eddies at each of those two stations against each other, and determines a time delay, and, from that, determines a velocity, that is really measuring information along a chord which corresponds, depending on the specifics of the profile, to something like 80 percent of the total diametral chord. It doesn't look at the whole profile, it looks at only a fraction of that, and that information can be found in Beck, the reference I cited earlier, that is 9, Tab 9, and also in Roger Horn's work, Tab 8, and I believe also -- is it 4, reference 4?

REGAN: Tell me where Horn is.

ESTRADA: Hitchcock.

REGAN: There is not a specific reference to the percentage of the diameter.

ESTRADA: No, but it says --

REGAN: But it is the facts that are referred to.

ESTRADA: Yes, it is well known. What I am trying to establish here is that it is well known that a cross-correlation meter, for reasons that we will get into, does not give you information about an annular region which may vary from, say, 10 or 15 percent to as much as 20 or 25 percent of the radius, and, therefore, can constitute roughly 35 to 40 percent of the flow area. You simply don't get information about that part of the flow field.

MAGINNIS: Excuse me. Before you put that --

ESTRADA: Sure.

MAGINNIS: I have a question. In the clamp-on case, -- this is Tom Maginnis. In the clamp-on case, you have drawn two paths connecting those transducers. Those transducers are connected on the outside of the plant. How do you even know what the sound power of those paths?

RICHARDS: Mr. Hastings, before we continue, may we ask the members of the public to hold their questions till the end of the meeting. So if he is with your group --

HASTINGS: He is.

RICHARDS: -- and you want to answer the question, that is fine.

HASTINGS: We do.

MAGINNIS: Who will answer it?

HASTINGS: I tried to explain --

RICHARDS: I couldn't keep track of, you know, who is with who.

HASTINGS: All right.

ESTRADA: Normally, with an externally mounted flow measurement, there is a substantial uncertainty about the exact angles that the acoustic paths make through the fluid flow and, therefore, a substantial uncertainty in the actual velocity. In our cases, we are applying this to precision flow measurement. We do experiments in which we make displacements of the transducers and measure the change in certain acoustic properties with the displacement of the transducer to establish, essentially, what the angle of the acoustic path is with respect to the flow. And, thereby, we reduce the uncertainty.

Now, you may not have noticed it in passing, but there was a substantial acoustic uncertainty associated with the externally mounted Caldon meter in the chart that Cal put up earlier, it is roughly four-tenths of a percent. At best it is not very good.

All right. Larry Lynnworth.

LYNNWORTH: Just one question. I just want to verify, in a cross-correlation, the righthand circle, if there were a second diameter, top to bottom, path which would also sample a segment, is it correct that there is still the same annular region that is --

ESTRADA: That's right. A second path, as with an external mount, adding a second path enhances some of the measurements, such as the time measurements, but it really provides you no more information about what is going on in this annular region toward the outside of the pipe.

MAGINNIS: Would it be correct to say that, because of the measurements that we made external to the pipe, transit time, pipe 1, comparing time measurements to theory and that you only take measurements, you have high confidence that it is --

ESTRADA: Yes. Among other things, we have made numerous pitot rate measurements to find out what the real profile is, according to a pitot rate, and then checked what our integration says versus that. Typically, they are within a fraction of a tenth of a percent, less than a tenth of a percent.

MAGINNIS: Do you know of any measurements that support the path that you have drawn of the plant as far as correlation?

ESTRADA: I do not.

Next slide. This is a -- excuse the cursor. Roger was not able to make that disappear. This is a 3D representation of Roger Horn's simplified model of how a cross-correlation meter works. This is, I want to emphasize, a cross-correlation depiction. What is show -- excuse me for turning, but I need to point at something. Let me show you a point here. What is shown here, first of all, is the pipe diameter, zero corresponds to the center line of the pipe, plus a half and minus a half corresponds to the outer walls of the pipe. On the vertical axis is the evaluation of the correlation coefficient itself. And now along this axis here, this third axis, is a time delay.

So what we are doing here is showing you, if I were able, obviously, a cross-correlation takes some aggregate result, but if I were able to reach inside the pipe and take slices of the flow, here at roughly 20 percent of the radius from the wall, I get a correlation whose mean time is roughly .085, and which is, in fact, approximately normally distributed about that, but if I waited long enough, that guy would correlate at .085. As I move in, of course, the eddies correlate at faster and faster times. This particular curve is drawn for nominally fully developed flow with, I believe, Roger, a friction coefficient of .00015 corresponding to --

HORN: .001.

ESTRADA: Roughly, fairly smooth pipe, as I recall.

Now, as I said, what a cross-correlation meter does is it takes the aggregate result of that. Before I leave this curve, I want to point out something to you. This is the -- here is the outer 20 percent. There is no significant correlation in this outer 20 percent because the eddies that are traveling out there are traveling too slow -- too slowly to be included in the correlation function. You can see that, I think, better on the next slide.

This is for the same graph that we just showed you, what the correlation function looks like, aggregate, using, again, Roger's Model.

I want to emphasize that this is a simple model. It's not intended to be rigorous in the sense that one can use it to bound all the uncertainties associated with this instrument.

It's a single line-of-sight piece of sound that's traveling across there, and you're looking at the eddies and how they modulate the received signal, how they accelerate or decelerate the received signal along that single line, and correlating.

It doesn't account for the breadth of the wave, and it is not, except in one instance in the book, it does not deal with distorted profiles; it deals strictly with mathematically describable, fully-developed profiles with various viscosities and roughnesses.

Now, those slow guys on the outside of the pipe, they're in there all right, but there' out here somewhere. I think there's a little lump out there. On one of the others you can see a little lump.

They don't contribute, really, to the peak, and they don't weight the peak strongly. You pick a number, and, in effect, you're representing something that's strongly representative of the middle of the pipe.

This is a slice through a time that corresponds to the peak time in that last graph that we showed you. In other words, this is showing you which eddies, and, therefore, which velocities are actually being correlated by the meter.

We're really not picking up the average velocity along that middle 80 percent, roughly, of the pipe diameter; we're picking up preponderantly eddies that are roughly a quarter of the diameter out.

Now, fortuitously in this case, that corresponds to something not too far away from the average velocity. But that doesn't always occur, as we will describe.

What I read out of this thing then is that it's sensitive to what the velocities that the eddies are traveling at. And from the graphs that we just showed you, those velocities were traveling along a relatively well-defined, developed profile.

These data, which are excerpted from Tab 6 of your book, which describes some Korean experiments with cross-correlation flow measurements, downstream of various complex hydraulic geometries, these data are taken from Tab 6 and show the change -- we didn't get that on here, I see.

Let me just tell you what they are: The vertical axis is the deviation from the straight line calibration coefficient of the instrument. In other words, this point here deviates from the straight line, from the fully-developed coefficient for the instrument pipe, roughly seven percent.

This point, downstream of a bend, 30 diameters, says that the calibration coefficient for this location varies from the straight line coefficient by about one and a half to two percent.

What this shows is that sure enough, hydraulic distance is important from hydraulic features like this. It's important as to what this instrument reads.

One doesn't simply put this instrument ten diameters downstream of a bend, and expect to read it the same as it would read if it was 30 diameters downstream from the bend. If you did, you'd make an error of about three or four percent, by the way I read that curve.

So, one has to model the hydraulic geometry for this instrument, the inertial effects, particularly, before you can use it.

Now, here's the point: These are big variations, six, seven percent, numbers like that. We talked about the Venturi and the transit time portal meter.

We said that if we stuck those things in a pipe without calibration, we would expect them to read within two or three tenths of a percent of what you would expect to read purely on the basis of theory in most hydraulic locations.

This instrument -- and, oh, by the way, an external map instrument is not like that. You must model the geometry. The result is sensitive to the geometry, and intrinsically then, you don't get protection. If you don't get the geometry right, your potential for error is intrinsically larger, and therefore your uncertainty is intrinsically larger than it is for an instrument whose first principles are well understood and whose sensitivity to outside effects are small.

Now, this does not describe the uncertainty of these measurements themselves. It simply describes the sensitivity of these measurements to where this instrument is in a hydraulic location.

The next slide, though, does give you some insight into that. These are the data that take -- that the author of Tab 6 took for various hydraulic locations as a function of Reynold's Number.

So what you should look at is clusters, in this case, a little bats or the little triangles or the squares, and you can see that, for example, regardless of Reynold's Number, the bats, for example, correspond to a location of five diameters downstream of a bend, and a spread of one and a half to two percent.

And that spread corresponds to the spread in each of these data sets, and, in fact, in some of them, they're larger.

What that means is that for this particular calibration experiment, the observational uncertainty which I would have to carry as part of the calibration coefficient for this instrument, is in the order of one and a half to two percent, or perhaps half of that, depending on if you're talking about spans, and you'd split the difference and take the mean.

It's not a trivial number. That same kind of effect is why we carry uncertainty coefficients for our external amount that are in the order of 7/10ths of a percent for hydraulic effects, because of that same kind of sensitivity.

Obviously, you have to carry the uncertainty of the calibration lab and the instrument they used to make the measurements, as well, but this one is a biggie in this case.

There's another point I want to make: To get precision with cross-correlation requires lots and lots and lots of samples. And the reason is that turbulence is inherently a noisy process, so you don't get very much signal for noise. The practice is in many instances, to average for extremely long periods of time to get a nice sharp correlation peak so as to define the time with low uncertainty.

It's hard to do that in a calibration lab. A weigh tank fills in 40 seconds to a minute. So you get one set of data in 40 seconds, and that's not much data, not enough to make a calibration coefficient.

And five runs that takes you maybe three or four minutes to empty the tank and get ready to run again, so yo run five times and that still doesn't get you enough data. If you have to get 12 hours, it's going to take two weeks worth of data at one specific location to get a precise measurement of the transit time.

Yes?

HASTINGS: Maybe you could clarify why you mentioned 12 hours.

ESTRADA: Yes, the 12 hours is based on two things: It's based on some numbers that we've made, but it's also based on data that we see in the literature. The reference at Tab 4 shows 12-hours, or times varying from nine to 12 hours, as used to get precision.

And we agree with that, that that's the kind of number that it takes to get the precision of the transit time measurement for this instrument.

HASTINGS: If I just might add a point, as I understand it --

REGAN: Say your name.

HASTINGS: Cal Hastings, sorry. One characteristic of this instrument that Herb is describing, it has what we would call a low, poor repeatability, short-term repeatability. In the short term, if you didn't average data very long, you would get a lot of scatter.

The way that one deals with that, if he wishes to use such an instrument, is, he averages the data for a long time, maybe ten or 12 hours.

And so unlike other instruments that are used where they have quick time response where you can change and pick up transients, this one is not useful. I think it's one reason, probably the foremost, of why this technology is not used in mainstream flow measurement, because you should not use it for process control.

There are not many applications where you can get away with an instrument that has to average for 10 hours or 12 hours.

ESTRADA: The punchline from this set of slides is that without putting a precise number on it, the calibration coefficient will carry a substantial uncertainty; we believe, in the neighborhood of a percent.

Now, I have measured a calibration coefficient in the lab. I now have to take that under my arm and go out in to the field and make a flow measurement in the field.

And here is where that outer part of the pipe comes back to bite me, because things change between the lab and the field. There are differences between the lab and the field which are intrinsically hard to bound, although I can make the effort.

I don't know what the roughness is going to be for the pipe I walk up to in the field. I can, however, choose a very smooth pipe in the lab, and perhaps a pipe that I believe to be representatively rough and bound -- at least establish a bound of the uncertainty.

I don't believe that if I did that with a cross-correlation meter, the range of coefficients I would find to be acceptable; that is to say, that would force me to take too large of an uncertainty, and we're going to talk about that.

There is another factor as well; the viscosity changes from the lab to the field. If I say, gee, I've got very smooth pipe in the lab, and that's simulates the low viscosity that I will see in the field. A viscosity of 450 is maybe one-fifth of what it is in a typical calibration lab.

And I still have a problem because I make smooth pipe in the lab, but I can make low viscosity and smooth pipe in the lab, so I have the twin variables of viscosity and wall roughness to deal with, and I have to methodically put bounds on what I see in the lab, so that I can carry these numbers to the field.

The notes, by the way, in the viewgraphs, refer to where these subjects are developed further in the book that we've sent you.

Let me go back to the technicolor marvel here. This is, again, the base case, same case we saw before, and you'll recall that I think the average correlation time was something like .075 seconds for that case.

Now, if I might, here is the correlation time that we had for the first curve. If I now increase roughness by -- relative roughness by what is not absurd, a factor of 10, this corresponding to commercial steel pipe, new; this corresponding to relatively rough but not inconceivable -- we've encountered this kind of pipe in the field -- I see a change in transit time, correlated transit time of 3.2 percent.

If I say, okay, I'm going to handle that by taking it as an uncertainty, I'll take the coefficient that's halfway in between those two, and I have an uncertainty of 1.6 percent, clearly not an acceptable procedure for a half-percent flow instrument.

And this simply shows the two correlation peaks. The slower time with the higher wall roughness drags these guys forward, and winds up correlating eddies that are closer to the center line of the pipe.

Now, wall roughness in nuclear power plants is not a constant. But we have data from one of our customers who has a chordal meter. We get profile data from the chordal meter.

We have data that indicates changes in service on the order of 25 percent of the amount of -- the equivalent amount of wall roughness. That is to say, the change in the profile that we see, based on the chordal flow measurement corresponds to a change in wall roughness of about 20 percent.

If such a change occurred in service with a cross-correlation meter, that would result in a 6/10ths of a percent shift in its calibration coefficient.

Incidentally, with the chordal meter, one can prove that the change is less than 500ths of a percent. It's trivial because it's making a careful integration across the entire pipe.

Incidentally, we can make available to you. That is not in the book but we can make it available to you if you'd like, and our analysis of it.

Finally, in traveling from the lab to the field, I have to deal with the acoustics. The wavelength of the sound beams that are being transmitted across the lab, not across the pipe, is the quotient of the sound velocity and the frequency, and the sound velocity in water at 450 degrees Fahrenheit is in the neighborhood of 4,000 feet a second, while it's around 5,000 feet a second in the typical calibration lab.

So the wavelength is shorter in the field than it is in the lab. Now, the way this thing works is, the eddies whose dimensions are in the order of the wavelength are those that are most strongly correlated by the ultrasound as it passes through the beam.

So it's fair to say that the eddies that I correlated in the lab may be a different set than those that I correlated in the field, and since the eddies, the dimensions of the eddies that are traveling through the pipe tend to vary as a function of radius, small eddies start at the wall, and the biggest eddies tend to gravitate toward the middle, we may be looking at a different segment of the velocity in the field than we were in the pipe, so that the calibration coefficient that we have to deal with has to account in some way for that uncertainty.

I think I've said most of this, but we do note -- and this is not in any sense a proof -- but there were experiments done at Pt. LePreau where transmit frequency was varied, and there was a change of around two percent in the calibration coefficient. It's possible, though, as I emphasized, not proved, that that sensitivity was, in fact, a wavelength sensitivity.

I know this in that regard: We do see different amplitude modulation effects in hot water than we see in cold. That's the way it affects it, but that doesn't change the times any, but the ultrasound fluctuates, owing to the turbulence, and we see different amplitudes in hot water than we do in cold water. The amplitude fluctuations tend to be much larger in the field than they are in the lab.

Now, at this point, I wanted to invite Dr. Maginnis and others of the folks to present a separate and different experience from us in this regard, about which we did not know till yesterday. I would like them to speak to that, because Foxboro, as I said, did a fair amount of work in cross-correlation instruments, and Tom will share some of that with us.

MAGINNIS: I have to apologize to everyone because I didn't have a whole lot of time to prepare for this, but I did however clear what I am going to say with Jay Morris, who is the attorney at Foxboro who was a patent attorney at the time I was there.

RICHARDS: Would you identify yourself for the transcript?

MAGINNIS: Yes. My name is Tom Maginnis. I am here as an independent flow consultant. I was good enough to be invited by Cal Hastings.

Now they found out that I had some knowledge that might be relevant to this question and I will try to make this very brief and show you some experimental data.

I would like to say a few words first. There were four or five people at least who worked at Foxboro. We did a high level effort. We did it from 1979 to about 1985. The company did not proceed to commercialize the product, which they often did not. I also worked on transit time ultrasonic flow meters. I steered them away from Doppler because I felt that was not a viable technology and everything that I have heard today confirms me on that. It doesn't even prove up as one of the possibilities.

Now this is very old but it makes a point. When you are measuring something with ultrasound you have to generate the sound, get it into the process, and there will be some interaction in there that has to take place, and then you have to get the ultrasound out, detect the change, and extract the useful information. You have to know what you are doing to extract the useful information, so you need a good theoretical basis.

Now when it comes to putting acoustical energy through a pipe, how do you know that you are getting the sound through there? It is not the situation like the medical ultrasound where the human body is very close to water in its acoustic properties. The sound goes right through except for a little scattering of the bones. It is not like x-rays going through the human body. There is only one kind of pipe where sound goes through like that, in a direct straight path, and that is PVC pipe.

PVC plastic is very close in its acoustic impedance to water and so it essentially makes this inside boundary disappear and the sound can go right through, a straight path, no problem.

When you use steel you might have an acoustic mismatch between the water and the steel which causes an 80 percent or thereabouts energy reflection to occur when a beam or a pulse hits that interface. The result is that you can send sound in. It's going to hit this interface and then bounce -- and of course this transducer on the far side will pick up sound. It's to that frequency, but there is no way to tell from out here what path it's going to follow getting from one transducer to another.

In fact, acoustic short circuit has been occasionally a problem even with clamp-on transit time meters.

So the question comes up what path does the sound follow and also what characteristics should that path through there have?

Now I am going to show you -- this describes a measurement, all right? If you want to find out how well your transmission process works to go through here, you can do it this way. You have a transducer now in the pipe, whatever transduction mechanism you use, piezoelectric -- crystals. If you have a frequency synthesizer, which is an instrument that will put out a very precisely defined frequency and vary it in a controlled manner, in this case I believe we rank it in time, that would send out a signal which electrically might be characterized this way -- sine wave, electrical sine wave, which will cause this transducer to put out an acoustical sound wave or an ultrasonic sound wave.

That will then make its way somewhere into the other crystal where it will be detected and if there is any kind of wave this wave may differ in magnitude from the other wave and also in phase, so you can define a transfer function, which is a function of frequency, which is basically a complex number.

There is a meter that will pick that up and I have left the line. Out here there should be a line coming over here to reference this phase to the frequency synthesizer, so this instrument will compare the sound coming out, the signal coming out to the signal going in, and compares them --

That could be transferred over to a strip chart recorder which will display pictures. I will show you the phase on one chart and the energy transmission on the other chart, on a logarithm scale, decibel scale.

So first I am going to show you a PVC pipe -- oh, first, what would you like to have? What is the ideal you would like to have coming out of here? If you had a straight pass across there the only difference -- we'd like to have the same magnitude come out. We probably won't get that. There will probably be some reduction in magnitude. What about the phase? We would like the phase to be linear with frequency. You want a pure delay so as you go up in frequency you get more wavelengths in that and it turns out that that will correspond to a phase characteristic that is proportional to frequency with a negative slope and the slope will give you the delay time.

PVC -- this is what you get -- PVC, plastic. Now the frequency range on this is from about 900 kilohertz on the left to about 1.2 megahertz on the right. This is basically the magnitude of the transmission on a logarithm scale. It is not absolutely flat.

It does fall off some. There is a peak, but you expect something like that because the crystal has a peak frequency,

The phase is nice an linear. The jags here are resets when it gets to minus 180th -- it jumps up to plus 180 again, but in between those you get nice linear phase. That is perfect -- see that?

HASTINGS: Speed it up.

MAGINNIS: I'm sorry. All right, well, very quickly if you do it with steel, this is stainless steel, you see all of these resonances and you see the phase, this kind of stuff, reverse phase. You don't have a nice transmission channel and in particular if you have a little different problem upstream and down stream that can foul up your correlation measurement. The correlation measurement requires identical properties on both channels.

Now I have some photos to show you, one other measurement which I did, which actually visualizes the sound flow inside the pipe and we use a system like this called a Schlieren system. I can provide more details on that later for those interested.

What it does, it creates a plane wave of light which goes through a sound field. On the far side almost all the energy is blocked a little dot at the focus, so only scattered light gets through and picked up by the camera and viewed on a monitor. You can do this for the pipe.

The optical path is this way. It gives us a glass put on the end of the pipe, the sound is put in here and you can tune this manually and you view the interior wave pattern on the monitor.

I haven't found a good way to reproduce these but I am just going to pass them around and let you look at these. These are recorded in that manner. These are photos of the sound field. Bright is high pressure; black is low pressure; these are standing waves inside the pipe which have a great variety of different patterns. Apparently this repeated 21 times in a row, cycles as you went through frequency.

ESTRADA: This is a way of visualizing?

MAGINNIS: This is a way of visualizing where the sound actually is inside the pipe, so what this shows is there is a great deal of variability.

If you look at the frequencies, these are very close in frequency. There's something like 7 kilohertz separating the whole family. If you work out the Bessel functions all of these would be degenerate for perfectly circular pipe. When you go to an elliptical pipe they get split and so you go through these patterns one after the other in a regular sequence as you raise the frequency, so these are very sensitive to temperature because as temperature changes the sound velocity in the wall, the sheer, and longitudinal velocity will change with a different temperature coefficient and the sound velocity in the water, so a small change in temperature can throw these patterns from one to the other.

They were able to sit in the lab and just the energy coming in to create the sound field which slowly warm the water and if we left the frequency fixed we could watch the system walk through these different patterns as the temperature changed.

PHILIPS: It's very helpful -- Malcolm Philips by the way -- very helpful to us but we have until 4:30.

MAGINNIS: Okay, I'll stop.

PHILIPS: Fifteen minutes left --

MAGINNIS: The final thing is we decided at Foxboro after investigating this for six years, and very high level modeling, that you would be between one and two percent with this technique and to get better than that you really have to have a good physical understand of that little correlation function, which is a single channel -- to be able to predict it.

Finally, I was at Foxboro when the Three Mile Island incident occurred, and so I know about the importance of reliability and the fact that instruments often or let's say occasionally may be needed to be used in non-nominal situations.

If this correlation meter works with the accuracy that's claimed at very high flow, which I sincerely doubt, what would happen if an emergency occurred and it was called upon to operate in a lower frequency? Now at Foxboro we had one of the few functioning sensors after the event at Three Mile Island was inside the containment vessel. It was a pressure vessel. It wasn't a primary pressure vessel or pressure sensor. It was monitoring oil pressure and some kind of hydraulic thing for a pump, but it continued to function and it was one of the key sources of information about what was the situation inside that vessel after the failure, so with that, I will stop and let someone else talk.

RICHARDS: Thank you. Do you think we could get copies or make copies of the slides that you presented today?

MAGINNIS: Certainly.

ESTRADA: This slide presents information which is included in a 1999 report prepared I believe by MPR Associates on nuclear feedwater measurement and cited -- that report included the claims made for cross-correlation flow measurement at that time, and I don't claim that this represents what is in the topical report because I don't know.

In this case the acoustical and the calibration coefficient uncertainties, which we have talked about, or which Tom has talked about, have got to be wrapped up in this quarter percent number and there is no way in my opinion that they can approach that or even the bottom line uncertainty of a half percent.

Our conclusion is that the uncertainties associated with acoustics and profile have got to be greater than 1 percent. That is the conclusion of my section, but I would like to invite Larry, Seth, George and others to comment.

MATTINGLY: My name is George Mattingly. I have a document I would like to read to the records here if I could --

RICHARDS: I just want to make sure -- if someone is going to speak, Mr. Hastings, as we have discussed before, they need to be part of your presentation.

HASTINGS: They all are. If they aren't I will tell you.

RICHARDS: The floor is not open to the public.

HASTINGS: Yes, I appreciate that.

MATTINGLY: I just want to mention that from the standpoint of NIST there is a lot of emphasis on NIST's part in ultrasonic flow metering techniques. We think it's a technique that actually can be extended, echoing the comments of Herb Estrada that we think it is essentially a well-understood technology that could evolve into a primary standard status and that is how highly we think at NIST of the technology.

What I want to say, extremely briefly, the full story is in the handout, is we have made tests at NIST of a couple of different kinds of clamp-on flow meters and one particular kind of a multichordal, an eight chordal path called "U" in this thing here. It happens to be a unit that was manufactured by Mr. Seth Fisher, a four chordal meter with eight paths.

What we wanted to do was we wanted at NIST to take a look at the existing clamp-on technology as it is in the industry now and what we did is we made, we invited a number of participants to participate in this. We had for example Controlotron and Panametrics, we had AMAG and Krohne and Mesa Labs -- I think that is the lot.

What I am showing you here is data that we have taken at NIST where we have clamped on these meters and we have measured the flow with the national standards for flow measurement, .1 percent accuracy facilities, and what we have gotten is this kind of a range of performances for each of the meters, all anonymous, listed here A through F, and what I am finding here is the actual data -- that is the actual datapoint you get when you calibrate that meter against the bucket.

What you have done is you have averaged the meter response over the 30 or 40 second collection time and the error bars on this chart represent the temporal excursions over the 40-second interval, and the dot at the center of these points represents the mean.

That is not how we recommend accuracy be looked at in a flow meter. What we recommend is that repeated tests, as Herb was saying, be done and you look at, for example, repeatability. What this means is that we have done separate tests five times each condition and we have averaged those five and gotten the standard deviation of those, and you can see here the scale is zero to 5 is about an inch on the real plot and what I applying here are the means and standard deviations of those, so that is repeatability. That is the best precision you will ever see, but we don't call that accuracy either.

Accuracy that we define is called reproducability and that is when you have done that same test under "turn off the pipe and turn it back on again." So the kind of things that we get out of that performance is shown here. What we do before we declare an accuracy -- by the way, on this plot this is a percent here. There is no manufacturer on that plot that's better than a percent, none, and we have not even added in the NIST contribution from my .1 percent to this kind of situation, so the there is nothing on this collection that is one percent.

The point I would drive home is that when you take multichord meters like the one that Mr. Fisher manufactures and you do the same kind of test for his meter and here is the reproducability for his, notice there is a significant scale change here, about 5 to 1, so this is a tenth -- this is two-tenths of a percent here.

The dark plots are a low velocity, which is bordering on the edge of the performance of this device. The high flows are the blue and the red. What you can see here is that across the both he's two-tenths or better and my facility is only a tenth, so the bottom line is here, and this is in ideal conditions when you have measured the flow. We know exactly what the Reynolds numbers are and we have done a lot of work to characterize the facility and this is the kind of performance we get with a multipath, four chordal unit. With the clamp-ons the ranges go up to about 3 percent, so 1 to 3 percent is what we get for the clamp-ons.

The conclusion I would like to leave you with is that the profile really does matter. I am telling you about a pristine, ideal test situation. Once we get into a power plant, where we get into an elbow situation or the roughness vagaries that Herb just talked about, I don't think you are going to see performance anything like the ones I have just showed you here.

I will stop there. If there are questions, I'd be happy to try to answer them. I think the conclusion is profile really matters. Even in a flow lab the performance we get for clamp-ons at this stage is not 1 percent. It is more like 3 percent. In a real power plant, I just shudder to think what the excursions could be from those levels.

RICHARDS: Dr. Mattingly, could we get a copy of your slides also, please?

MATTINGLY: Yes, they are in what I gave you.

RICHARDS: Thank you very much.

REGAN: Jane Regan. I would like to make a comment. Dr. Mattingly's data are also in the book in Tab 16.

FISHER: I am Seth Fisher and as he told you, I have been involved in ultrasonic flow measurement since 1960.

I have done a lot of testing and I certainly can confirm what is being said today about profiles and how they don't necessarily show the classical expectation based on the mathematics.

I have done a lot of testing at NIST. I have done a lot of testing at Alden Labs. I have done testing at Cap Line and I have done testing at Smith Meter -- all with flow facilities, and none of those facilities have produced the velocity distribution that one would predict based on the Reynolds number of operation.

If you take the Reynolds number that the meter shows versus the Reynolds number that is true for the viscous and inertial forces, I find that it varies from a ratio of .2 to one and this means then that any meter that is sensitive to that is going to have errors.

I would like to talk a little bit about the technique of tagging a section of flow and then measuring how long that section takes to travel a certain distance down the pipe. That technology is incorporated in the Allen salt method of measuring the flow and the dye dilution method of measuring flow and the isotope method of measuring flow as well as the correlation technique that's presented today. The difference is that this method of defining the section of flow is ultrasonic as opposed to salt. I am quite familiar with the Allen salt velocity method of measuring flow. They take great pains to distribute the salt slug that defines a section of flow in the pipe throughout the pipe, so they measure the whole wall-to-wall circumference, the circumference of the flow, and then they take that and then measure how long it takes that slug to move down to another set of sensors that then define the volume that the flow has passed through and measure the time. You can then calculate the flow.

That technique has never produced an accuracy better than 1 percent, and the experts in the field that have spent years trying to perfect that technology never quote accuracies any better than 1 percent, and that technology has been around for 100 years or so.

The other thing that I'm impressed with what's been said to day is that the cross-correlation method doesn't measure from wall-to-wall; it measures a certain portion of the velocity in the center of the pipe, the typical number being 80 percent.

That 80 percent means that one is not looking at 36 percent of the flow in that pipe, and that's a huge amount of flow not being accounted for, and that leads me to the conclusion that I don't believe that this technology, as I understand it, is capable of achieving a half a percent accuracy.

RICHARDS: Thank you, Mr. Fisher.

LYNNWORTH: Can we stop in five minutes?

RICHARDS: We're not going to run off.

[Discussion off the record.]

LYNNWORTH: I will talk fast.

HASTINGS: Larry Lynnworth.

LYNNWORTH: I'll try to save some time here. I have concerns in three areas, and I'll cover these in two minutes, I think: Theory, experiments, and independent verification. These are the three areas that I'm troubled by as an outside observer and competitor of Caldon.

I might say I'm here at my own expense, other than traveling.

The problem before us is to measure the true mean flow velocity, and what that means is to measure the average velocity of all the molecules going down the pipe. And the question I have is, how many of those molecules can we afford to disregard?

Yesterday was Super Tuesday. I'll draw a brief analogy to that. If anybody tried to predict the outcome of the November election by using a one-quart sample right down parallel to the Mississippi, the results would not be likely to be accurate. So, say, I'll do better, I'll also go from New York to Los Angeles or Honolulu, and maybe stop at Anchorage.

It still would not be an adequate sample and give me a good way to predict the outcome of the election. And I think there is an analogous problem here in looking at one or two diameters, as opposed to the quad chords.

I'll do one quick arithmetic exercise for you. I'm familiar with the 3, 4, 5 triangle and most of you are, in terms of an RMS. If you recall, earlier on page 8, there's an error budget that's roughly .3 percent associated with dimensions.

If the hypotenuse of the RMS triangle is going to be.5, that leaves .4 for all errors associated with acoustic fluid interactions.

The last point is on independent verification, including looking at installation effects and disturbances that change or drift over time, like roughness.

So it seems -- you know, this is not a criminal situation where one is innocent until proven guilty. It seems to me, as a manufacturer, that the burden is on a manufacturer to prove the validity of his claims, his or her claims, because I don't know who drafted them.

My final comment, my final concern is the proposed one- or two- path cross-correlation tag method. Is this like a wonder drug, a cure for a very complicated disease, or is it something where it looks like a cure, and side effects are yet to be observed?

RICHARDS: Thank you.

HORN: I'm Roger Horn. I'm with ProDesCon.

I just wanted to amplify on what Herb said about this. Some of the analysis that I did was based upon a fully-developed flow, and that's what this diagram represents, which has a classic falloff, and it's very smooth.

The relative roughness for fully developed flow, as that varies over the range from .00015 to the .0015, has a larger effect upon the accuracy of the -- the uncertainty of the cross-correlation meter than it does as you get closer to the pipe bend.

And that was one difficulty I had in the analysis, is that as you get closer to a pipe bend and you have the disturbances, there is, as far as I could find in the literature, no analytical expression for how you develop that flow profile. And it's pretty much based upon experiment.

One of the things we had to do, but we don't want to short-change the cross-correlation meter, as you get closer to the band, the uncertainty is going to be less.

One of the things we were able to do, though, was related to some of the external mount meter and how its uncertainty is affected as you get closer to a bend. We actually did just a simple linear extrapolation.

When you're at fully developed flow, it's around 1.6 percent, and the using the same linear extrapolation you do for an external mount LEFM meter, we extrapolated that down to about one, maybe 1.1 percent for cross-correlation flow meter.

So what we did in the analysis was try to give the cross-correlation meter as much of a leeway as possible, and put it in the same situation that you would put an LEFM meter in, in order to come up with some reasonable uncertainty bounds.

So there are the numbers that are in the table, a proprietary document, Tab 8, where there is worst-case and best-case. Those were cases where we tried to fit it in with what we knew how the velocity profile was affected in an LEFM meter, fitted to a cross-correlation meter, because we do not have that in an analytical form.

Thank you.

RICHARDS: Thank you very much.

PHILIPS: Malcolm Philips. And this was kind of a very unusual meeting. In the preparation for the meeting, a number of experts came down here, and these experts didn't come together till last night, basically.

And last night and this morning, we all sat around the table talking. Our presentation was totally different until last night when we started asking each other the question of, is the cross-correlation flow meter capable of achieving the accuracy claimed?

And to a person, there was a resounding no. So we wanted to try to get something akin to a blue ribbon panel and bring them before you and say there's something wrong here.

And that's what these people tried to do. I tried to monitor time, and I apologize for rushing them, because they each had a piece to say, and they each wanted to get it out in their convincing way. But all of them, at bottom, had that one significant concern, which is, can the cross-correlation flow meter such as proposed by ABB, achieve the accuracy claimed?

And to the person, it was, in their professional opinion -- and we're talking about years and years and years of professional opinion here -- was no. And that's what they've said here today, and I just wanted to stand up and apologize for rushing things through.

I was trying to assure that we got it out on time, and not like it was a mistake on my part. But I wanted to make sure that you understood that.

RICHARDS: All right, thank you.

HASTINGS: With all that's been said, it seems that I could add very little. I'd just like to summarize the way I see it.

All the information that we provided in our submittal, I think that the points that were made here today tell me that you cannot conclude that this instrument can achieve an accuracy of a half of a percent; you can't do it.

I would say that it tells me that we cannot write an SER that says this meter has a half percent accuracy. The risks of that being wrong are just too great.

RICHARDS: Do you have any other presentations to make?

HASTINGS: I have none. I would say that I might even -- because I spoke to you by phone, I had thought we could make a recommendation. I always like, when I'm involved in something like this, to make a positive recommendation.

But as I thought about it, it's inappropriate for me to tell the NRC how to go about making their decisions. It just seems to me that I cannot do that.

All I can do is present to you, why I was concerned. I hope that I was able to convey how strongly I feel about it.

RICHARDS: What I was going to ask is, if there are no other presentations, if you would bear with us for a few minutes, I think we'd like to ask the members of the staff who were involved in the review to step outside so we can caucus separately.

HASTINGS: Surely.

RICHARDS: We'll join you again in a minute.

[Recess.]

RICHARDS: If I could everyone to have a seat, please?

Mr. Hastings, we very much appreciate you and your colleagues coming into today. It was a very well done presentation.

We've talked separately as the staff, and I can say that most of the material that you presented today, the staff is familiar with. We have done some review of the material that you presented us.

You have mentioned the review of the ABB submittal that we are presently looking at. Of course, we're not here today to debate that with you.

So at this point, we've talked, and we really don't have any questions. If we do, if you don't mind, we'll give you a call, but unless you have any other comments, we, again, appreciate your coming in, and we'll take the information you provided us under consideration.

Any other comments? Mr. Hastings?

HASTINGS: No, I have no more. I would thank you very much for the opportunity to come here and clarify.

RICHARDS: All right, thank you very much. That concludes the meeting.

[Whereupon, at 4:41 p.m., the meeting was concluded.]