Westinghouse Electric Corporation
Energy Systems
Box 355
Pittsburgh Pennsylvania 15230-0355

AW-96-1009

September 12, 1996

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

ATTENTION: T. R. QUAY

APPLICATION FOR WITHHOLDING PROPRIETARY INFORMATION FROM PUBLIC DISCLOSURE

SUBJECT: RETRANSMITTAL OF WESTINGHOUSE RESPONSE TO NRC REQUESTS FOR ADDITIONAL INFORMATION ON THE NOTRUMP COMPUTER CODE

Dear Mr. Quay:

The application for withholding is submitted by Westinghouse Electric Corporation ("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 report. In conformance with 10CFR Section 2.790, Affidavit AW-96-1009 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 10CFR Section 2.790 of the Commission's regulations.

Correspondence with respect to this application for withholding or the accompanying affidavit should reference AW-96-1009 and should be addressed to the undersigned.

Very truly yours,

Brian A. McIntyre, Manager
Advanced Plant Safety and Licensing

/nja

cc: Kevin Bohrer NRC 12H5

2920A

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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) contained within parentheses 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 Section (4)(ii)(a) through (4)(ii)(f) of the affidavit accompanying this transmittal pursuant to 10 CFR2.790(b)(1).

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared Brian A. McIntyre, 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 Corporation ("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:

Brian A. McIntyre, Manager
Advanced Plant Safety and Licensing

Sworn to and subscribed
before me this 13th day
of September, 1996

Notary Public

Notarial Seal
Janet A. Schwab, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires May 22, 2000
Member, Pennsylvania Association of Notaries

(1) I am Manager, Advanced Plant Safety And Licensing, in the Advanced Technology Business Area, of the Westinghouse Electric Corporation 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 Energy Systems Business Unit.

(2) I am making this Affidavit in conformance with the provisions of 10CFR 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 Energy Systems Business Unit 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 10CFR 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) Enclosed is Letter NSD-NRC-96-4820, September 12, 1996 being transmitted by Westinghouse Electric Corporation (W) letter and Application for Withholding Proprietary Information from Public Disclosure, Brian A. McIntyre (W), to Mr. T. R. Quay, Office of NRR. The proprietary information as submitted for use by Westinghouse Electric Corporation is in response to questions concerning the AP600 plant and the associated design certification application and is expected to be applicable in other licensee submittals in response to certain NRC requirements for justification of licensing advanced nuclear power plant designs.

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

(a) Demonstrate the design and safety of the AP600 Passive Safety Systems.

(b) Establish applicable verification testing methods.

(c) Design Advanced Nuclear Power Plants that meet NRC requirements.

(d) Establish technical and licensing approaches for the AP600 that will ultimately result in a certified design.

(e) Assist customers in obtaining NRC approval for future plants.

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 advanced plant licenses.

(b) Westinghouse can sell support and defense of the technology to its customers in the licensing process.

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 advanced nuclear power designs 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 developing analytical methods and receiving NRC approval for those methods.

Further the deponent sayeth not.

ENCLOSURE 2

Question 440.326

Re: WCAP-14206 (NOTRUMP CAD)
Figure 1-1 presents the nodalization of a current generation nuclear steam supply system. While this nodalization is informative as to how one models conventional plants, it is of little or no use in understanding AP600 NOTRUMP nodalization. Instead of a conventional plant diagram, an AP600 nodalization would be more appropriate for presentation. Also, no break spectrum analyses were included in this document. It would be appropriate to include the AP600 break spectrum analyses and nodalization in this document instead of the information pertaining to current generation plants that could have been more appropriately referenced. Please provide the analyses from References 12 and 19 or the most up-to-date AP600 small break LOCA analysis.

Response:

The Preliminary SSAR Chapter 15.6 analysis submitted in July, 1995 (Reference 440.326-1) presents an AP600 small break LOCA spectrum performed using the same version of NOTRUMP which was applied in the OSU and SPES-2 Preliminary Validation Reports (References 440.326-2 and 440.326-3). The NOTRUMP nodalization shown in Figure 15D-1 of Reference 440.326-1 and employed in the Reference 440.326-1 analysis is consistent with the nodings used in the Reference 440.326-2, 3, 4 and 5 test facility simulations. The noding scheme has been taken directly from the NRC approved NOTRUMP Evaluation Model nodalization presented in WCAP-14206, Figure 1-1 where possible. However, it has been altered where necessary to implement the improved models described in Chapter 4 of References 440.326-2 and 3. As in the NOTRUMP Evaluation Model, steady-state controller fluid nodes and flow links are initially used to assist in establishing a steady 102% power condition at the time of the LOCA.

SSAR Revision: NONE

References:

440.326-1 Letter NTD-NRC-95-4503, "Preliminary Marked Up Sections of SSAR Chapter 15, Revision 5", July 10, 1995

440.326-2 P.E. Meyer et.al., "PXS-GSR-002: NOTRUMP Preliminary Validation Report for SPES-2 Tests," Westinghouse Electric Corporation, July 1995.

440.326-3 M.G. Willis et.al.,"LTCT-GSR-001:NOTRUMP Preliminary Validation Report for OSU Tests," Westinghouse Electric Corporation, July 1995.

440.326-4 J.P. Cunningham et.al., "MT01-GSR-001: AP600 NOTRUMP Core Makeup Tank Preliminary Validation Report," Westinghouse Electric Corporation, October 1994.

440.326-5 H.C. Yeh et.al.,"RCS-GSR-003:AP600 NOTRUMP Automatic Depressurization System Preliminary Validation Report," Westinghouse Electric Corporation, April 1995.

Question 440.328

Re: WCAP-14206 (NOTRUMP CAD)
On page 2-5 the limiting failure is a failure of one fourth-stage ADS. Please explain what analyses were performed supporting this conclusion. Also, in view of changes to the ADS, is this still a valid statement? Please explain or provide new information for the limiting failure.

Response:

The limiting single active failure in an AP600 small break LOCA analysis depends on the postulated break size and location. In the Reference 440.328-1 break spectrum, the failure of a single fourth-stage ADS valve was modeled in the inadvertent ADS actuation and two-inch cold leg break cases. However, for the double-ended direct vessel injection line break and the double-ended balance line break the postulated failure that renders a single first-stage and a single third-stage ADS valve unavailable is limiting.

The AP600 passive safeguards systems are designed such that no single active failure in either the safety injection or PRHR heat exchanger loops can deprive the reactor of a core makeup tank, accumulator, IRWST or PRHR delivery path. Only failures within the ADS can eliminate safety-related path(s) which otherwise would be in operation during a small break LOCA event. Among the small break LOCAs, the time in the event at which the minimum reactor coolant system mass inventory occurs determines which postulated ADS failure is more limiting. As shown in the attached Figures 440.328-1 and 2, both of the double-ended breaks from Reference 440.328-1 exhibit their minimum RCS mass inventories early in the transient, at about the time at which ADS stage one is actuated. Recovery from this minimum mass condition is accomplished via accumulator injection; therefore, if failure of an ADS stage one valve can delay the time at which fully effective accumulator flow is achieved, the minimum RCS mass will be adversely affected for these larger small breaks. Furthermore, the break itself is large enough in these cases to constitute a significant vent path which augments the ADS paths; the degradation in venting associated with the failure of a fourth stage ADS valve is less important in the depressurization of the reactor to achieve IRWST injection. A sensitivity case verified that the postulated stage one/three valve failure is indeed limiting for the AP600 double-ended rupture small break LOCA cases.

In contrast, two-inch cold leg break and inadvertent ADS actuation transients in Reference 440.328-1 exhibit minimum mass inventories (Figures 440.328-3 through 5) when IRWST injection begins. Because depressurizing the reactor to the point at which IRWST injection begins is totally dependent on ADS capability for the smaller small break LOCAs, the postulated failure of one of the largest ADS valves present, a fourth-stage ADS valve, is limiting. Prior to fourth-stage ADS actuation, each of these cases reaches a quasi-equilibrium pressure value which is almost independent of whether a single failure exists among the ADS stage one/two/three valves.

SSAR Revision: NONE

Reference:

440.328-1 Letter NTD-NRC-95-4503, "Preliminary Marked Up Sections of SSAR Chapter 15, Revision 5", July 10, 1995

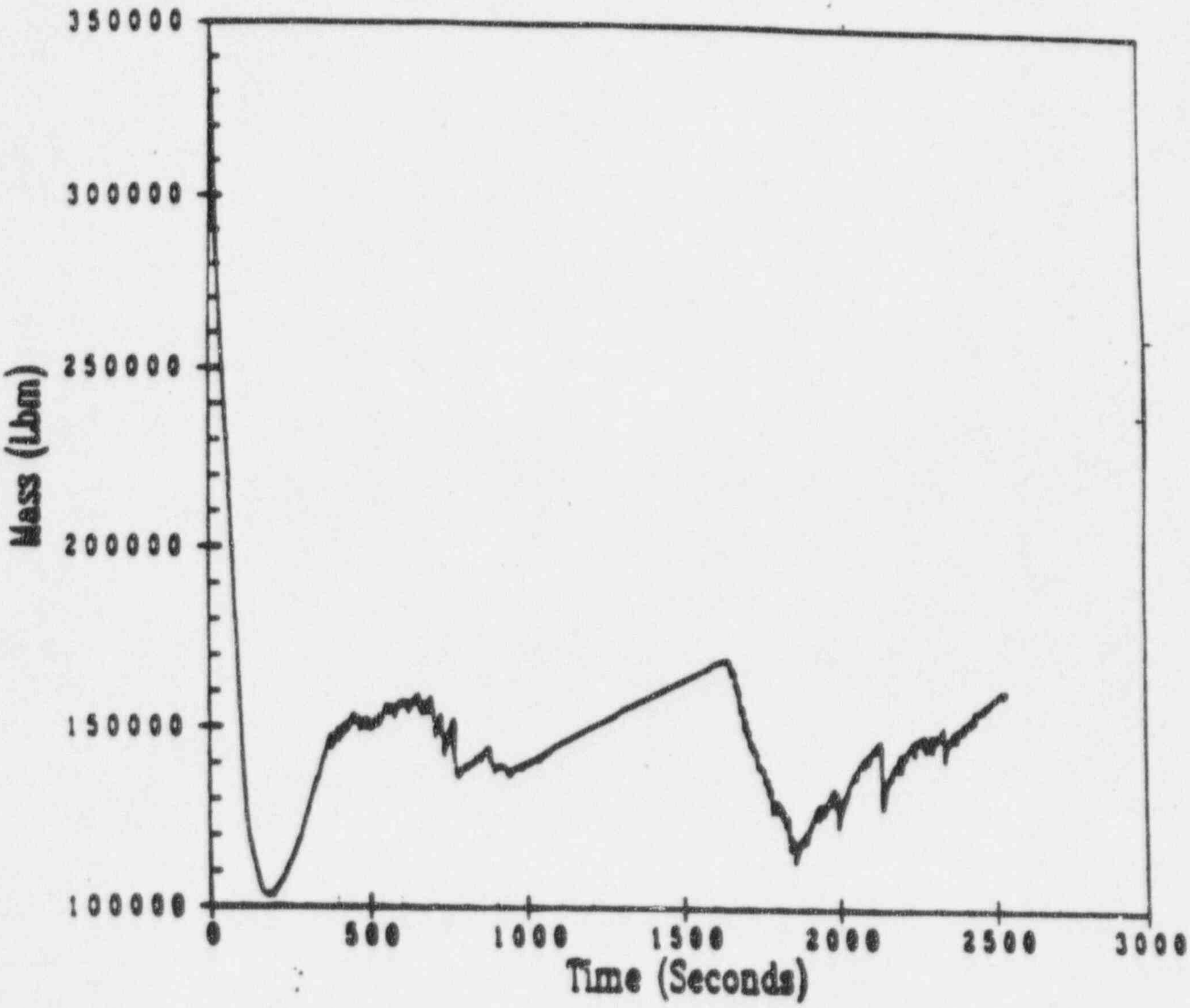

Figure 440.328-1 Double Ended Balance Line Break, Reactor System Coolant Inventory

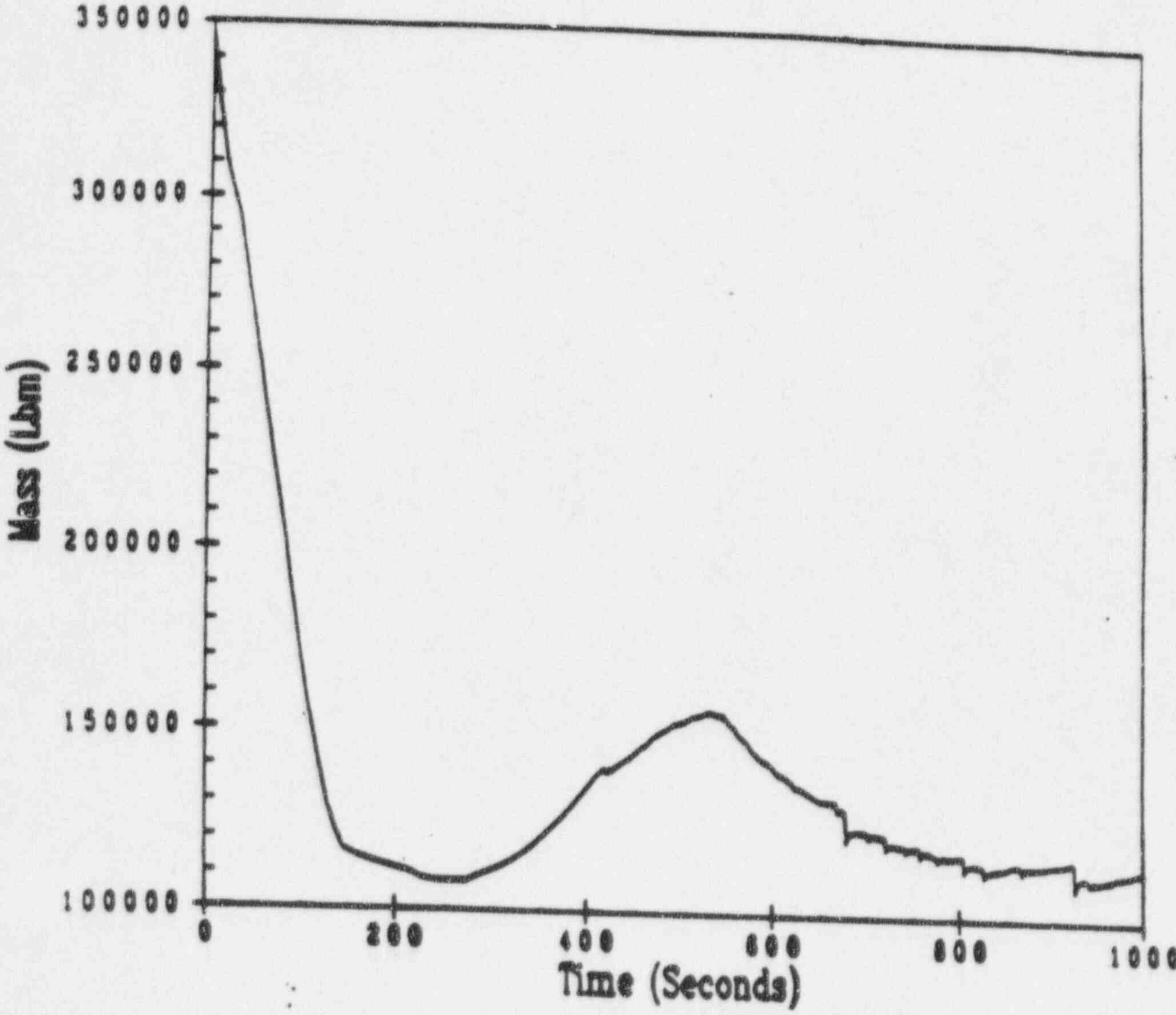

Figure 440.328-2 Double Ended DVI Line Break, Reactor System Coolant Inventory

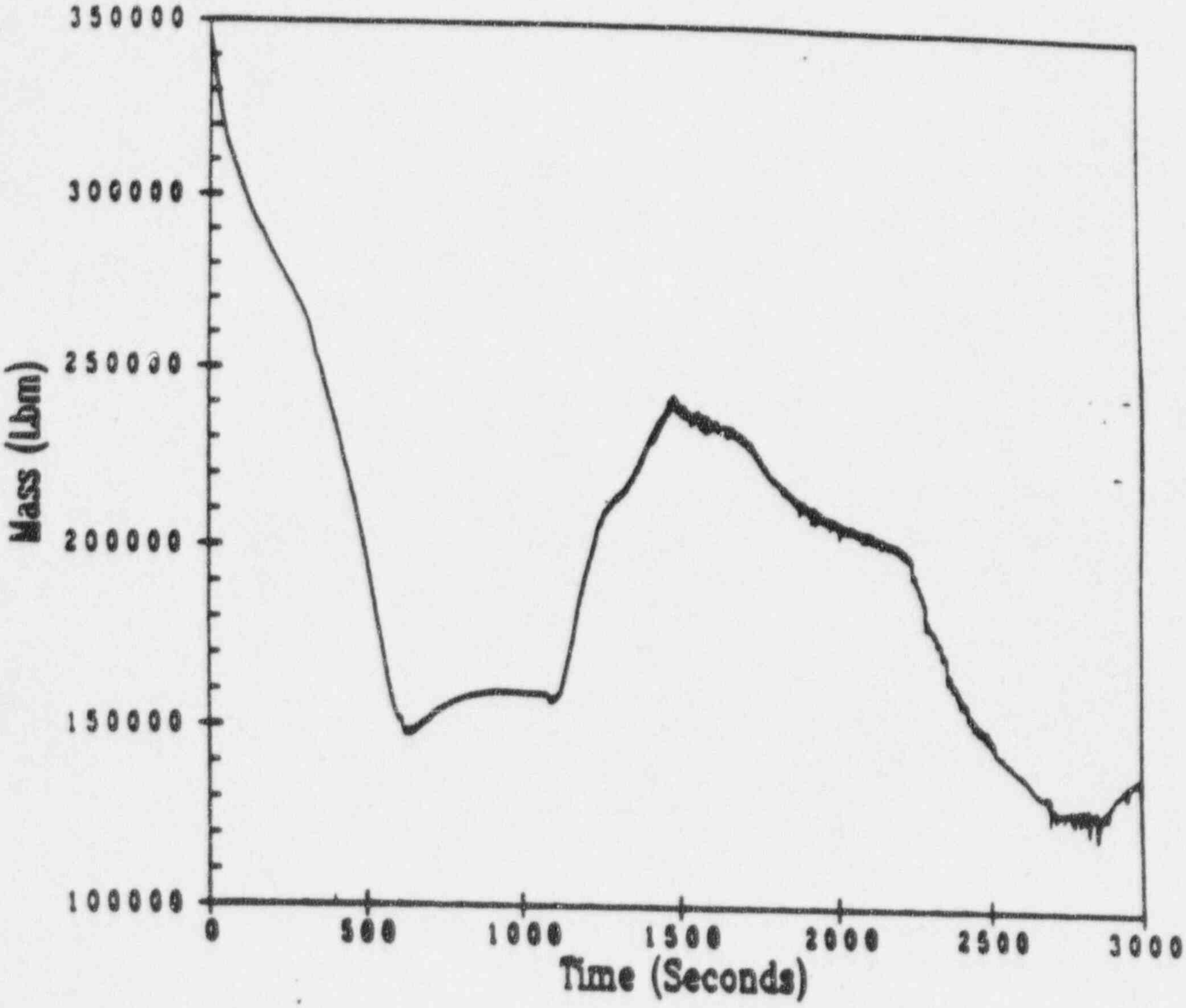

Figure 440.328-3 Two Inch Cold Leg Break In Balance Line Loop, Reactor System Coolant Inventory

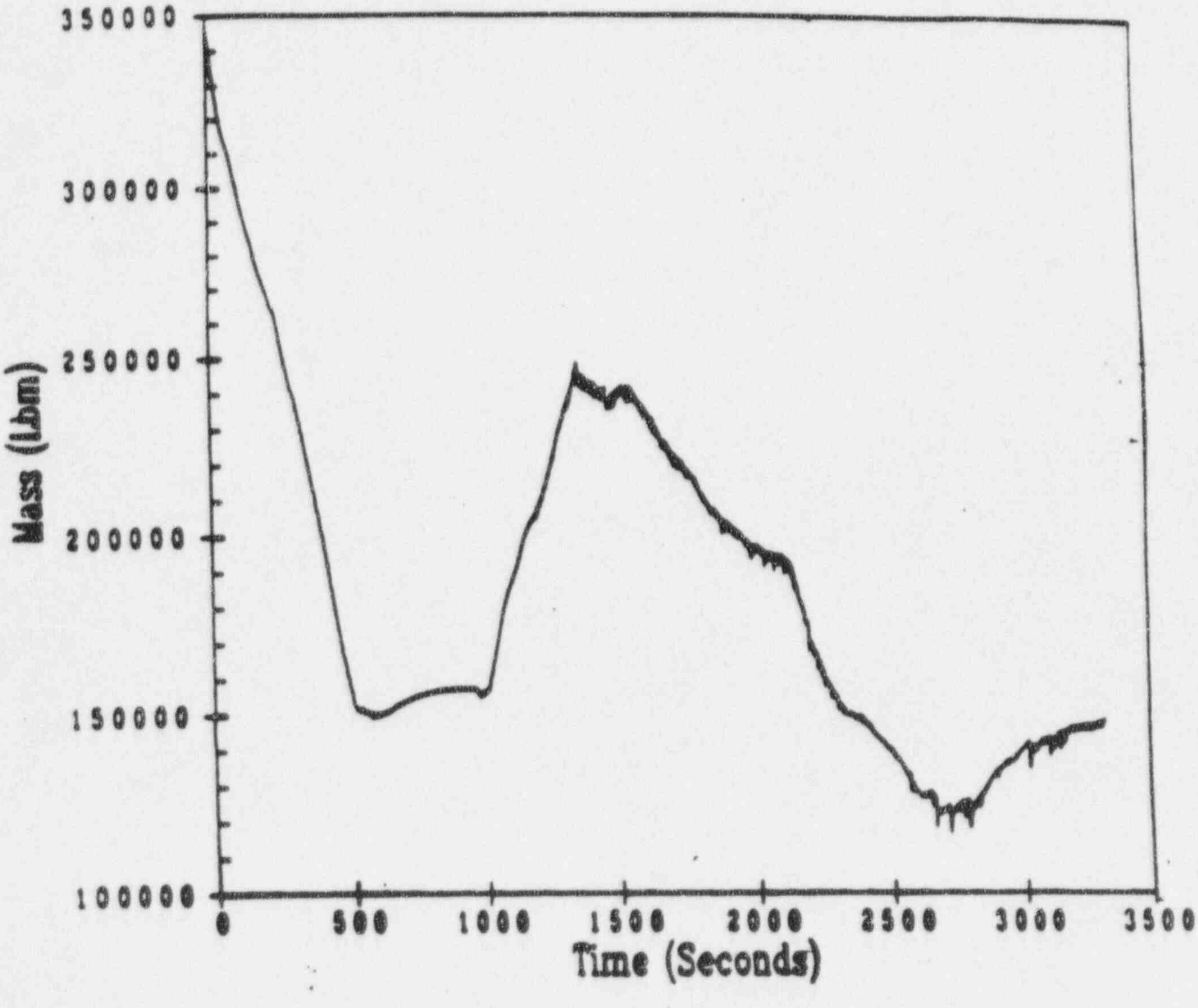

Figure 440.328-4 Two Inch Cold Leg Break In PRHR Loop, Reactor System Coolant Inventory

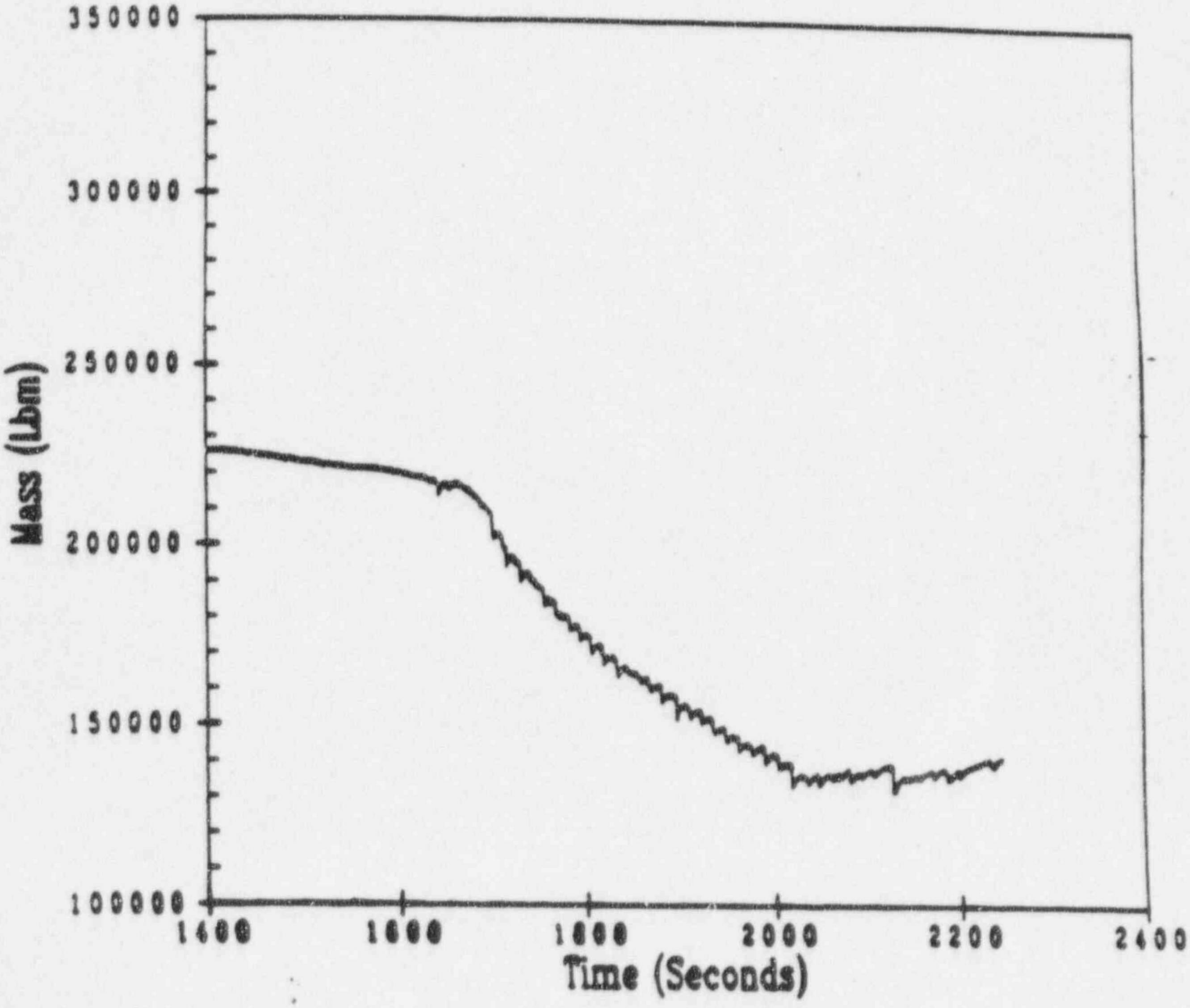

Figure 440.328-5 Inadvertent ADS Actuation, Reactor System Coolant Inventory

Question 440.330

Re: WCAP-14206 (NOTRUMP CAD)
On page 3-2, Section 3.2 identifies possible enhancements to NOTRUMP. Were enhancements made to the code for the analyses of Ref. 12? If so, please describe the enhancements. Also Table 3-1 describes variables added to the NOTRUMP code for AP600. Please describe the physical expressions added to the code to incorporate these new variables. In fact, it may be appropriate to include a separate report describing the new variables and physical models and methods added to NOTRUMP for AP600.

Response:

Section 4 in both Reference 440.330-1 and Reference 440.330-2 describes the model and method enhancements made to NOTRUMP to aid in predicting AP600 small break LOCA phenomena. NOTRUMP with the enhancements has been applied not only in test facility simulations described in those references but also in the AP600 Preliminary SSAR small break LOCA analysis provided in Reference 440.330-3.

Table 3-1 of WCAP-14206 identifies the input variables added to the NOTRUMP user externals to enable modeling the actuation and the functional design of the AP600 passive safety systems. Other variables identified in that table were introduced for use solely in test simulations with NOTRUMP. The user externals are libraries which perform simple, plant-specific functional and physical property calculations to support the NOTRUMP base code solution of the nodal mass, energy and momentum equations. Subsequent to the issuance of WCAP-14206, additional capability was added to NOTRUMP AP600 user externals to further model the AP600 passive safety systems. The new input parameters added to those previously identified in Table 3-1 of WCAP-14206 include:

Individual heat link specification via input to

1. compute wall condensation using the Shah and Nusselt correlations for steam generator and PRHR primary side heat transfer,

2. use a constant value of the condensation wall heat transfer coefficient as supplied by the user for wall condensation in the core makeup tanks.

An ADS logic generalization to permit individual stage activation based on the mixture level in either core makeup tank. This eliminates a potential need for user intervention to activate ADS.

Access to the physical properties of Inconel-690 which have been placed into the NOTRUMP user externals routines CMETAL, DCMETAL and CPMETAL for use in heat transfer computations involving the steam generator and the PRHR heat exchanger tubes.

References:

440.330-1 M.G. Willis et.al.,"LTCT-GSR-001:NOTRUMP Preliminary Validation Report for OSU Tests." Westinghouse Electric Corporation, July 1995.

440.330-2 P.E. Meyer et.al., "PXS-GSR-002: NOTRUMP Preliminary Validation Report for SPES-2 Tests." Westinghouse Electric Corporation, July 1995.

440.330-3 Letter NTD-NRC-95-4503, "Preliminary Marked Up Sections of SSAR Chapter 15, Revision 5", July 10, 1995

SSAR Revision: NONE

Question 440.341

Re: WCAP-14206 (NOTRUMP CAD)
Please describe in detail, the IRWST model. Please also include the PRHR model descriptions detailing how the horizontal and vertical section are simulated. Also describe the sparging models and how plumes are handled and their influence on IRWST injection and PRHR heat removal.

Response:

The NOTRUMP Model of the IRWST (Reference 440.341-1) consists of two fluid nodes stacked vertically to model thermal stratification in the tank. The upper node receives the steam and water discharged from the ADS stage 1-3 sparger and also receives the energy transferred through the PRHR tubes during PRHR heat exchanger operation. Overflow of the liquid in this upper node is predicted to occur during some small break LOCA cases. Meanwhile, the lower fluid node is predicted to heat up negligibly from its initial temperature during the course of small break LOCA events; this is consistent with the observed behavior of the simulated IRWST in the the OSU facility experiments (Reference 440.341-2). The lower IRWST fluid node extends from just below the bottommost PRHR heat exchanger tube to the bottom elevation of the IRWST. Since the entirety of the upper part of the IRWST is modeled in the top fluid node, perfect mixing occurs for plumes in the tank and/or sparger outflow. A single flow path models flow delivery from the sparger arms into the IRWST upper fluid node. This degree of detail is adequate for the time span of the NOTRUMP small break LOCA calculation, which is conducted only until stable IRWST injection of the cold water at the bottom of the IRWST into the reactor vessel downcomer has been established. In further support of the NOTRUMP nodalization, Reference 440.341-2 indicates that the top region of the OSU facility is well mixed during the time period of interest.

As documented in Reference 440.341-3, the PRHR heat exchanger becomes ineffective once ADS stages 1 through 3 are actuated. After ADS actuation, modeling of the IRWST is not significant as regards PRHR heat transfer and its impact on the primary system transient. Refer to the response to RAI 440.513 for further discussion of the NOTRUMP PRHR heat exchanger modeling.

References:

440.341-1 Letter NTD-NRC-95-4503, "Preliminary Marked Up Sections of SSAR Chapter 15, Revision 5, Appendix 15D", July 10, 1995.
440.341-2 WCAP-14252, "AP600 Low Pressure Integral System Test at Oregon State University: Final Data Report [LTCT-T2R-100]
440.341-3 WCAP-14292, Revision 1, "AP600 Low-Pressure Integral Systems Test at Oregon State University Test Analysis Report", Section 7.1.1, [LTCT-T2R-600]

SSAR Revision: NONE

Question 440.438

Re: AP600 NOTRUMP ADS Preliminary Validation Report (RCS-GSR-003)
Please explain the inconsistency in the discussion of the effect of the tank pressure on quality on page 4-3, the middle of the second paragraph. The explanation suggests that both low and high tank pressures will lead to lower qualities.

Response:

The discussion on page 4-3 is dealing with two different pressures, which have opposite effects on the quality, rather than just tank pressure. The two pressures discussed are the tank pressure and the local pressure at the instrumented locations. Increasing the local pressure has the effect of lowering the quality, while increasing the tank pressure has the effect of increasing the quality as discussed below (which is also discussed on page 4-2).

In the equation for the quality:

$$\chi = \frac{1}{H_{fg}}\left[e_{L,ST} - H_L - \frac{M_{L,ST}}{m_{mix}}\left(\frac{\partial e_{L,ST}}{\partial t}\right)\right]$$

where:

$e_{L,ST}$	=	specific liquid internal energy in the supply tank (Btu/lb$_m$)
H_L	=	specific liquid enthalpy (Btu/lb$_m$)
H_{fg}	=	enthalpy of evaporation (Btu/lb$_m$)
m_{mix}	=	steam/water mixture flow rate (lb$_m$/sec)
$M_{L,ST}$	=	mass of liquid in the supply tank (lb$_m$)
t	=	time (sec)
χ	=	quality

H_{fg} and H_L depend on the local pressure. The larger the local pressure, the smaller the H_{fg} and the larger the H_L. However, since the effect of H_{fg} is smaller than that of H_L except near the critical pressure (the local pressure is generally much lower than the critical pressure), the net effect of increasing the local pressure is to decrease the quality, χ. All other variables in the equation depend on the supply tank pressure. The larger the supply tank pressure, the larger the $e_{L,ST}$. The effect of the supply tank pressure on the last term in the equation is very complicated, as is discussed on page 4-2. However, since the value of this term is generally smaller than $e_{L,ST}$, the net effect of the increasing supply tank pressure is to increase the quality.

SSAR Revision: NONE

Question 440.463

Re: NOTRUMP PVR FOR OSU TESTS, LTCT-GSR-001, JULY 1995
Fig. 2-1 presents the NOTRUMP nodalization where a single volume represents the secondary system. Please justify the ability of this nodalization to properly model two-phase level swell on the secondary side. Please explain the potential for partial uncovery of the tube bundle following transients and how a single volume will properly model the hydrostatic fluid balance between the downcomer and tube side in addition to the subcooled level at the bottom of the bundle.

Response:

The single steam generator secondary node used in the AP600 test facility and SSAR models is consistent with the approved NOTRUMP Evaluation Model approach. A sensitivity study to steam generator secondary nodalization in NOTRUMP is documented in Reference 440.463-1. In that study, the results obtained using a four-node SG secondary, including a separate downcomer fluid node, are compared with the results of the PWR Evaluation Model single node SG secondary model for a small break LOCA spectrum. The more detailed SG secondary model produces transient predictions almost identical to those obtained using the evaluation model methodology.

The Reference 440.463-1 study finds that inside the SG tubes some slight effect of enhanced condensation occurs with the more detailed secondary representation applied in NOTRUMP. Condensation inside the tubes indicates heat is being transferred from primary to secondary. With this situation, boiling occurring in the saturated fluid on the secondary side will swell the level there. The fact that the transient predictions correspond so closely between the single node and four node NOTRUMP SG secondary representations shows that the secondary level swell is predicted equally well with either noding.

This slight effect is of even less importance in the AP600 than conventional PWR analyses because the steam generator secondary is a much less important heat sink during AP600 small break LOCA transients. Because AP600 startup feedwater is a non-safety related system, it is not credited in either the baseline OSU tests or in the SSAR design basis small break LOCA analysis. The steam generator secondary is isolated during the early stage of a small break LOCA with no auxiliary cooling flow provided. In addition, the SG secondary is a heat sink that removes energy from the primary system for a relatively short length of time during any size AP600 small break LOCA due to actuation of the PRHR heat exchanger upon an "S" signal. It is the behavior of the PRHR heat exchanger heat sink which establishes the AP600 system pressure at the time at which core makeup tank recirculation ends and CMT draining begins.

The simple, single-volume model of the steam generator secondary acting as a heat source to the primary is adequate for the prediction of the overall small break LOCA ECCS performance of the AP600. NOTRUMP properly predicts collapse of the SG secondary mixture at such time as the secondary becomes a heat source, because bubbles are no longer being generated therein. The AP600 steam generator secondary contains an adequate inventory of mass that when fully collapsed the mixture level covers the top of the tube bundle; no partial uncovery will occur. The same holds true for the OSU test facility.

In summary, a more detailed model of the SG secondary is not necessary in NOTRUMP modeling of the AP600 small break LOCA events. This is consistent with the low importance rating shown in the PIRT rating of SG heat transfer (medium during the natural circulation phase) in WCAP-14206, Table 1-1, especially since the PRHR heat exchanger rather than the steam generator is the most important heat sink during AP600 natural circulation.

References

440.463-1 Lee, N. et.al., "Westinghouse Small Break ECCS Evaluation Model Using the NOTRUMP Code," WCAP-10054-P-A (Proprietary) and WCAP-10081-A (Non-Proprietary), August 1985, Section 6-3-4 through 9.

SSAR Revision: NONE

Question 440.466

For the SIMARC drift-flux model, if the flow is concurrent up or down the flow link void fraction is taken from the upstream volume. For countercurrent flow, it is not clear how the flow link void fraction is computed from the disucssion in Section 4.2. Please describe how the void fraction is computed for countercurrent flow conditions.

Response:

Section 4.2 of LTCT-GSR-001 and PXS-SGR-002 will be replaced in the NOTRUMP Final V&V report with the following Section 4.2.

4.2 SIMARC Drift Flux Methodology

Difficulties in NOTRUMP were related to nonphysical behavior of the drift velocity models, which used the void propagation approach described in Reference 1. Under certain conditions, especially in cases of low-void fraction above high-void fraction, this approach would exhibit nonphysical levitation of liquid above vapor or would predict phasic flows from nodes which had little, if any, of that phase to provide to the flow link. These difficulties were exacerbated by the lower pressures reached in AP600-related analyses than typically reached in small-break loss-of-coolant accident (SBLOCA) analyses of operating plants.

The difficulties described above are not unique to NOTRUMP. They can occur in any thermal-hydraulic network code that uses different control volumes for mass and energy conservation than for momentum conservation, i.e., fluid node/flow link, or staggered mesh codes. Some codes, including NOTRUMP, use a single momentum equation for the net flow rate and a drift flux model to decompose the net flow into phasic (liquid and vapor) flows. In addition to the net flow rate in a flow link, which is known, the drift flux model requires the void fraction in the flow link, which is not known. NOTRUMP, as described in Reference 1, had two approaches to this problem. The first, the flux-weighted void fraction approach, as stated in the NRC NOTRUMP SER, "contributes to the smoothing of the numerical problems to assure that the solution is well-behaved." Unfortunately, it is quite cumbersome to apply to all but the simplest drift velocity correlations. The second, the void propagation approach, while approved as being physically sound, has been found over the years to lead to the difficulties described above.

Since 1985, additional valuable experience has been gained in the use of drift flux in fluid node/flow link codes. Much of this experience was gained in the Westinghouse Simulators Department, which developed the SIMulator Advanced Real-time Code (SIMARC) technology for application in various Westinghouse-built nuclear power plant real-time training simulators. The SIMARC technology is very similar to NOTRUMP in the equations solved, although the solution scheme is quite different and the correlations used (in particular for drift flux) are typically simpler. These differences are primarily a result of the constraint that the SIMARC codes run at a constant time-step size (typically 0.25 seconds) in order to run in real-time all of the time.

To resolve these difficulties, a new methodology for applying drift correlations to flow links was developed. The resulting methodology, referred to as the SIMARC drift flux methodology, has been refined and applied to several different drift velocity correlations, but the central concepts remain the same. It is based on the fact that the net

[ ]a,c

[ ]a,c

[ ]a,c

[ ]a,c If in concurrent flow, the flow link void fraction (and other properties) are taken from the donor end. If in countercurrent flow, [ ]a,c

[ ]a,c

Applying this methodology has shown that it can help to solve the two categories of difficulties discussed above. The case of all liquid above the link and all gas below is handled very easily. Experience has also shown that the methodology works better when applied on a volumetric flow basis, but even when applied on a mass flow basis, it works well. A detailed description of the mathematical formulation of the SIMARC drift flux methodology follows.

The drift flux relationships for the phases volumetric fluxes $\langle j_f \rangle$ and $\langle j_g \rangle$ in terms of the net volumetric flux $\langle j \rangle$ can be written as:

$$\langle j_f \rangle = (1-\Psi^Q) \cdot \langle j \rangle - \phi^Q \quad (4.2\text{-}1)$$

and

$$\langle j_g \rangle = \Psi^Q \cdot \langle j \rangle + \phi^Q \quad (4.2\text{-}2)$$

where

$$\langle j \rangle = \frac{Q}{A}, \quad (4.2\text{-}3)$$

$$\Psi^Q \equiv \langle \alpha \rangle C_o \quad (4.2\text{-}4)$$

and

$$\phi^Q \equiv \langle \alpha \rangle \langle V_{gj} \rangle \quad (4.2\text{-}5)$$

Equations (4.2-1) and (4.2-2) are equivalent to equations (G-16) and (G-17) of Reference 1. The notation is also the same. These are the drift flux relationships used when the momentum equation is cast in terms of the net volumetric flow rate Q.

The drift flux relationships for the phasic volumetric fluxes $\langle j_f \rangle$ and $\langle j_g \rangle$ in terms of the net mass flux $\langle G \rangle$ can be written as:

$$<j_\ell> = \frac{<G_\ell>}{\rho_\ell} \qquad (4.2\text{-}6)$$

and

$$<j_g> = \frac{<G_g>}{\rho_g} \qquad (4.2\text{-}7)$$

where

$$<G_\ell> = (1-\Psi^W) \cdot <G> - \Phi^W \qquad (4.2\text{-}8)$$

$$<G_g> = \Psi^W \cdot <G> + \Phi^W \qquad (4.2\text{-}9)$$

and where

$$<G> = \frac{W}{A}, \qquad (4.2\text{-}10)$$

$$\Psi^W = \frac{<\alpha>C_o\rho_g}{<\alpha>C_o\rho_g + (1-<\alpha>C_o)\rho_\ell}, \qquad (4.2\text{-}11)$$

and

$$\Phi^W = \frac{\rho_\ell\rho_g<\alpha> \ll V_{gj} \gg}{<\alpha>C_o\rho_g + (1-<\alpha>C_o)\rho_\ell}. \qquad (4.2\text{-}12)$$

Equations (4.2-6) - (4.2-9) are equivalent to equations (G-24) and (G-25) of Reference 1. These are the drift flux relationships used when the momentum equation is cast in terms of the net mass flow rate W.

The notation up to this point has been that of Appendix G of Reference 1. For the sake of brevity and clarity, the brackets (< >) and double brackets (≪ ≫) will be omitted but are implied.

As was stated earlier, the SIMARC methodology is based on the fact that [ ]a,c

[ ]a,c

[ ]a,c (4.2-13)

or

(4.2-14)

[ ]a,c

[ ]a,c (4.2-15)

or

(4.2-16)

[ ]a,c

[ ]a,c (4.2-17)

or

(4.2-18)

[ ]a,c

[ ]a,c (4.2-19)

or

(4.2-20)

[ ]a,c

If the flow is concurrent, then the phasic fluxes are evaluated from equations (4.2-1) and (4.2-2) or equations (4.2-6)-(4.2-9) using the void fraction and other properties from the donor end of the link. If the flow is countercurrent, [ ]a,c

[ ]a,c

[ ]a,c

(4.2-21)

and

(4.2-22)

where

(4.2-23)

When the momentum equation is cast in terms of W, the phasic mass fluxes are

[ ]a,c

(4.2-24)

and

(4.2-25)

where

(4.2-26)

It will now be shown that, as the upper and lower void fractions approach one another, the equations for the phasic fluxes for countercurrent flow in the SIMARC drift flux methodology reduce to the form of the standard drift flux equations. That is, equations (4.2-21)-(4.2-23) reduce to the form of equations (4.2-1) and (4.2-2) and equations (4.2-24)-(4.2-26) reduce to the form of equations (4.2-8) and (4.2-9). Thus for equal upper and lower void fractions, the standard drift flux form of the equations is valid over the whole range of flow (concurrent downflow, countercurrent flow, and concurrent upflow). Since flooding curves are made up of drift flux lines for a family of void fractions, the countercurrent methodology gives the typical flooding curves for equal upper and lower void fractions.

Now for the mathematical details. Using equation (4.2-23) in equation (4.2-21) gives

[ ]a,c

(4.2-27)

or

(4.2-28)

Using equations (4.2-13) and (4.2-17) in equation (4.2-28) gives

[ ]a,c (4.2-29)

or (4.2-30)

Similarly, using equation (4.2-23) in equation (4.2-23) in equation (4.2-22) gives

[ ]a,c (4.2-31)

or j_g (4.2-32)

Using equations (4.2-13) and (4.2-17) in equation (4.2-32) gives

[ ]a,c (4.2-33)

or (4.2-34)

Equations (4.2-30) and (4.2-34) can be written in drift flux form, i.e., in the form of equations (4.2-1) and (4.2-2) as follows:

$$j_f = (1-\bar{\Psi}^o) \cdot j - \bar{\phi}^o \quad (4.2\text{-}35)$$

and

$$j_g = \bar{\Psi}^o \cdot j + \bar{\phi}^o \quad (4.2\text{-}36)$$

where

[ ]a,c (4.2-37)

and

[ ]^{a,c} (4.2-38)

It can now be seen that as the upper and lower void fractions (and all other pertinent properties approach one another, i.e., as [ ]^{a,c} equations (4.2-35) - (4.2-38) reduce to the form of equations (4.2-1) - (4.2-5), i.e.,

[ ]^{a,c}

(4.2-39)

and

(4.2-40)

This shows that, in the limit of equal upper and lower void fractions (and the other pertinent properties, the SIMARC countercurrent flow equations reduce to the appropriate drift flux relationships and, therefore, the associated flooding curves.

When the momentum equation is cast in terms of W, it can be shown in the same manner that equations (4.2-21) - (4.2-26) reduce to the form of equations (4.2-6) - (4.2-9).

The average link void fraction is a quantity which must be calculated in addition to the phasic fluxes. It is needed for other flow link calculations such as two-phase frictional pressure drop and elevation head in a link (if there is an elevation difference across a link). As stated earlier, for concurrent flow, the link void fraction is the void fraction from the donor end of the link. For countercurrent flow, the phasic fluxes are calculated (without the need to first calculate an average void fraction) using equations (4.2-21) and (4.2-22) for volumetric flow-based momentum equations and equations (4.2-24) and (4.2-25) for mass flow-based momentum equations. An average void fraction in the link is then defined by and calculated using

[ ]^{a,c}

(4.2-41)

or

(4.2-42)

[ ]^{a,c}

The SIMARC drift flux methodology, as described above, treats flooding naturally. An overlayed flooding curve is no longer necessary. The inconsistency problem of this overlayed flooding curve with given drift flux correlations and its potential negative impact on robustness and stability then disappears. Flooding curves are only made of drift flux lines at different void fractions. Experimental flooding curves are given in terms of a single measured void fraction for specified liquid and gas fluxes. For code applications, two void fractions (upper and lower) and the net flux are known and the phasic fluxes must be found. The SIMARC drift flux methodology treats flooding naturally

since it handles low (or zero) upper void fraction and high (or one) lower void fraction cases very well. These are precisely the cases in which many applications of drift flux correlations exhibit nonphysical levitation of liquid. It was shown above that as the upper and lower void fractions approach one another, the SIMARC drift flux methodology gives the typical flooding curve for a single void fraction.

Several points should be made regarding the implementation of the SIMARC drift flux methodology. First, as with all drift flux methodologies, the case of all vapor above all liquid ($\alpha_{top} = 1$; $\alpha_{bot} = 0$) is difficult because the flow is either concurrent single-phase liquid upflow or concurrent single-phase vapor downflow. To see this for

[ ]^{a,c}

There is therefore no region of countercurrent flow. This case is now well handled in the code when the momentum equation is cast in terms of the net volumetric flow rate rather than net mass flow rate. In fact, this is probably the best example of where the use of the volumetric flow rate Q as the momentum equation state variable is superior to the use of the mass flow rate W, in that the phasic mass flow rates can change instantaneously as the net volumetric flow rate varies between positive and negative. This case is not that uncommon; it occurs during draining in node stacks representing the CMT's. It also could occur in other node stacks, e.g., the balance lines, the steam generator tubes, the downcomer, and the inner vessel.

Second, the SIMARC drift methodology handles well the case of all liquid above all vapor ($\alpha_{top} = 0$; $\alpha_{bot} = 1$). This is a case where other drift flux methodologies, for example the void propagation approach often have difficulties. There is some additional calculational effort for this case for the SIMARC methodology, as will be shown below, but reasonable results are obtained. To see this, note the limits for equations (4.2-14) and (4.2-18) [ ]^{a,c}

[ ]^{a,c}

[ ]^{a,c} (4.2-43)

Since it is a physical requirement in drift flux that V_{gj} approaches 0 and αC_o approaches 1 as α approaches 1, both the numerator and denominator of equation (4.2-43) approach zero. L' hospital's Rule is therefore used to give

[ ]^{a,c} (4.2-44)

The limit for [ ]^{a,c} is more straightforward

[ ]^{a,c} (4.2-45)

or

(4.2-46)

[ ]^{a,c} Thus SIMARC treats this case well.

The decision to use the SIMARC drift flux methodology instead of the flux-weighted void fraction approach or the void propagation approach is based on the following: (1) While the NRC felt that the flux-weighted void fraction approach was nonphysical, it was accepted as a means to "the smoothing of the numerical problems to assure that the solution is well-behaved." While this approach has the desirable feature (as does the SIMARC drift flux methodology) of being able to handle the cases of liquid above gas without nonphysical levitation of the liquid, unfortunately it was only applied to very simple drift flux correlations. The drift flux models currently used in the NOTRUMP small-break evaluation model (#13 and #15) are too complex to use this approach. The SIMARC drift flux methodology, on the other hand, is more physical in that it is based on [ ]^{a,c} In addition, it can be successfully applied to more complex drift flux correlations. (2) While the NRC accepted the void fraction propagation approach as "physically sound," it can be demonstrated that this approach has great difficulty in handling the cases of liquid above gas. The SIMARC drift flux methodology does not suffer from this deficiency and is a physically based approach.

The decision to generally not use an overlayed flooding curve on the drift flux model is based on the following: (1) The SIMARC drift flux methodology can be demonstrated to handle flooding naturally. The void-propagation approach models could not be demonstrated to handle flooding naturally; therefore, an overlayed flooding-curve approach was necessary. (2) With a model that handles flooding naturally and consistently, numerical problems are avoided to "assure that the solution is well-behaved."

Note: The final NOTRUMP V&V report will contain a list of variable nomenclature. The following nomenclature will be included in the list.

A = flow area (ft^2)

C_o = drift flux distribution parameter
G = total mass flux (lbm / sec / ft^2)
j = volumetric flux (ft^3 / sec / ft^2)
Q = volumetric flow rate (ft^3 / sec)
α = void fraction
V_{gj} = drift velocity of vapor relative to the total volumetric flux (ft / sec)
ρ = density (lbm / ft^3)
W = net mass flow rate (lbm / sec)
X = quality (-)

Subscripts:

bot = bottom end of flow link or bottom node
D = downflow transition point
f = liquid phase
g = vapor (gas) phase
top = top end of flow link or top node
U = upflow transition point

Reference:

440.466-1 P. E. Meyer, et. al., "NOTRUMP - A Nodal Transient Small Break and General Network Code", WCAP-10079-P-A (Proprietary), WCAP-10080-A (Non-proprietary), August 1985

SSAR Revision: NONE

Question 440.467

Re: NOTRUMP PVR for OSU tests; Modifications to Drift Flux Correlations
Two drift flux models were added to NOTRUMP as discussed in Section 4.2 and 4.3 on page 4-4. Which model is to be used in the NOTRUMP small break LOCA AP600? Under what conditions would each of the models be used? Please explain and provide supporting data for each of the models.

Response:

Both revised drift flux models implemented with the SIMARC methodology are used in the NOTRUMP small-break LOCA AP600 calculations. The revised Yeh correlation is generally used in open flow geometries such as tanks and vessels as opposed to vertical pipes and tubes where the TRAC-P1 correlations are used.

For AP600 (and OSU and SPES-2), the Yeh correlation is used for the fluid nodes and flow links representing the downcomer, inner vessel, pressurizer, CMTs, and IRWST secondary side. The revised TRAC-P1 correlations are used elsewhere for vertical drift flux and bubble rise.

Supporting data for the Yeh correlations are provided in the following references.

J. P. Cunningham, H. C. Yeh, "Experiments and Void Correlation for PWR Small-Break LOCA Conditions," Trans. Am. Nucl. Soc. 17 (1973) 369-370.

H. C. Yeh, L. E. Hochreiter, "Mass Effluence During FLECHT Forced Reflood Experiments," Nuclear Engineering and Design 60 (1980) 413-429.

F. M. Anklam, et. al., "Experimental Investigations of Uncovered-Bundle Heat Transfer and Two-Phase Mixture Level Swell Under High-Pressure Low-Heat-Flux Conditions," NUREG/CR-2456 or ORNL-5848 (1982).

F. M. Anklam, R. F. Miller, "Void Fraction Under High Pressure, Low Flow Conditions in Rod Bundle Geometry," Nuclear Engineering and Design 75 (1982) 99-108.

Koizumi, et. al., "Temporary Core Liquid Level Depression During a Cold-Leg Small Break Loss-of-Coolant Accident: The Effect of Break Size and Power Level," Nuclear Technology 96 (1991) 290-301.

Y. Anoda, et. al., "Void Fraction Distribution in Rod Bundle Under High Pressure Conditions," HTD-V.155, Am. Soc. Mech. Eng. (ASME), Winter Annual Meeting, Dallas, Nov. 25-30, 1990.

Supporting data for the TRAC-P1 vertical flow model are provided in References 15-17 of WCAP-10079-P-A.

As part of the response to this RAI, Section 4.3 of LTCT-GSR-001 and PXS-GSR-002 will be replaced in the NOTRUMP Final V&V Report with the following Section 4.3.

AP600

4.3 Modifications to Drift Flux Correlations

Three modifications were made to NOTRUMP's drift flux correlations in order to apply them with the SIMARC Drift Flux Methodology. First, NOTRUMP's use of the Yeh void fraction correlation was modified. Second, the Improved TRAC-P1 Flow Regime Map was modified. Third, the distribution parameter used in conjunction with the bubbly and slug flow drift correlations was modified.

Reference 1 presents NOTRUMP's current use of the Yeh void fraction correlation as a drift flux correlation. It is the code's thirteenth drift flux model. In this implementation, the Yeh drift flux correlation does not predict physically meaningful interphase velocities as void fractions approach zero or one. As void fractions approach zero, the interphase velocity also approaches zero. As void fractions approach one, the interphase velocity becomes enormous since the void fraction actually used to calculate the drift velocity is limited to one-half. These properties of the existing Yeh drift flux correlation make it incompatible with the SIMARC Drift Flux Methodology since the methodology needs physically meaningful transitions between concurrent flow and countercurrent flow.

NOTRUMP's implementation of the Yeh void fraction correlation as a drift flux correlation was changed to produce reasonable interphase velocities as void fractions approach zero and one. As void fractions approach zero, the computed interphase velocity was prevented from dropping below V_{bcr}, the critical bubble rise velocity defined in the Yeh void fraction correlation. As void fractions approach one, the correlation is based on the actual void fraction instead of a void fraction limited to 0.5.

The modified form of the Yeh correlation drift velocity (see equations (G-86) and (G-87) of Reference 1) is

$$\left[\qquad \right]^{a,c} \qquad (4.3\text{-}1)$$

where

[ ]a,c (4.3-2)

For this model, $C_o = 1$ and $0 \leq \langle\alpha\rangle \leq 1$.

The second modification to NOTRUMP's drift flux correlations needed to implement the SIMARC drift flux methodology affects the improved TRAC-P1 Flow Regime Map. This flow regime map is presented in Reference 1 and is used in NOTRUMP's existing drift flux models 12 and 15. Region 7 of this map is an interpolation region between the annular region and a void fraction of one. The interpolation scheme used in this region produces unreasonably high interphase velocities as void fractions approach one. In order to produce reasonable interphase velocities, the portion of region 7 between void fractions of 0.95 and 1.0 was replaced with a general droplet flow correlation. Within this region the drift velocity is computed from the correlation used in NOTRUMP's fifth drift flux model.

The third modification to NOTRUMP's drift flux correlations needed to implement the SIMARC drift flux methodology affects the distribution parameter, C_o, used in conjunction with the bubbly and slug flow drift correlations. As shown in Equations G-64 and G-67 of Reference 1, the distribution parameter used in conjunction with these drift correlations is set to the inverse of the flow link void fraction under some circumstances. As shown in Equation G-24 of Reference 1, this results in the liquid flow through a link that is independent of the net mass flow through the link. Under these circumstances it became impossible to solve for the net flow through a flow link, corresponding to the transition from concurrent upflow to countercurrent flow, at which the flow of liquid through the link equals zero. This also lead to unrealistic interphase velocities under some circumstances.

This problem was eliminated by changing Equations G-64 and G-67 to use the inverse of the square root of the flow link void fraction instead of the inverse of the flow link void fraction itself.

SSAR Revision: NONE

Question 440.473

In the mixture level overshoot model discussed in Section 4.8, negative mass and energy in an upper node are added to the lower nodes mixture region. Adding the negative mass and energy to another node destroys mass and energy. While rectifying one problem, this approach violates conservation of mass and energy. Please demonstrate that the approach does not introduce errors into the NOTRUMP solution that could change the results or conclusions of an AP600 analysis. Also, identify the cumulative error in this method so that the analyst would see to avoid excessive errors in the calculations due to many level overshoots.

Response:

Section 4.8 of LTCT-GSR-001 and PXS-GSR-002 discusses the mixture level overshoot model. There is one important omission in this discussion which makes the concerns stated in this RAI understandable. That omission is that, after (1) adding to another region (in the same or another node) the mass and energy of a region whose mass and/or energy was non-positive, (2) the mass and energy are zeroed for the region whose mass and/or energy was non-positive. It is the combination of these two actions, which ensures the conservation of mass and energy. Since mass and energy are conserved, there is no error. Therefore, a demonstration that these "errors" do not affect the NOTRUMP solution has no meaning, and there is no cumulative error.

Another way of understanding the model is to think about the consequences of various actions when the mass and/or energy of a region go non-positive. If nothing were done to correct the non-positive mass and/or energy, then overall mass and energy would certainly be conserved. The code, however, has no way of dealing with a region with non-positive mass and/or energy insofar as the node pressure search and fluid property evaluation (described in pages L-11 through L-27 of WCAP-10079-P-A) are concerned. Both mass and energy for a region must be positive, i.e., the region exists, or they must both be zero, i.e., the region does not exist. It is for this reason that non-positive mass and/or energy in a region must be resolved in some way .

If the only action were to be the zeroing of the mass and energy of the region whose mass and/or energy was non-positive, then indeed overall conservation of mass and energy would be violated. The reason for this is that enough mass and energy would have been convected out of a region (to another region) to drive its mass and/or energy non-positive. By simply zeroing the mass and energy of the region whose mass and/or energy was non-positive, an amount of mass and energy equal to the difference between zero and the mass and energy (before zeroing) would be "created." What has to be done in addition to action (1) is action (2). This assures overall mass and energy conservation.

One other point deserves attention. Both the original region depletion logic and this new optional mixture level overshoot logic for stacks conserve mass and energy. The new logic does so in a more "robust" manner. The original logic often overdepleted the region to which the non-positive mass and/or energy was added, resulting in the code aborting. The new logic is much less susceptible to this.

To complete the response to this RAI, Section 4.8 of LTCT-GSR-001 and PXS-GSR-002 will be replaced in the final NOTRUMP V&V Report with the following Section 4.8.

4.8 Mixture Level Overshoot

NOTRUMP's stratified node and stacking models allow the user to track the movement of a mixture level between nodes. Early attempts to model the AP600 tests demonstrated that NOTRUMP's existing logic for passing a level between neighboring nodes was not capable of reliably predicting a natural crossing of the node boundary (either draining or filling).

For a given fluid node, NOTRUMP tracks four state variables: the total mass in the mixture region, the total internal energy in the mixture region, the total mass in the vapor region, and the total internal energy in the vapor region. NOTRUMP calculates all the other fluid node properties from these four state variables and the known total node volume. Among these calculated properties are the volumes of the mixture and vapor regions.

During the time step in which a node drains, more mass and/or energy may be taken out of the lower region of that node than exist in the lower region. As a result, the lower region's mass and/or internal energy become non-positive. The non-positive values of mass and/or energy must be resolved before the fluid property evaluation begins.

The original region-depletion logic simply adds mixture region mass and energy (when either or both are non-positive) to the vapor region mass and energy, respectively. Then it zeroes the mass and energy in the mixture region. However, if the mixture level was apt to overshoot the bottom of the node boundary by an appreciable amount, the resulting mass and energy in the vapor region will either be negative or result in a nonphysically high temperature and/or pressure.

The optional, new mixture-level overshoot logic passes the mixture elevation out of a node into the node below it in the following four steps. First, it estimates the volume of the vapor region, which should have formed in the lower node. Second, it adds the upper-node mixture-region mass and energy to the lower node's mixture region. Third, it takes a volume-weighted fraction of the mass and energy of the upper node's vapor region and places it into the lower node's vapor region. Fourth it zeroes the upper-node mixture-region mass and energy.

A completely analogous situation exists in a node filling event and is handled in a similar way in the new logic.

SSAR Revision: NONE

Question 440.475

Re: NOTRUMP PVR FOR OSU TESTS, LTCT-GSR-001, JULY 1995
Please provide a mathematical description of the modified pump model equations and comparisons of the old and new model results with a benchmark calculation.

Response:

Following is the requested description. This description is in the form of a revision to Section 4.10 which will be included in the NOTRUMP Final V&V Report. A response to the requested benchmark calculation will be provided in a future revision to RAI 440.475.

4.10 Pump Model

The original NOTRUMP pump model was developed by starting with the features of the SATAN large-break LOCA pump model and is described in Reference 1. Some of these features are not necessary for small-break LOCA analysis, but were retained because they did not have any negative impact on code robustness for standard plant calculations. For AP600 calculations, however, the lower pressures reached during small-break LOCA transients caused difficulties in the pump model after the initial pump coastdown when the pump no longer had a significant impact on the transients. The simplified pump model addresses these problems without sacrificing the level of detail needed for small-break LOCA analyses. The use of the simplified pump model allows the code to run without modification to the pump model.

The pump model, as used for AP600 applications, consists of three simplifications. First, the inlet density model is used rather than the equivalent density model. Both have always been options in the code. The pump head "inlet density" model simply uses the donor-specific volume for the head-specific volume. The pertinent equations from Appendix P of Reference 1 are:

$$\upsilon_H = \upsilon_D \quad \text{(P-27)}$$

where, for a subcooled donor fluid state,

$$T_D = T\ (P_D,\ h_D) \quad \text{(P-2)}$$

and

$$\upsilon_D = \upsilon\ (P_D,\ T_D), \quad \text{(P-4)}$$

for a saturated donor fluid state,

$$X_D = \frac{h_D - (h_f)_D}{(h_g)_D - (h_f)_D} \qquad \text{(P-9)}$$

and

$$\upsilon_D = (1 - X_D) \cdot (\upsilon_f)_D + X_D \cdot (\upsilon_g)_D, \qquad \text{(P-10)}$$

and for a superheated donor fluid state,

$$T_D = T\,(P_D, h_D) \qquad \text{(P-20)}$$

and

$$\upsilon_D = \upsilon\,(P_D, T_D). \qquad \text{(P-21)}$$

The pump head "equivalent density" model is described by Equations (P-28) to (P-34) of Reference 1. It is a more complex model than is necessary for small-break LOCA analysis and was susceptible to difficulties at the low pressures reached for AP600 calculations after pump coastdown, when the pump is really not a factor in the transients.

The second simplification to the pump model is a simpler, more robust discharge pressure calculation. The original pump discharge pressure calculation is given by Equations (P-35) to (P-65). The simplified pump discharge pressure calculation, rather than trying to solve the transcendental Equation (P-33) for P_R, approximates P_R by using the first two terms on the right-hand side of Equation (P-61), i.e.,

$$P_R = P_D + \frac{1}{144 \cdot \upsilon_D} \left[\frac{g}{g_c} \cdot H\right] \qquad \text{(4.10-1)}$$

This is adequate for small-break analyses since the approximation

[ ]^{a,c} (P-59)

holds and

[ ]^{a,c} (P-60)

and the momentum flux terms in Equation (P-61) are small.

The third simplification to the pump model is to not use the pump critical flow calculation. It is not really necessary for small-break LOCA analyses since the flow area through the pump is larger than the break area for small breaks.

Note: The final NOTRUMP V&V report will contain a list of variable nomenclature. The following nomenclature will be included in the list.

g = acceleration of gravity (ft / sec^2)
g_c = 32.174 lbm ft / lbf / sec^2
h = specific enthalpy (Btu / lbm)
H = pump head (ft)
J = Joule's constant, 778.156 (ft-lbf / Btu)
P = pressure (psia)
s = entropy (Btu / lbm / °F)
T = temperature (°F)
υ = specific volume (ft^3 / lbm)
X = quality (-)

Subscripts:
D = donor
f = liquid phase
g = vapor (gas) phase
R = recipient

References:

440.475-1 P. E. Meyer, et. al., "NOTRUMP - A Nodal Transient Small Break and General Network Code," WCAP-10079-P-A (Proprietary), WCAP-10080-A (Nonproprietary), August 1985

SSAR Revision: NONE

Question 440.477

Re: NOTRUMP PVR for OSU tests: NOTRUMP Levelizing Model
Please provide the new levelizing drift velocity correlation referred to in Section 4.12 and provide benchmark justifying its validity.

Response:

The NOTRUMP horizontal drift flux model (levelizing model) consists of a levelizing drift velocity correlation implemented using the SIMARC drift flux methodology (see RAI 440.466). The correlation defines a drift velocity whose magnitude and direction are based on the collapsed levels at each end of the horizontal flow link. This gives the potential for countercurrent flow with the liquid flowing toward the end of the links with the lower collapsed level (levelizing).

The form of the correlation currently used was developed heuristically but the appropriate dimensions and effects are incorporated. It is

$$\langle\langle V_{gj} \rangle\rangle = \Big[\qquad \Big]^{a,c} \qquad (440.477\text{-}1)$$

and

$$C_o = \Big[\qquad \Big]^{a,c} \qquad (440.477\text{-}2)$$

ΔZ is defined as the collapsed level difference (downstream minus upstream end of link). The "sign" function returns the sign of the argument (ΔZ) with a magnitude of 1.

In order to show that the form of equation (440.477-1) is reasonable, one can use the concepts of channel flow. One example of this is Wallis' results for waves in a rectangular horizontal duct (Graham R. Wallis, "One Dimensional Two-Phase Flow," McGraw-Hill 1969, pp. 139-141). His "flooding" curve for a horizontal rectangular duct of height H is

$$j_1^{*\frac{1}{2}} + j_2^{*\frac{1}{2}} = 1 \qquad (440.477\text{-}3)$$

where

$$j_1^* = \left[\frac{\rho_1}{gH\,(\rho_2-\rho_1)}\right]^{\frac{1}{2}} \cdot j_1 \qquad (440.477\text{-}4)$$

and

$$j_2^* = \left[\frac{\rho_2}{gH\,(\rho_2-\rho_1)}\right] \cdot j_2 \qquad (440.477\text{-}5)$$

Considering phase 1 to be gas and phase 2 to be liquid and using $|\Delta Z|$ for H, equation 440.477-3 can be written as:

$$\frac{(j_g)^{\frac{1}{2}}}{(J_g)^{\frac{1}{2}}} + \frac{(-j_f)^{\frac{1}{2}}}{(J_f)^{\frac{1}{2}}} = 1 \qquad (440.477\text{-}6)$$

where

$$J_g = \left[\frac{(\rho_f-\rho_g)\;g\;|\Delta Z|}{\rho_g}\right]^{\frac{1}{2}} \qquad (440.477\text{-}7)$$

and

$$J_f = \left[\frac{(\rho_f-\rho_g)\;g\;|\Delta Z|}{\rho_f}\right]^{\frac{1}{2}} \qquad (440.477\text{-}8)$$

This can be written in the commonly used form

$$(j_g)^{\frac{1}{2}} + M^{\frac{1}{2}} \cdot (-j_f)^{\frac{1}{2}} = K^{\frac{1}{2}} \qquad (440.477\text{-}9)$$

where

$$K = J_g = \left[\frac{(\rho_f - \rho_g)\, g\, |\Delta Z|}{\rho_g}\right]^{\frac{1}{2}} \qquad (440.477\text{-}10)$$

and

$$M = \frac{J_g}{J_f} = \left[\frac{\rho_f}{\rho_g}\right]^{\frac{1}{2}} \qquad (440.477\text{-}11)$$

A drift velocity correlation which leads to a flooding correlation of the form of equation (440.477-9) is

$$\langle\langle V_{gj}\rangle\rangle = \left[\qquad\qquad\right]^{a,c} \qquad (440.477\text{-}12)$$

and

$$C_o = \left[\qquad\qquad\right]^{a,c} \qquad (440.477\text{-}13)$$

Using equations (440.477-10) and (440.477-11) gives

$$\langle\langle V_{gj}\rangle\rangle = \left[\qquad\qquad\right]^{a,c} \qquad (440.477\text{-}14)$$

or

$$\langle\langle V_{gj}\rangle\rangle = \left[\qquad\qquad\right]^{a,c} \qquad (440.477\text{-}15)$$

[ ]^{a,c}

Returning to the general form of equations (440.477-9) to (440.477-11), it is of interest to note that for the case of all liquid over all gas, the SIMARC drift flux methodology (see RAI 440.466) predicts the appropriate endpoints of the flooding curve, equation (440.477-9), i.e., the j_g where $j_f = O\,(j^U)$ and the j_f where $j_g = O\,(j^D)$. To see this, note that from equation (4.2-4) and (4.2-5),

[ ] a,c (440.477-16)

and

[ ] a,c (440.477-17)

and therefore

[ ] a,c (440.477-18)

and

[ ] a,c (440.477-19)

Equation (4.2-13) for j^U at $\alpha_{bot} = 1$ is indeterminate. L'hospital's Rule is therefore used to give

$j^U|_{\alpha_{bot}=1} =$ [ ] a,c (440.477-20)

Equation (4.2-17) for J^D at $\alpha_{top} = 0$ is also undeterminate so L'hospital's rule is again used to give

$j^D|_{\alpha_{top}=0} =$ [ ] a,c (440.477-21)

Thus it has been shown that these two transition points are consistent with the general flooding curve, equation (440.477-9) and thus also with the specific Wallis horizontal "flooding" curve represented by equations (440.477-1 through 440.477-8).

Another drift velocity correlation which leads to a flooding correlation of the form of equation (440.477-9) is

$$\langle\langle V_{gj} \rangle\rangle = \quad (440.477\text{-}22)$$

and

$$C_o = \left[\quad \right] \quad (440.477\text{-}23)$$

The same conclusions can be reached as for equations (440.477-12) and (440.477-13). The form of equations (440.477-22) and (440.477-23) is not as easily compared to equations (440.477-1) and (440.477-2) as is the form of equations (440.477-12) and (440.477-13).[ ]

As part of the response to this RAI, Section 4.12 of LTCT-GSR-001 and PXS-GSR-002 will be replaced in the NOTRUMP Final V&V Report with the following Section 4.12. A response to the requested benchmark calculation will be provided in a future revision to RAI 440.477.

4.12 Horizontal Flow Drift Flux Model (Levelizing Model)

The NOTRUMP horizontal stratified flow models were originally developed to allow countercurrent flow in horizontal pipes, in particular the RCS hot and cold legs, since no way was then known to apply drift flux concepts to horizontal flow links. The levelizing drift velocity correlation is an outgrowth of work done over a number of years to apply drift flux concepts to horizontal flow links.

The NOTRUMP horizontal stratified flow model (levelizing model) consists of a levelizing drift velocity correlation implemented using the SIMARC drift flux methodology described in Section 4.2. The levelizing drift velocity correlation (IIDRFTFLI=22) is a particular correlation developed for application in NOTRUMP. The basic idea behind the correlation is that it defines a drift velocity the magnitude and direction of which are dependent on collapsed levels at each end of the horizontal flow link. It does this so that there is the potential for countercurrent flow with the liquid flowing toward the end of the link with the lower collapsed level (and the gas flowing in the other direction), thus trying to drive the collapsed levels toward one another (levelizing). Since this correlation is used within the NOTRUMP drift flux model, the actual phasic flows will be concurrent or countercurrent depending on the net flow link in the link. For high sufficient net flow in either direction, the flow will be concurrent in that direction. For low flows, it will be countercurrent with the liquid flowing toward the end of the link with the lower collapsed level. Even for concurrent flow; however, the liquid will preferentially flow (relative to the gas) toward the end of the link with the lower collapsed level.

The actual form of the correlation was developed heuristically, but the appropriate dimensions and effects were incorporated. The buoyancy and gravity effects are treated with a phasic density difference times acceleration of gravity times collapsed level difference term.

The correlation currently used is

$$\langle\langle V_{gj} \rangle\rangle = \left[\qquad \qquad \right]^{a,c} \tag{4.12-1}$$

and

$$C_o = \left[\qquad \right]^{a,c}$$

ΔZ is defined as the collapsed level difference (downstream minus upstream end of the link). The "sign" function returns the sign of the argument (ΔZ) with a magnitude of 1. This correlation is simply enough that its implementation using the SIMARC drift flux methodology (Section 4.2) is quite straightforward. Equation (4.2-14), when applied to this correlation gives

$$j_U = \left[\qquad \qquad \right]^{a,c} \tag{4.12-2}$$

Equation (4.2-16) gives

$$G_U = \left[\qquad \qquad \right]^{a,c} \tag{4.12-3}$$

Equation (4.2-18) gives

$$j_D = \left[- \qquad \qquad \right]^{a,c} \tag{4.12-4}$$

Equation (4.2-20) gives

$$G_D = \qquad (4.12\text{-}5)$$

Note that in this implementation, because of the definition of the direction of $<<V_{gj}>>$ using sign (ΔZ) in equation (4.12-1), α_{bot} is always greater than or equal to α_{top}. Therefore, for two-phase conditions, i.e., $0 < \alpha_{bot} \leq 1$ or $0 \leq \alpha_{top} < 1$, equations (4.12-3) and (4.12-4) are always non-zero and equations (4.12-5) and (4.12-6) are always non-zero and of the opposite sign of (4.12-3) and (4.12-4) unless $\Delta Z = 0$ (or at the critical pressure). Therefore, there is always a countercurrent flow region and thus the potential for countercurrent flow (levelizing).

This correlation can be applied to all horizontal links. It can be used to replace the NOTRUMP horizontal stratified flow models. For AP600 calculations, it is being used in the horizontal links at the top of the steam generator U-tubes, in the horizontal link at the top of the hot leg-to-PRHR line, and horizontal links within the PRHR. These are the links that previously had to be predefined in direction and required other drift velocity correlations and assumed homogeneous flow. This correlation provides a more natural way to model these links.

SSAR Revision: NONE

Question 440.494

Re: NOTRUMP PVR FOR OSU TESTS, LTCT-GSR-001, JULY 1995

The test data for CMT-2 identifies the drain time as 1486 seconds while the report states that the CMT-2 NOTRUMP simulation drain time is >1000 seconds. Fig. 5.3-4 shows that the NOTRUMP code predicts a delayed CMT-2 drainage time and at 1000 seconds is overpredicting the CMT-2 level. Since the test data continues to at least 1486 seconds, please explain why the NOTRUMP simulation was stopped at 1000 seconds. Provide the comparisons out to the CMT-2 drain time. Discuss the impact of the delayed CMT-2 drainage on the core/upper plenum level response and the ability to identify the potential for core uncovery for the AP600 calculations.

Response:

The NOTRUMP simulation was stopped at 1000 seconds because the criteria for transitioning to the long term cooling calculation were met. These criteria include the activation of the ADS Stage 4 valves and sustained IRWST injection (see Figures 5.3-18 through 5.3-20). The delayed CMT-2 draining is conservative during the portion of the transient simulated by NOTRUMP since the delayed draining results in less inventory contributing to the downcomer head. For this break, the CMT inventory would all end up in the downcomer which would lead to a higher core/upper plenum level if the CMT level decrease was not delayed.

SSAR Revision: NONE

Question 440.497

Re: NOTRUMP PVR FOR OSU TESTS, LTCT-GSR-001, JULY 1995
Please explain the statement that the NOTRUMP code allows a "short spurt of flow at the break" in reference to Figure 5.3-22.

Response:

At the initiation of the break, the depressurization of the fluid nodes in the balance line and CMT-1 causes a swell of liquid due to the change in density. The "short spurt of flow" is the result of NOTRUMP calculating the amount of volume to be removed to allow the pressure between the check valve at the CMT-1 exit and the break in the connected balance line to equalize.

SSAR Revision: NONE

Question 440.500

Re: NOTRUMP PVR FOR OSU TESTS, LTCT-GSR-001, JULY 1995
Fig. 5.3-34 displays highly unstable temperature oscillations in CMT-1 computed by the NOTRUMP code. Please explain why the apparently numerical instabilities were not corrected and the simulation rerun. Have these instabilities occurred in the AP600 plant calculations and what is the impact of these numerical problems on AP600 plant response.

Response:

Although these oscillations were explained in the figure description on page 5-100 of the OSU report, further clarification is provided here. The temperature plot exhibiting the oscillations is for the vapor region of the NOTRUMP fluid node in question. During the time period in which the oscillations occur, the vapor region in that fluid node has not yet been created or is being created. In NOTRUMP, the temperature which is tracked for a non-existent region defaults to the saturation temperature for the given fluid node pressure. The oscillations that appear are actually an indication of pressure oscillations in the fluid node. The isolation of this CMT from the rest of the system, as further evidenced by the lack of flow in Figure 5.3-15, shows that this phenomenon has no meaningful impact on the rest of the system and so the simulation was not rerun.

In the DE balance line break of Reference 440.500-1, similar oscillations are observed, but for less than 100 seconds. They have no meaningful impact on the rest of the system in the NOTRUMP SSAR analysis.

Reference:

440.500-1 Letter NTD-NRC-95-4503, "Preliminary Marked Up Sections of SSAR Chapter 15, Revision 5", July 10, 1995

SSAR Revision: NONE

Question 440.510

Re: NOTRUMP PVR FOR OSU TESTS, LTCT-GSR-001, JULY 1995
Please explain why the NOTRUMP code overpredicts the IRWST flow rates for this test shown in Figs. 5.5-20 and 5.5-21.

Response:

The NOTRUMP predictions for IRWST flow are typically higher than the test data for all the tests. However, in light of Figure 5.8.2-16 of the Test Analysis Report (Reference 440.510-1) as well as Figure 5.4-20 of the OSU Preliminary V&V Report (Reference 440.510-2), it is clear that the magnitude predicted by NOTRUMP is consistent with the steady state value seen in the test. The discrepancy is how quickly the NOTRUMP prediction comes up to this final plateau value. This timing deviation is due to over prediction of ADS 4 flow (Figures 5.5-18 and 5.5-19) which results in the NOTRUMP simulation reaching atmospheric pressure in the RCS earlier than the test facility. The NOTRUMP prediction is intended only to achieve sustained IRWST flow. The long term cooling calculation with the WCOBRA/TRAC code models the remaining phases of the transient.

References:

440.510-1 WCAP-14292, Revision 1, "AP600 Low-Pressure Integral Systems Test at Oregon State University Test Analysis Report," [LTCT-T2R-600]

440.510-2 AP600 NOTRUMP Preliminary Validation Report for OSU Tests, [LTCT-GSR-001]

SSAR Revision: NONE

Question 440.511

Re: NOTRUMP PVR FOR OSU TESTS, LTCT-GSR-001, JULY 1995
As discussed in Section 5.1.2.1 the secondary steam generator safety valve was reduced from 350 psia to 310 psia to compensate for the underpredicted PRHR heat transfer. Please explain if this approach is to be used in the AP600 plant calculations. Also, please describe the impact of the increased steam generator heat removal on natural circulation and system performance in general. For example, the increased steam generator heat removal could be the source of the excessive depressurization experienced early in the tests for the Double-ended Guillotine Break of the Cold Leg Balance Line and the Inadvertent ADS Actuation transients. Please explain.

Response:

This method was not used in the AP600 plant calculations and is not intended to be used in the final set of calculations for the OSU test facility. This artifice (lowering the secondary side safety valve set pressure) was used only to obtain reasonable agreement with the test data depressurization up to ADS actuation. The modeling of the PRHR heat transfer will be improved and checked against both the OSU and SPES-2 data as part of the IRWST nodalization study, the results of which will be included in the final validation report for NOTRUMP.

SSAR Revision: NONE

Question 440.513

Re: NOTRUMP PVR FOR OSU TESTS, LTCT-GSR-001, JULY 1995
The nodalization of the OSU PRHR shows more spatial detail than that for the SPES-2 tests, yet NOTRUMP was still unable to predict the PRHR heat transfer. Please describe the model that will be used for the AP600 plant calculations.

Response:

The OSU PRHR heat exchanger is nodalized in greater detail in Reference 440.513-1 than are the SPES-2 (Reference 440.513-2) or AP600 (Reference 440.513-3) PRHR units in NOTRUMP. Although the nodalizations of the PRHR heat exchanger primary sides differ, the secondary side (IRWST) noding is the same in all cases. Review of the NOTRUMP simulations against test data indicates that the PRHR heat transfer is typically underpredicted for both test facilities. It is believed that the main difficulty in the NOTRUMP predictions of the PRHR heat transfer lies in the IRWST-side modeling. Alternate IRWST nodalizations near the PRHR will be investigated for the NOTRUMP final validation report.

As noted in Reference 440.513-4, a large fraction of the total PRHR heat transfer occurs in the initial horizontal section of tubes. Therefore, greater spatial detail in this region than was used for SPES-2 in Reference 440.513-2 may be required to obtain closer agreement with the test data. While an identical PRHR nodalization will be applied to the SPES-2 and OSU simulations in the NOTRUMP final validation report, SPES-2 will be the more critical of the simulations because its transients involve the same temperature gradients between the primary system and IRWST as the AP600. SPES-2 is therefore the more prototypic facility for validating the NOTRUMP PRHR heat exchanger heat transfer modeling.

The results of the PRHR nodalization study, which will be contained in the NOTRUMP final V&V report, will be reviewed to determine if the AP600 SSAR calculations contained in Reference 440.513-3 require modification.

References:

440.513-1 M.G. Willis et.al.,"LTCT-GSR-001:NOTRUMP Preliminary Validation Report for OSU Tests," Westinghouse Electric Corporation, July 1995.

440.513-2 P.E. Meyer et.al., "PXS-GSR-002: NOTRUMP Preliminary Validation Report for SPES-2 Tests," Westinghouse Electric Corporation, July 1995.

440.513-3 Letter NTD-NRC-95-4503, "Preliminary Marked Up Sections of SSAR Chapter 15, Revision 5", July 10, 1995

440.513-4 WCAP-14292, Revision 1, "AP600 Low-Pressure Integral Systems Test at Oregon State University Test Analysis Report", Section 6.1.2 [LTCT-T2R-600]

SSAR Revision: NONE