March 18, 2003

Mr. W. E. Cummins
AP600 & AP1000 Projects
Nuclear Plant Projects
Westinghouse Electric Company
P. O. Box 355
Pittsburgh, PA 15230-0355

SUBJECT: AP1000 REQUEST FOR DATA TO RESOLVE LIQUID ENTRAINMENT REQUESTS FOR ADDITIONAL INFORMATION (RAIS) AND TELEPHONE CONFERENCE CALL SUMMARY FOR MARCH 10, 2003 (TAC NOS. MB5491; MB7247)

Dear Mr. Cummins:

By letter dated March 28, 2002 (ADAMS Accession No. ML020910357), you submitted an application for design certification and final design approval of the AP1000 design. The Nuclear Regulatory Commission (NRC) staff documented, in a letter dated February 28, 2003 (ADAMS Accession No. ML030550362), that RAIs 440.151, 440.152, 440.154, 440.157, 440.160, 440.161, 440.162, 440.164, 440.169, 440.171, and 440.173 are designated as unresolved and addressed the issue of liquid entrainment phenomena in the upper plenum during certain accident conditions. This issue was also identified as an area that needed further review in the NRC staff's pre-application review assessment, dated March 25, 2002 (ADAMS Accession No. ML020110011).

Specific NRC staff comments related to RAIs associated with the liquid entrainment phenomena in the upper plenum are contained in Enclosure 1 of this letter. These comments were sent to Mr. Michael Corletti, of your staff, via electronic mail on March 6, 2003, and were used to facilitate discussions during a subsequent telephone conference call on March 10, 2003. Enclosure 2 includes a summary of the telephone discussion for each RAI. A list of call participants is included in Enclosure 3.

The NRC staff has reviewed issues involving liquid entrainment from the automatic depressurization system-stage 4 (ADS-4) of the AP1000 design such as might occur during the recovery from a small break loss-of-coolant accident (SBLOCA). We have determined that additional experimental verification is necessary to complete our review. The discussions below describe our data needs.

The issue of liquid entrainment out of the ADS-4 during the early phases of the SBLOCA recovery was raised with Westinghouse Electric Company (Westinghouse) during Phase 2 of the AP1000 pre-application review. The staff concern was that greater than expected quantities of liquid water might be expelled from the ADS-4 during the period prior to significant in-containment refueling water storage tank (IRWST) injection resulting in inadequate cooling of the reactor core. The staff reviewed the experimental database for SBLOCA analysis including the adequacy of the scaling of that data for the AP1000. Conclusions from this review were transmitted to you in a letter dated March 25, 2002 (James E. Lyons to W. E. Cummins, ADAMS Accession No. ML020110011). The NRC staff concluded that none of the facilities used by Westinghouse to justify ADS-4 entrainment are sufficiently well scaled so that they provide an acceptable database to validate thermal-hydraulic codes for the liquid entrainment that is expected to occur in an AP1000 plant during ADS-4 depressurization and transition to IRWST injection periods of an SBLOCA.

In response to these concerns, Westinghouse submitted WCAP-15833-P "WCOBRA/TRAC AP1000 ADS-4/IRWST Phase Modeling." This proprietary report describes modifications to the WCOBRA/TRAC computer code designed to more accurately predict ADS-4 entrainment in comparison to the NOTRUMP computer code which is the normal method of SBLOCA analysis. The report benchmarks NOTRUMP against the WCOBRA/TRAC predictions. WCOBRA/TRAC is benchmarked against test data designed to assess thermal/hydraulic codes for the AP600. In addition, Westinghouse performed sensitivity studies by varying the entrainment parameters in the WCOBRA/TRAC models to show that core cooling is not sensitive to assumptions for liquid entrainment.

The NRC staff has reviewed WCAP-15833-P and the response to several RAIs and has concluded that Westinghouse has not provided sufficient justification for the models and correlations in WCOBRA/TRAC that predict liquid entrainment from the ADS-4. In particular the correlations for entrainment within the upper plenum have not been justified. Entrainment within the upper plenum is significant since liquid entrained there will likely remain entrained to be carried into the hot legs and out of the ADS-4. The staff concludes that the entrainment correlations in WCOBRA/TRAC have been derived using data from relatively small diameter vessels, low gas flow rates, and for some data, air-water as opposed to steam-water in the AP1000. Because of the small vessel size used in collection of this data, conditions were essentially one-dimensional. Flow in the upper plenum of the AP1000 vessel is expected to be non-uniform and three-dimensional. Thus, a suitable database for assessing entrainment correlations in the upper plenum has not been established. The staff agrees that the sensitivity studies documented in WCAP-15833-P might lead one to conclude that entrainment out of ADS-4 is not a significant consideration for core cooling. However, if the correlations themselves are not predicting the actual physical processes that would occur in the plant, then conclusions from the sensitivity studies might not be valid. In addition, the staff has concluded that the AP600 test data used to benchmark the WCOBRA/TRAC code for the AP1000 entrainment analysis is insufficiently scaled for that purpose.

To facilitate the timely disposition of this issue, the NRC staff requests that Westinghouse present new test data for the purpose of justifying the modeling of entrainment processes, including upper plenum entrainment, that occur during an SBLOCA. Justifications for the scaling of the test facility to the AP1000 design should be provided. This new data should then be used to justify that the models within the computer codes used by Westinghouse to model liquid entrainment during SBLOCA for the AP1000 design basis are predicting the physical processes correctly.

In addition, the NRC staff is requesting a documented schedule for the availability of the testing data and identification of the specific test facility being used to provide the data in order to facilitate a quality assurance (QA) test control implementation inspection. The NRC staff plans to perform a QA test control implementation inspection to determine if testing activities performed at the test facility associated with the design of the AP1000 are conducted in accordance with the Westinghouse 10 CFR Part 50, Appendix B, QA program as described in Chapter 17 of the AP1000 Design Control Document (DCD).

The NRC will review QA provisions relevant to the identified facility as described in the applicable AP1000 Test Project Quality Plan and Test Procedures. In particular, the team will examine the areas covered by the QA program to confirm that the test activities were accomplished under suitably controlled conditions by properly trained personnel and that pertinent test data used to furnish documentary evidence of activities affecting quality were properly recorded and maintained.

As discussed in the March 10, 2003, telephone conference call, Westinghouse agreed to provide a schedule for submission of the requested data as well as identification of the specific test facility being used to conduct the testing, by April 9, 2003.

Please contact one of the following members of the AP1000 project management team if you have any questions or comments concerning this matter: Mr. John Segala (Lead Project Manager) at (301) 415-1858, jps1@nrc.gov; Mr. Joseph Colaccino at (301) 415-2752, jxc1@nrc.gov; or Ms. Joelle Starefos at (301) 415-8488; jls1@nrc.gov.

Sincerely,

/RA/

James E. Lyons, Director
New Reactor Licensing Project Office
Office of Nuclear Reactor Regulation

Docket No. 52-006

Enclosure: As stated

cc: See next page

accordance with the Westinghouse 10 CFR Part 50, Appendix B, QA program as described in Chapter 17 of the AP1000 Design Control Document (DCD).

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Sincerely,

/RA/

James E. Lyons, Director
New Reactor Licensing Project Office
Office of Nuclear Reactor Regulation

Docket No. 52-006

Enclosure: As stated

cc: See next page

Distribution: See next page

ADAMS ACCESSION NUMBER: ML030720132

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NUCLEAR REGULATORY COMMISSION STAFF COMMENTS THAT WERE SENT TO WESTINGHOUSE TO FACILITATE DISCUSSIONS OF THE REQUESTS FOR ADDITIONAL INFORMATION (RAI) RESPONSES FOR CALL HELD ON MARCH 10, 2003

Comments on RAI 440.151 Response:

The response supplied in the November 1, 2002, memo (W Ref.: DCP/NRC1529; ADAMS Accession No. ML023110249) is not sufficient. Westinghouse correctly notes in their response that coefficients of entrainment onset correlations having the form of Equation 2-24 of WCAP-15833, "WCOBRA/TRAC AP1000 ADS-4/IRWST Phase Modeling," have been determined from experiments in which the value of d/D is significantly smaller than that in the AP1000. In addition, even Westinghouse points out on pages 2-3 and 2-4 of WCAP-15833 that the general form of this correlation is questionable. It lacks a dependence on viscous effects and surface tension, which have been found in other studies to be important in predicting the onset of entrainment. Thus, Westinghouse has not provided justification that the above relation is "reasonable" when it is applied well outside of its established range of validity.

In its response, Westinghouse cites sensitivity studies using WCOBRA/TRAC-AP in which coefficients of the entrainment onset correlation were varied and makes the claim that the correlation is applicable because the sensitivity is small. Westinghouse has not claimed, nor attempted to demonstrate that the coefficients were varied over a sufficiently wide range. In the Figure associated with this RAI, it is clearly evident that representative data from the ATLATS has a much lower flow quality to the ADS-4 than would be predicted by traditional entrainment rate correlations. For the Westinghouse sensitivity study to have value, the coefficients should be ranged such that the predicted flow quality is approximately that of the experimental data. Then, if the delay in the in-containment refueling water storage tank (IRWST) initiation (as in the comparisons of Figures A.4.4-3, A.4.4-6, and A.4.4-9) remains small, then it will be demonstrated that the AP1000 is not sensitive to hot leg entrainment.

The final paragraph of the response suggests that the flow regime in the hot leg of the ATLATS tests is not the same as in the AP1000. Westinghouse fails to recognize that the hot leg flow regime is indeed an important factor in phase separation at the ADS-4 branch line. What sets the AP1000, APEX, and ATLATS apart from most other geometries in which phase separation to an upward oriented branch line occurs, is that the steam generator (SG) inlet plenum acts to trap water. In studies such as those by Shrock [3], the pipe exit is unrestricted, and a horizontal stratified flow pattern was established. In ATLATS, visualization showed that the flow pattern in the hot leg was not horizontal stratified. The SG inlet plenum caused oscillating plugs to form in the region between the branch line and the plenum. High rates of entrainment occurred when the liquid plug periodically covered the branch line inlet. Clearly, the mechanisms responsible for phase separation to the branch line are different in the case of ATLATS than in conventional studies such as Shrock.

Westinghouse may not be aware that the ATLATS facility is scaled 1:1 with the APEX facility and tests were run so that gas velocities in the hot leg and branch line were comparable. Thus, the flow patterns that existed in ATLATS should also be present in APEX tests. Assuming APEX is correctly scaled, the same flow patterns should be expected in the AP600 and the AP1000.

To resolve this RAI, the following approach is suggested:

(1) Augment the WCOBRA/TRAC-AP sensitivity study on hot leg entrainment onset by providing an additional case in which the models are biased to predict the very low branch line flow qualities suggested by the ATLATS data. The Westinghouse case is supported if the delay in IRWST remains small.

(2) The scaling rationale presented on pages 4-38 and 4-39 of WCAP-15613, "AP1000 PIRT and Scaling Assessment," should consider the onset correlation by Welter, K. B., Wu, Q., Yao, Y., and Reyes, J. N., "New Model for Predicting Two-Phase Entrainment Rates in Tees," ANS Trans., Winter Annual Meeting, Washington DC, 2002. Their onset correlation, which is based on ATLATS data and thus presumably embeds the effect of hot leg flow pattern, is given by:

$$\left(w_3^{\,2}\right)^* = \frac{K\left(\frac{h_b}{d}\right)^3\left[a\left(\frac{h_b}{d}\right)+1\right]^2}{\left[1-\left(\frac{h_b}{d}\right)^2\right]}$$

where,

$$\left(w_3^{\,2}\right)^* = \frac{w_3^{\,2}}{d^5\rho_g g\Delta\rho}$$

In these expressions, w_3 is the mass flow rate in the branch line, r is the density, d is the branch line diameter, D is the main pipe diameter, h_b is the entrainment height, and K=0.66 and a=0.22 are experimentally determined constants.

A stronger argument that the APEX tests were appropriately scaled for hot leg entrainment might be made by using the first equation. By using the definition in the above expression, and assuming pressure similitude,

$$\left\{\frac{\left(q_{core}\right)^2\left[1-\left(\frac{h_b}{D}\right)^2\right]}{d^5\left(\frac{h_b}{d}\right)^3\left[a\left(\frac{h_b}{d}\right)+1\right]^2}\right\}_R = 1.0$$

Using the appropriate values for pipe diameters, values for P_R in the following Table can be generated for various assumptions on entrainment height h_b.

h_b	P_R
0.05 * D	1.97
0.50 * D	1.71
0.95 * D	1.55

For each height, the scaling ratio is within the acceptance range of $0.5 < P_R < 2$.

While scaling in this manner suggests that the tests conducted for the AP600 are appropriately scaled for the AP1000, it remains to be shown that the ATLATS correlation, the scaling ratio above, and the data from which it was developed can be extended to the full sized hot leg. The process of entrainment observed in the ATLATS tests was not due to the stripping of droplets from the surface of a horizontal-stratified layer. Instead, most entrainment occurred when oscillating liquid slugs covered the branch line, and large portions of the slug were sheared away. Thus, the frequency of oscillation of the slugs between the branch line and the SG inlet plenum, and the wave height of the slug are relevant to the process. Some consideration of these should be made in scaling the hot leg entrainment process.

<u>Comments on RAI 440.152 Response:</u>

Response supplied in the October 18, 2002, memo is not sufficient. Needed is a description of what the code does when the quality predicted by an offtake expression does not correspond to the quality (inferred from the void fraction) in the top cell of the Channel in the hot leg where the branch line connects. For example, if there are insufficient droplets in the top cell to satisfy the branch line quality demand, where does the “extra” liquid get extracted from? Are mass and momentum conserved as implemented?

<u>Comments on RAI 440.154 Response:</u>

This response was supplied in the November 15, 2002, transmittal memo (W Ref.: DCP/ NRC1532).

The response to part (b), Figures 440.154-1 and -2 were not included in the official transmittal memo. Figures sent via e-mail, Figures 440.154-1 and -2, must be officially submitted.

The response to part (c) is not sufficient, since the response to RAI 440.151 was not considered sufficient. The response to part (c) of this RAI implies that because the code predicted the flow pattern to be horizontal-stratified, a correlation of the form of Equation 2-24 of WCAP-15833 must be applicable.

It is not clear why the 50 percent ranging on branch line quality performed in the sensitivity study is adequate. Early in the DEDVI and inadvertent ADS transients discussed in the response to RAI 440.163, the mass flow rate into the hot legs are nominally between 20 and approximately 70 lbm/sec (9 and 32 kg/sec). At 22 psia (0.152 MPa), the Froude number at the ADS-4 branch line will vary between approximately 1.5 and 5.5. In the Inadvertent ADS case, it is generally less that 3.0. The response does not provide sufficient information on why the ranging performed in the sensitivity study is adequate from these low Froude numbers. A convincing argument that hot leg phase separation is not a dominant process in the AP1000 may be made if the ranging were performed such that branch line flow quality at low Froude numbers was more strongly affected.

The response to part (c) also discusses the data from the ATLATS facility. These data were obtained as part of an experimental investigation performed at Oregon State University. The vessel, SG inlet plenum, and hot leg of the ATLATS test facility itself is scaled 1:1 with the APEX facility, and the approximate flow phenomena that occurred in the APEX integral tests. If ATLATS is non-prototypical of the AP1000, then additional information on why the APEX tests remain adequately scaled to the AP1000 should be provided, since APEX would have the same problem. A description of the ATLATS facility, data, and test procedures is available upon request.

Comments on RAI 440.157 Response:

Regarding the response supplied in the November 26, 2002, transmittal memo (W Ref.: DCP/NRC1535; ADAMS Accession No. ML023360097), revisions must be made to 2.2.1.4 to eliminate the incorrect statement.

Comments on RAI 440.160 Response:

Regarding the response supplied in the November 1, 2002, transmittal memo (W Ref.: DCP/NRC1529; ADAMS Accession No. ML023110249), Figures 2-9, 2-11, and 2-13 in the RAI response must replace the originals in a revision to WCAP-15833.

Comments on RAI 440.161 Response:

No additional information required from Westinghouse at this time.

Comments on RAI 440.162 Response:

The response supplied in the December 2, 2002, transmittal memo (W Ref.: DCP/NRC1525; ADAMS Accession No. ML023400058) was evaluated with the following conclusions:

(a) The WCAP must be revised characterizing the agreement between WCOBRA/TRAC and data as being within oscillations exhibited by the data rather than “extremely well.”

(b) The three new figures (440.162-1 to 440.162-3) must be added to WCAP-15833.

Comments on RAI 440.164 Response:

The response to this RAI was supplied in the November 1, 2002, transmittal memo (W Ref.: DCP/NRC1529; ADAMS Accession No. ML023110249). The response sufficiently answers the request, but results raise additional questions on the WCOBRA/TRAC simulations. Thus, the information provided is not sufficient to resolve the basic concern of this RAI, which is the non-conservative prediction of the core two-phase mixture level.

The goal of Westinghouse's approach is to show NOTRUMP is conservative for use with the AP1000 because NOTRUMP is conservative with respect to the more realistic WCOBRA/TRAC results. In WCAP-15833, Figures 3-25 and in particular Figure 3-16 show that WCOBRA/TRAC predicts less vessel mass than NOTRUMP for the Inadvertent ADS and DEDVI cases. This suggests that NOTRUMP is non-conservative with respect to vessel mass (which is affected by several models in the codes). The figures supplied as part of the RAI 440.164 response show very high void fractions at the top of the active core. The high void fractions persist for at least 200 seconds in each case presented. In Figure 440.164-3 for example, the void fraction for the top 3.5 feet of the core is 0.994. The same figure shows a very large void fraction gradient between Core cells 3 and 4, in which the void increases from 0.16 to 0.91. WCOBRA/TRAC does not have a level tracking model to determine the top of a two-phase mixture level and relies instead upon axial nodalization to resolve sharp hydraulic gradients. If a more detailed axial nodalization were used, would core uncovery and cladding heat up occur, and if so what is the peak cladding temperature (PCT) and equivalent cladding reacted (ECR)? If WCOBRA/TRAC predicts uncovery and cladding heat up, why should NOTRUMP still be considered adequately conservative?

The high void fraction in the top cell also suggests that radial nodalization may be important. In the AP1000 WCOBRA/TRAC model, the core is represented by a single Channel. Liquid draining from either of the upper plenum channels is available to all rods in the top cell of Channel 10. If a more detailed radial nodalization were used, such as that approved for use in the large break methodology, would the hot assembly void and cladding heat up, and if so what is the PCT and ECR?

Comments on RAI 440.169 Response:

The response supplied in the October 18, 2002, transmittal memo is not sufficient.

The pre-Design Certification phase of the review concluded that tests conducted in the APEX, ROSA, and SPES facilities for the AP600 were non-conservatively scaled for the AP1000. That is, the scaled entrainment rates in those facilities were expected to be significantly less than that expected in the AP1000. Models and correlations for entrainment, including Kataoka-Ishii, generally have a strong dependence on the gas phase velocity. Entrainment increases rapidly with the gas flux. Models and correlations, which may be adequate for low gas flux conditions, may have significant uncertainty and underpredict the entrainment if applied at high gas flux. Thus, models that were acceptable for conditions in the APEX, ROSA, and SPES facilities at the scaled, lower gas flux conditions of the AP600 must be re-assessed for the high gas flux conditions of the AP1000.

The RAI response assumes that the WCOBRA/TRAC models and correlations for upper plenum entrainment are appropriately assessed, because the code predicted entrainment rate agrees with that predicted by the Kataoka-Ishii model. There are two overall concerns with the approach; applicability of the Kataoka-Ishii correlation, and modeling in the upper plenum. They are discussed next.

<u>Applicability of the Correlation</u>

The basis for why the Kataoka-Ishii model adequately represents entrainment in an upper plenum has not been established. The correlations developed in Reference 1 were developed using data from several small scale experiments. The vessel diameter in these experiments was small (D_H<0.3 m) and gas velocities low (J_g<3 m/s). It is not clear that conditions in the test data, in which the flows were essentially one-dimensional, are representative of those in the upper plenum of a full scale plant. In order to make the WCOBRA/TRAC calculations and sensitivity studies meaningful, it remains to be shown that the Kataoka-Ishii expressions are conservative, or at least approximate the net entrainment from a pressurized water reactor (PWR) upper plenum. The most effective way to do this is to obtain and evaluate experimental data from tests in the APEX facility run at a power scaled to the AP1000.

<u>Modeling and Flow Patterns</u>

Entrainment in the upper plenum using WCOBRA/TRAC is accomplished using the models in the "cold wall" flow regimes. Most of the entrainment occurs when liquid is entrained from an annular film, which is not assumed to form until the void fraction in the cell is greater than 0.5. Little or no entrainment occurs when the cell is in the Small Bubble or Large Bubble regimes. High entrainment rates, as suggested in Appendix A.3 and A.4, are due to the code annularizing and then entraining the film. This may be a compensating error, as agreement (with Kataoka-Ishii) is obtained by assuming the wrong flow regime.

Reference

[1] Kataoka, I., and Ishii, M., "Mechanistic Modeling and Correlations for Pool Entrainment Phenomenon," NUREG/CR-3304, 1983.

<u>Comments on RAI 440.171 Response:</u>

Regarding the response supplied in the November 1, 2002, transmittal memo (W Ref.: DCP/NRC1529; ADAMS Accession No. ML023110249), the figure must be included in a revision to WCAP-15833.

<u>Comments on RAI 440.173 Response:</u>

The response supplied in the November 26, 2002, transmittal memo (W Ref.: DCP/NRC1535; ADAMS Accession No. ML023360097) cannot be fully evaluated. The transmittal is missing all except the first 20 figures listed in the response.

SUMMARY OF DISCUSSIONS
FOR CALL HELD ON MARCH 10, 2003
BETWEEN NRC STAFF AND WESTINGHOUSE
REGARDING RAIS DESCRIBED IN ENCLOSURE 1

RAI 440.151

Westinghouse is preparing a revised response to the RAI and WCAP-15833.

RAI 440.152

Westinghouse is preparing a revised response to the RAI.

RAI 440.154

Westinghouse indicated that the revision to RAI 440.151 should address the concerns of RAI 440.154 b. and c.

RAI 440.157

Westinghouse agreed to update WCAP-15833 to address the concern discussed in Enclosure 1.

RAI 440.160

Westinghouse agreed to update WCAP-15833 to address the concern discussed in Enclosure 1.

RAI 440.161

No additional information required from Westinghouse at this time.

RAI 440.162

Westinghouse agreed to update WCAP-15833 to address the concern discussed in Enclosure 1.

RAI 440.164

Westinghouse acknowledged that they understood the question and agreed to determine what action was required to address issue.

RAI 440.169

This open RAI forms the basis for the associated request for new test data from Westinghouse for the purpose of justifying the modeling of entrainment processes, including the upper plenum entrainment, that occur during an SBLOCA.

RAI 440.171

Westinghouse agreed to update WCAP-15833 to address the concern discussed in Enclosure 1.

RAI 440.173

Westinghouse indicated that this issue was resolved with the submission of Revision 1 to RAI 440.173 (ADAMS Accession No. ML030520376). The NRC staff will reevaluate the issue considering the revised information.

TELEPHONE CONFERENCE CALL
ON MARCH 10, 2003
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Enclosure 3

cc:

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