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Docket No.: STN-52-003

May 21, 1997

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

ATTENTION: T. R. QUAY

SUBJECT: AP600 RESPONSE TO REQUESTS FOR ADDITIONAL INFORMATION

Dear Mr. Quay:

Enclosed are the Westinghouse responses to NRC requests for additional information, DSER open items, and meeting action items related to the heat and mass transfer aspects of the AP600 passive containment cooling system. Specifically, responses are provided for RAIs 480.319, 320, 321, 322, 323, 324, 340, 341, 343, 344, 359, 360, 361, 362, 365, 366, 367, 368, 369, 370, 371, 375, 403, 404, 405, 406, 608, 609; DSER Open Items DSER 21.6.5-2, 3, 22c, 22d, 22e, 22g, 22h, 23; and a meeting action item from a meeting held on March 17, 1995 to discuss AP600 PCS.

These responses close, from the Westinghouse perspective, these items. The NRC should review these responses and inform Westinghouse of the status to be designated in the "NRC Status" column of the OITS. The OITS numbers associated with these items are identified for each of the enclosed items.

Please contact Bruce Rarig on (412) 374-4358 if you have any questions concerning this transmittal.

Brian A. McIntyre

Brian A. McIntyre, Manager
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jml

Enclosure

E004/1

cc: D. Jackson, NRC (w/ Enclosure)
N. J. Liparulo, Westinghouse (w/o Enclosure)

OITS 2492
RAI 480.319

(WGOTHIC MODELS AND PHENOMENA) ENTRANCE EFFECTS
In "Experimental Basis for the Heat Transfer Correlations Selected for Modeling Heat transfer from the AP600 Containment Vessel," PCS-GSR-004, Westinghouse Electric Corp., August 31, 1994, WEC describes a formalism for treating enhanced heat transfer at the entrance of the external annulus, but insufficient detail is given to permit inference as to the values of the governing input parameters that would be specified for either the LST or the AP600 analyses. It is not clear that the treatment is based upon entrance geometries sufficiently similar to the AP600 geometry (two right-angle bends at the base of the downcomer adjoining the base of the riser) to permit applicability to the AP600 analysis.

Entrance effects in the external annulus are discussed on p 76 where it is argued that they are small (4% for LST, 2% for AP600) and thus introduce no more than a 2% distortion in LST vs. AP600 comparisons. Only effects enhancing heat transfer are considered; possible reductions (e.g., due to a laminar region) are not considered. It would be desirable to present sensitivity calculations in order to illustrate the effect of the entrance effects being assumed in the more recent WEC modeling efforts. WEC needs to give a better justification for the treatment to take credit for these effects.

WEC acknowledges in PCS-GSR-004 that there may be a region near the entrance for which the flow is laminar rather than turbulent as assumed in the WGOTHIC model. Neglecting the laminar regime is stated to be conservative for the shell inner surface and nonconservative for the outer surface. However, WEC asserts that the effect in either direction is minor and that it may be neglected. It is not clear, however, that neglecting this effect in the exterior channel is really consistent with taking credit for the enhanced entrance heat transfer, since the enhancement factors assumed are applied to the Colburn heat transfer values, which are for turbulent flow, while it is presumably in the entrance region that any laminar region exists.

A preliminary analysis of the LST experimental configuration, in which a much more detailed hydrodynamic model was used, is of interest here. In this simulation, there is a high local Nusselt number in the immediate entrance region, which rapidly decreases to a low value in a laminar region whose extent is considerably greater than the region of enhanced Nu at the entrance; Nu eventually increases substantially as the result of the onset of turbulence. It is not at all clear that the net effect integrated over the channel length is enhancement relative to what would be obtained by simply using the Colburn turbulent correlation with no entrance effects throughout, and it seems quite likely that the treatment allowing for enhancement at the entrance while neglecting the laminar region may be nonconservative. However, this preliminary calculation is for the LST and it may be that neither the entrance effect nor the laminar region are as important for the AP600.

480.319 What values of the governing input parameters for treating entrance effects would be specified for the LST and AP600 analyses, and what justification is available for the values chosen?

Response:

Westinghouse has submitted Reference 480.319-1 which supersedes Reference 480.319-2 on which the original questions were based. The following response is written relative to Reference 480.319-1.

LST Entrance Effects

The entrance effect multipliers used for the analysis of the LST are presented in Reference 480.319-1, Table 3.5-1. The entrance effect multiplier was included in WGOTHIC LST models to more accurately model the heat transfer in the large scale tests. This approach is consistent with the use of nominal LST input to better isolate the numerical effects of noding and momentum formulation. The entrance effect multiplier was also used for the predicted heat transfer coefficient correlation comparisons to test data in Reference 480.319-1, Section 3.5.

AP600 Entrance Effects

Entrance effects multipliers are conservatively neglected in the heat and mass transfer correlations used in the AP600 containment DBA evaluation model. As presented in Reference 480.319-1, Section 2.2, the entrance effect at the bottom of the riser annulus is partially offset by the lower heat transfer rate in the well region below the baffle, and the remaining increase in net heat transfer is neglected.

Basis for Use of Entrance Effects

The local heat and mass transfer data comparisons for separate effects tests presented in Reference 480.319-1, Sections 3.1 to 3.9 are significantly better than they would have been without entrance effect multipliers, which provides confidence in the use of the approach. This can be seen by comparing the magnitude of the entrance effect multipliers presented for each test in Reference 480.319-1 Sections 3.1 to 3.9 with the variance of the measured and predicted heat transfer coefficient correlations. (Please see the response to RAI 480.367 for additional discussion of entrance effect multipliers for a typical separate effects test.)

References

480.319-1 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

480.319-2 NTD-NRC-94-4287, (PCS-GSR-004), "Experimental Basis for the Convective Heat Transfer Correlations Selected for Modeling Heat Transfer from the AP600 Containment Vessel," August 31, 1994, Westinghouse Electric Corporation.

SSAR Revision: NONE

OITS 2492
RAI 480.320

480.320 The data base cited for entrance effects involves a geometry rather different from the AP600 geometry; how is applicability to the AP600 geometry established?

Response:

Westinghouse has submitted Reference 480.320-1 which supersedes Reference 480.320-2 on which the original questions were based. The following response is written relative to Reference 480.320-1.

The heat and mass transfer to the AP600 riser annulus is calculated assuming fully-developed heat transfer over the riser height as discussed in Reference 480.320-1, Section 2.2, with no entrance effect. The calculations presented in Reference 480.320-1, Section 2.2 show this simple modeling approach is slightly conservative for AP600.

Please see the response to RAI 480.319 for additional discussion of entrance effects used in PCS test analyses.

References

480.320-1 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

480.320-2 NTD-NRC-94-4287, (PCS-GSR-004), "Experimental Basis for the Convective Heat Transfer Correlations Selected for Modeling Heat Transfer from the AP600 Containment Vessel," August 31, 1994, Westinghouse Electric Corporation.

SSAR Revision: NONE

OITS 2492
RAI 480.321

480.321 What sensitivity studies have been performed to demonstrate the magnitude of the entrance effect?

Response:

Westinghouse has submitted Reference 480.321-1 which supersedes Reference 480.321-2 on which the original questions were based. The following response is written relative to Reference 480.321-1.

The magnitude of the entrance effect in the separate effect tests used to validate the AP600 containment heat and mass transfer correlations is represented by the values of the entrance effect multipliers presented in Reference 480.321-1, Sections 3.1 to 3.9. Except for the Hugot tests, the multipliers produce nearly nominal predictions, and even for the Hugot tests the multipliers produce results closer to nominal than would result without multipliers.

References

480.321-1 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

480.321-2 NTD-NRC-94-4287, (PCS-GSR-004), "Experimental Basis for the Convective Heat Transfer Correlations Selected for Modeling Heat Transfer from the AP600 Containment Vessel," August 31, 1994, Westinghouse Electric Corporation.

SSAR Revision: NONE

OITS 2492
RAI 480.322

480.322 Since the enhancement factors are applied to the Colburn heat transfer values for turbulent flow, while a laminar region may exist in the entrance region, how is neglecting the effect of a laminar region in the exterior channel consistent with taking credit for enhanced entrance heat transfer?

Response:

Westinghouse has submitted Reference 480.322-1 which supersedes Reference 480.322-2 on which the original questions were based. The following response is written relative to Reference 480.322-1.

The Metais and Eckert (Reference 480.322-3) plot in Reference 480.322-1, Section 2, shows the riser operates in turbulent forced convection. The deviation from fully-developed turbulent forced convection heat transfer in the AP600 riser is discussed and quantified in Reference 480.322-1, Section 2.2. The calculations show the reduced heat transfer in the region below the baffle is more than offset by the increased heat transfer in the channel formed between the baffle and shell.

References

480.322-1 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

480.322-2 NTD-NRC-94-4287, (PCS-GSR-004), "Experimental Basis for the Convective Heat Transfer Correlations Selected for Modeling Heat Transfer from the AP600 Containment Vessel," August 31, 1994, Westinghouse Electric Corporation.

480.322-3 B. Metais and E. R. G. Eckert, "Forced, Mixed, and Free Convection Regimes", *Journal of Heat Transfer*, Vol. 86, pp 295-296, 1964.

SSAR Revision: NONE

OITS 2492
RAI 480.323

480.323 Based on the preliminary results of a detailed hydrodynamic model it is likely that a treatment allowing for enhancement at the entrance while neglecting the laminar region may be nonconservative. This issue needs to be addressed by WEC.

Response:

Westinghouse has submitted Reference 480.323-1 which supersedes Reference 480.323-2 on which the original questions were based. The following response is written relative to Reference 480.323-1.

The laminar and entrance region effects in AP600 are quantified and presented in Reference 480.323-1, Section 2.2. See also response to RAI 480.322.

References

480.323-1 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

480.323-2 NTD-NRC-94-4287, (PCS-GSR-004), "Experimental Basis for the Convective Heat Transfer Correlations Selected for Modeling Heat Transfer from the AP600 Containment Vessel," August 31, 1994, Westinghouse Electric Corporation.

SSAR Revision: NONE

OITS 2492
RAI 480.324

480.324 Are entrance effects and the laminar region as important for the AP600 as they are in the LSTs?

Response:

Westinghouse has submitted Reference 480.324-1 which supersedes Reference 480.324-2 on which the original questions were based. The following response is written relative to Reference 480.324-1.

The laminar and entrance region effects in AP600 are quantified and presented in Reference 480.324-1, Section 2.2. See also response to RAI 480.322. The AP600 riser channel length-to-hydraulic diameter ratio is approximately twice that of the LST, so entrance effects are expected to be less overall in AP600 than in the LST.

References

480.324-1 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

480.324-2 NTD-NRC-94-4287, (PCS-GSR-004), "Experimental Basis for the Convective Heat Transfer Correlations Selected for Modeling Heat Transfer from the AP600 Containment Vessel," August 31, 1994, Westinghouse Electric Corporation.

SSAR Revision: NONE

OITS 2498
RAI 480.340

(WCAP-13246)TURBULENT BOUNDARY LAYER THICKNESS
On p. 7, Eq. (2.1) is given for the turbulent (momentum) boundary layer thickness:

delta(x) = 0.37(x)/(REx**0.2)

while p. 55 infers a turbulent boundary layer thickness at the base of the shell interior in LST of 0.33" or 0.0084 m. The base of the shell corresponds to x = 3 m, in which case the above equation gives a boundary layer thickness of about 0.08 m, for the stated conditions; i.e., an order of magnitude greater than the 0.33" estimate. The text on p 8 also notes that Eq. (2.1) gives a thickness of 2.3 inches (0.06 m) for x=5 ft under LST conditions. If the boundary layer thickness is a significant parameter for the actual calculations, this apparent discrepancy needs to be resolved. For example, if flow velocities calculated for the nodes adjacent to the shell interior are to be used as free-stream velocities in a forced flow correlation, the boundary layer thickness should be much less than the wall node thickness. However, the boundary layer thickness given by Eq. (4) is about equal to the wall node thickness, for the LST analysis.

480.340 There is an apparent discrepancy between Eq. 2.1 on page 7 and the text on page 8, versus the text on page 55. WEC needs to resolve this apparent discrepancy.

Response:

Westinghouse has submitted Reference 480.340-1 which supersedes Reference 480.340-2 on which the original questions were based. The following response is written relative to Reference 480.340-1.

The boundary layer thickness calculations in Reference 480.340-2 were provided as background information. The difference in values is ascribed in the text of Reference 480.340-2, p. 58, to the laminar sublayer for the smaller value and the turbulent layer of heavier air-rich mixture for the higher value.

The AP600 evaluation model described in Reference 480.340-2 uses free convection boundary layer heat and mass transfer correlations inside containment based on bulk node properties. The previously calculated forced convection boundary layer thickness is not used in the PCS DBA calculation.

References

480.340-1 D. L. Paulsen, et. al., "WGOTHIC Code Description and Validation," WCAP-14382, May, 1995, Westinghouse Electric Corporation.

480.340-2 J. Woodcock, D. R. Spencer, M. D. Kennedy, K. S. Howe, "Westinghouse-GOTHIC: A Computer Code for Analyses of Thermal Hydraulic Transients for Nuclear Plant Containments and Auxiliary Buildings", WCAP-14246, July 1992, Westinghouse Electric Corporation.

SSAR Revision: NONE

OITS 2499
RAI 480.341

(WCAP-13246)FOG FORMATION IN THE EXTERNAL ANNULUS
On p. 52, it is noted that fog (i.e., water aerosol) can form in the riser of the annulus. It is stated that some of this water aerosol may collect on the baffle and run down but will re-evaporate before reaching the bottom; why it necessarily re-evaporates is not made clear nor is it clear whether this is an important assumption. The mass of the water present as fog should be taken into account in calculating the gas densities. If not, buoyancy forces driving the flow in the annulus may be overestimated somewhat.

480.341 Why is water that collects on the baffle assumed to evaporate before reaching the bottom?

Response:

Westinghouse has submitted Reference 480.341-1 which supersedes Reference 480.341-2 on which the original questions were based. The following response is written relative to Reference 480.341-1.

The quoted text is an overview description of AP600 phenomena based on general test observations. The evaporation of baffle condensate before reaching the bottom of the baffle was an LST observation, not an evaluation model assumption. The WGOTHIC evaluation model (Reference 480.341-1) uses a mass transfer correlation that calculates condensation or evaporation from a clime surface as appropriate based on the wall surface and bulk gas steam partial pressures. The mass transfer correlation is presented in Reference 480.341-3, Sections 2.5, 4.2, and 4.3.

References

480.341-1 D. L. Paulsen, et. al., "WGOTHIC Code Description and Validation," WCAP-14382, May, 1995, Westinghouse Electric Corporation.

480.341-2 J. Woodcock, D. R. Spencer, M. D. Kennedy, K. S. Howe, "Westinghouse-GOTHIC: A Computer Code for Analyses of Thermal Hydraulic Transients for Nuclear Plant Containments and Auxiliary Buildings", WCAP-14246, July 1992, Westinghouse Electric Corporation.

480.341-3 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

SSAR Revision: NONE

OITS 2500
RAI 480.343

(WCAP-13246)STEAM DIFFUSIVITY IN AIR
The treatment of the diffusivity of steam in air requires clarification. The diffusivity, Dv, is stated on p. 78 to be given by

Dv = 0.892(14.21/P)*(T/460)**1.81

Although the nomenclature list states that T is temperature in degrees F, this equation only makes sense (and only gives reasonable results) if T is in degrees Rankine, in which case it gives values of Dv about 10% larger than those given by the Wilke-Lee modification of the Hirschfelder, Bird, and Spotz (WL-HBS) model, for use when accurate values of binary diffusivities are desired (Ref: R. H. Perry and C. H. Chilton (eds), Chemical Engineers' Handbook, Fifth Edition, McGraw-Hill Book Co., 1973). WEC needs to clarify the equation given for the diffusivity and justify its selection.

480.343 The treatment of the diffusivity of steam in air requires additional clarification based on the differences as compared to the WL-HBS model.

Response:

Westinghouse has submitted Reference 480.343-1 which supersedes Reference 480.343-2 on which the original questions were based. The following response is written relative to Reference 480.343-1.

The air-steam diffusion coefficient used in the mass transfer calculations is presented in Reference 480.343-1, Section 2.6. The presentation compares the correlation to data from several sources and draws conclusions relative to the effect of the correlation on predictions.

References

480.343-1 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

480.343-2 J. Woodcock, D. R. Spencer, M. D. Kennedy, K. S. Howe, "Westinghouse-GOTHIC: A Computer Code for Analyses of Thermal Hydraulic Transients for Nuclear Plant Containments and Auxiliary Buildings", WCAP-14246, July 1992, Westinghouse Electric Corporation.

SSAR Revision: NONE

OITS 2500
RAI 480.344

(WCAP-13246)STEAM DIFFUSIVITY IN AIR
The treatment of the diffusivity of steam in air requires clarification. The diffusivity, Dv, is stated on p. 78 to be given by

Dv = 0.892(14.21/P)*(T/460)**1.81

Although the nomenclature list states that T is temperature in degrees F, this equation only makes sense (and only gives reasonable results) if T is in degrees Rankine, in which case it gives values of Dv about 10% larger than those given by the Wilke-Lee modification of the Hirschfelder, Bird, and Spotz (WL-HBS) model, for use when accurate values of binary diffusivities are desired (Ref: R. H. Perry and C. H. Chilton (eds), Chemical Engineers' Handbook, Fifth Edition, McGraw-Hill Book Co., 1973). WEC needs to clarify the equation given for the diffusivity and justify its selection.

480.344 Should the temperature in the diffusivity equation on page 78 be given in degrees Rankine, rather than degrees F?

Response:

Westinghouse has submitted Reference 480.344-1 which supersedes Reference 480.344-2 on which the original questions were based. The following response is written relative to Reference 480.344-1.

The temperature used in the air-steam diffusion coefficient was corrected to be in degrees Rankine in Reference 480.344-1, Section 2.6.

References

480.344-1 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

480.344-2 J. Woodcock, D. R. Spencer, M. D. Kennedy, K. S. Howe, "Westinghouse-GOTHIC: A Computer Code for Analyses of Thermal Hydraulic Transients for Nuclear Plant Containments and Auxiliary Buildings", WCAP-14246, July 1992, Westinghouse Electric Corporation.

SSAR Revision: NONE

OITS 2506
RAI 480.359

(PCS-GSR-004) SIEGEL AND NORRIS TESTS
These involved heated parallel vertical plates with a constant wall heat flux, height = 5.833 ft; 8 tests with the test section open to the bottom were analyzed. L/Dh ranged from 3.0 to 24.00, Grd from $6.43x10^5$ to $6.1x10^8$, and Red from $1.65x10^3$ to $1.13x10^4$; thus, both Grd and Red are subprototypic. Convection was treated as assisted mixed convection. P/E values averaged 0.857 with SD = 0.0903. It is stated that predicted Nu matches experimental values fairly well at low L/Dh but increasingly underpredict Nu as L/Dh is increased. It is also stated that four tests performed at constant L/Dh illustrate the effect of progressively increasing the loss coefficient from 1.5 to 35.6 (no information is given as to how this was done); Nu is increasingly underpredicted as flow is reduced.

480.359 It is stated that four tests performed at constant L/Dh illustrate the effect of progressively increasing the loss coefficient from 1.5 to 35.6; how was this done?

Response:

Westinghouse has submitted Reference 480.359-1 which supersedes Reference 480.359-2 on which the original questions were based. The following response is written relative to Reference 480.359-1.

Reference 480.359-1, Section 3.3 states that the increased loss coefficients were obtained by the experimenters by adding extensions to the bottom of the test section channel that successively decreasing the space between the channel inlet and the lab floor. The result was a decrease in the inlet flow area. Westinghouse estimated the loss coefficients based on the open inlet area and used the loss coefficients in the calculation model. The value of the loss coefficient for each test is presented in the title of the corresponding figure, Figures 3.3-1 to 3.3-8.

References

480.359-1 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

480.359-2 NTD-NRC-94-4287, (PCS-GSR-004), "Experimental Basis for the Convective Heat Transfer Correlations Selected for Modeling Heat Transfer from the AP600 Containment Vessel," August 31, 1994, Westinghouse Electric Corporation.

SSAR Revision: NONE

OITS 2507
RAI 480.360

(PCS-GSR-004) EXPERIMENTAL COMPARISONS (GENERAL)
Experimental comparisons are presented in a way that needs more explanation. All the comparisons are for channel geometry (heated vertical parallel plates or pipe geometry. The comparisons are plots of calculated and experimental local Nu values versus a dimensionless distance, x/d. Neither x nor d are defined but x appears to be distance along the channel and d related to channel width or pipe diameter. The local Nu values increase approximately linearly as a function of x/d and would therefore yield heat transfer coefficients approximately independent of distance if one uses these values in a relation of the form h = kNu/x. This is the expected behavior: except near the entrance, the heat transfer coefficient should be approximately independent of distance down the channel. For channels, however, it is more usual to define the controlling nondimensional numbers in terms of a width or hydraulic diameter (d), and evaluate h from h = kNu/d; thus defined these Nusselt numbers should be independent of x/d, except for entrance effects. In general the presentation seems to imply that this convention is being used in the text when discussing channel geometries; e.g., Reynolds and Grashof numbers are represented as "Red" and "Grd". However, the values of local Nu plotted in the figures would make no sense if they were interpreted in this way (h would increase linearly with distance up the channel if h = kNu/d were to be used). Clarification is needed.

In the presentations of the experimental comparisons, clarification is required as to what correlation is used to obtain the predicted values of Nu (Colburn, flat plat forced flow, etc) in the various cases and what value of the characteristic length is being used to evaluate Re and Gr. Justification for the treatments chosen is also needed because, while all experiments are based upon channel geometry, the L/D values vary over a wide range, with some of the values being too small to permit fully-developed channel flow.

480.360 Clarification of the convention being used in discussing channel geometries is needed.

Response:

Westinghouse has submitted Reference 480.360-1 which supersedes Reference 480.360-2 on which the original questions were based. The following response is written relative to Reference 480.360-1.

The convention used in discussing channel geometries is clearly defined in Reference 480.360-1, Sections 2.1, and 3.1 to 3.8. The channel hydraulic diameter is used as the characteristic length in the channel Nusselt, Sherwood, Grashof, and Reynolds numbers.

References

480.360-1 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

480.360-2 NTD-NRC-94-4287, (PCS-GSR-004), "Experimental Basis for the Convective Heat Transfer Correlations Selected for Modeling Heat Transfer from the AP600 Containment Vessel," August 31, 1994, Westinghouse Electric Corporation.

SSAR Revision: NONE

OITS 2507
RAI 480.361

(PCS-GSR-004)EXPERIMENTAL COMPARISONS (GENERAL)
Experimental comparisons are presented in a way that needs more explanation. All the comparisons are for channel geometry (heated vertical parallel plates or pipe geometry. The comparisons are plots of calculated and experimental local Nu values versus a dimensionless distance, x/d. Neither x nor d are defined but x appears to be distance along the channel and d related to channel width or pipe diameter. The local Nu values increase approximately linearly as a function of x/d and would therefore yield heat transfer coefficients approximately independent of distance if one uses these values in a relation of the form h = kNu/x. This is the expected behavior: except near the entrance, the heat transfer coefficient should be approximately independent of distance down the channel. For channels, however, it is more usual to define the controlling nondimensional numbers in terms of a width or hydraulic diameter (d), and evaluate h from h = kNu/d; thus defined these Nusselt numbers should be independent of x/d, except for entrance effects. In general the presentation seems to imply that this convention is being used in the text when discussing channel geometries; e.g., Reynolds and Grashof numbers are represented as "Red" and "Grd". However, the values of local Nu plotted in the figures would make no sense if they were interpreted in this way (h would increase linearly with distance up the channel if h = kNu/d were to be used). Clarification is needed.

In the presentations of the experimental comparisons, clarification is required as to what correlation is used to obtain the predicted values of Nu (Colburn, flat plat forced flow, etc) in the various cases and what value of the characteristic length is being used to evaluate Re and Gr. Justification for the treatments chosen is also needed because, while all experiments are based upon channel geometry, the L/D values vary over a wide range, with some of the values being too small to permit fully-developed channel flow.

480.361 Clarification is required as to which correlations (e.g., Colburn versus flat plate) are being used to analyze the various experiments, what values of the characteristic lengths are specified for the analyses, what are the justifications for the values chosen.

Response:

Westinghouse has submitted Reference 480.361-1 which supersedes Reference 480.361-2 on which the original questions were based. The following response is written relative to Reference 480.361-1.

The correlations, characteristic lengths (see response to RAI 480.360), and justification are provided in Reference 480.361-1, Sections 2 and 3.

References

480.361-1 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

480.361-2 NTD-NRC-94-4287, (PCS-GSR-004), "Experimental Basis for the Convective Heat Transfer Correlations Selected for Modeling Heat Transfer from the AP600 Containment Vessel," August 31, 1994, Westinghouse Electric Corporation.

SSAR Revision: NONE

OITS 2508
RAI 480.362

(PCS-GSR-004) EXPERIMENTAL COMPARISONS (GENERAL)
Comparisons between WGOTHIC and experiment are stated to yield "acceptable results" and the calculated local heat transfer coefficients "demonstrate the proper trends"

480.362 In comparisons between WGOTHIC and experimental results, what criteria were applied in selecting the terms "acceptable", "proper", etc?

Response:

Westinghouse has submitted Reference 480.362-1 which supersedes Reference 480.362-2 on which the original questions were based. The following response is written relative to Reference 480.362-1.

The undefined qualitative terms in Reference 480.362-2 were replaced in the Reference 480.362-1 by statistical measures of comparison. In addition, Westinghouse has changed its modeling approach to use bounding mass transfer correlations, as presented in Reference 480.362-1, Section 4.5.

References

480.362-1 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

480.362-2 NTD-NRC-94-4287, (PCS-GSR-004), "Experimental Basis for the Convective Heat Transfer Correlations Selected for Modeling Heat Transfer from the AP600 Containment Vessel," August 31, 1994, Westinghouse Electric Corporation.

SSAR Revision: NONE

OITS 2509
RAI 480.365

(PCS-GSR-004) EXPERIMENTAL COMPARISONS (GENERAL)
The comparisons offered do show approximate agreement, as expected since the basic Nusselt number formulations employed are standard. However, the report says little as to what inferences may be drawn as to the adequacy of the heat transfer modeling for AP600 analysis. In particular, there is no attempt to apply the results to draw quantitative inferences concerning the conservatism and/or the uncertainties that must be allowed for when applying these correlations to AP600 analysis.

The following specific points are noted:

- Based upon the results presented, there appears to be no basis for claiming conservatism in these correlations; predicted to experimental (P/E) values greater than unity are at least as common as values less than unity.
- Results are consistent with the correlations' being best-estimate (BE) correlations. However, BE analysis is generally acceptable in this context only if it is accompanied by an assessment of the uncertainties.
- All the experimental tests considered involve an approximation to channel geometry but some are characterized by L/D values too small to permit full flow development in the channel.
- In the experiments, the channels (or pipe) are symmetrically heated, while the AP600 channel heating is very asymmetric. Heat transfer coefficients for asymmetrically heated channel surfaces may not be the same as for symmetrically heated channel surfaces.
- Not one of the 23 experiments, for which results are summarized, provides experimental support for the belief that entrance effects significantly enhance local Nu values. In all cases in which significant enhancement was predicted, the prediction is in error. Continued use of the entrance effect enhancement in WGOTHIC analysis requires a considerably stronger defense than any given to date.
- Although the cases analyzed are stated to correspond to assisted mixed convection, there is no consideration as to whether the mixed convection formulation used gives any improvement over what would be obtained assuming either natural or forced convection by itself. It would be instructive to include Nu numbers for both natural and forced convection calculated individually. This would permit conclusions to be drawn as to which process dominates; whether the mixed result is differing significantly from Max(Nufree,Nuforc); and whether the mixed formulation is offering any improvement over Max(Nufree,Nuforc).

480.365 All the experimental tests considered involve an approximation to channel geometry, although some results were obtained for L/D values too low to provide fully-developed channel flow. Will WEC use the comparisons to claim validation for heat transfer modeling in the channel, on the shell interior surface, or both? Justification is required for whatever applications are intended.

Response:

Westinghouse has submitted Reference 480.365-1 which supersedes Reference 480.365-2 on which the original questions were based. The following response is relative to Reference 480.365-1.

The comparisons between the test data and analytical correlations for heat and mass transfer presented in Reference 480.465-1, Sections 3 and 4 show the correlations predict the test data both inside containment and outside containment in the PCS air flow path. With the factors determined in Section 4.5, the mass transfer correlations become bounding correlations that can be used in the AP600 evaluation model.

References

480.365-1 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

480.365-2 NTD-NRC-94-4287, (PCS-GSR-004), "Experimental Basis for the Convective Heat Transfer Correlations Selected for Modeling Heat Transfer from the AP600 Containment Vessel," August 31, 1994, Westinghouse Electric Corporation.

SSAR Revision: NONE

OITS 2509
RAI 480.366

480.366 The experiments all involve symmetrically-heated channels (or pipes), while heating of the AP600 channel is quite asymmetric. How large an uncertainty does the asymmetry of the AP600 channel heating introduce into the analysis, when the only validation data are for a symmetrically heated channel?

Response:

Westinghouse has submitted Reference 480.366-1 which supersedes Reference 480.366-2 on which the original questions were based. The following response is relative to Reference 480.366-1.

Reference 480.366-1 presents comparisons to heat and mass transfer measurements in channels for both symmetrically-heated and asymmetrically heated channels. The Section numbers and references are as follows. The symmetrically-heated tests include Hugot (Section 3.1), Eckert and Diaguila (Section 3.2), Siegel and Norris (Section 3.3), and Gilliland and Sherwood (Section 3.6). The asymmetrically-heated tests include the Westinghouse dry flat plate heat transfer (Section 3.4), the Westinghouse LST dry heat transfer (Section 3.5), the Westinghouse flat plate evaporation tests (Section 3.7), and the University of Wisconsin condensation tests (Section 3.8). Since the data include results for asymmetrically heated channels, no additional uncertainty need be considered to account for asymmetry.

References

480.366-1 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

480.366-2 NTD-NRC-94-4287, (PCS-GSR-004), "Experimental Basis for the Convective Heat Transfer Correlations Selected for Modeling Heat Transfer from the AP600 Containment Vessel," August 31, 1994, Westinghouse Electric Corporation.

SSAR Revision: NONE

OITS 2509
RAI 480.367

480.367 The WEC model for entrance effects predicts enhanced heat transfer close to the entrance for a number of the experiments. In every instance, this prediction is in error: not one of the 23 experiments for which results are summarized provides experimental support for the belief that entrance effects significantly enhance local Nu values. How does WEC reconcile this result with the continued use of the entrance effect model in WGOTHIC?

Response:

Westinghouse has submitted Reference 480.367-1 which supersedes Reference 480.367-2 on which the original questions were based. The following response is relative to Reference 480.367-1.

Reference 480.367-1, Sections 3.1 to 3.8 show comparisons of predicted-to-measured Nusselt number ratios as a function of dimensionless test lengths for the various separate effects tests. The predicted values include the entrance effect multiplier discussed in Section 2.2, with multiplier values that range up to 7.7. Seven of the eight test comparisons show that with the entrance effect multipliers the mean predictions are within a few percent of the mean measurements. The exception is the Hugot tests (Section 3.1) in which the first measurement is significantly over predicted. The first measurement is located at $x/d_h = 0.3$ in two tests and at $x/d_h = 1.0$ in three tests. The multiplier was used for $L/D < 1.0$, even though its use is not recommended for $L/D < 2.0$ (Reference 480.367-3), in lieu of any other recommended method.

The AP600 PCS DBA evaluation model assumes fully-developed heat and mass transfer over the riser height with no entrance effect.

References

480.367-1 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

480.367-2 NTD-NRC-94-4287, (PCS-GSR-004), "Experimental Basis for the Convective Heat Transfer Correlations Selected for Modeling Heat Transfer from the AP600 Containment Vessel," August 31, 1994, Westinghouse Electric Corporation.

480.367-3 F. Kreith, *Principles of Heat Transfer*, Second Edition, International Textbook Company, 1968, pp. 370-372.

SSAR Revision: NONE

OITS 2509
RAI 480.368

480.368 Does the mixed convection formulation give any improvement over what would be obtained assuming either natural or forced convection by itself? It would be instructive to include Nu numbers for both natural and forced convection calculated individually.

Response:

Westinghouse has submitted Reference 480.368-1 which supersedes Reference 480.368-2 on which the original question was raised. The following response is relative to Reference 480.368-1.

Reference 480.368-1, Section 2 presents the analytical correlations used to model heat and mass transfer inside and outside the containment shell. Free convection only is used to model heat and mass transfer inside containment as described in Section 2.5. Mixed convection models are used to model heat and mass transfer outside containment in the PCS air flow path as described in Section 2.1. The Eckert and Metais (Reference 480.368-3) plot in Section 2 shows the riser and downcomer operate predominantly in forced convection, so mixed convection is expected to produce the same heat and mass transfer rates as forced convection. The chimney operation ranges from free to forced, so the mixed convection correlation that is asymptotic to free and forced convection is more appropriate. When free and forced convection are of similar magnitude, the difference versus mixed convection is maximized.

References

480.368-1 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

480.368-2 NTD-NRC-94-4287, (PCS-GSR-004), "Experimental Basis for the Convective Heat Transfer Correlations Selected for Modeling Heat Transfer from the AP600 Containment Vessel," August 31, 1994, Westinghouse Electric Corporation.

480.368-3 B. Metais and E. R. G. Eckert, *Journal of Heat Transfer*, Vol. 86, pp 295-296, 1964.

SSAR Revision: NONE

OITS 2510
RAI 480.369

(PCS-GSR-006)
The following questions are based on "Experimental Basis for the Mass Transfer Correlations Selected for Modeling Condensation and Evaporation on the AP600 Containment Vessel," PCS-GSR-006, Westinghouse Electric Corp., October 1994.

This document discusses the correlations used for Nusselt numbers and briefly summarizes the heat/mass transfer analogy used to define the Sherwood (Sh) number and the mass transfer coefficient. Comparisons between the code and experimental results are expressed in terms of the ratio of predicted to experimental values of Sh for three different sets of experimental data: the University of Wisconsin Condensation Tests, the Gilliland and Sherwood Evaporation Tests, and the Westinghouse STC Flat Plate Evaporation Tests. Values reported are averages over the test surface. There is no attempt to present comparisons in terms of local values as was done for Nu.

UNIVERSITY OF WISCONSIN (UW) CONDENSATION TESTS

In the tests for which comparisons are given, the experiments involved measuring condensation rates for a steam/air mixture flowing through a channel with a cooled surface in an apparatus that could be tilted in order to study the effect of inclination angle upon condensation rates. When the test section was inclined, the text seems to imply that the steam/air source was at the low end (implying opposed mixed convection); however, published descriptions (see for example, I. K. Huhtiniemi and M. L. Corradini, "Condensation in the Presence of Noncondensible Gases," Nuclear Engineering and Design 141 (1993) 429-446.) of the experiments indicate that the steam/air mixture enters at the high end (implying assisted mixed convection).

When the inclination angle is low, it is not clear that either the "assisted" or the "opposed" mixed convection treatment is appropriate.

Results are presented for 59 tests. The average P/E value is 0.968 with SD = 0.203. P/E values are plotted against inclination angle over the range 0-90°, against Red over the range $7x10^3$ - $2.5x10^4$, and against steam mole fractions (0.12 - 0.65). Results suggest a tendency for P/E to increase slightly with increasing angle, with increasing Red, and with decreasing steam mole fraction. These trends are weak but, just by visually inspecting the data, they appear to be statistically significant, at least marginally (no statistical significance tests are given in the Huhtiniemi and Corradini paper). These trends suggest a potential for nonconservatism in modeling the exterior channel which, relative to these tests, would be characterized by high inclination angle, high Red, and low steam mole fraction for most of the surface.

480.369 The text implies that the steam-air mixture enters at the low end of the apparatus while it is believed that it enters at the high end. WEC needs to check this and revise the text as appropriate.

Response:

Westinghouse has submitted Reference 480.369-1 which supersedes Reference 480.369-2 on which the original question was raised. The following response is relative to Reference 480.369-1.

Reference 480.369-1 describes the University of Wisconsin test section in the correct orientation.

References

480.369-1 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

480.369-2 NTD-NRC-94-4327, (PCS-GSR-006), "Experimental Basis for the Mass Transfer Correlations Selected for Modeling Condensation and Evaporation on the AP600 Containment Vessel," October 21, 1994, Westinghouse Electric Corporation.

SSAR Revision: NONE

OITS 2510
RAI 480.370

480.370 Are the "assisted" versus "opposed" mixed convection classifications appropriate at low inclination angles? What was assumed in analyzing the low-angle experiments?

Response:

Westinghouse has submitted Reference 480.370-1 which supersedes Reference 480.370-2 on which the original questions were based. The following response is relative to Reference 480.370-1.

The distinction between assisted and opposed convection is expected to disappear as the inclination angle decreases, although the correlations do not predict this. The consequence of this for AP600 is discussed in Reference 480.370-1, Section 2.1. The low angle experiments were analyzed with assisted mixed convection.

References

480.370-1 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

480.370-2 NTD-NRC-94-4327, (PCS-GSR-006), "Experimental Basis for the Mass Transfer Correlations Selected for Modeling Condensation and Evaporation on the AP600 Containment Vessel," October 21, 1994, Westinghouse Electric Corporation.

SSAR Revision: NONE

OITS 2510
RAI 480.371

480.371 The P/E ratios appear to increase with increasing inclination angle, with increasing Red, and with decreasing steam mole fraction; do these trends indicate that there is a potential for nonconservatism in modeling the PCS channel?

Response:

Westinghouse has submitted Reference 480.371-1 which supersedes Reference 480.371-2 on which the original questions were based. The following response is relative to Reference 480.371-1.

Westinghouse is using the multipliers defined in Reference 480.371-1, Section 4.5 to produce bounding mass transfer correlations for use in the evaluation model, which affects the applicability of the above question. By the use of the multipliers, the correlations bound the worst data points over the range of inclination angles from 0 to 90° and steam concentrations up to 70%. Since only free convection is assumed inside containment, the Reynolds number is not a variable.

References

480.371-1 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

480.371-2 NTD-NRC-94-4327, (PCS-GSR-006), "Experimental Basis for the Mass Transfer Correlations Selected for Modeling Condensation and Evaporation on the AP600 Containment Vessel," October 21, 1994, Westinghouse Electric Corporation.

SSAR Revision: NONE

OITS 2513
RAI 480.375

(PCS-GSR-006) OBSERVATIONS
The basic observations on these results are similar to those for the heat transfer correlations. The results clearly show that the correlations give Sh of the right order of magnitude and are defensible as best estimate values but not unconditionally conservative values. No "bridge" between these results and quantitative implications for AP600 analysis is provided: i.e., no effort is made to evaluate a quantitative uncertainty for the correlations when applied to the AP600 or to quantitatively assess implications for the accuracy and/or conservatism of WGOTHIC results for the AP600.

The UW condensation tests exhibit some weak trends that, if extrapolated to AP600 conditions, suggest that the treatment of evaporation from the shell exterior could be somewhat nonconservative. The other test series considered exhibited no such trends, however. It is not clear whether a more detailed review of the test series and/or of the WGOTHIC analyses would lead to a better understanding of these differences and whether they are of any concern for AP600 analysis.

480.375 P/E ratios for the UW condensation tests exhibit some weak trends suggesting that the treatment of evaporation from the shell exterior in the AP600 could be somewhat nonconservative. However, no systematic trends in P/E ratios were evident in the other two test series. A more detailed review of these test series and/or of the WGOTHIC analyses needs to be performed by WEC to provide a better understanding of this issue and how it impacts the AP600 analyses.

Response:

Westinghouse has changed its approach to use a bounding lumped parameter evaluation model, which affects the applicability of the above question.

Westinghouse has submitted Reference 480.375-1 which supersedes Reference 480.375-2 on which the original questions were based. The following response is relative to Reference 480.375-1.

The University of Wisconsin condensation tests provided data for condensation under mixed convection in a channel. The data presented in Reference 480.375-2, Sections 3.8 and 4.3 were correlated using a flat plate correlation without entrance effects. The data comparisons were revised and presented in Reference 480.375-1, Sections 3.8 and 4.3. The revised correlations use the Colburn correlation with an entrance effect multiplier as discussed in Sections 2.1, 2.2, and 2.5. The revised predictions are presented in Figures 3.8-2 through 3.8-6 and Figures 4.3-1 through 4.3-3. The use of a constant bias which provides a bound of the worst data point over the range of test data (Reference 480.375-2, Section 4.5) effectively addresses concerns with small residual trends in the separate effects data.

References

480.375-1 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

480.375-2 NTD-NRC-94-4327, (PCS-GSR-006), "Experimental Basis for the Mass Transfer Correlations Selected for Modeling Condensation and Evaporation on the AP600 Containment Vessel," October 21, 1994, Westinghouse Electric Corporation.

480.375-3 NTD-NRC-95-4563, "GOTHIC Version 4.0 Documentation, Enclosure 2: Technical Manual," September 21, 1995.

SSAR Revision: NONE

OITS 3409
RAI 480.403

For the Scaling, SSAR (AP600) WGOTHIC, and LST WGOTHIC analyses, please list the heat transfer correlations (to be) used in the riser and baffle regions. Also include the dynamic and geometric conditions for which each correlation is valid, whether it is a free, mixed, or forced correlation, and whether its use in the particular analysis is considered conservative or best estimate.

Response:

Scaling Analysis

The heat and mass transfer correlations used in the scaling analysis are documented in Reference 480.403-1, Section 4. The heat and mass transfer correlations used inside containment are turbulent free convection. Outside containment, turbulent forced convection heat and mass transfer are used in the riser and downcomer, while turbulent mixed convection is used in the chimney. All correlations are best estimate. The ranges of the validation data relative to AP600 operating conditions are presented in Sections 10.1.1, 10.1.2, and 10.1.3, and in Figures 10-1 and 10-2.

SSAR (AP600) WGOTHIC

The heat and mass transfer correlations used in the WGOTHIC analysis are documented in Reference 480.403-2, Section 2.1, 2.3, 2.4, and 2.5. The heat and mass transfer correlations used inside containment are turbulent free convection. Outside containment, turbulent mixed convection heat and mass transfer are used in the riser, downcomer, and chimney. The heat and mass transfer correlations are bounded. The ranges of the validation data relative to AP600 operating conditions are presented in Sections 4.1, 4.2, and 4.3. The bounding multipliers are derived in Section 4.5.

LST WGOTHIC

The heat and mass transfer correlations used in the LST WGOTHIC lumped parameter analysis are documented in Reference 480.403-2, Section 2.1, 2.3, 2.4, and 2.5. The heat and mass transfer correlations used inside containment are turbulent free convection. Outside containment, turbulent mixed convection heat and mass transfer are used in the riser and chimney. The heat and mass transfer correlations are best estimate. The validation data for free convection mass transfer was derived from the LST, so the data base covers the range of use for LST predictions. The validation data for mixed convection evaporation outside containment includes the Westinghouse flat plate test results that cover a wider range of Reynolds numbers than does LST operation.

References

480.403-1 D. R. Spencer, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, February 1997, Westinghouse Electric Corporation.

480.403-2 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

SSAR Revision: NONE

OITS 3410
RAI 480.404

408.404 On page 3-61 in WCAP-14326, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlation," it is stated that only tests with film coverage greater than 90% were included in the comparison because lower film coverage affected the circumferential averaging. This eliminated 17 of the 25 tests. In Table 3-3 in WCAP-14382, "WGOTHIC Code Description and Validation," the 13 tests selected for validation and verification all had a target coverage of 75% or less. In Table 7-1 of WCAP-14382, five of the tests (excluding the two dry tests) had actual coverage of less than 90%. Provide a description of the method used to obtain the circumferential average. Why is this method not valid if the coverage is less than 90%? Explain why it is acceptable to verify the water coverage model for tests with less than 90% coverage while it is not possible to use test data at less than 90% to verify the heat and mass transfer correlations.

Response:

Circumferential averaging is used since it cannot be determined from the test data which shell temperature measurements are influenced by the wet/dry interfaces on the outside of the shell. Near the wet/dry interface, conduction heat transfer in the shell deviates significantly from one-dimensional radial conduction. It is estimated the extent of influence of each interface is on the order of the shell thickness, so a thermocouple (TC) within this distance of the interface may have been influenced. One-dimensional radial conduction is a major assumption for the data reduction. By limiting the data selection to tests with dry regions no more than 10% there exists a higher probability the thermocouple triad (fluid, inside shell, outside shell) was not influenced by the wet/dry interface. Averaging also "averages out" any such limited, locally anomalous data. The averaging process is as follows:

At each elevation, the temperature measured by each fluid TC was averaged, each inner surface TC was averaged, and each outer surface TC was averaged.

The difference between the inner and outer TC average temperatures was used with the shell thickness and thermal conductivity to infer the average heat flux. (This inferred heat flux is the important parameter most affected by external dry regions.)

The fluid and inner surface average temperatures were used with the heat flux to calculate the gas-to-liquid film surface temperature difference.

The shell heat flux was increased by the enthalpy of the liquid film to get the total energy transferred from the gas to the liquid surface. This represents the sum of the radiation heat transfer, convection heat transfer, and condensation energy transfer.

The condensation energy transfer was determined by subtracting radiation and convection heat transfer from the total energy transfer. Typically the radiation, convection, and liquid film energies account for 15 to 20% of the total energy transfer, so their uncertainties have only a small effect on the calculated condensation energy transfer. Although it includes some calculated adjustments, the condensation energy transfer rate is the so-called "measured" value.

The "measured" condensation energy rate was combined with gas properties evaluated at the bulk and surface temperatures, and the bulk air/steam concentration measurement to derive the "measured" mass transfer coefficient and Sherwood number. (The air/steam concentration is a dominant parameter in the mass transfer calculation [Reference 480.404-1, Table 2-1], so only tests with air/steam concentration measurements can be used.)

Since this method assumes 100% wetted circumferential coverage, it becomes less valid for reduced coverage. 90% was selected as the acceptance limit to avoid excessive bias of the results.

Water coverage can be easily verified by external observations and measurements. The verification of the wetting model requires the use of data that range from low coverage to high coverage to bound the expected range for AP600. Consequently, wetted coverage less than 90% is desirable for water coverage modeling.

Reference

480.404-1 D. R. Spencer, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, February 1997, Westinghouse Electric Corporation.

SSAR Revision: NONE

OITS 3411
RAI 480.405

480.405 On page 3-62 in WCAP-14326, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlation," reference to Figure 3.9-1 says it is a plot of predicted-to-measure Nusselt numbers for the seven large-scale PCS tests. The actual figure on page 3-63 is a plot of predicted-to-measure Sherwood (Sh) numbers. Note that there is one data point near a predicted-to-measured Sherwood number of about 1.5, at lowest heated length. Either provide a corrected figure that supports the discussion in Section 3.9 of WCAP-14326 or modify the discussion to be consistent with the figure.

Response:

Westinghouse has submitted Reference 480.405-1 which supersedes Reference 480.405-2 on which the original questions were based. The following response is relative to Reference 480.405-1.

The text on page 3-62 of Reference 480.405-2 was corrected in Reference 480.405-1, page 3-64.

References

480.405-1 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

480.405-2 NTD-NRC-95-4428, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, April 13, 1995, Westinghouse Electric Corporation.

SSAR Revision: NONE

OITS 3412
RAI 480.406

480.406 In the attachment to letter NTD-NRC-95-4570, dated September 28, 1995, a plot of predicted-to-measured Sherwood number versus Reynolds number is used to show the bounding predicted-to-measured value for evaporation. For the condensation comparison, the predicted-to-measured Sherwood number versus P/P ratio is used. There is no obvious reason as to why the independent variable should be different for this use. However in reviewing WCAP-14326, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlation," it appears that in Figure 4.3-1 of that report (the Sherwood number versus Reynolds number comparison for condensation) the outlier (at P/P = 1.491) is either missing or outside that plotted range. Provide a corrected Figure 4.3-1 for WCAP-14326 that includes this data point.

Response:

The first paragraph on page 4-8 of Reference 480.406-1 addresses Figure 4.3-1 and states:

> "Note, local Reynolds number values could not be determined from the measured internal condensation data from the large-scale PCS tests, therefore, only the Wisconsin condensation test data are shown on Figure 4.3-1."

The outlier is one of the large-scale PCS test data points, so it is not, and can not be shown as a function of Reynolds number. However, the outlier is shown on Figures 4.3-2 and 4.3-3, both of which are plotted for independent variables that are defined for the PCS tests.

References

480.406-1 R. P. Ofstun, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, April 13, 1995, Westinghouse Electric Corporation.

SSAR Revision: NONE

OITS 4542
RAI 480.608

In WCAP-14407, Section 3, the last paragraph on page 3-7 states: "The convection heat transfer in any large containment vessel will primarily be turbulent rather than laminar." On page 3-8, the second paragraph states: "Approximately 95 percent of the condensing shell surface is expected to operate in the turbulent (GR > 10^{10}) free convection range." Please provide quantitative justification for these statements, particularly for long term conditions hours after the blowdown phase of a loss of coolant accident (LOCA) event has finished.

Response:

Section 3.4 of Reference 480.608-1 contains the text referred to in this RAI. That section was replaced by a reference to Reference 480.608-2 which contains a similar statement on the magnitude of vertical height inside the AP600 containment shell that operates in turbulent free convection. The statement refers to operation close to the time of peak pressure. Several hours to days into the transient the height of the inside that operates in laminar free convection is greater. Kreith (Reference 480.608-3, Figures 7-3 and 7-4) show the heat transfer coefficients for laminar free convection are greater than for turbulent free convection extrapolated to lower Grashof numbers. Consequently, the turbulent free convection correlation underestimates heat transfer at low Grashof numbers. This approach is conservative.

References

480.608-1 A. Forgie, J. Narula, R. Ofstun, D. L. Paulsen, S. K. Slabaugh, M. Sredzinski, D. R. Spencer, J. Woodcock, "WGOTHIC Application to AP600," WCAP-14407, Section 3.

480.608-2 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

480.608-3 F. Kreith, *Principles of Heat Transfer*, Second Edition, International Textbook Company, 1968, pp. 334-335.

SSAR Revision: NONE

OITS 4543
RAI 480.609

In WCAP-14407, Section 3 (p. 3-10), Westinghouse states that GOTHIC applies a single heat transfer correlation which combines turbulent forced convection and free convection. The turbulent forced convection component will be computed using the flat plate correlation. However, Westinghouse has stated (Ref: NTD-NRC-95-4545, August 31, 1996) that is will bound forced convection inside containment by using free convection only. Please explain.

Response:

The heat and mass transfer correlations used in the WGOTHIC model are defined in Reference 480.609-1. The equations presented in Reference 480.609-2, Sections 3.4 and 3.5 were replaced by references to Reference 480.609-1, Section 2. Fee convection only is assumed for the heat and mass transfer rate calculations inside the AP600 shell as described in Reference 480.609-1, Section 2. The mass transfer correlations are made bounding with the multipliers derived in Section 4.5.

References

480.609-1 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-1432', Revision 1, May 1997, Westinghouse Electric Corporation.

480.609-2 A. Forgie, J. Narula, R. Ofstun, D. L. Paulsen, S. K. Slabaugh, M. Sredzinski, D. R. Spencer, J. Woodcock, "WGOTHIC Application to AP600," WCAP-14407, Section 3.

SSAR Revision: NONE

OITS 3190
DSER 21.6.5-2

Westinghouse needs to address the staff's concern on the use of Westinghouse form of the Chun and Seban correlation in the heat and mass transfer models for WGOTHIC.

Response:

The Chun and Seban correlation (Reference 21.6.5-2-1) for evaporating liquid films is compared to the evaporating Chun and Seban data (41 points) and the condensing Wisconsin data (28 points, Reference 21.6.5-2-2) in Reference 21.6.5-2-1, Section 3.10. The comparison shows the correlation is a reasonable best estimate model for both condensing and evaporating films.

Since the temperature drop through the film is only a small fraction of the total temperature drop from the inside bulk gas to the riser bulk gas, and since the film conductance is ranked low importance in the PIRT (Reference 21.6.5-2-3), it is sufficient to use a nominal film conductance correlation for AP600 analyses.

The original Nusselt film correlation (Reference 21.6.5-2-4, Section 10-3) applies only to smooth laminar films, which transition from smooth laminar to wavy laminar at a Reynolds number of approximately 30 (References 21.6.5-2-5 and -6). In lieu of a theoretical development for the very complicated wavy laminar film, the dimensionless, empirical approach of Chun and Seban is reasonable.

The application of the correlation to inclined surfaces is supported by the comparisons to the Wisconsin test data that included inclination angles ranging from horizontal to vertical. The data for horizontal surfaces, with the prototypic AP600 inorganic zinc coating, showed the film on the underside of a horizontal surface formed drops that rained off with a heat transfer coefficient value higher than the average values measured for all inclined surfaces. Rain was observed for surface inclinations less than 1° of inclination, and film flow for greater angles. The Chun and Seban correlation is not applied to horizontal surfaces in the Evaluation Model. Rather, the value of the heat transfer coefficient for angles of inclination less than 1° is set equal to the value calculated at an angle of 1°. This produces results that are conservative relative to the horizontal surface measurements.

References

21.6.5-2-1 K. R. Chun and R. A. Seban, "Heat Transfer to Evaporating Liquid Films", *Journal of Heat Transfer*, November 1971.

21.6.5-2-2 I. Huhtiniemi, A. Pernsteiner, M. L. Corradini (University of Wisconsin), "Condensation in the Presence of a Noncondensable Gas: Experimental Investigation," WCAP-13307, April 1991, Westinghouse Electric Corporation.

21.6.5-2-3 M. Loftus, D. R. Spencer, J. Woodcock, "Accident Specification and Phenomena Evaluation for AP600 Passive Containment Cooling System", (WCAP-14811) December 1996, Westinghouse Electric Corporation.

21.6.5-2-4 F. Kreith, *Principles of Heat Transfer*, Second Edition, International Textbook Company, 1968.

21.6.5-2-5 T. B. Benjamin, "Wave Formation in Laminar Flow Down and Inclined Plane", *Journal of Fluid Mechanics*, **2**: 554-574.

21.6.5-2-6 A. M Binnie, "Experiments on the Onset of Wave Formation on Film of Water Flowing Down a Vertical Plane, *Journal of Fluid Mechanics*, **2**: 551-553.

SSAR Revision: NONE

OITS 3191
DSER-21.6.5-3

Westinghouse needs to address the staff's concern on liquid film stability and rainout effects in the heat and mass transfer models for WGOTHIC.

Response:

(1) The inside roughness values for the prototypical AP600 steel shell are expected to lie in the range of 150 to 250 micro inches RMS. This is based on measurements of 154 to 249 micro inches for the LST, 196 to 246 micro inches for the SST, and 227 to 250 micro inches for the flat plate surfaces. Each of these surfaces was prepared consistent with the coating application instructions that specify a dry abrasive blast to obtain a 1 to 3 mil blast surface profile.

(2) The inside roughness value for the LST is expected to be 150 to 250 micro inches. Although this was not measured, the inner and outer surface coatings were applied according to the same surface preparation specification and by the same operator. Therefore, the inner and outer surface roughnesses of the LST are expected to be similar.

(3) Since the average film thickness of 0.005 inches is 25 times the height of the roughness, the surface roughness is expected to have little effect on the heat transfer through the film. The relatively high noncondensable concentrations in AP600 and the LST make the bulk-to-liquid film surface heat transfer resistance orders of magnitude greater than the liquid film heat transfer resistance.

The effect of increased coating resistance due to corrosion or degradation was evaluated by sensitivity calculations reported in Reference 21.6.5-3-1 and shown to have a minor effect.

(4) Any process that induces instability or rainout from the internal film will decrease the net thermal resistance of the film. Consequently, rainout is conservatively neglected in the evaluation model.

Reference

21.6.5-3-1 A. Forgie, J. Narula, R. Ofstun, D. L. Paulsen, S. K. Slabaugh, M. Sredzinski, D. R. Spencer, J. Woodcock, "WGOTHIC Application to AP600," WCAP-14407, Section 10.

SSAR Revision: NONE

OITS 3212
DSER 21.6.5-22c

21.6.5-22c
Westinghouse needs to address the RAI on the Siegel and Norris tests.

Response:

A response to RAI 480.359 on the Siegel and Norris tests has been provided to the NRC.

OITS 3213
DSER 21.6.5-22d

Westinghouse needs to address the RAIs on the separate effects heat transfer tests.

Response:

Responses to RAI's 480.360 to 480.368 on heat transfer - separate effects tests have been provided to the NRC.

OITS 3214
DSER 21.6.5-22e

Westinghouse needs to address the RAI on the University of Wisconsin condensation tests.

Response:

Responses to RAI's 480.369 to 480.371 on University of Wisconsin condensation tests have been provided to the NRC.

OITS 3216
DSER 21.6.5-22g

Westinghouse needs to address the RAIs on the LST tests used to support the heat and mass transfer correlation.

Response:

Responses to RAI's 480.404, 480.405, and 480.406 on WCAP 14326, Rev 0 have been provided to the NRC.

OITS 3217
DSER 21.6.5-22h

Westinghouse needs to acceptably address the RAIs on the separate effects of mass transfer tests.

Response:

Responses to RAI's 480.373, 480.374, and 480.375 on General Concerns with Mass Transfer - Separate Effects Test have been provided to the NRC.

OITS 3218
DSER 21.6.5-23

Westinghouse needs to present the separate-effects test data used to assess the mass and heat transfer correlations in the WGOTHIC computer program to be used for the AP600 DBA evaluation model with uncertainties shown for the test data.

Response:

Uncertainty bands are presented on the Westinghouse test data in Reference 21.6.5-23-1, Figures 3.4-1, 3.7-3, 3.8-6, and 3.9-4. The biases used to make the mass transfer correlations bounding correlations are presented in Section 4.5.

Reference

21.6.5-23-1 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

OITS 2405

Provide experimental basis for evaporation taking place on the AP600 dome, as it relates to the degree of subcooling on the LST dome.

Re: NRC Meeting on PCS (3/17/95)

Response:

The experimental basis for evaporation on the dome and side walls of AP600 is presented in Reference 2405-1, Section 4.2. The analytical model for the liquid film evaporation, presented in Reference 2405-1 Section 2.5, accounts for the film temperature, and thereby the film subcooling. The data used in the comparisons include a range of subcooling, and show the correlation predicts the data.

Reference

2405-1 F. Delose, R. P. Ofstun, D. R. Spencer, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," WCAP-14326, Revision 1, May 1997, Westinghouse Electric Corporation.

SSAR Revision: NONE