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Docket No.: STN-52-003

January 19, 1996

Document Control Desk
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 Design Certification Test Program. Topics discussed in this transmittal include the NOTRUMP compute code, LOFTRAN computer code and the WCOBRA/TRAC computer code. A listing of the NRC requests for additional information responded to in this letter is contained in Attachment A. These responses are also provided as electronic files in WordPerfect 5.1 format with Mr. Kenyon's copy.

Correspondence with respect to this transmittal should be addressed to Brian A. McIntyre, Manager of Advanced Plant Safety and Licensing, Westinghouse Electric Corporation, P.O. Box 355, Pittsburgh, Pennsylvania, 15230-0355.

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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

Attachments
Enclosures

cc: T. Kenyon, NRC (w/o enclosures)
W. Huffman, NRC (1E)
R. C. Jones, NRC (w/o enclosures)
G. D. McPherson, NRC (w/o enclosures)
F. Eltawila, NRC (w/o enclosures)
R. Landry, NRC (1E)
L. Lois, NRC (1E)
A. Levin, NRC (1E)
P. Boehnert, ACRS (4E)
N. J. Liparulo, Westinghouse (w/o enclosures)

NTD-NRC-96-4626

ATTACHMENT A

RAI's addressed in the January 19, 1996 submittal:

LOFTRAN	440.267
	440.270
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NOTRUMP	440.445
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	440.501
WCOBRA/TRAC	
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	440.565

Question 440.267

Re: LOFTRAN Code Applicability Document (CAD)

In reviewing the report it is evident that Westinghouse plans to maintain two versions of LOFTRAN for the AP-600 work and two versions of the code for PWR analysis. This is four total versions of LOFTRAN, a high number of computer programs to update and maintain. How many staff members will be making changes to these versions of the code? How will the QA be performed? Why can't one version of the code be used for AP-600 analysis? Please explain.

Response:

QA for the AP600 versions of LOFTRAN and LOFTTR2, and all other Westinghouse computer codes, is performed in accordance with the Westinghouse Electric Corporation, Energy Systems Business Unit, Quality Management System (QMS). These procedures assure that all computer programs are updated and maintained in a controlled and traceable manner (irrespective of the number of staff members making changes). The merits of maintaining the AP600 codes separately from the standard PWR codes were weighed against the costs incurred due to additional record keeping. It was decided that the codes will remain separate until the AP600 obtains final design approval. At that time the decision will be reviewed.

SSAR Revision: NONE

Question 440.270

Re: LOFTRAN Code Applicability Document (CAD)
Page 1-4. It is stated that the code can be initialized for positive flow in the core. During a transient, can LOFTRAN calculate reverse flow in the core and local regions within the core, due to phenomena such as manometric effects. Please explain.

Response:

LOFTRAN can not calculate reverse flow in the core. The LOFTRAN codes are only used for analysis of non-LOCA and SGTR transients, which will always maintain a positive core flow.

SSAR Revision: NONE

Question 440.308

Re: WCAP-14234 (LOFTRAN CAD)

Are any iterations being performed in LOFTRAN between the RCS, the CMT, the IRWST, or the accumulators ? Please show the type of iteration, a typical number of iterations, and the convergence characteristics. Do the components ever hit the iteration limit ? How is error assessed if this occurs ?

Response:

As described in the response to Question 440.295, IRWST injection is not used to mitigate non-LOCA transients and is not simulated in LOFTRAN.

The CMT and the accumulators models are implemented explicitly with respect to the RCS. A converged solution is found for the main RCS loop. Using the RCS pressure at the accumulator injection point, the accumulator flow is calculated. Similarly, using the RCS pressure at the CMT injection and balance line connection points and the enthalpy at the balance line connection point, the CMT flow is calculated. No iterations are performed between the RCS and the accumulators or the CMT.

SSAR Revision: NONE

Question 440.320

Re: LOFTRAN Code Applicability Document (CAD)
The amount of mixing in LOFTRAN is user input. What data will be used to determine this number.

Response:

The CMTs remain water solid during the SSAR non-LOCA and SGTR transients. This is confirmed by the SPES-2 results and well predicted by the LOFTRAN code (Reference 440.320-1). Simulations of the CMT 500 Matrix Test series in Reference 1 show that the LOFTRAN CMT model accurately predicts the upper-layer CMT temperature evolution, without any additional mixing phenomena other than water replacement. Consequently, the user input mixing is no longer used for the final AP600 SSAR calculations. No special correlations are required to model the sparger injecting subcooled water from the balance line into a steam space at the top of the CMT, since a steam space does not form for the transients analyzed with the LOFTRAN codes.

References

440.320-1 WCAP-14307, LOFTRAN-AP and LOFTTR2-AP Final Verification and Validation Report, June 1995

SSAR Revision: NONE

Question 440.321

Re: LOFTRAN Code Applicability Document (CAD)
What correlations will LOFTRAN have available for the spargers in the CMT?

Response:

See the response to RAI 440-320 which discusses the modeling of fluid introduced into the top of the CMT.

SSAR Revision: NONE

Question 440.445

Re: NOTRUMP CMT PVR (MT01-GSR-011)
440.445 As discussed in Section 5.0, the time averaged flows over the entire test may show good comparisons, however the first half or early portions of the event may show the time averaged flows are over-predicted by NOTRUMP. The early flow rates are over-predicted partially due to the coarse nodalization which increases the driving head and increases the flow. The results and conclusions may be different if the plots are divided into two portions, a time averaged flow condition for the first half (i.e. when the temperatures in the CMT are over-predicted) and the second half of each event. Please discuss the behavior of the NOTRUMP code with this time average splitting. While the overall transient response of the time averaged inlet flow may be in agreement, the first half of the event may not and incorrectly affect the RCS loop temperatures and system behavior later in the event.

Response:

The calculated and measured temperatures and the flow comparisons have been compared in more detail as requested by the RAI to determine if the numerical diffusion of the fluid temperatures were effecting the calculated CMT drain flow relative to the test data.

For test C0059502, the measured flow is higher than the NOTRUMP predicted flow for the first 100 seconds of the transient. When the comparisons of the fluid temperatures in the CMT are examined for this time period, the only difference is in the second node (15% of the CMT volume) where the NOTRUMP calculated temperature is 40 °F higher. The higher NOTRUMP calculated temperature would give a slightly lower CMT flow. However, the small temperature difference on a relatively small CMT node does not explain the difference between the data and the prediction in this time period. The initial flow spike in the experiment may have been caused by the pressure spike as seen in Figure 4.2-1 from Reference 440.445-1. The average pressure was modeled in the NOTRUMP calculation. Test C059502 is the only test that exhibits the measured flow spike behavior. After the initial flow spike, the NOTRUMP calculation agrees very well with the test data.

For test C0061504, at the beginning of the transient, the calculated drain flow and the measured drain flow agree very well. As time progresses, NOTRUMP tends to underpredict the drain flow from the CMT. At 600 seconds into the test, the drain flow is approximately 10% lower than the data. The thermal diffusion has heated the lower NOTRUMP nodes such that the effective density of the water in the CMT is less than the data. This would result in a reduced effective driving head and the lower drain flow rate as observed in Figure 4.2-17. However, the difference is small, 10% at 600 seconds and 14% at 1000 seconds. Clearly the numerical diffusion is a bias in the code which will result in reduced injection flow to the reactor vessel which is conservative.

In test C064506, the NOTRUMP drain flow is initially higher than the data, and then crosses the data and is lower. For the initial period (first 300 seconds) when NOTRUMP is calculating a higher drain flow, the average fluid temperatures predicted by NOTRUMP are the same or lower for the top two fluid nodes, and are higher for the bottom two fluid nodes which contain 75% of the CMT fluid volume (see Figures 4.2-23 to 4.2-26 from Reference 440.445-1). The NOTRUMP predicted flow is approximately 6% higher than the measured flow for this time period. Since the NOTRUMP average fluid temperatures are higher than the data and the NOTRUMP flow is also higher during this time period, numerical diffusion is not responsible for this difference. As time progresses, the

NOTRUMP calculation does indicate decreasing flow from the CMT . However, the fluid temperatures predicted by NOTRUMP are lower then those observed in the experiment. The numerical diffusion results in a more smeared fluid temperature which is lower than that measured in the test. The lower NOTRUMP fluid temperatures should result in higher flows since the driving head is larger. However, as seen in Figure 4.2-26, the NOTRUMP calculation is approximately 22% lower than the data at the worst time (700 seconds), and is approximately 12% lower than the data over the time period from 350 to 1650 seconds. Numerical diffusion can not be used to explain the observed differences in this experiment, but the differences between the test data and the NOTRUMP calculation are still small (+ 6% to - 12%). Also during the time period that NOTRUMP underpredicts the drain flow from the CMT, the calculation does agree very well with the injection flow as seen in Figure 4.2-27.

In test C076507, NOTRUMP over predicts the CMT drain flow for the majority of the transient. The NOTRUMP fluid temperatures do show the effects of numerical diffusion particularly for the lowest fluid node as seen in Figure 4.2-7 where the calculated fluid temperature is higher than the measured average temperature for that node. If the temperatures are averaged over the time period of interest, 0 to 350 seconds, the calculated CMT average temperature is higher in the NOTRUMP calculation as compared to the test data, which should result in a CMT drain flow reduction since the buoyant driving head is reduced. The opposite was observed in the comparisons with NOTRUMP over-estimating the average drain flow by approximately 4%. NOTRUMP also over-estimated the injection flow by 12 %. Again, the effects of numerical diffusion do not explain these differences.

In test C074508, NOTRUMP initially over-predicts the CMT drain flow then lies below the test data as seen in Figure 4.3-17. The fluid temperatures are lower than the test data for the top three nodes, while the larger bottom node temperature, which contains 60% of the CMT volume, is higher such that the average CMT temperature is slightly hotter then the data. The hotter predicted CMT temperatures would be expected to reduce the buoyant driving head, however, NOTRUMP is predicting 10% higher flow during this time period (0 to 300 seconds). As the transient progresses, the NOTRUMP predicted flow decreases below the measured flow values. The NOTRUMP calculated fluid temperatures are cooler then the measured average temperature which should increase the buoyant driving head and the resulting flow, however, the predicted flow is lower. The NOTRUMP predicted average flow is 23% below the average of the test data (300 to 925 seconds). When comparing the inlet flow, NOTRUMP is 10% higher in the early time period, which is consistent with the higher drain flow; and later NOTRUMP is 8% lower then the measured inlet flow when the NOTRUMP drain flow is lower. Again, a lower predicted flow is conservative since the flow to the reactor vessel is lower.

The same behavior is observed in test C072509, where the NOTRUMP drain flow is initially higher than the measured drain flow, than later in the transient, NOTRUMP drops below the measured drain flow. The NOTRUMP temperatures are slightly higher in the first portion of the transient when the NOTRUMP flows are higher (0 to 300 seconds), which should reduce the buoyant head. Later in the transient, the NOTRUMP calculated temperatures are lower then the data while the flows are lower. In the initial period, NOTRUMP over predicts the flows by 8% while in the later period (300 to 1500 seconds), NOTRUMP under-predicts the flow by 16%. The agreement with the inlet flows is slightly better with NOTRUMP over-predicting the flow for the first period in the transient by 9% and under-predicting the second period by 5%.

For all the tests, the NOTRUMP drain flow curve shows a continuously decreasing flow behavior which is what one expect as the hot fluid enters the CMT and decreases the effective buoyant driving head. Some of the data shows different flow plateaus with a very distinct slope change in the draining rate. This is not consistent with a flow reduction caused by a decreasing buoyant driving head. Tests C059502, C061504 and test C076507 all have similar flow curves which agree better with the NOTRUMP predictions and indicate the gradual flow decrease due to the reduction of the buoyant driving force. Tests C064506, C074508, and C072509 indicate a different flow signature for the CMT draining behavior which is different than the earlier tests. For these tests, NOTRUMP does predict the average behavior of the flow curve very well as indicated in Figure 5-1 of reference 440.445-1. The above discussion also indicates that, in addition to predicting the average flow behavior well, NOTRUMP does predict the individual portions of the flow curves also reasonably well with only one point being different by 20%.

Therefore, the coarse noding used by NOTRUMP to model the CMT gives an accurate prediction of the average draining rate during the recirculation period. The calculation may over-predict and under -predict portions of the draining curve, but these over and under predictions are generally small, and the code predicts the average draining rate accurately.

References

440.445-1 Jaroszewicz, J. and L.E. Hochreiter, " AP600 NOTRUMP Core Makeup Tank Preliminary Validation Report for 500-Series Natural Circulation Tests", MT01-GSR-011, April 1995.

SSAR Revision: NONE

Question 440.448

Re: 440.448 RAI on WCAP-14307
On page 3-3, it is stated that the AP600 plant system design is shown in Figure 1-1. This figure is missing from the document.

Response:

Attached please find a copy of Figure 440.448-1

SSAR Revision: NONE

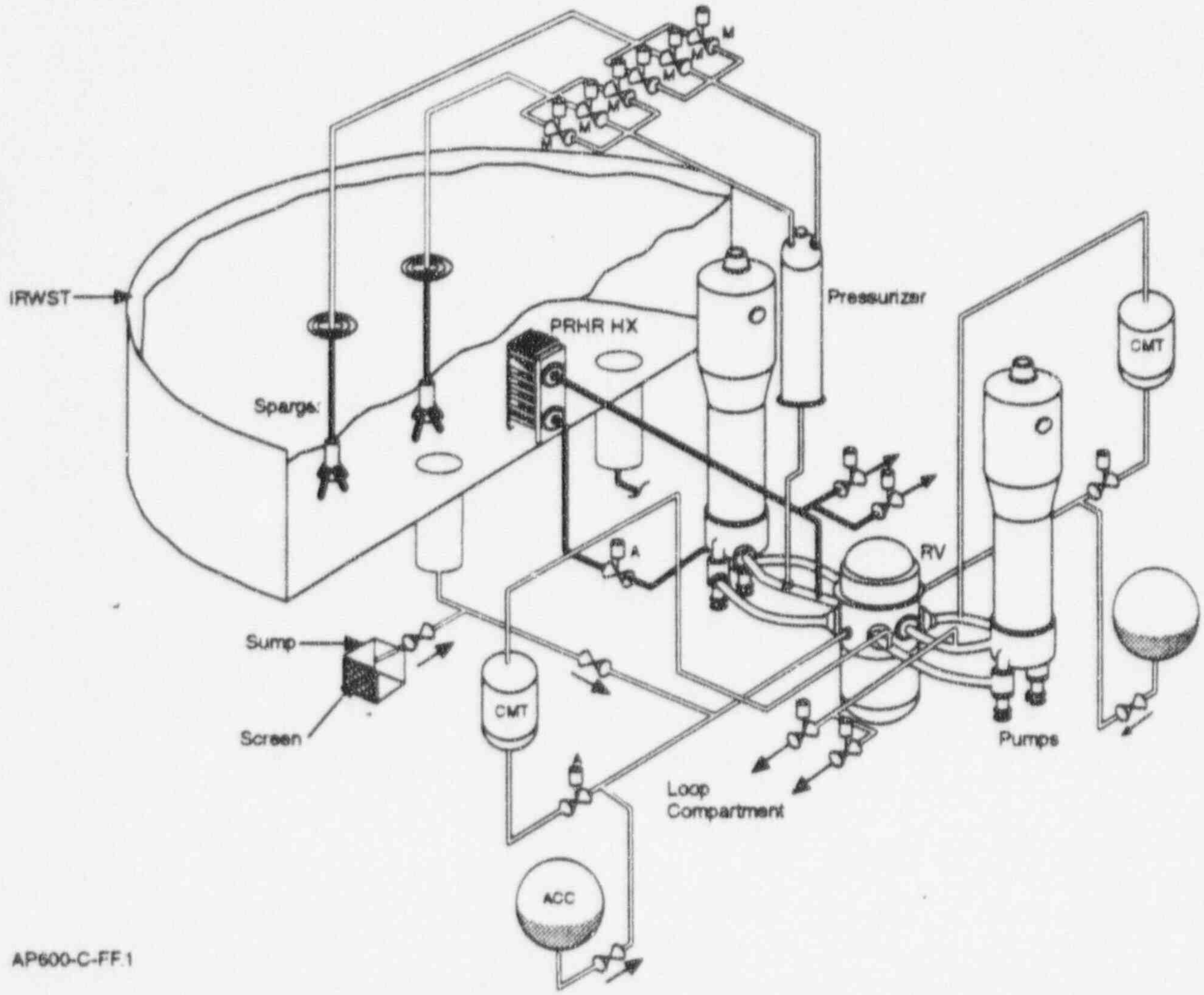

Figure 440.448-1 AP600 Passive Safety Systems Configuration

Question 440.479

Re: NOTRUMP PVR FOR OSU TESTS, LTCT-GSR-001, JULY 1995

440.479 Provide a comparison of the NOTRUMP Shah condensation model prediction to condensation test data demonstrating applicability of the model to the range of conditions expected in AP600.

Response:

The Shah condensation correlation, Reference 440.479-1 is a general flow correlation for condensation inside pipes and tubes typical of the PWR steam generator and the PRHR. The equations for the Shah condensation heat transfer correlation, as implemented in NOTRUMP are:

$$h = h_L \left[(1 - x)^{0.8} + \frac{3.8\ x^{0.76}\ (1 - x)^{0.04}}{p_r^{0.38}} \right] \qquad 440.479\text{-}1$$

$$h_L = 0.023 Re_L^{0.8}\ pr_L^{0.4}\ \frac{k_L}{d_h} \qquad 440.479\text{-}2$$

where:

h	=	Film heat-transfer coefficient [Btu/sec/ft²/°F]
h_L	=	Heat-transfer coefficient assuming all the mass flowing as liquid [Btu/sec/ft²/°F]
x	=	Thermodynamic quality of fluid in channel [—]
p_r	=	Reduced pressure [—]
Re_L	=	Reynolds number assuming all the mass flowing as liquid [—]
Pr_L	=	Prandtl number of liquid [—]
k_L	=	Conductivity of iiquid [Btu/sec/ft²/°F]
d_h	=	Hydraulic diameter of channel [ft]

The correlation is a function of the Reynolds number, which assumes that the total mass flow is the liquid phase; the channel hydraulic diameter, the liquid Prandtl number, reduced pressure, and the quality of the fluid in the channel. Since the Shah correlation is expressed in the form of dimensionless parameters, its applicability and data base can be developed from fluids other than water. The recommended range of conditions for the correlation given in Table 2 of Reference 440.479-1 are shown below. Comparison between the correlation and data are contained in reference 440.479-1.

Table 2. The complete range of parameters in which the correlation has been tested and the range in which its use is recommended

Parameter	Tested range	Recommended range
Flow channel	Pipes, annulus	Pipes, annuli
Flow direction	Horizontal, vertical, 15° inclined to horiz.	All directions
Pipe ID, mm	7.4 - 40	7 - 40
T_f, °C	21 - 310	21 - 310
x, %	0 - 100	0 - 100
q, W/m²	158 - 1,893,000	All values
G, kg/m²h	30,000 - 5,758,400	39,000 - 5,758,400
p,10⁶ N/m²	0.07 - 9.8	0.07 - 9.8
p_r	0.0019 - 0.44	0.002 - 0.44
Re_L		
pipes	104 - 62,900	350 and higher
annulus	670 - 6,700	3000 and higher
V, m/s	3 - 300	3 - 300
Pr_l	1 - 13	>0.5
Flow patterns	All	All

The recommended tube diameter range is 7 - 40 mm or 0.2755 to 1.574 inches which encompasses both the steam generator tubes (0.608 inches) and the PRHR tubes (0.62 inches). The liquid Prandtl number recommended range is from 0.5 to 13 which covers the full range for water flows, and the quality range is from 0 to unity. The correlation uses a reduced pressure to correlate the data. The upper range on the reduced pressure is P_r = 0.44, which for a water system is 1410.2 psia. This upper range covers the small-break LOCA conditions since the break will quickly depressurize the primary system to the secondary side pressure at approximately 1100 psia, before significant draining occurs. Once the primary system is draining, a two-phase mixture can enter the steam generators and the PRHR to be condensed.

The two-phase mixture mass flow effects, in the Shah correlation, are captured by a liquid Reynolds number which is based on the total mixture flow being liquid. Figures 440.479-1 to 440.479-3 show the calculated liquid equivalent two-phase mixture Reynolds number for three small-break cases (a 1-inch, 2-inch and DEDVI break cases) plotted as a function of inlet quality. The liquid equivalent Reynolds number is calculated for the times when a two-phase mixture enters the PRHR for each of these cases. The lower limit for the Reynolds number in the Shah correlation for pipes is 104 from Table 2, and the recommended lower limit is 350. All the points on Figures 440.479-1 to 400.479-3 are above the lower recommended limit of 350. While the correlation data base upper limit on the Reynolds number is 62,900 for pipes; there is no recommended Reynolds number upper limit in Table 2. There are a number of calculated Reynolds points from NOTRUMP which are higher than the data range used to test the correlation, however, if the upper limit of the mass flux in Table 2 is used to calculate a Reynolds number the upper limit is 286,000.0 which exceeds the values calculated by NOTRUMP for the PRHR. Therefore, the Shah correlation is appropriate for modeling condensation in the PRHR and steam generator tubes.

Reference 440.479-1 Shah, M.M., "A General Correlation for Heat Transfer During Film Condensation Inside Pipes," Int. J. Heat Mass Transfer, Vol. 22, Pg. 547-556, (1979).

SSAR Revision: NONE

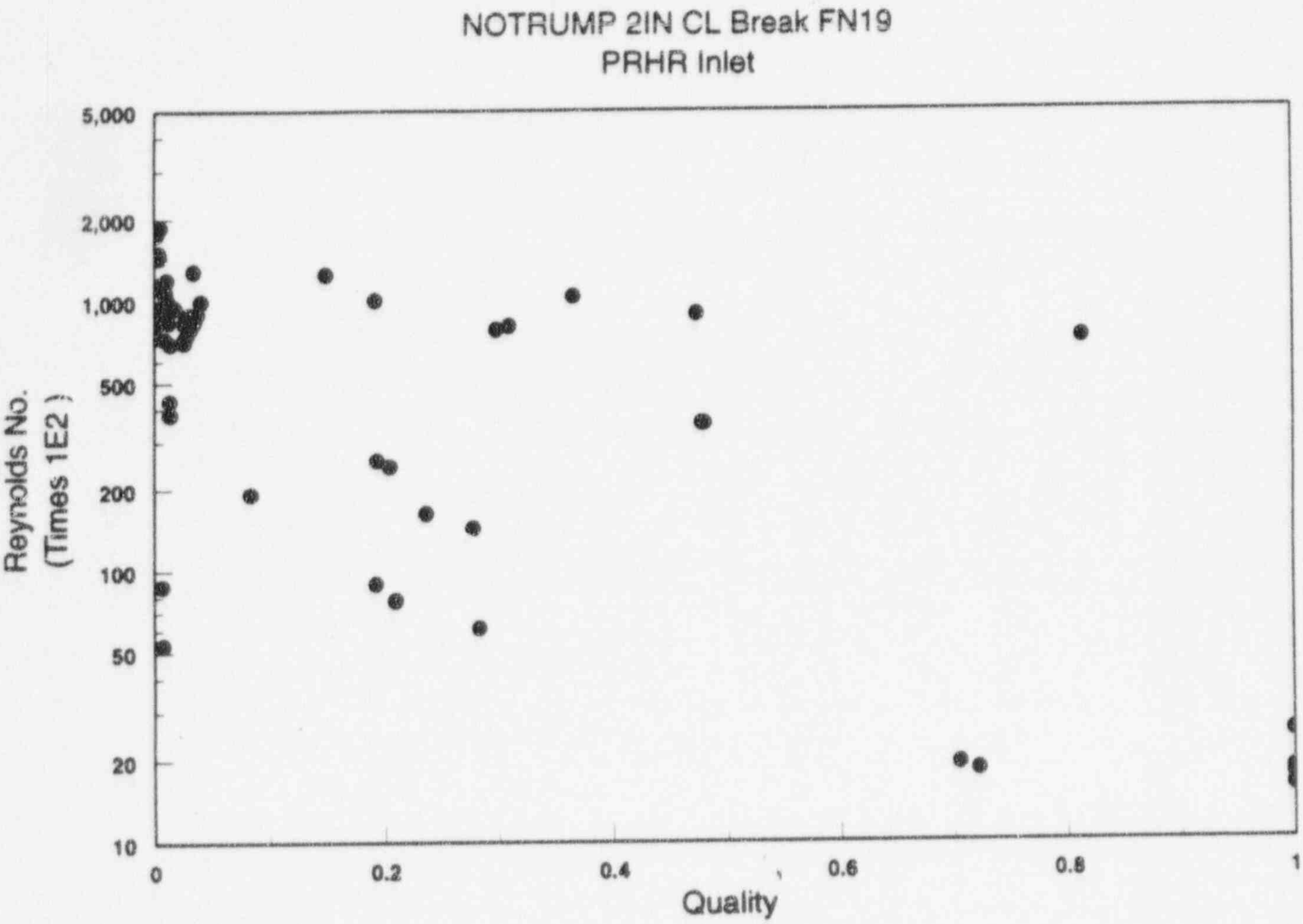

Figure 440.479-1

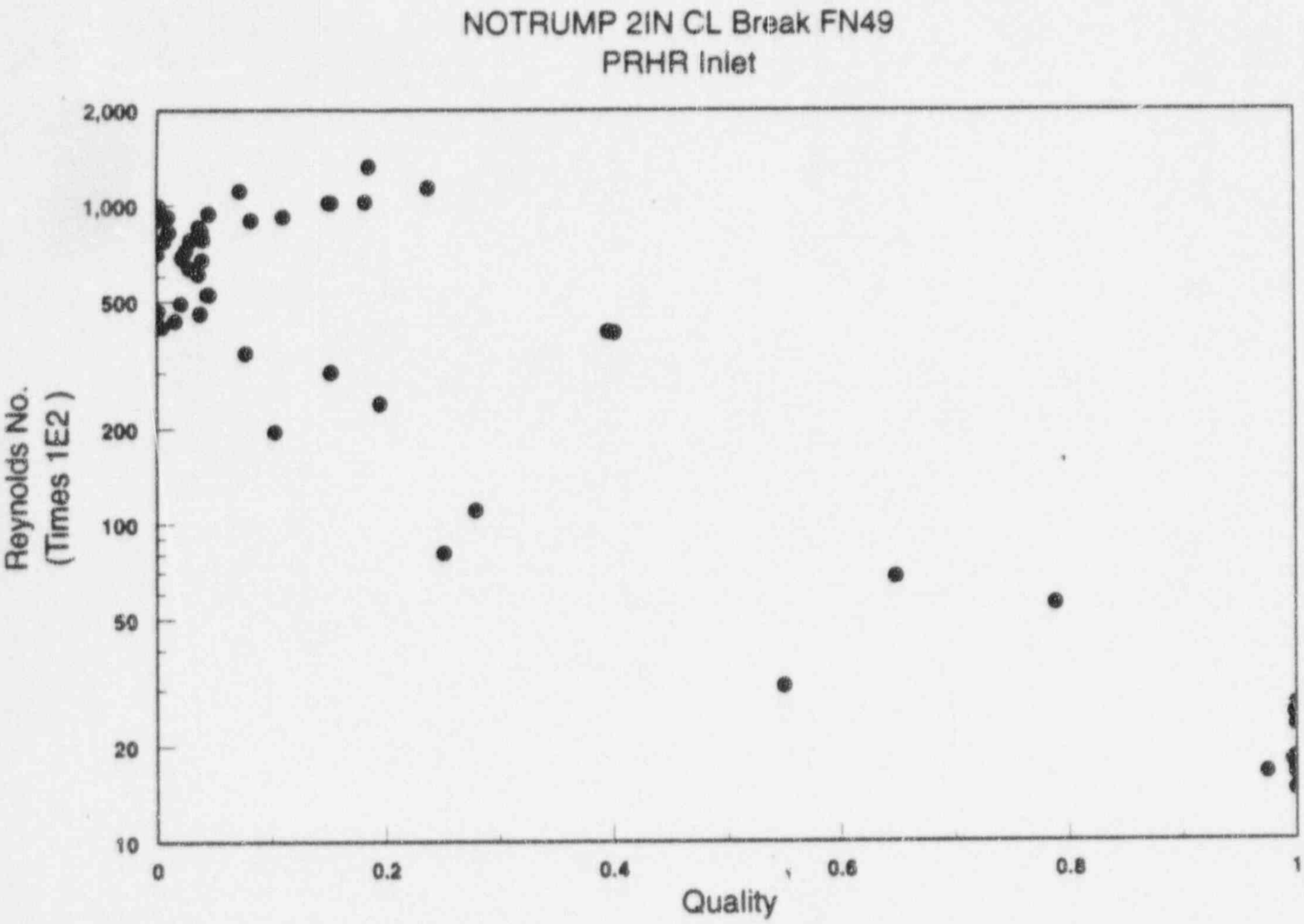

Figure 440.479-2

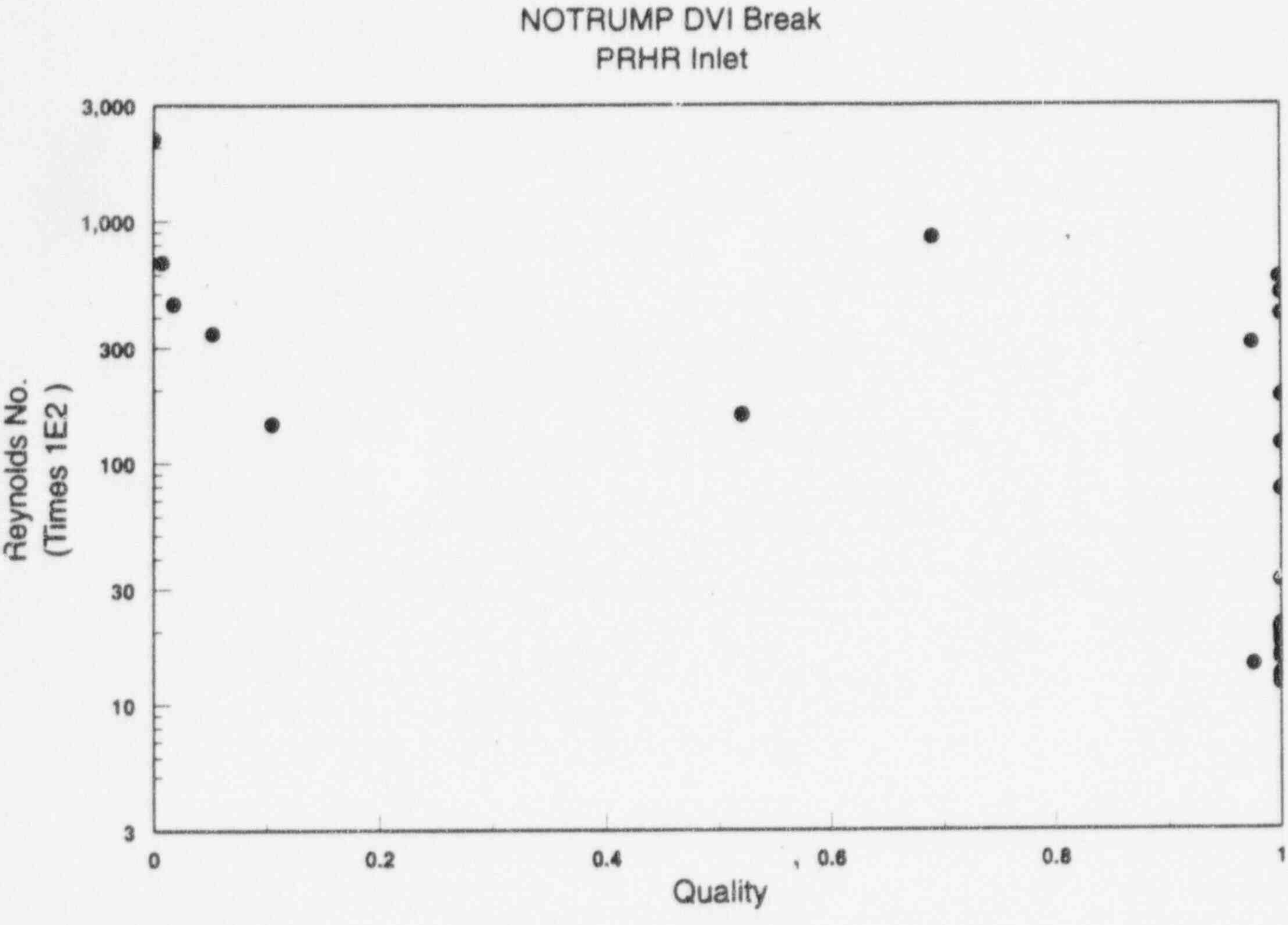

Figure 440.479-3

Question 440.480

Re: NOTRUMP PVR FOR OSU TESTS, LTCT-GSR-001, JULY 1995
Provide a comparison of the results of the as implemented Zuber critical heat flux correlation to test data over the range of conditions expected for AP600 small break LOCAs.

Response:

The Zuber critical heat correlation is used as a lower limit for critical heat flux for stagnant flow situations. In the original NOTRUMP documentation, the McBeth correlation is used for calculating the critical heat flux on structural heat transfer surfaces, other than the fuel rods, in the reactor system as discussed in Section 6 in Reference 440.480-1.

In Equations 6-39 and 6-45 from Reference 440.480-1, the lower limit on the critical heat flux is given as 90,000/3600 Btu/ft^2-sec. In some situations, when the flow is stagnant, particularly in the steam generator and on the IRWST pool side of the PRHR, the use of this lower bound for the critical heat flux will result in NOTRUMP calculating transition boiling, rather than saturated natural convection. When NOTRUMP calculates transition boiling, there is excessive secondary side energy release to the primary side fluid. To prevent this situation from occurring, and to provide a more realistic limit for the stagnate flow situation, the Zuber critical heat flux correlation is used.

The original Zuber critical heat flux correlation was used as documented in the OSU and SPES preliminary validation reports and was validated in the original publication as given in Reference 440.480-2 over a pressure range from atmospheric to 0.8 of the critical pressure for a range of fluids as shown in Figure 1 of Reference 440.480-2.

More recently, the Zuber correlation has been modified for vertical surfaces by Lienhardt and Dhir as discussed in Collier and Thome, pages 163-167 (Reference 440.480-3) and Bjornard and Griffith (Reference 440.480-4). Bjornard and Griffith further modified the Zuber correlation as

$$q_{crit} = 0.9(1 - \alpha)\,\frac{\pi}{24} h_{fg} \rho_g \left[\sigma\, g\, g_c\, \frac{(\rho_f - \rho_g)}{\rho_g^2}\right]^{1/4} \left[\frac{\rho_f}{\rho_f + \rho_g}\right]^{1/2} \qquad (440.480\text{-}1)$$

where:

Q_{crit}	=	Critical heat flux [Btu/ft^2/sec],
ρ_f	=	Density of saturated liquid [lbm/ft^3],
ρ_g	=	Density of saturated vapor [lbm/ft^3],
σ	=	Surface tension [lbf/ft],
g	=	Gravitional acceleration [ft/sec^2],
g_c	=	32.174 [lbm ft/lbf/sec^2],
h_{fg}	=	Latent heat of vaporization [Btu/lbm],

to validate the correlation expression against other low flow CHF experiments. While much of the validation for Equation 440.480-1 was based on Freon data, Bjornard and Griffith argued that the correlation is on "firm ground due to the physical basis of the Zuber relation and its proven wide range of applicability." The modified Zuber correlation has also been validated against the transient CHF in the Semiscale experiments for the large break LOCA as given in Reference 440.480-5.

The version of the Zuber correlation in use in the NOTRUMP code does not reflect the refinements made by Bjornard and Griffith. These additional refinements will be investigated for inclusion in the final version of the code. If included, the correlation will be validated in the NOTRUMP final V&V report. The preliminary validation reports did validate the use of the early version of the correlation for the lower CHF limit for the small break LOCA.

References

440.480-1 Meyer, P. E., "NOTRUMP. A Nodal Transient Small Break and General Network Code," WCAP 10079-P-A, (1985).

440.480-2 Zuber, N., "On the Stability of Boiling Heat Transfer," Trans ASME, Vol. 80, pg. 711, (1958).

440.480-3 Collier, J. G. and J. R. Thome, Convective Boiling and Condensation, Clarendon Press, Oxford, (1994).

440.480-4 Jones, O. C. and S. G. Bankoff (editors), Light Water Reactors Vol. 1, ASME Sym. on Thermal and Hydraulic Aspects of Nuclear Reactor Safety, Atlanta, Georgia, pgs. 17-41, (1977).

440.480-5 Snider, D. M., "Analysis of the Thermal-Hydraulic Behavior Resulting in Early Critical Heat Flux and Evaluation of CHF Correlations of the Semiscale Core," EG&G Idaho, Inc., Technical Report TREE-NUREG-1073, (1977).

SSAR Revision: NONE

Question 440.501

Re: NOTRUMP PVR FOR OSU TESTS, LTCT-GSR-001, JULY 1995
440.501 Please explain what is being done to correct the numerical diffusion problems which result in the premature increase in mixture temperature for CMT-2.

Response:

This RAI is similar to RAIs 440.440 and 440.445, which concern the NOTRUMP predictions of the recirculating flow from the 500 series CMT tests. As discussed in the response to RAI 440.445, the numerical diffusion observed in the NOTRUMP calculation has only a small effect on the simulations. However, the observed differences between the NOTRUMP calculations and the data were small with the exception of one portion of the test,where the difference was 22%. All other cases showed good agreement. NOTRUMP predicted the average drain flow from the experiments accurately (see Figure 5-1 of Reference 440.501-1). The code predictions were also very good for the different transient portions of the tests as indicated in the response to RAI 440.445.

In the response to RAI 440.440, the comparisons of the NOTRUMP predictions to the measured CMT recirculation flow for the OSU and the SPES to the integral systems was discussed and it was determined that the four node NOTRUMP model also gave very good comparisons to the intergral tests as well as the CMT series 500 separate effects tests.

Therefore, there is no need to revise the numerical diffusion effects calculated by NOTRUMP for the modeling of the CMT. The comparisons to both the separate effects tests and the integral systems tests indicate that the noding which has been chosen will result in accurate predictions of the CMT drain flows. If condensation and mixing occurs at the top of the CMT, the noding used in the CMT model will also give an accurate modeling of the reduced CMT drain flow and the delay time for the full drain flow to occur, as seen in Reference 440.501-2. The CMT noding which has been developed from the CMT separate effects tests has been verified with the AP600 integral systems tests and is suitable for AP600 plant analysis.

References

440.501-1 Jaroszewicz, J. and L. E. Hochreiter, "AP600 NOTRUMP Core Makeup Tank Preliminary Validation Report for 500-Series Natural Circulation Tests", MT01-GSR-011, April 1995.

440.501-2 Cunningham, J. C. , Haberstroh, R. C. , Hochreiter, L. E., and J. Jaroszewicz, "AP600 NOTRUMP Core Makeup Tank Preliminary Validation Report", MT01-GSR-001, Oct. 1994.

SSAR Revision: NONE

Question 440.555

Re: 440.555 Re: LTCT-GSR-003
The LTC window is supposed to represent a stable set of conditions demonstrating that the core remains covered and the system is able to dissipate the decay heat. Yet this does not seem to be the case in that there are still evolutions in the system parameters for the following figures: (1) the break flow integrals (Figures 5.5-4, 5.6-4, 5.7-4 and 5.8-5) (2) the ADS flow integrals (Figures 5.5-16, 5.6-16, 5.7-12 and 5.8-17) and the steam flow generated in the core (Figures 5.5-23, 5.6-23 and 5.7-19). In view of the above: why is the code converging?, why is the code stable? and why is the code suitable for the problem?

Response:

All of the plots cited in this RAI are integrated flows. For this type of plot the slope of the line represents the flow rate. In order to conclude that a stable flow has occurred in the test or WCOBRA/TRAC has predicted a stable flow rate, the lines on the plots must be approximately straight, but not necessarily horizontal. Although there are oscillations seen in the measured flow lines on some of the plots (FIGS 5.7.4 and 5.8.5), in general it can be concluded from these plots that the measured flow rates and the WCOBRA/TRAC predicted flow rates are essentially stable.

SSAR Revision: NONE

Question 440.556

Re: 440.556 Re: LTCT-GSR-003
Section 15.6.5.4C.1.0 states that an entire transient was modeled. Please show the results of such a transient if it is available. If not why not?

Response:

SSAR section 15.6.5.4c.1.0, stating that an entire transient calculation was to be modeled, was written before the WCOBRA/TRAC OSU long-term cooling calculations were performed. It was found that the computational time required for a full OSU transient calculation was too great to be accomplished. Consequently, the preliminary report included two calculations for each test: from the start of the transient to the start of IRWST injection, and a window at the start of sump injection (end of IRWST injection for test SB12) of approximately 1000 seconds. The initial conditions for the second calculation were taken from the final conditions of the first calculation. The approach adopted was that the second calculation would converge to the correct quasi-steady state for the long-term cooling injection, from any reasonable set of initial conditions. To verify this window-mode approach, it is proposed that in the Final Validation Report set of calculations, one of the tests will be simulated three times, each with a different set of initial conditions for vessel inventory, downcomer liquid temperature, cold leg inventory and hot leg inventory. These initial conditions will be taken from test measurements at times corresponding to minimum LTC-phase vessel inventory, IRWST 50% full and IRWST 10% full. In each calculation the water in the core will be specified at saturation temperature and the metal temperature will be taken from test measurements at the beginning of sump injection. The three simulations of the selected test at sump injection initiation will thus begin from a wide range of initial conditions; if they all converge to similar quasi-steady state predictions, the assumptions inherent in the window-mode approach will be justified. The remaining tests will then be each modelled once, using initial conditions from an appropriate time during IRWST draining.

SSAR Revision: NONE

Question 440.557

Re: 440.557 Re: LTCT-GSR-003
On page 5.2-3 the presence of non condensable (air) caused a 500 sec delay to CMT draindown initiation. Is the presence of the accumulator cover gas accounted in the system during the transient?

Response:

A rewritten paragraph is provided below.

Figures 5.2-7 to 5.2-10 show the comparisons between the test and the WCOBRA/TRAC simulation for CMT-1. Note that due to the location of the break in the balance line, CMT-1 injected water into the reactor vessel in the same way as the IRWST, driven by the gravitational head of the water in the tank. In the WCOBRA/TRAC simulation CMT-1 injection started at 550 seconds, while in the test the injection started at 1000 seconds. The difference in timing is because the reactor vessel pressure is lower in the prediction than in the test over this period of time. Although the timing of the start of injection from CMT-1 was different, the integrated flow rate and rate of decrease of the CMT-1 level were well predicted.

The release of accumulator nitrogen is modeled during the SBLOCA part of the test predictions provided in LTCT-GSR-003.

SSAR Revision: NONE

Question 440.559

Re: 440.559 Re: LTCT-GSR-003
There is a significant discrepancy from 320 sec to 440 sec in the CMT injection flow rate Fig. 5.4-12. In addition the direction of the simulation is opposite to that of the calculation. The same trend is manifested in Figures 5.3-14, 5.2-12 and 5.1-8. What caused the discrepancy and what does it mean for the code?

Response:

The CMT and accumulator flows discharge through the same DVI lines into the vessel. The test results show that when the accumulator is discharging, this tends to interrupt the discharge from the CMTs (see Figs 5.1.8, 5.2.12, 5.4.8 and 5.4.12). Whether the accumulator flow suppresses the CMT flow is determined by the balance of the driving forces of the two flows and the flow resistance losses in the accumulator and CMT discharge lines upstream of the point where the lines merge. Since performing the calculations reported in LTCT-GSR-003, the test data measuring the line losses has been re-analyzed, and more accurate line losses are now available. They will be employed in the WCOBRA/TRAC Final Validation report. The fact that CMT flow suppression by accumulator flow is not predicted in the calculations reported in LTCT-GSR-003 in the same way as in the tests is attributed in part to inaccuracies in the input loss coefficients applied to the accumulator and CMT discharge lines. In the predictions of discharge from CMT-1 and CMT-2 in test SB01 (Figs. 5.1.8, 5.1.12) and CMT-2 in test SB21 (Fig.5.4.12) it can be seen that the CMT flow is predicted to increase for a period of time to a value higher than the typical CMT discharge rate. This is attributed to the unsteady nature of the predicted CMT flow and is not connected with the predicted accumulator flow which occurs at approximately the same time.

SSAR Revision: NONE

Question 440.560

Re: 440.560 Re: LTCT-GSR-003
What is the consequence of the systematic underprediction of the IRWST level in Figures 5.5-1, 5.6-1 and 5.7-1?

Response:

The correct initial liquid level in the IRWST was input to WCOBRA/TRAC, but for the calculations of SB01, SB10 and SB12 some of the water exited from the top of the IRWST. This problem did not occur in the SB21 calculation. This computational problem will be resolved in the final calculations. It should be noted that for tests SB01,SB10 and SB21, the calculations model the period at the start of sump injection and during this period the IRWST injection is comparable to the sump flow. For test SB12, the calculation models the period at the end of IRWST injection. The important thing is to predict the correct total mass flow and average temperature at the DVI nozzles and demonstrate the ability of the AP600 to maintain long-term cooling with these flows. This point is discussed further in the response to question 440.565.

SSAR Revision: NONE

Question 440.561

Re: 440.561 Re: LTCT-GSR-003
The WC/T ADS 1,2,3 flow integrals in Figures 5.5-16, 5.7-12 and 5.8-17 disagree with the OSU results and in addition show inconsistent trends. The trends do not point to a stabilized regime as expected for LTC. Please comment.

Response:

As stated on page 5.7-2, the back pressure at the ADS 1-2-3 nozzles was specified too high in the SB12 calculation, resulting in a predicted negative flow into the pressurizer. This will be corrected in the final calculations. It can be seen that WCOBRA/TRAC overpredicts the integrated ADS 1-2-3 flow for test SB01 and underpredicts for tests SB10 and SB21 However, the ADS 1-2-3 does not play an important role during long-term cooling because the predicted and measured flows are small compared to the ADS4 flows. It is judged that any mis-prediction of ADS1-2-3 flows has little impact on the calculation results as a whole since, only steam exits through ADS 1-2-3.

SSAR Revision: NONE

Question 440.562

Re: 440.562 Re: LTCT-GSR-003
There is a large initial discrepancy (which persists throughout the window) in the core level estimates as shown in Figures 5.5-24, 5.6-24, 5.7-20 and 5.8-25. Please comment on this phenomenon and its significance.

Response:

The initial discrepancy in the core liquid level at the end of IRWST discharge occurs because the window mode simulations do not presume the core level rise during the IRWST discharge period. The window-mode simulation core level initial condition is taken from the end of the SBLOCA portion of the transient at the start of the IRWST discharge. For tests SB01, SB10 and SB21 (Figs. 5.5.24, 5.6.24 and 5.8.25) the predicted core level approaches the measured core level during the 400 seconds which establish the window-mode calculation, and the difference between the quasi-steady predicted and measured collapsed core levels is typically 3-4 in., which is regarded as good agreement. For test SB12 (Fig.5.7.20), the core level is underpredicted by 7 in., which is not as good but still acceptable agreement. The core is still predicted to be covered with a two-phase mixture for this test. Also, in all of the tests, the WCOBRA/TRAC predictions are conservative, in that the amount of water in the core is under-predicted.

SSAR Revision: NONE

Question 440.563

Re: 440.563 Re: LTCT-GSR-003
The upper plenum pressure is underpredicted in Figures 5.6-2, 5.7-2 and 5.8-3. The corresponding break flows in Figures 5.6-4, 5.7-4 and 5.8-5 are inconsistent in that they should all be overpredictions. Aren't pressure predictions crucial for the core LTC behavior in that small pressure differences (from the real ones) can change the outcome of the transient? What are the step decreases in the beginning of these windows?

Response:

It is important to accurately predict the vessel pressure during long-term cooling, because this will determine the rate of penetration of water from the sump. It can be seen from the plots of Ref 440.563.1 that the liquid levels in the primary sump during sump injection are 76 inches for tests SB01, SB10 and SB21 and is 81 inches for test SB12. This corresponds to a delivery pressure at the DVI nozzles of 15.6 psia for tests SB01, SB10 and SB21 and 15.8 psia for test SB12. This excludes flow losses in the DVI line, which would cause the delivery pressure at the nozzles to drop. Since it is known that the sump injects into the vessel during this phase of the test, the vessel pressures cannot be higher than the above pressures. The vessel pressures predicted by WCOBRA/TRAC in all of the tests and the measured pressure in test SB01 are close to these sump delivery pressures. The measured vessel pressures for tests SB10, SB12 and SB21 are approximately 2 psi higher. This suggests that the pressure measurements are inaccurate. The pressure is measured by a transducer capable of measuring 500 psi. It is stated in Ref. 440.563.2 that errors of the order of 2 psi were observed with these wide-range pressure transducers.

The step decreases seen at the beginning of the predictions are due to the transition from the initial conditions of the window calculation (taken from the earlier calculation at the start of IRWST injection) to the conditions at the time of sump injection. Results from this part of the calculation are not used to assess the ability of WCOBRA/TRAC to model long-term cooling.

References

440.563.1 AP600 Low Pressure Integral Systems Test at OSU. Final Data Report. C L Dumsday et al. WCAP-14252 May 1995.

440.563.2 AP600 Low Pressure Integral Systems Test at OSU. Test Analysis Report. T S Andreychek et al. WCAP-14292 September 1995.

SSAR Revision: NONE

Question 440.564

Re: 440.564 Re: LTCT-GSR-003
Figure 5.7-21 indicates the upper plenum level to increase while in this window the inventory should have stabilized. Please explain. In the remaining upper plenum data, there is a step level change. What is this due to?

Response:

This window calculation should have been continued until a steady predicted upper plenum level was achieved, but the calculation was terminated at 9000 seconds. Our intention is to continue all of the calculations in the final validation report until steady values of all key predicted parameters are achieved. The step change at the start of the calculation is transient behavior before a quasi-steady state is established. Results from this transient part of the calculation are not used to assess the WCOBRA/TRAC modeling of long-term cooling.

SSAR Revision: NONE

Question 440.565

Re: 440.565 Re: LTCT-GSR-003
In Figure 5.8-14 there is a significant DVI nozzle temperature underprediction, attributed to the contribution of the IRWST water. Is IRWST still operating this late in the transient?

Response:

The window selected for test SB21 starts at 10,800 seconds, and the IRWST injects in this test beyond 11,800 seconds. At the beginning of sump injection there is still some IRWST injection in all of the tests considered. Inspection of the calculated and measured sump and IRWST flows shows that they are not well predicted. Also, there is still injection occurring from CMT-2 in test SB01, but in the calculation of test SB01 it is assumed that the CMT's are empty. Consequently, the total DVI flow is not well predicted in the preliminary calculations. Since the sump and IRWST water are at different temperatures, the temperature at the DVI nozzles is also not well predicted for tests SB01 and SB21. Since carrying out the calculations reported in LTCT-GSR-003, the losses in the sump and IRWST lines have been recalculated. In the Final Validation report calculations the revised loss coefficients will be used and the CMT initial inventories will be correctly modelled for each window. Thus, it is anticipated that better agreement will be achieved in the final calculations. To assess the adequacy of the preliminary calculations to represent the correct flow rate and temperature at the DVI nozzles, the table below shows the quasi-steady total DVI flow (DVI-1 and DVI-2 combined) and the quasi-steady average temperature of the total DVI flow for the tests and the preliminary calculations. In general, the predicted values of both the total injection flow and its temperature, are below the measured values during long-term cooling.

	SB01	SB10	SB12	SB21
TOTAL FLOW RATE, TEST (LB/SEC)	0.9	1.0	0.5	0.5
TOTAL FLOW RATE, CALC (LB/SEC)	0.5	0.8	0.25	1.2
AVERAGE TEMPERATURE, TEST (°F)	140	130	90	125
AVERAGE TEMPERATURE, CALC (°F)	125	125	90	100

SSAR Revision: NONE