NRC Review of Combustion Engineering CENPD-397-P-A

"Improved Flow Measurement Accuracy Using CrossFlow Measurement Technology"

Draft Safety Evaluation for Withdrawal of Acceptance

Comments by PJR, NRR/DE/EICB

The draft SE was distributed via EMail on September 21, 2006 to EICB staff for general review.

The following comments include rhetorical questions, as well as direct comments on the text of the draft SE. These comments and questions are based upon the opinion and understanding of the reviewer, without detailed consideration of the original submittal or supplementary materials, and may therefore address matters already covered but not documented in the draft SE. It has been the reviewer's intent to cover the subject as broadly as possible, even at the risk of raising issues that have already been settled.

1. The draft Safety Evaluation does not address the fundamental elements of the CrossFlow approach to the estimation of volumetric flowrate. If there are problems with the instrument, it lies in an incomplete or inadequate accommodation of one or more of those elements. The fundamental elements are (and there may be others):

   a. measurement of the velocity of fluid eddies
   This includes consideration of the ultrasonic pulse rate and chirp frequency, of eddie size and geometry (especially relative to the chirp wavelength), and of the width and shape of the detection zones within which an eddie is first observed and later recognized.

   b. radial distribution & physical size of eddies used to infer fluid velocity
   Are eddies distributed evenly or do they cluster toward the pipe axis? Is the probability that an eddie will be observed or recognized related to the distance from the pipe wall? Are the eddies reliably small enough that the exact position of the leading and trailing "edges" of an eddie is unimportant to the question of just exactly where the eddie is located when it is detected? Are the eddies reliably large enough compared to the wavelength of the detection pulse that wavelength-related effects are unimportant or at least reliably predictable?

   c. likelihood and consequences of incorrect pairings of eddie signatures
   Are the eddies unique and stable enough that the likelihood of pairing a downstream signature with the wrong upstream signature is sufficiently small? What is that probability, and how does XFlow account for this? What is the influence of reflections of the ultrasonic beam within the fluid, and of ultrasonic energy transmitted directly through the pipe wall? Westinghouse confirmed, some time subsequent to the original NRC acceptance of XFlow, that XFlow is susceptible to acoustic resonances within the piping system. Are there any other sensitivities to acoustic noise? How was the answer to this

question determined? Since eddie velocity is a function of radial displacement, eddies will sometimes pass one another, or be lined-up axially at one detector but not at the other. How does XFlow account for this? Are there few enough eddies that confusion of one eddie with another is unlikely? How many detectable eddies might there be in transit between the transducer pairs at any given time?

d. effect of swirl
It has been stated that the deleterious effect of swirl is minimized because off-axis eddies will tend to rotate out of the detection area and be lost, and so the inferred fluid velocity would be weighted toward the central velocity which would be higher than the average and hence conservative. But unless the signature-comparison algorithm is sufficiently sensitive and robust, extraneous eddies that rotate into the detection zone might be erroneously paired with eddies that have been lost and compromise this theoretical tendency toward conservatism. How is it demonstrated that this will not happen frequently enough to compromise the measurement? Also, a rotating asymmetrical flow profile could at least theoretically have an on-axis velocity that is actually lower than the bulk cross-sectional average. This would fundamentally challenge the argument even if detection probabilities were perfect.

e. profile correction factor for ideal flow conditions
This correction factor relates the measured fluid velocity to the average velocity under ideal conditions (fully-developed flow in a perfectly round ideal pipe). The velocity averaged over the cross-sectional area of the inside of an ideal pipe will be slightly lower than the velocity at the pipe axis. This value can be predicted theoretically and can be confirmed in a laboratory to the extent that ideal conditions can be simulated.

f. application-specific correction factor for flow profile at the installed location
This correction factor addresses the fact that the actual flow profile at the in-plant instrument mounting location will differ from the profile under ideal conditions. It seems doubtful that the actual flow profile could be accurately predicted or enveloped, so laboratory testing using the intended installed geometry, including, elbows, branches, etc. some distance to either side of the flowmeter under test would likely be required. Note that, depending upon the nature and severity of the distortion of the flow profile, it seems at least theoretically possible that the observed velocity (even without consideration of measurement error) might exceed the average by a margin smaller than the corresponding margin under ideal conditions, leading to a nonconservative estimate of core thermal power. Has the testing been comprehensive enough to address as-installed conditions to an adequate level? If each individual installation is not tested, how is it established that the tested configurations are "close enough?"

g. variations in the shape of the flow profile at the installed location
How is it known that the flow profile under all conditions under which the flowmeter is needed will be close enough to the profile upon which calibration is based that calibration will not be compromised?

2. The SE cites concerns over the use of laboratory data for application-specific correction factors. To ensure proper calibration, *two* aspects of laboratory data are required:

(1) confirmation of the correction factor for converting the fluid velocity as measured under ideal conditions to a cross-sectional average velocity that can then be multiplied by the cross-sectional area to infer volumetric flowrate, and

(2) a similar correction factor relating the flow profile at the instrument location to the ideal profile.

The final sentence of the first paragraph of Section 3.1 the draft SE addresses the second correction factor for "such conditions as the distance from an upstream elbow" but does not elaborate any further. Since this is likely to be a major consideration in the uncertainty of the XFlow UFM, it would seem appropriate to delve further into this matter. Do we accept this approach as adequately addressing the actual as-installed condition of the flowmeter? Do we believe that the instructions are sufficiently clear and comprehensive that users will not experience accuracy reduction due to unanticipated flow profiles? What about the effects of multiple bends and branches, pipe reducers/expanders, flow straighteners, venturis, venturi access ports, etc.?

3. The general indictment of laboratory-based calibration that is suggested in the SE as-written would also apply to laboratory calibration of venturis in accordance with ASME standards and to the laboratory calibration of LEFM and other types of flowmeters. It does not appear that laboratory calibration *per se* is the problem, but rather that the calibration is incomplete. If laboratory calibration adequately models the as-installed piping configuration in the plant, it can be beneficial. Calibration factors provided to account for flow conditions such an upstream elbow would need to be justified, and means provided for combining such factors. It seems doubtful that the myriad configurations that might actually be seen in operation could be effectively accommodated by a set of pre-established coefficients: as a minimum, we would need to understand the derivation and application of such coefficients.

4. The relationship between flow stability and fully-developed flow is not clearly addressed. Stability means only that the flow profile does not change. It does not imply that the profile is known. Fully-developed flow has a known profile, but is difficult to achieve. It is fully-developed flow that gives rise to the correction factor addressed above for ideal flow. Stable flow is necessary, and the difference between the stable flow in operation and fully-developed flow is addressed in the second correction factor addressed above. Note that an axially-symmetrical flow profile could meet the axial and rotational criteria described in the 6th paragraph of section 3.1 an also be stable, but still not match a fully-developed profile. The treatment of such a profile as "fully developed" might be conservative or nonconservative depending upon the details of the radial distribution of axial velocities.

5. There are several assertions to the effect that plants have experienced overpower conditions as a result of underestimation of feedwater flow. Since the measured feedwater flowrate is itself both the major determinant of estimated core power and the quantity that is deemed questionable on the basis of estimated core power, it would be helpful if the basis of the alternative estimates of core power were explained. How is the alternative estimate of core power derived and deemed to be sufficiently accurate to challenge the accuracy of the flowmeter?

6. There is a statement near the end of the 5th paragraph of Section 3.1 of the draft SE to the effect that fully-developed flow is not likely to exist in feedwater piping. This statement suggests that venturi-based flowmeter installations are also inadequate, since they too presume fully-developed flow. In fact, under ideal conditions venturis are far more accurate than the 2% allowance in Appendix K, and part of the margin in that 2% allowance accommodates the effects of real-world flow profiles. One of the major improvements that can be provided by an advanced flowmeter is reduced sensitivity to flow profile deviation from the ideal. If the laboratory calibration does not directly and reliably duplicate the

as-installed flow profile, then some reliable basis must be provided for estimating the increased measurement uncertainty that results from the flow profile deviation. Laboratory calibration factors that are based only upon a presumption of fully-developed flow are obviously inadequate.

7. re 3.1 ¶7: The conclusion that "a stable velocity profile did not exist" due to the presence of swirl does not seem warranted. The definition of "stable velocity profile" presented in the previous paragraph of the same section would not preclude swirl. Nevertheless the presence of swirl may influence the measurement for other reasons, as suggested in the discussion of influences at the beginning of these comments. W/AMAG may have already answered questions regarding swirl, and those responses should be addressed if swirl is to be deemed inadequately addressed.

8. re 3.2 ¶ 4: As noted earlier in these comments, venturis are also susceptible to flow profile deviation from the ideal. If the Appendix k margin is to be reduced on the basis of flowmeter calibration derived from a venturi in a line with a suboptimal flow profile (and footnote 1 in section 3.1 of the draft SE indicates that more than 100 pipe diameters are needed for fully-developed flow, and the 5th paragraph of that section indicates that fully-developed flow is not likely to exist), then the effects of the non-ideal flow profile must be accommodated in the uncertainty estimate for that venturi-based flow measurement. The uncertainty of the instrument(s) used to measure the differential pressure developed by the venturi must also be accommodated, although the magnitude of those uncertainties can be minimized through the use of recently-calibrated laboratory devices in lieu of installed plant instrumentation. In summary, while the use of a recently cleaned and calibrated venturi-based flowmeter to calibrate an installed XFlow device seems intuitively satisfying, it must be recognized that both devices are susceptible to flow profile deviation from ideal and so the degree of accuracy of such calibration is not obvious. It is not clear that the resulting calibration would be any more accurate than what is gained by the elimination of venturi fouling and the temporary improvement in differential pressure measurement accuracy.

9. The main limitation on the self-diagnostic process described in the first paragraph of Section 3.4 is that the process only addresses the behavior of the instrument itself, and not the correct accommodation of the flow profile at the installed location. Also, the reference in the second sentence to "calibration factor" appears to have been intended to be to the venturi correction factor rather than to the XFlow flow profile correction factor. Similarly, the reference at the beginning of the 2nd paragraph to the XFlow on-line monitoring and calibration uncertainty is unclear: the on-line monitoring process is primarily to monitor the "health" of the instrument, not the calibration uncertainty. It should be recognized, however, that detailed statistical analysis of the eddie signatures in the two detection zones could lead to recognition of changes in the flow profile (regardless of what it changes "from" or "to") that could alert a user to increased uncertainty in the flow measurement so that a compensatory reduction in power could be initiated. This would need to be addressed in the Technical Specifications, if the TS limits were based upon margins too close to the uncertainty limits of the flowmeter.