Westinghouse Electric Corporation

Energy Systems

Box 355
Pittsburgh Pennsylvania 15230-0355

AW-96-915

January 4, 1996

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

ATTENTION: MR. T. R. QUAY

APPLICATION FOR WITHHOLDING PROPRIETARY INFORMATION FROM PUBLIC DISCLOSURE

SUBJECT: WESTINGHOUSE RESPONSES TO NRC REQUESTS FOR ADDITIONAL INFORMATION ON THE AP600

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-96-915 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-96-915 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

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AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

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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

Brian A. McIntyre, Manager
Advanced Plant Safety and Licensing

Sworn to and subscribed
before me this 5 day
of January, 1996

Rose Marie Payne

Notary Public

Notarial Seal
Rose Marie Payne, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires Nov. 4, 1996
Member, Pennsylvania Association of Notaries

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(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 NTD-NRC-96-4619, January 4, 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.

NTD-NRC-96-4619

ENCLOSURE 2

NON-PROPRIETARY

Question 440.284

Re: WCAP-14234 (LOFTRAN CAD)
How has Westinghouse verified that the water in the cold legs will never get hot enough to flash at the CMT connections during non-LOCA simulations using LOFTRAN over the range of short, middle, and long term transients? Please provide this information.

Response:

As described in the CAD (Section 3.1, Page 3-3), boiling inside the CMT and the balance line is automatically detected by LOFTRAN at each time step for each fluid node if the water subcooling in the node is smaller than a user input value. If boiling is detected, a penalty is appl' 'd to the buoyancy head of the cold leg balance line. In addition to the penalty a message is printed in the output of the code. Since this message is printed at each time step where boiling is detected, the code user is informed of the situation. This message has been incorporated to prevent the code from being used in areas where its physical modelling is not appropriate.

SSAR Revision: NONE

Question 440.287

Re: WCAP-14234 (LOFTRAN CAD)
Section 3.1, page 3-1. Please substantiate that lagging to past time values is not performed for the CMT to RCS connections in order to smooth the response.

Response:

Lagging to past time values is not performed for the CMT to RCS connections in order to smooth the response. The detail of the connection between the CMTs and the RCS is provided in the response to RAI 440.291.

SSAR Revision: NONE

Question 440.300

Re: WCAP-14234 (LOFTRAN CAD)
Pages, 3-3,3.4,3-5. Please provide more detail on the metal heat slabs calculation for the CMT. Is Tmetal at the new or old time step? Is Twater at new or old time? Is the heat transfer coefficient a constant or can it be obtained from a boiling curve? Is Twater a function of pressure and energy?

Response:

The metal heat slabs calculation is performed for each CMT internal time step. The heat transferred from the CMT fluid node to the CMT metal node over the time step is calculated using:

$$Q_{Inner_i} = UA_{Inner_i} \left(T_{Metal_i}^{(t-dt)} - T_{Water_i}^{(t-dt)} \right) dt \qquad \text{Equation 440.300-1}$$

The heat transfer between the CMT metal node and the containment atmosphere is similarly calculated using:

$$Q_{Outer_i} = UA_{Outer_i} \left(T_{Metal_i}^{(t-dt)} - T_{air}^{(t-dt)} \right) dt \qquad \text{Equation 440.300-2}$$

and the metal node temperature and the water enthalpy are updated using:

$$T_{Metal_i}^{(t)} = T_{Metal_i}^{(t-dt)} - \frac{\left(Q_{Inner_i} + Q_{Outer_i} \right)}{MCp_i} \qquad \text{Equation 440.300-3}$$

$$H_{Water_i}^{(t)} = H_{Water_i}^{(t-dt)} + \frac{Q_{Inner_i}}{M_{Water_i}} \qquad \text{Equation 440.300-4}$$

where the subscript "i" indicates the node being evaluated and:

$T_{Metal_i}^{(t)}$ = metal node temperature at time equal to t, °F

$T_{Metal_i}^{(t-dt)}$ = metal node temperature from the previous time step at time equal to t - dt, °F

$H_{Water_i}^{(t)}$ = water node enthalpy at time equal to t, °F

$H_{Water_i}^{(t-dt)}$ = water node enthalpy from the previous time step at time equal to t - dt, °F

MCp_i = metal node heat capacity, Btu/°F

T_{metal} is the metal temperature at the end of the CMT time step. T_{water} is the metal temperature at the end of the CMT time step. The user provides the metal node inside and outside heat transfer coefficient time surface area and the metal node heat capacity. These values are held constant for the analysis. Values may be entered for each of the 15 metal nodes. The containment atmosphere temperature is also a code input parameter. T_{water} is a function of the enthalpy of the individual CMT node and the pressure at the top of the CMT.

SSAR Revision: NONE

Question 440.301

Re: WCAP-14234 (LOFTRAN CAD)
Pages, 3-3,3-4,3-5. Please provide the details of how the CMT mixture level is calculated and how it is used to calculate heat transfer from the metal slabs above and below the mixture level.

Response:

The CMT mixture level is not calculated or modeled. Therefore, the heat transfer is always from the liquid to the wall. Please see the Westinghouse response to RAI 440.315 for additional information.

SSAR Revision: NONE

Question 440.311

Re: WCAP-14234 (LOFTRAN CAD)
The CMT injection lines appear to be valved out until the proper signal is received to open the valves. How much boron is in the lines downstream of the valves? How cold is the water downstream of the valves? Colder water injected directly into the vessel downcomer could cause some positive reactivity insertion, but injected into the cold legs, it would have time to mix and warm. Have any sensitivity studies been performed to address the differences between cold lag injection and DVI for the CMTs? How was this decision arrived at? Please explain.

Response:

In LOFTRAN, no CMT calculations are performed before the signal is generated to open the injection lines valves. The initial conditions in the injection line nodes are defined by user's input, in a conservative manner (See RAI 440.280). All nodes downstream of the injection line valves are assumed to be at the cold leg temperature with a boron concentration equal to the initial RCS boron concentration.

Injection into the cold leg rather than the downcomer allows for mixing of the cold unborated water assumed in the CMT injection lines (downstream of the valve) with some water in the RCS cold leg before it flows into the core. The effect of this approximation is minimized because LOFTRAN offers the possibility to put the injection point close to the reactor vessel. (See RAI 440.282)

No sensitivity studies have been performed to address the difference between cold leg injection and DVI for the CMTs because the reactivity insertion is treated in a conservative manner by the CMT model:

- The initial boron concentration in the injection line is assumed to be equal to the RCS boron concentration before CMT actuation.

- The LOFTRAN model assumes perfect mixing of the boron in the CMT. CMT component test results (Reference 440.311-1) show that there is a long delay before the temperature increases at the bottom of the CMT. The same should be true for the boron concentration.

References

440.311-1 "LOFTRAN-AP and LOFTTR2-AP Final Verification and Validation Report," WCAP-14307, June, 1995

SSAR Revision: NONE

Question 440.315

Re: WCAP-14234 (LOFTRAN CAD)
Page 3-3. Has the code been benchmarked against any experimental data to verify the "penalty" model for steam accumulation on the cold leg to CMT connection? The use of the penalty model basically says that LOFTRAN has no capability for two phase behavior in the cold legs or connecting lines that would transfer steam to the CMT. Is this a correct statement? Can the accuracy of this penalty term be assessed for its effect on flow to or from the CMT? Is this a stratified flow situation in the cold leg? How is the penalty term incorporated into the energy equation? Please provide the details that show conservation of energy is maintained where the penalty term is applied.

Response:

The penalty model was developed to prevent using the code in an area where its physical modelling is not appropriate. Westinghouse does not intend to develop a realistic model (in LOFTRAN) when "generalized boiling" occurs in the CMT or in the lines.

In the AP600 design there is no piping between the pressurizer and the top of the CMT. The CMTs remain water solid during the SSAR non-LOCA and SGTR transients. This physical behavior is confirmed by the SPES-2 results and well predicted by the LOFTRAN code (Reference 440.315-1). SGTR Matrix Tests 9 and 10 show that even with the RCS at saturated conditions (or close to saturation) no generalized boiling occurs inside the CMT. During Matrix Test 10, boiling occurs inside the hottest part of the upper head of the vessel and of the upper plenum up to the top of the hot legs. No boiling occurs in the CMTs for this test because the CMTs are connected on the cold leg, which is around 40 °F colder than the hot leg, in natural circulation.

Although boiling in the CMT should not occur in the CMT for the non-LOCA and SGTR transients, the CMT model can simulate two phase conditions in the CMT, using an homogeneous model. The model assumes that steam and water are in thermal equilibrium and the steam and water velocity are equal (no slip). As a results, there is no mixture level simulation. Since this model does not simulate the separation of steam and water that could happen at the top of the CMT at low flow rates conservative simulations have been developed in the LOFTRAN CMT model. Therefore:

- The code does not need to be benchmarked against any experimental data to verify the "penalty" model for steam accumulation. The main reason is that no boiling occurs in the CMT during the non-LOCA AND SGTR tests. Analytical simulations have been performed to verify that the model behaves as expected. Also, CMT Matrix Test 506 and 509 were simulated (Reference 440.315-1), artificially increasing the balance line inlet temperature in order to force boiling in the line. The behavior of the code was acceptable.

- The penalty term was introduced to offer the possibility to perform conservative calculations if boiling is detected. Using a high penalty stops the natural flow circulation as soon as boiling is detected. The driving pressure $\Delta P_{driving}$ (see Reference 440.315-2 - page 3-2) becomes negative. The flow stops, because LOFTRAN simulated the check valves installed in the CMT injection lines. No assessment is needed for conservative calculations because the results provided by the code with this assumptions are bounding.

Conservation of Energy

Reference 440.315-2, page 3-3, describes the penalty term that is applied in the momentum equation of the CMT loop. It increases the buoyancy of the balance line BH_{BL}. As a result, the driving pressure $\Delta P_{driving}$ is reduced, leading to a decrease of the CMT injection flow. The penalty has no impact on the energy equation.

The Reference 440.315-1 discussion of CMT Tests 506 and 509 include simulations (Runs 5 and 7) with an artificial increase of the balance line inlet temperature, in order to force boiling. The cumulated energy error during the simulations was always lower than 1.5 percent for both simulations.

References

440.315-1 LOFTRAN-AP and LOFTTR2-AP Final Verification and Validation Report.WCAP-14307, June 95

440.315-2 LOFTRAN & LOFTTR2 AP600 Code Applicability Document. WCAP-14234, November 1994

SSAR Revision: NONE

Question 440.316

Re: WCAP-14234 (LOFTRAN CAD)
Does LOFTRAN allow reverse flow in the cold legs and in the CMT connection lines? If not, please explain.

Response:

LOFTRAN allows reverse flow in the RCS loops, except for the loop with the pressurizer. In the AP600 design the CMT cold leg balance line are connected to the RCS loop without the pressurizer. Therefore, LOFTRAN allows reverse flow in the RCS cold leg where the CMTs are connected.

Reverse flow is not simulated by LOFTRAN in the CMT balance and injections lines because this flow configuration is not possible for the non-LOCA and SGTR design basis transients. The AP600 design operates only in the recirculation mode for non-LOCA and SGTR transients and check valves prevent reverse flow in the CMT injection line.

SSAR Revision: NONE

Question 440.470

Re: NOTRUMP PVR FOR OSU TESTS, LTCT-GSR-001, JULY 1995
Eq. 4.5-1 describes two terms added to the momentum equation; however, the equation appears to be inconsistent with the volumetric flow based formulation described in Section 4.4 of the report. Please provide the new momentum equation terms in terms of the volumetric formulation. Also describe how the new formulation was validated to justify the modifications. Also clarify if the dW/dt term is to be replaced by the two new terms, and is the plus sign a typographical error in Eq. 4.5-1? Also, show the finite difference form of the new momentum equation and describe how the dA/dt and dρ /dt terms are to be computed.

Response:

Section 4.5 was revised to clarify the new momentum equation and to include the requested additional information. Specifically, the revised Section 4.5 provides a complete derivation of the momentum equation applied to the modified horizontally stratified model. The text accompanying the new derivation clarifies that the equation is still cast in terms of the net mass flow through the link. The modified Section 4.5 also provides the finite difference form of the new momentum equation, and it describes how the dA/dt and dρ/dt terms are calculated. In response for the request for validation, a calculation will be performed which will be similar to that performed using WCOBRA/TRAC by Takeuchi, et al in References 440.470-1 and 440.470-2. The calculation is basically a computation of horizontal CCFL. This work is currently scheduled for completion and transmittal to the NRC by the end of March, 1996.

4.5 Horizontally Stratified Flow Model

NOTRUMP's horizontally stratified flow link model is one of two models that allow the code to simulate geometries in which the direction of vapor flow, relative to liquid flow can change during a transient. The connection between a PWR's hot leg and reactor-vessel upper plenum is an example of such a geometry. When the coolant level in the upper plenum is higher than the coolant level in a hot leg, liquid can flow from the upper plenum into the hot leg, while vapor flows from the hot leg into the upper plenum. When the coolant level in the hot leg is higher than the coolant level in the upper plenum, liquid can flow from the hot leg into the upper plenum, while vapor flows from the upper plenum into the hot leg.

NOTRUMP's horizontally stratified flow link model simulates such a geometry by dividing it into two flow links, an upper link to convect vapor between the adjoining nodes and a lower link to convect liquid between the nodes. In order to adequately simulate the AP600, the model was modified in three ways. First, its method for determining the cross-sectional area of the two links was changed. Second, the equation governing its links' temporal flow derivative was changed. Third, the model's method for partitioning the links' flows into the recipient node's two regions was changed.

The first modification made to NOTRUMP's horizontally stratified flow model affects the determination of the areas and properties used in the component flow links. The original model assumes the vapor component of a horizontally stratified pair convects only vapor, and the liquid component convects only liquid. Based on this assumption, it sets the area of the liquid component equal to [ ]^{a,c}

[ ]a,c and it sets the area of the vapor component equal to [ ]a,c

The modified model uses an [ ]a,c to determine the component areas, and it assumes the flow in each component is [ ]a,c The mixture component flow area is set equal to [ ]a,c void fraction in that mixture region. The modified model uses an analogous method to determine the area of the vapor component of the horizontally stratified flow link pair. Once the areas are determined, the modified model [ ]a,c and it computes the phasic flows in each component [ ]a,c

The second modification made to NOTRUMP's horizontally stratified flow model affects the equation governing the links' temporal flow derivative. These modifications were needed to re-incorporate some of the terms of the equation which had been dropped in the original model.

The flow through the links comprising a horizontally-stratified flow link pair is [ ] Flow through these links is therefore governed by one-dimensional, single-phase conservation of momentum, which is given by:

$$\rho\left(\frac{\partial V}{\partial t} + V\frac{\partial V}{\partial x}\right) = \rho g\cos\theta - 144g_c\left[\left(\frac{\partial P}{\partial x}\right)_{driving\ head} - \left(\frac{\partial P}{\partial x}\right)_{friction}\right] \qquad (4.5\text{-}1)$$

The gravitational term can be neglected since the flow is horizontal by definition, and the momentum flux term can be neglected since it is insignificant in small break LOCA applications. With these simplifications, the governing equation becomes:

[ ]a,c (4.5-2)

Although the equation governing flow through most links used in the AP600 evaluation model has been re-formulated in terms of the net volumetric flow through those links, the equation governing flow through the links in horizontally stratified flow link pairs is still formulated in terms of net mass flow. The reason for this is rather arbitrary. The modifications to the horizontally stratified flow link model were developed and tested before the decision to re-formulate the rest of NOTRUMP's links in terms of volumetric flow, and the horizontally stratified flow link model itself was not re-formulated in terms of volumetric flow since the modified model performed adequately.

In order to re-write Equation 4.5-2 in terms of mass flow, consider the relationship between mass flow and volumetric flow.

$$W = \rho V A \qquad (4.5\text{-}3)$$

Differentiating Equation 4.5-3 with respect to time and then solving for the left hand side of Equation 4.5-2 in terms of mass flow yields

$$\rho \frac{\partial V}{\partial t} = \frac{1}{A}\frac{\partial W}{\partial t} - \frac{W}{A^2}\frac{\partial A}{\partial t} - \frac{W}{\rho A}\frac{\partial \rho}{\partial t} \tag{4.5-4}$$

Substituting Equation 4.5-4 into Equation 4.5-2 and re-arranging yields

[ ]^{a,c} (4.5-5)

Discretizing Equation 4.5-5 in space yields the equation applied to each horizontally stratified flow link.

[ ]^{a,c} (4.5-6)

Although Equation 4.5-5 is a partial differential equation governing the flow at every point throughout a horizontal channel, Equation 4.5-6 is an ordinary differential equation governing the flow through each flow link in the numerical model of the channel. The variable W in Equation 4.5-5 is a function of both time and space, while the variable W_n in Equation 4.5-6 is a function of time alone. Equation 4.5-5 represents the single equation governing flow throughout the entire channel. Equation 4.5-6 has to be solved for each flow link comprising the channel.

The friction term in Equation 4.5-6 accounts for both wall shear and interfacial shear between the two links comprising a horizontally stratified flow link pair. Both of the wall and interfacial friction models were adopted without modification from the original horizontally stratified flow model.

The density and area temporal derivatives in Equation 4.5-6 are calculated from the following three sets of information:

- the partial derivatives of the donor node's mixture and vapor region volumes with respect to the node's state variables
- the temporal derivatives of the donor fluid node's state variables
- geometric constraints

NOTRUMP's fluid node property routines determine the partial derivatives of each node's mixture and vapor region volumes with respect to that node's four state variables. These partial derivatives are given by Equations (L-97), (L-99), (L-101), (L-103), and (L-122) through (L-125) of Reference 440.470-3. The temporal derivatives of the four state variables are given by Equations (2-1) through (2-4) of Reference 440.470-3. Equations 4.5-7 and 4.5-8 use these partial derivatives and the temporal derivatives of a node's state variables to calculate the temporal derivative of the node's mixture and vapor region volumes.

$$\frac{dV_M}{dt} = \frac{\partial V_M}{\partial U_M}\frac{dU_M}{dt} + \frac{\partial V_M}{\partial M_M}\frac{dM_M}{dt} + \frac{\partial V_M}{\partial U_V}\frac{dU_V}{dt} + \frac{\partial V_M}{\partial M_V}\frac{dM_V}{dt} \tag{4.5-7}$$

$$\frac{dV_V}{dt} = \frac{\partial V_V}{\partial U_M}\frac{dU_M}{dt} + \frac{\partial V_V}{\partial M_M}\frac{dM_M}{dt} + \frac{\partial V_V}{\partial U_V}\frac{dU_V}{dt} + \frac{\partial V_V}{\partial M_V}\frac{dM_V}{dt} \tag{4.5-8}$$

Since the density of a region is simply the ratio of the region's mass to its volume, knowledge of the temporal derivatives of both the region's mass and volume allow the temporal derivative of the region's density to be calculated, using the quotient rule for differentiation, as

$$\frac{d\rho_M}{dt} = \frac{d}{dt}\left(\frac{M_M}{V_M}\right) = \frac{\left(\frac{dM_M}{dt} - \rho_M \frac{dV_M}{dt}\right)}{V_M} \tag{4.5-9}$$

$$\frac{d\rho_V}{dt} = \frac{d}{dt}\left(\frac{M_V}{V_V}\right) = \frac{\left(\frac{dM_V}{dt} - \rho_V \frac{dV_V}{dt}\right)}{V_V} \tag{4.5-10}$$

[ ]a,c

The calculation of the flow component's temporal area derivative involves some geometry. Figure 4.5-1 illustrates a typical situation to which horizontally-stratified flow link pairs are applied. It shows a cylindrical node connected to a rectangular node, and it arbitrarily denotes the rectangular node as the upstream node and the cylindrical node as the downstream node. The figure also shows the mixture elevation in both the rectangular and cylindrical nodes, and the mixture elevation of the rectangular node just happens to fall between the top and bottom of the cylindrical node at an elevation which differs from the mixture elevation of the cylindrical node itself.

As any node's mixture region swells or shrinks by an infinitesimal amound, the change in the node's mixture region volume, dV_M, is equal to the product of the interfacial area between the node's mixture and vapor regions, A_{MV}, and the change in the node's mixture elevation, dE_M.

$$dV_M = A_{MV}\, dE_M \tag{4.5-11}$$

Therefore, the derivative of a node's mixture elevation with respect to the mixture region volume is given by:

$$\frac{dE_M}{dV_M} = \frac{1}{A_{MV}} \qquad (4.5\text{-}12)$$

In nodes such as the rectangular node of Figure 4.5-1, the interfacial area, A_{MV}, is not a function of the node's mixture elevation. However, in nodes such as the cylindrical node in Figure 4.5-1, the interfacial area is a function of the node's mixture elevation.

[ ]a,c In this situation, the centerline elevation and diameter would typically be the same as those of the cylindrical node, and this is assumed to be the case for the remainder of this discussion. Figure 4.5-2 presents a cross-sectional view of the flow link pair.

[ ]a,c

As shown in Figure 4.5-2, as the height of the mixture component changes by an infinitesimal amount, the change in the mixture component's flow area, dA_M, is equal to the product of the length of the secant, c, and the change in the mixture component's height, dh.

$$dA_M = c\ dh \qquad (4.5\text{-}13)$$

Therefore, the derivative of the mixture component's flow area with respect to the mixture component's height is given by:

$$\frac{dA_M}{dh} = c \qquad (4.5\text{-}14)$$

Analogously, the derivative of the <u>vapor</u> component's flow area with respect to the height of the <u>mixture</u> component is given by:

$$\frac{dA_V}{dh} = -c \qquad (4.5\text{-}15)$$

The calculation of the mixture component's temporal area derivative begins with the temporal derivative of the donor node's mixture region volume, given in Equation 4.5-7. The temporal derivative of the donor node's mixture elevation is then calculated from

$$\frac{dE_M}{dt} = \frac{dE_M}{dV_M}\frac{dV_M}{dt} \qquad (4.5\text{-}16)$$

The mixture component's temporal area derivative is then calculated from the following equation:

$$\frac{dA_M}{dt} = \frac{dA_M}{dh}\frac{dE_M}{dt} \qquad (4.5\text{-}17)$$

Analogously, the calculation of the vapor component's temporal area derivative begins with an application of Equation 4.5-16 to its donor node in order to calculate the temporal derivative of its donor node's mixture elevation. The vapor component's temporal area derivative is then calculated from the following equation:

$$\frac{dA_V}{dt} = \frac{dA_V}{dh}\frac{dE_M}{dt} \qquad (4.5\text{-}18)$$

The third modification made to NCTRUMP's horizontally stratified flow model affects the model's partitioning of flow between the bounding nodes' two regions. [

]a,c

In the modified model, [

]a,c

In the modified model, the vapor component link of a horizontally stratified flow link pair [

] Under all circumstances but one, the code will place the convected mass and energy of a vapor component link into the vapor region of the recipient node, creating such a region if it does not already exist. [

]a,c

The modified horizontally stratified flow link model is activated when a flow link pair is assigned ITYPEFL values of 5 and 6, rather than the ITYPEFL values of 2 and 3, which activate the original model. The mixture component has to be assigned an ITYPEFL value of 5, and the vapor component has to be assigned an ITYPEFL value of 6. Other than ITYPEFL, the rest of the input needed for the modified model is the same as for the original model.

Note: The NOTRUMP Final Validation Report will contain a list of variable nomenclature. The following nomenclature will be included in the list.

A = flow area (ft^2)
E = elevation (ft)
g = acceleration of gravity (ft / sec^2)
g_c = 32.174 lbm ft / lbf / sec^2
L = flow link length (ft)
M = mass (lbm)
P = pressure (psia)
ρ = density (lbm / ft^3)
t = time (sec)
U = internal energy (Btu)
V = volume (ft^3) or velocity (ft / sec)
υ = specific volume (ft^3 / lbm)
W = mass flow rate (lbm / sec)
x = spacial dimension (ft)
θ = angle between vertical and the direction of flow (radians)

Subscripts:

down,fl	=	downstream of flow link
fl	=	flow link
M	=	mixture region
MV	=	interface between mixture and vapor regions
up,fl	=	upstream of flow link
V	=	vapor region

References

440.470-1 Takeuchi, K., Bajorek, S. M., Hochreiter, L. E., Kemper, R. M., "Horizontal Stratified Flow in Hot and Cold Legs at a Small Break LOCA of a PWR," ASME Paper 93-HT-1, Presented at the National Heat Transfer Conference, Atlanta, Georgia, August 8-11, 1993.

440.470-2 Takeuchi, K., Bajorek, S. M., Hochreiter, L. E., Kemper, R. M., "Horizontal Stratified Flow in a Small Break LOCA," Transactions ANS 64, 1991, pp. 638, 639.

440.470-3 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

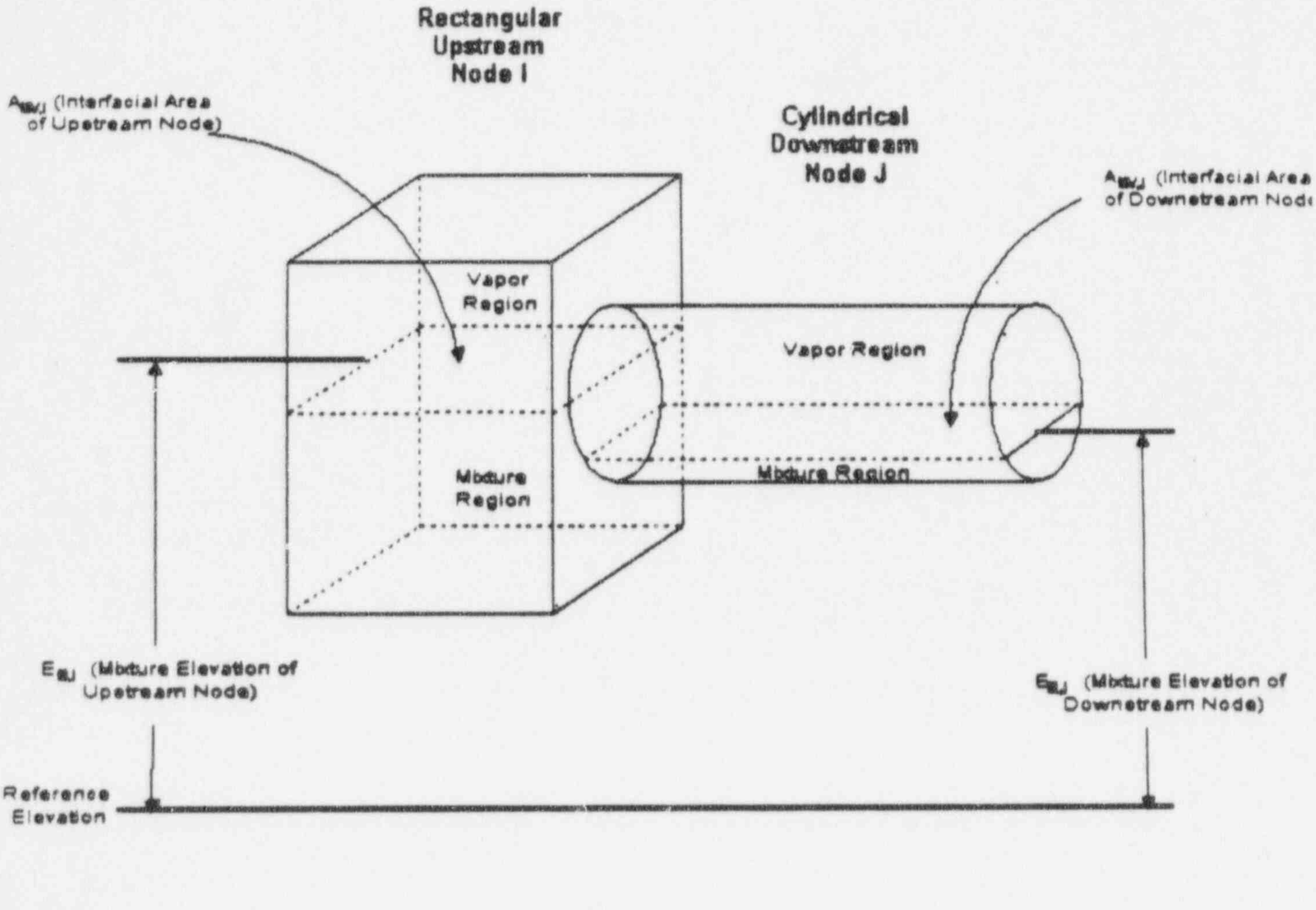

Figure 4.5-1
Geometry to Which the Horizontally Stratified Flow Link Pair Model Would Typically be Applied

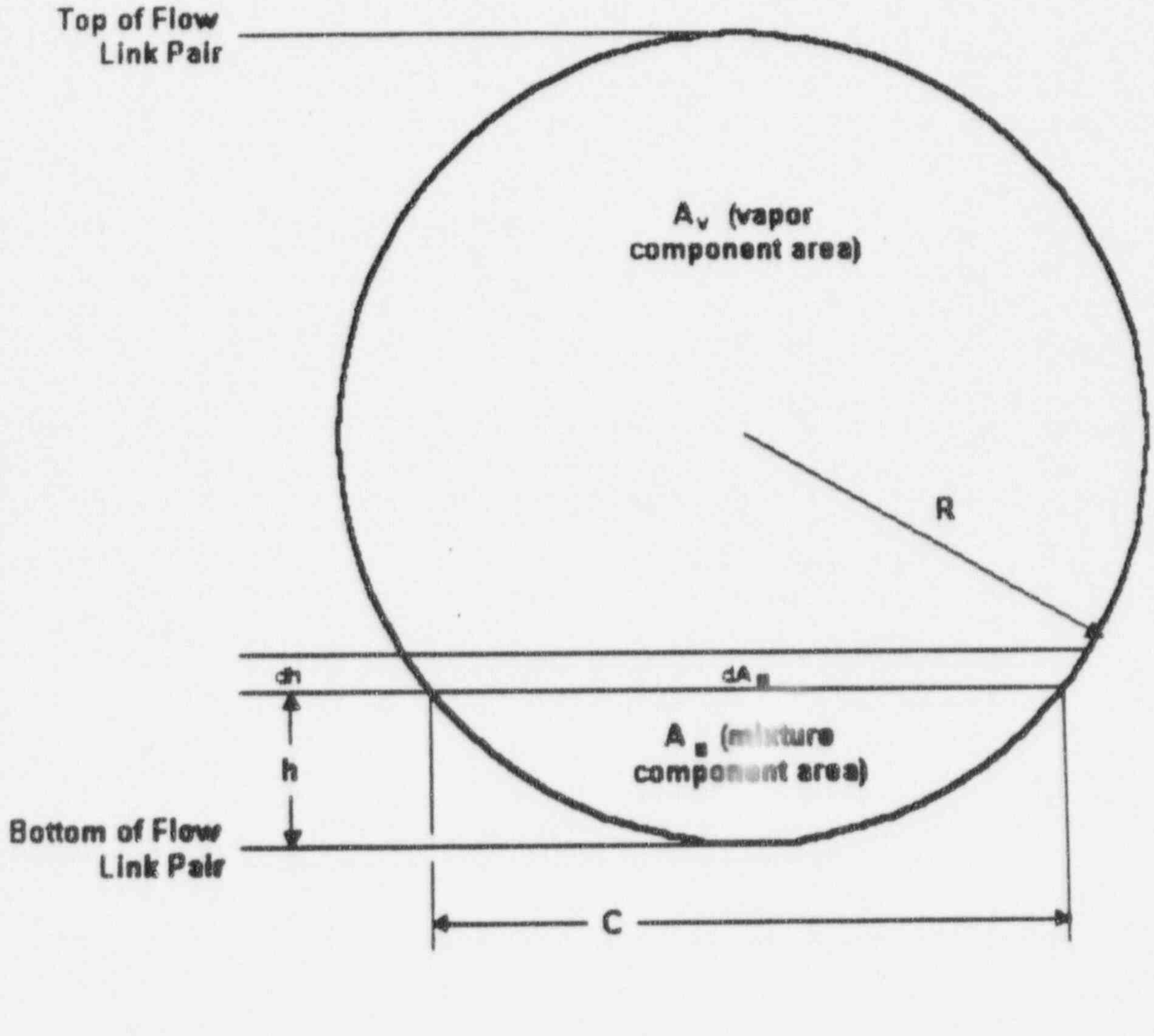

Figure 4.5-2
Cross-Section of Horizontally-Stratified Flow Link Pair