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

ATTENTION: T. R. QUAY

SUBJECT: AP600 RESPONSE TO REQUESTS FOR ADDITIONAL INFORMATION

Reference: (1) Westinghouse letter DCP/NRC/0933, dated 6/24/97

Dear Mr. Quay:

Enclosed are the Westinghouse responses to NRC requests for additional information related to the AP600 PCS scaling analysis. The RAI responses are consistent with the information contained in WCAP-14845, Rev. 2, "Scaling Analysis for Containment Pressure During Design Basis Accidents", June 1997 sent to you via Reference 1. Specifically, responses are provided for:

1/1
E004

030021

OITS	RAI	OITS	RAI	OITS	RAI
5390	480.967	5415	480.992	5440	480.1017
5391	480.968	5416	480.993	5441	480.1018
5392	480.969	5417	480.994	5442	480.1019
5393	480.970	5418	480.995	5443	480.1020
5394	480.971	5419	480.996	5444	480.1021
5395	480.972	5420	480.997	5445	480.1022
5396	480.973	5421	480.998	5446	480.1023
5397	480.974	5422	480.999	5447	480.1024
5398	480.975	5423	480.1000	5448	480.1025
5399	480.976	5424	480.1001	5449	480.1026
5400	480.977	5425	480.1002	5450	480.1027
5401	480.978	5426	480.1003	5451	480.1028
5402	480.979	5427	480.1004	5452	480.1029
5403	480.980	5428	480.1005	5453	480.1030
5404	480.981	5429	480.1006	5454	480.1031
5405	480.982	5430	480.1007	5455	480.1032
5406	480.983	5431	480.1008	5456	480.1033
5407	480.984	5432	480.1009	5457	480.1034
5408	480.985	5433	480.1010	5458	480.1035
5409	480.986	5434	480.1011	5459	480.1036
5410	480.987	5435	480.1012	5252	480.1017
5411	480.988	5436	480.1013	5253	480.1018
5412	480.989	5437	480.1014	5254	480.1019
5413	480.990	5438	480.1015	5255	480.1020
5414	480.991	5439	480.1016	5256	480.1021

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.

Typographical errors and inconsistencies identified by the NRC in the previous revision of WCAP-14845 were corrected in the text of WCAP-14845 Rev. 2, except for:

- (page 7-9) change + to = did not get implemented, and
- (page 7-14) It was intended to change $\pi_{m,evap,p}$ to $\pi_{m,p}$ in Equation 108, but the "evap" subscript did not get deleted.

Two typographical errors are noted in WCAP-14845, Rev. 2:

- page 10-24, second paragraph, the reference to Table 10-2 should be to Table 10-3
- page 11-6, two references to Table 10-10 should be to Table 10-3.

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

Brian A. McIntyre, Manager
Advanced Plant Safety and Licensing

Enclosure

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

OITS 5390
RAI 480.967

(General) Many of the numbered equations, e.g. (1), contain multiple formulas and it is difficult to tell when one formula ends and another begins. Insert semicolons or some other separator so it is clear where the separation between formulas is intended.

Response:

The equations were revised in Reference 480.967-1 to include additional space, both horizontal and vertical, to clearly separate equations.

Reference

480.967-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5391
RAI 480.968

(Page xv) Table E-1 has no π groups listed for Liquid Film Energy Transport, while Table 2-1 has two π groups listed. A second π group is missing in Table E-1 for Radiation Heat Transfer. Also, what is the basis for the 14 percent of condensation energy carried away by the film on the inside and 8 percent on the outside?

Response:

Table E-1 was deleted and Table 2-1 was revised in Reference 480.968-1 to specify the pi group ratios that define the Liquid Film Energy Transport. A note was added to clearly define the source and values for the pi groups. The 14% and 8% values are defined by the ratios in this note.

A note was added to Table 2-1 that radiation accounts for approximately 1/2 of the sensible heat transfer to and from the shell and heat sinks.

References

480.968-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5392
RAI 480.969

(Page xl) Two points in Table P-1 should be clarified. The need was apparently identified for a 1/8 scale test and also for testing to determine the effect of hydrogen on heat transfer. Was the need for the 1/8 scale test satisfied by the large scale test (LST)? If so, it would help to state this. Also, this is the only mention of hydrogen effects. It would help to state how this concern was addressed.

Response

The needs originally identified for the LST were satisfied by the test.

A need for hydrogen was originally identified and was part of the LST test matrix. However, the data needed for design basis accidents, that are the subject of the containment evaluation model, do not include hydrogen (see PIRT, Reference 480.969-1, Section 4.4.2E). Consequently, Table P-1 of Reference 480.969-2 was revised by deleting the reference to hydrogen.

References

480.969-1 M. Loftus, D. Spencer, J. Woodcock, "Accident Specification and Phenomena Evaluation for AP600 Passive Containment Cooling System", WCAP-14812, Rev. 1, Westinghouse Electric Corporation.

480.969-2 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5393
RAI 480.970

(Page xxiii) The differences between the results of the scaling model and the evaluation model will need to be explained in more detail than what is provided here.

Response

The discrepancy between the scaling model and the evaluation model presented in Reference 480.970-1 resulted from a comparison of nominal scaling model predictions to biased evaluation model predictions. Revised results presented in Reference 480.970-2 show both the trend and magnitude of predictions are similar when applied to the same case.

References

480.970-1 D. Spencer, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 0, Westinghouse Electric Corporation.

480.970-2 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5394
RAI 480.971

(Page xxxiv) The wording in the first paragraph needs to be changed to have the same meaning as in the body of the report on Page 10-20. The transient π group $\pi_{e,i}$ clearly does not equal zero as stated here. (See wording in Section 10, Page 10-20.)

Response:

The executive summary was extensively revised in Reference 480.971-1 and this text was deleted.

Reference

480.971-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5395
RAI 480.972

(Page xiii) The last paragraph in Element 2 refers to the distributed parameter WGOTHIC calculations. If these calculations are no longer a part of the submittal this reference should be deleted.

Response:

The paragraph was deleted in Reference 480.972-1.

Reference

480.972-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5396
RAI 480.973

(Page xiii) Where are the sensitivity calculations referred to in Element 3 documented? Give a reference.

Response:

The sensitivities are documented in Reference 480.973-1, Section 5. This reference was added to the text.

Reference

480.973-1 A. Forgie, J. Narula, R. Ofstun, D. Paulsen, S. Slabaugh, M. Sredzienski, D. Spencer, J. Woodcock, "WGOTHIC Application to AP600", WCAP-14407, Westinghouse Electric Corporation.

OITS 5397
RAI 480 974

(Page 1-3) The third bullet makes reference to "LASL." Should this reference be to Sandia?

Response:

The text was corrected in Reference 480.974-1 to identify Sandia as the reviewer.

Reference

480.974-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5398
RAI 480.975

(Pages 2-2 and 2-3) The table given here is very useful in locating where each phenomena is addressed. However, some of the π groups could not be found in Section 8, where π groups are evaluated. These are: $\pi_{p,g,j}$, $\pi_{e,f,f}$, $\pi_{e,c,j}$ and $\pi_{e,r,j}$. Also, listing "parameter" under π group does not give any information on where the phenomenon is addressed. It would help to show which π group the parameter is in.

Response:

The pi groups, $\pi_{p,g,j}$, $\pi_{e,f,f}$, $\pi_{e,c,j}$, and $\pi_{e,r,j}$ were replaced in Table 2-1 of Reference 480.975-1 with defined pi groups. See the response to RAI 480.968.

The left column of Table 2-1 includes an extra subdivision that shows which phenomena the "parameters" are in. For example, Mixing and Stratification is one of several parameters in Condensation Mass Transfer.

Reference

480.975-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5399
RAI 480.976

(Page 2-3) No π group is listed for baffle conduction in Table 2-1. Why are $\pi_{e,q,bf}$ and $\pi_{e,q,bfx}$ listed in Table 8-4 not appropriate for addressing this phenomenon?

Response:

The baffle pi groups, $\pi_{e,q,bf}$ and $\pi_{e,q,bfx}$, listed in Table 8-4 represent sensible heat transfer to and from the baffle. Since the importance of baffle conduction must be similar to the importance of the fluxes in and out, the two groups were added to Table 2-1 of Reference 480.976-1.

Reference

480.976-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5400
RAI 480.977

(Pages 3-1 and 3-2) Values given for the volumes and surface areas of steel and steel-jacketed heat sinks are different from those given in (Phenomena Identification and Ranking Table) PIRT (WCAP-14812) Table 3-1. Please explain.

Response:

The heat sink surface areas and volumes listed in the PIRT, Table 3-1 (Reference 480.977-1), are correct. The values used for scaling reduced the values in the PIRT for the following:

- All heat sinks were eliminated in dead-ended compartments, since steam access is not dependable.
- All upward facing concrete heat sinks were eliminated, since the concrete floors in all rooms may blanket with noncondensables, and/or thick water films that prevent heat transfer.
- All upward facing, horizontal steel heat sinks more than 2 ft wide were eliminated, since they may develop liquid films too thick to drain rapidly and permit efficient heat transfer.

The net effect of these reductions is to reduce the PIRT areas and volumes to the values presented in Table 3-1. This discussion was added to the text in Section 3.1 of Reference 480.977-2.

References

480.977-1 M. Loftus, D. Spencer, J. Woodcock, "Accident Specification and Phenomena Evaluation for AP600 Passive Containment Cooling System", WCAP-14812, Rev. 1, Westinghouse Electric Corporation.

480.977-2 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5401
RAI 480.978

(Page 3-3) Why is the third plateau in mass flow rate beyond 80,000 seconds not shown in Figure 3-1 as it is in PIRT (WCAP-14812) Figure 3-7? Is the correct flow rate beyond 80,000 seconds shown in the PIRT Figure?

Response:

Reference 480.978-1 presents a revised Figure 3-1 that shows the external water flow rate to 7 days. The figures in the PIRT (Reference 480.978-2) and the Scaling Analysis (Reference 480.978-1) are consistent.

References

480.978-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

480.978-2 M. Loftus, D. Spencer, J. Woodcock, "Accident Specification and Phenomena Evaluation for AP600 Passive Containment Cooling System", WCAP-14812, Rev. 1, Westinghouse Electric Corporation.

OITS 5402
RAI 480.979

(Page 3-10) Please explain the decrease in pool surface area which occurs between 2,500 and 5,000 seconds shown in Figure 3-8.

Response:

The pool surface area decreases at approximately 2000 ft^3 of pool volume as the rising surface encounters the bottom of the reactor vessel. The reactor vessel has a large cross section that reduces the pool area. Thereafter, the area only increases as additional compartments flood.

OITS 5403
RAI 480.980

(Page 4-7, Section 4.3.2) What is the basis for the belief that the correlation for the air-steam diffusion coefficient produces values which are 10 percent high? Why is this acceptable?

Response:

The Heat and Mass Transfer report,Reference 480.980-1, Section 2.6, shows a comparison of the air-steam diffusion coefficient with test data in the range of temperatures for AP600 containment analysis. The comparison shows the correlation is 10% too high. The Heat and Mass Transfer report reference was added to the Scaling Analysis, Reference 480.980-2.

The 10% difference is acceptable because the correlation is used consistently for all data comparisons and AP600 predictions, and is biased in the evaluation model to bound the test data as shown in Reference 480.980-2, Section 4.5.

References

480.980-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14345, Rev. 2, Westinghouse Electric Corporation

480.980-2 F. Delose, D. Spencer, R. P. Ofstun, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations", WCAP-14326, Rev. 1, Westinghouse Electric Corporation.

OITS 5404
RAI 480.981

(Page 6-1, Section 6) The wording of the last sentence in this section could be modified to better convey the thought. It appears that you have adopted and adhered to a sign convention and this assures that the direction of heat flow is unambiguous and determined by the sign of the solution.

The paragraph was reworded to clarify the sign convention in Reference 480.981-1.

References

480.981-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5405
RAI 480.982

(Page 6-7) The statement that u_{min} can be defined which corresponds to the system with the specific internal energies of water and air at the same temperature and pressure needs further explanation.

The discussion of the reference temperature was expanded in Section 6.2, Reference 480.982-1.

Reference

480.982-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5406
RAI 480.983

(Page 6-7) It would be helpful to the reader to state that Equation (56) in the form:

$$dm_{stm}/dt = m_{g,brk} - S\ m_{stm,j}$$

is used to obtain Equation (67).

Response:

The discussion of the development of the energy equation was expanded in Section 6.2, Reference 480.983-1, to include the use of Equation (56).

Reference

480.983-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5407
RAI 480.984

(Page 6-9) In Equation (69), the work term has been left out of the final equation, although a π group for the term is included. When the equation is used in Chapter 9, as Equations (191) and (197), this same term is also missing. Please explain.

Response:

The work term for displacement of air by water was inadvertently left out of Equation (69). This term was included in Equation (69) of Reference 480.984-1.

The work term for displacement of air by water was inadvertently left out of Equations (191) and (197). This term was included in Equations (191) and (197) of Reference 480.984-1.

Reference

480.984-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5408
RAI 480.985

(Page 6-16) In Table 6-3, it would be helpful to add the time period for each phase to the headings.

Response:

The transient time was added to each time period in Reference 480.985-1, Table 6-3.

Reference

480.985-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5409
RAI 480.986

(Page 6-18) According to the nomenclature section, ρ_a in Equation (84) is the containment ambient density. How is this number calculated from the reference values given in Table 6-3? What phase of the DECLG LOCA (double ended cold leg guillotine loss-of-coolant-accident) is used to get the values in Table 6-4? How is the value determined for LST?

Response:

The ambient density, ρ_a, in Equation (84) is equal to the total density, ρ_o in Table 6-3.

The AP600 values in Table 6-4 are independent of the phase, with the exception of the ratio ρ_o/ρ_a that varies only a few percent for the different time phases.

The LST values in Table 6-4 are independent of the test conditions, with the exception of the ratio ρ_o/ρ_a that varies only a few percent for the different tests.

OITS 5410
RAI 480.987

(Page 6-18) The criterion for stable stratification, based on the volumetric Froude number, does not include the diameter of the large volume within which the jet is released. This means that the criterion applies equally to a volume whose diameter is only slightly larger than the jet diameter, d_0, and to an infinitely large diameter volume. There must be some assumption in Peterson's approach which limits the size of the applicable volume relative to the jet. Clearly, a jet located in an infinitely large volume does not affect the stratification of the entire volume. Please explain the limitations on the application of Peterson's approach as the volume size increases.

Response

The stratification data referenced by Peterson were developed for large, shallow pools. For such a geometry, the pool width, W, is greater than the depth, H, and both are much greater than the jet diameter, d_0. Application of Peterson's results to AP600, with H/W = 1.0, approximately, is expected to overestimate the jet Reynolds number required to break up stable stratification. Consequently, following a large LOCA or MSLB, stratification may not appear until later (at lower break flow rate) than predicted. Use of Peterson's criteria for stable stratification is considered to be conservative for AP600 analysis.

OITS 5411
RAI 480.988

(Page 6-22) Fr_v at the stability limit presented in Table 6-4 is stated to be calculated using Equation (89),

$$Fr_v = (1 + d_o/(4 \sqrt{2}\, a\, H))^2$$

$$Fr_v = (1 + 11.1/(4 \sqrt{2}\, 0.05\ 109))^2$$

$$Fr_v = 1.85$$

which doesn't agree with the number in the table. Please explain.

Response

The values of "Fr_v at Stability Limit" were all corrected and presented in Reference 480.988-1.

Reference

480.988-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5412
RAI 480.989

(Page 7-7, Section 7.1.1) A formula for the shell conductance is given just before Equation (96) which includes the coating on both sides. Later, on the bottom of Page 7-11, a formula for the conductance is given without the coatings. Which formula was actually used?

Response

The formula with coatings was used to define the value of $h_{sh,o}$. The statement at the bottom of p 7-11 was corrected in Reference 480.989-1.

Reference

480.989-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5413
RAI 480.990

(Page 7-13, Table 7-2) What is the reason for choosing the design pressure (60 psia) as "P" total for the long term phase? Would this not tend to overestimate the heat transfer to the heat sinks?

Response

It was desired to include the design pressure in the scaling analysis to avoid the concern that only nominal conditions, with their much lower pressures and transfer rates, might somehow produce less severe results. The heat transfer to the heat sinks and shell are all increased at higher pressure conditions, but the relative magnitude of each process is not believed to change significantly.

OITS 5414
RAI 480.991

(Page 7-13, Table 7-3) Why does the table not include the long term phase? Why is the pool surface area different for the blowdown and refill phases even though the pool volume is the same? Why is the surface area during refill different in Tables 7-2 and 7-3? Figure 3-8 shows a pool surface area of 2,000 ft^2 compared to the 1,933 ft^2 shown in this table. Which is correct?

Response

The incomplete results in Table 7-3 and inconsistencies between Table 7-2, Table 7-3, and Figure 3-8 in Reference 480.991-1 were corrected in Reference 480.991-2, Section 7.2.2.

References

480.991-1 D. R. Spencer, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 0, Westinghouse Electric Corporation.

480.991-2 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5415
RAI 480.992

(Page 7-15) How was the film determined to be less than approximately 0.005 inches thick, as stated in the first paragraph. The arguments regarding the importance of the liquid film are based on this assumption. How would the assumption of a thicker film affect the calculated heat transfer through the shell?

Response

Please see the response to RAI 480.1027 for a discussion of the basis for a 0.005 inch thick film.

The minimum Nusselt number produces a heat transfer coefficient value of approximately 600 B/hr-ft^2-F, whereas a 0.005 in. film has an h of 900 B/hr-ft^2-F. When combined with the shell/coating conductance of 217 B/hr-ft^2-F and typical inside and outside mass transfer coefficients of 100 B/hr-ft^2-F the difference between 900 and 600 B/hr-ft^2-F for the film coefficient changes the overall heat transfer coefficient from 37.3 to 35.8, a 4% difference. This difference is not significant for a scaling analysis.

OITS 5416
RAI 480.993

(Page 7-16) How was the 165°F area-weighted average film temperature cited in the first paragraph calculated?

Response

The area weighted average film temperature was calculated using values from the spreadsheet that calculates numerical values for the scaling analysis. The film temperature for each of the steel, concrete, and jacketed concrete surfaces was multiplied by the respective surface area and divided by the total surface area.

OITS 5417
RAI 480.994

(Page 7-21, Section 7.5.5) In Section 3 (Page 3-1) and Section 4.7, steel heat sink thickness is given as 0.4 inches, while 0.5 inches is used here. Which is correct?

Response

The average steel heat sink thickness is 0.4 inches. The value 0.5 quoted in Section 7.5.5 was revised to 0.4 in Reference 480.994-1.

Reference

480.994-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5418
RAI 480.995

(Page 7-21, Section 7.5.5) Using 25 B/hr-ft-F for the conductivity of carbon steel and the average steel thickness of 0.5 inches, indicates that an h of 48 B/hr-ft^2-F was used to get a Biot number of 0.08. Apparently this is $h_{e,o}$. However, according to the values in Table 8-2, $p_{c,st}$ has an average value of about 0.4, indicating that $h_{e,o}$ is approximately 0.4 x 216.58 = 86.6 B/hr-ft^2-F. How was the value of 48 for $h_{e,o}$ determined?

Response

The value of $h_{e,o}$ ranges from 66 to 97 for the four time phases. Thus, k = 25 B/hr-ft-F and δ = 0.4 in. gives a maximum Biot number $h\delta/k$ = 0.13. The text of Section 7.5.5, Reference 480.995-1 was revised accordingly.

Reference

480.995-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5419
RAI 480.996

(Page 7-21, Section 7.5.5) Please explain in greater detail how the solution of Equation (118), given by Equation (126), was determined. In particular, what value was used for the containment atmosphere temperature and how was T_{srf} determined or related to T_{hs}?

Response

The text in Reference 480.996-1 was revised to note that since the heat sink Biot number is low, the heat sink is modeled as a lumped mass, so $T_{srf} = T_{hs}$. The containment atmosphere is modeled by the containment gas temperatures and times presented in Table 6-3. The solution given in Equation (126) assumes the gas temperature history is a linear function of time from one Table 6-3 temperature to the next.

Reference

480.996-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5420
RAI 480.997

(Page 7-21, Section 7.5.6) It is stated that the containment boundary condition was modeled as a step function over each time phase. What constant value was used for each phase?

Response

The text in Reference 480.997-1 was revised to define the containment gas temperature history as the containment gas temperature values presented in Table 6-3.

Reference

480.997-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5421
RAI 480.998

(Page 7-22, Section 7.5.6) Were integrations performed to obtain the time averaged value of h_c? Please explain which equation(s) were integrated or how the average values were determined. Since the peak containment gas temperature is used for T_∞, what is an estimate of the error in the overprediction of heat flux during the non-peak pressure phases? Where was Equation (128) used outside of containment? What temperature was used for T_∞ outside of containment?

Response

Integrations were not performed. The value of h_e calculated for each time phase was multiplied by the phase Δtime, the products summed, and the sum divided by the total time. The result was the time-weighted heat transfer coefficient.

The containment gas temperature (from Table 6-3) for <u>each</u> time phase was used as T_∞. This approximation resulted in a step change in the boundary temperature at the beginning of each time phase, and overestimated the heat fluxes. The magnitude of the overestimation is probably greater than a factor of 2 for the concrete heat sinks and chimney. Since the pi values for the concrete heat sinks and chimney are less than -0.12 in Table 8-4, the fact that heat flux is overpredicted by a factor of two or more means hte concrete is even less significant than indicated by the pi values.

Outside of containment, Equation 128 was used on the chimney concrete. The chimney gas temperature was used for T_∞.

OITS 5422
RAI 480.999

(Page 7-22, Section 7.5.7) It is stated that the modeling of two structures in parallel and taking the larger of the two is conservative for the steel-jacketed heat structures. This neglects the thermal resistance of the gap between the steel and the concrete, a factor considered in present evaluation models. Provide an estimate of the effect of the gap on your thermal model for the steel-jacketed heat sinks.

Response

The effect of a gas filled gap between the steel jacket and concrete can be estimated by considering the gap conductance in relationship to the concrete conductance. A 0.005 inch air gap has a conductance of 36 B/hr-ft^2-F. It takes only 0.28 inches of concrete to equal this conductance. In terms of conductance, the structure with a 0.005 in. gas gap looks like a structure with no gap, but with 0.28 inches more of thermal penetration into the concrete. The extra 0.28 in. of concrete requires additional time to saturate, that can be estimated from the structure time constant, $0.6\delta^2\rho c_v/k$ = 132 sec. Thus, after a delay on the order of 132 sec. the structure with the gas gap will be conducting heat into the concrete at approximately the same rate as a heat sink with no gap.

Thus, a conceptual model of the heat sink with a gap will behave much like the heat sink with no gap initially, until the steel jacket is saturated (approximately 1 minute). Conduction into the concrete with the gas gap then occurs at a rate similar to that in the solid heat sink after a time delay of just over 2 minutes. The effect on pi groups is expected to be minor during blowdown and refill, since the steel jacket dominates then. During the peak pressure phase the energy transfer is reduced. During the long term time phase the effect is small because the 132 sec time delay is only a small part of the total time.

OITS 5423
RAI 480.1000

(Page 7-25) Is Equation (134) based on treating the shell as a lumped mass? Please define the term T_{shx} (not in the nomenclature). Is T_{shx} assumed to be equal to T_{sh}?

Response

T_{sh} is the shell average temperature, that represents the total heat stored in the shell. The surface temperatures were revised in Reference 480.1000-1 to be consistent with Figure 7-3 nomenclature. The shell is treated as a thermally thick structure as defined by Wulff (Reference 480.1000-2) and solved using Wulff's solution presented in Equations 152 to 155.

References

480.1000-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

480.1000-2 W. Wulff, "Integral Methods for Simulating Transient Conduction in Nuclear Reactor Components", *Nuclear Engineering and Design 151 (1994) 113-129.*

OITS 5424
RAI 480.1001

(Page 7-25, last paragraph) What calculation of the "temperature of the evaporating film independently of the subcooled or dry regions" is referred to here? Please describe the calculation.

Response

The text preceding equation 135 in Reference 480.1001-1 was revised for clarity.

Reference

480.1001-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5425
RAI 480.1002

(Page 7-25) Please explain the meaning of Equation (135). The numerator is the energy flow rate needed to heat the external film flow from T_{in} to $T_{xf,s}$. One would expect the denominator to be the heat flux from the interior containment gas volume needed to heat the film flow over the area A_{sc}. Based on the nomenclature section, the heat transfer coefficient $h_{xf,ss}$ is between the subcooled shell interior and the external film, but the temperature difference is between the film and the subcooled shell external surface, with the sign indicating that the film is expected to be at a higher temperature than the subcooled shell exterior surface. Please explain or correct the equation.

Response

The text preceding equation 135 in Reference 480.1002-1 was revised for clarity. The incorrect temperature difference in the denominator was also corrected.

Reference

480.1002-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2 Westinghouse Electric Corporation.

OITS 5426
RAI 480.1003

(Page 7-29, last paragraph of Section 7.6.3) The reader can not tell what the relative magnitudes of time constants are from the equations in (140). It would be helpful to give the values to support the argument. Also, is the external heat transfer from the shell, rather than to the shell?

Response

The ratio of time constants for the inside and outside of the subcooled shell is equal to the ratio of the heat transfer coefficients, or $\tau_{scx}/\tau_{sc} = h_{e,sc,o}/h_{e,scx,o}$. The ratio of the heat transfer coefficients is equal to the ratio of the normalized conductances presented in Table 8-2, so the ratio of time constants is $\tau_{scx}/\tau_{sc} = \pi_{c,sc}/\pi_{c,scx} = 0.58/3.88 = 0.15$.

External heat transfer is from the shell to the subcooled liquid outside the shell.

OITS 5427
RAI 480.1004

(Page 7-30, Section 7.6.5) Which equation from Wulff is used to get the 22-second penetration time? If this is your Equation (151), this should be noted. What is the difference between this 22-second penetration time and the 18.4 seconds on page 7-31?

Response

Equation (151) of Reference 480.1004-1 was used to calculate the thermal penetration time for the shell. The value is 18.8 sec. and the text was revised to quote the correct value in two places and Equation (151) was referenced.

Reference

480.1004-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5428
RAI 480.1005

(Page 7-30, Section 7.6.5) Please explain how you apply the adiabatic boundary condition at the outer shell surface during blowdown when you are using the thermally thick structure model. The last sentence of the first paragraph of Section 7.6.5 implies that this is being done. If the thermally thick structure is used for the entire blowdown period, please provide an estimate of the non-conservatism introduced by this approximation.

Response

The text in Section 7.6.5 was revised in Reference 480.1005-1 to state that the shell is modeled with dry external heat transfer (not adiabatic) until the water appears below the second weir.

Reference

480.1005-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5429
RAI 480.1006

(Page 7-31) In Equation (152), it seems that (in Wulff's notation) g_1 and g_2 are taken as 1/2 when they should be 1/3.

Response

Equation (152) was corrected in Reference 480.1006-1. The values of gamma cancel out in the development of Equations 154 and 155, that are used to calculate pi values, so this error does not affect any pi values.

Reference

480.1006-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5430
RAI 480.1007

(Page 7-32, Section 7.6.5) Equation (153) is incorrect. The equation $d\bar{T}/dt = C_1 - C_2\bar{T}$ given in the line below Equation (153) is correct with C_1 and C_2 as defined in (155).

$\bar{T}(t_0) = \bar{T}_0$ is an initial condition for this ordinary differential equation, not a boundary condition. Please correct.

Response

Equation (153) was corrected in Reference 480.1007-1 and the initial condition was defined.

Reference

480.1007-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5431
RAI 480.1008

(Page 7-33, second paragraph) The wetted area below the second weir is given as 44662 ft^2. Actually, this is the total area below the second weir (52662 - 8000 = 44662). The 90 percent wetted area fraction has not been applied below the second weir. The maximum wetted area is also then incorrect. Is the shell area below the operating deck included in the total area? If so, please provide justification.

Response

The maximum wetted area below the second weir was corrected in Reference 480.1008-1 to be 0.9 x 44662 = 40196 ft^3. The calculations were revised consistent with this change. The shell heat transfer to the PCS is limited to the above-deck region.

Reference

480.1008-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5432
RAI 480.1009

(Page 7-33, second and third paragraphs) Why is 60 lbm/sec used for the flow rate in the second paragraph and 40 lbm/sec in the third paragraph?

60 lbm/sec is applied by the PCS, whereas the stability model (Reference 480.1009-1, Figure 7-11) shows that at 90% coverage, at the time of peak pressure, less than 20 lbm/sec runs off the shell. The difference is the 40 lbm/sec that evaporates. The flow that evaporates carries away most of the heat, but the full applied flow is important for subcooled heat capacity.

Reference

480.1009-1 A. Forgie, J. Narula, R. Ofstun, D. Paulsen, S. Slabaugh, M. Sredzienski, D. Spencer, J. Woodcock, "WGOTHIC Application to AP600", WCAP-14407, Westinghouse Electric Corporation.

OITS 5433
RAI 480.1010

(Page 7-35, Section 7.7, second paragraph) What is the magnitude of the Biot number for the baffle, and what h is used in the Biot number for this two-sided heat structure? Radiation heat transfer on the outside of the baffle is using the downcomer temperature as the sink temperature. Is it assumed that the shield building and downcomer temperatures are equal?

Response

The highest baffle Biot number for time phases after refill is:

$$h\delta/k = 11\ \text{B/hr-ft}^2\text{-F}\ 0.125\ \text{in}/(26\ \text{B/hr-ft-F}\ 12\ \text{in/ft}) = 0.0044$$

This Biot number was calculated using the maximum h on the baffle inside. The result of the calculation was added to the Reference 480.1010-1, Section 7.7 discussion.

It is assumed the shield building to downcomer heat transfer coefficient is very high, so any energy deposited in the shield building inner surface is transferred to the downcomer air with negligible temperature difference. The intent is to maximize the energy transfer to the downcomer air, and simultaneously, to maximize the negative buoyancy of the downcomer air.

Reference

480.1010-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5434
RAI 480.1011

(Page 7-36) Following Equation (158), it is stated that the downcomer operates in opposed mixed convection; however, Equation (158) lists a forced convection heat transfer coefficient for the baffle to the downcomer. Please explain.

Response

The text following Equation 158 was revised in Reference 480.1011-1 to state that both the riser and downcomer operate predominantly in forced convection, consistent with the results shown in Figure 4-1.

Reference

480.1011-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5435
RAI 480.1012

(Page 7-37) Equation (164) appears to be missing the term "+ $h_{m,ri,bf}$" in the numerator of the expression for "b." Please correct or explain.

Response

Equation (164) was truncated in printing. It was corrected in Reference 480.1012-1.

Reference

480.1012-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5436
RAI 480.1013

(Page 7-38, Section 7.7.4) In an earlier section, the notation "$\tilde{T}$" was used to represent average temperature. In Equation (166), it appears that this notation is now used to represent a/b. Also, is "T" in Equation (166) the same as T_{bl} in Equation (165)? Please clarify in the text.

Response

The character $\tilde{T}$ in Equation (166) confuses the discussion and was deleted in Reference 480.1013-1. Minor changes were made to the text to clarify the discussion.

Reference

480.1013-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5437
RAI 480.1014

(Page 7-38, Section 7.8) It would seem that the air in the downcomer could be heated by convection from the baffle and, in turn, heat the shield building wall by convection. Justify your conjecture that dry forced convection heat transfer is to the downcomer from the shield building wall.

Response

The downcomer air can transfer heat to the shield if the temperature difference is in the right direction. With heat transfer from the baffle to the shield, or from the downcomer to the shield the resulting downcomer air temperature will be less than calculated in the scaling analysis. For the scaling analysis it was assumed the radiation to the shield was deposited directly in the downcomer, which maximizes the downcomer temperature. Since the energy transfer rates are low enough that energy transfer rates are small, the effect on momentum is the important concern, so that concern was maximized.

OITS 5438
RAI 480.1015

(Pages 7-38 and 7-39) The description of the analysis in Section 7.9 must be improved. First, the terms need to be clearly defined; What is T_{ch}, the chimney concrete average temperature? Later in Section 7.9.4 it is stated that the chimney is treated as a thermally thick structure; so this lumped equation would not apply for the concrete? What is the difference between T_{ch} and $T_{ch,srf}$ and T_{srf}? Equation (167) indicates parallel mass transfer and convection plus series conduction across a film between two chimney temperatures T_{ch} and $T_{ch,srf}$? The π groups in Section 7.9.3, indicate energy transfer between several different temperatures, including $T_{f,ch}$ (which needs to be clearly defined). This carries over to Equation (172) where it is unclear as to what the temperature difference T_{ri} - $T_{f,ch}$ represents. Please explain and include a discussion of what variables are calculated and how they are used in the scaling analysis.

Response

Equations (167) and (168) were revised in Reference 480.1015-1 to correct errors. Additional text and definitions were added for clarity.

Summarizing the changes, four temperatures are defined and used:

- T_{ch} is the chimney gas temperature. The riser subscript, ri, in Equation (172) was corrected to ch for chimney gas.
- T_{cc} is the average chimney concrete temperature, used to calculate the rate of change of the chimney stored energy,
- $T_{ch,srf}$ is the chimney surface temperature that interacts with the average temperature, T_{cc}, by Wulff's equations for thermally thick structures, Equations (127), (128), and (129),
- $T_{f,ch}$ is the chimney liquid film surface temperature. This is the temperature that interacts with the chimney gas. Conduction through the film carries energy into the concrete from the gas.

Reference

480.1015-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5439
RAI 480.1016

(Page 8-1) In Table 8-1 state which heat structures are included for each phase; e.g. do they include above the operating deck plus circulating compartments? How does this compare to what is used in the WGOTHIC model?

Response

Section 3 of Reference 480.1016-1 was revised to define the basis for the heat sink volume and surface areas used for the LOCA and MSLB. The text in Section 8.1 was revised to refer the reader to Section 3.

Reference

480.1016-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5440
RAI 480.1017

(Page 8-2, Table 8-2) The anomalous value obtained for $\pi_{c,bf}$ for the long term phase is indicative of a problem in the approach used to combine conductances between different locations into a single conductance. The basic message is that conductances are only meaningful when combined in either series or parallel between the same locations. Other conductances calculated in the same manner as $\pi_{c,bf}$ include $\pi_{c,dsx}$ and $\pi_{c,esx}$. Provide values for all π groups (which were calculated using the above approach) leaving out the term with the temperature difference so that any additional anomalies can be identified.

Response

The detailed conductance calculations are presented in Westinghouse proprietary calculation note CN-CRA-96-120 that was reviewed by the NRC.

OITS 5441
RAI 480.1018

(Page 8-2, Table 8-2) Please provide a more detailed explanation of why the pool conductance is extremely low during refill compared to the other phases. The numerator of the pool conductance π group, $\pi_{c,p}$ is evaluated using Equation (105). The only parameters which could cause such a low value appear to be either DP_{stm} or Dr/r. For either DP_{stm} or Dr/r to have a low value, the partial pressure (or the density) of steam in the bulk containment would have to be very close to the value at the pool surface. What assumption is made which gives a low value when there is no break source?

Response

With no break source providing a saturated source of liquid, the pool surface is near thermal and pressure equilibrium with the atmosphere. Only the relatively slow rate of change of the gas temperature and pressure during the refill phase continue to cause some heat and mass transfer. However, the rate is much reduced as noted.

OITS 5442
RAI 480.1019

(Page 8-3, Section 8.2) The statement regarding external conductance on the evaporating shell at the time of peak containment pressure seems to refer to the values of conductances during the long term phase. This is confusing since there is also a peak pressure phase. Please clarify the discussion.

Response

The text was revised in Reference 480.1019-1 to replace the confusing reference to the time of peak containment pressure with the long term phase.

Reference

480.1019-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5443
RAI 480.1020

In the tables presented in Section 8, it is stated that a shaded entry indicates a value greater than 10 percent. Please verify the values. For example, $\pi_{m,st}$ in Table 8 3 and $\pi_{p,work,st}$ in Table 8.5, under "Long Term" are -0.02.

Response

The shadings were deleted in Reference 480.1020-1.

Reference

480.1020-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5444
RAI 480.1021

(Page 9-6) The first paragraph indicates that a simultaneous solution was obtained for eight named variables. Presumably the eight governing equations are the 3 mass conservation equations (173), the three energy conservation equations (175), the momentum equation (176) and the buoyancy equation (179). However, π groups are given in Table 9-1 only for the momentum equation (with a time constant from one of the mass conservation equations), indicating that perhaps a more simplified procedure was used. Please explain in more detail why only one equation is needed to scale the PCS air flow. Also, due to the coupling of the buoyancy pressure drop to the heat transfer, one would expect an iterative solution to be necessary. Was iteration required in the approach used?

Response

An iterative solution was required. The buoyant air flow rate results from equating the buoyant forces and drag forces in the air flow path. The buoyancy results from the density-elevation distribution through the air flow path and is affected by heat and mass transfer between the air flow path and the baffle, dry shell, evaporating shell, and chimney. The mass and energy fluxes are not strongly coupled to the air flow rate, so the iteration was simple and converged rapidly.

OITS 5445
RAI 480.1022

(Page 9-9, Table 9-1) Please explain why the buoyancy and friction π group values are not equal for the peak pressure and long term phases. According to the statement in the second paragraph of Section 9.3.1, the reference mass flow rate comes from the reference buoyancy term and the reference buoyancy is the steady-state solution of the momentum equation. This statement implies that the π group values should be the same.

Response

The coupled, iterative solution for the PCS air flow was solved as described in the response to RAI 480.1021, using dimensional equations. The solution increased the PCS air flow by the evaporated (or condensed) steam and used the net (air plus steam) flow to calculate the density and resistance pressure drop in each of the downcomer, riser, and chimney flow paths. The dimensionless resistance pi group, in contrast, is defined only in terms of the air flow rate (not including the steam flow rates), so gives a low value of scaled resistance when the steam flow rates are significant. Steam flow rates are significant during the peak pressure and long term time phases, hence the resistance pi values less than 1.0 for these time phases.

OITS 5446
RAI 480.1023

(Page 10-7, Section 10.1.2) The text describing Figure 10-2 refers to LST data while the figure refers to the STC Flat Plate Test. Which is correct?

Response

The text in Reference 480.1023-1 was revised to state the Westinghouse flat plate data are used in Figure 10-2, not LST data.

Reference

480.1023-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5447
RAI 480.1024

(Page 10-11, middle paragraph) The Reynolds number at the time of peak containment pressure, 163,000 from Table 9-1, is for the long term phase rather than the peak pressure phase. Please clarify the discussion so that there is no ambiguity as to what number was intended to be used.

Response

The text was changed in Reference 480.1024-1 to clarify the time phase reference to Table 9-1.

Reference

480.1024-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5448
RAI 480.1025

(Page 10-12, Section 10.1.6) Several terms in Equation (196) have not been defined, or as is the case for σ, are defined in the nomenclature differently than used here. Either here or in the nomenclature all terms should be unambiguously defined.

Response

All terms in Equations (196) were defined in Nomenclature in Reference 480.1025-1.

Reference

480.1025-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5449
RAI 480.1026

(Page 10-13, Table 10-7) The film Reynolds number for the AP600 upper sidewall given in Table 10-3 is more than a factor of 2 greater than the highest value for either the LST or the water distribution test. An even higher value of 4,000 is given as the upper range for AP600 in Figure 10-3. Justify your statement that the range of AP600 operation is adequately covered by the test data.

Response:

The Chun and Seban (Reference 480.1026-1) and Kutateladze, et.,al. (Reference 480.1026-2) test data show as the water Reynolds number increases above 4000 the Nusselt number also increases. Since the Nusselt number increases with Reynolds number, the film heat transfer coefficient also increases. Consequently, higher Reynolds numbers are not a concern. See also the response to RAI 480.1027.

References

480.1026-1 K. R. Chun and R. A. Seban, "Heat Transfer to Evaporating Liquid Films," *Journal of Heat Transfer*, November 1971.

480.1026-2 S. S. Kutateladze, I. I. Gogonin, N. I. Grigor'eva, A. R. Dorokhov, "Determination of Heat Transfer Coefficient with Film Condensation of Stationary Vapor on a Vertical Surface", *Thermal Engineering*, **27** (4), 1980.

OITS 5450
RAI 480.1027

(Page 10-13, Section 10.1.7) How does the film thickness in the Wisconsin and Chun and Seban data compare to the 0.005-inch thick liquid film assumed in the scaling model?

Response

Most experimenters do not attempt to measure the thickness of the wavy laminar or turbulent films that occur over the range of Reynolds numbers characteristic of AP600 films. It is easier and more useful to measure, or infer from other measurements, the film heat transfer coefficient. The film heat transfer coefficient was determined by Chun and Seban (Reference 480.1027-1), and by Westinghouse with the Wisconsin data (Reference 480.1027-2). Since the characteristic length used for film analysis is the property $(v^2/g)^{1/3}$, knowing the actual, time varying film thickness is unnecessary. However, given a heat transfer coefficient, an "effective" film thickness can easily be calculated from the simple relationship $\delta = k/h$. For water and a typical h of 900 B/hr-ft^2-F, δ = 0.005 in.

The heat transfer coefficients on the outside of AP600 can be ranged by considering the maximum value of Γ at the spring line, assuming 60 lbm/sec and 90% coverage, Γ = 0.163 lbm/ft-sec, Re = 2600, so h is approximately 700 B/hr-ft^2-F. At the bottom of the side wall, assuming the maximum evaporation rate of 40 lbm/sec, 20 lbm/sec runs off, so Γ = 0.054 lbm/ft-sec, Re = 867, and h is approximately 944 B/hr-ft^2-F. Thus, on the outside of AP600 h ranges from 700 to 944 with an average of 822 B/hr-ft^2-F. The corresponding "effective film thickness" is 0.0055 in.

Inside the AP600 containment shell the film flow will range from 0 at the top to approximately 40 lbm/sec at the bottom, since the net condensation is approximately equal to the net evaporation. Consequently, the heat transfer coefficient inside will have a higher average value than on the outside, with a thinner effective film thickness.

The Chun and Seban data cover a Reynolds number range of 300 to 20,000. The Wisconsin data extend the range down to 30. Consequently, the data cover the expected range of AP600 Reynolds numbers and Nusselt numbers (and also "effective film thicknesses" if one cares to calculate them). The above calculations also support the use of an effective film thickness of 0.005 in.

Kutateladze (Reference 480.1027-3) presents Nusselt number measurements for refrigerant-12 (Prandtl number approximately 4) over a Reynolds number range of 10 to 2000 that show similar trend but higher minimum Nusselt number than the Chun and Seban data.

Mudawar (References 480.1027-4 and 480.1027-5) measured the thickness of wavy-laminar propylene glycol/water mixtures and of turbulent water films. Their measured film thicknesses could be compared to the Nusselt smooth laminar film thickness, or to the effective film thickness.

References

480.1027-1 K. R. Chun and R. A. Seban, "Heat Transfer to Evaporating Liquid Films," *Journal of Heat Transfer*, November 1971.

480.1027-2 WCAP-13307, "Condensation in the Presence of a Noncondensable Gas-Experimental Investigation," Westinghouse Electric Corporation.

480.1027-3 S. S. Kutateladze, I. I. Gogonin, N. I. Grigor'eva, A. R. Dorokhov, "Determination of Heat Transfer Coefficient with Film Condensation of Stationary Vapor on a Vertical Surface", *Thermal Engineering*
, **27** (4), 1980.

480.1027-4 I. Mudawar and R. A. Houpt, "Measurement of Mass and Momentum Transport in Wavy-Laminar Falling Liquid Films", *International Journal of Heat and Mass Transfer*, Vol. 36, No. 17, pp 4151-4162, 1993.

480.1027-5 J. A. Shmerler and I. Mudawar, "Local Evaporative Heat Transfer Coefficients in Turbulent Free-Falling Liquid Films", *International Journal of Heat and Mass Transfer*, Vol. 31, No. 4, pp 731-742, 1988.

OITS 5451
RAI 480.1028

(Page 10-16) In Figure 10-4, clarify the location labeled "above." Is this all heat sinks above the operating deck? Also, please explain the very rapid heat absorption in the core makeup tank (CMT) room and add a curve showing heat rejection to the annulus.

Response

In Figure 10-4 the location labelled "Above" includes all the above-deck heat sinks, except the shell.

The CMT room contains more than half of all internal heat sinks. During blowdown the rapid pressurization of the steam generator compartment forces steam directly into the adjacent compartments, including the CMT room. The resulting steam-rich mixture lasts 27 seconds and produces heat transfer rates significantly greater than calculated in the well-mixed scaling analysis, hence the apparent time constant on the order of 20 seconds.

The purpose of Figure 10-4 is to show energy removal rates from the containment atmosphere corresponding to different regions. The energy rejection to the riser does not represent energy removal from the containment gas, so is not shown. However, according to the pi groups, by 1500 sec. the energy out of the shell is equal to the energy into the shell.

OITS 5452
RAI 480.1029

(Page 10-17, Section 10.2.1.1) In order to obtain the information for comparison of the π groups inside containment, it was necessary to calculate the state outside the vessel as noted on the bottom of Page 10-17. The scaling of evaporative cooling on the outside of containment is also a high ranked phenomena to which the LST scaling should be applicable, with the buoyancy pressure drop replaced by the forced flow pressure drop. Include an evaluation of the mass and energy π values for the LST air flow path outside containment.

Response

The last three rows of Table 10-3 represent the normalized values of sensible heat transfer from the shell to the riser, $\pi_{e,q,nsx}$, heat transfer from the shell to the subcooled water, $\pi_{e,q,ssx}$, and evaporation heat transfer from the film to the riser, $\pi_{e,fg,esx}$. These three pi groups are the significant energy transfer groups outside containment.

OITS 5453
RAI 480.1030

(Page 10-18, Section 10.2.1.2) The transient validation of the dP/dT equation is useful to the extent that it shows that the gas compressibility for air is being treated correctly in the scaling equations. The validation against LST steady-state test data in Section 10.2.1.1 shows that the scaling handles the inside containment shell heat transfer in a reasonable way. Ideally, the scaling equations should be integrated and compared to transient scaled test data to validate the entire model. In the case of AP600, such transient test data do not exist. In lieu of this, the staff has previously suggested that Westinghouse integrate the scaling equations for AP600 (as was done in WCAP-14190) to show that reasonable results are obtained. Given that the scaling equations predict a negative rate of pressure change for refill and beyond, as shown in Section 10.0, one need not integrate the scaling equations to conclude that the results will not compare well to WGOTHIC predictions. Westinghouse cites conservatisms in the WGOTHIC model (for example, use of Uchida and biases in shell heat and mass transfer models) as the suspected cause for the differences between the scaling model results and computer code best estimate predictions. Nevertheless, such significant differences raise concerns regarding the value of the scaling study as an indicator of the magnitude and importance of individual processes. In particular, have any of the phenomena been modeled non-conservatively in the scaling analysis?

The rate of pressure change scaling result is counterintuitive. From the π values in Table 10-5, the rate of pressure change at the start of the peak pressure phase is barely increasing, even when heat transfer to the shell is ignored. Neglecting the shell, the total π value on the right side of the equation is 1.03 - 1.02 = 0.01. When the shell is ignored, the AP-600 is similar to an existing plant (with no containment wall heat sink). Intuitively, based upon present plant containment analyses and testing, one would not expect the pressure to increase only during the relatively short blowdown period, and remain essentially constant immediately thereafter, especially when the containment wall heat sink is ignored. For the present generation of large dry containments, analyses show that the pressure turns around only when the sprays are activated. It is difficult to accept that the structural heat sinks alone, with the entire shell ignored, are sufficient to essentially stop the pressure increase.

Westinghouse should convincingly demonstrate that the scaling analysis does not model the heat sinks in a non conservative fashion.

Response

The results presented in Section 10 of Reference 480.1030-1 were revised and are presented in a new Section 8.6 of Reference 480.1030-2. The revised results compare predictions of the scaling model and a comparable WGOTHIC case, Case 6 of Reference 480.1030-3, Chapter 5. The comparisons show the two models predict similar trends, and similar rates of pressure change.

References

480.1030-1 D. R. Spencer, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 0, Westinghouse Electric Corporation.

480.1030-2 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

480.1030-3 A. Forgie, J. Narula, R. Ofstun, D. Paulsen, S. Slabaugh, M. Sredzienski, D. Spencer, J. Woodcock, "WGOTHIC Application to AP600", WCAP-14407, Westinghouse Electric Corporation.

OITS 5454
RAI 480.1031

(Page 10-21) What is the difference between the π values given in Table 10-10 for AP600 and those given in Table 10-4? Following the convention established in the earlier sections, the last 6 rows of π values in Table 10-10 would generally be negative. To what value does the footnote in Table 10-10 apply?

Response

The pi values presented in Table 10-10 of Reference 480.1031-1 were calculated according to the same definitions as those in Table 10-4. The difference is that the values in Table 10-10 are for a steady state, and at a different containment pressure than the values in Table 10-4.

The last 6 rows of pi values all represent energy transfer out, or negative values following the convention. However, for simplicity, they are presented without the negative sign in Reference 480.1031-2, Table 10-3.

The footnotes in Table 10-3, Reference 480.1031-2, were revised.

Reference

480.1031-1 D. R. Spencer, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 0, Westinghouse Electric Corporation.

480.1031-2 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5455
RAI 480.1032

(Page 11-1) Please provide a definition of distortion. This is essential in order to clarify how the evaluations in the third column of Table 11-1 were developed.

Response

A definition for distortion was added to the beginning of Section 11 in Reference 480.1032-1. The third column of Table 11-1 was deleted and distortion was instead discussed for each difference in the text.

Reference

480.1032-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5456
RAI 480.1033

(Page 11-2) One potential distortion not addressed is the non-prototypical scaled thickness of the shell. This item should also be addressed.

Response

The shell thickness was added as a difference and evaluated in Section 11.1 of Reference 480.1033-1

References

480.1031-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5457
RAI 480.1034

(Page 11-4) The LST feature "External Water Flow too High" is evaluated from the viewpoint that a range covering AP600, from no flow to very high flow was tested. The aspect that is not addressed is the larger amount of heat removed by the subcooled liquid in LST. This difference should also be addressed.

Response

The discussion of "External Water Flow too High" in Reference 480.1034-1 was revised to include the following points:

- The energy and pressure scaling pi groups for the subcooled shell presented in Reference 480.1034-1, Tables 8-4, 8-5, and 10-3 all show subcooled heat transfer effects are second-order phenomena. Consequently any distortions in the test are not significant to the system response.

- The results of scaling test 213.1C presented in Table 10-3 show the measured value of $\pi_{e,Q,ssx}$ is less than the calculated value for AP600. Consequently, the concern over the "larger amount of heat removed by the subcooled liquid in LST" is not valid.

Note that in Reference 480.1034-1, the text reference to Figure 10-10 should be to Figure 10-3.

Reference

480.1034-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5458
RAI 480.1035

(Page 11-5) Under "External water flow oscillations," it is stated that the data were evaluated using both the maximum and minimum flow rates. The evaluation does not appear to be in this scaling report. A reference to the evaluation needs to be included.

A reference to the WGOTHIC Application report, (Reference 480.1035-1) Appendix 7.A was added to the discussion of flow oscillations in Reference 480.1035-2

Reference

480.1035-1 A. Forgie, J. Narula, R. Ofstun, D. Paulsen, S. Slabaugh, M. Sredzienski, D. Spencer, J. Woodcock, "WGOTHIC Application to AP600", WCAP-14407, Westinghouse Electric Corporation.

480.1035-2 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5459
RAI 480.1036

(Page 12-1) The bullet under Item 1 refers to a non-existent Table 8-6. Please correct the reference. Also, considerable quantitative information has been developed which should be used for closure with the PIRT. The cursory statement in Item 2 should be expanded to discuss π values for the high and medium ranked PIRT phenomena.

Response

The conclusions were extensively revised in Reference 480.1036-1, Section 12.
The reference to Table 8-6 was corrected.

The PIRT-scaling closure is covered in the PIRT (Reference 480.1036-2).

References

480.1036-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

480.1036-2 M. Loftus, D. Spencer, J. Woodcock, "Accident Specification and Phenomena Evaluation for AP600 Passive Containment Cooling System", WCAP-14812, Rev. 1, Westinghouse Electric Corporation.

OITS 5252
RAI 480.1017

The report must be organized in a scrutable manner and the pertinent information must be clearly and unambiguously presented. In each section the premise on which the analysis is based needs to be stated and followed through in a logical manner to the conclusion. In its present form, the report is disjointed and lacks focus. Westinghouse should clearly state: (1) the purpose of each section, and (2) how the material supports the conclusions of the work. The key item is the pressure rate of change equation. Westinghouse must provide this equation in its final form, together with the π groups, in a single location.

Response

The revised scaling report, Reference 480.1017-1, is separated into three major parts: Part I - Executive Summary, Part II - PIRT Confirmation, and Part III - Separate Effects and Integral Test Scaling. In addition, each major section starts with a paragraph that explains the goal of the work in the section.

The system-level pressure rate of change used for scaling the LST is presented in Section 10.2 with each pi group clearly defined.

Reference

480.1017-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5253
RAI 480.1018

There are three related, and critical, items which must be addressed in order to establish that the Westinghouse approach is applicable at the scale of the AP600.

1. The Westinghouse scaling approach does not address the issue that the heat flux in the large scale test (LST) facility is too high and that the rate of pressure drop is too high by a factor of eight when compared to the AP600. The issue is that Westinghouse did not divide through by the coefficient on the dP/dt term (e.g., Equation (7) on Page xvii of WCAP-14845) in the pressure rate of change equation. The key variable of concern, in simple terms, is hA/V, where h is the heat transfer coefficient, A is the surface area for heat transfer and V is the containment volume. The governing equations show that this heat flux (Q = hA) to volume ratio is the key quantity that must be preserved, similar to the "power-to-volume" ratio that is used to scale primary system experimental facilities. With the 1/8 linear scaling of the LST, $(hA/V)_{LST} = 8 (hA/V)_{AP600}$. Thus this key top level scaling criteria is not met. This needs to be addressed as a major distortion of the LST, and the scaling analysis needs to be revised to include this item in the correct manner.

   The distortion caused by the difference in hA/V (or Q/V) between the AP600 and the LST is operative in the steady-state and the transient mode. The scaling approach can either divide through by this term, which appears on the left side of the pressure rate of change equation, or the scaling approach can define a dimensionless time and incorporate the term into the rate of change. This is what is done in the Westinghouse analysis. The scaling is then such that dimensionless time proceeds eight times faster in the LST than in the AP600, or looked at it in another way, the heat removal rate per unit volume is eight times higher. It cannot be argued that the LST is steady-state and therefore that time is irrelevant. Even in the steady-state the mixing, diffusion and condensation processes inside the containment volume and at the shell surface are rate dependent. Data from larger scale facilities is likely to be needed to address this distortion.

2. Scaling of mixing (circulation) and thermal stratification must be addressed. Data from international test programs, to supplement the LST data, will likely be needed to establish the applicability of the evaluation model at the AP600 scale. Data from HDR, Grenoble, and Japanese tests were identified as potentially being applicable to address this concern.

3. The distribution of noncondensibles is a function of scale. Westinghouse must establish the scaling for the distribution of noncondensibles as they affect condensation heat transfer. Data from HDR, Grenoble, and Japanese tests were also identified as potentially being applicable to address this concern.

Response

1. The Westinghouse LST scaling presented in Reference 480.1018-1, Section 10.2 develops pi groups, each of which represents the ratio of a specific, normalized transport process in the LST to the same process in AP600. The pi groups show the power-to-volume ratio in the LST divided by the power-to-volume ratio in AP600 is important, as is the power-to-area ratio in the LST divided by the power-to-area ratio in AP600 . The magnitude of this ratio was evaluated and the deviation from perfect scaling are discussed.

2,3. Westinghouse recognizes that the evaluation model can not predict the thermal, velocity, and air/steam density fields observed in the LST. Neither is the evaluation model expected to correctly predict the thermal, velocity, and air/steam density fields within AP600 containment. Furthermore, because of non-prototypic features of the LST, the fields observed in the LST are not believed to represent fields in AP600. Westinghouse does not believe it useful to attempt to substantiate WGOTHIC evaluation model predictions of thermal, velocity, and concentration fields inside containment, using either the LST or International tests.

Rather, Westinghouse is pursuing a bounding approach to predict the transport rates that depend on field properties inside containment. In the bounding approach, the transport rates are calculated using models that are biased so as to maximize containment pressure. Rather than attempting to justify the fields predicted by the evaluation model, the LST internal field data are considered with results from both smaller scale and larger scale (international tests) to develop methods for bounding the effects of circulation and stratification. In addition, sensitivities are performed to a range of postulated circulation patterns and a limiting scenario for containment pressure calculations is defined in Reference 480.1018-1.

The pressure rate of change equation shows the pressure in AP600 results from the difference between the heat and mass inputs and the heat and mass outflows. A conservatively predicted pressure occurs if the following are satisfied:

- The gas volume is minimized,
- The heat and mass flow rates in are upper bounded, and
- The heat and mass flow rates out are lower bounded.

The Westinghouse evaluation model does these three, thus the model predicts conservatively high pressure. At every time step throughout the transient these are satisfied.

Reference

480.1018-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5254
RAI 480.1019

Westinghouse has included drops dispersed into the containment atmosphere during blowdown as a heat sink or heat source in the scaling equations. In the study, the drops are assumed to remain in the atmosphere for all of the double ended cold leg guillotine loss-of-coolant-accident (DECLG LOCA) phases. This is non physical. The surface area used for the drops is an arbitrary number. While Westinghouse has argued that the scaling analysis shows that the drops do not have a significant effect, it is recommended that the drops not be included. A thermodynamic equilibrium model is suggested as being more appropriate, as a simpler and acceptable approach. At a minimum, a better discussion of why drops were considered and what conclusions can be drawn from their consideration needs to be provided at the beginning of the section.

Response

The discussion of drops presented in Section 7.1, Reference 480.1019-1 notes that the drop analysis concludes that equilibrium between the drops and the containment atmosphere is the expected result, and is modeled as such during all time phases. The result shows drops have only a minor effect on containment pressurization.

The discussion of the break liquid and pool in Section 7.2, Reference 480.1019-1, notes that equilibrium between the liquid and containment atmosphere is the expected result for blowdown, and is modeled as such during blowdown. After blowdown, a rate-limited maximum evaporation rate is calculated. The calculations show the pool has only a minor effect on containment pressurization, both during and after blowdown.

Reference

480.1019-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5255
RAI 480.1020

Section 11, on the identification and evaluation of distortions, needs to be supplemented with information which indicates how the distortions are handled when using the LST data to validate the evaluation model. This may include pointers to the PIRT (WCAP-14812) and application (WCAP-14407) reports, as appropriate.

Response

Section 11 was revised extensively in Reference 480.1020-1 to better address distortions and how they are handled in the evaluation model validation.

Reference

480.1020-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.

OITS 5256
RAI 480.1021

The "Conclusions" section of the report, Section 12, must directly and concisely state how Westinghouse uses the results of the scaling work. In particular,

1. Explain what use is made of the LST data for the WGOTHIC computer program validation and how does the scaling study support this usage;

2. Explain how the scaling study used to support the PIRT evaluation· and

3. Explain how the scaling study used to support the use of the various models and correlations in WGOTHIC at the scale of AP600.

Response

The use of the scaling study to support the use of the LST data for the WGOTHIC computer program validation, the WGOTHIC models and correlations, and the PIRT evaluation are discussed in the conclusion, Reference 480.1021-1, Section 12.

Reference

480.1021-1 D. Spencer, W. Brown, M. Roidt, J. Woodcock, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents", WCAP-14845, Rev. 2, Westinghouse Electric Corporation.