July 15, 2003

ORGANIZATION: WESTINGHOUSE ELECTRIC COMPANY

SUBJECT: SUMMARY OF MAY 29, 2003, MEETING WITH WESTINGHOUSE ELECTRIC COMPANY TO DISCUSS AP1000 THERMAL HYDRAULIC ISSUES ASSOCIATED WITH THE DESIGN CERTIFICATION REVIEW

The Nuclear Regulatory Commission (NRC) hosted a public meeting with Westinghouse Electric Company (Westinghouse) on May 29, 2003, at NRC Headquarters to discuss thermal hydraulic issues associated with the AP1000 design certification review. A non-proprietary summary of these discussions is provided as Attachment 1. A list of meeting attendees is provided in Attachment 2.

Westinghouse provided non-proprietary handouts during the meeting which can be accessed through the Agencywide Documents Access and Management System (ADAMS Accession Nos. ML031560369 and ML031550699). This system provides text and image files of NRC's publicly available documents. In addition, the agenda for the meeting is located in the ADAMS system (ADAMS Accession No. ML031550697). If you do not have access to ADAMS or, if there are problems in accessing the handouts located in ADAMS, contact the NRC Public Document Room (PDR) Reference staff at 1-800-397-4209, 301-415-4737 or by e-mail to pdr@nrc.gov.

In the letter (ADAMS Accession No. ML031060265) dated April 11, 2003, Westinghouse requested that a technical progress meeting be held to discuss the proposed resolution to the AP1000 liquid entrainment issues addressed in NRC's letter (ADAMS Accession No. ML030720132) to Westinghouse dated March 18, 2003. The purpose of the meeting was to review Westinghouse's proposed resolution to the NRC's concern that higher AP1000 power will result in increased liquid entrainment during the automatic depressurization system-stage 4/in-containment refueling water storage tank (ADS-4/IRWST) injection phase of the small break loss-of-coolant accident (SBLOCA) event. The proposed resolution will be presented to the Advisory Committee on Reactor Safeguards (ACRS) on July 16-18, 2003. During the open portion of the meeting, Westinghouse provided an overview of the meeting topics. During the remainder of the meeting, which was closed to the public Westinghouse presented test results of bounding parametric evaluations and sensitivity studies associated with the prediction of the core level.

Sincerely,

/RA/

Leslie C. Fields, Project Manager
New, Research and Test Reactors Program
Division of Regulatory Improvement Programs, NRR

Docket No.: 52-006

Attachments: 1. Non-proprietary Summary of May 29, 2003, Meeting
2. List of Meeting Attendees

cc w/atts: See next page

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Non-Proprietary Summary of Closed Portion of
May 29, 2003, Meeting with Westinghouse

On May 29, 2003, Westinghouse presented their proposed approach to resolve questions raised by the Advisory Committee on Reactor Safeguards (ACRS) at the Thermal-Hydraulic Subcommittee meeting held on March 19, 2003. The summary of the May 29, 2003, meeting discussions is provided to report NRC feedback prior to the ACRS meeting scheduled for July 16-18, 2003. To demonstrate how the core remains covered during small break loss-of-coolant accident (SBLOCA) and to validate the overall system performance, Westinghouse Electric Company (Westinghouse) presented test results associated with Level Swell Validation, NOTRUMP Bounding Calculations, FLOAD 4 modeling of momentum flux, NOTRUMP calculations of limiting SBLOCA, RELAP 5, Design Basis Accident System Performance, Validation of NOTRUMP against General Electric (GE) small vessel blowdown, ACHILLES, G2, SPES/OSU (APEX), integral facility simulation, test data relative to post-quench core coverage, and FLECHT Seaset full scale tests. Westinghouse presented test results to the staff to justify the assertion that NOTRUMP conservatively predicts the core two-phase level and that the calculation of average level swell are conservative. According to Westinghouse, the tests performed cover the range of expected conditions which include heated bundles and depressurization effects.

<u>WESTINGHOUSE CONCLUSIONS</u>

Westinghouse concluded that NOTRUMP closely predicts data trends observed in tests and conservatively estimates two-phase mixture level/void fraction. The ACHILLES test results showed consistent trends in results observed and for the same collapsed level NOTRUMP conservatively predicts a lower two-phase mixture level. The level swell validation summary showed that NOTRUMP calculations of average level swell are conservative for nearly all tests. Level swell validation showed that AP1000 indicates adequate core mixture level to preclude core uncovery.

The applicability of post-quench core coverage was also discussed. After the opening of the ADS-4 stage and before the IRWST injection a time period of minimum vessel liquid inventory is expected to occur. Using a detailed model of the active fuel region, the AP1000 WCOBRA/TRAC long-term cooling analysis predicts adequately high liquid levels and injection flow rates to comply with Title 10 of the *Code of Federal Regulations* (10 CFR) Section 50.46.

<u>STAFF OBSERVATIONS</u>

At the meeting the staff identified three areas that may need further clarification. They include:

(1) NOTRUMP prediction of core level during the ADS-4/IRWST transition phase;
(2) WCOBRA/TRAC-AP prediction of core level during long-term cooling (LTC); and
(3) Westinghouse analysis of boron precipitation during LTC.

<u>NOTRUMP prediction of core level during the ADS-4/IRWST</u>

During the discussion of the small break LOCA, prior to the LTC, it was stated that core inventory is at its minimum early in the IRWST injection phase. Westinghouse made the assertion that NOTRUMP conservatively predicts the core two-phase level during this period. To make this prediction, the collapsed liquid level must be known and the processes that determine the two-phase distribution must be adequately modeled. These processes are primarily interfacial drag and heat transfer.

To determine the ability of NOTRUMP to predict level swell for a given collapsed liquid inventory, code results were compared to data from the G2 and ACHILLES test series. The staff believes that the code should be compared to a more comprehensive set of low pressure data, including such test series as THETIS, G1, and FLECHT, as well as additional ACHILLES tests. This additional assessment is necessary because of the high importance ranking of this phenomenon and the uncertainty in the experimental data. The data should be at representative levels of inlet flow, subcooling, pressure, and power with a rod assembly configuration.

Two-phase level during the transient is also a function of the collapsed liquid level. At this stage of the transient, inventory is held up in the upper plenum through the counter-current flow limitation (CCFL). Westinghouse should address the impact of inventory draining from the upper plenum into the core by localized breakdowns of CCFL at some core regions. This effect would be non-conservative if predicted to occur prematurely at steam flow rates above the actual flooding limit.

Eventually the inventory in the upper plenum drains to the core. Therefore, the quantity of liquid that is entrained into the hot leg and discharged out of ADS-4 affects the core level during this period. The Westinghouse approach consists of a strategy to demonstrate that the entrainment is conservatively predicted by the code through comparison to scaled data from the APEX-1000 facility at Oregon State University. However, the vessel two-phase level affects the entrainment rate. This effect also needs to be addressed to ensure that entrainment is conservatively calculated. If NOTRUMP conservatively under-predicts two-phase level, then it may also non-conservatively predict the entrainment rate.

The ACRS Thermal/Hydraulic Subcommittee raised the issue of the effect of two-phase pressure drop through the core and upper plenum on the IRWST injection rate. A conservative under-prediction of inventory and two-phase level would tend to reduce the pressure drop through the vessel and result in an over-prediction of IRWST injection flow and collapsed liquid level.

Westinghouse presented information to justify that the level swell and collapsed liquid level were conservatively predicted. Individual phenomena, such as two-phase pressure drop and entrainment were asserted to be conservatively predicted by addressing the phenomena separately. However, Westinghouse should consider how these phenomena interact together to justify that the overall code prediction of core level is bounded.

<u>WCOBRA/TRAC-AP's prediction of core level during LTC</u>

Westinghouse presented WCOBRA/TRAC-AP results of core level during LTC which indicated that the void fraction at the core exit (i.e., the cell just below the top cell in the core) oscillated between approximately 75 to 100 percent. The staff believes this result warrants further consideration as discussed below. Westinghouse should assess the level swell predictive capability of the WCOBRA/TRAC-AP code using data at representative levels of inlet flow, subcooling, pressure, and power with a rod assembly configuration. Westinghouse should address the fact that an over-prediction of power and underestimation of subcooling would be conservative with respect to peak clad temperature, but would result in a non-conservative estimation of level swell. Based on the staff's review of applicable data, the staff expects that roughly the top 3 feet of the core may be uncovered given the collapsed liquid level predicted by WCOBRA/TRAC-AP. However, no rod heat up was predicted by WCOBRA/TRAC-AP.

WCOBRA/TRAC-AP models two separate fields of liquid, droplets and film. Westinghouse should present information that ensures the code predictions are appropriate and that apportioning of the liquid into either a film on the rod or droplets in the fuel channel is done correctly. Overestimating the amount of liquid that is a film on the rods would tend to overestimate heat transfer from the rods, a nonconservative effect. Particularly important is the justification for entrained drops in the upper exposed steam region during LTC. Such a condition needs to be justified since entrained liquid will preclude steam superheat and a clad temperature excursion in the steam region above the two-phase surface. The staff estimates that with the top 2-3 feet of the core exposed, rod temperatures may remain in the 1000-1500°F range, potentially resulting in a low rate heat oxidation process. Should such a condition be shown to exist, Westinghouse should show that clad oxidation limits are not violated. The oxidation model used to compute the low temperature oxidation should also be described and justified. The LTC analyses should also be continued until core quench or that time the cladding temperatures return to values very near the fluid saturation temperature.

A similar assessment of the competing effects of collapsed liquid level, entrainment and level swell on core level, as was presented for the ADS-4/IRWST injection phase, should be discussed to ensure that the results are conservative.

The input model for the WCOBRA/TRAC-AP run was modified from a 2 node core to a 10 node core, with the 10 node core predicting higher exit void fractions. The sensitivity of the results to nodalization should be addressed. For example, are appreciable changes in PCT predicted with a 15 to 20 node core?

Results of the LTC phase were shown at 4.5 hours into the transient and then at 14 days. The core level did not appear to be increasing conclusively at the end of 4.5 hour period. Westinghouse should run the LTC case to the point where a constantly increasing level is predicted before partitioning the LTC phase into time segments.

Lastly, the liquid level and void fraction plots exhibit severe oscillations. Westinghouse should demonstrate that these oscillations are physical and are not numerically induced. A stable or smoothly varying liquid level/swelled level response would be expected to result in clad heat-up in the top portions of the core.

<u>Boron precipitation during LTC</u>

Westinghouse presented an analysis demonstrating that adequate entrainment of liquid out ADS-4 would occur to prevent boron precipitation during late stages of the LTC phase. The staff does not agree with Westinghouse's assertion that entrainment would occur indefinitely and requests that the time at which measures should be taken to flush the core be determined and those measures be described.

As the core cools, the increase in coolant boric acid concentration is arrested. However, a high boric acid concentration remains in the core many hours into the event. Westinghouse must demonstrate that as the core becomes increasingly subcooled, these high boric acid concentrations will not result in boron precipitation in the core and that the analysis takes into consideration the effect of coolant temperature on boron solubility. Westinghouse should also demonstrate that the concentrations in the sump also do not approach precipitation limits at the maximum sump temperature subcoolings.

Westinghouse should also address the possible collection of boric acid crystals on the ADS-4 valves and exit piping as these equipment components cool during the event. Justification should be provided to discount the possibility for the ADS-4 valves/piping to become obstructed with boric acid crystals many hours into the event.

Public Meeting Roster
Thermal Hydraulics Liquid Entrainment
May 29, 2003

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Attachment 2

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