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Your ref: Docket No. 52-006
Our ref: DCP/NRC1664

January 5, 2004

SUBJECT: Retransmittal of Responses to AP1000 DSER Open Items

REFERENCE: Westinghouse Letter DCP/NRC1663 dated January 2, 2004

This letter supersedes our letter DCP/NRC1663, dated January 2, 2004, to correct references in the Application for Withholding Proprietary Information from Public Disclosure. The Open Item responses from DCP/NRC1663 are retransmitted by this letter even though the responses are not changed.

This letter transmits the Westinghouse responses to Open Items in the AP1000 Design Safety Evaluation Report (DSER). A list of the DSER Open Item responses transmitted with this letter is Attachment 1. The proprietary responses are transmitted as Attachment 2. The non-proprietary responses are provided as Attachment 3 to this letter.

The Westinghouse Electric Company Copyright Notice, Proprietary Information Notice, Application for Withholding, and Affidavit are also enclosed with this submittal letter as Enclosure 1. Attachment 2 contains Westinghouse proprietary information consisting of trade secrets, commercial information or financial information which we consider privileged or confidential pursuant to 10 CFR 2.790. Therefore, it is requested that the Westinghouse proprietary information attached hereto be handled on a confidential basis and be withheld from public disclosures.

This material is for your internal use only and may be used 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 Commission, the Office of Nuclear Reactor Regulation, the Office of Nuclear Regulatory Research and the necessary subcontractors that have signed a proprietary non-disclosure agreement with Westinghouse without the express written approval of Westinghouse.

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Correspondence with respect to the application for withholding should reference AW-04-1761, and should be addressed to Hank A. Sepp, Manager of Regulatory Compliance and Plant Licensing, Westinghouse Electric Company, P.O. Box 355, Pittsburgh, Pennsylvania, 15230-0355.

Please contact me at 412-374-4728 if you have any questions concerning this submittal.

Very truly yours,

R. P. Vijuk, Manager
Passive Plant Engineering
AP600 & AP1000 Projects

/Enclosure

1. Westinghouse Electric Company Copyright Notice, Proprietary Information Notice, Application for Withholding, and Affidavit AW-04-1761.

/Attachments

1. List of the AP1000 Design Certification Review, Draft Safety Evaluation Report Open Item Responses transmitted with letter DCP/NRC1664
2. Proprietary AP1000 Design Certification Review, Draft Safety Evaluation Report Open Item Responses dated January 2, 2004
3. Non-Proprietary AP1000 Design Certification Review, Draft Safety Evaluation Report Open Item Responses dated January 2, 2004

DCP/NRC1664
Docket No. 52-006

January 5, 2004

# Enclosure 1

Westinghouse Electric Company
Application for Withholding and Affidavit

Westinghouse

Westinghouse Electric Company
Nuclear Power Plants
P.O. Box 355
Pittsburgh, Pennsylvania 15230-0355
USA

January 5, 2004

AW-04-1761

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555

ATTENTION: Mr. John Segala

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

SUBJECT: Transmittal of Westinghouse Proprietary Class 2 Documents Related to AP1000 Design Certification Review Draft Safety Evaluation Report (DSER) Open Item Response

Dear Mr. Segala:

The application for withholding is submitted by Westinghouse Electric Company, LLC ("Westinghouse") pursuant to the provisions of paragraph (b)(1) of Section 2.790 of the Commission's regulations. It contains commercial strategic information proprietary to Westinghouse and customarily held in confidence.

The proprietary material for which withholding is being requested is identified in the proprietary version of the subject documents. In conformance with 10 CFR Section 2.790, Affidavit AW-04-1761 accompanies this application for withholding setting forth the basis on which the identified proprietary information may be withheld from public disclosure.

Accordingly, it is respectfully requested that the subject information which is proprietary to Westinghouse be withheld from public disclosure in accordance with 10 CFR Section 2.790 of the Commission's regulations.

Correspondence with respect to this application for withholding or the accompanying affidavit should reference AW-04-1761 and should be addressed to the undersigned.

Very truly yours,

R. P. Vijuk, Manager
Passive Plant Engineering
AP600 & AP1000 Projects

/Enclosures

AW-04-1761

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared James W. Winters, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Company, LLC ("Westinghouse"), and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief.

James W. Winters, Manager
Passive Plant Projects & Development
AP600 & AP1000 Projects

Sworn to and subscribed
before me this 5th day
of January, 2004

Lorraine M. Piplica
Notary Public

COMMONWEALTH OF PENNSYLVANIA
Notarial Seal
Lorraine M. Piplica, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires Dec. 14, 2007
Member, Pennsylvania Association Of Notaries

(1) I am Manager, Passive Plant Projects & Development, of the Westinghouse Electric Company LLC ("Westinghouse"), and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rulemaking proceedings, and am authorized to apply for its withholding on behalf of the Westinghouse Electric Company, LLC.

(2) I am making this Affidavit in conformance with the provisions of 10 CFR Section 2.790 of the Commission's regulations and in conjunction with the Westinghouse application for withholding accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by the Westinghouse Electric Company, LLC in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.790 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse.

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitutes Westinghouse policy and provides the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, e.g., by optimization or improved marketability.

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

(b) It is information which is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

(c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR Section 2.790, it is to be received in confidence by the Commission.

(iv) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(v) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in Attachment 2 as Proprietary Class 2 in the Westinghouse Electric Co., LLC document: (1) "AP1000 Design Certification Review, Draft Safety Evaluation Report Open Item Response."

This information is being transmitted by Westinghouse's letter and Application for Withholding Proprietary Information from Public Disclosure, being transmitted by Westinghouse Electric Company letter AW-04-1761 to the Document Control Desk, Attention: John Segala, CIPM/NRLPO, MS O-4D9A.

This information is part of that which will enable Westinghouse to:

(a) Provide documentation supporting determination of APP-GW-GL-700, "AP1000 Design Control Document," analysis on a plant specific basis

(b) Provide the applicable engineering evaluation which establishes the Tier 2 requirements as identified in APP-GW-GL-700.

Further this information has substantial commercial value as follows:

(a) Westinghouse plans to sell the use of similar information to its customers for purposes of meeting NRC requirements for Licensing Documentation.

(b) Westinghouse can sell support and defense of AP1000 Design Certification.

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar methodologies and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended for performing and analyzing tests.

Further the deponent sayeth not.

January 5, 2004

## Copyright Notice

The documents transmitted herewith each bear a Westinghouse copyright notice. The NRC is permitted to make the number of copies for the information contained in these reports which are necessary for its internal use in connection with generic and plant-specific reviews and approvals as well as the issuance, denial, amendment, transfer, renewal, modification, suspension, revocation, or violation of a license, permit, order, or regulation subject to the requirements of 10 CFR 2.790 regarding restrictions on public disclosure to the extent such information has been identified as proprietary by Westinghouse, copyright protection not withstanding. With respect to the non-proprietary versions of these reports, the NRC is permitted to make the number of copies beyond these necessary for its internal use which are necessary in order to have one copy available for public viewing in the appropriate docket files in the public document room in Washington, DC and in local public document rooms as may be required by NRC regulations if the number of copies submitted is insufficient for this purpose. Copies made by the NRC must include the copyright notice in all instances and the proprietary notice if the original was identified as proprietary.

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## PROPRIETARY INFORMATION NOTICE

Transmitted herewith are proprietary and/or non-proprietary versions of documents furnished to the NRC in connection with requests for generic and/or plant-specific review and approval.

In order to conform to the requirements of 10 CFR 2.790 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (4)(ii)(a) through (4)(ii)(f) of the affidavit accompanying this transmittal pursuant to 10 CFR 2.790(b)(1).

# Attachment 1

List of

Proprietary and Non-Proprietary Responses

| Table 1<br>"List of Westinghouse's Responses to DSER Open Items Transmitted in DCP/NRC1664" | |
|---|---|
| *21.5-2P, Item 22, Revision 1<br>21.5-2, Item 22, Revision 1<br><br>*Proprietary | |

DCP/NRC1664
Docket No. 52-006

January 5, 2004

**Attachment 3**

AP1000 Design Certification Review
Draft Safety Evaluation Report Open Item Non-Proprietary Responses

# AP1000 DESIGN CERTIFICATION REVIEW

## Draft Safety Evaluation Report Open Item Response

**DSER Open Item Number: 21.5-2 Item 22 Revision 1**

**Original RAI Number(s): None**

***Summary of Issue:***

For the NOTRUMP simulation of both DBA-02 and DBA-03 tests, Figures 21.5-2.19 and 21.5-2.44, respectively, show NOTRUMP overpredicts the core collapsed liquid level for the time period between about 100 to 400 seconds. Figures 21.5-2.20 and 21.5-2.45, respectively, indicate NOTRUMP underpredicts core average void fraction between the same time period. Westinghouse attributes the non-conservative NOTRUMP calculations to its lack of two-dimensional downcomer modeling and heating of DVI injection flow. The sensitivity study performed with higher injection temperature still show non-conservative, though reduced, NOTRUMP predictions (Figures 21.5-2.17 and 18).

Please explain why, with the same downcomer modeling deficiency, the NOTRUMP calculations of the core liquid level and void fraction are comparable with the tests after 400 seconds.

**Westinghouse Response:**

The NOTRUMP simulations are comparable with the DEDVI tests after 400 seconds because the test behavior is more consistent with NOTRUMP one dimensional modelling after this time. During the 100 to 350 second time period there is blowdown through the broken DVI nozzle on one side of the downcomer with high rates of injection of subcooled water from the intact DVI nozzle on the other side of the downcomer. This creates the two dimensional behavior observed in the tests during the 100 to 350 second time period. After ADS1 actuation, the break flow decreases as is shown in Figure 1. After 400 seconds the behavior is more one dimensional as the ADS4 flow paths become the dominant vent path and the injection rate is at the lower rate from the intact IRWST injection line.

***NRC Comment from 12/17/03 Status meeting:***

Provide justification of the acceptability of NOTRUMP SBLOCA analysis in light of its over-prediction of core collapsed liquid level in the early portion and propagation effects on the later stage of DVI line break transient as seen in (1) the NOTRUMP simulation of the APEX test DBA-2 and DBA-3 test data, (2) the NOTRUMP-RELAP5 comparison.

**Westinghouse Response (Revision 1)**

Attachment 21.5-2 Item 22 R1 –1 provides additional justification of NOTRUMP acceptability.

**Design Control Document (DCD) Revision:**

None

**PRA Revision:**

None

a,b,c

[ ]

**Figure 1: Comparison of Integrated Flow from the Break and ADS Flow Paths for DBA-02**

Attachment 21.5-2 Item 22 R1 – 1

## 1. Introduction

The comparison between the results obtained with NOTRUMP and RELAP5 for the simulation of the AP1000 DEDVI transient showed a discrepancy in core collapsed liquid level during the early ADS depressurization phase. In particular NOTRUMP results showed a higher core collapsed liquid than RELAP during this time period. A similar mismatch was observed between the NOTRUMP simulation of the APEX DBA-2 and DBA-3 tests and the data.

The objectives of this response are the following:

1) Provide an explanation of what causes NOTRUMP to over-predict the core collapsed liquid level in the early phase of the APEX DBA-2 and DBA-3 test simulations.
2) Demonstrate that the initial mismatch has negligible propagation effects on later stages of the DVI line break.
3) Assess the implications of the observed misprediction on the AP1000 safety analysis of the DVI line break and provide additional justification for NOTRUMP application for this AP1000 safety analysis.
4) Address the differences observed between NOTRUMP and RELAP5 for the early portion of the DVI line break simulation, in light of this assessment.

Note that this response is intended to supplement and clarify what is already contained in WCAP-15644-P (Reference 1) and previous responses to DSER open items 21.5-2 and 21.5-3.

## 2. Reasons for the NOTRUMP overestimation of core collapsed liquid during the ADS depressurization phase.

### 2.1 Observation of APEX DBA-02, DBA-03 simulations

Results of the NOTRUMP simulation of the APEX DBA-02 and DBA-03 tests are discussed in WCAP-15644-P (Reference 1). It was reported that during the early ADS-1-2-3 blowdown, the predicted core collapsed liquid level diverges from the measured value in the time period between 140 and 400 seconds. However, despite the fact that during this time period the core collapsed liquid level is over-predicted by the code, it re-converges to the test data after 400 seconds.

This time period corresponds approximately to the accumulator discharge period as reported in Table E1 and E2 of Reference 1. During the rest of the transient, which is the transition to the Long Term Cooling, the predicted core collapsed liquid level is in good agreement with the data.

During the accumulator discharge period, the following was also observed:

1) The total break flow and the intact DVI flow is close to data, while the total ADS1-2-3 total flow is underpredicted by NOTRUMP. This is consistent with the vessel inventory mismatch during the same time period.

2) NOTRUMP predicts significant subcooling in the lower plenum and at the core inlet which will tend to suppress vapor generation within the core.
3) Thermocouple readings in the test indicate subcooling is confined to the top of the downcomer region, nearby the intact DVI port. At the same time liquid conditions toward the bottom of the downcomer and lower plenum are close to saturation. This is discussed further in Section 2.2 and suggests significant downcomer condensation and mixing in the tests during the accumulator discharge period.
4) Both test and simulation shows approximately 0.8 ft of liquid head above the core in the upper plenum . The predicted value is in very good agreement with the measured value.

## 2.2 NOTRUMP Underprediction of Downcomer Condensation

The underprediction of condensation in the downcomer results in higher subcooling at the core inlet, which underestimates the vapor generation in the core, thus the core void fraction (over-prediction of core collapsed level).

Significant condensation is expected in the downcomer due to agitation of the interface by DVI flow which is essentially a downward flowing jet mixing into a pool of subcooled liquid. NOTRUMP code uses the Dittus-Bolter correlation to estimate the condensation heat transfer coefficient at the jet interface which is applied to the interface area based on the jet length exposed to the vapor space in the downcomer region. This treatment ignores the main condensing interface of the pool which is agitated by the jet as discussed by Janicot and Bestion (1993) [A. Janicot and D. Bestion, "Condensation modeling for ECC Injection," Nuclear Engineering and Design 145 (1993) 37-45]. While the specific configuration of their test is different from that in the DVI/downcomer geometry of AP1000, and thus their correlation is not directly applicable, it is informative to note their findings which are (a) for high enough liquid injection velocity, the condensing area extends well beyond the jet dimensions, and (b) the dependency on the liquid Reynolds number of the best fit is large ($R_l^{1.5}$). This suggests that in AP1000, the condensation is important when the liquid jet is relatively strong (during the blowdown and injection of ACC), and is less dominant after the ACC empties.

The observations discussed in the next section from the OSU test seem to confirm the view discussed above.

### 2.2.1 Test data indicates presence of significant condensation

DB02 test data indicates significant heatup of downcomer liquid due to condensation as seen in a series of figures below. The series of plots show a snapshot of downcomer temperature profile, one under the intact DVI and another under the broken DVI, as well as the prediction by NOTRUMP (DB02 case from Code Applicability Document).

The figures below show the fluid temperature as a function of elevation in downcomer. The DVI port elevation is also indicated with the broken line at 62 inch. The figures indicate much cooler temperature immediately below the intact DVI port which is injecting while the broken DVI side shows essentially saturated condition at all elevations. NOTRUMP prediction of downcomer

temperature and the saturation temperature based on the pressure at the top of the downcomer are also shown for comparison.

NOTE: CMT started to inject at 5.5 seconds, ADS1 opened at 85 sec. Accumulator injection has not yet started. At 100 seconds, the only injection is provided by the CMT.

a,b,c

NOTE: Accumulator injection started at 115 sec. ADS2 opened at 133 sec.

a,b,c

NOTE: ADS3 opened at 192 sec.

a,b,c

NOTE: ADS4 opened at 251, and 283 sec.

a,b,c

Accumulator emptied at 378 sec.

a,b,c

As seen in the above plots, the under prediction of downcomer temperature by NOTRUMP occurs during the Accumulator injection period.

### 2.3 NOTRUMP Sensitivity Studies to Address Effect of Downcomer Condensation

Figures 1 through 9 provide NOTRUMP comparison to test DBA02 data from the Code Applicability Document (CAD, WCAP-15644-P, Revision 1). The core inlet sub-cooling is overpredicted by NOTRUMP during the accumulator (ACC) injection period as can be seen in Figure 1. This was determined to affect the core and downcomer regions of the test simulation during the period between 180-400 seconds as observed in Figures 4, 5 and 7 respectively. A sensitivity study was performed in the CAD in which both the intact Core Makeup Tank (CMT) and ACC were heated to 200 F to assess the effects of higher core inlet temperature; however, since the period of mis-prediction is the ACC injection period, a new sensitivity study was performed in which only the intact ACC temperature was increased to 200 F. It is expected that by increasing the intact ACC injection temperature, core inlet subcooling will be reduced with a subsequent increase in core average void fraction. It is also expected to result in an increase in system pressures during the ACC injection period since the higher injection temperature reduces the downcomer condensation. These expectations are supported by the results of this new sensitivity analysis shown in Figures 9 through 15.

The effect of increasing the ACC temperature can be seen directly in the calculated core and downcomer region responses as observed in Figures 11, 12 and 14 respectively. As can be seen, the core and downcomer levels indicate an improved comparison to the test data with

very little impact on the upper plenum collapsed liquid. As expected, the downcomer pressure is now slightly higher than the base CAD simulation during the ACC injection period.

a,b,c

[ ]

Figure 1 – NOTRUMP DBA-02 CAD Simulation, Core Inlet Temperature

a,b,c

Figure 2 – NOTRUMP DBA-02 CAD Simulation, Downcomer Pressure

a,b,c

Figure 3 – NOTRUMP DBA-02 CAD Simulation, Collapsed Pressurizer Liquid Level

a,b,c

Figure 4 – NOTRUMP DBA-02 CAD Simulation, Core Collapsed Liquid Level

a,b,c

Figure 5 – NOTRUMP DBA-02 CAD Simulation, Core Average Void Fraction

a,b,c

Figure 6 – NOTRUMP DBA-02 CAD Simulation, Upper Plenum Collapsed Liquid Level

a,b,c

Figure 7 – NOTRUMP DBA-02 CAD Simulation, Downcomer Collapsed Liquid Level

a,b,c

Figure 8 – NOTRUMP DBA-02 CAD Simulation, Intact DVI Line Injection

a,b,c

Figure 9 – NOTRUMP DBA-02, 200 Deg. ACC, Downcomer Pressure

a,b,c

Figure 10 – NOTRUMP DBA-02, 200 Deg. ACC, Pressurizer Collapsed Liquid Level

a,b,c

Figure 11 – NOTRUMP DBA-02, 200 Deg. ACC, Core Collapsed Liquid Level

a,b,c

[ ]

Figure 12 – NOTRUMP DBA-02, 200 Deg. ACC, Core Average Void Fraction

a,b,c

[ ]

Figure 13 – NOTRUMP DBA-02, 200 Deg. ACC, Upper Plenum Collapsed Liquid Level

a,b,c

Figure 14 – NOTRUMP DBA-02, 200 Deg. ACC, Collapsed Downcomer Liquid Level

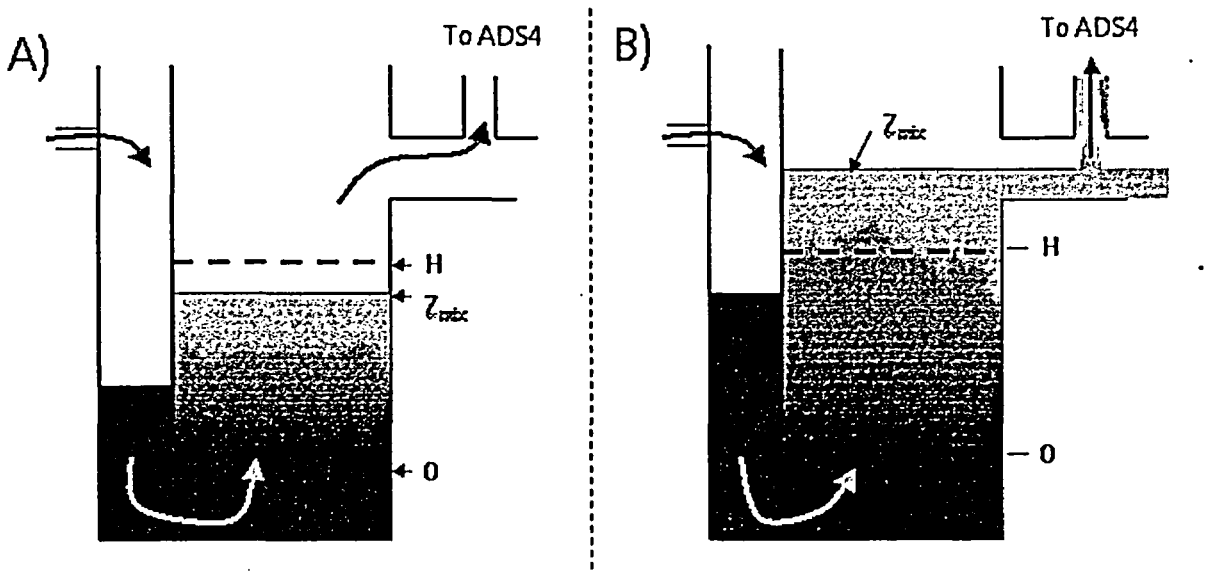
a,b,c

Figure 15 – NOTRUMP DBA-02, 200 Deg. ACC, Intact DVI Line Injection

### 2.4 Core Cooling Conditions

The AP1000 core cooling issue was discussed in general in the response to DSER Open Item Number 21.5-3P (Revision 1). The discussion is partially repeated and generalized here for convenience. The AP1000 mode of operation following a postulated SBLOCA event was characterized by two possible scenarios:

CASE A) The mixture level is within the core region
CASE B) The mixture level is above the core, in the upper plenum region




- CASE A: The location of the mixture level (dryout point) is a function of the level swell model used (similar to the boil-off tests). The supply of liquid is insufficient to remove the decay heat. The core exit quality is 100%. The top of the core is uncovered and expected to heat-up. This condition is also possible even when there is liquid accumulation in Upper Plenum if the upper core plate is flooded (vapor flow at the upper core plate is high and beyond the CCFL limit).

- CASE B: There is enough supply of liquid to the core such that the core exit quality is less than 100%. The location of mixture level is in proximity of the hot leg elevation and excess of liquid is discharged by the ADS valves. In this situation, the mixture level is virtually independent of the level swell model used within the core. There is a continuum of two-phase flow trough the core, which provides good cooling and prevents core heat-up from occurring. The condition is that there is good communication between the core region and the upper plenum. In other words the steam flow at upper core plate is below the CCFL limit.

During the DVI Break transient, NOTRUMP predicts the presence of a significant amount of water in the upper plenum throughout the transient (see Figures E-20 and E-45 of Reference 1). Moreover the upper plenum collapsed liquid level is in good agreement with the measured value. Similar conditions are predicted for the plant.

As mentioned before, a necessary conditions for the existence of case B is good communication between the core region and the upper plenum. The vapor flow through the upper core plate (UCP) is an important parameter in determining the CCFL condition at UCP and whether the liquid in the upper plenum is allowed to drain back into the core. The vapor Kutateladze (Ku(g)) is an indicator for the CCFL limit. If the vapor flow is sufficiently high (beyond no liquid downflow limit of Ku(g)*=3.2), the core would behave as in the boil-off situation. If Ku(g) is less than 3.2, liquid can flow back from the upper plenum into the core region. Note that even if Ku(g) is less than this limit, the liquid downflow may still be retarded such that the void fraction below such a flow restriction could be higher than the void fraction in the upper plenum.
To confirm that there is good communication between the core region and the upper plenum, the Kutateladze number at the upper core plate was estimated for the APEX test data, the NOTRUMP simulation of the tests, and the NOTRUMP simulation of the plant. Figure 1 shows the Kutateladze number as a function of time which was estimated from the test data.

a,b,c

[ ]

Figure 17 – Upper Core Plate Kutateladze Number Deduced from the Test Data

The Ku number for the test was calculated based on an upper bound estimated of the steam flow at the core exit. The steam flow was calculated from an energy balance assuming the entire core at saturation conditions. In this case the vapor generation is only a function of the decay heat. An additional source of vapor was added to account for the flashing of saturated liquid caused by the system depressurization. The flashing contribution was estimated assuming an iso-entropic expansion. It turns out the vapor source caused by the flashing of

saturated liquid is small and contributes at most an additional 10% to the steam generated because of decay heat.

Figure 18 shows the Ku number predicted by NOTRUMP for the same test (base case):

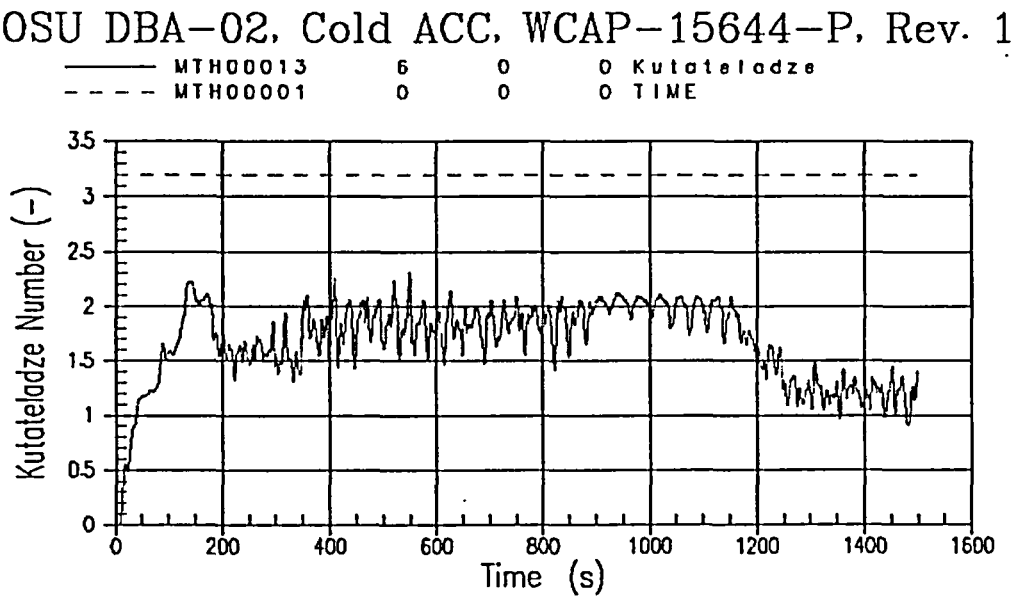



Figure 18

Figure 19 shows the results from the sensitivity case (hot accumulator):

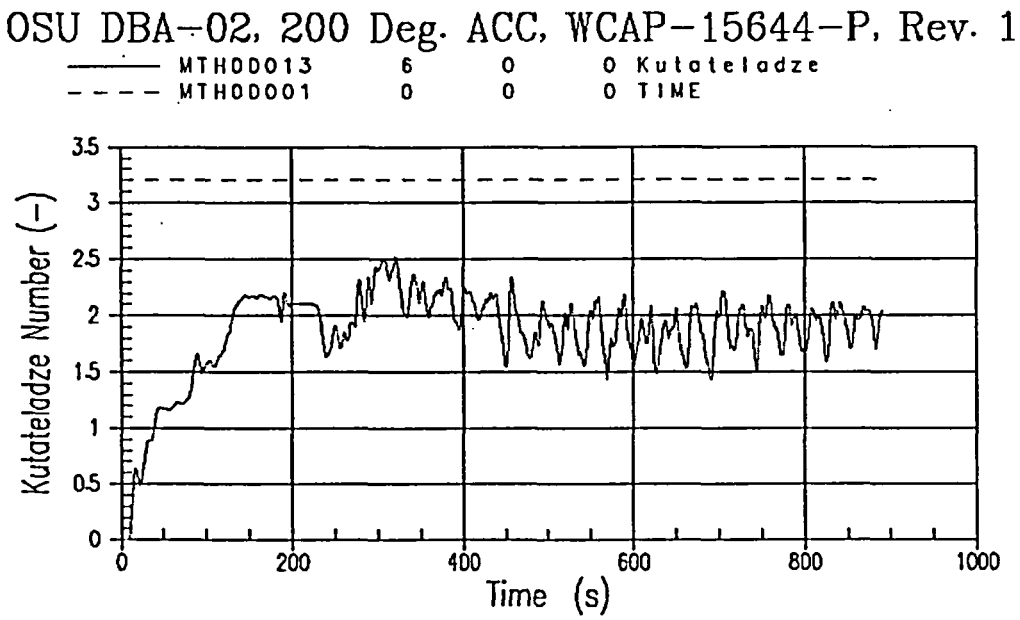



Figure 19

Figure 20 shows the Ku number predicted by NOTRUMP for the AP1000 DE DVI (14.7 containment back pressure).

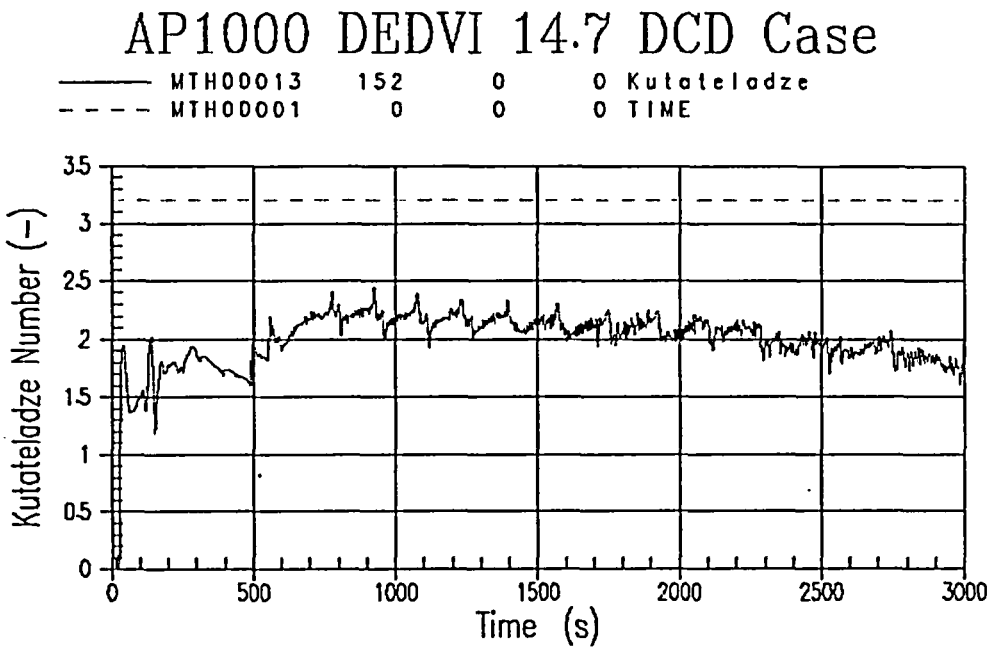



Figure 20

In all cases, the Kutateladze number is always less than 3.2 which corresponds to the CCFL limit. Note that the Kutateladze number tends to be relatively small during the early phase of the transient and increases to a stable value during the LTC period. This confirms that good communication between the core region and the upper plenum is also expected during the early ADS depressurization phase, when additional steam is generated because of flashing of saturated liquid as the system depressurizes.

The previous observations, i.e. liquid in the upper plenum and good communication between core region and upper plenum, are indications that the expected thermal-hydraulic conditions in the AP1000 vessel are consistent with the Case B depicted in the response to DSER Open Item 21.5-3 and section 2.4 of this document. A mixture level establishes at approximately the hot leg nozzle elevation and a good core flow is established to prevent core uncovery from occurring.

Cunningham-Yeh tends to under-predict the void fraction in the low void fraction region (as shown in Figure 1 of the response to DSER Open Item 21.5-3). This provides conservative results in term of level swell, but tends to over-predict the core collapsed liquid level when the core is fully covered by a two-phase mixture. Based on the conditions in the DBA-02 and

DBA-03 tests, it is expected that the use of Cunningham-Yeh void fraction model would contribute to at least another 10% collapsed liquid level overprediction which adds to the previous over-prediction attributed to the lack of condensation.

The core collapsed liquid level over-prediction during the early phase of the transient has a small impact on core cooling. A significant amount of water is stored in the upper plenum and, based on the previous CCFL arguments, liquid is free to flow back into the core and a continuum of two-phase mixture is maintained across the heated length and into the upper plenum. These thermal-hydraulic conditions are similar to the one observed and expected in the Long Term Cooling period, which was discussed in response to DSER Open Item 15.2.7-1 and DSER Open Item 21.5-3P (Revision 1).Under these circumstances, good core cooling is expected and is virtually independent of the average core void fraction. Moreover during the accumulator discharge period the core flow is higher than in the long term cooling period and the Kutateladze number at the upper core plate is expected to be lower, therefore providing even better liquid communication between the core and upper plenum regions.

### 3. NOTRUMP Code Acceptability for AP1000 DEDVI Break Transient

The intent of Section 2 was to provide an explanation of the reasons why NOTRUMP tends to over-predict the core collapsed liquid level during the early phase of the transient, and to show that the initial mis-prediction does not affect core cooling during the early phase. Despite the initial mismatch of the core collapsed liquid level, the general behavior of the test is still predicted well by the code.

Propagation of the NOTRUMP mis-prediction in the early phase to affect core cooling predictions in the later phases is not seen in the test predictions because an equilibrium condition is reached where the mixture level is maintained at approximately the hot leg elevation. This mode of operation was already discussed in the responses to DSER Open Items 15.2.7-1 and 21.5-3 (Revision 1) and depicted as case B in Section 2.4 The equilibrium point is virtually independent of the initial liquid mass. If more mass was present in the vessel, more liquid will be discharged by the ADS system until the same equilibrium point is reached. This conclusion is also supported by the sensitivity analysis with NOTRUMP discussed in Section 2.3. Despite the core collapsed level during the early phase being affected significantly by the accumulator temperature, the effect on the later period was negligible.

Core uncovery and subsequent heat up would be possible only if the mixture level drops below the upper core plate elevation, therefore bringing the system to a boil-off scenario (Case A). This was not observed in the tests nor in the NOTRUMP simulations. In the case of boil-off, the use of the Cunningham-Yeh void fraction model will tend to provide conservative results because the level swell phenomenon is underpredicted.

A boil-off condition was observed in the APEX test NRC-05, which was based on a beyond design basis accident scenario for the AP1000. Core uncovery was observed as soon as the upper plenum was drained and the mixture level drops within the core region. The transient and the core heat-up was well predicted by NOTRUMP.

Figure 21 shows that the predicted and measured upper plenum collapsed liquid level are in good agreement. Liquid is predicted to be collected in the upper plenum for most of the transient which supports the Case B scenario. At about 1000 seconds in the test and 900 seconds in the simulation the level starts to drop.

a,b,c

Figure 21

Figure 22 shows that, with the exception of the early portion of the transient, the predicted average core void fraction is in good agreement. At about 1100 seconds the mixture level drops below the top of the core (upper plenum is empty) and the thermal-hydraulic conditions in the system become consistent with a boil-off scenario (Case A). At this time core uncovery was predicted to occur and is consistent with the test observations.

a,b,c

Figure 22

Figure 23 shows that the core heatup prediction is consistent with the test observation.

a,b,c

Figure 23

**4. Comparison of NOTRUMP and RELAP**

For the AP1000 DEDVI predictions, NOTRUMP predicts higher core collapsed liquid level than does RELAP.

Discussions with NRC indicated that RELAP is known to overpredict the drag forces between steam and liquid phases. Therefore, it was decided to investigate the impact of the rod bundle interphase slip correlation used in RELAP. To assess the effect of rod bundle interphase slip a RELAP case was run using the same input deck used by NRC and enabling the Bestion correlation via card 1 option 19. The results of this case are compared to the original NRC and NOTRUMP results.

Figure 1 provides the core collapsed liquid level comparison. This shows the effect of the interphase slip model in RELAP. Comparisons of the correlations to experimental tests are reported in Reference 2. In Reference 3 it is shown that the Bestion correlation predicts a lower interfacial drag than the EPRI correlation used in the base RELAP case, and hence more water is predicted in the rod bundle when the Bestion correlation is used. RELAP with the Bestion rod bundle correlation provides results that compare better to the NOTRUMP calculation. NOTRUMP uses the Cunningham-Yeh void fraction model to represent interphase slip in the rod bundle and has been shown in Reference 1 to agree well with test data.

The deviation in predictions between 300 and 600 seconds results not only from the different rod bundle interphase slip models, but also from differences in downcomer modelling, break flow models, and initial accumulator pressure. During this time period there is blowdown through the broken DVI nozzle on one side of the downcomer with high rates of injection of subcooled accumulator water from the intact DVI nozzle on the other side of the downcomer. The AP1000 RELAP model has a detailed quasi-two-dimensional downcomer model (8 pipes connected in cross flow through multiple junctions) while in NOTRUMP the downcomer is modelled as a three axial node lumped pipe. The RELAP model uses a Henry-Fauske break flow model while NOTRUMP uses the Zaloudek/Moody break flow model. The RELAP model initial accumulator pressure is 651 psia while the NOTRUMP initial accumulator pressure is 715 psia. The net effect of these differences during this time period is that RELAP depressurizes more slowly, has a later ADS 1-3 actuation, has later and lower accumulator injection, and has less subcooling of the downcomer water feeding the core, as compared to NOTRUMP during this period. The lower injection and lower subcooling in RELAP result in lower core collapsed level during this period, as compared to NOTRUMP.

After 600 seconds the downcomer behavior is more one dimensional as the ADS4 flow paths become the dominant vent path rather than the DVI break and the injection rate is at the lower rate from the intact CMT and IRWST. After 600 seconds the NOTRUMP and RELAP Bestion core collapsed level predictions re-converge, while the RELAP EPRI prediction remains at a lower level. This difference in the long term is a result of the higher interfacial drag with the EPRI model, as noted above.

On the basis of the above comparison it is concluded that the differences between the NOTRUMP and RELAP calculation are explained by considerations related to different code modelling technique (downcomer model, condensation model), computer code constitutive models (two phase drag forces and slip correlations, break flow models), and input differences (initial accumulator pressure). Both the NOTRUMP and RELAP analyses predict no core heatup.

Overall the NOTRUMP and RELAP analyses predict the AP1000 core is well protected. Initially the intact CMT provides injection, then phased ADS actuation provides depressurization and hot leg venting with injection from the intact CMT, accumulator and IRWST. NOTRUMP provides an acceptable method for AP1000 SBLOCA analysis as discussed in Reference 1.

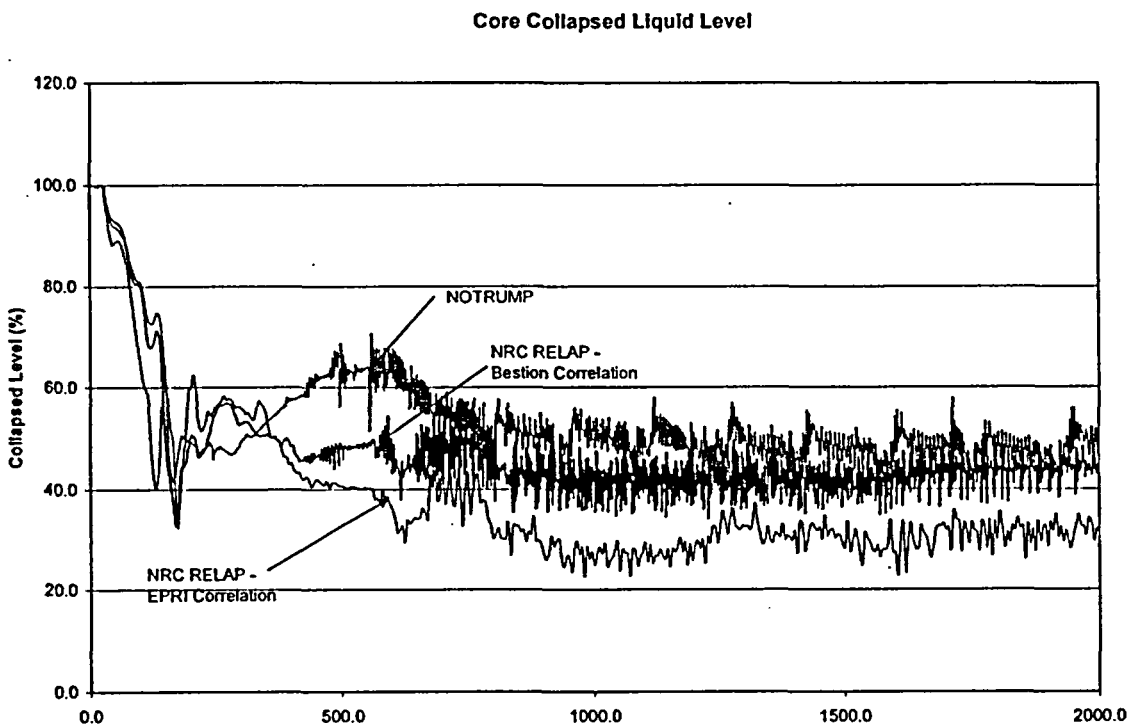



**Figure 1 – Core Collapsed Liquid Level (%)**

## 5. Summary

The NOTRUMP over-prediction of core collapsed liquid level during the accumulator injection period of APEX DEDVI tests is explained to be the result of underestimating condensation at the top of the downcomer. This NOTRUMP mis-prediction does not create potential for NOTRUMP to overestimate core cooling during this period because this is a period of high injection flow being pulled through the core by the ADS venting. This mis-prediction also does not influence the NOTRUMP capability to predict core cooling during later phases as evidenced by comparisons to test data and sensitivity analyses. A core cooling challenge for the DEDVI case was created in APEX test NRC-05 and was predicted by NOTRUMP.

Differences between the NOTRUMP and RELAP AP1000 DEDVI predictions are explained by considerations related to different code modelling technique (downcomer model, condensation model), computer code constitutive models (two phase drag forces and slip correlations, break flow models), and input differences (initial accumulator pressure). Both the NOTRUMP and RELAP analyses predict no core heatup. Overall the NOTRUMP and RELAP analyses predict the AP1000 core is well protected.

NOTRUMP provides an acceptable method for AP1000 SBLOCA analysis as discussed in Reference 1.

## References

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