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Docket No.: STN-52-003

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U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

ATTENTION: T. R. QUAY

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

Dear Mr. Quay:

Enclosed are three copies of the Westinghouse responses to NRC requests for additional information on the AP600 topics. Revised responses to RAIs on the WGOTHIC computer code are included in this transmittal. These RAI's have been revised to indicate Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the NRC questions. The change in the evaluation model addressed the staff's previous concern. The RAIs are listed in the Attachment.

The NRC technical staff should review these responses as a part of their review of the AP600 design.

Please contact Brian A. McIntyre on (412) 374-4334 if you have any questions concerning this transmittal.

Brian A. McIntyre, Manager
Advanced Plant Safety and Licensing

/nja

Attachment
Enclosures

cc: T. Kenyon, NRC (w/o enclosures)
D. Jackson, NRC (1E1)
E. Throm, NRC (w/o enclosures)
J. Kudrick, NRC (w/o enclosures)
P. Boehnert, ACRS (4E1)
N. Liparulo, Westinghouse (w/o attachments and enclosures)

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Add: T. R. Quay

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ATTACHMENT TO NSD-NRC-96-4751

WGOTHIC RAI's REVISED

480.279	480.306
480.281	480.308
480.282	480.309
480.283	480.310
480.284	480.311
480.288	480.312
480.295	480.313
480.296	480.317
480.297	480.318
480.298	480.352
480.301	480.363
480.303	480.364
480.305	480.373
	480.374

Question 480.279

Re: WGOTHIC MODELS AND PHENOMENA
Integral results alone may not constitute an adequate test of model validation; compensating effects can yield reasonable integral result comparisons even when important phenomena are not well represented, and there is no guarantee that compensation occurring in LST analyses will necessarily occur in AP600 analyses. For example, the fact that the mixed correlation gives better agreement with the experimental pressure than the free correlation does not prove that the mixed correlation is more correct; there are many possible reasons why the free-convection calculation may be overpredicting the pressures and the mixed convection calculation may be introducing a compensating error. How is WEC using the LST data to establish the validity of individual models such as the models for heat transfer, evaporation and condensation, and flow velocities? WEC should examine the performance of individual models at a greater level of detail, rather than relying entirely on integral results.

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

Westinghouse has used local heat and mass transfer data from the LST and other separate effects tests to validate the heat and mass transfer correlations used in the AP600 evaluation model. The dependence of these correlations on the dominant independent parameters, such as concentration and velocity, have been tested and validated to show that agreement is not due to competing effects.

An overview of the test and analysis program has been provided (Reference 480.279-1, Sections 3 and 4). Individual models for heat and mass transfer, used to predict evaporation and condensation, are validated as follows. Convective heat transfer and evaporation in the annulus is validated in Reference 480.279-2, Sections 3.1 through 3.6, 4.1, and 4.2. The external air annulus has been shown to operate in turbulent, forced convection once the containment shell-to-ambient temperature difference exceeds 2°F (Reference 480.279-2), consistent with the validation database. The LST has been used to validate evaporation predictions by comparing the measured total evaporation rate to WGOTHIC predictions in Reference 480.279-1, Section 8.1 and 8.2.

The condensation correlation is validated in Reference 480.279-2, Section 3.8 using separate effects data. Condensation is also validated using local data inside the integral Large Scale Test vessel in Reference 480.279-3, Section 3.9. To bound the effects of velocity on internal condensation rates in the AP600 PCS evaluation model, condensation is assumed to be by free convection only. This is implemented for the internal PCS surface by setting the forced convection component of the climes to essentially zero, and for the internal structure heat sinks by using the Uchida free convection correlation. Thus, the LST has been used to support the validity of models by examining local data and has also provided input to a bounding evaluation model.

References

480.279-1 WCAP-14382, "WGOTHIC Code Description and Validation"

480.279-2. WCAP-14326, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations"

480.279-3 NTD-NRC-95-4397, "Supporting Information for the Use of Forced Convection in the AP600 PCS Annulus," February 16, 1995

SSAR Revision: NONE

Question 480.281

Re: WGOTHIC MODELS AND PHENOMENA
What would be the effect of these velocity differences on the behavior of the heat transfer model and on the predicted pressures? The forced component is important to the calculation, and is dependent on the velocities used in the correlation.

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

The forced convection enhancement of in-containment heat and mass transfer due to velocity effects is neglected (see response to RAI 480.279). Consequently heat and mass transfer is bounded and pressure will be overpredicted in the AP600 PCS DBA evaluation model throughout the LOCA and steamline break transients. Therefore, the evaluation model results are not dependent on the predicted flow velocities.

SSAR Revision: NONE

Question 480.282

Re: WGOTHIC MODELS AND PHENOMENA (Lumped Parameter Model)
Why are the pressure results in better agreement with the experiment when WGOTHIC uses a mixed convective correlation with velocities that disagree with experimental measurements?

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

The test comparisons under discussion address the lumped parameter model only and were presented in November 1994 and show that velocity is overpredicted and steam concentration is underpredicted in the lumped parameter model (Reference 480.282-1). Velocity and concentration are the two dominant parameters in the mass transfer correlation. Sufficient instrumentation has been used in the LST to identify and quantify the competing effects.

The competing effects in the lumped parameter model results cited in the question have been quantified as follows. The use of measured velocities, rather than the higher, code calculated velocities, in the mixed convection correlation decreases the average predicted shell heat flux by about 15%. The lumped parameter model overmixes non-condensibles from below the steam jet/plume, and the non-condensibles above the operating deck lead to underpredicted steam concentrations which penalize PCS heat removal. Use of the measured steam concentration instead of code calculated concentrations is estimated to increase the average shell heat flux by 18%. It can be concluded that heat flux is overpredicted by 15% due to velocity and underpredicted by 18% due to concentration. It is clear that these are compensating errors of about the same magnitude in the lumped parameter code calculation. In this case the overpredicted velocity used with mixed convection compensated for the underpredicted steam concentration to give nearly correct pressures. When free convection was used in the WGOTHIC calculation, the steam concentration was still underpredicted with no compensation, so the pressure was overpredicted.

These results have been factored into the lumped parameter evaluation model. The use of free convection in the lumped parameter evaluation model eliminates the effects of calculated velocities and results in a conservatively well-mixed containment at 24 hours.

Please also see the response to RAI 480.283 for discussion of free versus mixed convection when measured velocities are considered.

Reference

480.282-1 WCAP-14382, "WGOTHIC Code Description and Validation," May 1995

SSAR Revision: NONE

Question 480.283

Re: WGOTHIC MODELS AND PHENOMENA (Lumped Parameter Model)
Why are the pressure results in better agreement when WGOTHIC uses a mixed convective correlation rather than a free convective correlation, when the experimentally measured velocities indicate that the free convection correlation should have been more nearly correct?

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

The question relates to lumped parameter calculations. An explanation of why the lumped parameter model results are in better agreement with vessel pressure when mixed convection is used follows.

Sufficient instrumentation was incorporated in the LST to be able to identify and quantify the potential for competing errors. Therefore, data has been used to show that free convection is the appropriate correlation for the inner shell, independent of WGOTHIC calculations (Reference 480.283-1).

Calculations show that the use of the measured test velocity in the mixed convection correlation would give results the same as using the free convection correlation only, confirming that the internal condensation is dominated by free convection for the velocities measured in the test. The lumped parameter model pressure results are in better agreement with the tests when mixed convection is used because the high predicted velocities used in the correlation offset the underpredicted steam concentration, as discussed in the response to RAI 480.282. These results have been used to develop the lumped parameter evaluation model used to address the 24 hour pressure reduction criterion.

Reference

480.283-1 WCAP-14326, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," March 1995, Section 3.9

SSAR Revision: NONE

Question 480.284

Re: WGOTHIC MODELS AND PHENOMENA
If the experimentally measured velocities are inaccurate or do not correspond well to the velocities used in the WGOTHIC correlations, how will the velocities calculated by the code and used in its correlations be validated?

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

Please see the Westinghouse response to RAI 480.279 for a discussion of how the effects of velocity on heat and mass transfer calculations are bounded. The velocities are not used in determining heat and mass transfer rates internal to containment since free convection is assumed in the evaluation model.

The validity of using a bulk flow velocity average value from the node nearest the wall is shown using the detailed distributed parameter model (Reference 480.284-1) which gave good agreement with measured vessel pressure and velocity instrumentation.

Reference

480.284-1 WCAP-14382, "WGOTHIC Code Description and Validation," May 1995, Appendix A

SSAR Revision: NONE

Question 480.288

Re: WGOTHIC MODELS AND PHENOMENA
In the WGOTHIC approach the forced flow Nusselt number will be higher on the dome than on the walls. However, the effect of subcooling on the dome is much greater for LST than AP600, and a higher heat transfer coefficient for the dome may therefore have different effects for LST analysis than for AP600 analysis. How does this affect code validation for AP600 applications?

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

The forced flow Nusselt number is higher on the dome where the plume flow turns and begins to flow down. This is due to the inverse proportionality to the length parameter in the forced convection flat plate correlation. This approach has been shown to predict LST data (Reference 480.288-1, Appendix A) using a detailed distributed parameter model. The model explicitly accounts for the combined effects of forced flow Nusselt number and subcooling on the dome and shows that important phenomena have been identified and modeled.

The Westinghouse response to RAI 480.279 contains a summary of the validation bases for the bounding evaluation model heat and mass transfer calculations. Free convection dominated mass transfer coefficients measured in the LST agree very well with predictions for both the dome and sidewall. Comparisons also have shown that free convection increasingly underpredicts data from LST tests with higher forced convection components. The use of free convection is conservative for all times and for both the dome and sidewall.

References

480.288-1 WCAP-14382, "WGOTHIC Code Description and Validation"

480.288-2 NTD-NRC-95-4545, "AP600 PCS Design Basis Accident Roadmaps," August 31, 1995

SSAR Revision: NONE

Question 480.295

Re: WGOTHIC MODELS AND PHENOMENA
It can be argued that the use of a free convective velocity in a forced flow correlation can leads to a significant spurious enhancement of heat transfer on the shell interior. Given this, explain why the WGOTHIC approach and results are valid for a free convection problem?

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

The question that has been posed is irrelevant to AP600 DBA because the evaluation model assumes only free convection. The Westinghouse PCS evaluation model bounds the uncertainty in velocity calculations by using only free convection heat and mass transfer on the inner PCS surface for both the LOCA and main steamline break (MSLB) transients. This eliminates any concern regarding "spurious velocities." Internal structures are modelled as heat sinks using the Uchida free convection correlation with revaporization. Limiting heat and mass transfer to that predicted with free convection correlations is conservative. The internal containment heat and mass transfer regime is mixed convection because of the injected steam plume combined with convective cooling at the shell. For times after blowdown in a LOCA, the forced convection contribution to heat and mass transfer is small and heat removal can be approximated using free convection. Results of correlation comparisons to local condensation data from the Large Scale PCS Tests (LSTs) with Froude numbers typical of a LOCA show that the free convection correlation chosen is appropriate for those conditions (Reference 480.295-1).

For an MSLB and for LOCA blowdown, an examination of AP600 Froude numbers shows that the jet has near sonic velocities and therefore is highly kinetic. Thus, it is believed that forced convection strongly contributes to mass transfer in those transients. Large Scale Tests with Froude numbers more typical of an MSLB show that the condensation mass transfer is considerably underpredicted, leading to overpredicting the pressure response, when the free convection correlation is compared to local condensation data.

Therefore, the use of free convection correlations for the AP600 LOCA and MSLB bounds the effects of forced convection.

References

480.295-1 WCAP-14326, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," March, 1995, Section 3.9.

SSAR Revision: NONE

Question 480.296

Re: WGOTHIC MODELS AND PHENOMENA
Given that the flows in the LST and AP600 are considerably more complex than in a simple free convective problem, can WEC show that any spurious enhancement to heat transfer caused by the use of a free convective velocity in a forced flow correlation is small?

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

Please see the Westinghouse response to RAI 480.295 for a discussion of why there is no spurious enhancement of heat transfer using the WGOTHIC mixed convection approach. The use of the free convection correlation on the inner PCS surface for the AP600 LOCA and MSLB eliminates any concern for spurious enhancement to heat transfer which has been postulated to occur when using a free convective velocity in a forced flow correlation.

A quantification of mixed convection correlation values at low velocities shows there is no significant enhancement to heat transfer when bulk flow velocities resulting from forced convection components are used in a free convection dominated regime. In AP600, at 51 psia, h_{free}= 2.2 Btu/hr-ft^2-°F. The ratio h_{mixed}/h_{free} can be used to assess the effect of velocity in the mixed convection correlation relative to the value obtained by the free convection correlation. The effect can be said to be small if $h_{mixed}/h_{free} \leq 1.10$. For a given velocity, the length over which mixed convection would predict heat transfer greater than free convection can be determined. For a velocity of 4 ft/sec or less, the length over which mixed convection effects are greater than 10% is 28 feet, corresponding to only 4.5% of the PCS shell surface. Therefore, mixed convection predicts approximately the same heat transfer as free convection over more than 95% of the inner PCS surface. For lower velocities expected in the postulated "startup flow" scenario, mixed convection approaches free convection values.

SSAR Revision: NONE

Question 480.297

Re: WGOTHIC MODELS AND PHENOMENA
In which LST/AP600 analyses was the forced flow option specified? What option was specified for the WGOTHIC 1.0 calculations cited in the model and margin assessment report (PCS-GSR-001)?

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

The final validation report for WGOTHIC (Reference 480.297-1) describes the models used for Large Scale PCS Test (LST) simulations. The distributed parameter LST simulations used the mixed convection correlations described in Section 2.0. In the lumped parameter simulations, the forced convection is set to zero on the inner PCS surface, so that only free convection is used.

The PCS evaluation model for the AP600 assumes only free convection by setting the forced convection component on the inner PCS surface to essentially zero (Reference 480.297-2). The evaluation model also uses free convection on all inner heat sink surfaces. This approach is reflected in the preliminary SSAR 6.2 markups (Reference 480.297-3) for both LOCA and MSLB lumped parameter models. This approach is not currently reflected in the distributed parameter model calculations for the preliminary draft SSAR markup (which used mixed convection).

The WGOTHIC 1.0 results (Reference 480.297-4) used the mixed convection correlation used in the 1992 SSAR calculations which differed from the WGOTHIC 1.2 mixed convection correlation as described in Reference 480.297-5.

References

480.297-1 WCAP-14382, "WGOTHIC Code Description and Validation," May, 1995.

480.297-2 Westinghouse Letter NTD-NRC-95-4545, "AP600 PCS Design Basis Accident Roadmaps," August 31, 1995.

480.297-3 Westinghouse Letter NTD-NRC-95-4504, "Proposed Draft Markups of SSAR Sections 6.2 and 6.4," July 10, 1995.

480.297-4 Westinghouse Letter NTD-NRC-94-4174, "AP600 Passive Containment Cooling System Design Basis Analysis Model and Margin Assessment," June 30, 1994.

480.297-5 PCS-GSR-001, "PCS Design Basis Analysis Model and Margin Assessment Report," June 1994, page 9

SSAR Revision: NONE

Question 480.298

Re: WGOTHIC MODELS AND PHENOMENA (Sensitivity to Nodalization in the Lumped Parameter Mode)
WEC needs to examine the sensitivity of WGOTHIC results to the nodalization scheme, particularly for the cells adjacent to the shell interior.

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

The lumped parameter noding has been established to best represent LST phenomena within the model limitation. No further adjustment of noding will be done for the lumped parameter model. Rather, the lumped parameter results have been used to define a bounding evaluation model approach as follows.

The lumped parameter calculation is used only to assess the 24 hour pressure reduction rate criterion. Since the PCS evaluation models consider only free convection on the inside, the impact on mass transfer of noding in the lumped parameter model is limited to its prediction of noncondensible distributions and their impact on heat sink efficiency. Based on validation with large scale tests, the lumped parameter nodalization is shown to overpredict the rate of mixing in the containment (Reference 480.298-1). Since the internal heat sinks have saturated and in most cases are releasing energy back to containment by 24 hours, the dominant internal pressure mitigation mechanism is condensation on the PCS surfaces above the operating deck. The possible range of noncondensible distributions can range from uniform, resulting from perfect mixing, to steam rich at higher elevations, resulting from plume-induced stratification. For the 24 hour criterion, a well mixed containment provides the limiting assumption and the lumped parameter model predicts a well mixed containment except for dead-ended compartments by about 30,000 seconds and beyond. The lumped parameter model bounds the effects of mixing and stratification at 24 hours by maximizing air concentration above the operating deck.

References

480.298-1 WCAP-14382, "WGOTHIC Code Description and Validation" Section 5.3

SSAR Revision: NONE

Question 480.301

Re: WGOTHIC MODELS AND PHENOMENA (Sensitivity to nodalization in the Lumped Parameter model)
Can a nodalization scheme developed to generate velocities that match the LST velocities predict the correct velocities in the AP600?

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

The effect of the nodalization used in the lumped parameter model have been identified (Reference 480.301-1, Section 8.2) and factored into the bounding evaluation model (Reference 480.301-2). The lumped parameter AP600 evaluation model overpredicts velocities similar to the LST lumped parameter model since the noding is directly scaled as discussed in the response to RAI 480.300. The effects of velocity are bounded in the AP600 PCS evaluation model by assuming only free convection so that the lumped parameter velocities predicted for the AP600 are not used in calculating heat and mass transfer rates.

References

480.301-1 WCAP-14382, "WGOTHIC Code Description and Validation," May 1995

480.301-2 Westinghouse Letter NTD-NRC-95-4545, "AP600 PCS Design Basis Accident Roadmaps," August 31, 1995

SSAR Revision: NONE

Question 480.303

Re: WGOTHIC MODELS AND PHENOMENA
WEC has stated that a well-mixed containment assumption is conservative. However, some of the effects of stratification may be non-conservative, making it difficult to support a blanket claim that a well-mixed atmosphere will yield conservative results. WEC needs to identify the potentially non-conservative effects of stratification and demonstrate that they do not compromise the case for design certification.

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

Sensitivities and first principles calculations have been performed to show that the potentially non-conservative effects of stratification are bounded. The PCS evaluation model bounds the effects of mixing and stratification for each phase of the LOCA and the MSLB (Reference 480.303-1), as follows. During the LOCA blowdown, the high steam release rate pressurizes the steam generator compartment, forcing steam through all openings into the compartments below deck and the open volume above deck. Therefore, stratification is not a concern during blowdown. The primary mode of pressure mitigation during LOCA blowdown is the volume pressurization, with a secondary effect of condensation on internal heat sinks and the containment shell. The AP600 evaluation model has been shown to perform essentially the same as a more traditional "few node style" approach during blowdown (Reference 480.303-2).

In the second LOCA phase, during which the peak pressure is reached, containment pressurization is mitigated primarily by condensation on internal heat sinks. Mixing and stratification affect internal steam distributions and thus affect the heat sink efficiency in various internal regions. The physics of plumes suggest that stratification may reduce the access of steam to lower heat sinks during this phase of the accident. The LST data show that with a plume entering the above-deck region, stratification can lead to a slight positive gradient in the open volume. Because of the large volume change associated with condensation of steam, there are significant driving forces for steam ingress into lower compartments. This driving force is orders of magnitude greater than the forces associated with large scale circulation or plume-induced stratification. Therefore, heat sinks in lower compartments absorb significant amounts of energy well before the second peak occurs. Stratification has only a weak potential to affect the containment pressurization. The distributed parameter model is used to address mixing and stratification for the peak pressure phase by biasing steam distribution to bound the effects of stratification.

During the long term LOCA phase the primary means of pressure mitigation is through condensation on the internal PCS surface, which is located above the operating deck (see also the response to RAI 480.298). Stratification would lead to increased steam concentration above the operating deck and thus would improve PCS performance. A well-mixed containment conservatively bounds the effects of stratification on heat removal through the PCS since mixing moves noncondensibles to the above-deck region next to the PCS and noncondensibles in the above-deck region penalize condensation. Thus, stratification during the long term LOCA would improve PCS performance. The use of the lumped parameter model bounds the effects of stratification as discussed in the response to RAI 480.282.

Please also see the response to RAI 480.314 for results of a Large Scale Test calculation that quantifies the effects of increased mixing on PCS heat removal.

References

480.303-1 Westinghouse Letter NTD-NRC-95-4545, "AP600 PCS Design Basis Accident Roadmaps", dated August 31, 1995

480.303-2 Westinghouse Letter NTD-NRC-95-4589, "AP600 Containment Analysis for LOCA Blowdown", dated November 7, 1995

SSAR Revision: NONE

Question 480.305

Re: WGOTHIC MODELS AND PHENOMENA
The effects of stratification in the LST experiments are quite nonprototypic in that the amounts of water applied to the shell substantially exceeded evaporation rates, and the effect of water subcooling was much more important than in the AP600. These issues need to be addressed as to their impact on the AP600 analyses.

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

The steam condensation rate is only a few percent of the above-deck steam circulation rate. Therefore, the degree of stratification is only weakly affected by the degree of subcooling. In fact, internal stratification has been observed even with a factor of 10 reduction in external cooling rate associated with no external water application. There could only be a negligible feedback of the somewhat higher LST condensation rates on the degree of stratification in the LST, relative to AP600. The effects of subcooling and stratification in the AP600 PCS evaluation model are addressed as follows.

In both the LST and the AP600, energy removal by sensible heating of the liquid film is a small fraction of the total heat removal. The LST experiments cover a range of fractions of external heat removed by subcooled liquid film (5-20%), with most of the tests at the higher range. The assumption of 120°F for the AP600 PCS water temperature results in only about 5% of the total heat being removed by the subcooled liquid film through most of the DBA transient.

LST data show that there is a small steam concentration gradient within the above-deck volume. The effect on the database of increasing liquid film subcooling is to increase the upper limit of the range of dome heat fluxes. As stated above, the presence in LST tests of higher proportions of subcooling relative to AP600 does not invalidate the LST stratification results.

Liquid film energy removal is addressed by using a convective energy transport model (Reference 480.305-1), and is bounded in the evaluation model by assuming an upper bound PCS water temperature. Data from the LST have been used to confirm the physics of stratification within open volumes. The effects of stratification in the AP600 will also be bounded for each accident/phase (see also response to RAI 480.303).

References

480.305-1 WCAP-14382, "WGOTHIC Code Description and Validation" Section 2.5

SSAR Revision: NONE

Question 480.306

Re: WGOTHIC MODELS AND PHENOMENA
The WEC scaling analysis indicates that internal heat sinks are almost as important in determining the peak pressure as is evaporation, and both processes are more important than any others up to the time of peak pressure. As a result, the effect of stratification in reducing the effectiveness of internal heat sinks is potentially important and needs to be addressed.

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

The effect of stratification on peak pressure is bounded in the PCS DBA evaluation model (Reference 480.306-1). Please also see response to RAI 480.303.

References

480.306-1 NTD-NRC-95-4545, "AP600 PCS Design Basis Accident Roadmaps," August 31, 1995

SSAR Revision: NONE

Question 480.308

Re: (WGOTHIC MODELS AND PHENOMENA)THE MSLB ACCIDENT SCENARIO
480.308 What analyses and sensitivity studies has WEC performed (or is planning to perform) for the main steam line break (MSLB) accident scenario?

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

Analyses and sensitivity studies for the main steamline break (MSLB) accident scenario have been performed, based on conclusions drawn from the LST Phase 3 tests with elevated, small diameter pipe at various orientations (Reference 480.308-1) and forced convection condensation separate effects tests (Reference 480.308-2). These studies were used to validate the use of WGOTHIC in lumped parameter mode with free convection for the MSLB evaluation model based on LST comparisons (Reference 480.308-3) and to identify the limiting MSLB mass and energy release scenario (Reference 480.308-4, Reference 480.308-5).

The LST showed that the high kinetic energy releases typical of MSLB scenarios drove mixing throughout the vessel and led to a significant forced convection component of heat and mass transfer on PCS surfaces. Meanwhile, the PIRT and energy partitioning for the AP600 show that the dominant heat removal mechanism on the inside of containment is condensation on the internal heat sink, (the accident is over before the PCS is assumed available). Thus, a conservative bias on heat and mass transfer correlations and the assumption of free convection on the inside PCS surface results in bounding condensation rates. With regard to the well mixed containment (per LST), placing the MSLB mass and energy boundary condition above the operating deck in the lumped parameter evaluation model leads to predicted stratification. This conseratively reduces the access of steam to internal heat sinks below deck. The combination of bounding condensation rates and predicted stratification for MSLB insures that the containment response evaluation model is bounding.

Mass and energy release scenarios have been examined. A failure of the main steam isolation valve (MSIV) is the limiting steamline break mass and energy release scenario. The failure of a main feedwater isolation valve (MFIV) does not result in any more mass discharge into containment than does the failure of an MSIV. An assumed MSIV failure in the mass and energy release analysis forces one steam generator to blow down regardless of break location, thus bounding several break location scenarios.

To confirm this, analyses of the mass and energy releases from 29 postulated steamline break cases, including various break sizes, initial power levels, and single failures, were performed, and the results of the two limiting cases have been presented (Reference 480.308-5). The spectrum of break sizes considers 1.388 ft^2 full double-ended ruptures, small double-ended ruptures ranging between 0.10 and 0.70 ft^2, and small split ruptures ranging between 0.37 and 0.442 ft^2. Power levels include low power cases (0% and 30% power) wherein more steam generator mass is available and high power cases (70% and 102% power) wherein more energy is available in the secondary fluid and the primary side. Single active system failures considered are the failure of the MSIV or the MFIV. Results from the analyses confirmed that the releases from a double-ended rupture of a main steam line with assumed MSIV failure is the limiting steamline break scenario. By performing sensitivities to break size, power level, and single

failures, it is shown that other combinations of parameters and control systems interactions do not lead to more limiting cases. There are no significant differences in the AP600 control systems or plant layout, relative to the spectrum sensitivities, that could invalidate this conclusion, so the results remain applicable to the current AP600.

References:

480.308-1 WCAP-14135, Final Data Report for PCS Large-Scale Tests, Phase 2 and Phase 3, Page 1-11, July 1994.

480.308-2 WCAP-14326, Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations, Sections 3.8 and 3.9, March 1995.

480.308-3 WCAP-14382, WGOTHIC Code Description and Validation, May, 1995, page 8-10

480.308-4 NTD-NRC-95-4611, AP600 Containment Design Basis Analysis (Break Spectrum Analysis), December 15, 1995.

480.308-5 NTD-NRC-95-4504, Proposed Draft/Markups of SSAR Section 6.2 and 6.4, July 10, 1995, Section 6.2.1.1.1, 6.2.1.1.3

SSAR Revision: NONE

Question 480.309

Re: WGOTHIC MODELS AND PHENOMENA
For MSLB, how important are the mixed/forced convection issues discussed previously?

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

The high kinetic energy of the releases from a main steamline break result in condensation on internal containment structures, that is strongly dominated by forced convection. An assumption of free convection heat and mass transfer on internal structures has been adopted for the PCS evaluation models, so that the enhancement of mass transfer due to forced convection is conservatively neglected. Therefore, while issues related to code velocity predictions are useful in understanding the nominal performance of the AP600 PCS, uncertainties related to the mixed/forced issues discussed previously are bounded.

SSAR Revision: NONE

Question 480.310

Re: WGOTHIC MODELS AND PHENOMENA
What are the flow velocities assumed at various heat sink locations within the containment for the MSLB analyses?

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

Because an assumption of free convection heat and mass transfer on internal structures has been adopted, there will be no velocity used in the calculation of heat and mass transfer to internal structures. Sufficient instrumentation was incorporated into the LST to identify and quantify compensating effects. For LST tests with Froude numbers representative of an MSLB, the internal condensation rates were significantly underpredicted when a free convection correlation was used. This is consistent with the expectation of large enhancements to heat and mass transfer resulting from a large forced convection component. Free convection is assumed for internal containment surfaces to conservatively bound velocity effects.

SSAR Revision: NONE

Question 480.311

Re: WGOTHIC MODELS AND PHENOMENA
For the MSLB, what is the validation basis for the velocities calculated by WGOTHIC for use in the correlations for forced and/or mixed convection?

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

The large scale test included elevated small diameter pipes to develop Froude numbers representative of a main steamline break. Comparisons of correlations to data showed that the assumption of free convection significantly underpredicts mass transfer, and would thus overpredict vessel pressures. Please see response to RAI 480.310 for how the evaluation model bounds the effects of velocity on heat and mass transfer.

SSAR Revision: NONE

Question 480.312

Re: WGOTHIC MODELS AND PHENOMENA
What is the potential for stratification to occur in the MSLB?

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

The main steamline break releases significant amounts of kinetic energy into containment, thus virtually eliminating the potential for stratification within the volume above the operating deck. It is expected that such high levels of kinetic energy would also promote vigorous mixing within the rest of containment because of the relatively large amount of flow area through the operating deck. A significant reduction in break releases would be required to lower the Froude number enough that stratification within the open volume above deck could occur. The evaluation model bounds the effects of stratification in the AP600 main steamline break (Reference 480.312-1).

References

480.312-1 Westinghouse Letter NTD-NRC-95-4545, "AP600 PCS Design Basis Accident Roadmaps," August 31, 1995

SSAR Revision: NONE

Question 480.313

Re: WGOTHIC MODELS AND PHENOMENA
If stratification does occur in the MSLB, what are the implications for the maximum containment pressure that results?

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

Please see the Westinghouse response to RAI 480.308 for a discussion of how the potential effect of stratification during the main steamline break are bounded.

SSAR Revision: NONE

Question 480.317

Re: WGOTHIC MODELS AND PHENOMENA
The WEC scaling analysis is based upon a well-mixed containment and includes only natural convection. As a result, the scaling analysis does not permit inferences from the LST results to be applied to the effects of stratification and/or mixed convection phenomena in the AP600. This issue needs to be addressed.

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

The referenced scaling analytical model is used to gain insight into the effects of mixing and stratification, which has been considered in development of the bounding evaluation model. It is not used to directly solve for mixing and stratification in the AP600. The scaling analyses provide insight into internal circulation and mixed convection effects as follows.

For simplicity the Westinghouse scaling analysis model is initially derived based on a single volume inside containment with all relevant processes considered. The model has been extended to include the option to consider multiple internal volumes with specified steam concentrations, to study the effects of mixing and stratification. Reference 480.317-1, Section 6.3 discusses the conclusions regarding mixing and stratification, considering the axial steam concentration gradients as measured from the LST.

The scaling analysis model is not intended to calculate internal velocities. It is used to assess the range of validity of free convection and to examine the effects of assumed velocities parametrically. It is concluded that the free convection model conservatively underpredicts mass transfer under conditions of high kinetic energy releases, such as during a LOCA blowdown or a main steamline break. Reference 480.317-1, section 7.0, provides a discussion of the Froude number and considers the effects of kinetic energy of the break source on mixing, or bulk gas motion, and stratification. The scaling analysis model is validated in Section 8.0 by comparison to LST tests that are representative of several points in time for the AP600. This provides confidence that the model reasonably represents the dominant phenomena and can be used to infer the scaling relations between the AP600 and LST and to draw conclusions regarding appropriate AP600 DBA modelling methods. The effects of mixing and stratification and mixed convection are bounded in the DBA evaluation models (Reference 480.317-2). The evaluation model uses free convection.

References

480.317-1 WCAP-14190, "Scaling Analysis for AP600 Passive Containment Cooling System"

480.317-2 Westinghouse Letter NTD-NRC-95-4545, "AP600 PCS Design Basis Accident Roadmaps," August 31, 1995

SSAR Revision: NONE

Question 480.318

Re: WGOTHIC MODELS AND PHENOMENA
If LST results concerning the effects of stratification and/or mixed convection phenomena are not applicable to the AP600, WEC needs to assess or bound the uncertainties these effects produce in the WGOTHIC results is needed. How will WEC address these uncertainties for the AP600 analyses?

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

LST results are used to provide insight into the potential effects of mixing and stratification in the AP600. Assessment of the effects of mixing and stratification is based on a combination of first principles, hand calculations, LST results, and sensitivity calculations. The effects of mixing and stratification are bounded in the AP600 PCS DBA evaluation model (Reference 480.318-1).

References

480.318-1 Westinghouse Letter NTD-NRC-95-4545, "AP600 PCS Design Basis Accident Roadmaps," August 31, 1995

SSAR Revision: NONE

Question 480.352

Re: PCS-GSR-001
What do the WGOTHIC results for the LST experiments mean in terms of the potential accuracy and/or conservatism of WGOTHIC for the AP600?

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

The LST has provided insight into the development of bounding AP600 evaluation models. The accuracy of the LST predictions is not directly applicable to the AP600; rather, comparisons of predicted and measured results have provided insight into the ability of the code to model important phenomena. An objective of the LST experiments was to provide validation of heat and mass transfer predictions in an integral setting. The following summarizes how the LST has been used to develop the PCS evaluation model.

The application of scaling to the LST (Reference 480.352-1) showed that the LST represents the AP600 heat and mass transfer, the dominant transport processes. A model of the LST was developed with the WGOTHIC computer code to make validation comparisons to the LST steady state and transient tests (Reference 480.352-2). The LST model utilized the most accurate and nominal phenomenological models, initial conditions, and boundary conditions available. The computer model represented the transport phenomena identified as important, as well as many others that are of medium and low importance. Comparisons of code predictions to the test data support code validation, and also confirm that the PIRT and scaling analysis have included the important phenomena.

The nominal LST models, both lumped parameter and distributed parameter, served as a starting point for the PCS DBA evaluation model of AP600 and showed a trend towards overpredicting pressure. However, the evaluation model is a bounding model, so it is necessary to input bounding initial and boundary conditions, as well as to bias the phenomenological models of the dominant transport processes to provide bounding results. The means by which the initial and boundary conditions and phenomenological models are bounded have been provided (Reference 480.352-3).

References

480.352-1 WCAP-14190, "Scaling Analysis for AP600 Passive Containment Cooling System"

480.352-2 WCAP-14382, "WGOTHIC Code Description and Validation"

480.352-3 Westinghouse Letter NTD-NRC-95-4545, "AP600 PCS Design Basis Accident Roadmaps," August 31, 1995

SSAR Revision: NONE

Question 480.363

Re: (PCS-GSR-004) EXPERIMENTAL COMPARISONS (GENERAL)
WEC should 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.

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

The uncertainties which must be allowed for when applying the correlations for AP600 analysis are bounded as follows. Separate effects tests and local integral test data has been used to validate the use of the heat and mass transfer correlations selected for use in the AP600 evaluation model (Reference 480.363-1). The bias and other statistics associated with those comparisons are given in Section 4.2 for evaporation and 4.3 for condensation. When the correlations are used in the AP600 PCS evaluation model, conservative biases bounding the data are employed (Reference 480.363-2).

References

480.363-1 WCAP-14326, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations"

480.363-2 Westinghouse Letter NTD-NRC-95-4570, "Bases for AP600 PCS DBA M[illegible] .ransfer Correlation Biases," September 28, 1995

SSAR Revision: NONE

Question 480.364

Re: PCS-GSR-004 - EXPERIMENTAL COMPARISONS (GENERAL)
Based upon the results presented, there is no basis for claiming conservatism in these correlations. Results are consistent with the correlations' being best-estimate (BE) correlations. However, BE analysis is acceptable in this context only if it is accompanied by an assessment of the uncertainties. How will WEC address uncertainties for the AP600 analyses?

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

Westinghouse has addressed uncertainties for the AP600 analyses by the use of a bounding approach. The AP600 PCS evaluation model includes multipliers on both the evaporation and condensation correlations that bound the separate effects test data (Reference 480.364-1).

References

480.364-1 Westinghouse Letter NTD-NRC-95-4570, "Bases for AP600 PCS DBA Mass Transfer Correlation Biases," September 28, 1995

SSAR Revision: NONE

Question 480.373

Re: PCS-GSR-006
WEC should 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.

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

Please see the Westinghouse response to RAI 480.363.

SSAR Revision: NONE

Question 480.374

Re: PCS-GSR-006
Based upon the results presented, there is little basis for claiming conservatism in these correlations. Results are consistent with the correlations' being best-estimate (BE) correlations. However, BE analysis is acceptable in this context only if it is accompanied by an assessment of the uncertainties, which has not been provided. How will WEC address uncertainties for the AP600 analyses?

Response:

Westinghouse has changed its approach to use a bounding evaluation model, which affects the applicability of the above question. The change in the evaluation model addressed the staff's previous concern.

Please see the Westinghouse response to RAI 480.364.

SSAR Revision: NONE