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U.S. Nuclear Regulatory Commission
Attn: Theodore R. Quay, Chief
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Office of Nuclear Reactor Regulation
Washington, DC 20555

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Project No.: 700
Our ref: LTR-NRC-04-2
16 January 2004

Subject: Response to Request for Additional Information Regarding the CROSSFLOW Ultrasonic Flow Measurement System (Proprietary / Non-proprietary)

References:
1. Letter, T. R. Quay (NRC) to R. O. Doney (Westinghouse), October 22, 2003
2. CENPD-397-P-A, Rev. 01, "Improved Flow Measurement Accuracy Using CROSSFLOW Ultrasonic Flow Measurement Technology", May 2000
3. Letter, S. A. Richards (NRC) to I. C. Rickard (ABB-CE), "Acceptance for Referencing of CENPD-397-P, Rev. 01-P, 'Improved Flow Measurement Accuracy Using CROSSFLOW Ultrasonic Flow Measurement Technology' (TAC No. MA6452)", March 20, 2000

Dear Mr. Quay:

On October 22, 2003, the Nuclear Regulatory Commission (NRC) sent Westinghouse Electric Company LLC (Westinghouse) a Request for Additional (RAI, Reference 1) regarding a review of the CROSSFLOW Ultrasonic Flow Measurement System. The CROSSFLOW technology and methodology is documented in CENPD-397-P-A, Rev. 01 (Reference 2) and was approved by the NRC on March 20, 2000 (Reference 3), for improved feedwater flow measurement accuracy. This letter provides both Proprietary and Non-proprietary responses to the NRC RAIs. Your letter (Reference 1) also requested that Westinghouse identify any proprietary information that may be contained in your statement of any of the RAIs. Our review determined that only RAI #5 contained proprietary information. This information has been appropriately delineated within brackets, as is done for all proprietary information contained in the RAI responses.

Also enclosed are:

1. One (1) copy of the Application for Withholding, AW-04-1770 with Proprietary Information Notice and Copyright Notice.
2. One (1) copy of Affidavit, AW-04-1770.

This submittal contains Westinghouse proprietary information consisting of trade secrets, commercial or financial information which we consider privileged or confidential pursuant to 10 CFR 9.17(a)(4). Therefore, it is requested that the Westinghouse proprietary information attached hereto be handled on a confidential basis and be withheld from public disclosure. Further, it should also be noted that some of the NRC RAIs transmitted by Reference 1 included Westinghouse proprietary information in their statement. Where this occurred, we have appropriately marked the proprietary information with brackets. This information should be removed before the letter is entered in the Public Document Room.

This material is for your internal use only and may be used solely for the purpose for which it is submitted. It should not be otherwise used, disclosed, duplicated, or disseminated, in whole or in part, to any other person or organization outside the Office of Nuclear Reactor Regulation without the expressed prior written approval of Westinghouse.

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Correspondence with respect to any Application for Withholding should reference AW-04-1770 and should be addressed to:

Westinghouse Electric Company LLC
Attn: James A. Gresham, Manager
Regulatory Compliance and Plant Licensing
P. O. Box 355
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Very truly yours,

C. M. Molnar

for James A. Gresham, Manager
Regulatory Compliance and Plant Licensing

Enclosure 2 to LTR-NRC-04-2

Westinghouse Electric Company LLC

Non-Proprietary Response to Request for Additional Information Regarding the CROSSFLOW Ultrasonic Flow Measurement System

Question 1:

The discrepancies in indicated feedwater flow between SONGS-2 and 3 and possibly other plants may be due in part to some kind of bias or systematic error in the CROSSFLOW equipment coupled with the random uncertainty that WEC/AMAG have not accounted for and that the equipment is not able to detect and compensate for.

Response:

Westinghouse was aware of the situation noted at SONGS-2 and 3 and has worked with Southern California Edison (SCE) on the issue. The differences existed before the CROSSFLOW system was installed, prior to the power uprate. Based on input from SCE, the difference in indicated feedwater flow between Units 2 and 3 is because there is a difference in generation (i.e., megawatt output) between the two units. This is attributed to a number of different reasons, many of which SCE has identified and resolved but the differences are real, not an indication of an issue with the CROSSFLOW ultrasonic flow measurement system.

Consistent with NSAL-03-12, Westinghouse/AMAG have also completed a review of frequency spectrum records for SCE and confirmed that there is no signal interference issue at SONGS 2 and 3.

Question 2:

The calibration curve for the CROSSFLOW UFM, i.e., VPCF vs. Reynolds number is based on a theoretical curve and on data taken at ARL with the highest value being at Re = 7E6, yet the ARL stated uncertainty of 0.25% is carried as the uncertainty of that curve without additional uncertainty for extrapolation to bounding plant flow conditions with Reynolds numbers around 30E6. CENPD-397-NP-A, Rev. 1, Section 4.2, "Profile Validation at Higher Reynolds Numbers," and Section 4.3, "Conclusions," asserts that the calibration can be extrapolated to the higher Reynolds numbers found in plants, and that the uncertainty need only be that of the original ARL uncertainty, by citing standard practice for venturis. However, standard practice for venturis, as prescribed in ASME PTC-6, is to add or expand uncertainty when extrapolating unless the special calibration specifications are strictly adhered to. Also, cross-correlation meters do not have the same physics or operational history as venturis. Further, in the case of venturis, the individual meters are calibrated and then the calibration is extrapolated to the operating conditions, but with the CROSSFLOW UFM, the calibration curve was developed with one meter and it was then generalized for all of the meters.

Response:

As documented in CENPD-397-P-A, Rev. 1, Figure 4-1 (Reference 1), it can be observed that [

Ex 4

][a,c] In addition, as discussed in Mr. Ken Cotton's turbine performance book (Reference 2), "...changes in water density and viscosity with changes in temperature are known accurately enough so that no additional uncertainty in the extrapolation is introduced with changes in temperature...", which is the primary reason why the Reynolds number is so much larger in an operating plant. The NRC concurs with this assessment, as indicated by their Safety Evaluation Report (SER), wherein they note 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."

As noted in CENPD-397-P-A, Rev. 1, Sections 2.0 and 4.0, under fully developed flow conditions, the flow profiles are well known and supported by extensive experimental tests over many decades (Reference 3). Since the CROSSFLOW meter is mounted external to the pipe, there is no flow disturbance introduced by the measurement device that must be accounted for (i.e., calibrated out) as is the case with other technologies.

PTC-6 (Reference 4) provides guidelines to compensate for upstream flow disturbances introduced by a flow straightener. We concur with these guidelines, however, CROSSFLOW is normally not installed downstream of a flow disturbance, like a flow straightener. For those cases where a flow disturbance is present, an in-situ or laboratory calibration would be performed and the associated uncertainty due to the calibration would be included.

Question 3:

The VPCF calibration curve is based on the performance of a particular single CROSSFLOW UFM. There is inadequate justification of the applicability of this instrument response curve to all other CROSSFLOW UFMs with zero additional uncertainty being carried to bound the effects of all the credible differences. Since there are no conclusive, repeatable comparisons with the performance of other CROSSFLOW UFMs under the same laboratory conditions, and against NIST-traceable standards, or even against other independent instruments that are inherently more accurate than (or even as accurate as) the CROSSFLOW UFM, how can identical, repeatable performance be assumed (noting exceptions taken to the plant confirmatory data)?

Response:

See response to Question No. 2. Because CROSSFLOW is non-intrusive to the flow, the VPCF curve is dependent only on the Reynold's number. The uncertainties associated with plant specific installation parameters or hardware upgrades are addressed as noted in the response to Question 4. These uncertainties do not affect the original flow profile calibration curve.

Question 4:

The calibration curve is based on the performance of a CROSSFLOW UFM under a set of laboratory conditions. In order to demonstrate applicability of that testing to all other conditions that may be encountered in actual plant installations, all the credible differences would need to be accounted for. The CROSSFLOW UFM total uncertainty would be expected to account for some kinds of credible differences by adding uncertainty in the correction factors for electronics, piping, configuration variance, transducer spacing, time delay measurement, and the accuracy of flow area determination. How are these correction factors extrapolated to plant Reynolds numbers without carrying additional uncertainty such that they can be assured to bound the: effects of all the credible differences under actual plant conditions when they were determined in the laboratory? The effects of specific plant conditions, such as flow velocity or upstream perturbations need to be modeled or measured and correction factors developed. The correction factors may be applied, but the uncertainties of the corrections are not included, only the uncertainty of the original calibration. Without these uncertainties being evaluated and accounted for, the calibration is only traceable to the particular instrument calibrated in the certified laboratory and for the conditions examined at that laboratory.

Response:

The reasons for not increasing the uncertainty in the VPCF are addressed in the response to Questions 2. As noted in CENPD-397-P-A, Rev. 1, Section 5.0 the site specific uncertainties are accounted for. This section explains how uncertainties regarding [Ex 4

Ex 4]^{a,c}

CENPD-397-P-A, Rev. 1, Section 5.6.1 notes that because of variations in plant piping layouts, it is not always possible to locate the CROSSFLOW meter in a piping section where the flow is fully developed. For these configurations, [Ex 4

Ex 4]^{a,c} Alternately, an in-situ calibration can be performed as explained in WCAP-15689-P, Section 2.5.2 (Reference 5). This approach allows the calibration to be performed under full power conditions, thus eliminating the need for extrapolation of flow conditions that may not be not fully developed.

Question 5:

The other way that the effects on flow of different plant conditions are addressed is to determine in the laboratory, where they can be measured to an accuracy greater than the claimed UFM accuracy, what the bounding conditions are and the limitations on these effects. Then install the UFM in locations beyond the reach of those effects. When the UFM cannot be installed beyond the reach of accuracy degrading effects, the so-called "in-situ" calibrations are performed. It is recognized that when this practice is employed, the uncertainties of the individual UFMs are combined. However, again it appears that the accuracy of one CROSSFLOW UFM is being confirmed by the accuracy of others, and there is inadequate traceability under those conditions to standards that are even as accurate as the instrument being calibrated. In addition, WEC/AMAG have determined that [Ex 4

Ex 4]a,c Please elaborate on how more complicated piping configurations are accounted for such as one or two non-planar bends?

Response:

As noted in the response to Question 4, Westinghouse/AMAG agree that when flow is not fully developed additional uncertainties must be included (e.g. uncertainties associated with installation of a second CROSSFLOW meter, referred to as in-situ calibration and discussed in WCAP-15689-P, Section 2.5.2). The most accurate in-situ calibration method is [Ex 4

Ex 4]a,c

For an in-situ calibration, when the calibration must be performed on [Ex 4

Ex 4]a,c The NRC recognized this capability in their SER for CENPD-397-P-A, Rev. 1 wherein they note that "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."

Question 6:

The plant confirmatory data has significant data scatter, but the uncertainty bounds are not given. They were taken over a range of Reynolds numbers from 11,000,000 up to 25,000,000 at different plants with different instruments whose accuracy was determined with varying degrees of rigor. For example, the highest value at Re=25E6 was taken from a recently calibrated venturi, while others around 20,000,000 for example were taken with "defouled" venturis. The fact that a few diverse raw data points happen to agree within some given value to the VPCF curve value for the corresponding Reynolds number during a given plant test does not mean they necessarily and repeatably agree, but only that there exist some data that happen to agree. Where there is relatively close agreement, it could simply be a fortunate superposition of errors. This sort of comparison is not valid empirically. It does not prove that the curve is accurate under all conditions to the claimed ±0.25% (the ARL uncertainty). This is because (1) the uncertainty of the comparison instruments has not been taken into account, (2) that uncertainty, when taken into account, will be at best, comparable to the UFM uncertainty when, the flow nozzle (and presumably the DP cell as well) is cleaned, calibrated at the lab, reinstalled, tested promptly, and then sent back to the lab for re-checking the calibration. Not all these provisions were met in all the tests. Therefore, using these data for confirmation of claimed accuracy of the VPCF calibration curve is trying to demonstrate an accuracy of 0.25% by comparison to a few data from instruments of lesser accuracy, at plant-comparable Reynolds numbers. It is normal practice to calibrate an instrument with a traceable standard of at least four times the accuracy the instrument being calibrated. Other data of ostensibly higher accuracy, again were taken at a lower Reynolds number (e.g., tracer, data at Re=11E6). Finally, there is an insufficient number of comparable raw data points to perform a meaningful statistical analysis.

Response:

Each of the [Ex4

Ex4]a,c Hence, the inference that the data set is a few diverse raw data points that happen to agree is not accurate.

As shown statistically in WCAP-15689-P, Section 2.7, [Ex4

Ex4]a,c

It is noted in Question 6 that it is normal practice to calibrate an instrument with a device that has an accuracy which is four times more accurate than the instrument to be calibrated. Reference 6, Section 10.2, item b) states "Well defined and documented measurement assurance techniques or uncertainty analyses may be used to verify the adequacy of a measurement process. If such techniques or analyses are not used, then the collective uncertainty of the measurement standards shall not exceed 25% of the acceptable tolerance (e.g., manufacturer's specification) for each characteristic of the measurement and test equipment being calibrated or verified." The services provided by ARL for calibrating venturis and other flow measurement systems (including transit-time meters) fall into the first clause and meet the appropriate industry standards for measurement assurance as defined in Section 3.12 of Reference 6.

Question 7:

The laboratory testing to determine the VPCF used long, straight, very smooth (plastic) pipe to minimize hydraulic anomalies, especially pipe wall roughness, to achieve classic "fully developed" flow. The corresponding flow velocity distribution or profile has a finite amount of curvature that, according to theory is a function of Reynolds number. This forms the fundamental characteristic programmed response of the CROSSFLOW UFM to flow of varying Reynolds number. However, aside from the metrology concerns about the accuracy and repeatability of this curve, there is data (e.g., Caldon Report ER-262) that indicates that there can be distortions to the flow velocity profile that (1) are flatter than classic fully developed flow (non-conservative), (2), asymmetrical, (3) that persist out to at least 45 L/D, (4) that change over time, independent of changes in plant configuration or readily recognizable events. One of the principle phenomena of concern is swirl which can create tangential velocity vectors with magnitudes as much as 20% of the axial velocity and can vary significantly over time. It is not clear from the WEC/AMAG documents how the CROSSFLOW UFM can adequately detect and properly correct for all those conditions that appear to be outside its design basis. What data does WEC/AMAG have that support the assumption that their smooth pipe assumption is always conservative?

Response:

Caldon Report ER-262 describes an abrupt decrease in feedwater pipe wall roughness that reportedly then introduced swirl, and then in one case immediately started to re-roughen again and in another case changed back at a later time (i.e., re-roughened, after 3 months). Based on past experience with transit-time technology and the plant chemistry programs at nuclear plants, Westinghouse believes that a more plausible explanation is that the ultrasonic transducers shifted during the downpower event due to the thermal contraction, which has been a known issue with transit-time technology. When the feedwater pipe started to heat-up again, the alignment was likely restored. CROSSFLOW is not subject to these types of problems, because the ultrasonic transducers are mounted on the external surface of the feedwater pipe and perpendicular to the pipe axis.

Upstream flow conditions and installation considerations are addressed in Section 2.5 of WCAP-15689-P. With respect to swirl, it is known that "swirl generators", such as feedwater pumps, have the potential to create a flatter or even inverted flow profiles. CROSSFLOW implementation procedures do not allow a CROSSFLOW meter to be installed in such a location.

The more likely scenario is that gentle swirl may exist in a run of pipe, for example, due to consecutive out of plane elbows in the upstream geometry. In WCAP-15689-P, Section 2.4, an explanation is provided explaining why transit-time technology is more sensitive to swirl and, in an unpredictable manner, due to the random way in which the radial and tangential fluid velocity components can add and subtract from the fluid axial velocity component that is being measured. Under the same conditions, [Ex 4

Ex 4]^{a,c}

As documented in Reference 1, the use of plastic piping for the initial CROSSFLOW calibration activities provided a limiting condition that created "fail-safe" test results. It is known (Reference 3) that smooth pipe walls will yield a flatter flow profile while pipe wall roughness will drive the flow profile in a more pointed pattern in the center region of the pipe. In the event that pipe wall roughness is present to the extent that the flow profile is affected, the CROSSFLOW technology will generate a conservative measurement with respect to actual flow. However, nuclear industry experience indicates that in general, the walls of nuclear plant feedwater pipe are smooth (Reference 5, Section 2.7), approaching the smoothness of plastic. In addition, as noted in Reference 5, Section 3.4, in Caldon Report ER-262, a revision was recommended to the flow profile factor for the transit-time clamp-on meter which was more in line with smooth wall pipe considerations.

Question 8:

It is not clear from existing WEC documentation (including recent information pertaining to Byron and Braidwood) how the CROSSFLOW UFM, even when operated in accordance with WEC guidelines, can recognize and effectively deal with acoustic anomalies (noise or "signal contamination") that may develop and change over time and that may bias it and degrade its accuracy.

Response:

Westinghouse has published a Nuclear Safety Advisory Letter, NSAL-03-12 (Reference 7), that addresses this issue. The NSAL contains updated guidance for addressing noise contamination with the continued operation of the CROSSFLOW system. It should be noted that Westinghouse/AMAG have completed a review of frequency spectrum records, or have obtained new records, for all Utilities currently using CROSSFLOW to adjust plant power. No signal interference issues generated by acoustic resonance were identified in any other plants that are currently using the CROSSFLOW system to monitor feedwater flow (i.e., except at Byron and Braidwood).

References:

1. CENPD-397-P-A, Rev. 1, "Improved Flow Measurement Accuracy Using CROSSFLOW Ultrasonic Flow Measurement Technology", May, 2000
2. "Evaluating and Improving Steam Turbine Performance", Copyright 1993, by Cotton Fact Inc., K.C. Cotton, President
3. H. Schlichting, "Boundary-Layer Theory", McGraw-Hill Book Company, 6th Edition
4. "Guidance for Evaluation of Measurement Uncertainty in Performance Tests of Steam Turbines", ASME PTC 6 Report – 1969
5. WCAP-15689-P, "Evaluation of Transit-Time and Cross-Correlation Ultrasonic Flow Measurement Experience with Nuclear Plant Feedwater Flow Measurement"
6. ANSI/NCSL Z540-1-1994, "American National Standard for Calibration-Calibration Laboratories and Measuring and Test Equipment-General Requirements"
7. NSAL-03-12, "CROSSFLOW Ultrasonic Flow Measurement System Flow Signal Interference Issues", December 5, 2003