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March 17, 2000

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Attention: Mr. Stuart A. Richards
Project Director
Project Directorate IV & Decomissioning

Subject: ABB Response to March 8, 2000 Caldon Meeting with NRC

Dear Mr. Richards:

On Monday, March 13, we received a copy of an ABB e-mail authored by Mr. Ian C. Rickard providing ABB's general perspective on the March 8, 2000 presentations of Caldon and ultrasonic flow meter industry experts to the NRC. While a number of issues raised in the e-mail are troublesome, I would like to bring two of them to your attention. (I provide the report portion of the e-mail as Attachment 1.)

The first issue relates to the fact that the CROSSFLOW meter does not view the entire flow profile, a point which was addressed in our March 8, 2000 presentation. However, in Attachment 1, ABB states that "The only possible new concept is that of coverage – since the eddies are less strong near the edge of the pipe, they tend not to contribute to the signal – therefore it can be argued that the instrument does not see 100% of the pipe". Of course, as we have discussed, the poor coverage of the flow profile by this meter is not a new concept and must be fully addressed in the ABB Topical Report to properly evaluate instrument accuracy.

The second issue relates to flow profiles in power plants. Regarding this issue, ABB states that "In practice, this is not an issue for CROSSFLOW because it is intended for use in areas of fully developed flow". As stated by industry experts during the March 8, 2000 meeting, the flow in feedwater pipes in nuclear power plants is rarely, if ever, fully developed. To apply an instrument to this application when the instrument is intended for use in areas of fully developed flow, implicitly introduces potentially large systematic errors. For CROSSFLOW, bounding the errors appears to be quite difficult even when the instrument is installed on long straight pipes that usually create fully developed flow. (For example, see Attachment 2, an evaluation of an ABB report provided to a licensee with plant specific data bearing on this issue. This report calls into question the ability to calibrate CROSSFLOW on a sound scientific basis.) Dr. Mattingly of NIST had this in mind when he stated in the March 8 meeting "In a real power plant I shudder to think what the excursions could be from those levels (of 1% to 3%)".

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I understand how difficult it can be to give meaningful review to the technical work of others when there is no adequate first-principles theory behind the work. Without first principles to support the theory, the only recourse is to analyze a large body of empirically derived data and to make conservative judgments. Actual field data available to Caldon. (as in Attachment 2 for example) highlight the need for greater theoretical understanding in order to control uncertainties, some of which exceeded 3%. Until better theory is available, it may be possible to conduct a number of well constructed tests to provide the data needed to understand and bound the uncertainties. I recommend that this be considered here.

In closing, it is our understanding that ABB and the NRC staff have agreed that ABB will provide written comments on the transcript answering the technical questions raised. I request that my letter of March 15, 2000 and this letter be made a part of that transcript requiring ABB response, as well. I appreciate your patience and understanding regarding our unusual involvement in this process. However, as stated during the March 8 meeting this is an important safety issue and all information bearing on it should be fully considered prior to a final decision. We would welcome the opportunity to meet with you and the staff again (or with ABB and the staff) to discuss these issues in an open forum.

Respectfully,

Calvin R Hastings

Calvin R. Hastings
President and CEO

CRH/ta

Attachments

cc: Brian W. Sheron
John S. Cushing

P.S. We have just received a copy of ABB's letter of March 13 to the NRC responding to the Caldon meeting with the NRC on March 8. It raises questions that we will respond to on Wednesday.

Attachment 1

Subject: Caldon Presentation to NRC, March 8, 2000

I attended the Caldon/NRC public meeting on March 8. I was accompanied by Chip French of ABB and Yuri Gurevich of AMAG. Because of the short notice, a transcript of the meeting was taken.

Cal Hastings, President & Founder of Caldon Inc., introduced the dozen or so people he had brought with him, including 2 attorneys (from Winston & Strawn) and half a dozen consultants (who he referred to as a blue ribbon panel). The purpose of the meeting was, in his words, to bring a serious matter to the attention of the NRC. The premise of the presentation was that ABB/AMAG's acuracy claims for CROSSFLOW, which were "published" in the Special Edition of CROSSFLOW Currents, datedJanuary, 2000, are unachievable by an externally mounted cross-correlation UFM. Caldon believes " that this issue is important to safety" and they "had to do something". Mr. Hastings was the very model of the indignant, public spirited individual. Given that, he did not explain why it was necessary to bring thirteen people, including two attorneys, to make his point.

The two main areas identified as major sources of error by Caldon were those from acoustic effects, such as scattering and reverberation of sound waves and those from flow distortions, often referred to as velocity profile effects. "You can see why I was surprised by the newsletter. By our accounting, the overall bounding uncertainty for an external cross-correlation flowmeter (such as the one under review by the NRC) is greater than 1.4%.") Caldon contends that this is a safety issue because it greatly increases the probability that a plant will operate in excess of licensed power. Caldon reviewed the submittal that they had made to the NRC. The documents are intended to provide published information about fluid flow and acoustic effects for each of the fluid flow measurement technologies. There was no acknowledgement that Caldon does not have access to the design of the Crossflow instrument nor do they have access to the proprietary information that forms the basis of the Crossflow Topical Report. That is why it has been relatively easy for the NRC reviewer to dismiss the majority of the Caldon concerns. Also, since Caldon does not know what was included, it is plain to me that this was a scatter-shot smear exercise, hoping that at least one of the allegations would take hold.

Caldon presented an overview of their concerns. The main contention, based on a simulation of how Caldon believes that the instrument is operated, is that there are inherent uncertainties in the cross-correlation technology that "would support an accuracy of between 1% and 3% rather than 0.5%." These issues have all been covered in depth in the ABB/AMAG Topical Report. There were no surprises - the ABB/AMAG experts understand these issues and have properly accounted for them in the Topical Report. It is believed that the NRC reviewer (Iqubal Ahmed) understands this and agrees that our analysis is correct. The only possibly new concept is that of coverage - since the eddies are less strong near the edge of the pipe, they tend not to contribute to the signal - therefore it can be argued that the instrument "does not see" 100% of the pipe. In practice this is not an issue for Crossflow because it is intended for use in areas of fully developed flow.

The "experts" each said a few words. They had very little time and added nothing specific about Crossflow performance because they know nothing about the specifics of its performance. They, for the most part recounted some of the general horrors associated with UFM measurements in general. The only somewhat disturbing presentation was from Dr. George Mattingly of NIST who has performed intercomparisons of UFMs. He made a blanket statement that clamp-on instruments of this type have uncertainties in the 1 to 3% range.

There were no NRC questions or comments during the 90 minutes of presentations. Stu Richards caucused briefly with members of the staff involved in the review. He thanked Caldon for coming in, said the staff is familiar with the material and that he was not in the meeting to debate the ABB Topical Report. They had no comments or questions and the NRC will take Caldon's comments under consideration.

I have the handouts from the meeting and the list of attendees. Please call me if you have any questions.

ABB will issue a rebuttal to this presentation.

Ian Rickard

Attachment 2

Memorandum

Date: March 17, 2000

To: Cal Hastings

From: Scott Corey

Subject: Experience at Palo Verde with AMAG Cross Correlation Meter

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Background

You requested that I obtain data from plants to be included in our analysis of ultrasonic cross correlation type flowmeters. The attached report includes data and results of the tests that were conducted Palo Verde Units 1, 2 and 3 with the AMAG Cross Correlation Meter (CROSSFLOW Meter). The attached report was prepared by ABB, to document the results of these tests and to justify the use of "corrected" CROSSFLOW measurements for adjusting plant power levels to recover possibly "lost" power due to venturi fouling. This memo discusses the results and their relevance to the accuracy of ultrasonic cross correlation meters. I believe that there are a number of fundamental weaknesses in the calibration and measurement approaches, assumptions and conclusions that are employed ABB in the report. Most importantly, this report includes direct evidence of significant systematic errors (over 3%) in the application of their meter that would not be eliminated no matter how many measurements were made in a plant.

Analysis

Tests were conducted on each of the Palo Verde units with the CROSSFLOW meter. Key points from the report and their relevance to the accuracy of the feedwater flow measurement are discussed below.

- The introduction of the report states that the "purpose of these tests was to independently measure the feedwater flow in Units 1 and 3 after having calibrated the meter on Unit 2." Specifically, ABB planned to determine appropriate profile factors for their meters by testing first on Unit 2 where the plant believed that the venturis were not fouled. Since the piping configuration in all three units is identical, they then planned to apply the profile factors determined based on the Unit 2 testing to the other units.
- The accuracy of these measurements is therefore limited by the accuracy of the Unit 2 venturi indications and the assumption that they are not fouled. Caldon demonstrated in their Topical Report ER-80P, that the typical accuracy of the venturi flow in a two loop plant was ±1.4%. The staff concluded that this estimate was probably low. This uncertainty would combine with the CROSSFLOW meter's other installation specific uncertainties to arrive at the total test uncertainty which would be over 1.4%.

- The report states that they used "the calibration coefficient (profile factor) which is based on smooth pipe" to obtain the "Uncalibrated" results. The CROSSFLOW results based on the laboratory profile factor, "Uncalibrated" results, are summarized in Table 1 below. These results show that the CROSSFLOW meter read over 3% above the Unit 2 venturis. This indicates a systematic bias in the application of the test laboratory profile factors to the plant of over 3%. ABB explains this bias as follows: "a review of the CROSSFLOW data for Palo Verde has led ABB to conclude that relatively high pipe wall friction is causing the high flow reading at Palo Verde. When friction is present, the velocity profile near the center of the pipe becomes greater due to the reduced velocity near the surface of the pipe. As a result the meters readings are biased high because it is only looking at the velocity profile near the center of the pipe. Thus, the calibration coefficient which is based on smooth pipe must be reduced to compensate for the increased velocity near the center of the pipe when friction is present." Note that this conclusion is consistent with the systematic uncertainty assessment owing to pipe wall roughness from Dr. Roger Horn's report.
- The recognition in the attached report that the CROSSFLOW meter only measures velocities "near the center of the pipe" is also consistent with Dr. Horn's report. It is inconsistent with ABB's statement in their e-mail of March 13, 2000, which states that Caldon raised a new issue in their March NRC meeting when they "argued that the instrument does not see 100% of the pipe." In this email, ABB states that "In practice, this is not an issue because it is intended for use in areas of fully developed flow." ABB concluded based upon in plant testing and testing at the National Research Center that the flow at Palo Verde was fully developed. Despite the fact that the flow was fully developed, these results, by their own admission, contain a systematic bias of over 3% due to wall roughness differences between the plant and the laboratory.
- Table 1 also includes the CROSSFLOW indications relative to the plant venturis after being calibrated to the Unit 2 venturis. On Unit 3, there is a significant difference between the fouling indicated by the CROSSFLOW meter on the two venturis (2.8%). A similar, although smaller disparity, is observed in the Unit 1 results. The report suggests that "if one reduces the Unit 1 Loop 2 plant data by 1.5%, the amount the plant believes the venturi is fouled, the agreement of the ratios (Loop 1 to Loop 2 ratio) is improved significantly." This exercise in manipulation demonstrates the necessity for an instrument that can be calibrated independent of plant instruments with large uncertainties. The report concludes that the results after all of these calibration adjustments are "quite close to the predicted level of fouling." This is not surprising because the assumptions were modified to match CROSSFLOW instrument results.
- The report documents systematic uncertainties greater than 3% and potentially large random uncertainties as indicated by the flow splits, justifies the results by modifying the assumptions to match the results and concludes with the recommendation to increase power based on the results. On this basis, the

report concludes " the rations of the CROSSFLOW meter readings are in good agreement with the ratios of the plant flow data."

- As you know, thorough analysis of plant heat balance data and redundant plant indicators can yield estimations of venturi fouling which are reasonable guesses. However, clearly these guesses do not have anywhere near the accuracy required to apply absolute corrections for fouling or they would be used for that purpose and there would be no need for independent flow measurement devices like the LEFM and CROSSFLOW meter. In fact, Palo Verde performed a detailed uncertainty analysis on the accuracy of their fouling predictions and concluded that it was not sufficiently accurate to correct the venturis for dynamic fouling let alone correct for absolute venturi biases. ABB selectively uses data to support their results.

Table 1. Comparison between AMAG Meter and Palo Verde Venturis: Pre and Post Calibration to Unit 2 Venturis

	Uncalibrated Difference Between Plant Venturis and AMAG Meter (Note 1)	Calibrated Difference Between Plant Venturis and AMAG Meter(Note 1)
Unit 1, Loop A	4.0%	0.6%
Unit 1, Loop B	2.4%	-0.8%
Unit 2, Loop A	3.4%	0.0%
Unit 2, Loop B	3.2%	0.0%
Unit 3, Loop A	1.2%	-2.2%
Unit 3, Loop B	3.8%	0.6%

Notes:

1. Negative sign indicates that the AMAG meter was below the plant venturi.
2. This table is copied from Table II from the attached ABB report.

CALIBRATION OF THE PALO VERDE FEEDWATER VENTURIS USING THE AMAG CROSSFLOW ULTRASONIC FLOWMETER

INTRODUCTION:

On December 2, 1996, ABB and its contractor, AMAG conducted ultrasonic feedwater flow measurements using the AMAG CROSSFLOW meter. The purpose of these tests was to independently measure the feedwater flow in Units 1 and 3 after having calibrated the meter on Unit 2. If it could be shown that the venturis are reading high due to venturi fouling, then adjusting the venturi flow coefficients to compensate for the fouling would allow the electrical output of the Units 1 and 3 to be increased.

CROSSFLOW METER OPERATION:

The CROSSFLOW meter measures flow by injecting an ultrasonic signal through the pipe wall and into the feedwater perpendicular to the axis of the pipe. This signal which is modulated by the eddies within the fluid is received by a second transducer mounted on the opposite side of the pipe. A second set of transducers are mounted a known distance downstream of the first set. The ultrasonic signal from these transducers is also modulated by same eddies but displaced in time by the time that it takes for the eddies to pass between the two sets of transducers.

Both the upstream and downstream signals are passed through low pass filters which remove the high frequency carrier frequency leaving only a modulated wave form which is characteristic of the eddies passing through the ultrasonic signal. Since the two wave forms from the upstream and downstream transducers sets are similar but displaced in time by the time that it takes for the eddies to pass between the two sets of transducers, a mathematical process called cross-correlation can be used to determine the time displacement between the waves. By dividing the physical distance between the two transducer sets by the time displacement, one can calculate the velocity of the eddies and hence the velocity of the fluid within the pipe

Because the eddies that are tracked by the meter are mainly located near the center of the pipe, the velocity that is measured by the meter is higher than the bulk velocity of the fluid. To correct for this, the meter is calibrated at a hydraulic laboratory where the bulk velocity is measured using a weigh tank. The meter velocity is then divided into the weigh tank velocity to obtain a correction factor for the meter velocity. The resulting flow equation for the CROSSFLOW meter is:

where:

W_{fw}	=	the feedwater flow
C_f	=	the calibration coefficient which converts the measured velocity to the bulk fluid velocity.
A_p	=	the cross-sectional flow area of the pipe
ρ	=	the density of the fluid.
L	=	the physical distance between the two sets of transducers.
Δt	=	the time that it takes for the eddies to move between the two sets of transducers.

METHOD OF TESTING:

The planned method of testing was to measure the feedwater flow in loops 1 and 2 of Unit 2 and then to develop a calibration factor for each loop by taking the ratio of the venturi readings for these loops and dividing them by the corresponding output of the CROSSFLOW meter. At the time, it was believed that the Unit 2 venturis were clean and would provide the most accurate calibration for the CROSSFLOW meter. The meter would then be mounted on Units 1 and 3 where they would be used to independently measure the flow in each of the loops using the Unit 2 calibration factors.

In order to determine the flow in each loops, it was necessary to measure the outside diameter and pipe wall thickness of each pipe Using the average diameter and pipe wall thickness, one can calculate the cross-sectional flow area of the pipe. The transducer spacing was determined after the brackets were mounted on the pipes. This allowed the brackets to come into thermal equilibrium with the pipes, thus accounting for any increase in the spacing due to thermal expansion of the bracket

Feedwater flow and temperature was recorded while the CROSSFLOW meter readings were being taken. This information provided an average plant flow and feedwater density so that a one to one comparison could be made between the meter and plant instrumentation.

Several difficulties were encountered while performing these tests. While measuring the pipe diameters and wall thicknesses, it was observed that the outside surface of the pipes was marred by a pattern of small groves. When an attempt was made to measure the pipe wall thickness using a UT meter, difficulties were encountered in obtaining a reading because the small groves scatter the ultrasonic signal. To overcome this, the surface of the pipes were sanded in the areas where the readings were to be taken. Unfortunately, this had the affect of reducing the pipe wall thickness in relation to the diameter readings which included the groves. Ultimately, it was decided to sand the pipes where the thickness measurements were to be taken and then measure the diameter in the same locations.

When the pipe diameter data was evaluated, it was determined that there was a discontinuity in the Unit 1 loop 2 pipe diameter. Because it was not possible to determine the impact of the flow disturbance on the CROSSFLOW meter readings, it was decided repeated the measurements on this loop in January.

During the January test, flow measurements readings were taken downstream and upstream of the discontinuity which showed that the readings had been affected by the discontinuity. Thus, new readings were taken upstream of the discontinuity for the final flow measurements to be used in this report.

At the time of January test, measurements were also taken using a 12 in bracket spacing - all previous readings had been taken with a 24 inch spacing. These readings were significantly lower than the corresponding readings with the 24 inch brackets. Since this shift was not understood, a commitment was taken to investigate this affect at a hydraulics laboratory. The results of hydraulic laboratory tests confirmed that the spacing could affect the meter readings. Table I summarizes the laboratory results:

From this data, it can be seen that the flow coefficient for the National Research Center 6 inch spacing is higher than for the 12 and 24 inch spacings. This means that a 6 inch spacing or more generically, a spacing which is 0.5 pipe diameters must be multiplied by a larger coefficient than the 12 or 24 inch spacings when measuring the same flow. We see a similar difference between the Palo Verde spacings of 0.59 and 1.18 pipe diameters. For example on Unit 3, the 0.59 diameter spacing gave a reading of 8,705 while the flow for the 1.18 diameter spacing was 8,862 K#/hr. If one multiplies the 0.59 diameter flow by the ratio of the change in flow coefficients (assuming a linear variation in the coefficient between 0.5 and 1.0 diameters), a flow is obtained which is much closer to the 1.18 diameter reading, 8,851 versus 8,862 K#/hr. Although this is not a precise comparison, it does demonstrate that correcting the coefficient for the particular spacing helps to align the different readings obtained by the meter.

Another significant difference was the absolute readings obtained by the meter and the venturis (see Table II, Plant - Uncalibrated Difference column). Differences of as much a 4% were observed. Several tests were run in an attempt to determine the root cause of this difference. They included a tests for swirl and meter position.

The swirl test was run by disconnecting the downstream bracket frame that holds the transducers and rotating it about the pipe. It was reasoned that if the fluid was rotating in the pipe, the eddies passing through the upstream transducer set would be rotated out of the plane of the downstream transducers, thus limiting the correlating eddies to region near the center of the pipe where the velocity is the highest which in turn would cause the meter to produce a higher flow reading. This test showed that the maximum time delay and hence the maximum correlation was obtained when the frame were not rotated. Thus, it was concluded that little if any swirl is present in the feedwater pipes.

The second test involved moving the bracket downstream of the original test location. The purpose of this test was to verify that the flow was fully developed. Again, the measurements were quite close to the readings taken at the test section. This result was consistent with the National Research Center measurements which indicated that fully developed flow downstream of a 180 degree bend should be achieved in about 18 pipe diameters.

RESULTS:

The results of these tests are presented in Table II where plant data from Unit 2 was used to calibrate the CROSSFLOW meter for each of the loops. The calibration factors from these loops were then used to predict the flows in Units 1 and 3.

The column "Plant-Calibration Difference" shows the potential increase in electrical power that can be achieved. Because Unit 2 plant data was used to calibrate the meter, there is no corresponding increase in electrical power for this Unit. The Unit 1 data shows that the loop 1 plant instrumentation is providing a flow that is lower than the CROSSFLOW measurement while the loop 2 plant data is higher than the CROSSFLOW readings. Thus, there is a net gain in electrical output for Unit 1 of only 0.095%.

The Unit 3 data shows a similar pattern with the loop 1 plant data being significantly higher than the CROSSFLOW readings while the loop 2 plant data is lower. Implementing these corrections would result in a net increase in electrical output of 0.80%.

A review of the data in Table II also shows that "Uncalibrated CROSSFLOW" data is greater than the corresponding "Plant Data" yet the ratios of CROSSFLOW loop flows and plant data loop flows are quite close for Unit 2, 1.040 versus 1.043. Units 1 and 3 do not show such close agreement. However, if one reduces the Unit 1 loop 2 plant data by 1.5%, the amount that the plant believes the venturi is fouled, the agreement of loop ratios is improved significantly. This is shown in Table III where the ratios are 1.035 and 1.036

A similar adjustment to the Unit 3 loop 1 plant data improves the ratio but does not show the close agreement seen with Units 1 and 2 In this case, the loop 1 plant data was reduced by 0.7%, the amount of fouling that plant personnel believe had occurred on this venturi. One would conclude from these results that Unit 3, loop 1 venturi has fouled more than originally believed.

As noted earlier, it was believed that the Unit 2 venturis had not fouled. However, it was also believed that Unit 1 loop 1 and Unit 3 loop 2 had also not fouled. Therefore, one should also be able to calibrate the CROSSFLOW meter using these loops Table IV presents the results if these loops are used for the calibration. Referring to the "Plant - Calibration Difference" column, results appear to be more consistent. There are no positive readings indicating that a venturi in low, a non-conservative condition. Furthermore, the Unit 1 loop 2 difference is now -1.36% which is quite close to the predicted level of fouling, 1.5%. This table also shows that Unit 2 is slightly fouled, -0.61 and -0.57% for a net difference of -0.59%. Thus, using Unit 1, loop 1 and Unit 3, loop 2 for the calibration standard, it can be shown that the output on Unit 2 can also be increased.

CONCLUSIONS AND RECOMMENDATIONS:

It is recommended that Unit 1, loop 1 and Unit 3, loop 2 be used as the calibration standards rather than Unit 2. If these loops are used, the electrical output of Unit 1 can be increased 9.05 MWe, Unit 2 by 7 9 MWe and Unit 3 by 18.5 MWe. If Unit 2 were to be used as the calibration standard, the increase in electrical output would be 1.3 MWe for Unit 1 and 10.7 MWe for Unit 3. There would be no increase for Unit 2 since it is assumed to be correct.

It is recommended that these corrections be made immediately rather than wait until the venturis are cleaned. Even if there is a small amount of fouling on the venturis that are to be used as the calibration standards, this will only result in the Units not being run at full power, it will not create a situation where the Units would exceed their licensed power limits. For example, if Unit 1, loop 1 and Unit 3, loop 2 were still fouled by 0.5%, this would mean that the three Units would all be running at 99.5% rather than 100% power. Implementing this recommendation would allow APS to recover over 35 MWe in the near term. In this example, the final 0.5% could be recovered once the venturis are cleaned. It should be noted that these additional corrections could be made without further testing, since the CROSSFLOW meters would already be in-place.

The results of these test indicate that the CROSSFLOW meter correctly predicts the relative amounts of flow for Units 2 and Unit 1 when an adjustment is made for fouling in loop 2 Unit 1. For Unit 3, where agreement is not as close, steam to feedwater flow data gathered over several fuel cycles indicates that the flow has probably decreased more than is presently being assumed. To confirm this, it is recommended that the documented change in steam to feedwater flow be reviewed for the past few cycles to determine first if the change was ever constant and if it was, how much the ratio has changed. It is also recommended that the steam to feedwater flow ratios be reviewed for the remaining loops. This would be particularly important for those loops that are going to be used as the standards for the flow calibrations.

The data also shows that the absolute measurements of feedwater flow with the CROSSFLOW meter is significantly higher than any of the plant flows. Although this problem is avoided by selecting specific plant flow loops to be used at the standards, it is still recommended that an independent verification of the flow be made. The simplest approach would be to calculate the corresponding steam flows. The flow loops that are selected to be the standards should fall within the uncertainty of the steam flow calculation. If this criteria is not met, then other measures should be taken to independently verify the accuracy of the selected flow elements.

An alternative approach might be to resurrect the steam to feedwater flow calibrations that were done following the startup of the plant. The steam venturis were probably calibrated at that time using the feedwater venturis Since the accuracy of the feedwater venturis was verified during a PTC 6.0 heatrate test, a steam venturi calibration using the feedwater venturi at that time should also be accurate. Thus, it is suggested that the steam venturi coefficient established at that time of the PTC 6.0 test be used in conjunction with the current steam venturi delta-P data to independently verify the current accuracy of the feedwater venturis.

A review of the CROSSFLOW data for Palo Verde has led ABB to conclude that relatively high pipe wall friction is causing the high flow readings at Palo Verde. When friction is present, the velocity profile near the center of the pipe becomes greater due to the reduced velocity near the surface of the pipe. As a result the meters readings are biased high because it is only looking at the velocity profile near the center of the pipe Thus, the calibration coefficient which is based on smooth pipe must be reduced to compensate for the increased velocity near the center of the pipe when friction is present

It should be noted that the presence of friction does not invalidate the conclusions of this test, since the velocity profile distortion can be corrected by simply multiplying the existing CROSSFLOW equation by a constant. This is why the ratios of the CROSSFLOW meter readings are in good agreement with the ratios of the plant flow data.

Table I

Nation Research Center Transducer Spacing Test Results

Transducer Spacing (inches)	Palo Verde Transducer Spacing (Spacing/ Pipe Diameter)	NRC Transducer Spacing (Spacing/ Pipe Diameter)	Flow Coefficient from NRC Tests C_f
6	N/A	0.5	0.947
12	0.59	1.0	0.928
24	1.18	2.0	0.926

TABLE II

PALO VERDE CALIBRATION DATA

USING UNIT 2 LOOP FLOWS AS THE STANDARD

Unit/Loop	Calibrated CROSSFLOW	Plant Data	Uncalibrated CROSSFLOW	Plant-Cal Difference (%)	Plant -UnCal Difference (%)	Ratio of Plant Loop 1 to Loop 2	Ratio of Meter Loop 1 to Loop 2
						1.040	1.043
U-2/L-1	8783	8783	9082	0.00	3.40		
U-2/L-2	8443	8443	8711	0.00	3.17		
						1.020	1.036
U-1/L-1	8716	8663	9012	0.61	4.03		
U-1/L-2	8429	8497	8697	-0.80	2.35		
						1.027	1.001
U-3/L-1	8564	8754	8856	-2.17	1.16		
U-3/L-2	8577	8528	8849	0.57	3.78		

ave 2.46

TABLE III
PALO VERDE CALIBRATION DATA
UNIT 1 LOOP D AND UNIT 3 LOOP 1 PLANT DATA
MODIFIED TO REFLECT EXPECTED VENTURI FOULING

Unit/Loop	Calibrated CROSSFLOW	Plant Data	Uncalibrated CROSSFLOW	Plant-Cal Difference (%)	Plant -UnCal Difference (%)	Ratio of Plant Loop 1 to Loop 2	Ratio of Meter Loop 1 to Loop 2
U-2/L-1	8783	8783	9082	0.00	3.40	1.040	1 043
U-2/L-2	8443	8443	8711	0.00	3.17		
U-1/L-1	8716	8663	9012	0.61	4.03	1.035	1 036
U-1/L-2	8429	8370	8697	0.72	3.91		
U-3/L-1	8564	8693	8856	-1.48	1.88	1.019	1 001
U-3/L-2	8577	8528	8849	0.57	3.76		

TABLE IV
PALO VERDE CALIBRATION DATA USING
UNIT 1 LOOP 1 AND UNIT 3 LOOP 2 AS THE CALIBRATION STANDARD

Unit/Loop	Calibrated CROSSFLOW	Plant Data	Uncalibrated CROSSFLOW	Plant-Cal Difference (%)	Plant -UnCal Difference (%)	Ratio of Plant Loop 1 to Loop 2	Ratio of Meter Loop 1 to Loop 2
U-2/L-1	8730	8783	9082	-0.61	3.40	1.040	1.043
U-2/L-2	8395	8443	8711	-0.57	3.17		
U-1/L-1	8663	8663	9012	0 00	4.03	1.020	1.036
U-1/L-2	8382	8497	8697	-1.36	2.35		
U-3/L-1	8513	8754	8858	-2.76	1 18	1.027	1 001
U-3/L-2	8528	8528	8849	0.00	3 76		