

**CENPD-397-NP-A  
REVISION 01**

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**IMPROVED FLOW MEASUREMENT ACCURACY  
USING CROSSFLOW ULTRASONIC FLOW  
MEASUREMENT TECHNOLOGY**

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**MAY 2000**

**CE NUCLEAR POWER LLC**



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**CENPD-397-NP-A, REV. 01**

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**CE NUCLEAR POWER LLC**

**IMPROVED FLOW MEASUREMENT ACCURACY USING  
CROSSFLOW ULTRASONIC FLOW MEASUREMENT TECHNOLOGY**

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**MAY 2000**

Prepared by  
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**U.S. Nuclear Regulatory Commission**

**Safety Evaluation Report**

**March 20, 2000**

**Acceptance for Referencing of CENPD-397-P, Revision-01-P,  
Improved Flow Measurement Accuracy Using CROSSFLOW  
Ultrasonic Flow Measurement Technology (TAC No. MA6452)**



UNITED STATES  
NUCLEAR REGULATORY COMMISSION

WASHINGTON, D.C. 20555-0001

March 20, 2000

Mr. Ian C. Rickard, Director  
Nuclear Licensing  
ABB Combustion Engineering  
2000 Day Hill Road P.O. Box 500  
Windsor, Connecticut 06095-0500

**SUBJECT: ACCEPTANCE FOR REFERENCING OF CENPD-397-P, REVISION-01-P,  
"IMPROVED FLOW MEASUREMENT ACCURACY USING CROSSFLOW  
ULTRASONIC FLOW MEASUREMENT TECHNOLOGY" (TAC NO. MA6452)**

Dear Mr. Rickard:

We have concluded our review of the subject topical report submitted by ABB Combustion Engineering Nuclear Power, Inc (ABB-CE) by letters dated January 6, January 25, March 8, and March 13, 2000. This topical report documents the theory, design, and operating features of the Crossflow ultrasonic flow meter (UFM) and its ability to achieve increased accuracy of flow measurement, which is generically applicable to nuclear power plants.

The staff review of the topical report indicated that the Crossflow UFM can achieve the accuracy stated in the topical report when the plant-specific operating conditions and flow measurement uncertainty determination strictly follow the guidelines in the topical report. The enclosed safety evaluation documents the staff's acceptability of the topical report for referencing in license applications and provides additional guidelines for the licensees who want to use the Crossflow UFM for a power uprate. Both proprietary and nonproprietary versions must be referenced in future license applications.

Pursuant to 10 CFR 2.790, we have determined that the enclosed safety evaluation does not contain proprietary information. However, we will delay placing the safety evaluation in the public document room for a period of ten (10) working days from the date of this letter to provide you with the opportunity to comment on the proprietary aspects only. If you believe that any information in the enclosure is proprietary, please identify such information line by line and define the basis pursuant to the criteria of 10 CFR 2.790.

We do not intend to repeat our review of the matters described in the report, and found acceptable, when the report appears as a reference in license applications, except to assure that the material presented is applicable to the specific plant involved. Our acceptance applies only to matters described in the report.

In accordance with procedures established in NUREG-0390, "Topical Report Review Status," we request that ABB Combustion Engineering publish accepted versions of this topical report, proprietary and non-proprietary, within 3 months of receipt of this letter. The accepted versions shall incorporate this letter and the enclosed SE between the title page and the abstract. It must be well indexed such that information is readily located. Also, it must contain in appendices historical review information, such as questions and accepted responses, and

Mr. Ian C. Rickard

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March 20, 2000

original report pages that were replaced. The accepted versions shall include an "-A" (designating accepted) following the report identification symbol.

Should our criteria or regulations change so that our conclusions as to the acceptability of the report are invalidated, ABB-CE and/or the applicants referencing the topical report will be expected to revise and resubmit their respective documentation, or submit justification for the continued applicability of the topical report without revision of their respective documentation.

Sincerely,

A handwritten signature in black ink, appearing to read "S.A. Richards", with a large, stylized flourish at the end.

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

Project No. 692

Enclosure: Safety Evaluation

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

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

ABB COMBUSTION ENGINEERING NUCLEAR POWER TOPICAL REPORT

CENPD-397-P, REVISION 01

"IMPROVED FLOW MEASUREMENT ACCURACY USING CROSSFLOW ULTRASONIC  
FLOW MEASUREMENT TECHNOLOGY"

1.0 INTRODUCTION

By letter dated August 23, 1999, (Reference 1) ABB Combustion Engineering Nuclear Power (ABB-CE) submitted Topical Report CENPD-397-P, Revision 00, "Improved Flow Measurement Accuracy Using Crossflow Ultrasonic Flow Measurement Technology." This report documents the theory, design, and operating features of the "Crossflow" ultrasonic flow meter (UFM) and its ability to achieve increased accuracy of flow measurement, which is generically applicable to nuclear power plants. ABB-CE stated that this meter provides at least 50 percent improvement in feedwater flow measurement accuracy as compared to the currently installed venturi-type flow meters in most nuclear power plants. This reduction in flow measurement uncertainty will allow a nuclear power plant licensee to achieve the following:

- (1) Use the increased accuracy of the UFM to support a reduction in the power level margin used in the plant emergency core cooling system (ECCS) evaluation. The licensee may then seek a license amendment to operate the power plant at higher power levels. This power level margin is 2 percent of the licensed reactor power and is required by the Code of Federal Regulations, 10 CFR Part 50, Appendix K, "ECCS Evaluation Model," to account for power measurement uncertainty.
- (2) Apply the reduced instrumentation uncertainty to gain benefits other than power uprate.
- (3) Have an in-plant capability to periodically recalibrate the feedwater venturi for the effect of fouling, thereby allowing recovery of the lost generating capacity while staying within the plant's licensed operating power level.

By letter dated November 19, 1999, (Reference 2) the staff requested additional information to continue its review of the topical report, to which ABB-CE responded in its letter dated December 17, 1999 (Reference 3). ABB-CE also submitted Revision 01 to the topical report by letter dated January 6, 2000, (Reference 4) and submitted supplemental information on the topical report by letters dated January 25, 2000, (Reference 5) March 8, 2000, (Reference 6) and March 13, 2000 (Reference 7). The ABB-CE topical report contains mostly proprietary information, except for headings and general introduction of the Crossflow technology, including development and capability of the Crossflow UFM. Therefore, the staff's safety evaluation

report includes only the nonproprietary information of the topical report that describes the Crossflow UFM and its ability to measure feedwater flow with an uncertainty of 0.5 percent or less at a 95 percent confidence interval.

## 2.0 BACKGROUND

Nuclear power plants are licensed to operate at a specified core thermal power and the uncertainty of the calculated values of this thermal power is a factor in determining the probability of exceeding the power levels assumed in the design basis transient and accident analyses. In this regard, Appendix K to 10 CFR Part 50 requires that loss-of-coolant accident (LOCA) and ECCS analyses assume continuous reactor operation of at least 102 percent of licensed thermal power with the maximum peaking factor allowed by the plant technical specifications to allow for uncertainties such as instrument error. This reactor thermal power is continuously indicated by the neutron flux instrumentation, which must be periodically calibrated to accommodate the effects of fuel burnup, flux pattern changes, and instrumentation setpoint drift.

The neutron flux instrumentation is calibrated to the core thermal power, which is determined by an automatic or manual calculation of energy balance around the plant nuclear steam supply system. This calculation is called a "secondary calorimetric," in the case of a pressurized water reactor, and a "heat balance," in the case of a boiling water reactor. The accuracy of this calculation depends primarily upon the accuracy of feedwater flow and feedwater net enthalpy measurements. As such, an accurate measurement of feedwater flow and temperature is necessary for an accurate calibration of the nuclear instrumentation. Of the two instruments (flow and temperature), the most important in terms of calibration sensitivity is the feedwater flow (1 percent error in flow instrumentation calibration produces a corresponding 1 percent error in the nuclear instrumentation calibration).

The typical elements used for measuring feedwater flow are an orifice plate, a venturi meter, or a flow nozzle, which generate a differential pressure proportional to the feedwater velocity in the pipe. Of the three differential pressure devices, the venturi meter is the most widely used for feedwater flow measurement in nuclear power plants. The major advantage of the venturi meter is the relatively low head loss as the fluid passes through the device. However, fouling of the device is the major disadvantage of this meter or any other nozzle-based flow meter. Fouling is a metallic plating on the throat area of the meter, which causes the meter to indicate a higher differential pressure and thus a higher than actual flow rate. This result leads plant operators to calibrate nuclear instrumentation high. Calibrating nuclear instrumentation high is conservative with respect to reactor safety, yet it causes the electrical output to be proportionally low when the plant is operated at its thermal power rating. In addition to fouling, the transmitter and the analog-to-digital converter of the venturi meter introduce errors in the flow measurement thus necessitating removal, cleaning, and recalibration of the flow device. Because of the desire to improve flow instrumentation uncertainty and to operate the plant closer to the licensed rating, the industry assessed alternate flow measurement techniques and found the UFM to be a viable alternative. The UFM is an electronic transducer that is controlled by computer and is not susceptible to fouling because it does not have differential pressure elements.

There are many ultrasonic techniques for measuring flow. The following four techniques are identified in NUREG/CR-5501, "Advanced Instrumentation and Maintenance Technologies for Nuclear Power Plants," (Reference 8) as major UFM types commonly used for industrial applications, including nuclear power plants.

- (1) Transit time (contrapropagation)
- (2) Doppler frequency
- (3) Vortex shedding
- (4) Cross-correlation (tag time-of-flight)

The installation of the first two UFM types (transit time and doppler frequency) is either intrusive or clamp-on while the third (vortex shedding) is only intrusive and the fourth (cross-correlation) is only clamp-on. (Clamp-on refers to the method of attaching ultrasonic transducers used in the flow measuring process by means of a clamp device mounted external to the pipe.) The transit time technology injects an ultrasonic signal diagonally through the fluid and then measures the difference in the time it takes the signal to travel upstream versus downstream. The difference in these times is proportional to the velocity of the fluid in the pipe. The cross- correlation technique measures the velocity of the fluid by determining the time taken by a unique pattern of eddies in the fluid to pass between two sets of transducers, each set at a certain known distance apart, injecting ultrasonic signals perpendicular to the pipe axis.

The cross-correlation UFM was first developed by the Canadian General Electric for Ontario Hydro. However, the system was not optimized for application over a wide range of flow velocities and pipe diameters. The task of optimizing the cross-correlation technique was carried out by the Advanced Measurement Analysis Group, Inc. (AMAG), and ABB CE. This work resulted in an improved cross-correlation flow meter called "Crossflow." These new flow meters have been installed to measure reactor coolant flow and steam generator feedwater flow in several nuclear power plants (more than 40 -plants) in the United States, Canada, South America, and Europe. However, licensees have not taken credit for the Crossflow UFM in regulatory applications.

### 3.0 EVALUATION

The ABB-CE topical report, CENPD-397-P, provided a detailed description of the cross-correlation theory, the Crossflow UFM system, instrumentation uncertainties, instrumentation testing and calibration, and field implementation of the UFM.

#### 3.1 Theory, Development, and Testing of the Crossflow UFM

Flow meters measure the velocity of the fluid flowing in the pipe. Also, the velocity profile of a fluid flowing through a pipe is dependent upon the inertial force of the fluid in the pipe and the fluid viscosity. The inertial force makes the fluid flow through the pipe, while the viscous force makes the flow slow down as the fluid passes over the pipe wall. The ratio between the inertial force and the viscous force is a dimensionless number called the Reynolds (Rd) number. Rd numbers greater than 4000 are generally accepted as being in the turbulent flow region (where eddies are formed). In the feedwater system of a typical nuclear power plant, Rd numbers are as high as approximately 30 million.

The operation of a cross-correlation UFM is based on the fact that when an ultrasonic beam travels across fluid flowing in a pipe, the ultrasonic beam is affected (modulated) by the turbulence (eddies) present in the flowing liquid. When this modulated signal is processed, a random signal, which is a signature of the flowing eddies, can be obtained. The cross-correlation meter measures the time a unique pattern of eddies takes to pass between two sets of ultrasonic transducers. The upstream transducer injects an ultrasonic signal perpendicular to the pipe axis. The eddies in the fluid modulate the ultrasonic signal, creating a phase shift, which is unique to the eddies passing through the ultrasonic signal at that moment. The same eddies pass through a second ultrasonic signal injected by the downstream transducer at a known distance from the upstream transducer. These eddies modulate the second ultrasonic signal in the same manner as they modulated the first (upstream) ultrasonic signal. Both modulated signals are then demodulated to obtain two wave forms that are the unique signatures of the eddies. The cross-correlation algorithm calculates the time the eddies took to pass the two signals by mathematically shifting the downstream signal wave from backwards in time to a point at which there is a maximum correlation between the two demodulated signals. The known distance between the two sets of transducers is then divided by the calculated time to obtain the flow velocity. This measured velocity is not an average velocity (highest velocity is at the center of the pipe) and must be multiplied by a factor called the velocity profile correction factor (VPCF) to obtain the average velocity of the fluid flowing in the pipe.

The topical report includes the AMAG-developed numerical techniques, algorithm, and formulae for calculating the time the eddies take to pass through the two ultrasonic signals and for finding the values of VPCF as a function of the Rd number with a fully developed turbulent flow in a straight pipe. The topical report also includes a VPCF versus Rd number curve developed for VPCF as a function of only Rd number. This curve assumed that the velocity profile is fully developed and that the pipe wall friction is small. Formulae and guidelines are provided for determining the additional correction factors to be applied to the VPCF for the piping configuration where the flow is not fully developed, such as downstream of an elbow. These formulae were used to calculate the VPCF for the entire spectrum of pipe Rd numbers in a typical nuclear power plant. The Crossflow UFM was calibrated at the Alden Research Laboratory (ARL) for Rd numbers ranging from 0.8 million to 7 million, using plastic pipe. This calibration involved using the theoretical VPCF and fitting it to ARL experimental data (weigh tank data) using statistical techniques. The ARL extrapolated the experimental data to the Rd numbers of up to 30 million and developed the VPCF versus the Rd number curve. A close agreement was found between the theoretical and experimental VPCF curves. The result of this comparison is included in the topical report, and the differences between the measured and the predicted VPCF are well within the uncertainty of the ARL weigh tank test accuracy of  $\pm 0.25$  percent with a repeatability uncertainty of  $\pm 0.1$  percent. Therefore, the calibrated VPCF accuracy is the same as the ARL weigh tank test VPCF accuracy, with a 95 percent confidence interval. The VPCF curve developed in the topical report assumes that the velocity profile is fully developed, and the curve compared favorably to experimental data from the tests using smooth pipe. The low pipe wall friction of smooth pipe, relative to the friction expected in a typical feedwater pipe of a nuclear power plant, provides a limiting condition that maximizes the velocity measured by the Crossflow UFM. This limiting condition provides confidence that the velocity measured by the UFM will be equal to or greater than the actual flow velocity.

In addition to the ARL tests, the Everest Laboratory (Chatou, France) conducted tests for Rd numbers 0.7 million to 1.3 million on the Crossflow UFM and showed the same values of

uncertainty and repeatability of the test results as those at the ARL (Reference 9). The National Institute of Standards and Technology conducted tests on six different UFM's from different developers, at an Rd number of 0.4 million, and found the Crossflow UFM to contain nearly zero errors (Reference 9). This information was provided to the staff by letter dated February 25, 1999, from ABB-CE.

Since the laboratory tests cannot create the Rd numbers normally present in a nuclear power plant, the AMAG collected Crossflow UFM feedwater flow measurement data from two operating nuclear power plants in the United States where the accuracy of the in-plant flow instrumentation was independently confirmed through weigh tank tests at ARL. Those data, which range up to a 25 million Rd number, were used to calculate the corresponding VPCF in the same way as was done for the ARL tests. These calculated VPCFs were found to compare with the ARL experimental VPCF curve. This comparison sufficiently demonstrates that the low Rd number calibration curve, which is extrapolated to the higher Rd numbers, can be used to determine the VPCFs for a nuclear power plant feedwater flow.

Based on its review of the theory and test data provided, the staff concludes that the Crossflow UFM approach is suitable for nuclear power plant applications.

### 3.2 System Components

The Crossflow UFM consists of four ultrasonic transducers (two transmitters and two receivers) mounted to a support frame (M/TSF), which is externally attached to the pipe in which the flow is to be measured. The ultrasonic transducers are connected to a signal conditioning unit (SCU) and a data processing computer (DPC). There are two transducer designs in use: one with the aluminum box-type M/TSF and the other with the carbon steel saddle-type M/TSF. The box-type M/TSF is field assembled and is no longer offered. Currently, the saddle-type M/TSF is used, in which the transducer holes are bored in one run on a computerized numerical control machine. This frame provides an exceptionally accurate alignment of the transducers, and no field adjustments are needed. The DPC, with its Crossflow software, performs digital signal processing on the demodulated ultrasonic signals and calculates the delay time for use in the flow calculation. The Crossflow software verification and validation are performed in accordance with the ABB-CE quality and implementing procedure manuals. To ensure the accuracy claimed for the Crossflow system, the report listed several techniques (proprietary) for verification and diagnostics. Verification is normally carried out at a predetermined periodic interval, and the diagnostics are performed if a system failure occurs. The report provided details of the system hardware, software, operation verification and diagnostics, and component classification (proprietary) to establish that the Crossflow UFM will perform its function as an in-plant instrument for updating the calibration of the feedwater venturi. The Crossflow hardware and software do not perform a safety function and are therefore classified non-safety-related. The topical report stated that the Crossflow software does not interact with the plant computer or with any safety-related systems, and the UFM hardware and software development, tests, and calculation data are maintained as quality records.

### 3.3 Flow Measurement Uncertainties

The topical report provided a methodology for determining measurement uncertainty of the Crossflow UFM. This methodology uses specific guidelines and equations for determining

uncertainty values of the Crossflow input parameters with a 95 percent confidence interval. The parameters that contribute to feedwater flow measurement uncertainty are pipe inside diameter, transducer spacing, feedwater density, Crossflow time delay, pipe wall roughness, and the VPCF. The topical report included typical uncertainties for each of the input parameters, except for the pipe wall roughness, and overall flow measurement uncertainty of the Crossflow UFM for a typical feedwater loop (straight pipe, fully developed flow). Actual uncertainties will be determined on a plant-specific basis by using the guidelines and equations provided in the topical report. Most of these uncertainties are affected by temperature change and, therefore, the topical report recommended improving the accuracy of the feedwater temperature instrumentation to reduce the total uncertainty of the feedwater flow measurement. The accuracy of the Crossflow time delay is confirmed monthly in the field for a specified acceptable value, and the power plant licensee is advised in the topical report to accurately measure the feedwater temperature. The methodology specified additional correction factors to be applied to the VPCF of a fully developed flow in a straight pipe when determining the VPCF for plant-specific conditions and pipe configuration.

As stated in the topical report, the Crossflow UFM and its associated hardware and software is able to achieve flow measurement uncertainty of 0.5 percent or better, with a 95 percent confidence interval for a fully developed flow. A staff review of the Crossflow UFM design and test results indicates that this meter can achieve the accuracy stated in the topical report when the plant-specific operating conditions and flow measurement uncertainty determination strictly follow the guidelines in the topical report. Ultrasonic flow meters have shown significant improvement in recent years, with calibration laboratory test results showing accuracies better than 0.2 percent of flow (straight pipe, fully developed flow) and commercially available systems claiming accuracies of better than 0.5 percent of flow (including Crossflow UFM).

### 3.4 Crossflow UFM Field Implementation

As described in the topical report, the Crossflow UFM is simple to install and operate. The installation of the UFM follows a standard procedure identified in the topical report. The installation procedure requires documentation of key installation/setup steps and important parameter values. The topical report stated that a trained representative from ABB-CE or AMAG will perform a pre-installation survey to identify the installation location on the basis of piping configuration and will also determine the pipe's outside diameter and pipe material. This information will be used to custom fabricate the transducer mounting hardware (M/TSF) for the specific feedwater pipe. Since the support frame is mounted externally on the pipe surface, the feedwater pressure boundary is not affected, and the installation and commissioning can be performed while the plant is in operation. Additionally, if the piping configuration is such that the velocity profile is not fully developed at the desired location for permanent installation of the UFM, a second UFM can be installed at a location where the velocity profile is fully developed and the second meter can be used to calibrate the permanent meter on-line at the desired location.

In addition to the guidelines outlined in Topical Report CENPD-397-P, the following criteria shall be addressed by licensees referencing this topical report in their request for license amendment:

- (1) The licensee should discuss the development of maintenance and calibration procedures that will be implemented with the Crossflow UFM installation. These procedures should include process and contingencies for an inoperable Crossflow UFM and the effect on thermal power measurement and plant operation.
- (2) For plants that currently have the Crossflow UFM installed, the licensee should provide an evaluation of the operational and maintenance history of the installed UFM and confirm that the instrumentation is representative of the Crossflow UFM and is bounded by the requirements set forth in Topical Report CENPD-397-P.
- (3) The licensee should confirm that the methodology used to calculate the uncertainty of the Crossflow UFM in comparison to the current feedwater flow instrumentation is based on accepted plant setpoint methodology (with regard to the development of instrument uncertainty). If an alternative methodology is used, the application should be justified and applied to both the venturi and the Crossflow UFM for comparison.
- (4) The licensee of a plant at which the installed Crossflow UFM was not calibrated to a site-specific piping configuration (flow profile and meter factors not representative of the plant-specific installation) should submit additional justification. This justification should show that the meter installation is either independent of the plant-specific flow profile for the stated accuracy, or that the installation can be shown to be equivalent to known calibration and plant configurations for the specific installation, including the propagation of flow profile effects at higher Reynolds numbers. Additionally, for previously installed and calibrated Crossflow UFM, the licensee should confirm that the plant-specific installation follows the guidelines in the Crossflow UFM topical report.

#### 4.0 CONCLUSION

On the basis of the staff's review of Topical Report CENPD-397-P, Revision 01 (Proprietary and Non-Proprietary), the staff concludes that the Crossflow UFM is designed and tested to achieve the flow measurement uncertainty of 0.5 percent or better, with a 95 percent confidence interval. This level of accuracy is achievable only when the plant-specific operating conditions and flow uncertainty parameters strictly follow the guidelines in the Crossflow UFM topical report. Additionally, the guidelines and the equations provided in the report were sufficiently clear for incorporating plant-specific pipe configurations and plant operating conditions in the flow measurement uncertainty calculations. The staff agrees with the statement in the topical report that the report is generically suitable for reference by utilities employing the Crossflow UFM to pursue plant operation at a higher power level, within the limitations of the license.

#### 5.0 REFERENCES

1. ABB-CE Topical Report CENPD-397-P, Revision 00, "Improved Flow Measurement Accuracy Using Crossflow Ultrasonic Flow Measurement Technology," dated August 1999, transmitted to NRC by Ian C. Rickard (ABB-CE) letter dated August 23, 1999.
2. J. Cushing (NRC) letter to I. C. Rickard (ABB-CE), dated November 19, 1999, "Request for Additional Information (RAI) on Topical Report CENP-397P, Revision 00."

3. Ian C. Rickard (ABB-CE) letter to NRC, dated December 17, 1999, "Response to NRC RAI on Topical Report CENPD-397P, Revision 00."
4. ABB-CE Topical Report CENPD-397-P, Revision 01, "Improved Flow Measurement Accuracy Using Crossflow Ultrasonic Flow Measurement Technology," dated January 2000, transmitted to NRC by Ian C. Rickard (ABB-CE) letter dated January 6, 2000.
5. ABB-CE Topical Report CENPD-397-P, Revision 01, "Supplemental Information," transmitted to NRC by Ian C. Rickard (ABB-CE) letter dated January 25, 2000.
6. Ian C. Rickard (ABB-CE) letter to NRC, "Response to Verbal Request For Additional Information," dated March 8, 2000.
7. Ian C. Rickard (ABB-CE) letter to NRC, "General Response to Public Meeting Regarding Caldon, Inc. Ultrasonic Flow Measurement Representation of Cross-Correlation Flowmeters Technology," March 13, 2000.
8. NUREG/CR-5501, "Advanced Instrumentation and Maintenance Technologies for Nuclear Power Plants," dated July 1998.
9. Ian C. Rickard (ABB-CE) letter to NRC, "Non-Proprietary Meeting Presentation Material," dated February 25, 1999.

Principle Contributors: Iqbal Ahmed  
Joseph Donoghue

Date: March 20, 2000

# CE NUCLEAR POWER LLC

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## ABSTRACT

The CROSSFLOW Ultrasonic Flow Measurement (UFM) System, developed by the Advance Measurement and Analysis Group (AMAG) of Mississauga, Ontario, is being marketed to nuclear power plants worldwide in conjunction with CE Nuclear Power LLC (CENP) of Windsor, CT. The CROSSFLOW UFM System provides a means for plant operators to recover power, currently lost to electric output, by increasing feedwater flow measurement accuracy. CROSSFLOW consists of four (4) ultrasonic transducers mounted on a metal support frame that attaches, externally, to the feedwater piping (or any pipe in which the flow rate is to be measured). The ultrasonic transducers are connected to a Signal Conditioning Unit (SCU) and a Data Processing Computer (DPC). A Multiplexer (MUX) is also available for automatically sequencing measurements on multiple channels. There is one (1) upstream and one (1) downstream transducer station, each station consisting of one (1) transmitting and one (1) receiving transducer which send out the turbulence signatures to the DPC through the demodulating and filtering stages of the SCU. Signatures from the upstream and downstream transducer stations are compared, using the cross-correlation mathematical technique imbedded in proprietary CROSSFLOW software, to obtain a highly accurate feedwater flow rate measurement. A unique advantage of the CROSSFLOW UFM System is that it does not require any intrusion into plant piping and, consequently, cannot compromise pressure boundary integrity. Additionally, maintenance and/or system trouble shooting, if necessary, are also simplified by not requiring any repeated pipe boundary intrusion protocols. The entire CROSSFLOW system is external to the pipe in which flow is to be measured; penetrating pressure boundary piping is unnecessary.

CENPD-397-P provides information on the CROSSFLOW UFM System design, its underlying principles of ultrasonic measurement, experimental data validating system accuracy and an overview of installation, proprietary software and setup procedures. The combined effect of these elements is to provide an improvement in flow measurement accuracy over current flow measurement systems. This increased flow measurement accuracy can be translated into a like improvement in the accuracy of the core power level calculation, due to the use of a more accurate feedwater flow in the calorimetric (PWR terminology)/heat balance (BWR terminology) calculation. The measurement uncertainty reduction allows a Utility to:

- 1) Operate the plant at a higher power level without exceeding the 10 CFR 50, Appendix K mandated 102% power margin (attributed to instrument uncertainty).
- 2) To apply the reduced uncertainty to overall margin improvement.
- 3) Recovery of lost generating capacity due to feedwater venturi fouling while staying within the plant's licensed operating power level.
- 4) Possess an in-plant capability for periodically recalibrate the feedwater venturi flow coefficient to adjust for the adverse effect of fouling.

CENPD-397-P does not, however, address the pertinent information for justifying either a higher power level or margin improvement (Items 1 and 2 above). This justification must be provided on a plant specific basis depending upon the application to which individual licensees decide to apply CROSSFLOW's improved flow measurement accuracy. CROSSFLOW can be used in various applications as determined by the Utility. Of the various applications to which CROSSFLOW can be applied, only the justification of operation at a power level that would exceed the Utility's current licensed power level requires prior interaction with the Nuclear Regulatory Commission (NRC).

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## LIST OF ACRONYMS

|       |  |
|-------|--|
| AMAG  | Advance Measurement and Analysis Group         |
| CENP  | CE Nuclear Power LLC                           |
| ANSI  | American National Standards Institute          |
| ARL   | Alden Research Laboratory                      |
| ASME  | American Society of Mechanical Engineers       |
| BNC   | Bayonet N-Type Compact                         |
| BWR   | Boiling Water Reactor                          |
| CFR   | Code of Federal Regulations                    |
| CNC   | Computerized Numerical Control                 |
| COAX  | Coaxial Cabling                                |
| DPC   | Data Processing Computer                       |
| ECCS  | Emergency Core Cooling System                  |
| EIA   | Environmental Information Association          |
| FSAR  | Final Safety Analysis Report                   |
| LMIE  | Liquid Metal Induced Embrittlement             |
| LSSS  | Limiting Safety System Setting                 |
| M/TSF | Mounting/Transducer Support Frame              |
| MUX   | Multiplexer                                    |
| NIST  | National Institute of Standards and Technology |
| NRC   | Nuclear Regulatory Commission                  |
| NSSS  | Nuclear Steam Supply System                    |
| OH    | Ontario Hydro                                  |
| OL    | Operating License                              |
| PWR   | Pressurized Water Reactor                      |
| RCS   | Reactor Coolant System                         |
| Re    | Reynolds Number                                |
| RG    | Regulatory Guide                               |
| RSSI  | Received Signal Strength Indicator             |
| SCU   | Signal Conditioning Unit                       |
| SMIE  | Solid Metal Induced Embrittlement              |
| SRSS  | Square Root Sum of the Square Method           |
| UFSAR | Updated Final Safety Analysis Report           |
| VPCF  | Velocity Profile Correction Factor             |

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## IMPROVED FLOW MEASUREMENT ACCURACY USING CROSSFLOW ULTRASONIC FLOW MEASUREMENT TECHNOLOGY

### 1.0 INTRODUCTION

The CROSSFLOW Ultrasonic Flow Measurement (UFM) System is a joint venture of the Advanced Measurement and Analysis Group (AMAG) of Mississauga, Ontario and CE Nuclear Power LLC (CENP) of Windsor, CT. Currently, the CROSSFLOW UFM System provides a means for nuclear power plant operators to recover lost electrical generation capacity resulting from venturi fouling. This lost power recovery is accomplished within a plant's current licensed power level and has become feasible because of CROSSFLOW's ability to perform a feedwater flow venturi recalibration to remove the adverse effects of fouling.

CROSSFLOW has been in operation in Canada since 1987 and at this writing has been used in tests or installed for continuous monitoring at over 40 commercial nuclear power reactors in the United States, Canada, South America and Europe over the last ten (10) years. Some utilities have reported a recovery of electrical generating capacity of ~20 MWe or more that would have otherwise been lost due to venturi fouling. Consequently, CROSSFLOW offers utilities a significant operational cost benefit.

Comparisons have been made with plant flow instrumentation, which demonstrate stable CROSSFLOW system performance and accuracy. Further confidence in CROSSFLOW's accuracy has been gained through comparisons with recently calibrated plant instrumentation and chemical tracers. In each case, these independent measurements have actually demonstrated a repeatable accuracy of [        ].

### 1.1 GENERAL DESCRIPTION

CROSSFLOW consists of four (4) ultrasonic transducers mounted on a metal support frame that attaches, externally, to the feedwater piping (or any pipe in which the flow rate is to be measured). The ultrasonic transducers are connected to a Signal Conditioning Unit (SCU) and a Data Processing Computer (DPC). A Multiplexer (MUX) is also available for automatically sequencing measurements on multiple channels. There is one (1) upstream and one (1) downstream transducer station, each station consisting of one (1) transmitting and one (1) receiving transducer which send out the turbulence signatures to the DPC through the demodulating and filtering stages of the SCU. Signatures from the upstream and downstream transducer stations are compared, using the cross-correlation mathematical technique imbedded in proprietary CROSSFLOW software, to obtain a highly accurate feedwater flow rate measurement. A unique advantage of the CROSSFLOW UFM System is that it does not require any intrusion into plant piping and, consequently, cannot compromise pressure boundary integrity. Additionally, maintenance and/or system trouble shooting, if necessary, are also simplified by not requiring any repeated pipe boundary intrusion protocols. The entire CROSSFLOW system is external to the pipe in which flow is to be measured; penetrating pressure boundary piping is unnecessary.

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CENPD-397-P provides information on the CROSSFLOW UFM System design, its underlying principles of ultrasonic measurement, experimental data validating system accuracy and an overview of installation, proprietary software and setup procedures. All modes of CROSSFLOW application take advantage of the increased flow measurement accuracy achieved. The combined effect of these elements is to provide an improvement in flow measurement accuracy over current flow measurement systems (e.g., a venturi). This increased flow measurement accuracy can be translated into a like improvement in the accuracy of the core thermal power level calculation, due to the use of a more accurate feedwater flow in the calorimetric (PWR terminology)/heat balance (BWR terminology) calculation. The measurement uncertainty reduction allows a Utility to:

- 1) Use of the increased accuracy to support a license amendment justifying operation at a higher power level (~1%) by requesting a like reduction in the 10 CFR 50, Appendix K mandated 2% instrument uncertainty margin applied to power level.
- 2) Apply the reduced uncertainty to overall margin improvement.
- 3) Recover lost generating capacity due to feedwater venturi fouling while staying within the plant's licensed operating power level.
- 4) Possess an in-plant capability for periodically re-calibrating the feedwater venturi to adjust for the effect of fouling; thereby, allowing recovery of lost generating capacity while staying within a facility's licensed power level.

To take advantage of operation at a higher power level, based on relief from certain aspects of 10 CFR 50, Appendix K<sup>1</sup>, Nuclear Regulatory Commission (NRC) interaction in the form of review and approval of a license amendment would be necessary. It is to this application (Item 1 above) that CENPD-397-P is focused. In this regard, CENPD-397-P does not provide the pertinent plant specific information justifying operation at a higher power level. Rather, that justification must be provided by the Utility, on a plant specific basis, depending upon the application to which the Utility decides to utilize the CROSSFLOW UFM System. Instead, CENPD-397-P only addresses, and seeks NRC acceptance of, the increased flow measurement accuracy achieved using the CROSSFLOW UFM System and which are generically applicable to any Utility.

## 1.2 COMPARISON OF CROSS-CORRELATION AND TRANSIT TIME TECHNOLOGIES

Referring to Figure 1-1, the basic difference between the cross-correlation and transit time technologies, is the way that each of these meters measures the velocity of the fluid within the pipe. The transit time technology injects an ultrasonic signal diagonally through the fluid and then measures the difference in the time that it takes the signal to travel upstream versus downstream. It can then be shown that the difference in these times is proportional to the velocity of the fluid in the pipe.

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<sup>1</sup> An exemption to 10 CFR 50, Appendix K will only be necessary until the NRC completes the rulemaking process which is geared toward recognizing the substantial improvement in instrumentation measurement technology and, therefore, the consequential justification for decreasing the currently mandated 2% instrument uncertainty factor applied to power level.

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The fluid flowing within the pipe causes the difference in the upstream and downstream times. When injecting a signal downstream and diagonally across the pipe, the velocity vector of the fluid in the plane of the ultrasonic signal adds to the acoustical velocity of the fluid. Consequently, the velocity of the ultrasonic signal going downstream is slightly faster than the acoustical velocity of the fluid. When the process is reversed and the ultrasonic signal is injected upstream and diagonally across the pipe, the velocity vector of the fluid in the plane of the ultrasonic signal now subtracts from the acoustical velocity. This results in an ultrasonic velocity that is slightly less than the acoustical velocity of the fluid. The difference in these times is on the order of a few microseconds.

The two equations that describe the time for the ultrasonic signal to travel upstream and downstream can be written as:

$$t_u = L_t/[a - V \cos(\alpha)] \quad \text{Eq. 1-1}$$

$$t_d = L_t/[a + V \cos(\alpha)] \quad \text{Eq. 1-2}$$

where:  $t_u$  is the time that it takes for the ultrasonic signal to travel upstream through the fluid. If the transducers are mounted on the outside of the pipe, the measured time delays must be corrected for the time that it takes the ultrasonic signal to travel through the walls of the pipe.

$t_d$  is the time that it takes for the ultrasonic signal to travel downstream. This signal must also be corrected for transport time through the pipe walls, if the transducers are mounted on the outside of the pipe.

$L_t$  is the diagonal distance that the ultrasonic signal must travel through the fluid when using the transit time technology.

$a$  is the acoustical velocity of the ultrasonic signal in the fluid

$V$  is the velocity of the fluid in the pipe

$\alpha$  is the angle that the diagonal signal makes with the axis of the pipe

Equations 1-1 and 1-2 can be combined to obtain an expression for the velocity of the fluid in the pipe as a function of these parameters:

$$V = a^2(t_u - t_d)/2L_t \cos(\alpha) \quad \text{Eq. 1-3}$$

The cross-correlation meter measures the velocity of the fluid by determining the time that it takes for a unique pattern of eddies to pass between two sets of transducers. When using this meter to measure the velocity, an ultrasonic beam is injected perpendicular to the axis of the pipe rather than diagonally as is required for the transit time meter. As the ultrasonic signal passes through the fluid, the eddies within the fluid modulate the ultrasonic signal, creating a phase shift, which is unique to the eddies passing through the ultrasonic beam at that moment in time. These same eddies then pass through a second ultrasonic beam that is located a known distance downstream of the first beam. Once again these eddies modulate the second ultrasonic beam in the same manner as they did the first beam. The only difference between the two modulated signals is the difference in the time that it took for the eddies to pass between the two ultrasonic beams.

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Both modulated beams are demodulated, by removing the high frequency carrier signal, leaving two wave forms that are unique signatures of the eddies passing through the beams. The cross-correlation process mathematically calculates the difference in the time that it took for the eddies to pass between the two beams by mathematically shifting the downstream signature backwards in time to a point where there is maximum correlation between the two demodulated signals. Knowing this time, which is referred to as the delay time and the physical distance between the two ultrasonic beams, allows one to calculate the velocity of the fluid by dividing the distance by the delay time. The magnitude of the delay time is on the order of 50 milliseconds. The equation for the fluid velocity, when using the cross-correlation technology becomes:

$$V = L_{c-c} / \tau \quad \text{Eq. 1-4}$$

where:  $V$  is the velocity of the fluid  
 $L_{c-c}$  is the physical distance between the two ultrasonic beams  
 $\tau$  is the time that it takes for the eddies to pass between the two ultrasonic beams

## 1.3 REASON FOR SELECTING THE CROSS-CORRELATION TECHNOLOGY

The cross-correlation technology offers several distinct advantages over conventional venturis for feedwater flow measurements that are to be used for secondary heat balance calculations. Since the system mounts on the outside of the feedwater pipe, it is not subject to the build-up of corrosion products as is common with venturis. Because the venturi throat sensing port is exposed to the flow, corrosion products can form upstream of the port altering the boundary layer, which in turn reduces the differential pressure being monitored by the differential pressure transmitter.

The differential pressure can also be affected when the sensing tube that goes from the throat of the venturi to the outside of the feedwater pipe has also been known to crack. When this occurs, the fluid from the stagnate pressure region between the venturi and the surface of the pipe flows into the sensing tube, lowering the differential pressure.

The upstream sensing port can also be affected by erosion of the carbon steel piping around the sensing port boss. When this occurs, the port sees a lower dynamic rather than a static pressure. When this occurs, the differential pressure is reduced, giving a non-conservative lower flow readings.

Each of these mechanical problems is avoided with the cross-correlation meter, since it does not rely on a differential pressure to measure flow. Moreover, the cross-correlation meter would actually act to correct these problems, thus preventing either an underpower or overpower conditions because of one of these failures.

In addition to avoiding the mechanical problems noted above, the cross-correlation meter is much less sensitive to electronic drift. A conventional venturi uses both a differential transmitter and analogue to digital converters that introduce error in to the flow measurement. Moreover, unlike venturis, electronic checks can be activated on-line to confirm that both the electronics and transducers are operating as designed.

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## 1.4 CROSSFLOW INSTALLATION AND OPERATING FEATURES

The CROSSFLOW UFM System offers features that are beneficial during both system installation and operation. Although CROSSFLOW does not replace the plant venturisi, it offers significant advantages over the venturisi in its ability to precisely measure feedwater flow. The uncertainties associated with venturisi accuracy such as fouling, instrumentation drift and calibration are essentially eliminated for the CROSSFLOW UFM System. Therefore, the uncertainty of the flow measurement can be reduced from well over 1%, in many cases, to 0.5% or less, depending on the specific plant installation.

Some of CROSSFLOW's more significant features are summarized below.

### 1.4.1 EXTERNALLY MOUNTED

The CROSSFLOW UFM System externally attached Mounting/Transducer Support Frame (M/TSF) offers significant flexibility in both the timing and ease of installation. Since the M/TSF is mounted externally on the surface of the pipe, it is not necessary to cut into the pressure boundary to install a spool piece. This one feature precludes the necessity of scheduling the installation during a plant outage. Rather, installation and commissioning can be performed while the plant is on-line (only installations in a high radiation area would preclude an on-line installation). This has the additional advantage of allowing work to be done when plant staff is less likely to be distracted by other pressing needs due to typically tight outage schedules.

### 1.4.2 INSTALLATION LOCATION FLEXIBILITY

Another unique feature of the CROSSFLOW UFM System that has become apparent is the ability to calibrate the meter where the velocity profile may not be fully developed. For example, it is possible to encounter a piping configuration where the upstream flow conditions prevent the flow from being fully developed at the desired installation location. However, flow conditions may be fully developed at a location further upstream or downstream of the desired installation point. Because of the ease with which the CROSSFLOW meter can be installed, it is possible to install a second meter at one of these locations and calibrate the permanent meter on-line; at the desired installation location. This has a distinct advantage, in that the meter is calibrated at full power under actual operating conditions, thus eliminating the need to perform model tests.

### 1.4.3 VELOCITY PROFILE CORRECTION FACTOR ALGORITHM

Perhaps the most important feature of the CROSSFLOW UFM System is the algorithm used to calculate the Velocity Profile Correction Factor (VPCF). The theoretical bases for this equation which, for fully developed flow, is only a function of Reynolds Number is discussed in Section 2.0 of this report. Section 4.0 discusses how the algorithm was verified at a national hydraulics laboratory. It is shown through multiple weigh tank and limited in-plant tests, where the accuracy of the in-plant instrumentation had recently been verified, that this simple algorithm accurately predicts the changes in the VPCF for Reynolds Numbers ranging from below  $<1 \times 10^6$  to  $\sim 25 \times 10^6$ . Furthermore, it is shown that the equations that form the bases for this algorithm can be traced to classical hydraulics

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that have withstood the test of time through many years of laboratory and field verifications.

## 1.4.4 STATISTICALLY ROBUST FLOW MEASUREMENTS

Another feature of the CROSSFLOW UFM System that contributes to its accuracy and repeatability is the statistically robust nature in which it achieves the flow measurements. Unlike other algorithms that rely on a time-of-flight principle of one or more ultrasonic beams, the CROSSFLOW meter tracks thousands of eddies within the fluid, with each eddy imparting its own distinct time to the determination of the velocity of the fluid. With this large amount of data and the ability to conduct these measurements in millisecond rather than nanoseconds, the reliability and repeatability of the meter is greatly improved.

## 1.4.5 TRANSDUCER ORIENTATION

Repeatability is also enhanced by the simple perpendicular orientation of the ultrasonic transducers to the flow stream. Because of the perpendicular orientation, errors due path length and path angle, which must be dealt with when using the transit time technology, are eliminated along with their associated uncertainties when using cross-correlation technology.

## 1.5 CROSSFLOW UFM SYSTEM ACCURACY

Based on the above features (and others discussed later), the CROSSFLOW UFM System is able to achieve an accuracy of 0.5% or better with a 95% confidence interval. When credit is taken for this feedwater flow measurement accuracy in a plant's thermal power calculation, it can easily be shown that the uncertainty of the calculation falls well below 1% with a 95% confidence interval. Thus, a utility is presented with the opportunity to take advantage of a power uprate to increase the electrical output of their plant, yet still remain bounded by the existing Appendix K ECCS analyses.

## 1.6 REASON FOR TOPICAL REPORT

The purpose of CENPD-397-P is to provide a source for a CROSSFLOW UFM System description and justification of improved measurement accuracy, suitable for reference (i.e., the generic elements) by Utilities employing the CROSSFLOW UFM System to pursue operation at a higher power level; based on the improved flow measurement accuracy achieved. In so doing, the resources of the Utility, AMAG, CENP and the NRC are conserved by providing a one time review and approval for the generically applicable elements of the CROSSFLOW UFM System. Each Utility should, therefore, only have to provide the plant specific implementation information and safety analysis considerations on their docket via a 10 CFR 50.90 license amendment; along with an exemption request to 10 CFR 50, Appendix K and a reference to the NRC approved version (i.e., "-A") of CENPD-397-P.

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## 1.6.1 TOPICAL REPORT ORGANIZATION

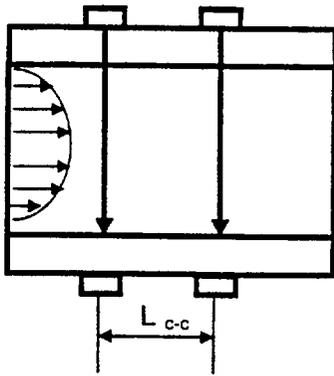
The information contained in CENPD-397-P is presented in a manner that takes the reader through the following report sections:

1. Introduction
2. Theory of CROSSFLOW Ultrasonic Flow Measurement
3. CROSSFLOW System Description
  - Hardware
  - Software
4. CROSSFLOW Calibration and Validation
5. Determination of Feedwater Flow and Flow Uncertainty
6. CROSSFLOW Materials Considerations
7. CROSSFLOW Reliability
8. CROSSFLOW Field Implementation

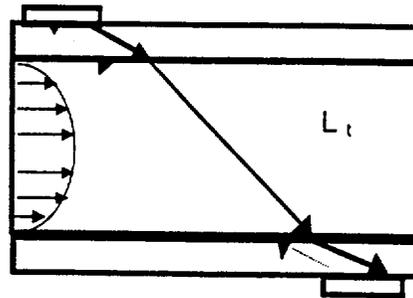
References are provided at the end of each section, as appropriate.

**FIGURE 1-1**

**COMPARISON OF CROSS-CORRELATION AND TRANSIT TIME TECHNOLOGIES**



**Cross-Correlation Meter**



**Transit Time Meter**

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## 2.0 THEORY OF CROSSFLOW ULTRASONIC FLOW MEASUREMENT

Starting from first principles, this section develops the equations that are used by the CROSSFLOW meter to measure flow in a pipe.

### 2.1 THE FLOW EQUATION

Flow in a pipe is defined by the equation:

$$W = \rho A V_a \quad \text{Eq. 2-1}$$

where:  $W$  is the mass flowrate  
 $\rho$  is the density of the fluid  
 $A$  is the cross-sectional flow area  
 $V_a$  is the average velocity of the fluid in the pipe

A cross-correlation meter measures the time that it takes for eddies within the fluid to pass between two ultrasonic beams that are perpendicular to the axis of the pipe (and, therefore, the flowstream). Knowing the physical distance between these two beams, the velocity of eddies can be calculated and hence, the velocity of the fluid that contains them.

$$V_m = L/\tau \quad \text{Eq. 2-2}$$

where:  $V_m$  is the velocity of the eddies in the fluid that are tracked by the cross-correlation meter  
 $L$  is physical distance between the two ultrasonic beams  
 $\tau$  is the time that it takes for the eddies to pass between the two beams

This velocity,  $V_m$ , is not the average velocity,  $V_a$ , of the fluid. Hence, the measured velocity  $V_m$  must be multiplied by a velocity profile correction factor,  $C_0$ , to obtain the average velocity of the fluid in the pipe.

$$V_a = C_0 V_m = C_0 (L/\tau) \quad \text{Eq. 2-3}$$

Substituting Equation 2-3 into Equation 2-1 gives the flow equation for the cross-correlation meter.

$$W = C_0 \rho A L / \tau \quad \text{Eq. 2-4}$$

### 2.2 CROSS-CORRELATION TECHNIQUE

A cross-correlation meter measures  $\tau$ , the time that it takes for eddies to pass between two ultrasonic beams that are directed through the flowing fluid perpendicular to the axis of the pipe.

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## 2.2.1 EFFECT OF TURBULENCE ON AN ULTRASONIC SIGNAL

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## 2.2.2 MATHEMATICAL FORMULATION OF CROSS-CORRELATION

Cross-correlation is a mathematical process for determining the displacement in time between similar curves. In the case of CROSSFLOW, this is the time for the eddies to pass between the two sets of transducers.

In general, the cross-correlation of two functions is defined according to the following equation:

$$R_{AB}(y) = \int_{-\infty}^{\infty} A(x)B(x+y)dx \quad \text{Eq. 2-5}$$

If the two functions represent time-dependent properties  $A(t)$  and  $B(t+\tau)$  at time  $t$  and  $t+\tau$ , respectively, then the cross-correlation function will also be time-dependent and can be written as:

$$R_{AB}(\tau) = \frac{1}{T} \int_0^T A(t)B(t+\tau)dt \quad \text{Eq. 2-6}$$

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Equation 2-6 is the cross-correlation function, which measures the degree of correlation between the two functions,  $A(t)$  and  $B(t)$  provided that each of the signals are random with a mean value equal to zero. Hence, if  $A(t)$  and  $B(t)$  are not correlated, the product of any two points on the curves  $A(t)$  and  $B(t)$  at some time  $t$  have an equal probability of being either positive or negative. Thus, the average of all these products,  $R_{AB}(\tau)$ , over the time interval  $T$  would be approximately equal to zero indicating no correlation.

However, if signals  $A(t)$  and  $B(t)$  are correlated, when  $A(t)$  is positive,  $B(t)$  is also positive and the product of  $A(t) B(t)$  is positive. Furthermore, if  $A(t)$  is negative,  $B(t)$  would also be negative and the product  $A(t) B(t)$  would again be positive. Thus, the function,  $R_{AB}(\tau)$ , over the time interval  $T$  would be positive indicating a correlation exists between the two signals.

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Now, if signals  $A(t)$  and  $B(t)$  are correlated but displaced in time by  $\tau$ , the function,  $R_{AB}(\tau)$ , will reach a maximum value when  $B(t)$  is shifted by the time that it takes for the eddies to traverse the distance,  $L$  between the two ultrasonic beams. Knowing this time,  $\tau$ , which produces a maximum value for the function  $R_{AB}(\tau)$  and the distance between the beams, one can then calculate the velocity of the eddies and, hence, the velocity of the fluid,  $V_m$  at the location in the velocity profile, where a correlation exists between the signals.

$$V_m = L/\tau$$

Eq. 2-7

## 2.2.3 NUMERICAL TECHNIQUE

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## 2.2.4 FLOW TRAVEL TIME DETERMINATION

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## 2.3 VELOCITY PROFILE CORRECTION FACTOR FOR A SMOOTH PIPE

The velocity profile correction factor (VPCF),  $C_0$ , is defined as the ratio of the average velocity of the fluid in the pipe,  $V_a$ , divided by the velocity of the fluid measured by the cross-correlation meter,  $V_m$ .

$$C_0 = V_a / V_m \quad \text{Eq. 2-11}$$

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Eq. 2-17

This equation is plotted in Figure 2-2 as a function of Reynolds Number using Equations 2-14 and 2-13. Experimental data, which was obtained from laboratory tests and plants where the venturi readings were known to be correct have also been entered on the same plot. In order to plot the experimental data points on Figure 2-2, the VPCF,  $C_o$ , was calculated for each data point using the following equation:

$$C_o = \frac{Q_{measured}}{Q_{CROSSFLOW}} \quad \text{Eq. 2-18}$$

where:  $Q_{measured}$  is the volumetric flow measured by the weigh tank or plant venturi  
 $Q_{CROSSFLOW}$  is the corresponding volumetric flow measured by the meter without the velocity profile correction factor.  $Q_{CROSSFLOW}$  is defined as:

$$Q_{CROSSFLOW} = A L / \tau \quad \text{Eq. 2-19}$$

where: A is the flow area  
L is the spacing between the ultrasonic beam  
 $\tau$  is the time that it takes for the eddies to pass between the ultrasonic beams

The close agreement between Equation 2-17 and the experimental data over a wide range of Reynolds Numbers provides confidence that the bases for the theoretical equation is well founded.

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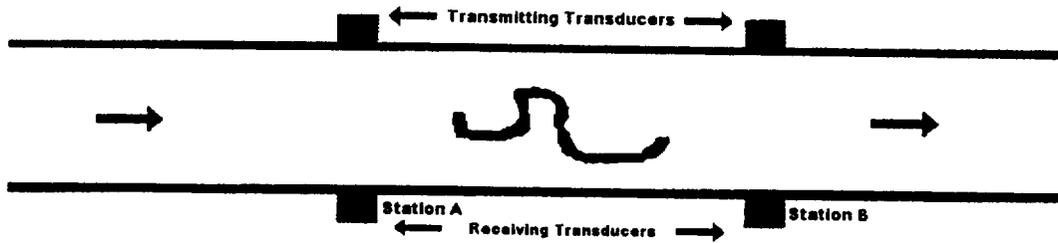
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## 2.4 REFERENCES

- 2-1 H. Schlichting, "Boundary-Layer Theory", McGraw-Hill Book Company, 6<sup>th</sup> Edition
- 2-2 Proceedings of The 9<sup>th</sup> International Conference on Flow Measurement, FLOMECO'98. Edited by Jerker Delsing, June 15-17, 1998, Lund, Sweden

**FIGURE 2-1**

**SCHEMATIC OF CROSSFLOW MEASUREMENT ARRANGEMENT**



**FIGURE 2-2**

**VALIDATION OF THE THEORETICAL FUNCTION**



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## 3.0 CROSSFLOW SYSTEM DESCRIPTION

CROSSFLOW consists of the following principal components:

1. Mounting/Transducer Support Frame (M/TSF); which is externally attached to the pipe in which the flow is to be measured
2. Four (4) Ultrasonic Transducers; two transmitters & two receivers
3. Signal Conditioning Unit (SCU)
4. Multiplexer (MUX) (optional)
5. Coaxial Cabling (COAX)
6. Data Processing Computer (DPC)
7. CROSSFLOW Software

There two (2) ultrasonic transducer (UT) stations; one (1) upstream and one (1) downstream that are generally denoted as A and B in CENPD-397-P, respectively. Each station consists of a transmitting and receiving transducer pair, mounted on a support frame, which send and receive the acoustic signals, across the pipe diameter. The SCU generates the high frequency voltage that is fed to the transmitting transducers and receives the carrier wave signal that is generated by the receiving transducers. It then extracts the turbulence modulations from the carrier wave and passes them to the DPC and its resident CROSSFLOW software. The software determines the pipe flow rate using built-in signal processing algorithms. The following sections discuss each of these CROSSFLOW components. In the CROSSFLOW software description, the online and off-line diagnostics and system functional verification are addressed.

## 3.1 CROSSFLOW HARDWARE

Figure 3-1 is a schematic of the current CROSSFLOW system hardware components. The following subsections describe these hardware components.

### 3.1.1 MOUNTING/TRANSDUCER SUPPORT FRAME

There are two (2) Mounting/Transducer Support Frame (M/TSF) designs. The old frame design is a box-type structure made of aluminum bar stock (see Figure 3-2). This early frame design is no longer offered. The current frame design, and the one used at almost all plants today, is a saddle-type structure made of carbon steel bar stock (see Figure 3-3). This frame design is now standard for all CROSSFLOW systems. Each of these M/TSF designs accommodates four (4) transducers; one (1) transmitting and one (1) receiving at each of two (2) transducer mounting stations as described above.

#### 3.1.1.1 Box-Type Support Frame Design

The box-type M/TSF design, shown in Figure 3-2, is field assembled for the pipe on which it is to be mounted. The frame sub-components (i.e., the aluminum bar stock) are bolted together in order to make up the completed frame assembly. The four (4) [ ] bodied transducers screw directly into their respective locations on the M/TSF. The transducers interface with the pipe surface via an elastomeric couplant. The M/TSF was

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made from anodized aluminum and its four connecting bars maintain the spacing between the transducers. [

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## 3.1.1.2 Saddle-Type Support Frame Design

The saddle-type M/TSF design, shown in Figure 3-3, is shop fabricated for the pipe on which it is to be mounted. The frame sub-components (i.e., the carbon steel bar stock) are welded together in order to make up each half of the complete frame assembly. These are then precision machined to the finished dimensions. The two halves of the frame assembly are bolted together to complete the mounting assembly. Four (4) [ ] bodied transducers bolt into a mounting fixture that is an integral part of the frame assembly. The transducers interface with the pipe through a [ ] over the ultrasonic crystal.

## 3.1.2 ULTRASONIC TRANSDUCER

Like the M/TSF, the ultrasonic transducers have evolved from their early design to the current design. As with the M/TSF, the evolving designs were primarily driven by improvements to installation, reliability, longevity and maintenance flexibility rather than by a technological need for a transducer flow measurement performance improvement. Today there are just two transducer designs in use; specifically, generations 3 and 4 listed below. One of these transducer designs is used with the aluminum box-type M/TSF, the other with the carbon steel saddle-type M/TSF. For the sake of comprehensiveness, the complete transducer design evolution is described below.

Four (4) generations of CROSSFLOW transducers can be identified:

1. Original Ontario Hydro Transducer - This transducer is included only for completeness, it has not been used on any CROSSFLOW systems.
2. Original CROSSFLOW Transducer - Used in combination with aluminum M/TSFs
3. No-twist Transducer - Used in combination with aluminum M/TSFs.
4. Permanent Transducer - Used in combination with saddle-type M/TSFs.

A brief description of each of these transducer designs follows.

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3.1.2.2 [

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3.1.2.3 [

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3.1.2.4 [

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## 3.1.3 INFLUENCE OF TRANSDUCER DESIGN ON CROSSFLOW PERFORMANCE

This section discusses the potential influence of variations in the transducer design evolution on CROSSFLOW performance.

### 3.1.3.1 Transducer Frequency

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### 3.1.3.2 Transducer Diameter and Acoustic Field

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## 3.1.3.3 Acoustic Couplant

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3.1.3.4 Mounting/Transducer Support Frame (M/TSF)

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5. Transducer alignment is important in achieving two well-defined ultrasonic beams inside the pipe. Since both transducer holes on each side of the saddle-type

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M/TSF are bored in one run on a computerized numerical control (CNC) machine tool and no further adjustments are made during installation, this frame delivers exceptional transducer alignment as manufactured. Although the box-type M/TSF is assembled during installation at the site, proper alignment is still assured since all M/TSF components are CNC machined.

## 3.1.3.5 Installation Location

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## 3.1.4 SIGNAL CONDITIONING UNIT

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### 3.1.4.1 Transmitter Circuit

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3.1.4.2 Receiver Circuit

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## 3.1.4.3 Digital Bus

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## 3.1.4.4 Test Signal Modulator Circuit

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## 3.1.5 CABLES

The are two (2) principal types of cable used for signal interconnection in the CROSSFLOW system. The ultrasonic transmission signal cables and data communication/control cables.

The standard cables used for ultrasonic transmission system are coaxial cables (COAX). These cables are high bandwidth, low loss, with good electromagnetic interference (EMI) shielding which are suitable for transmitting the ultrasonic signal of the CROSSFLOW

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system. These standard coaxial cables, which are used for permanent installations, satisfy IEEE 383, or equivalent, flame test requirements. Optionally, custom-made fiberglass coaxial cable for use in high temperature applications is also available.

The data communication and control cables for signal and data interfacing between various electronic components in the CROSSFLOW system are standard data transmission cables. These cables allow high data throughput and low interference for data transmission.

Additionally, the cables used in the CROSSFLOW system not only optimize the signal transmission but also ensure that the delay in the cable is negligible. [

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## 3.1.6 DATA PROCESSING COMPUTER

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## 3.2 CROSSFLOW SOFTWARE

The CROSSFLOW software and the DPC make up the central processing unit of the CROSSFLOW system. It is used to control the SCU and the MUX, perform digital signal processing on the demodulated signals and derive the delay time for use in the flow calculation.

### 3.2.1 SOFTWARE FUNCTIONALITY

The CROSSFLOW software is used in conjunction with the system hardware to measure pipe flow. Its major functions include:

1. Provision of a user to CROSSFLOW system interface
2. Communication and control of the CROSSFLOW SCU and MUX
3. Digital Signal Processing
4. Flow Calculation
5. Report Generation

The CROSSFLOW software design specification is written around two architectural models. The first model, called the CROSSFLOW Software External Function Model, defines the structure of the software system functions and the relationship among those functions. This model gives insight into how system users interface with the software. The second model, called the CROSSFLOW Software Internal Design Model, defines how the software design is organized internally. These models are discussed in the following sections.

### 3.2.2 EXTERNAL FUNCTION MODEL

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#### 3.2.2.1 Top Level Panel

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## 3.2.2.2 Options Screen

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## 3.2.2.3 RSSI Scan

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## 3.2.2.4 Channel Configuration

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## 3.2.2.5 Hardware Setup Screen

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## 3.2.2.6 [ ] and Discriminator Criteria Configuration Screen

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## 3.2.2.7 Measurement Initialization Screen

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## 3.2.2.8 Measurement Screen

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## 3.2.3 INTERNAL DESIGN MODEL

The CROSSFLOW Software Internal Design Model shows the major system components that make up the software system. These components, or modules, are grouped by function and include the following:

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The CROSSFLOW Software Internal Design Model is depicted schematically in Figure 3-6 and its principal elements are discussed in the subsections below.

### 3.2.3.1 General System Property Management

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## 3.2.3.10 Error Handling System

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## 3.2.4 CROSSFLOW SOFTWARE FUNCTIONAL REQUIREMENTS SPECIFICATION

The Functional Requirements Specification discusses the required CROSSFLOW software functions. The topics discussed include:

1. File System and Data Structure
2. SCU/MUX Interface
3. Data Acquisition System
4. Frequency Modes
5. Data Filtration Criteria
6. DSP and Flow Calculation

### 3.2.4.1 CROSSFLOW Software File System and Data Structure

This section discusses the file types that the CROSSFLOW software utilizes, specifically, data files naming convention, automatic file name creation, and file data structure.

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### 3.2.4.2 Signal Conditioning Unit (SCU) and Multiplexer (MUX) Interface

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## 3.2.4.3 Data Acquisition

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## 3.2.4.4 Frequency Modes

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## 3.2.4.5 Data Filtration Criteria

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## 3.2.4.6 Digital Signal Processing and Flow Calculation

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## 3.2.5 SOFTWARE VERIFICATION AND VALIDATION

CROSSFLOW software is under configuration control and, verification and validation (V&V) is performed in accordance with the CENP, Quality Procedures Manual, QPM 101, Section QP 3.13 – Computer Software (Reference 3-4). Following this procedure, the software is evaluated to determine its adequacy for its intended use, V&V activities are identified and documentation needed to be placed under configuration control defined.

Prior to release of a CROSSFLOW software version revision, the V&V of the software is performed in accordance with CENP implementing procedure, MISC-PENG-TOP-007, Revision 00, 08-26-1997, "Procedure for the Verification and Validation of the AMAG CROSSFLOW Meter Software" (Reference 3-5). This procedure utilizes software verification tests performed in accordance with AMAG procedure, AMAG-I-004, Revision 03, "Software Verification and Validation Instruction" (Reference 3-6).

### 3.2.5.1 Verification and Validation Method - Time Delay and Flow Rate Calculation

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### 3.3 CROSSFLOW SYSTEM OPERATION VERIFICATION AND DIAGNOSTICS

From the initial development and application of the CROSSFLOW UFM System, accuracy and reliability have continuously improved. It is a priority to ensure that system uncertainty is always within the design bounds during normal operation. A number of verification and diagnostic techniques and tools have been developed to ensure accuracy claims for the CROSSFLOW system. The following subsections discuss these features.

Verification is normally carried out at pre-determined periodic intervals. Diagnostics are performed if a system failure occurs. Some of the verification techniques are used during the system's initial installation as a baseline for any subsequent troubleshooting.

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The following subsections discuss each of these techniques.

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## 3.4 CROSSFLOW COMPONENT CLASSIFICATION

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## 3.4.1 CROSSFLOW APPLICATION

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## 3.4.2 CROSSFLOW HARDWARE SAFETY SIGNIFICANCE

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## 3.4.3 CROSSFLOW SOFTWARE SAFETY SIGNIFICANCE

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## 3.4.4 CROSSFLOW CALIBRATION AND PLANT SPECIFIC UNCERTAINTY ANALYSIS ACTIVITIES

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## 3.5 REFERENCES

3-1 Metals Handbook, Vol. 11, Failure Analysis and Prevention, American Society for Metals, 1986

3-2 Materials Characterization 28:279-289 (1992)

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Table 3-1

Typical CROSSFLOW SCU Filter Settings



A large, empty bracketed area, consisting of two large square brackets facing each other, indicating that the content of the table is missing or redacted.

**FIGURE 3-1**

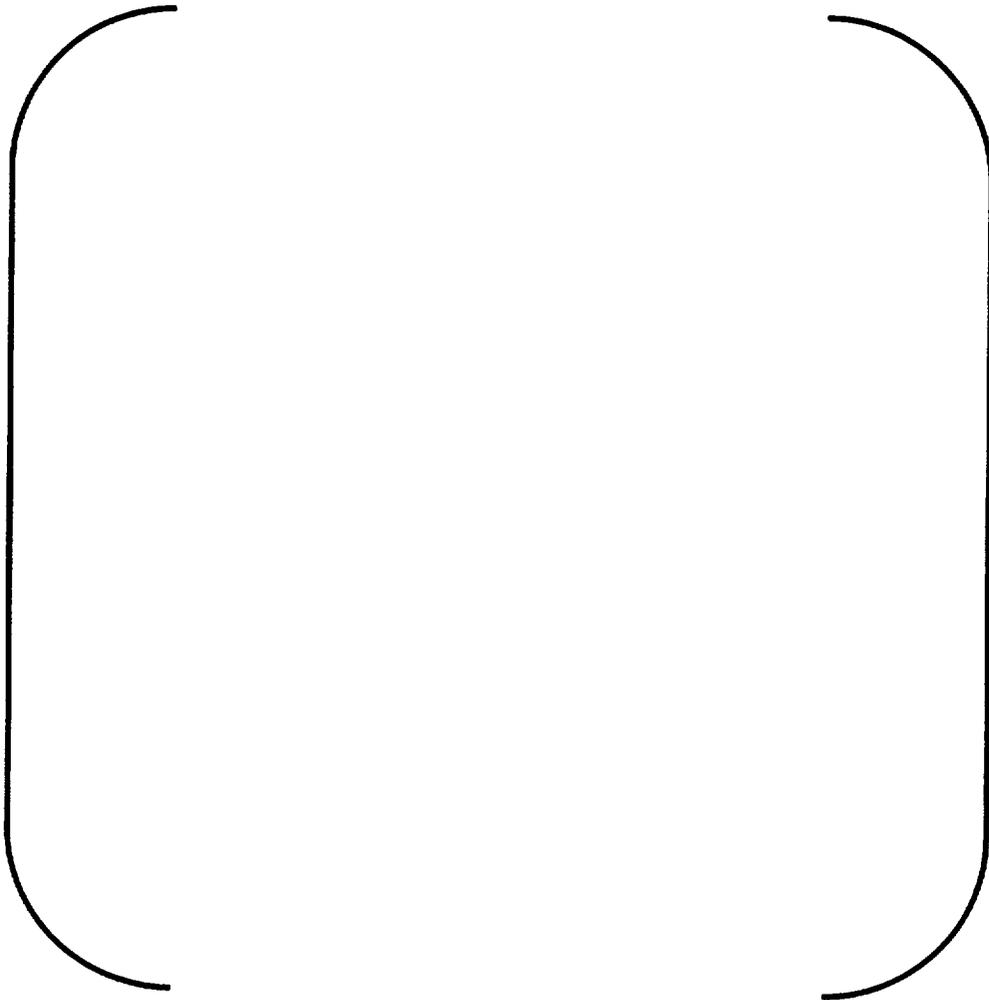
**CROSSFLOW SYSTEM PRINCIPAL HARDWARE COMPONENTS**



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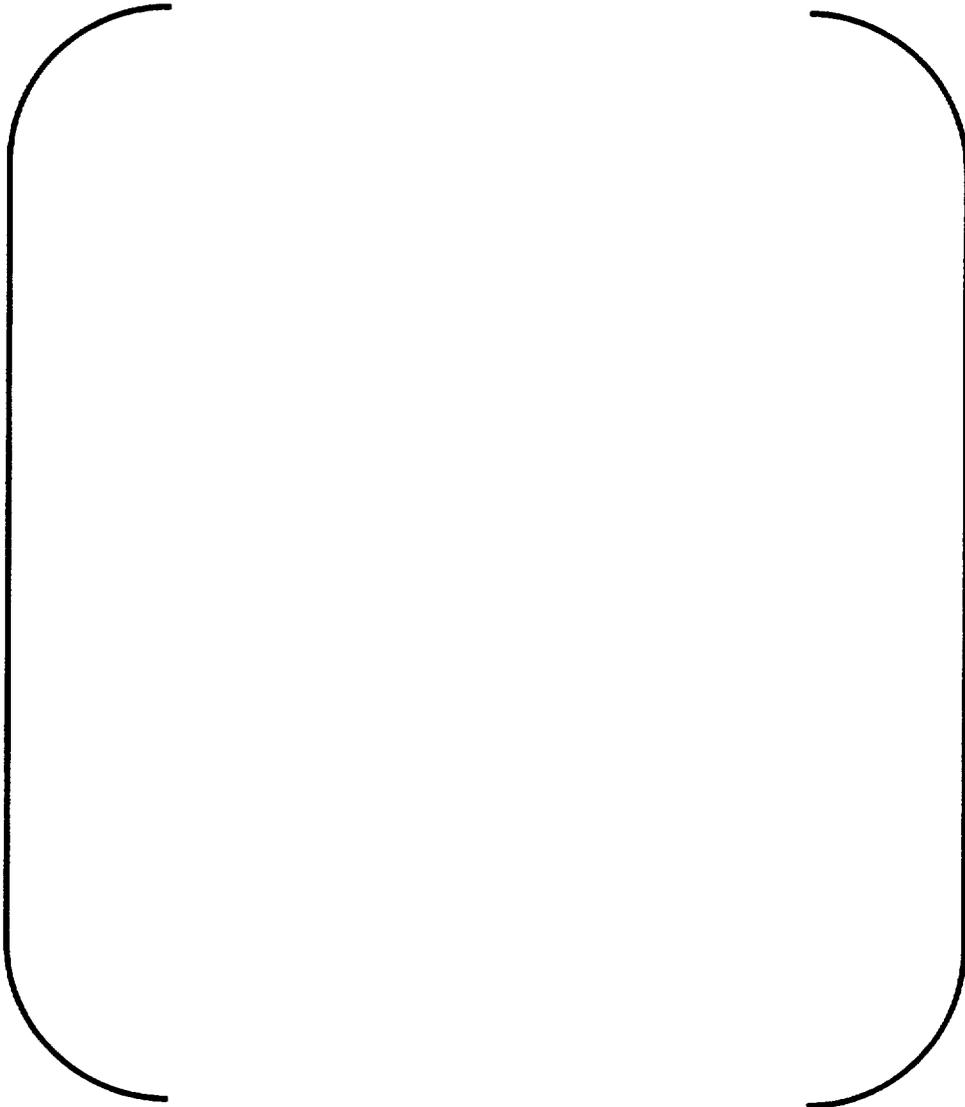
**FIGURE 3-2**

**BOX-TYPE MOUNTING/TRANSDUCER SUPPORT FRAME**



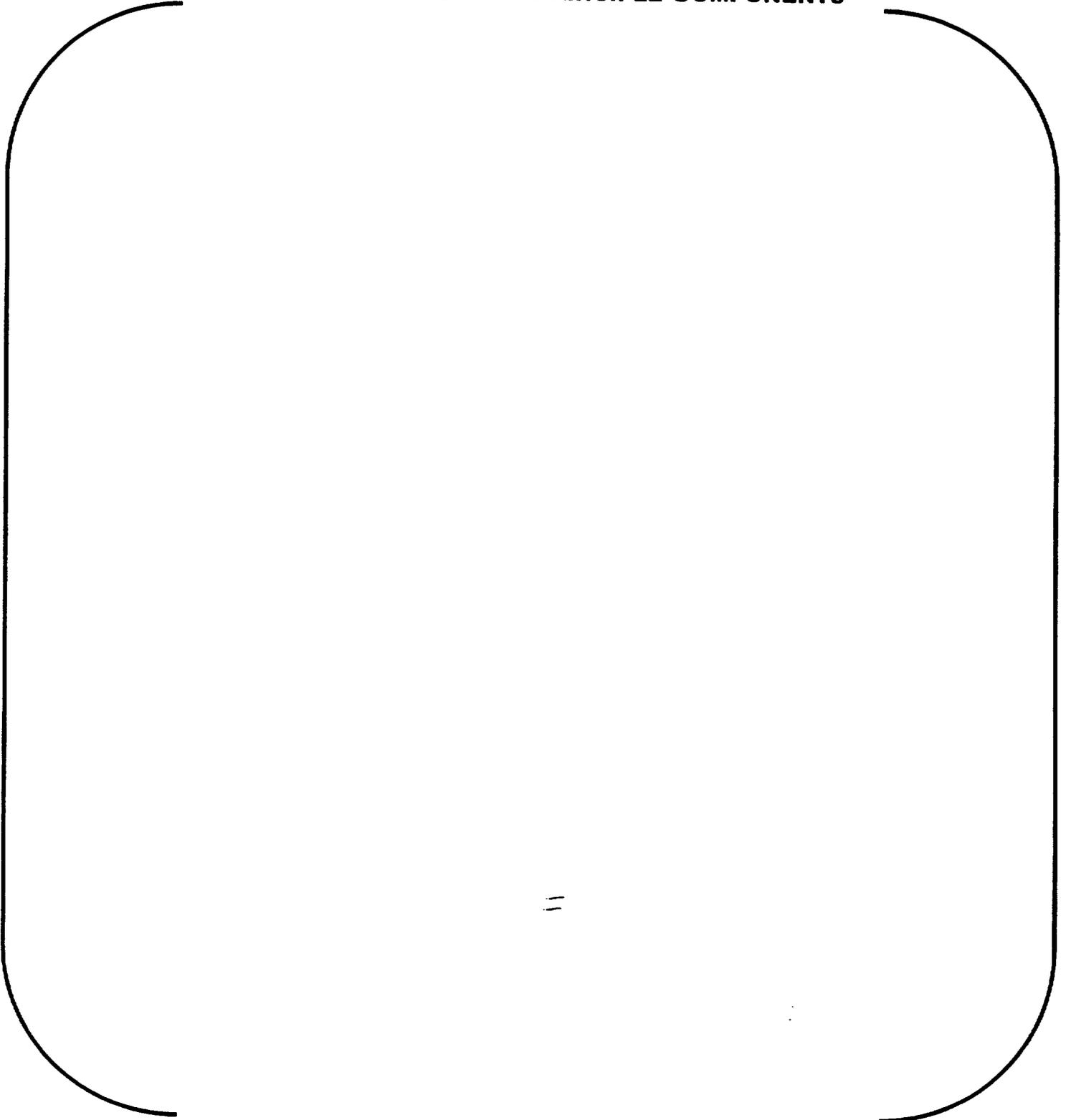
**FIGURE 3-3**

**SADDLE-TYPE MOUNTING/TRANSDUCER SUPPORT FRAME**



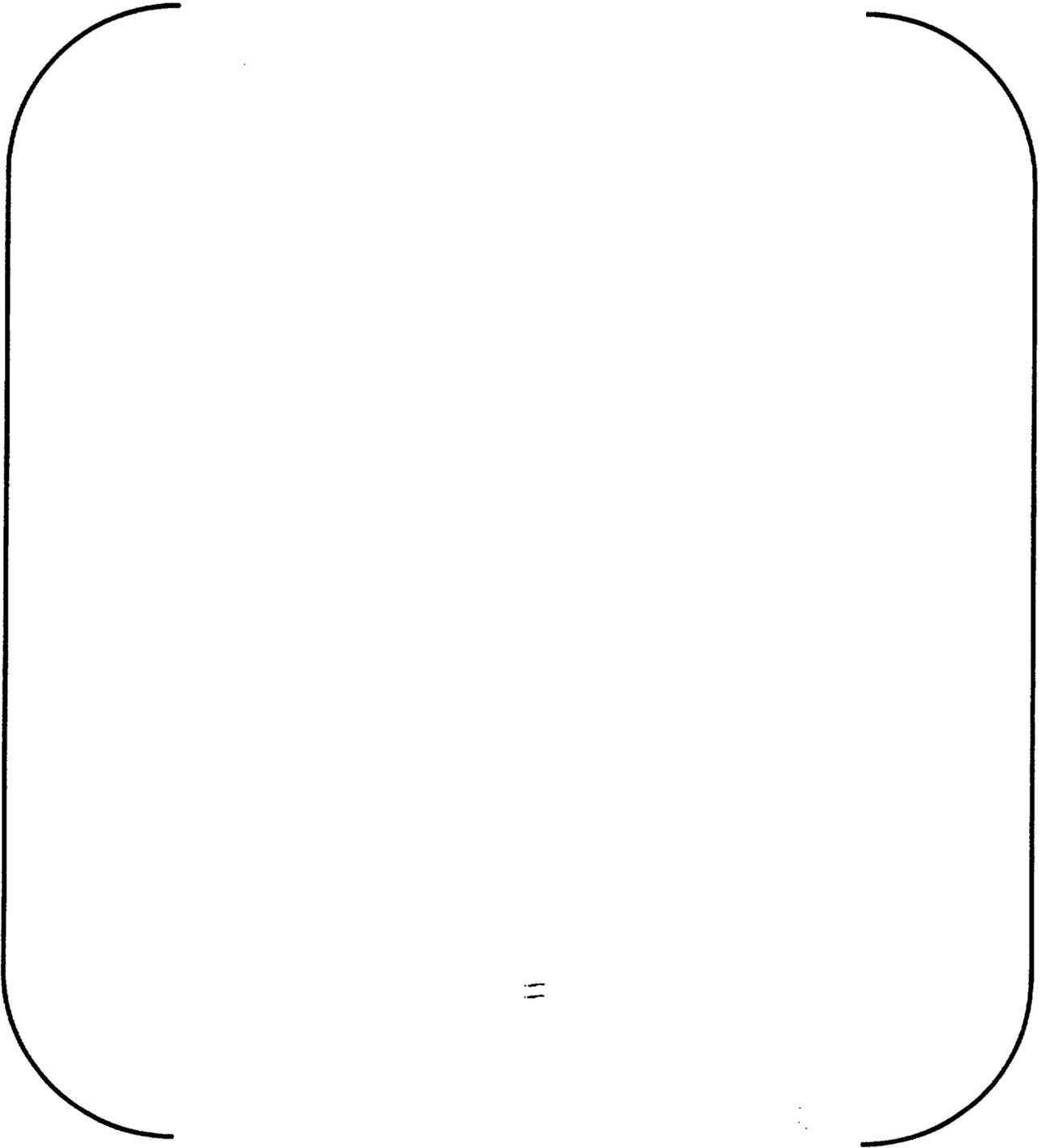
**FIGURE 3-4**

**SIGNAL CONDITIONING UNIT PRINCIPLE COMPONENTS**



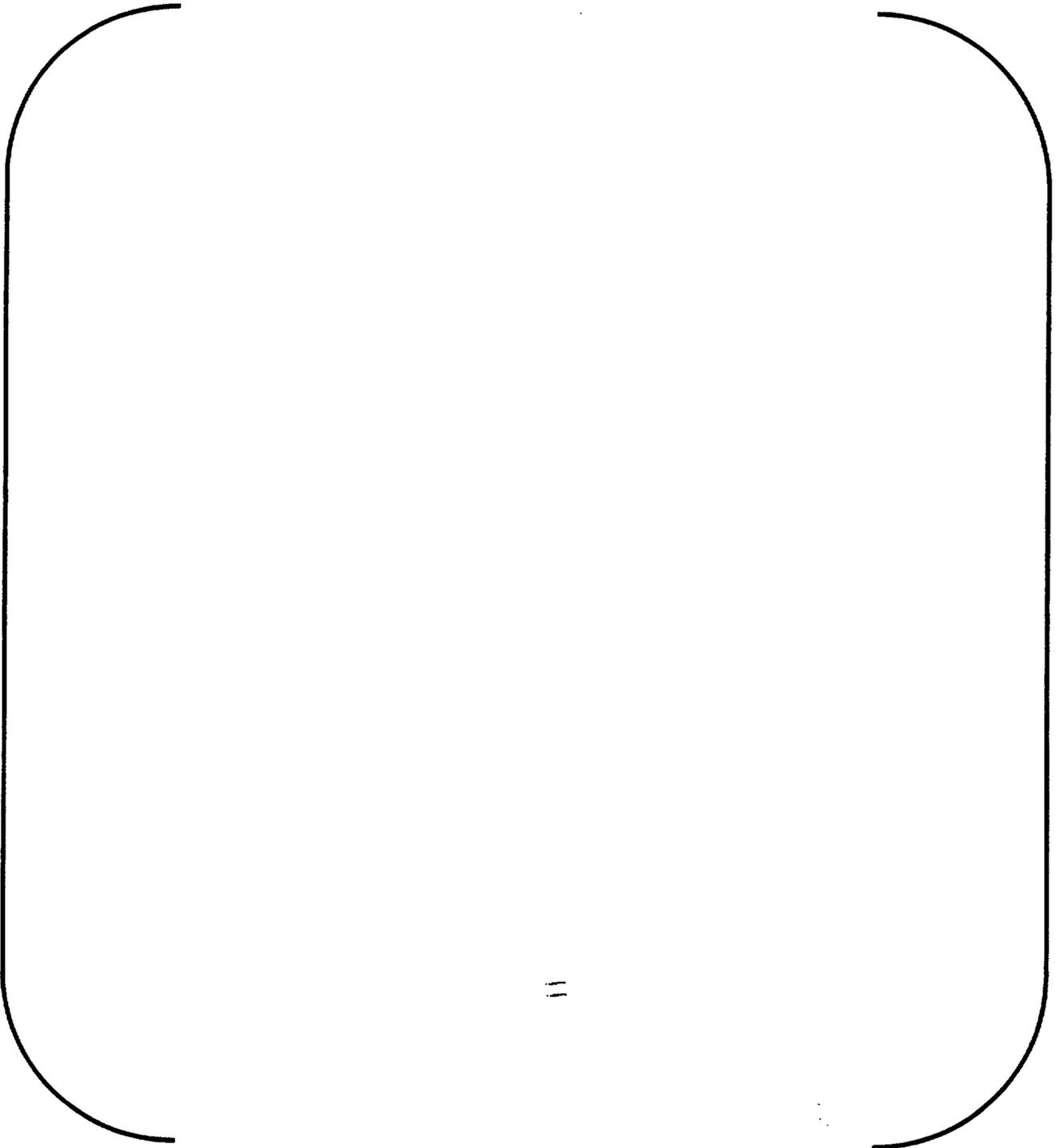
**FIGURE 3-5**

**CROSSFLOW SOFTWARE EXTERNAL FUNCTION MODEL**



**FIGURE 3-6**

**CROSSFLOW SOFTWARE INTERNAL DESIGN MODEL DIAGRAM**



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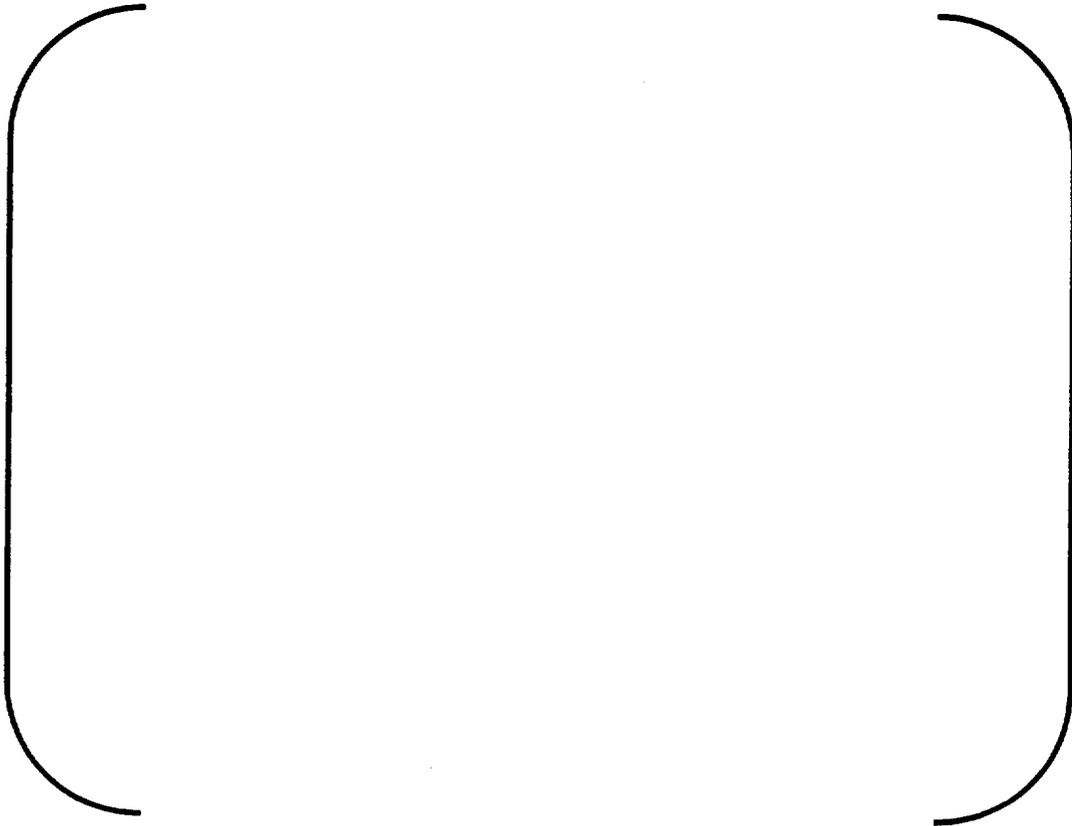
## FIGURE 3-7

### RANDOM FREQUENCY RANGES CONFIGURATION



**FIGURE 3-8**

**SETUP FOR THE NIST TRACEABLE TIME DELAY TEST**



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## 4.0 CROSSFLOW CALIBRATION AND VALIDATION

The CROSSFLOW UFM System was calibrated at the Alden Research Laboratory (ARL) for Reynolds Numbers (Re) ranging from  $0.8 \times 10^6$  -  $7 \times 10^6$ .

The objective of the calibration was to determine an expression for the Velocity Profile Correction Factor (VPCF) using the form of the equation established in the previous theory discussion (see Section 2.2). This approach provides a traceable calibration to the National Institute of Standards and Technology (NIST) with a verifiable uncertainty for the VPCF.

This section describes the method of calibration, the results and the uncertainty of VPCF. A discussion is also presented regarding the extension of the VPCF to higher Reynolds Numbers. That is, to conditions representative of those encountered in nuclear power plant feedwater systems ( $\sim 30 \times 10^6$ ).

## 4.1 CROSSFLOW CALIBRATION

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Eq. 4-5

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Eq. 4-7

The accuracy of the VPCF is  $\pm 0.25\%$ . [

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## 4.2 PROFILE VALIDATION AT HIGHER REYNOLDS NUMBERS

The calibrated VPCF was developed using weigh tank data from the ARL. Due to the nature of these cold water tests, it was not possible to reproduce the operating conditions and the Reynolds Numbers that are normally present in nuclear power plant feedwater systems. Hence, a limited amount of data has been collected from several plants where the accuracy of the in-plant flow instrumentation was independently confirmed through weigh tank tests at ARL. This data, which ranges up to a Reynolds Number of  $25 \times 10^6$ , was used to calculate a VPCF much like what was done for the ARL tests. These data points have been included in Figure 4-2 for comparison with the calibrated VPCF curve. In addition to the two (2) data points from operating plants, data has also been included from Ontario Hydro's specially constructed high temperature test loop plus other verification tests from the Everest Hydraulic Laboratory in Chatou France and NIST. Thus, a spectrum of independent data is provided covering both the expected operating and the calibrated range for the CROSSFLOW cross-correlation meter.

Two additional data points, "plant data 3" have also been included in Figure 4-2. This data was obtained from a plant, where CROSSFLOW meters were installed on two smaller feedwater pipes that were feeding into a common header with a third CROSSFLOW meter. Equation 4-6 was used for all three measurements, but it was possible to use correction factors from Equation 4-6 as standards that were just above or below the "OH High Temp" data to compare with CROSSFLOW readings that were significantly higher than the "OH High Temp" data.

## 4.3 CONCLUSIONS

An accurate curve has been developed for the velocity profile correction factor that is only a function of Reynolds number. This curve assumes that the velocity profile is fully developed and that the pipe wall friction is small. The use of plastic piping for the calibration provides a limiting condition that maximizes the velocity measured by the CROSSFLOW meter.

To demonstrate the accuracy of the Alden Calibration curve, which has been extrapolated from a Reynolds number of 7 million to nearly 30 million in Figure 4-2, two plant data points have been superimposed on the curve. These points help to confirm that the calibration curve, which was developed using Reynolds Numbers below 7 million, is also applicable at higher Reynolds numbers that would be encountered in the feedwater systems of operating nuclear power plants.

It will be observed that the two data points do not lie on the curve but are slightly above and below it. This does not create a concern, because the Alden Calibration curve for the CROSSFLOW meter has an uncertainty of  $\pm 0.25\%$ . Thus, a specific data point can fall above or below this curve by as much as  $0.25\%$  and still be acceptable. This criterion for acceptability is consistent with Nuclear Industry practice for venturis. Each venturi is calibrated at a hydraulic laboratory under low Reynolds number conditions and is assigned an uncertainty equal to the uncertainty of the calibrating instrument - for the Alden Research laboratory, this value is  $\pm 0.25\%$ . The venturis are then operated at much higher Reynolds numbers with no additional compensation for a higher uncertainty.

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## 4.4 REFERENCES

4-1 [

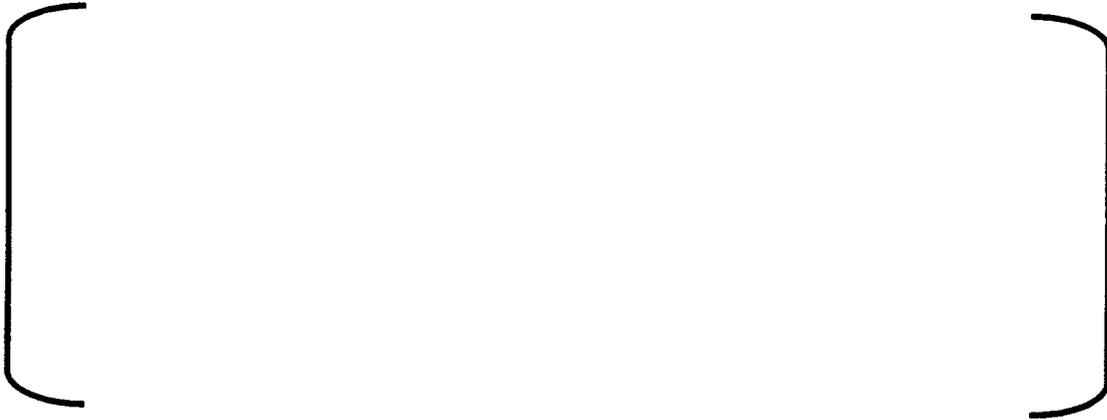
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**TABLE 4-1**

**DATA TAKEN AT ALDEN RESEARCH LABORATORY**



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**TABLE 4-2**

**COMPARISON OF PREDICTED AND MEASURED  
VELOCITY PROFILE CORRECTION FACTOR**



The table content is missing, indicated by large empty brackets on either side of the page.

**FIGURE 4-1**  
**COMPARISON OF THEORETICAL CURVE VERSUS**  
**CALIBRATION CURVE USING ALDEN DATA**



**FIGURE 4-2**

**VERIFICATION OF THE ALDEN CALIBRATION CURVE  
AT HIGHER REYNOLDS NUMBER**



**FIGURE 4-3**

**VERIFICATION OF THE ALDEN RESEARCH LABORATORY CALIBRATION CURVE**

**AT HIGHER REYNOLDS NUMBER**



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## 5.0 DETERMINATION OF FEEDWATER FLOW AND FLOW UNCERTAINTY

The methodology for determining the CROSSFLOW input parameters, feedwater flow and associated feedwater flow measurement uncertainty is presented below.

### 5.1 GENERAL EQUATION FOR CALCULATION OF FEEDWATER FLOW

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### 5.2 ERROR ANALYSIS

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**5.3 STATISTICAL EVALUATION**

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## 5.4 INSIDE PIPE DIAMETER

### 5.4.1 INSIDE PIPE DIAMETER MEAN

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[

] Eq. 5-8

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## 5.4.2 INSIDE PIPE DIAMETER 95% CONFIDENCE INTERVAL

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Eq. 5-15

## 5.5 TRANSDUCER SPACING

### 5.5.1 MEAN TRANSDUCER SPACING

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## 5.5.2 TRANSDUCER SPACING 95% CONFIDENCE INTERVAL

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## 5.6 VELOCITY PROFILE CORRECTION

### 5.6.1 VELOCITY PROFILE CORRECTION FACTOR

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5.6.2 VELOCITY PROFILE CORRECTION FACTOR CONFIDENCE INTERVAL

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## 5.7 FEEDWATER FLOW DENSITY 95% CONFIDENCE INTERVAL

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## 5.8 95% CONFIDENCE INTERVAL FOR THE TIME DELAY

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[

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Eq. 5-29

**5.9 FEEDWATER FLOW**

5.9.1 FEEDWATER FLOW DETERMINATION

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Eq. 5-30

5.9.2 FEEDWATER FLOW 95% CONFIDENCE INTERVAL

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Eq. 5-31

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## 5.10 UNCERTAINTY SUMMARY

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## 5.11 REFERENCES

- 5-1 USNRC Regulatory Guide 1.105, Revision 2, "Instrument Setpoints for Safety-Related Systems."
- 5-2 ANSI/ISA-S67.04, Part I-1994, "Setpoints for Nuclear Safety-Related Instrumentation."
- 5-3 ANSI/ISA-RP67.04, Part II-1994, "Recommended Practice For Methodologies For The Determination of Setpoints for Nuclear Safety-Related Instrumentation."
- 5-4 Statistical Methods for Business and Economics, R.C. Pfaffenberger and J.H. Patterson, Publisher - Richard D. Irwin, Inc.
- 5-5 Practical Stress Analysis in Engineering Design, Alexander Blake, 1982, Publisher Marcel Dekker Inc.
- 5-6 ASME B&PV Code Section II Table 1A, "Section I; Section III, Class 2 and 3; And Section VIII, Division 1 Maximum Allowable Stress Values S For Ferrous Materials.
- 5-7 ASME B&PV Code Section II Part D, Properties.
- 5-8 Crane Technical Paper No. 410, "Flow Of Fluids Through Valves, Fittings, And Pipe," Twenty-Fifth Printing - 1991).
- 5-9 Marks' Standard Handbook For Mechanical Engineers, Ninth Edition.
- 5-10 NIST/ASME Steam Properties, Version 2.11, in accordance with "Computer Program Release Notice CA-FE-1021" and "Implementation Report For NIST/ASME Steam Properties Version 2.11," W.B. Terney, VV-FE-0444, Revision 00, June 11, 1998.

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**TABLE 5-1**

**TYPICAL CROSSFLOW UNCERTAINTY**

**95% CONFIDENCE INTERVAL**

PARAMETER

Velocity Profile Correction Factor

$\pm 0.25\%$



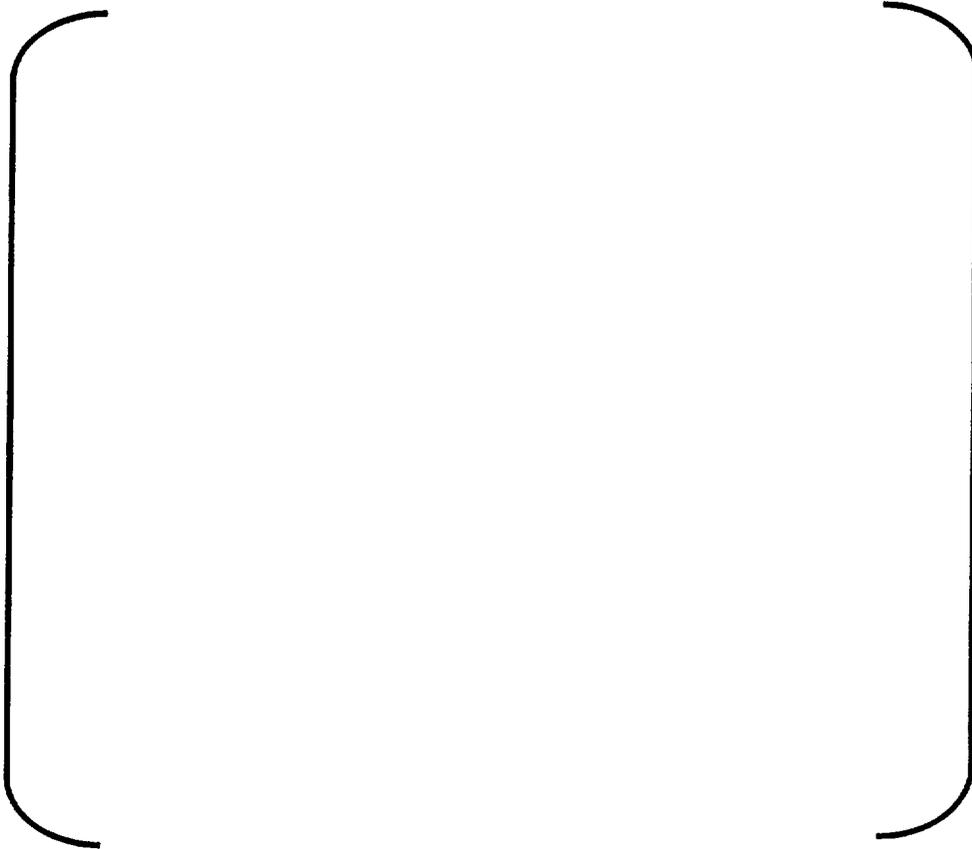
**FIGURE 5-1**

**SAMPLE FEEDWATER PIPE REFERENCE LOCATIONS AND POSITIONS**



**FIGURE 5-2**

**TRANSDUCER SPACING MEASUREMENTS**



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## 6.0 CROSSFLOW MATERIALS CONSIDERATIONS

CROSSFLOW has several components that contact the feedwater piping system on which it is mounted. As discussed in Section 3.0 there are design variations because of the evolution of the CROSSFLOW UFM System, which present differences in materials usage;

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For a more detailed discussion of CROSSFLOW design features see Section 3.0. [

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## 6.1 METALLURGICAL CONSIDERATIONS OF TRANSDUCER/PIPE INTERFACE

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6.1.1 [ ]

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## 6.2 FEEDWATER PIPE MATERIAL

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## 6.3 REFERENCES

6-1 Materials Characterization 28:279-289 (1992)

6-2 Metals Handbook, Vol. 11, Failure Analysis and Prevention, American Society for Metals, 1986

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## 7.0 CROSSFLOW RELIABILITY

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## 7.1 POTENTIAL FOR NON-CONSERVATIVE PREDICTION OF FLOW RATE

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7.1.1 [ ] =

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7.1.2 [

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7.1.3 [

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## **8.0 CROSSFLOW FIELD IMPLEMENTATION**

CROSSFLOW is simple to install and operate. This section discusses the principal steps taken during installation of the CROSSFLOW system to assure proper performance with the high degree of accuracy discussed in Section 5.0. In addition to the physical installation, initial system setup is also discussed. The discussion that follows is simply an overview. An actual CROSSFLOW installation and setup is governed by detailed step-by-step procedures (reference 8-1) that require the documentation of key installation/setup steps and important parameter values.

## **8.1 HARDWARE INSTALLATION - GENERAL**

A trained CENP or AMAG representative performs the initial installation of both the CROSSFLOW hardware and software. [

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The initial step performed by the installation team is a pre-installation survey. This survey identifies the installation location, the pipe outside diameter, the pipe material and its method of fabrication (i.e. rolled plate, forged, extruded, etc.). From this information the transducer mounting hardware is custom fabricated to the specific pipe on which it will be mounted. [

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## 8.1.1 DETERMINATION OF PIPE GEOMETRY INFORMATION

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## 8.1.1.1 Pipe Outside Diameter Determination

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## 8.1.1.2 Pipe Wall Thickness Determination

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[

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## 8.1.2 MOUNTING/TRANSDUCER SUPPORT FRAME (M/TSF) INSTALLATION

[

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## 8.1.3 ULTRASONIC TRANSDUCER INSTALLATION

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## **8.1.4 SOFTWARE INSTALLATION**

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## **8.2 CROSSFLOW SYSTEM / PLANT COMPUTER INTERFACE**

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## **8.3 MAINTENANCE**

The CROSSFLOW SCU and MUX are electronic hardware assemblies that contain no moving parts requiring periodic scheduled maintenance or replacement. Except for the

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commercial power supplies used, there are no user adjustable components. Periodic checks of the functionality of the electronics is recommended and discussed in the following subsections.

## 8.3.1 SIGNAL CONDITION UNIT (SCU)

Maintenance of the SCU involves the user performing some basic functionality checks using the CROSSFLOW internal Test Signal at regular intervals to gather historical data on the SCU performance [

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## 8.3.2 MULTIPLEXER (MUX)

As with the SCU, maintenance of the MUX involves the user performing some basic functionality checks. Using CROSSFLOW software in the Hardware Setup Screen Mode (see Section 3.0 for further discussion of this feature) and exercising the various functions available therefrom, the operator can perform a systematic checkout of both the SCU and the MUX.

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## 8.4 REFERENCES

- 8-1 Standard Procedure for Ultrasonic Measurement of Feedwater Flow, MISC-PENG-TOP-003

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## **APPENDIX A**

### **NRC REQUEST FOR ADDITIONAL INFORMATION - NOVEMBER 19, 1999**



UNITED STATES  
NUCLEAR REGULATORY COMMISSION

WASHINGTON, D.C. 201

November 19, 1999

Mr. Ian C. Rickard, Director  
Nuclear Licensing  
ABB Combustion Engineering Nuclear Operations  
Post Office Box 500  
2000 Day Hill Road  
Windsor, Connecticut 06095-0500

SUBJECT: REQUEST FOR ADDITIONAL INFORMATION (RAI) REGARDING  
CENPD-397-P, "IMPROVED FLOW MEASUREMENT ACCURACY  
USING CROSSFLOW ULTRASONIC FLOW MEASUREMENT  
TECHNOLOGY" (TAC NO. MA6452)

Dear Mr. Rickard:

CENPD-397-P, "Improved Flow Measurement Accuracy Using Crossflow Ultrasonic Flow Measurement Technology" was submitted for staff review by ABB Combustion Engineering (ABB-CE) letter LD-99-047 dated August 23, 1999. As a result of the review, the staff has determined that additional information is needed to complete the review. The information needed is detailed in the enclosure.

The enclosed request was discussed with Mr. Molnar of your staff on November 9, 1999. A mutually agreeable target date of November 24, 1999, was established for responding to the RAI. If circumstances result in the need to revise the target date, please call me at your earliest opportunity at (301) 415-1424.

Sincerely,

A handwritten signature in cursive script, appearing to read "Jack Cushing".

Jack Cushing, Project Manager, Section 2  
Project Directorate IV & Decommissioning  
Division of Licensing Project Management  
Office of Nuclear Reactor Regulation

Project No. 692

Enclosure: Request for Additional Information

cc w/encl: See next page

CE OWNERS GROUP

Project No. 692

cc: Mr. Gordon C. Bischoff, Project Director  
CE Owners Group  
ABB Combustion Engineering Nuclear Power  
M.S. 9615-1932  
2000 Day Hill Road  
Post Office Box 500  
Windsor, CT 06095

Mr. Ralph Phelps, Chairman  
CE Owners Group  
Omaha Public Power District  
P.O. Box 399  
Ft. Calhoun, NE 68023-0399

Mr. Ian C. Rickard, Director  
Nuclear Licensing  
ABB Combustion Engineering Nuclear Power  
2000 Day Hill Road  
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Windsor, CT 06095

Mr. Charles B. Brinkman, Manager  
Washington Operations  
ABB Combustion Engineering Nuclear Power  
12300 Twinbrook Parkway, Suite 330  
Rockville, MD 20852

## REQUEST FOR ADDITIONAL INFORMATION

### CENPD-397-P. "IMPROVED FLOW MEASUREMENT ACCURACY USING CROSSFLOW ULTRASONIC FLOW MEASUREMENT TECHNOLOGY"

1. Figure 2-2 compares the plot of the velocity profile correction factor (VPCF) vs. Reynolds number to experimental results. The topical report claim of high confidence in the extension of the VPCF to high Reynolds number is supported by limited data. Provide additional data for high Reynolds numbers plotted in Figure 2-2, or provide additional basis for the topical report claim.
2. The topical report associates Equations 2-15 and 2-19 with Reference 2-1 (Schlichting), yet the equations do not appear in the same form in the Schlichting reference. Provide the basis for the equations using a derivation traceable to something in Schlichting or some other source.
3. Summarize the detailed analysis mentioned in Section 2.3 supporting Equation 2-22 for  $r^*$ , and provide the reference(s) containing the supporting analysis.
4. Section 3.4.1 discusses the intended application of the Crossflow system. The Crossflow output is not to be directly used as input to the calorimetric calculation of thermal power, but to provide data to adjust the venturi flowmeter flow coefficient. What uncertainty components are introduced in the calibration of the venturi measurement from the Crossflow data? How are venturi-related uncertainties accounted for in power measurement in order to support a reduced (i.e., less than 2 percent) margin? Provide supporting details.
5. How were the values of measured  $C_o$  given in Table 4-1 determined (appears to be inverse of Equation 4-9)? What measurement or supporting experimental information is represented by  $V^*$  in the table?
6. Equation 4-6 should be the inverse of Equation 4-3, but Equation 4-6 appears to be missing the  $V_a$  term. If the omission is confirmed, provide corrections to the equations and other material in the topical report that follow from Equation 4-6.
7. Explain the apparent disparity among the curves and plant data depicted in Figures 2-2, 4-1, and 4-2.
8. Provide Reference 4-2.
9. What is the effect of corrosion products on the ultrasonic measurement of inside pipe diameter discussed in Section 5.4.1 of the topical report? Discuss how operating procedures or plant specific data should be used to demonstrate that the measured value of pipe inner diameter remains valid for operation of the Crossflow system.
10. Explain why sensor angular orientation relative to the flow disturbance is not a factor in determining the pipe configuration correction factor (Equation 5-24)?

11. Error analysis and uncertainty calculation based on square root sum-of-the-squares methods discussed in Section 5 must use contributors that are random, normally distributed, and independent. Explain how, for a specific installation, that each of the terms in Equation 5-34 can be assured to meet the randomness, distribution, and independence requirements. For example, explain how independence of the profile correction factor and feedwater density error terms is assured if each error involves measurement of feedwater temperature using the same instrumentation.
12. Explain the basis for the flow disturbance factor ( $\Delta C$ ) in Equation 5-24.
13. How does the internal time delay check mentioned in Sections 3.3.5 and 5.8 confirm the values input to Equation 5-29 (the time delay confidence interval)? Explain how the terms on the right side of Equation 5-29 are independent.
14. Section 2.2.2 defines cross-correlation as a "mathematical process for determining the displacement in time between similar curves." Explain Equations 2-9 and 2-10 graphically identifying the similar curves. Are the two signals  $A(t)$  and  $B(t + \tau)$  through two different eddies or through the same eddy traveling between station A and station B?
15. The asterisk (\*) in Equation 2-12 indicates the complex conjugate of a function. What does \* mean in Equations 2-15, 2-18, 2-22, and  $\tau = \tau^*$  in Section 2.2.2.
16. Section 3.2.4.5 states that the Crossflow software includes data filtration criteria, yet not all of the criteria are explained.
17. Section 3.2.4.6 states that the "cumulative cross-correlation function is the result of the summation of all instantaneous cross-correlation functions that are processed in each data acquisition cycle over a user specified average size." What is a data acquisition cycle and what is the basis for specifying an average size.
18. Section 4.2 states that a limited amount of data has been collected from several plants where the accuracy of the in-plant flow instrumentation was independently confirmed at Alden Research Laboratory (ARL). It is understood that the plant data are all for 25 million or higher Reynolds numbers whereas the ARL tests were limited to a lower Reynolds number shown on Figure 2-2. Explain how the plant data with high Reynolds numbers were confirmed at ARL and how Figures 2-2 and 4-1 curves were developed without sufficient data needed to perform a regression analysis.
19. In Section 5.6.1, definition of  $C_p$  indicates that VPCF is affected by the upstream piping configuration/disturbance other than an elbow. Has the ABB report provided methodology for calculating PCCF.
20. Section 5.8 indicates that a random normally distributed uncertainty is procedurally controlled and periodically verified by an internal time delay check. On what basis did AMAG assign this uncertainty value to the Crossflow UFM instrumentation? Explain the control procedure and verification method and the guideline if the assigned uncertainty is exceeded.

21. Table 5-1 shows uncertainty of measured and calculated parameters at various power plants. What is the reason for such a wide range of difference in the minimum and maximum values? Did the plants follow other methodologies than those outlined in Sections 5.5, 5.7, and 5.8 for the measurement uncertainties of the respective parameters.
22. What is the confidence level of repeatability and reproducibility of ARL test results? Explain how extrapolation for higher Reynolds numbers is performed and how its uncertainty is bounded by the AMAG assigned uncertainty value.
23. What is the indication of the Crossflow UFM instrumentation failure and what actions are recommended?

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## **APPENDIX B**

**LD-99-0062 - DECEMBER 17, 1999**

**RESPONSE TO NRC REQUEST FOR ADDITIONAL INFORMATION  
SUPPORTING TOPICAL REPORT CENPD-397-P REVIEW ACTIVITIES**

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17 December, 1999  
LD-1999-0062

U. S. Nuclear Regulatory Commission  
Attn: Document Control Desk  
Washington, D.C. 20555

**SUBJECT: RESPONSE TO NRC REQUEST FOR ADDITIONAL INFORMATION  
SUPPORTING TOPICAL REPORT CENPD-397-P REVIEW ACTIVITIES  
{ENCLOSURE 1 CONTAINS PROPRIETARY INFORMATION}**

- References: 1) Letter, I. C. Rickard (ABB CENP) to USNRC Document Control Desk, "Submittal of CENPD-397-P, Rev. 00 – Improved Flow Measurement Accuracy Using CROSSFLOW Ultrasonic Flow Measurement Technology", LD-99-047, August 23, 1999
- 2) Letter, J. Cushing (NRC) to I. C. Rickard (ABB CENP), "Request for Additional Information (RAI) Regarding CENPD-397-P, Improved Flow Measurement Accuracy Using CROSSFLOW Ultrasonic Flow Measurement Technology (TAC No. MA6452)", November 19, 1999

By letter dated August 23, 1999 (Reference 1), ABB Combustion Engineering Nuclear Power, Inc. (ABB CENP) submitted and requested Nuclear Regulatory Commission (NRC) review and approval of CENPD-397-P, Rev. 00 – Improved Flow Measurement Accuracy Using CROSSFLOW Ultrasonic Flow Measurement Technology". On November 19, 1999 (Reference 2), the NRC issued a Request for Additional Information (RAI) necessary for completion of the CENPD-397-P review effort. Enclosure 1 (PROPRIETARY) provides ABB CENP's response to the NRC RAIs. Enclosure 2 provides the non-proprietary response to the NRC RAIs.

If the information provided herewith resolves the NRC reviewer RAIs, ABB CENP will revise and reissue CENPD-397-P as Revision 01; as indicated in the responses (Enclosure 1).

ABB CENP has determined that the material provided in Enclosure 1 is PROPRIETARY in nature. Consequently, it is requested that Enclosure 1 be withheld from public disclosure in accordance with the provisions of 10 CFR 2.790 and that these copies be appropriately safeguarded. The reasons for the classification of this information as PROPRIETARY are delineated in the affidavit provided in Enclosure 3.

ABB Combustion Engineering Nuclear Power, Inc.

If you have any questions concerning this matter, please do not hesitate to call me or Chuck Molnar of my staff at (860) 285-5205.

Very truly yours,  
ABB COMBUSTION ENGINEERING NUCLEAR POWER, INC.



*for* Ian C. Rickard, Director  
Nuclear Licensing

Enclosures: As stated

- xc: R. A. Browning (DAEC) *ll*  
J. A. Calvo (NRC/NRR/DE/EEIB)  
J. S. Cushing (NRC/NRR/DLPM/LPD4)  
R. O. Doney (ABB CENP)  
J. E. Donoghue (NRCNRR/DSSA/SRXB)  
A. Lopez (AMAG)  
E. C. Marinos (NRC/NRR/DE/EEIB)  
N. N. Sikka (DAEC) *ll*

**PROPRIETARY INFORMATION**

**ABB Combustion Engineering Nuclear Power, Inc.**

**RESPONSE TO NRC REQUEST FOR ADDITIONAL INFORMATION  
SUPPORTING TOPICAL REPORT CENPD-397-P REVIEW ACTIVITIES**

**PROPRIETARY INFORMATION**

# **ABB Combustion Engineering Nuclear Power**

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## **RESPONSE TO NRC REQUEST FOR ADDITIONAL INFORMATION SUPPORTING TOPICAL REPORT CENPD-397-P REVIEW ACTIVITIES**

This information can be found in the proprietary version of the topical report, CENPD-397-P-A, Rev. 01.

**Enclosure 2 to LD-1999-0062**

**ABB Combustion Engineering Nuclear Power, Inc.**

**NON-PROPRIETARY RESPONSE TO NRC REQUEST FOR  
ADDITIONAL INFORMATION SUPPORTING TOPICAL REPORT  
CENPD-397-P REVIEW ACTIVITIES**

# ABB Combustion Engineering Nuclear Power

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## NON-PROPRIETARY RESPONSE TO NRC REQUEST FOR ADDITIONAL INFORMATION SUPPORTING TOPICAL REPORT CENPD-397-P REVIEW ACTIVITIES

### RAI - 1

Figure 2-2 compares the plot of the velocity profile correction factor (VPCF) vs. Reynolds Number to experimental results. The topical report claim of high confidence in the extension of the VPCF to high Reynolds Number is supported by limited data. Provide additional data for high Reynolds Numbers plotted in Figure 2-2, or provide additional basis for the topical report claim.

### ABB-CENP RESPONSE

Extrapolation of the calibration results to high Reynolds Number (Re) is also the subject of RAI 18. Hence, responses to RAI's 1 and 18 are provided here.

Justification for the extrapolation of the Velocity Profile Correction Factor (VPCF) can best be explained by considering the origin of the equations that are used to calculate the velocity profile correction factor at higher Re. Equation 2-16 and the supporting Equations 2-13 and 2-14 from the topical report are all fundamental equations taken from Schlichting's book, "Boundary Layer Theory". Furthermore, Equation 2-13 for the frictional velocity has its bases in the Moody diagram of friction factor versus Re, ASME Transaction, Volume 68, 1944, Page 672. This equation is the mathematical expression that describes how the friction factor,  $\lambda$ , in the Moody diagram varies with Re for fully developed turbulent flow in a smooth pipe.

[

]

In order to plot the experimental data points on Figure 2-2, the VPCF,  $C_o$ , was calculated for each data point using the following equation:

$$C_o = \frac{Q_{measured}}{Q_{CROSSFLOW}}$$

where:  $Q_{measured}$  is the volumetric flow measured by the weigh tank or plant venturi

$Q_{CROSSFLOW}$  is the corresponding volumetric flow measured by the meter without the velocity profile correction factor.  $Q_{CROSSFLOW}$  is defined as:

$$Q_{CROSSFLOW} = A L/\tau$$

where: A is the flow area

L is the spacing between the ultrasonic beam

$\tau$  is the time that it takes for the eddies to pass between the ultrasonic beams

# **ABB Combustion Engineering Nuclear Power**

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A comparison of the VPCF curve with plant operating data must be done at a plant. Because of the high fluid temperatures required to achieve these Reynolds Numbers ( $Re$ ), it is not possible to use a weigh tank test to independently measure the flow. Hence, the comparisons are limited to in-plant tests, where it is known that the venturi and plant instrumentation have recently been calibrated and will provide an accurate measurement of the flow.

It is a rare opportunity, when these conditions can all be met. For the plant data point shown on Figure 2-2, the plant had just sent their ASME flow element back to the Alden Research Laboratory (ARL) for calibration. It was then returned to the plant and reinstalled in the feedwater line, where the measurements were taken shortly after reaching full power before any potential venturi fouling could significantly affect the results.

FIGURE 2-2



# ABB Combustion Engineering Nuclear Power

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## RAI - 2

The topical report associates Equations 2-15 and 2-19 with Reference 2-1 (Schlichting), yet the equations do not appear in the same form in the Schlichting reference. Provide the basis for the equations using a derivation traceable to something in Schlichting or some other source.

## ABB-CENP RESPONSE

### A. Equation 2-15

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### B. Equation 2-19

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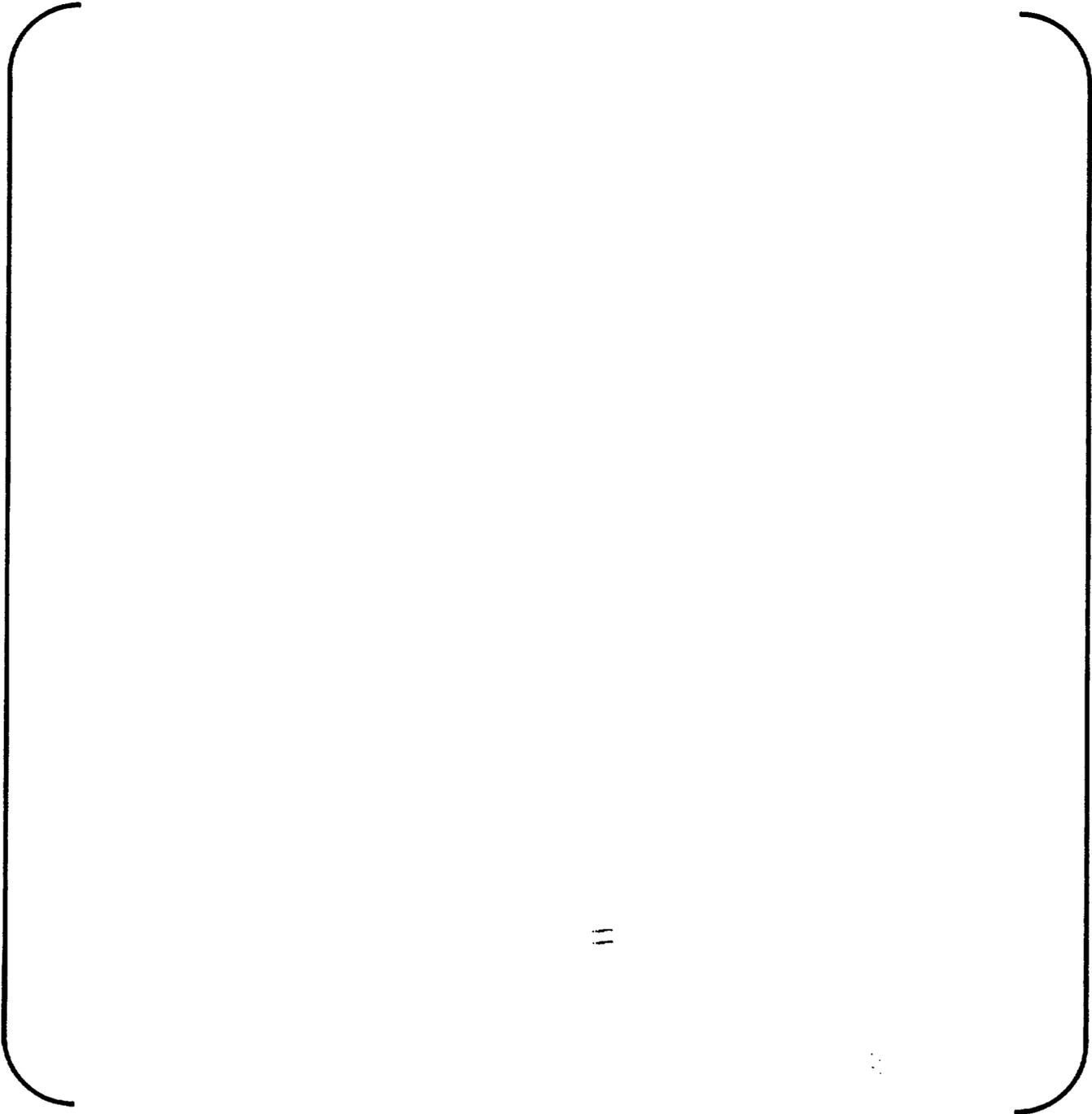
# ABB Combustion Engineering Nuclear Power

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To demonstrate that the two equations are essentially the same, the following table compares

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# ABB Combustion Engineering Nuclear Power

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## RAI - 3

Summarize the detailed analysis mentioned in Section 2.3 supporting Equation 2-22 for  $r_1^*$  and provide the reference(s) containing the supporting analysis.

## ABB-CENP RESPONSE

It should be noted that Section 2.3 of the topical report, CENPD-397-P, has been revised. Equation 2-22 is now Equation 2-16 and  $r_1^*$  is now  $r^*$ .

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## **RAI - 4**

Section 3.4.1 discusses the intended application of the Crossflow system. The Crossflow output is not to be directly used as input to the calorimetric calculation of thermal power, but to provide data to adjust the venturi flowmeter flow coefficient. What uncertainty components are introduced in the calibration of the venturi measurement from the Crossflow data? How are venturi-related uncertainties accounted for in power measurement in order to support a reduced (i.e. less than 2 percent) margin? Provide supporting details.

## **ABB-CENP RESPONSE**

As described in Section 3.4.1 of CENPD-397-P, Rev. 00, the CROSSFLOW meter is used to calibrate the existing feedwater venturis. This adjustment would only be applied to the feedwater flow that is used in the thermal power calculation. The adjustment is not applied to the feedwater flow used by the feedwater level controllers or by the feedwater flow trips.

This calibration process [

]

# **ABB Combustion Engineering Nuclear Power**

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[

]

Portions of this response have been added to Section 5.9.2 of the topical report.



# ABB Combustion Engineering Nuclear Power

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## RAI - 6

Equation 4-6 should be the inverse of Equation 4-3, but Equation 4-6 appears to be missing the  $V_a$  term. If the omission is confirmed, provide corrections to equations and other material in the topical report that follow from Equation 4-6.

## ABB-CENP RESPONSE

It should be noted that Section 4.1 of topical report, CENPD-397-P has been revised. Equation 4-6 is now shown in Section 4.1 as Equation 4-1 and Equation 4.3 is no longer needed.

Equation 4-1 will be changed in the topical report to read:

( )

# **ABB Combustion Engineering Nuclear Power**

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## **RAI - 7**

Explain the apparent disparity among the curves and plant data depicted in Figures 2-2, 4-1, and 4-2.

## **ABB-CENP RESPONSE**

There was an error in plotting the plant data shown on Figure 2-2 of CENPD-397-P, Rev. 00. The topical report will be revised to correct this error. Additionally, the same symbols will be used in each figure for a particular data set. The revised figures are provided on the following pages.

FIGURE 2-2



FIGURE 4-1

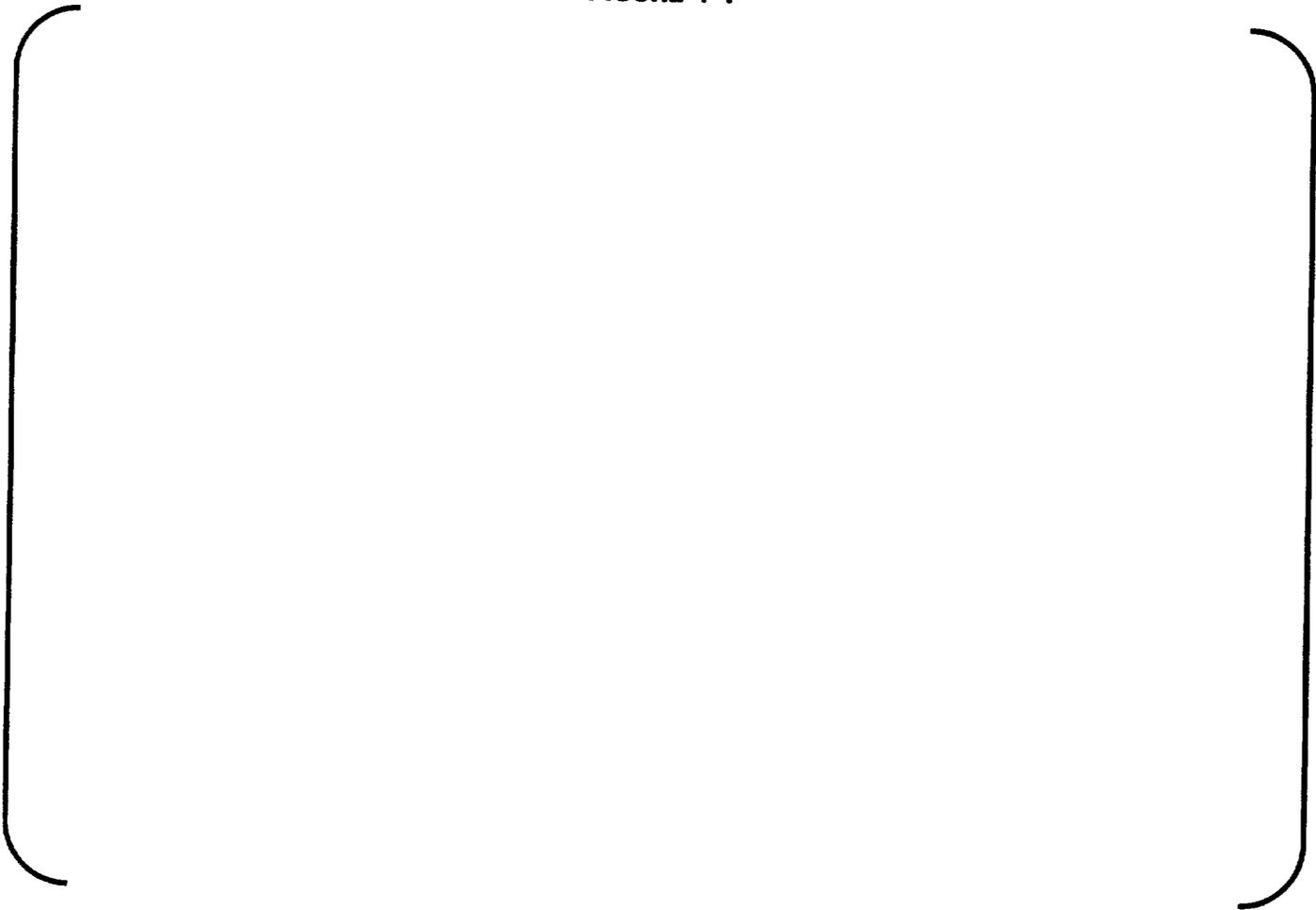


FIGURE 4-2



# **ABB Combustion Engineering Nuclear Power**

---

## **RAI - 8**

Provide Reference 4-2.

## **ABB-CENP RESPONSE**

Please find attached a copy of CENPD-397-P, Rev. 00, Reference 4-2, [

]

This reference has also been added to Section 4.4 as Reference 4-1 of the topical report.

# ABB Combustion Engineering Nuclear Power

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## RAI - 9

What is the effect of corrosion products on the ultrasonic measurement of inside pipe diameter discussed in Section 5.4.1 of the topical report? Discuss how operating procedures or plant specific data should be used to demonstrate that the measured value of pipe inner diameter remains valid for operation of the Crossflow system.

## ABB-CENP RESPONSE

When the pipe wall thickness is measured using an ultrasonic thickness meter, the actual measurement includes both the thickness of the pipe wall and the thickness of any magnetite corrosion products since the composition of the corrosion products is essentially the same as that of the pipe wall. Thus, when the measured thickness is subtracted from the pipe outside diameter, a true measurement of the pipe's flow area is obtained.

ABB CENP understands that several plants have seen deposition of oxides on feedwater pipe internal surfaces that may change the surface roughness and increase the indicated flow. However, the deposition does not usually change flow area to a measurable degree. Pipe wall thickness measurements are not routinely monitored or trended.

Throughout the industry, there is little evidence of pipe wall loss in straight runs of feedwater piping systems. Since the CROSSFLOW UFM is recommended for application on straight runs of feedwater piping, it is unlikely that the inside diameter of the feedwater pipe would be subject to long-term wall loss of a type that would impact meter performance. However, it is recommended that a Utility evaluate this potential on a plant-by-plant basis. This evaluation could utilize the site Flow Accelerated Corrosion Program, or a separate program of pipe wall monitoring. It is also recommended that this evaluation/monitoring be performed near the location of the CROSSFLOW UFM, or at a point in the feedwater line where a potential wall loss rate would be equal to (or greater than) the rate where the meter is installed. If wall losses are identified, then it is expected that the Utility would take appropriate actions to reflect any pertinent changes in the feedwater flow calculations.

Portions of this response have been added to Section 8.1.1.2 of the topical report.

# **ABB Combustion Engineering Nuclear Power**

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## **RAI - 10**

Explain why sensor angular orientation relative to the flow disturbance is not a factor in determining the pipe configuration correction factor (Equation 5-24)?

## **ABB-CENP RESPONSE**

The angular orientation of the sensors is important when using Equation 5-24 to obtain a VPCF downstream of a 90° elbow. This equation is only applicable when the sensors are orientated in the plane of the elbow. The topical report will be revised to reflect this constraint on the use of Equation 5-24.

Portions of this response have been added to Sections 5.6.1 and 8.1.1 of the topical report.

# ABB Combustion Engineering Nuclear Power

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## **RAI - 11**

Error analysis and uncertainty calculation based on square root sum-of-the-squares methods discussed in Section 5 must use contributors that are random, normally distributed, and independent. Explain how, for a specific installation, that each of the terms in Equation 5-34 can be assured to meet the randomness, distribution, and independence requirements. For example, explain how independence of the profile correction factor and feedwater density error terms is assured if each error involves measurement of feedwater temperature using the same instrumentation.

## **ABB-CENP RESPONSE**

Traditionally, a majority of the utilities have utilized methodologies presented in ANSI/ASME PTC 19.1 to determine feedwater flow/flow uncertainty for input to the core thermal power evaluations where the SRSS method is an accepted practice for combining "biases" at the 95% confidence level. However, [

]

# ABB Combustion Engineering Nuclear Power

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[

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]

# **ABB Combustion Engineering Nuclear Power**

---

[ ]

Portions of this response have been added to Section 5.9.2 of the topical report.

# **ABB Combustion Engineering Nuclear Power**

---

## **RAI - 12**

Explain the basis for the flow disturbance factor ( $\Delta C$ ) in Equation 5-24.

## **ABB-CENP RESPONSE**

Equation 5-24 is based on [

]

# **ABB Combustion Engineering Nuclear Power**

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## **RAI - 13**

How does the internal time delay check mentioned in Sections 3.3.5 and 5.8 confirm the values input to Equation 5-29 (the time delay confidence interval)? Explain how the terms on the right side of Equation 5-29 are independent.

## **ABB-CENP RESPONSE**

[

]

Portions of this response have been added to Section 5.8 of the topical report.

# ABB Combustion Engineering Nuclear Power

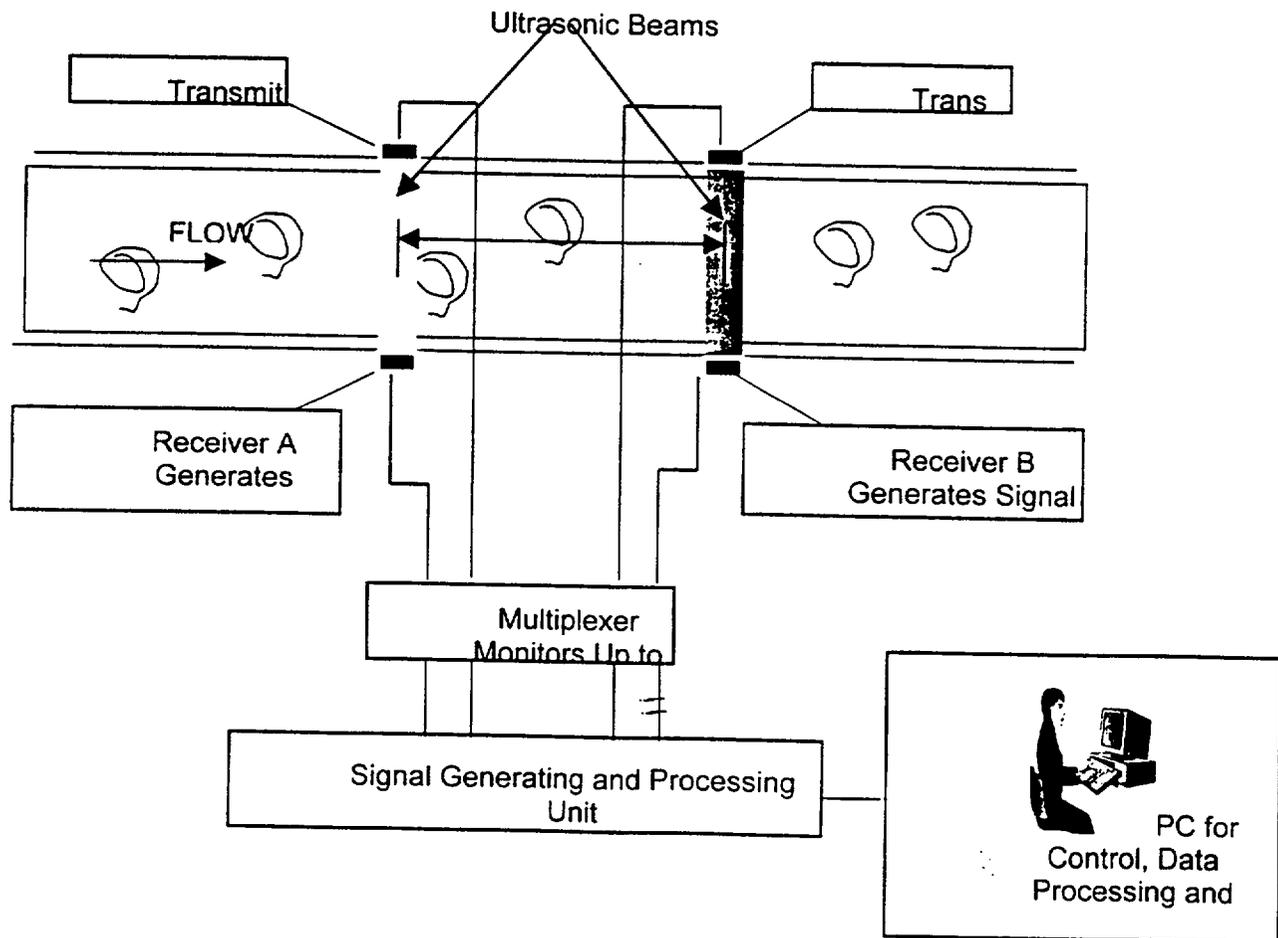
## RAI - 14

Section 2.2.2 defined cross-correlation as a "mathematical process for determining the displacement in time between similar curves." Please explain equations 2-9 and 2-10 and graphically identify the similar curves. Are the two signals  $A(t)$  and  $B(t + \tau)$  through two different eddies or through the same eddy traveling between station A and station B?

## ABB CENP Response

It should be noted that the equations in Section 2.2.2 have been renumbered due to revisions in Section 2.1 of the topical report, CENPD-397-P, Rev. 00. Equation 2-9 is now Equation 2-5 and Equation 2-10 is now Equation 2-6.

The underlying principle of the cross-correlation technique is illustrated in the following figure:



# **ABB Combustion Engineering Nuclear Power**

---

[

]

Portions of this response have been added to Section 2.2.2 of the topical report.

# ABB Combustion Engineering Nuclear Power

---

## RAI - 15

The asterisk (\*) in equation 2-12 indicates the complex conjugate of a function. What does \* mean in equations 2-15, 2-18, 2-22, and  $\tau=\tau^*$  in section 2.2.2.

## ABB-CENP RESPONSE

It should first be noted that the equations in Sections 2.1 through 2.3 have been renumbered due to revisions in these sections of the topical report, CENPD-397-P, Rev. 00. Equation 2-12 is now Equation 2-8 and Equations 2-15 and 2-22 are now respectively Equations 2-12 and 2-16. Equation 2-18 has been eliminated.

[

]

# **ABB Combustion Engineering Nuclear Power**

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## **RAI - 16**

Section 3.2.4.5 states that the CROSSFLOW software includes data filtration criteria, yet, not all of the criteria are explained.

## **ABB-CENP RESPONSE**

[

]

Portions of this response have been added to Section 3.2.4.5 of the topical report.

# ABB Combustion Engineering Nuclear Power

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## RAI - 17

Section 3.2.4.6 states that the "cumulative cross-correlation function is the result of the summation of all instantaneous cross-correlation functions that are processed in each data acquisition cycle over a user specified average size." What is a data acquisition cycle and what is the basis for specifying an average size?

## ABB-CENP RESPONSE

The data acquisition cycle is the time interval, T, in Equation 2-6. For feedwater flow measurements, it is typically [                    ]

The cumulative cross-correlation function is simply an average of the cross-correlation function. The user can specify through input the number of time delays he would like to be averaged.  
[

]

Portions of this response are included in Section 3.2.4.6 of the topical report.

# **ABB Combustion Engineering Nuclear Power**

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## **RAI - 18**

Section 4-2 states that a limited amount of data has been collected from several plants where the accuracy of the in-plant flow instrumentation was independently confirmed at Alden Research Laboratory (ARL). It is understood that the plant data are all for 25 million or higher Reynolds numbers whereas the ARL tests were limited to a lower Reynolds number shown on Figure 2-2. Explain how the plant data with high Reynolds numbers were confirmed at ARL and how Figures 2-2 and 4-1 curves were developed without sufficient data needed to perform a regression analysis.

## **ABB-CENP RESPONSE**

See response to RAI No. 1.

# **ABB Combustion Engineering Nuclear Power**

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## **RAI - 19**

In section 5.6.1, definition of  $C_p$  indicates that VPCF is affected by the upstream piping configuration/disturbance other than an elbow. Has ABB report provided methodology for calculating PCCF?

## **ABB-CENP RESPONSE**

CENPD-397-P, Rev. 00 does [

]

Portions of this response are included in Sections 5.6.1 and 8.1.1 of the topical report.

# **ABB Combustion Engineering Nuclear Power**

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## **RAI - 20**

Section 5.8 indicates that a random normally distributed uncertainty is procedurally controlled and periodically verified by an internal time delay check. On what basis did the Advanced Measurement and Analysis Group (AMAG) assign this uncertainty value to the CROSSFLOW UFM instrumentation? Explain the control procedure and verification method and the guideline if the assigned uncertainty is exceeded.

## **ABB-CENP RESPONSE**

As noted in RAI 13, there are [

]

Portions of this response are included in Section 5.8 of the topical report.

# **ABB Combustion Engineering Nuclear Power**

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## **RAI - 21**

Table 5-1 shows uncertainty of measured and calculated parameters at various power plants. What is the reason for such a wide range of difference in the minimum and maximum values? Did the plants follow other methodologies than those outlined in sections 5.5, 5.7, and 5.8 for the measurement uncertainties of the respective parameters?

## **ABB-CENP RESPONSE**

The methodologies are the same for all measurements. The reason for the variations [

]

# **ABB Combustion Engineering Nuclear Power**

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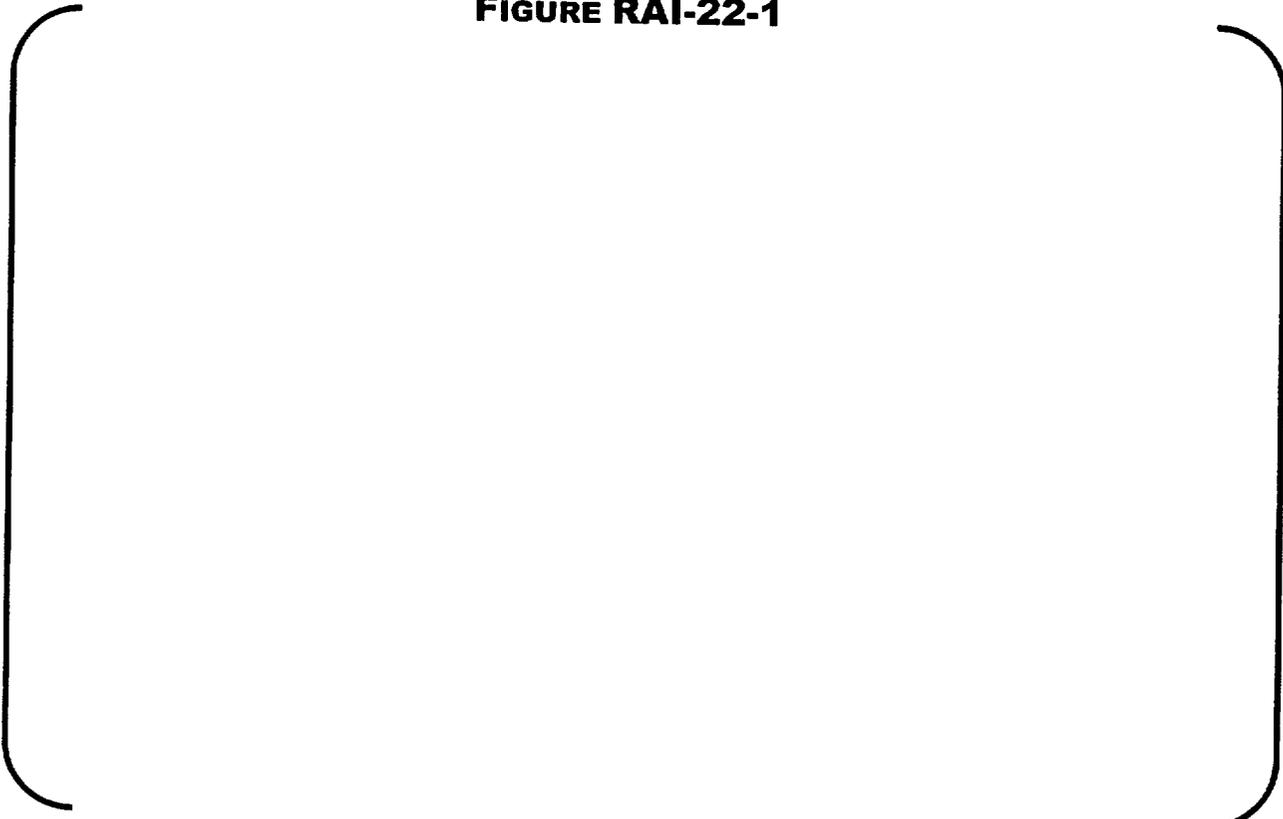
## **RAI - 22**

What is the confidence level of repeatability and reproducibility of ARL test results? Explain how extrapolation for higher Reynolds numbers is performed and how its uncertainty is bounded by the AMAG assigned uncertainty value.

## **ABB-CENP RESPONSE**

The 95% confidence level for Alden Research Laboratory (ARL) test results is [

**FIGURE RAI-22-1**



# **ABB Combustion Engineering Nuclear Power**

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## **RAI - 23**

What is the indication of the CROSSFLOW UFM instrumentation failure and what actions are recommended?

## **ABB-CENP RESPONSE**

In case of a CROSSFLOW UFM System failure, [

]

Portions of this response are included in Section 3.3.6 of the topical report.

**ABB Combustion Engineering Nuclear Power, Inc.**

**Proprietary Affidavit Supporting**

**ENCLOSURE 1-P - RESPONSE TO NRC REQUEST FOR  
ADDITIONAL INFORMATION IN SUPPORT OF TOPICAL REPORT  
CENPD-397-P, REV. 00 REVIEW ACTIVITIES**

**AFFIDAVIT PURSUANT**

**TO 10 CFR 2.790**

See original letter submittal for a copy of the affidavit.

# **CE NUCLEAR POWER LLC**

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## **APPENDIX C**

**LD-2000-0002 – JANUARY 6, 2000**

**SUBMITTAL OF CENPD-397-P, REV. 01 – “IMPROVED FLOW  
MEASUREMENT ACCURACY USING CROSSFLOW ULTRASONIC FLOW  
MEASUREMENT TECHNOLOGY”**



6 January, 2000  
LD-2000-0002

U. S. Nuclear Regulatory Commission  
Attn: Document Control Desk  
Washington, D.C. 20555

**Subject: Submittal of CENPD-397-P, Rev. 01 – “Improved Flow Measurement Accuracy Using Crossflow Ultrasonic Flow Measurement Technology”**  
[PROPRIETARY INFORMATION ENCLOSED]

References:

1. Letter, I. C. Rickard (ABB CENP) to USNRC Document Control Desk, “Submittal of CENPD-397-P, Rev. 01 – “Improved Flow Measurement Accuracy Using Crossflow Ultrasonic Flow Measurement Technology”, AUGUST 23, LD-99-047
2. Letter, I. C. Rickard (ABB CENP) to USNRC Document Control Desk, “Response to NRC Request for Additional Information Supporting Topical Report CENPD-397-P Review Activities”, December 17, 1999, LD-1999-062
3. Letter, J. Cushing (NRC) to I. C. Rickard (ABB CENP), “Request for Additional Information (RAI) Regarding CENPD-397-P, Improved Flow Measurement Accuracy Using CROSSFLOW Ultrasonic Flow Measurement Technology (TAC No. MA6452)”, November 19, 1999

ABB C-E Nuclear Power, Inc. (ABB CENP) submits herewith topical report CENPD-397-P, Revision 01 – “Improved Flow Measurement Accuracy Using CROSSFLOW Ultrasonic Flow Measurement Technology” for Nuclear Regulatory Commission (NRC) review and approval. Revision 01 incorporates, as necessary and appropriate, the ABB CENP responses (Reference 2) to the NRC Request for Additional Information issued on November 19, 1999 (Reference 3). CENPD-397-P, Revision 01 supercedes Rev 00, submitted via Reference 1, in its entirety; please destroy all copies of CENPD-397-P, Rev 00. In accordance with NUREG-0390, Enclosure 1 provides 15 copies (Nos. 1 to 15) of CENPD-397-P, Rev. 01 for NRC use. ABB CENP is also providing the required twelve (12) non-proprietary versions (i.e., CENPD-397-NP, Revision 01) in Enclosure 2.

ABB CENP has determined that information contained in CENPD-397-P, Revision 01 is proprietary in nature. As such, ABB CENP requests that the information contained in CENPD-397-P, Revision 01 be safeguarded and withheld from public disclosure pursuant to 10 CFR 2.790. The reasons for this determination are documented in the proprietary affidavit provided in Enclosure 3.

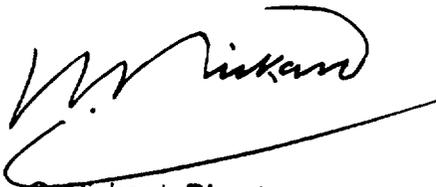
ABB C-E Nuclear Power, Inc.

P.O. Box 500  
2000 Day Hill Rd.  
Windsor, CT 06095-0500

Telephone (860) 285-9678  
Fax (860) 285-3253

If you have any questions concerning this matter, please do not hesitate to call Chuck Molnar of my staff at (860) 285-5205.

Sincerely,  
ABB C-E NUCLEAR POWER, INC.

A handwritten signature in black ink, appearing to read "I. C. Rickard", written over a horizontal line.

Ian C. Rickard, Director  
Nuclear Licensing

Enclosures: 1) CENPD-397-P, Revision 01 (Copy Nos. 1 to 13)  
2) CENPD-397-NP, Revision 01 (12 unnumbered copies)  
3) ABB CENP Proprietary Affidavit

xc: J. S. Cushing (NRC) (w/ Proprietary Copy No. 14)  
I. Ahmed (NRC) (w/ Proprietary Copy No. 15)

xc: (w/o Enclosures)  
R. A. Browning (DAEC)  
Q. B. Chou (AMAG)  
S. Dembek (NRC)  
J. E. Donoghue  
A. Lopez (AMAG)  
E. C. Marinos (NRC)  
V. Safavi-Ardebli (AMAG)  
N. N. Sikka (DAEC)

**Enclosure 1 to LD-2000-0002**

**ABB C-E Nuclear Power, Inc.**

**CENPD-397-P, Rev. 01**

**Improved Flow Measurement Accuracy Using Crossflow  
Ultrasonic Flow Measurement Technology**

**PROPRIETARY INFORMATION**

**Enclosure 2 to LD-2000-0002**

**ABB C-E Nuclear Power, Inc.**

**CENPD-397-NP, Rev. 01**

**Improved Flow Measurement Accuracy Using Crossflow  
Ultrasonic Flow Measurement Technology**

**ABB C-E Nuclear Power, Inc.**

**Proprietary Affidavit**

**for**

**CENPD-397-P, Rev. 01**

**Improved Flow Measurement Accuracy Using Crossflow  
Ultrasonic Flow Measurement Technology**

=

**AFFIDAVIT PURSUANT**

**TO 10 CFR 2.790**

See original letter submittal for a copy of the affidavit.

# **CE NUCLEAR POWER LLC**

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## **APPENDIX D**

**LD-2000-0007 – JANUARY 25, 2000**  
**CENPD-397-P, REV. 01 SUPPLEMENTAL INFORMATION TRANSMITTAL**

=



25 January, 2000  
LD-2000-0007

U. S. Nuclear Regulatory Commission  
Attn: Document Control Desk  
Washington, D.C. 20555

**SUBJECT: CENPD-397-P, REV. 01 SUPPLEMENTAL INFORMATION TRANSMITTAL  
{ENCLOSURE 1-P CONTAINS PROPRIETARY INFORMATION}**

- References: 1) CENPD-397-P, Rev. 01, "Improved Flow Measurement Accuracy Using CROSSFLOW Ultrasonic Flow Measurement Technology", January 2000  
2) Letter, I. C. Rickard (ABB CENP) to U.S. NRC Document Control Desk, "Submittal of CENPD-397-P, Rev. 01 - "Improved Flow Measurement Accuracy Using Crossflow Ultrasonic Flow Measurement Technology", LD-2000-0002, JANUARY 6, 2000

The purpose of this letter is to provide supplemental information supporting the Nuclear Regulatory Commission (NRC) review of the ABB C-E Nuclear Power, Inc. (ABB CENP) Topical Report CENPD-397-P, Rev. 01, "Improved Flow Measurement Accuracy Using CROSSFLOW Ultrasonic Flow Measurement Technology", Reference 1. CENPD-397-P, Rev. 01 was submitted on January 6, 2000 (Reference 2). Following discussions with Mr. Iqbal Ahmed of the NRC staff regarding his review of CENPD-397-P, Rev. 01 it has been agreed that supplemental modifications will be made to the Topical Report. Generally, the supplemental information addresses two (2) items; 1) the de-propietaryization of selected parameter values and 2) clarification of material presented in Section 4.1, "CROSSFLOW Calibration", Section 4.2, "Profile Validation at Higher Reynolds Numbers" and Table 5-1, "Typical CROSSFLOW Uncertainty" of the Topical Report. The supplemental information is provided in Enclosure 1-P.

ABB CENP has determined that information contained in Enclosure 1-P is PROPRIETARY in nature. As such, ABB CENP requests that the information be safeguarded and withheld from public disclosure pursuant to 10 CFR 2.790. The reasons for this determination are documented in the PROPRIETARY AFFIDAVIT provided in Enclosure 2. Enclosure 3 provides a non-propietary version of Enclosure 1-P for your use.

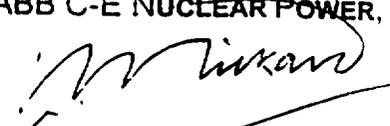
ABB Combustion Engineering Nuclear Power, Inc.

P.O. Box 500  
2000 Day Hill Rd.  
Windsor, CT 06095-0500

Telephone (860) 285-9678  
Fax (860) 285-3253

If you have any questions concerning this matter, please do not hesitate to call me or Chuck Molnar of my staff at (860) 285-5205.

Very truly yours,  
ABB C-E NUCLEAR POWER, INC.



Ian C. Rickard, Director  
Nuclear Licensing

Enclosures: As stated

xc: (w/o Enclosures)  
I. Ahmed (NRC)  
R. A. Browning (DAEC)  
Q. B. Chou (AMAG)  
S. Dembek (NRC)  
J. E. Donoghue  
A. Lopez (AMAG)  
E. C. Marinos (NRC)  
N. N. Sikka (DAEC)

**PROPRIETARY INFORMATION**

**ABB C-E NUCLEAR POWER, INC.**

**CENPD-397-P, Rev. 01**  
**SUPPLEMENTAL INFORMATION TRANSMITTAL**

**PROPRIETARY INFORMATION**

**CENPD-397-P, Rev. 01**  
**SUPPLEMENTAL INFORMATION TRANSMITTAL**

This information can be found in the proprietary version of the topical report, CENPD-397-P-A, Rev. 01.

Enclosure 2 to LD-2000-0007

**ABB C-E NUCLEAR POWER, INC.**

**PROPRIETARY AFFIDAVIT  
FOR  
ENCLOSURE 1-P TO LD-2000-0007**

**AFFIDAVIT PURSUANT**  
**To 10 CFR 2.790**

See original letter submittal for a copy of the affidavit.

Enclosure 3 to LD-2000-0007

**ABB C-E NUCLEAR POWER, INC.**

**CENPD-397-P, Rev. 01**  
**NON-PROPRIETARY SUPPLEMENTAL INFORMATION**  
**TRANSMITTAL**

**CENPD-397-P, Rev. 01**  
**NON-PROPRIETARY SUPPLEMENTAL INFORMATION TRANSMITTAL**

Pursuant to discussions with Mr. Iqbal Ahmed of the Nuclear Regulatory Commission (NRC) staff regarding his review of the ABB C-E Nuclear Power, Inc. (ABB CENP) Topical Report CENPD-397-P, Rev. 01, "Improved Flow Measurement Accuracy Using CROSSFLOW Ultrasonic Flow Measurement Technology", it has been agreed that supplemental modifications will be made to the Topical Report. In general, the supplemental information is in regard to; 1) the de-propietarization of selected parameter values and 2) clarification of material presented in Section 4.1, "CROSSFLOW Calibration", Section 4.2, "Profile Validation at Higher Reynolds Numbers" and Table 5-1, "Typical CROSSFLOW Uncertainty".

The revised material, which is presented below, will be integrated into the Topical Report at the time the accepted version (i.e., "-A") is produced following NRC issuance of their Safety Evaluation Report (SER). It is our understanding that use of the information provided herewith will allow the NRC review to be completed without revision of the Topical Report prior to issuance of the SER.

**ITEM 1: DE-PROPRIETARIZATION OF SELECTED PARAMETER VALUES**

**Section 1.4 CROSSFLOW INSTALLATION AND OPERATING FEATURES**

This section will be revised to de-propietarize the quoted CROSSFLOW UFM System accuracy (i.e., 0.5%), thereby allowing it to be included in the non-propietary version of the Topical Report.

**Section 1.5 CROSSFLOW UFM SYSTEM ACCURACY**

This section will be revised to de-propietarize the quoted CROSSFLOW UFM System accuracy (i.e., 0.5%), thereby allowing it to be included in the non-propietary version of the Topical Report.

**4.1 CROSSFLOW CALIBRATION**

This section will be revised to de-propietarize the quoted VPCF accuracy (i.e., 0.25%), thereby allowing it to be included in the non-propietary version of the Topical Report.

**ITEM 2: CLARIFICATION OF MATERIAL PRESENTED IN SECTIONS 4.1, 4.2 AND TABLE 5.1**

**Section 4.1 CROSSFLOW Calibration**

This section will be replaced and superseded in its entirety by the following write-up to provide a clearer explanation of how calibration of the Velocity Profile Correction Factor (VPCF) was performed.

**4.1 CROSSFLOW CALIBRATION**

[

=

]

[

]

The accuracy of the VPCF is  $\pm 0.25\%$ . [

]

=

**FIGURE 4-3  
VERIFICATION OF THE ALDEN RESEARCH LABORATORY CALIBRATION CURVE  
AT HIGHER REYNOLDS NUMBERS**



11

**SECTION 4.2 PROFILE VALIDATION AT HIGHER REYNOLDS NUMBERS**

The words "plant data" in the second paragraph of this section will be modified to read "plant data 3".

**TABLE 5-1 TYPICAL CROSSFLOW UNCERTAINTY**

The following revised Table 5-1 will replace the current Table 5-1 in the Topical Report. The modification simply reflects that all values are reported in percent (%).

**TABLE 5-1  
TYPICAL CROSSFLOW UNCERTAINTY  
95% CONFIDENCE INTERVAL**

| <u>PARAMETER</u>                   |              |
|------------------------------------|--------------|
| Velocity Profile Correction Factor | $\pm 0.25\%$ |

# **CE NUCLEAR POWER LLC**

---

## **APPENDIX E**

**LD-2000-0017 – MARCH 8, 2000  
RESPONSE TO VERBAL REQUEST FOR ADDITIONAL INFORMATION  
REGARDING NRC REVIEW OF CENPD-397, REV. 1**

=



8 March, 2000  
LD-2000-0017

U. S. Nuclear Regulatory Commission  
Attn: Document Control Desk  
Washington, D.C. 20555

**SUBJECT: RESPONSE TO VERBAL REQUEST FOR ADDITIONAL INFORMATION  
REGARDING NRC REVIEW OF CENPD-397, REV. 1  
{CONTAINS PROPRIETARY INFORMATION}**

References: Letter I. C. Rickard (ABB CENP) to USNRC Document Control Desk, "Submittal of CENPD-397-P, Rev. 01 – Improved Flow Measurement Accuracy Using CROSSFLOW Ultrasonic Flow Measurement Technology", LD-2000-0002, January 6, 2000 {Contains Proprietary Information}

Messrs. John Donoghue and Iqbal Ahmed, both of the Nuclear Regulatory Commission (NRC), contacted Mr. Charles French of ABB C-E Nuclear Power, Inc. (ABB CENP) regarding their review of CENPD-397, Rev. 01, "Improved Flow Measurement Accuracy Using CROSSFLOW Ultrasonic Flow Measurement Technology". CENPD-397, Rev. 01 was submitted to the NRC on January 2, 2000 via the referenced ABB CENP letter. Specifically, three (3) questions were asked during a telephone conference call on March 2, 2000. Although the questions have already been responded to verbally, this letter transmits ABB CENP's formal response.

Enclosure 1-P contains the three questions and ABB CENP's responses. ABB-CE has determined that Enclosure 1-P contains information that is PROPRIETARY in nature. Consequently, it is requested that Enclosure 1-P be withheld from public disclosure in accordance with the provisions of 10 CFR 2.790 and that these copies be appropriately safeguarded. The reasons for the classification of this information as PROPRIETARY are delineated in the affidavit provided in Enclosure 2. Enclosure 3 provides a NON-PROPRIETARY copy of ABB CENP's response.

**ABB C-E NUCLEAR POWER, INC.**

P.O. Box 500  
2000 Day Hill Rd.  
Windsor, CT 06095-0500

Telephone (860) 285-9678  
Fax (860) 285-3253

U.S. NRC Document Control Desk  
8 March, 2000

LD-2000-0017  
Page 2

If you have any questions concerning this matter, please do not hesitate to call me or Chuck Molnar of my staff at (860) 285-5205.

Very truly yours,  
ABB C-E NUCLEAR POWER, INC.



Ian C. Rickard, Director  
Nuclear Licensing

Enclosure: As stated

xc: I. Ahmed (NRC)  
J. S. Cushing (NRC)  
J. E. Donoghue (NRC)

**Enclosure 1-P to LD-2000-0017**

**PROPRIETARY INFORMATION**

**ABB C-E Nuclear Power, Inc.**

**RESPONSE TO VERBAL REQUEST FOR ADDITIONAL INFORMATION  
REGARDING NRC REVIEW OF CENPD-397, REV. 1**

**PROPRIETARY INFORMATION**

**RESPONSE TO VERBAL REQUEST FOR ADDITIONAL INFORMATION  
REGARDING NRC REVIEW OF CENPD-397, REV. 1**

This information can be found in the proprietary version of the topical report, CENPD-397-P-A, Rev. 01.

**ABB C-E Nuclear Power, Inc.**

**Proprietary Affidavit**

**for**

**RESPONSE TO VERBAL REQUEST FOR ADDITIONAL  
INFORMATION REGARDING NRC REVIEW OF CENPD-397,  
REV. 1**

**AFFIDAVIT PURSUANT**

**TO 10 CFR 2.790**

See original letter submittal for a copy of the affidavit.

**ABB C-E Nuclear Power, Inc.**

**NON-PROPRIETARY RESPONSE  
TO VERBAL REQUEST FOR ADDITIONAL INFORMATION  
REGARDING NRC REVIEW OF CENPD-397, REV. 1**

**NON-PROPRIETARY RESPONSE TO VERBAL REQUEST FOR ADDITIONAL INFORMATION  
REGARDING NRC REVIEW OF CENPD-397, REV. 1**

Messrs. John Donoghue and Iqbal Ahmed, both of the Nuclear Regulatory Commission (NRC), contacted Mr. Charles French of ABB C-E Nuclear Power, Inc. (ABB CENP) regarding their review of CENPD-397, Rev. 01, "Improved Flow Measurement Accuracy Using CROSSFLOW Ultrasonic Flow Measurement Technology". ABB CENP's responses to the three (3) questions follows:

**Question 1:**

[

]

**Response:**

[

]

**Question 2:**

What are the bases for Equation 5-24 in CENPD-397-P Rev. 01?

**Response:**

[

]

**Original paragraph Section 5.6:** [

]

**Modified paragraphs, Section 5.6:** [

]

[

]

=

**Question 3:**

[

]

**Response:**

The Alden Calibration curve for the CROSSFLOW meter has an uncertainty of +0.25%. Thus, a specific data point can fall above or below this curve by as much as 0.25% and still be acceptable. This criterion for acceptability is consistent with Nuclear Industry practice for venturis. Each venturi is calibrated at a hydraulic laboratory under low Reynolds number conditions and is assigned an uncertainty equal to the uncertainty of the calibrating instrument - for the Alden Research laboratory, this value is +0.25%. The venturis are then operated at much higher Reynolds numbers with no additional compensation for a higher uncertainty.

To help clarify these differences in the Topical Report Sections 4.3 and 5.6.2 will be modified as follows:

**Original paragraph, Section 4.3:** An accurate curve has been developed for the VPCF that is only a function of Reynolds Number. This curve assumes that the velocity profile is fully developed and that pipe wall friction is small. The use of plastic piping for the calibration provides a limiting condition that assures that the velocity measured by the CROSSFLOW cross-correlation meter will be equal to or greater than the actual velocity of the fluid. This in turn assures that the mass flow and, hence, the thermal power will be equal to or greater than the actual output of the reactor - a conservative condition.

Moreover, the high Reynolds Number tests confirmed that the calibration curve, which was developed at low Reynolds Numbers, is also applicable at higher values which includes those conditions that would be encountered in operating nuclear power plant feedwater systems.

**Modified paragraph, Section 4.3:** An accurate curve has been developed for the velocity profile correction factor that is only a function of Reynolds number. This curve assumes that the velocity profile is fully developed and that the pipe wall friction is small. The use of plastic piping for the calibration provides a limiting condition that maximizes the velocity measured by the CROSSFLOW meter.

To demonstrate the accuracy of the Alden Calibration curve, which has been extrapolated from a Reynolds number of 7 million to nearly 30 million in Figure 4-2, two plant data points have been superimposed on the curve. These points help to confirm that the calibration curve, which was developed using Reynolds Numbers below 7 million, is also applicable at higher Reynolds numbers that would be encountered in the feedwater systems of operating nuclear power plants.

It will be observed that the two data points do not lie on the curve but are slightly above and below it. This does not create a concern, because the Alden Calibration curve for the CROSSFLOW meter has an uncertainty of +0.25%. Thus, a specific data point can fall above or below this curve by as much as 0.25% and still be acceptable. This criterion for acceptability is consistent with Nuclear Industry practice for venturis. Each venturi is calibrated at a hydraulic laboratory under low Reynolds number conditions and is assigned an uncertainty equal to the uncertainty of the calibrating instrument - for the Alden Research laboratory, this value is +0.25%. The venturis are then operated at much higher Reynolds numbers with no additional compensation for a higher uncertainty.

Original paragraph, Section 5.6.2: [

]

Modified paragraph, Section 5.6.2: [

]

# **CE NUCLEAR POWER LLC**

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## **APPENDIX F**

### **CENPD-397-P, REV. 01 REPORT PAGES THAT WERE REPLACED**

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# **CE NUCLEAR POWER LLC**

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## **CENPD-397-P, REV. 01 REPORT PAGES THAT WERE REPLACED**

As requested by the NRC in their cover letter transmitting the SER for CENPD-397-P, Rev. 01, this appendix includes copies of the original Rev. 01 version topical report pages that were changed since its submittal on January 6, 2000. The nature of the change(s) made is annotated on the right-hand page margin. In general, the changes resulted from:

- 1) A change in the company name from ABB Combustion Engineering Nuclear Power, Inc. to CE Nuclear Power LLC<sup>2</sup>
- 2) Deletion of selected proprietary brackets
- 3) Response to NRC RAIs
- 4) Inclusion of supplemental information

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<sup>2</sup> Although this change was made in the header of essentially all pages in the topical report, only those pages on which the name change occurred in the body of the report are included in this appendix.

# ABB COMBUSTION ENGINEERING NUCLEAR POWER

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## ABSTRACT

The CROSSFLOW Ultrasonic Flow Measurement (UFM) System, developed by the Advance Measurement and Analysis Group (AMAG) of Mississauga, Ontario, is being marketed to nuclear power plants worldwide in conjunction with ABB Combustion Engineering Nuclear Power (ABB CENP) of Windsor, CT. The CROSSFLOW UFM System provides a means for plant operators to recover power, currently lost to electric output, by increasing feedwater flow measurement accuracy. CROSSFLOW consists of four (4) ultrasonic transducers mounted on a metal support frame that attaches, externally, to the feedwater piping (or any pipe in which the flow rate is to be measured). The ultrasonic transducers are connected to a Signal Conditioning Unit (SCU) and a Data Processing Computer (DPC). A Multiplexer (MUX) is also available for automatically sequencing measurements on multiple channels. There is one (1) upstream and one (1) downstream transducer station, each station consisting of one (1) transmitting and one (1) receiving transducer which send out the turbulence signatures to the DPC through the demodulating and filtering stages of the SCU. Signatures from the upstream and downstream transducer stations are compared, using the cross-correlation mathematical technique imbedded in proprietary CROSSFLOW software, to obtain a highly accurate feedwater flow rate measurement. A unique advantage of the CROSSFLOW UFM System is that it does not require any intrusion into plant piping and, consequently, cannot compromise pressure boundary integrity. Additionally, maintenance and/or system trouble shooting, if necessary, are also simplified by not requiring any repeated pipe boundary intrusion protocols. The entire CROSSFLOW system is external to the pipe in which flow is to be measured; penetrating pressure boundary piping is unnecessary.

Changed  
company  
name.

CENPD-397-P provides information on the CROSSFLOW UFM System design, its underlying principles of ultrasonic measurement, experimental data validating system accuracy and an overview of installation, proprietary software and setup procedures. The combined effect of these elements is to provide an improvement in flow measurement accuracy over current flow measurement systems. This increased flow measurement accuracy can be translated into a like improvement in the accuracy of the core power level calculation, due to the use of a more accurate feedwater flow in the calorimetric (PWR terminology)/heat balance (BWR terminology) calculation. The measurement uncertainty reduction allows a Utility to:

- 1) Operate the plant at a higher power level without exceeding the 10 CFR 50, Appendix K mandated 102% power margin (attributed to instrument uncertainty).
- 2) To apply the reduced uncertainty to overall margin improvement.
- 3) Recovery of lost generating capacity due to feedwater venturi fouling while staying within the plant's licensed operating power level.
- 4) Possess an in-plant capability for periodically recalibrate the feedwater venturi flow coefficient to adjust for the adverse effect of fouling.

CENPD-397-P does not, however, address the pertinent information for justifying either a higher power level or margin improvement (Items 1 and 2 above). This justification must be provided on a plant specific basis depending upon the application to which individual licensees decide to apply CROSSFLOW's improved flow measurement accuracy. CROSSFLOW can be used in various applications as determined by the Utility. Of the various applications to which CROSSFLOW can be applied, only the justification of operation at a power level that would exceed the Utility's current licensed power level requires prior interaction with the Nuclear Regulatory Commission (NRC).

# ABB COMBUSTION ENGINEERING NUCLEAR POWER

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to reflect page flow and  
addition of appendices.

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## LIST OF ACRONYMS

|          |  |
|----------|--|
| AMAG     | Advance Measurement and Analysis Group         |
| ABB CENP | ABB Combustion Engineering Nuclear Power       |
| ANSI     | American National Standards Institute          |
| ARL      | Alden Research Laboratory                      |
| ASME     | American Society of Mechanical Engineers       |
| BNC      | Bayonet N-Type Compact                         |
| BWR      | Boiling Water Reactor                          |
| CFR      | Code of Federal Regulations                    |
| CNC      | Computerized Numerical Control                 |
| COAX     | Coaxial Cabling                                |
| DPC      | Data Processing Computer                       |
| ECCS     | Emergency Core Cooling System                  |
| EIA      | Environmental Information Association          |
| FSAR     | Final Safety Analysis Report                   |
| LMIE     | Liquid Metal Induced Embrittlement             |
| LSSS     | Limiting Safety System Setting                 |
| M/TSF    | Mounting/Transducer Support Frame              |
| MUX      | Multiplexer                                    |
| NIST     | National Institute of Standards and Technology |
| NRC      | Nuclear Regulatory Commission                  |
| NSSS     | Nuclear Steam Supply System                    |
| OH       | Ontario Hydro                                  |
| OL       | Operating License                              |
| PWR      | Pressurized Water Reactor                      |
| RCS      | Reactor Coolant System                         |
| Re       | Reynolds Number                                |
| RG       | Regulatory Guide                               |
| RSSI     | Received Signal Strength Indicator             |
| SCU      | Signal Conditioning Unit                       |
| SMIE     | Solid Metal Induced Embrittlement              |
| SRSS     | Square Root Sum of the Square Method           |
| UFSAR    | Updated Final Safety Analysis Report           |
| VPCF     | Velocity Profile Correction Factor             |

*Modified  
Company Name.*

# ABB COMBUSTION ENGINEERING NUCLEAR POWER

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## IMPROVED FLOW MEASUREMENT ACCURACY USING CROSSFLOW ULTRASONIC FLOW MEASUREMENT TECHNOLOGY

### 1.0 INTRODUCTION

The CROSSFLOW Ultrasonic Flow Measurement (UFM) System is a joint venture of the Advanced Measurement and Analysis Group (AMAG) of Mississauga, Ontario and ABB Combustion Engineering Nuclear Power (ABB CENP) of Windsor, CT. Currently, the CROSSFLOW UFM System provides a means for nuclear power plant operators to recover lost electrical generation capacity resulting from venturi fouling. This lost power recovery is accomplished within a plant's current licensed power level and has become feasible because of CROSSFLOW's ability to perform a feedwater flow venturi recalibration to remove the adverse effects of fouling.

*Changed  
company  
name.*

CROSSFLOW has been in operation in Canada since 1987 and at this writing has been used in tests or installed for continuous monitoring at over 40 commercial nuclear power reactors in the United States, Canada, South America and Europe over the last ten (10) years. Some utilities have reported a recovery of electrical generating capacity of ~20 MWe or more that would have otherwise been lost due to venturi fouling. Consequently, CROSSFLOW offers utilities a significant operational cost benefit.

Comparisons have been made with plant flow instrumentation, which demonstrate stable CROSSFLOW system performance and accuracy. Further confidence in CROSSFLOW's accuracy has been gained through comparisons with recently calibrated plant instrumentation and chemical tracers. In each case, these independent measurements have actually demonstrated a repeatable accuracy of [            ].

### 1.1 GENERAL DESCRIPTION

CROSSFLOW consists of four (4) ultrasonic transducers mounted on a metal support frame that attaches, externally, to the feedwater piping (or any pipe in which the flow rate is to be measured). The ultrasonic transducers are connected to a Signal Conditioning Unit (SCU) and a Data Processing Computer (DPC). A Multiplexer (MUX) is also available for automatically sequencing measurements on multiple channels. There is one (1) upstream and one (1) downstream transducer station, each station consisting of one (1) transmitting and one (1) receiving transducer which send out the turbulence signatures to the DPC through the demodulating and filtering stages of the SCU. Signatures from the upstream and downstream transducer stations are compared, using the cross-correlation mathematical technique imbedded in proprietary CROSSFLOW software, to obtain a highly accurate feedwater flow rate measurement. A unique advantage of the CROSSFLOW UFM System is that it does not require any intrusion into plant piping and, consequently, cannot compromise pressure boundary integrity. Additionally, maintenance and/or system trouble shooting, if necessary, are also simplified by not requiring any repeated pipe boundary intrusion protocols. The entire CROSSFLOW system is external to the pipe in which flow is to be measured; penetrating pressure boundary piping is unnecessary.

# ABB COMBUSTION ENGINEERING NUCLEAR POWER

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CENPD-397-P provides information on the CROSSFLOW UFM System design, its underlying principles of ultrasonic measurement, experimental data validating system accuracy and an overview of installation, proprietary software and setup procedures. All modes of CROSSFLOW application take advantage of the increased flow measurement accuracy achieved. The combined effect of these elements is to provide an improvement in flow measurement accuracy over current flow measurement systems (e.g., a venturi). This increased flow measurement accuracy can be translated into a like improvement in the accuracy of the core thermal power level calculation, due to the use of a more accurate feedwater flow in the calorimetric (PWR terminology)/heat balance (BWR terminology) calculation. The measurement uncertainty reduction allows a Utility to:

- 1) Use of the increased accuracy to support a license amendment justifying operation at a higher power level ([     ]) by requesting a like reduction in the 10 CFR 50, Appendix K mandated 2% instrument uncertainty margin applied to power level.
- 2) Apply the reduced uncertainty to overall margin improvement.
- 3) Recover lost generating capacity due to feedwater venturi fouling while staying within the plant's licensed operating power level.
- 4) Possess an in-plant capability for periodically re-calibrating the feedwater venturi to adjust for the effect of fouling; thereby, allowing recovery of lost generating capacity while staying within a facility's licensed power level.

Brackets  
removed.

To take advantage of operation at a higher power level, based on relief from certain aspects of 10 CFR 50, Appendix K<sup>3</sup>, Nuclear Regulatory Commission (NRC) interaction in the form of review and approval of a license amendment would be necessary. It is to this application (Item 1 above) that CENPD-397-P is focused. In this regard, CENPD-397-P does not provide the pertinent plant specific information justifying operation at a higher power level. Rather, that justification must be provided by the Utility, on a plant specific basis, depending upon the application to which the Utility decides to utilize the CROSSFLOW UFM System. Instead, CENPD-397-P only addresses, and seeks NRC acceptance of, the increased flow measurement accuracy achieved using the CROSSFLOW UFM System and which are generically applicable to any Utility.

## 1.2 COMPARISON OF CROSS-CORRELATION AND TRANSIT TIME TECHNOLOGIES

Referring to Figure 1-1, the basic difference between the cross-correlation and transit time technologies, is the way that each of these meters measures the velocity of the fluid within the pipe. The transit time technology injects an ultrasonic signal diagonally through the fluid and then measures the difference in the time that it takes the signal to travel upstream versus downstream. It can then be shown that the difference in these times is proportional to the velocity of the fluid in the pipe.

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<sup>3</sup> An exemption to 10 CFR 50, Appendix K will only be necessary until the NRC completes the rulemaking process which is geared toward recognizing the substantial improvement in instrumentation measurement technology and, therefore, the consequential justification for decreasing the currently mandated 2% instrument uncertainty factor applied to power level.

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The fluid flowing within the pipe causes the difference in the upstream and downstream times. When injecting a signal downstream and diagonally across the pipe, the velocity vector of the fluid in the plane of the ultrasonic signal adds to the acoustical velocity of the fluid. Consequently, the velocity of the ultrasonic signal going downstream is slightly faster than the acoustical velocity of the fluid. When the process is reversed and the ultrasonic signal is injected upstream and diagonally across the pipe, the velocity vector of the fluid in the plane of the ultrasonic signal now subtracts from the acoustical velocity. This results in an ultrasonic velocity that is slightly less than the acoustical velocity of the fluid. The difference in these times is on the order of a few microseconds.

The two equations that describe the time for the ultrasonic signal to travel upstream and downstream can be written as:

$$t_u = L_t/[a - V \cos(\alpha)] \quad \text{Eq. 1-1}$$

$$t_d = L_t/[a + V \cos(\alpha)] \quad \text{Eq. 1-2}$$

where:  $t_u$  is the time that it takes for the ultrasonic signal to travel upstream through the fluid. If the transducers are mounted on the outside of the pipe, the measured time delays must be corrected for the time that it takes the ultrasonic signal to travel through the walls of the pipe.

$t_d$  is the time that it takes for the ultrasonic signal to travel downstream. This signal must also be corrected for transport time through the pipe walls, if the transducers are mounted on the outside of the pipe.

$L_t$  is the diagonal distance that the ultrasonic signal must travel through the fluid when using the transit time technology.

$A$  is the acoustical velocity of the ultrasonic signal in the fluid

*Corrected capitalization.*

$V$  is the velocity of the fluid in the pipe

$\alpha$  is the angle that the diagonal signal makes with the axis of the pipe

Equations 1-1 and 1-2 can be combined to obtain an expression for the velocity of the fluid in the pipe as a function of these parameters:

$$V = a^2(t_u - t_d)/2L_t \cos(\alpha) \quad \text{Eq. 1-3}$$

The cross-correlation meter measures the velocity of the fluid by determining the time that it takes for a unique pattern of eddies to pass between two sets of transducers. When using this meter to measure the velocity, an ultrasonic beam is injected perpendicular to the axis of the pipe rather than diagonally as is required for the transit time meter. As the ultrasonic signal passes through the fluid, the eddies within the fluid modulate the ultrasonic signal, creating a phase shift, which is unique to the eddies passing through the ultrasonic beam at that moment in time. These same eddies then pass through a second ultrasonic beam that is located a known distance downstream of the first beam. Once again these eddies modulate the second ultrasonic beam in the same manner as they did the first beam. The only difference between the two modulated signals is the difference in the time that it took for the eddies to pass between the two ultrasonic beams.

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## 1.4 CROSSFLOW INSTALLATION AND OPERATING FEATURES

The CROSSFLOW UFM System offers features that are beneficial during both system installation and operation. Although CROSSFLOW does not replace the plant venturimeter, it offers significant advantages over the venturimeter in its ability to precisely measure feedwater flow. The uncertainties associated with venturimeter accuracy such as fouling, instrumentation drift and calibration are essentially eliminated for the CROSSFLOW UFM System. Therefore, the uncertainty of the flow measurement can be reduced from well over 1%, in many cases, to [ ] or less, depending on the specific plant installation.

Bracket  
removed.

Some of CROSSFLOW's more significant features are summarized below.

### 1.4.1 EXTERNALLY MOUNTED

The CROSSFLOW UFM System externally attached Mounting/Transducer Support Frame (M/TSF) offers significant flexibility in both the timing and ease of installation. Since the M/TSF is mounted externally on the surface of the pipe, it is not necessary to cut into the pressure boundary to install a spool piece. This one feature precludes the necessity of scheduling the installation during a plant outage. Rather, installation and commissioning can be performed while the plant is on-line (only installations in a high radiation area would preclude an on-line installation). This has the additional advantage of allowing work to be done when plant staff is less likely to be distracted by other pressing needs due to typically tight outage schedules.

### 1.4.2 INSTALLATION LOCATION FLEXIBILITY

Another unique feature of the CROSSFLOW UFM System that has become apparent is the ability to calibrate the meter where the velocity profile may not be fully developed. For example, it is possible to encounter a piping configuration where the upstream flow conditions prevent the flow from being fully developed at the desired installation location. However, flow conditions may be fully developed at a location further upstream or downstream of the desired installation point. Because of the ease with which the CROSSFLOW meter can be installed, it is possible to install a second meter at one of these locations and calibrate the permanent meter on-line; at the desired installation location. This has a distinct advantage, in that the meter is calibrated at full power under actual operating conditions, thus eliminating the need to perform model tests.

### 1.4.3 VELOCITY PROFILE CORRECTION FACTOR ALGORITHM

Perhaps the most important feature of the CROSSFLOW UFM System is the algorithm used to calculate the Velocity Profile Correction Factor (VPCF). The theoretical bases for this equation which, for fully developed flow, is only a function of Reynolds Number is discussed in Section 2.0 of this report. Section 4.0 discusses how the algorithm was verified at a national hydraulics laboratory. It is shown through multiple weigh tank and limited in-plant tests, where the accuracy of the in-plant instrumentation had recently been verified, that this simple algorithm accurately predicts the changes in the VPCF for Reynolds Numbers ranging from below  $<1 \times 10^6$  to  $\sim 25 \times 10^6$ . Furthermore, it is shown that

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the equations that form the bases for this algorithm can be traced to classical hydraulics that have withstood the test of time through many years of laboratory and field verifications.

## 1.4.4 STATISTICALLY ROBUST FLOW MEASUREMENTS

Another feature of the CROSSFLOW UFM System that contributes to its accuracy and repeatability is the statistically robust nature in which it achieves the flow measurements. Unlike other algorithms that rely on a time-of-flight principle of one or more ultrasonic beams, the CROSSFLOW meter tracks thousands of eddies within the fluid, with each eddy imparting its own distinct time to the determination of the velocity of the fluid. With this large amount of data and the ability to conduct these measurements in milliseconds rather than nanoseconds, the reliability and repeatability of the meter is greatly improved.

## 1.4.5 TRANSDUCER ORIENTATION

Repeatability is also enhanced by the simple perpendicular orientation of the ultrasonic transducers to the flow stream. Because of the perpendicular orientation, errors due to path length and path angle, which must be dealt with when using the transit time technology, are eliminated along with their associated uncertainties when using cross-correlation technology.

## 1.5 CROSSFLOW UFM SYSTEM ACCURACY

Based on the above features (and others discussed later), the CROSSFLOW UFM System is able to achieve an accuracy of [ ] or better with a 95% confidence interval. When credit is taken for this feedwater flow measurement accuracy in a plant's thermal power calculation, it can easily be shown that the uncertainty of the calculation falls well below [ ] with a 95% confidence interval. Thus, a utility is presented with the opportunity to take advantage of a power uprate to increase the electrical output of their plant, yet still remain bounded by the existing Appendix K ECCS analyses. Brackets removed.

## 1.6 REASON FOR TOPICAL REPORT

The purpose of CENPD-397-P is to provide a source for a CROSSFLOW UFM System description and justification of improved measurement accuracy, suitable for reference (i.e., the generic elements) by Utilities employing the CROSSFLOW UFM System to pursue operation at a higher power level; based on the improved flow measurement accuracy achieved. In so doing, the resources of the Utility, AMAG, ABB CENP and the NRC are conserved by providing a one time review and approval for the generically applicable elements of the CROSSFLOW UFM System. Each Utility should, therefore, only have to provide the plant specific implementation information and safety analysis considerations on their docket via a 10 CFR 50.90 license amendment; along with an exemption request to 10 CFR 50, Appendix K and a reference to the NRC approved version (i.e., "-A") of CENPD-397-P. Changed company name.

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## 3.2.4.6 Digital Signal Processing and Flow Calculation

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## 3.2.5 SOFTWARE VERIFICATION AND VALIDATION

CROSSFLOW software is under configuration control and, verification and validation (V&V) is performed in accordance with the ABB CENP, Quality Procedures Manual, QPM 101, Section QP 3.13 – Computer Software (Reference 3-4). Following this procedure, the software is evaluated to determine its adequacy for its intended use, V&V activities are identified and documentation needed to be placed under configuration control defined.

Prior to release of a CROSSFLOW software version revision, the V&V of the software is performed in accordance with ABB CENP implementing procedure, MISC-PENG-TOP-007, Revision 00, 08-26-1997, "Procedure for the Verification and Validation of the AMAG CROSSFLOW Meter Software" (Reference 3-5). This procedure utilizes software verification tests performed in accordance with AMAG procedure, AMAG-I-004, Revision 03, "Software Verification and Validation Instruction" (Reference 3-6).

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### 3.2.5.1 Verification and Validation Method - Time Delay and Flow Rate Calculation

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## 4.0 CROSSFLOW CALIBRATION AND VALIDATION

The CROSSFLOW UFM System was calibrated at the Alden Research Laboratory (ARL) for Reynolds Numbers ( $Re$ ) ranging from  $0.8 \times 10^6$  -  $7 \times 10^6$ .

The objective of the calibration was to determine an expression for the Velocity Profile Correction Factor (VPCF) using the form of the equation established in the previous theory discussion (see Section 2.2). This approach provides a traceable calibration to the National Institute of Standards and Technology (NIST) with a verifiable uncertainty for the VPCF.

This section describes the method of calibration, the results and the uncertainty of VPCF. A discussion is also presented regarding the extension of the VPCF to higher Reynolds Numbers. That is, to conditions representative of those encountered in nuclear power plant feedwater systems ( $\sim 30 \times 10^6$ ).

## 4.1 CROSSFLOW CALIBRATION

[

*Discussion  
modified.*

]

*Discussion  
modified.*  
Eq. 4-5

[

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Figure 4-1 shows the close correlation between the theoretical Equation 2-17 for the velocity profile correction factor and Equation 4-7, the correction factor based on the [ ]. Although Equation 4-7 is based on Reynolds Numbers of less than  $7 \times 10^6$ , it can be seen that when this curve is extrapolated to much higher Reynolds Numbers, it still tracks the theoretical curve quite closely.

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modifi

## 4.2 PROFILE VALIDATION AT HIGHER REYNOLDS NUMBERS

The calibrated VPCF was developed using weigh tank data from the ARL. Due to the nature of these cold water tests, it was not possible to reproduce the operating conditions and the Reynolds Numbers that are normally present in nuclear power plant feedwater systems. Hence, a limited amount of data has been collected from several plants where the accuracy of the in-plant flow instrumentation was independently confirmed through weigh tank tests at ARL. This data, which ranges up to a Reynolds Number of  $25 \times 10^6$ , was used to calculate a VPCF much like what was done for the ARL tests. These data points have been included in Figure 4-2 for comparison with the calibrated VPCF curve. In addition to the two (2) data points from operating plants, data has also been included from Ontario Hydro's specially constructed high temperature test loop plus other verification tests from the Everest Hydraulic Laboratory in Chatou France and NIST. Thus, a spectrum of independent data is provided covering both the expected operating and the calibrated range for the CROSSFLOW cross-correlation meter.

Two additional data points, "plant data 2" have also been included in Figure 4-2. This data was obtained from a plant, where CROSSFLOW meters were installed on two smaller feedwater pipes that were feeding into a common header with a third CROSSFLOW meter. Equation 4-6 was used for all three measurements, but it was possible to use correction factors from Equation 4-6 as standards that were just above or below the "OH High Temp" data to compare with CROSSFLOW readings that were significantly higher than the "OH High Temp" data.

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## 4.3 CONCLUSIONS

An accurate curve has been developed for the VPCF that is only a function of Reynolds Number. This curve assumes that the velocity profile is fully developed and that pipe wall friction is small. The use of plastic piping for the calibration provides a limiting condition that assures that the velocity measured by the CROSSFLOW cross-correlation meter will be equal to or greater than the actual velocity of the fluid. This in turn assures that the mass flow and, hence, the thermal power will be equal to or greater than the actual output of the reactor; a conservative condition.

*Discussion  
modified.  
Figure 4.3  
added.*

Moreover, the high Reynolds Number tests confirmed that the calibration curve, which was developed at low Reynolds Numbers, is also applicable at higher values which includes those conditions that would be encountered in operating nuclear power plant feedwater systems.

## 4.4 REFERENCES

4-1 [  
    ]  
    ]

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modified

] Eq. 5-24

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## 5.6.2 VELOCITY PROFILE CORRECTION FACTOR CONFIDENCE INTERVAL

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*Discussion  
modified.*

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## 5.7 FEEDWATER FLOW DENSITY 95% CONFIDENCE INTERVAL

[

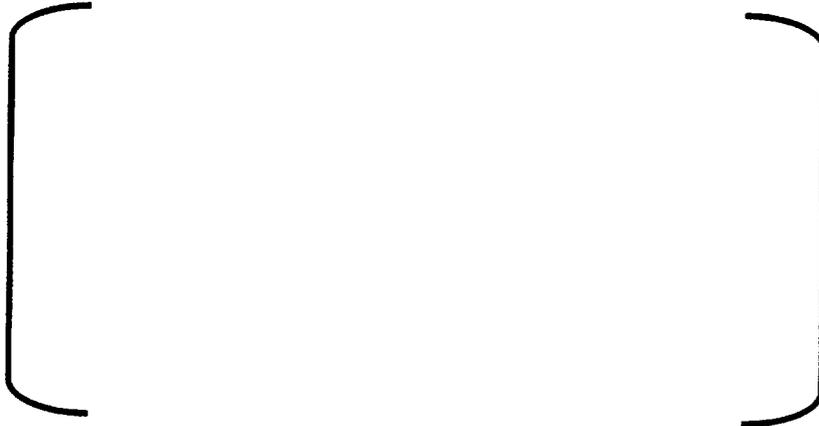
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**TABLE 5-1**

**TYPICAL CROSSFLOW UNCERTAINTY**

**95% CONFIDENCE INTERVAL**

PARAMETER



The table content is missing, indicated by large empty brackets.

Table presentation  
modified.

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## 8.0 CROSSFLOW FIELD IMPLEMENTATION

CROSSFLOW is simple to install and operate. This section discusses the principal steps taken during installation of the CROSSFLOW system to assure proper performance with the high degree of accuracy discussed in Section 5.0. In addition to the physical installation, initial system setup is also discussed. The discussion that follows is simply an overview. An actual CROSSFLOW installation and setup is governed by detailed step-by-step procedures (reference 8-1) that require the documentation of key installation/setup steps and important parameter values.

## 8.1 HARDWARE INSTALLATION - GENERAL

A trained ABB CENP or AMAG representative performs the initial installation of both the CROSSFLOW hardware and software. [

*Changed  
company  
name.*

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The initial step performed by the installation team is a pre-installation survey. This survey identifies the installation location, the pipe outside diameter, the pipe material and its method of fabrication (i.e. rolled plate, forged, extruded, etc.). From this information the transducer mounting hardware is custom fabricated to the specific pipe on which it will be mounted. [

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## 8.1.1.1 Pipe Outside Diameter Determination

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## 8.1.1.2 Pipe Wall Thickness Determination

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name.

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