Westinghouse Electric Corporation **Energy Systems**

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AW-96-920

January 31, 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: AP600 CONTAINMENT DBA EVALUATION MODEL (WATER COVERAGE MODEL)

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-96-920 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-96-920 and should be addressed to the undersigned.

Very truly yours,

JM Brennan For

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 James M. Brennan, 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:

James M Brennan

James M. Brennan, Manager
Operating Plant Licensing

Sworn to and subscribed
before me this 31 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

(1) I am Manager, Operating Plant Licensing, in the Nuclear Technology Division, 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-96-4635, January 31, 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.

Summary of Applicability of the Zuber-Staub Film Stability Model and Method to Address Water Coverage in the AP600 PCS Evaluation Model

Introduction

The cooling effectiveness of the AP600 PCS depends primarily on how much of the gravity driven PCS water film flowrate is evaporated. This letter summarizes the approach Westinghouse is using to provide a conservative estimate of the amount of the gravity driven PCS film flowrate that does not evaporate from the shell. The conservatively estimated runoff amount is subtracted from the amount applied to the shell in the AP600 containment DBA evaluation model.

A separate letter will provide responses to the RAIs concerning the range of test parameters used to validate the model. A more detailed description of the application of this model to AP600 and sketches of key supporting observations from tests will also be provided in the Water Coverage chapter of the Applications Report. An outline of the Water Coverge chapter, with cross references to existing documentation is attached.

Test Observations

Observations and/or measurements of film coverage on the prototypical inorganic-zinc coated surface were made in several PCS tests. Various methods for covering the surface with water were tried in the Film Formation Tests (Ref. 1). The prototypical weir system that was developed for spreading the water on the dome of the AP600 containment shell was tested in the full scale, unheated Water Distribution Tests (Ref. 2). The primary purpose of the STC Wet Flat Plate Tests (Ref. 3), the Small Scale Tests (Ref. 4) and the Large Scale Tests (Ref. 5) was to provide data to validate heat and mass transfer correlations over a range of expected post-accident conditions in the AP600 containment, however, these tests also provided data on the effects of heat flux on water coverage.

A liquid film was applied to an elliptical dome surface by weirs in the full-scale, unheated Water Distribution Tests (with maximum plate misalignment based on ASME weld butt-up tolerances) and by J-tubes in the 1/8-scale, heated Large Scale Tests. In both methods, the film was applied by many uniformly spaced water streams. The Water Distribution Tests showed that with flowrates scaled to the initial PCS flowrate on the AP600, the water streams spread within a few inches of their application point to form a relatively thick, continuous wavy laminar film on the lower dome and sidewall. At lower scaled PCS flowrates, the individual source streams were not able to spread to complete circumferential coverage, so the film distribution below the second weir was characterized by alternating wet and dry stripes. Splitting of the continuous film was observed in some of the Large Scale Tests, after the film had flowed further down below the J-tube stream application sites on the dome, however film splitting was not observed on the vertical sidewall.

In the Large Scale Tests, evaporation and spreading on the inclined surface of the dome caused the thickness of the streams to decrease and the width (or coverage area) to increase as they flowed down the outer surface of the elliptical dome. The stream width was observed to remain relatively constant as it flowed down the vertical sidewall. Observations from the small-scale and heated flat plate tests indicate that the film continued to thin while maintaining a relatively constant width (or coverage area), rather than narrowing (with a subsequent reduction in coverage area) as it evaporated and eventually disappeared.

Analytical and Experimental Background

The stability of liquid films has attracted the attention of many analysts and experimenters over the last 40 years. The list of papers considered for application to AP600 is extensive and will not be given here. However, in a summary article (Ref. 6), Bankoff provided an extensive list of relevant papers, many of which have been considered for application to AP600. The current state of the art is focused on the "moving contact line", which was also considered for application to AP600, but is generally not very practical for engineering application. Overall, however, investigators have identified momentum, surface tension, thermocapillary, and vapor thrust as the dominant forces affecting film stability. These forces are typically expressed as functions of flow rate, heat flux, fluid properties, and wetting angle. Vapor thrust can be neglected in AP600 because the heat flux is low, less than 10,000 BTU/hr-ft^2. Consequently, for AP600, it is necessary to address momentum, surface tension, and thermocapillary forces.

Fujita and Ueda (Ref. 7) performed tests that showed highly subcooled films become unstable at flow rates several times higher than saturated films. This observation is supported by the work of Hallett (Ref. 8), Bohn and Davis (Ref. 9), and in one of the earliest works by Hartley and Murgatroyd (Ref. 10), data were presented that showed large differences in stable flow rates. (Subcooled films absorb the heat from the solid surface internally whereas saturated films transfer all the heat from the film surface to the gas atmosphere). An apparent explanation for the reduced stability of subcooled films is the existence of significantly higher temperature gradients that give rise to increased thermocapillary forces. The AP600 has a small region of subcooled film where the film is first applied to the dome (less than 5% of the surface), and a much larger region of saturated film over the lower portion of the dome and the vertical side of the shell. Consequently, liquid film stability for AP600 must address both subcooled and saturated films.

It should be noted that the inorganic zinc coating that covers both sides of the AP600 containment shell is a wettable surface. It is easily demonstrated that a small drop of water spread around on the surface does not contract, or snap back into a drop, showing that the receding static wetting angle is zero. Measurements have also shown that the static advancing angle is approximately 20°. Thus, the inorganic zinc surface is unlike the stainless steel and copper surfaces typically used in stability studies. Stainless steel and copper do not wet and consequently are expected to exhibit less stable films than the prototypic inorganic zinc coated steel shell. Therefore, it is important and appropriate to use stability data on the prototypic surface to validate the AP600 film stability correlation.

The correlation selected to perform AP600 film stability calculations was developed by Zuber and Staub (Ref. 11) to predict the conditions under which a stable dry patch will form. This correlation was selected for AP600 because it includes each of the dominant terms: momentum, surface tension, and thermocapillary. The Zuber-Staub model considers the stability of a dry patch located within a uniform, flowing film, i.e. the inability of the liquid film to recover the dry patch. The Zuber-Staub model uses a vertical force balance at the tip of a postulated dry patch to determine the minimum uniform film thickness required to rewet the dry patch. This minimum film thickness is a function of the surface heat flux, the film properties (including the wetting angle between the film and surface), and the surface inclination angle. Since the Zuber-Staub model relies on local film and surface conditions, it is applicable to any size structure.

According to the Zuber-Staub model, if the uniform film thickness were greater than the minimum stability value, any dry patch created in the film would be washed over and would readily disappear after formation due to the momentum of the flowing film. Conversely, if the film thickness were equal to or less than the minimum stability value, a dry patch, if formed, would be predicted to be stable, i.e. the uniform film would not be able to recover the dry patch. The Zuber-Staub model does not consider the effects of waves in recovering the dry patch.

By the use of a single calibration constant, the Zuber-Staub correlation was adapted for use on both subcooled and saturated films. Consequently, the correlation is applied twice to evaluate film stability for AP600. The first application is at the lower weir and includes a constant that accounts for decreased stability where the effects of subcooling and nonuniform application may be significant. The constant was calibrated, as discussed below, using test data that included heat fluxes, fluid properties, and flow rates more extreme than the range encountered in AP600. The data also included the prototypic flow application to account for initial flow nonuniformities. The stability model predicts the fraction of the vessel circumference that is covered by the liquid film below the lower weir at the top of the vertical shell, also known as the springline.

The film is assumed to flow in constant width stripes down from the springline, consistent with observations of behavior on the Water Distribution Tests and Large Scale Tests discussed above. The stripe width remains constant until evaporation thins the film to a value equal to the minimum flow rate predicted by the second application of the Zuber-Staub model, with a calibration constant of 1.0 as determined by data comparisons to the Large Scale Test data for drying out films. From another point of view, these observations imply that the film breakdown to form a dry spot occurs at a lower film Reynolds number than the critical Reynolds number for rewetting. This is not surprising, since the contact angle formed in enlarging a small dryspot is smaller (~0) than in rewetting it. A number of breakdown correlations, such as Refs 7, 9, and 10 can be found in the literature. Another reason that the Zuber-Staub correlation is conservative is that it does not take into account hydrostatic forces (Ref. 12), which promote rewetting on a vertical wall. The Zuber-Staub film stability model, used in this way, predicts an exponential decay in stripe width, and thus always predicts some amount of water runoff from the shell. This assumed behaviour is conservative based on heated surface test observations that the film continues to thin until completely evaporated without running off the surface.

Zuber-Staub Model Characteristics Relative to AP600 Conditions

The mass flowrate per unit perimeter, Γ, is related to the film thickness and is more easily measured than the film thickness. The local minimum stable film flowrate, Γ_{min}, can be calculated using the Zuber-Staub model. The sensitivity of the predicted Γ_{min} value to the wetting angle and film temperature is shown as a function of the heat flux in Figure 1. Γ_{min} decreases with increasing film temperature. At small wetting angles, Γ_{min} increases as the heat flux a,c

Figure 1 Minimum Stable Film Flow Rates Predicted by the Zuber-Staub Model Showing Sensitivity to Heat Flux, Temperature and Wetting Angle increases. Γ_{min} is less sensitive to heat flux in the range expected for post-accident conditions in AP600 at the [ ]^{a,c} wetting angle used in the Westinghouse film coverage model.

Figure 1 also shows the lowest measured, Γ values for several tests. These measured, Γ values, which should fall at or above the stability limit, are consistent with the assumption of very small wetting angles. These Γ values simply represent stable test conditions. They do not represent incipient instability which presumably occurs, it it occurs, at lower flowrates. All the other available test data fall above the plotted data points, but do not provide additional insight into minimum stable values of Γ.

In this figure, the Zuber-Staub model can be seen to segregate the region of stable film flow from the set of conditions where one might expect the film to split. The Zuber-Staub model, with the [ ]^{a,c} wetting angle, gives higher predicted values of Γ_{min} than observed in the tests, and higher values of Γ_{min} are conservative in this application.

Conservatisms in the Zuber-Staub Stability Model

1. Observations from the Small Scale and STC flat plate tests show a film stripe on the inorganic-zinc coated surface continues to thin at a relatively constant width as it evaporates and eventually disappears. In contrast, the Zuber-Staub model assumes a stable dry patch will be formed whenever the film reaches the minimum film stability value, Γ_{min}, and as a result, the width (and therefore, the coverage area) will be predicted to decrease as the film stripe continues to evaporate.

2. As shown in Figure 1, test data indicate that the film-surface wetting angle can be assumed to be close to 0°. A film-surface wetting angle of [ ]^{a,c} is used in the Westinghouse film coverage model instead. This results in a conservatively higher value for Γ_{min}, and results in relative insensitivity to heat flux in the expected AP600 heat flux range [ ]^{a,c}.

Dome Stability Margin Multiplier

To provide a conservative estimate of the initial sidewall water coverage for AP600, it is necessary to determine an upper bounding value for the minimum stable film flowrate on the dome. In the Westinghouse film coverage model, the local Zuber-Staub minimum stable film flowrate on the dome is multiplied by a stability margin value, R_{ref}, to determine an upper bound, below which a continuous film on the dome will split. The stability margin multiplier accounts for the effects of subcooling, plate misalignment and the method of film application on the initial film splitting behavior.

Conservatisim in the Dome Stability Margin Multiplier

The stability margin value, R_{ref}, that is used in the Westinghouse film coverage model to determine the initial film coverage on the sidewall, was obtained by bounding the film coverage test data covering a range of film flowrates and heat flux.

Determination of Film Input for the AP600 Evaluation Model

The amount of water evaporated by the PCS is a function of the heat flux, film flowrate and water coverage area. All three of these parameters vary with time and position on the shell. The local heat flux is an unknown. The gravity driven, PCS film flowrate is dependent on the water level in the PCS storage tank and varies with time as the tank drains. As shown by the full scale Water Distribution Tests, the water coverage developes early in the transient and later decreases as the PCS film flowrate decreases.

The evaluation model is limited to a constant value for the water coverage fraction input on the shell. Given this limitation, the pre-calculated, gravity driven film flowrate is reduced by subtracting a conservatively estimated runoff amount to account for changes in the water coverage fraction predicted by the Zuber-Staub model. This effectively reduces the PCS evaporation rate as a function of time in the evaluation model.

The amount of predicted runoff increases as the applied flowrate increases and as the sidewall heat flux and initial sidewall water coverage decrease. Therefore, to place an upper bound on the amount of evaporation, the Westinghouse film coverage model is used to calculate a conservative lower bound on the initial sidewall water coverage, and thus maximize the calculated runoff flow. The following method is used to determine a conservative, applied film flowrate for the evaluation model as a function of time.

1. Since the Zuber-Staub model is relatively insensitive to heat flux at the chosen wetting angle, a conservatively high dome heat flux value for AP600 is used to calculate a conservatively high minimum film stability value, $R_{ref}\Gamma_{min}$, at the location of the second weir. This in turn is used to calculate a bounding initial water coverage fraction at the springline for evaporation on the vertical sidewall.

2. The amount of the applied film flowrate that runs off the shell without being evaporated is calculated at various times using the Zuber-Staub Γ_{min} value and assuming a constant average sidewall evaporative heat flux over the time period. Choosing a lower value for the assumed heat flux in this portion of the calculation is conservative since this reduces the evaporation rate and maximizes the predicted runoff flowrate.

3. The calculated runoff amount from step 2 is subtracted from the pre-calculated, gravity driven film flowrate and input to the WGOTHIC evaluation. model.

4. If the average sidewall evaporative heat flux calculated by the evaluation model is less than the assumed value, the runoff amount is recalculated using the lower heat flux value and a new film flowrate is input to the evaluation model.

Sensitivity calculations show the pressure calculated with the lumped parameter evaluation model is not sensitive to the location of the evaporating film (dome or sidwall). Thus it is necessary only to determine a maximum amount of evaporating flow and to apply a conservative minimum PCS water flow rate.

Conclusions

A relatively simple method has been developed to reduce the number of parameters which must be considered in defining the film coverage input for the AP600 PCS evaluation model. The conservatively developed film coverage model is insensitive to heat flux, and is bounding for all time. A method has been selected to normalize the model to bound data from both 1/8 scale heated tests and full scale unheated tests with maximum geometric tolerances. The method provides a conservative, bounding minimum applied PCS water flow rate and eliminates concerns regarding the coverage fraction assumed in the AP600 PCS evaluation model.

References

1. WCAP-13884, "Water Film Formation on AP600 Reactor Containment Surface", Pieczynsiki and Stewart, November 1993

2. WCAP-13960, "PCS Water Distribution Phase 3 Test Data Report", Gilmore, December 1993

3. WCAP-12665 Rev. 1, "Tests of Heat Transfer and Water Film Evaporation on a Heated Plate Simulating Cooling of the AP600 Reactor Containment", Stewart, Pieczyniski and Conway, April 1992

4. WCAP-14134, "AP600 Passive Containment Cooling System Integral Small-scale Tests Final Report", Batiste, August 1994

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6. S. G. Bankoff, "Dynamics and Stability of Thin Heated Liquid Films", *Transactions of the ASME - Journal of Heat Transfer*, Vol. 112, pp 538-546, (1990).

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10. D. E. Hartley and W. Murgatroyd, "Criteria for the Break-up of Thin Liquid Layers Flowing Isothermally over Solid Surfaces", *International Journal of Heat and Mass Transfer*, Vol 8, pp 1003-1015 (1964)

11. N. Zuber and F. W. Staub, "Stability of Dry Patches Forming in Liquid Films Flowing over Heated Surfaces", *International Journal of Heat and Mass Transfer*, Vol. 9, pp 897-905 (1966)

12. G. D. McPherson, "Axial Stability of the dry Patch formed in dryout of a Two-phase Annular Flow", *International Journal of Heat and Mass Transfer*, Vol 13, pp 1133 -1149 (1970)

Draft Outline for the Applications Report Water Coverage Chapter

I. Introduction

II. Water Coverage Tests

- Summary of results
  - LST
  - SST
  - Wet flat plate
  - Water Distribution Test
  - Film Formation Test

Scientech Presentation (part G) from Dec 6-7, 1995

- Ranges of test parameters vs AP600

new material to be issued by end of February

- Effects of scale

III. Description of the Water Coverage model

- Zuber-Staub
  - Critical parameters, model features, assumptions
  - Conservatisms and bounding assumptions
  - Limitations of model
  - Model sensitivities to critical parameters

Summary Letter

- Model Validation

IV. Description of AP600 transient wetting behavior

Scientech Presentation (part G)

V. Application for the PCS Evaluation Model

- Assumed PCS chronology
- Timing and wall temperature

new material to be issued by end of February

- Sensitivity cases
  - Water film location
  - Paint thermal conductivity (for corrosion)

new material to be included in final Chapt

VI. Effects of Surface contamination and aging

- Wetting versus aging, supplier data and application
- Wetting test for first application (ITAAC)
- In-Service-Inspection for contamination and cleaning

RAI responses
480.326
480.327

VII. Conclusions