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TECHNICAL EVALUATION REPORT ON THE TENNESSEE VALLEY AUTHORITY'S PROPOSED METHOD TO CALCULATE ENVIRONMENTAL CONDITIONS INSIDE CONTAINMENT FOR QUALIFICATION OF SAFETY-RELATED ELECTRICAL EQUIPMENT DURING A MAIN-STEAM-LINE BREAK

by

J. N. Edwards
Los Alamos National Laboratory

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1. SUMMARY

The Tennessee Valley Authority (TVA) has proposed a new method to calculate the environmental conditions inside a containment during a main-steam-line break (MSLB). The calculated environmental conditions will be used to establish the conditions for qualification of electrical safety equipment inside a containment.

The US Nuclear Regulatory Commission (NRC) requires MSLB analyses of containment environments for qualification of electrical equipment to comply with NUREG-0588 guidelines.[1] TVA's proposed method does not comply with these guidelines, and the results of the Los Alamos National Laboratory's review of the TVA's proposed method to determine if it is sufficiently conservative to allow its use in lieu of the NUREG-0588 methods are presented here.

TVA first did a demonstration analysis of the Carolinas Virginia Tube Reactor[2] (CVTR) containment experiments using their MONSTER containment computer code.[3] For its analysis, TVA used the CVTR experimentally determined heat-transfer coefficients and parametrically varied the revaporization rate to achieve a good-fit analysis for the CVTR temperature data (Fig. 1). TVA chose a 10% revaporization rate and considered this analysis conservative because MONSTER over-predicted the maximum CVTR experimental temperature by

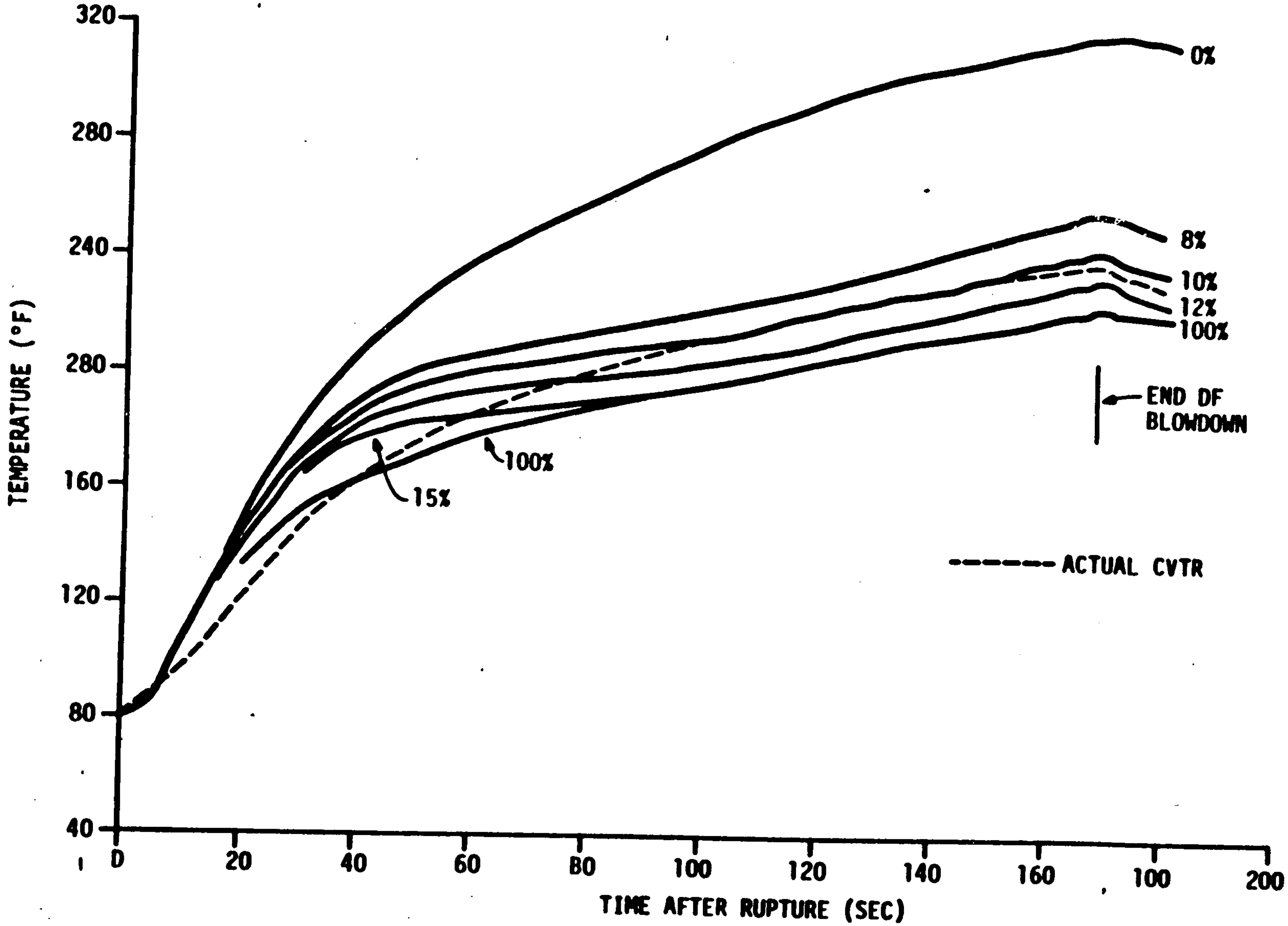

Fig. 1. CVTR containment temperature profiles predicted with average CVTR heat transfer coefficients and bulk temperature with various revaporization rates compared to maximum measured temperature profile (Ref. 3, Fig. 7).

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4°F. Considering the large spatial temperature variations observed in the CVTR tests (more than 100°F), Los Alamos disagrees with TVA's conclusion that theirs is a conservative analysis of CVTR.

TVA proposes to apply the CVTR results to the Bellefonte Nuclear Plant (BLN) by scaling the CVTR heat-transfer coefficients to BLN. Their scaling approach assumes that the same maximum heat-transfer coefficient would be observed in BLN as was observed in CVTR. TVA also assumed that the form of the Tagami correlation[4] would be valid in scaling from CVTR to BLN, but the CVTR report[2] already has shown that the Tagami correlation predicted the CVTR results poorly. By using the form of the Tagami equation and assuming that the maximum heat-transfer coefficient is the same in CVTR and BLN, TVA's scaling method results in scaling the time of the peak heat-transfer coefficient for BLN. The peak occurs earlier in BLN by the ratio of the integrated blowdown energy rates per unit containment volume. Los Alamos reviewed the literature and concluded that the TVA scaling method is not an orthodox approach and is not based on basic physical principles. Also, as a new model, the TVA scaling method is not supported by comparison with experimental data. Based on these arguments, Los Alamos does not believe that TVA has proposed a demonstrably conservative alternative to the NRC-required method.

2. INTRODUCTION

Around 1977, NRC licensing analyses showed that some MSLB calculations predicted higher temperatures in some pressurized water reactor (PWR) dry containments than did calculations for primary coolant loss-of-coolant accidents (LOCAs). The problem this indicated was that the equipment inside containment necessary for plant safety under accident conditions had to be qualified for the most severe environment in which it would be required to operate during the life of the plant. LOCA temperatures were calculated to be 300°F or less, whereas MSLB temperatures were calculated as being in excess of 400°F. (These higher temperatures were found to last for 100 s or less.) The equipment inside the containment was being qualified for the lower temperatures seen in LOCAs. NRC then performed analyses to formulate a licensing position on this issue.[5] The new licensing requirements are contained in NRC report NUREG-0588, which is entitled "Interim Staff Position on Environmental Qualification of Safety Related Equipment" and was published in July 1981.[1]

TVA submitted an analytical method[3] and Final Safety Analysis Report (FSAR) revision[3] for its BLN that would be acceptable for MSLB and at the same time be less restrictive than the analyses for this case in its current FSAR.

3. NUREG-0588 REQUIREMENTS

3.1 Requirements

NUREG-0588 is the principal document governing the specific requirements for calculating environmental conditions for qualification of safety-related electrical equipment. NUREG-0588 deals with a number of issues related to equipment qualification, one of which is calculating temperature and pressure conditions inside containment for an MSLB.

The NUREG-0588 requirements are divided into two categories based on when the plant was licensed. Category I is applicable to equipment qualified in accordance with IEEE Standard 323-1974; Category II is applicable to equipment qualified in accordance with IEEE Standard 323-1971. [Category II is a grandfather clause to require less stringent treatment of plants whose qualification already had begun when NUREG-0588 was published (July 1981)]. The most specific requirements are given for Category II, and are these listed in Appendix B of NUREG-0588. For Category I equipment, NUREG-0588 states that the plant-specific model must be reviewed and approved by the staff; Appendix B of NUREG-0588 is not invoked specifically for Category I, which implies that the criteria are more stringent for Category I. In discussions with the NRC staff, we understood that Category II plants could use 8% revaporization as stated in NUREG-0588, Appendix B, but Category I plants had to use 0% revaporization. BLN is believed to be a Category I plant. TVA compares their new calculative method with the method specified in NUREG-0588, Appendix B, which is reviewed below.

3.1.1. NUREG-0588 Appendix B Requirements for MSLBs for Category II Plants

3.1.1.1. Heat-Transfer Coefficient

For heat transfer to heat sinks, the Uchida[6] heat-transfer correlation should be used for MSLBs that occur while the plant is in the condensing mode. A natural convection heat-transfer coefficient should be used at all other times. These correlations should be applied as follows (from Appendix B).

"(1) Condensing heat transfer

$q/A = h_{cond} \bullet (T_s - T_w)$,

where q/A = the surface heat flux,
h_{cond} = the condensing heat-transfer coefficient,
T_s = the steam saturation (dew point) temperature, and
T_w = surface temperature of the heat sink.

(2) Convective heat transfer

$q/A = h_c \bullet (T_v - T_w)$,

where h_c = convective heat-transfer coefficient and
T_v = bulk vapor temperature.

All other parameters are the same as for the condensing mode."[1]

3.1.1.2. Heat Sink Condensate Treatment

The heat sink condensate treatment in Appendix B is as follows.

"When the containment atmosphere is at or below the saturation temperature, all condensate formed on the heat sinks should be transferred directly to the sump. When the atmosphere is superheated, a maximum of 8% of the condensate may be assumed to remain in the vapor region. The condensed mass should be calculated as follows.

$$M_{cond} = X \bullet q/ (h_v - h_L),$$

where M_{cond} = mass condensation rate,
X = mass condensation fraction (0.92)
q = surface heat-transfer rate,
h_v = enthalpy of the superheated steam, and
h_L = enthalpy of the liquid condensate entering the sump region (that is, average enthalpy of the heat sink condensate boundary layer)."[1]

These models are developed based on analyses performed by P. Baronowsky and discussed in an NRC Memorandum;[5] the development is discussed in the next section.

3.2 Analytical Basis

The analysis reported in Tedesco's memorandum (Ref. 5) was the principal one done to develop the requirements of NUREG-0588. It is entitled, "Best Estimate Evaluation for Environmental Qualification of Equipment Inside Containment Following a Steam Line Break." Of the issues that Ref. 5

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considered, the condensing heat-transfer coefficient and condensate revaporization are relevant to our review.

3.2.1. Condensing Heat-Transfer Coefficient

Under this heading in Ref. 5, the authors point out that steam-line break analyses traditionally have used the Uchida correlation to model condensing heat transfer throughout the accident. Tedesco presents arguments that, for large MSLBs, the Tagami heat-transfer correlation will predict higher heat-transfer coefficients but points out that the CVTR tests showed that the Tagami correlation was still conservative by a factor of 4 or 5. Tedesco[5] recommends using the Tagami correlation for the large MSLBs until the end of the blowdown phase and then using an exponential decay down to the values calculated using the Uchida correlation.

Reference 5 noted that the condensing heat-transfer coefficient is determined adequately for small steam-line breaks using the Uchida correlation for steam in air condensing in a relatively quiescent container. For heat-transfer consideration, Ref. 5 defines small steam-line breaks as those breaks that result in a prediction of containment conditions such that the Uchida heat-transfer rate exceeds the Tagami heat-transfer rate.

3.2.2. Condensate Revaporization

"Condensate revaporization" is the term used to describe the fact that all of the heat transferred to the containment or other heat-sink surfaces is not from the condensing steam; some of it comes from the air and superheated steam first being cooled to the saturation temperature. It is called condensate revaporization because it originally was thought to be just that in the CVTR tests--condensate that first was condensed and later was revaporized.

Analytical comparisons[5] with the CVTR experiments indicate that during the blowdown phase, when the atmosphere is superheated, the revaporization rate is high. The CVTR test results show that essentially all of the heat-sink condensate remains in the liquid state in the post-blowdown phase. In Fig. 2 (Tedesco's Fig. 3), the CVTR test results are compared with temperatures predicted using revaporization rates of 9.6% and 7.6%. They note that a revaporization rate of 9.6% gives a best fit to the CVTR data and that 7.6% bounds the CVTR data. A revaporization rate of 7.6% is used for the remainder of the analyses presented in Ref. 5.

In addition to discussing the condensing heat-transfer coefficient and condensate revaporization rate, Ref. 5 discusses liquid entrainment in the break effluent and heat transfer to components, which are not issues in the current review. Reference 5 then applies the methods and assumptions listed in the paragraph above to the MSLB analyses for a Westinghouse plant and makes a generalized extension of the method to Babcock and Wilcox and Combustion Engineering NSSS-supplied plants. Throughout its analyses, Ref. 5 uses the Tagami and/or Uchida correlations with 7.6% and 0% revaporization. These results then were used to establish the requirements of NUREG-0588.

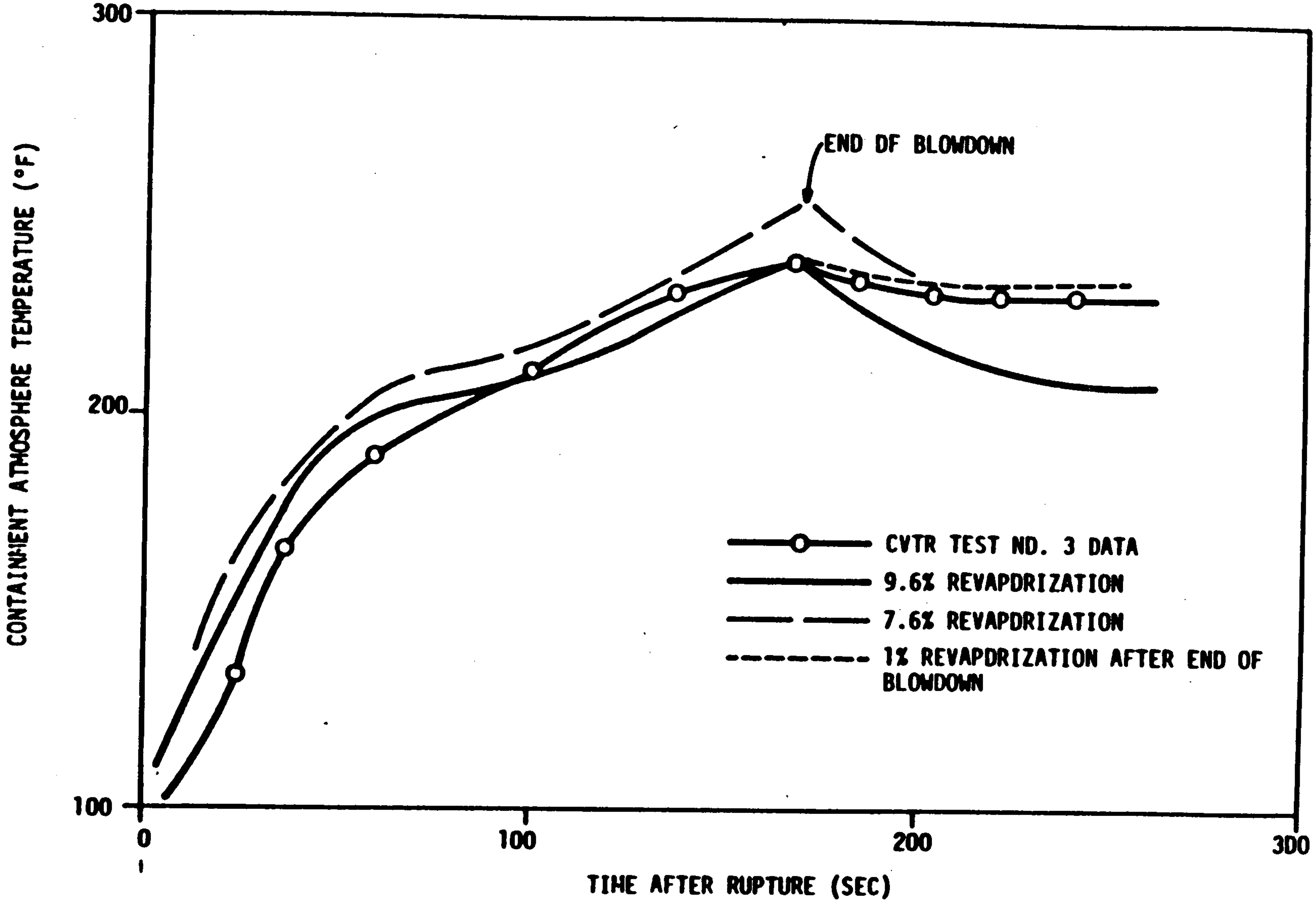

Fig. 2. NRC's comparison of various revaporization rates used in modeling the CVTR test data (Ref. 8) (Ref. 5, Fig. 3 and Ref. 3, Fig. 1).

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4. TVA'S PROPOSED ANALYTICAL METHOD

TVA's objective is to justify using a method that is less conservative than the NRC approach required by NUREG-0588 but that still is reasonably conservative. Their method is based on using CVTR experiments to quantify the heat-transfer coefficient that would be expected in BLN during an MSLB. To do this, their analysis has two parts. First, TVA analyzed the CVTR experiments to demonstrate their predictive methods for analyzing these data and show that their analysis is conservative for CVTR. The second element necessary to establish their method for BLN was to develop a method of scaling the CVTR results to BLN.

4.1. Analysis of CVTR Experiments

In Fig. 3 (TVA's Fig. 2 from Ref. 3), TVA presents the results of a MONSTER computer code analysis of the CVTR experiments using the NRC NUREG-0588 required methods showing the hottest CVTR experimental temperatures and the temperatures calculated using the Uchida correlation with ΔT based on the saturation temperature and calculated for 0% and 8% revaporization. The peak temperatures are as follows.

CVTR experimental value: 236°F
MONSTER with 8% revaporization: 318°F
MONSTER with 0% revaporization: 360°F

These results demonstrate the conservative nature of the NUREG-0588 method. In Fig. 1, TVA's results of MONSTER calculations for CVTR using the average experimentally observed CVTR heat-transfer coefficients were presented. These heat-transfer coefficients are used with ΔT based on the bulk atmosphere temperature. Results were plotted for various revaporization rates. Based on this figure, TVA proposes that the calculation using 10% revaporization is a conservative evaluation for CVTR. This is an important point in their analysis; however, in looking at Fig. 1, Los Alamos cannot agree. First, based only on the figure, the 10% curve lies right on top of the experimental data for a significant portion of the time and ends up 4°F higher at the peak. This is not a conservative estimate in our opinion, particularly when you consider that a temperature stratification of more than 100°F was observed

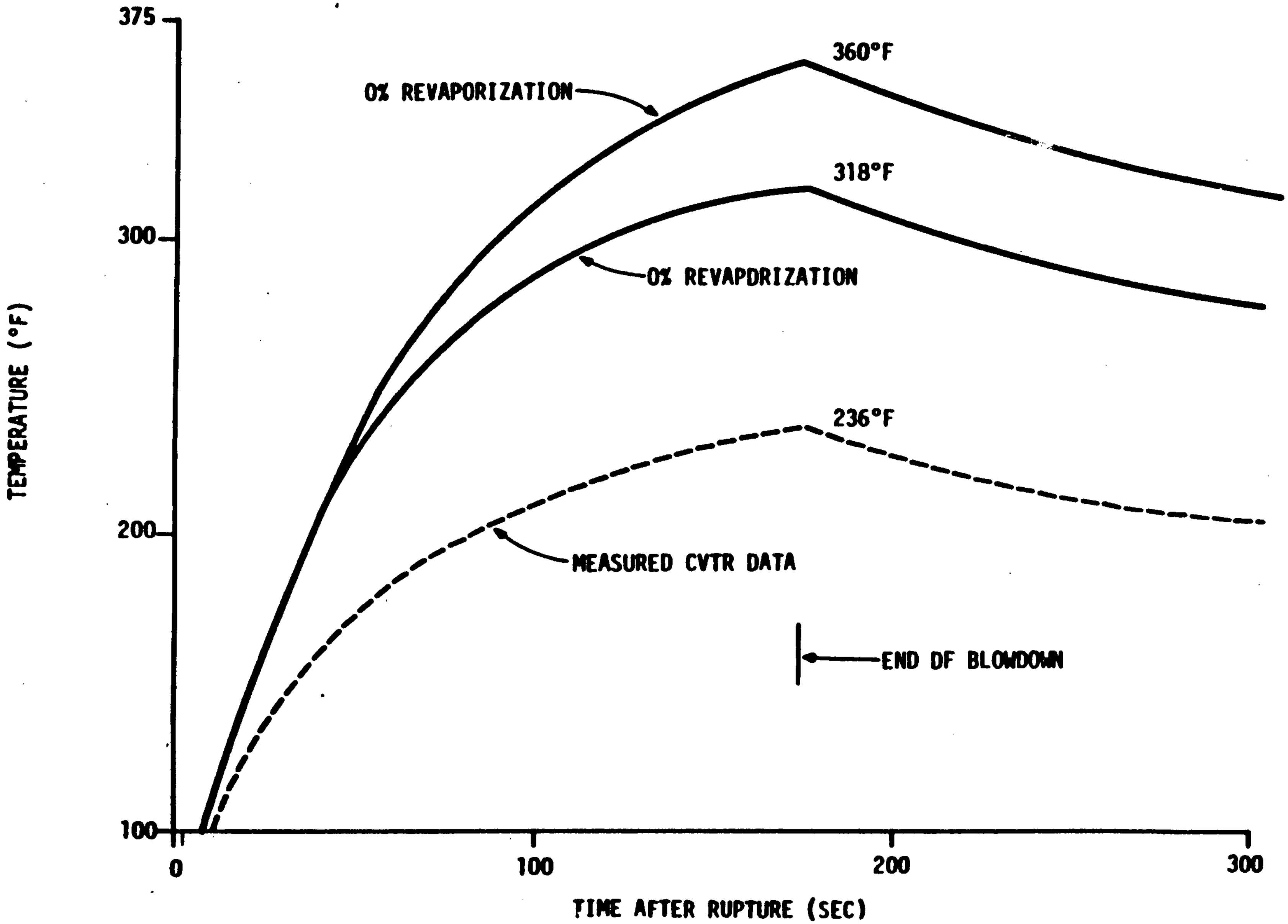

Fig. 3. CVTR containment temperature profiles predicted with Uchida correlation and saturation temperature compared to maximum measured temperature profile (Ref. 3, Fig. 2).

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in the CVTR experiments. The CVTR heat-transfer coefficients were measured at two locations differing in elevation by 18 ft, but they had peak heat-transfer coefficients of 145 Btu/(ft^2-h-°F) at the lower location and 258 Btu/(ft^2-h-°F) at the upper location. We do not consider that an analysis could be considered conservative when it exceeds the peak temperature by such a small amount and does not include any basic understanding of the large spatial variation in the experimental data.

The analysis also did not deal with the temporal variations of the revaporization rate. In Ref. 5, Tedesco reported that analyses indicated a revaporization rate of 7.6% during the blowdown phase and 1% after the blowdown phase.

Our conclusion is that, in light of the significant unanalyzed nonhomogeneous effects observed in the CVTR experiments and the small margin by which TVA over-predicts the peak CVTR experimental temperature, the TVA analysis of CVTR is not conservative.

4.2 TVA's Scaling of the CVTR Heat-Transfer Coefficients

In Sec. II.D.2 of Ref. 3, TVA states that

> "In order to use the CVTR heat transfer correlation, a method for scaling is necessary. Because the high heat transfer coefficients are believed to be primarily due to turbulence, and the turbulence is caused by the blowdown, it was considered appropriate to scale on the blowdown rate. The method for doing this is not rigorous, but it does have a precedent in the development of the Tagami correlation. The Tagami correlation relates the peak coefficient to the volumetric energy release rate. Higher volumetric energy release rates produce higher levels of turbulence and thus higher heat transfer coefficients. The Tagami correlation ramps the heat transfer coefficient linearly from zero at the beginning of the blowdown to the maximum value at the end of blowdown. Because the method was developed from constant blowdown experiments, this, in effect, makes the heat transfer coefficient a function of the integrated energy release."
>
> "For the scaling method developed here, the assumption was made that the heat transfer coefficient is a function of the integrated volumetric energy release."

Based on this rationale, TVA arrives at a scaling approach that keeps the peak value of the CVTR heat-transfer coefficient the same but compresses the time scale by a factor of 4.38 to account for the relative magnitudes of BLN's integrated blowdown rate per unit volume compared with the integrated blowdown rate per unit volume for CVTR. Figure 4 shows the results of this scaling operation. This means that the time of the peak heat-transfer coefficient in BLN is 1/4.38 of the time of the peak for CVTR. The peak occurs about 110 s for CVTR and 26 s for BLN. Calculatively, this earlier peak heat-transfer coefficient will reduce the peak temperatures calculated for BLN.

The method of scaling that TVA has developed is not supported by any data independent from CVTR nor are the effects on containment temperature calculatio evaluated by sensitivity studies.

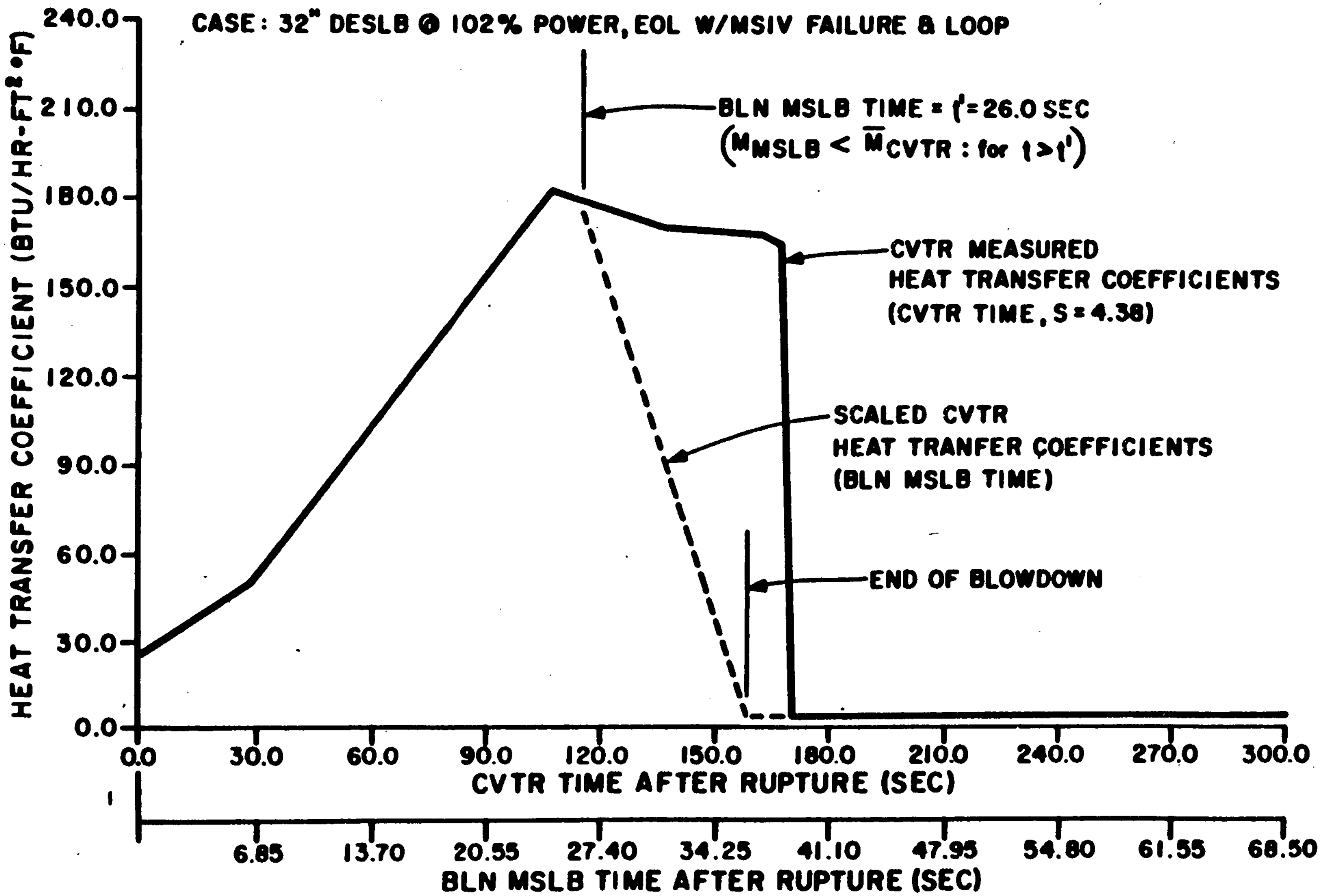

Fig. 4. CVTR average heat transfer coefficients measured and scaled for Bellefonte MSLB (Ref. 3, Fig. 10).

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5. REVIEW OF ORTHODOX SCALING METHODS

Los Alamos examined the literature to evaluate what would be an orthodox method of scaling the CVTR data. Reference 7 is a literature survey of heat-transfer correlations for containment response done by Lin and Maise.

Lin and Maise reviewed 13 correlations and methods.[7] These are classified into three groups.

1. Empirical correlations, which include the Tagami and Uchida correlations
2. Formulas based on condensate film theory
3. Formulas based on vapor/gas boundary layer theory

The problem with the empirical formulations (Group 1) is that empirical formulations that are not based on underlying physical principles are difficult to justify for conditions outside the range of the original data, which is a limitation for the Tagami and Uchida correlations. The CVTR data have shown that they did not scale well for predicting the CVTR experimental data, but they did under-predict the heat-transfer coefficient for CVTR and therefore are conservative for most uses. The formulas based on the condensate layer film (Group 2) are not useful for containment analysis for two reasons. First, in containment analysis, we are interested in the containment atmosphere temperature and pressure, not the condensate layer conditions. Second, analytical results[8-10] have shown that the resistance to energy transfer through the liquid film is negligible when compared with that of the vapor/gas boundary layer. Therefore, the heat-transfer process is controlled by the vapor/gas dynamics. This leaves us with the formulas based on the vapor/gas boundary layer (Group 3). The limitation of this group is that the equations are the most complex. The complexity comes in the theoretical treatment of the boundary layer. However, a good deal of physical understanding can be gained from examining the basic formulation of the energy equation.

The total energy transfer rate between the atmosphere and the heat-absorbing structures includes two contributions: the mass transfer (condensation) because of a density concentration gradient and the sensible heat transfer because of a temperature gradient:

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$$q_T = h_s (T_\infty - T_w) + \beta_s (\rho_{v\infty} - \rho_{vw}) h_{fg},^* \quad (1)$$

where q_T = total heat flux [Btu/(h-ft^2)],
h_s = sensible heat-transfer coefficient [Btu/(h-ft^2-°F)],
T_∞ = bulk atmosphere temperature (°F),
T_w = wall temperature (°F),
β_s = mass-transfer coefficient for a semipermeable membrane (ft/s),
h_{fg} = latent heat of vaporization (Btu/lbm),
$\rho_{v\infty}$ = vapor (steam) density at a distance removed from the wall, and
ρ_{vw} = vapor density at the wall.

This is the basic energy equation for the vapor/gas boundary layer; the acceptance of this equation is supported by its wide use in the literature even though its exact form and nomenclature varies. Equivalent forms can be found in Almenas, Eq. (2);[8] Whitley, Chan, and Okrent, Eq. (9);[9] Corradini, Eq. (1) and Eq. (20);[10] and Krotiuk, Eq. (1).[11] This equation is a well-established principle to calculate the heat transfer to the wall from a vapor/gas environment, and Los Alamos feels it should be the starting point for developing a scaling method. The question is "How well does it predict the CVTR experimental and other data?" Of the authors and references listed above, several have compared their derived equations with the CVTR, Tagami, and Uchida data.

Whitley, Chan, and Okrent had very good results predicting the Uchida data;[9] Whitley et al.'s formula has a velocity term that must be supplied. For the quiescent conditions of the Uchida test apparatus, Whitley et al. bounded the Uchida data with velocities of 1 and 5 ft/s (0.3 and 1.5 m/s). The results were not as good for the Tagami data. For a blowdown orifice of 10 mm (0.394 in.), a velocity of 15 ft/s (4.6 m/s) fit the data, whereas for the 90-mm (3.54-in.) orifice, it took a 90-ft/s (27-m/s) velocity to fit the data. It was felt that this was unrealistically high (Whitley et al.,[9] Fig. 6). Whitley, Chan, and Okrent suspected that the large orifice led to

*A. Koestel, "Development of Condensing Heat Transfer Coefficient for Turbulent Free-Convection Boundary Layer on a Flat Plate," private communication (February 1987).

significant nonhomogeneous effects. For the CVTR test data, the results again were mixed (Whitley et al.,[9] Fig. 7), and again it was felt that the difference was related to the nonhomogeneous effects.

To evaluate the nonhomogeneous effects further, Los Alamos took the basic Eq. (1) above and applied it to the CVTR data. Our first attempt was to evaluate the basic thermodynamic potentials using the CVTR data. $T_\infty - T_W$ is available directly from the CVTR data (Tables B-VI and B-VII).[2] However, the $\rho_{V\infty} - \rho_{VW}$ term had to be evaluated indirectly. The vapor density at the wall was evaluated as the density at a quality of 1.0 and a temperature equal to the wall temperature. However, the vapor density at a distance from the wall, $\rho_{V\infty}$, had to be evaluated by first finding the steam partial pressure. This was taken as the measured total pressure minus the original air pressure corrected for the temperature at the time the partial pressure is being evaluated. The $\rho_{V\infty}$ term then was evaluated at the steam partial pressure and atmosphere vapor temperature. The results were poor the first time through this exercise. The calculated $\rho_{V\infty} - \rho_{VW}$ term became negative around the time the peak experimental heat-transfer coefficient was observed. This indicates that the wall temperature is above the vapor temperature, and no condensing would take place. However, it was quite obvious from the observed heat-transfer coefficients [150-250 Btu/(h-ft^2-°F)] that condensation was taking place.

We considered a number of things that could be wrong with this calculation and concluded that the error was the homogeneous assumption that the local air pressure was 14.7 psia (corrected for temperature). We felt the air and steam are far from being mixed homogeneously because, at CVTR conditions, the density of the steam is one-half the density of the air. This provides a large buoyancy force that causes the steam to rise as it comes out of the diffuser in the CVTR experiments, which causes the air to be compressed down below. This model is supported by the CVTR photographs,[2] the large observed temperature stratifications, and similar conclusions by Schmitt et al.[2] and Whitley et al.[9]

To test this hypothesis, we reran the calculation with the CVTR data assuming various initial air pressures from 2 psia to 14.7 psia. When the air pressure was reduced, the data became convincingly like the actual CVTR data. We ran through the data for two models. First,

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$$q_T = k\,[(T_\infty - T_w) + (\rho_{v\infty} - \rho_{vw})\,h_{fg}], \qquad (2)$$

where a value of k was selected so the maximum calculated q_T agreed with the CVTR data and the other terms are the same as previously listed. The calculations were done for both CVTR heat plugs using the same value of k, and the results are shown in Fig. 5. The air pressures were selected to give the best results; in the case of Fig. 5, the air pressure for heat plug 2 was 2.0 psia, and the air pressure for heat plug 1 was 10 psia. These pressures maximized the calculated difference at the peak between heat plug 1 and 2.

The second model we looked at was

$$q_T = k\,[(T_\infty - T_w) + 10\,(\rho_{v\infty} - \rho_{vw})\,h_{fg}], \qquad (3)$$

where the 10 is based on estimates that the condensing heat transfer is an order of magnitude larger than the sensible heat transfer. These results are shown in Fig. 6. Here the air pressures used were 7.0 psia at heat plug 1 and 4.5 psia at heat plug 2. These pressures are based on best fit of the CVTR data for an analytical development* for the sensible heat-transfer coefficient based on Eckert and Jackson's "Analysis of Turbulent Free-Convection Boundary Layer on Flat Plate."[12] We feel these models did a reasonable job of predicting the shape of the observed CVTR heat flux data. There is a consistent tendency to predict the peak value earlier than was observed for CVTR. We believe this is a result of thermal lag because the experimental CVTR heat flux is based on calculations made using the internal wall temperatures; this lag should be calculable. We also did not predict as large a difference between heat plug 1 and heat plug 2 as was observed for CVTR.

In this section, we compared the scaling method proposed by TVA with the containment heat-transfer literature. There is a clear consensus. Whitley, Chan, and Okrent in their paper made the following statement about the Tagami and Uchida correlations.

*A. Koestel, "Development of Condensing Heat Transfer Coefficient for Turbulent Free-Convection Boundary Layer on a Flat Plate," private communication (February 1987).

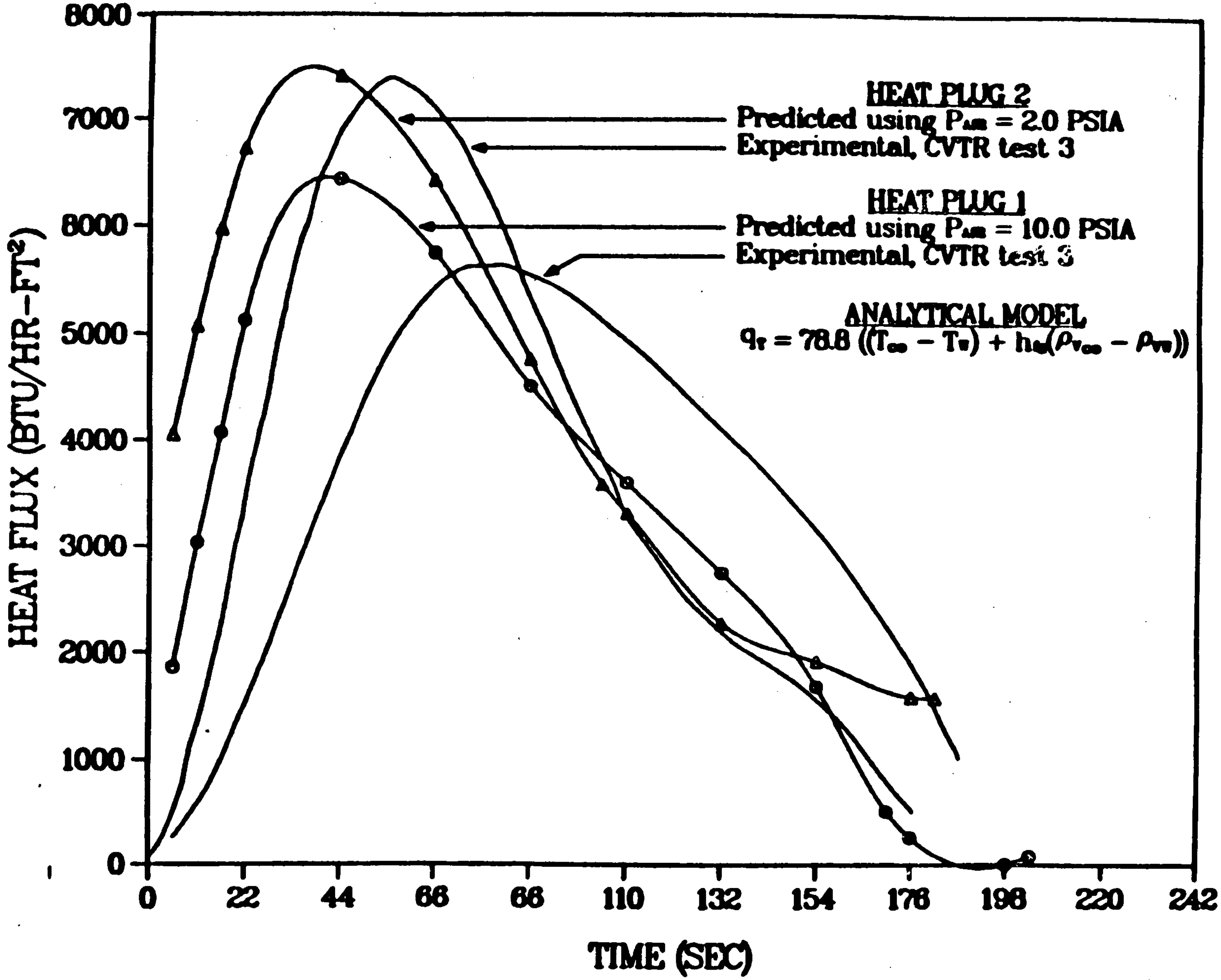

Fig. 5. CVTR Test 3 heat flux comparison of experimental and Los Alamos predicted values using the listed analytical model .

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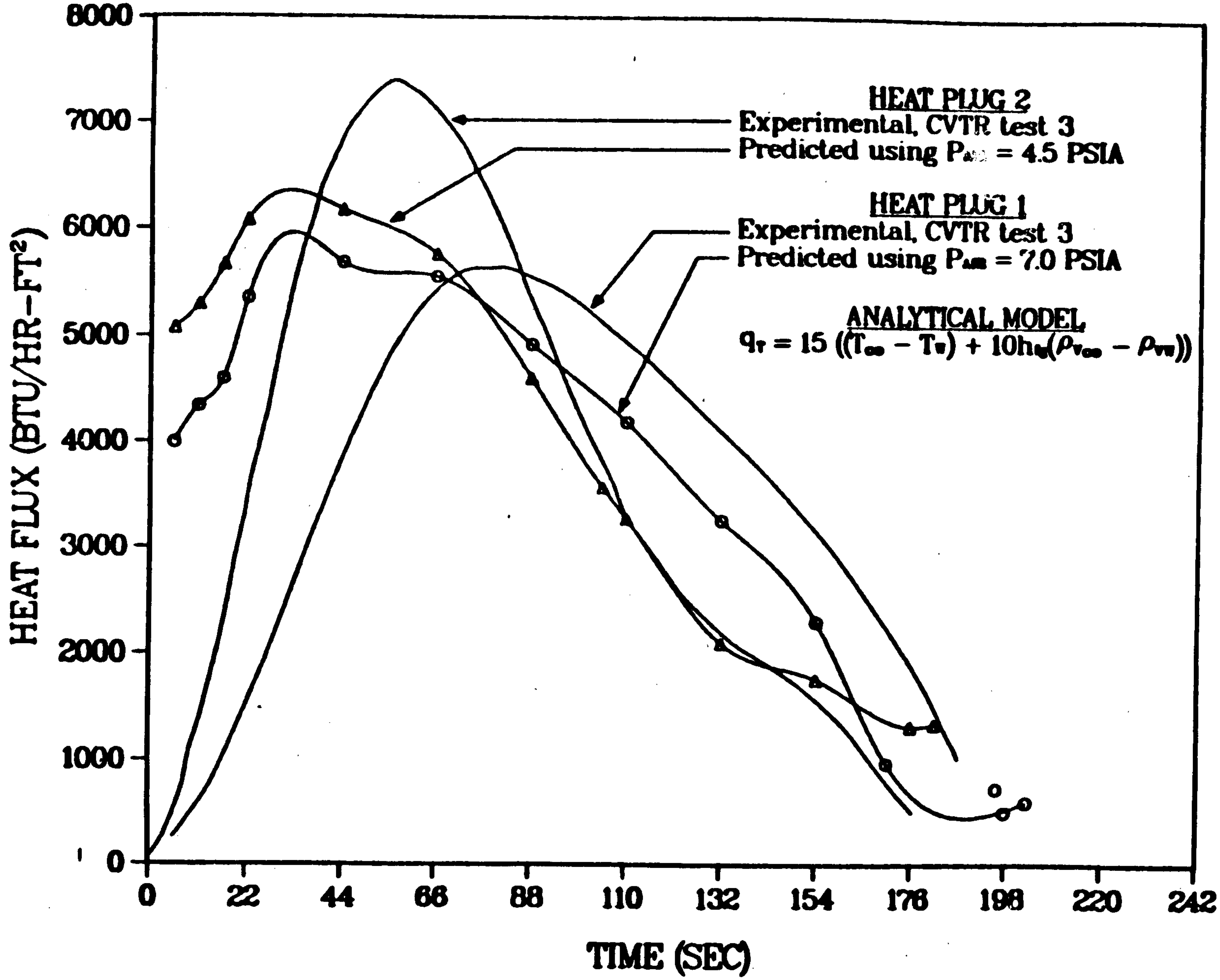

Fig. 6. CVTR Test 3 heat flux comparison of experimental and Los Alamos predicted values using the listed analytical model.

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> "These two correlations have not been confirmed by experiments with various sizes and geometrical configurations and their theoretical basis is not completely known. In view of the uncertainties involved in the application of these correlations to a large scale containment during LOCA conditions and the discrepancies between these small scale experimental data and large scale experimental data, the need for a better understanding of the steam condensation process inside the containment exists."[9]

We have shown that a number of authors have developed fundamental equations based on the physical principles shown to be important. These authors have compared their methods with the Tagami, Uchida, and CVTR data with varying degrees of success. The CVTR data present the most difficulty analytically. We have presented evidence based on our simple models that the problem is the nonhomogeneous response of CVTR and not basic errors in the analytical models. The next step that is needed is a containment model to deal with these nonhomogeneous effects. An attempt at this was done in the original CVTR report in which they used a simple containment modeling code with two volumes. The code was CONDRU II, and it showed marked improvement at predicting the observed temperature stratification (Fig. 7). In their discussion of the CONDRU II results, the CVTR report authors noted that "to account for separate vapor-to-air ratios each compartment had different heat-transfer coefficients." The authors also felt that two volumes were insufficient to predict the stratification observed in CVTR.

We believe what is needed to pull all of this work together is a three-dimensional analysis that will account for the gravity and mixing effects, including elevation of the steam source, buoyancy of the steam in air, and the principal CVTR geometric features (operating floor and annulus).

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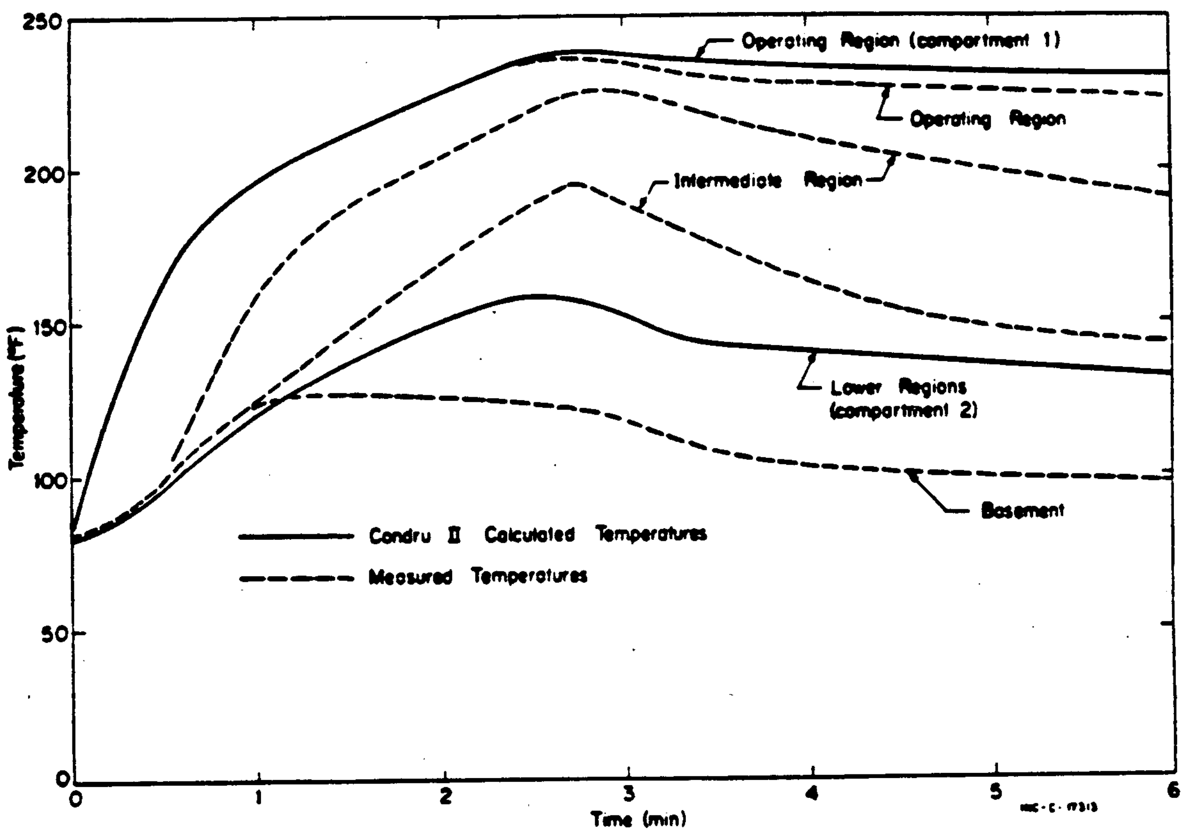

Fig. 7. CONDRU II temperature calculation results for steam Test 3. (Ref. 2, Fig. 70).

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6. REVIEW OF TVA CONCERNS THAT ERRORS OCCURRED IN THE SUPPORTING ANALYSES FOR NUREG-0588

In Sec. II.C.1 of their report,[3] TVA compares their method with the NUREG-0588 recommended analysis for the CVTR experiment. Figure 3 shows that TVA calculated a peak temperature for CVTR test 3 of 360°F using 0% revaporization and 318°F using 8% revaporization, as compared with the CVTR experimental value of 236°F. For these calculations TVA used the NUREG-0588 Appendix B method with the Uchida correlation and the temperature difference based on the saturation temperature. TVA compared their results with Fig. 3 of Ref. 5 (our Fig. 2) in which NRC calculated a peak temperature of 250°F using a 7.6% revaporization rate. TVA could not explain the difference between their calculated peak temperature of 318°F and NRC's calculated peak temperature of 250°F for what TVA believed to be identical calculations. Unfortunately, the NRC calculation (Fig. 2) does not state explicitly what heat-transfer coefficients were used. TVA requested that NRC provide additional information, and Los Alamos sent three code input decks to TVA. Upon examining these decks, TVA found that the heat-transfer coefficients used were the actual CVTR values and not the Uchida model that TVA used and that is required by NUREG-0588. TVA raised the question as to whether this was intended or was in error.

We have reviewed this issue and conclude that the analysis reported in Ref. 5 (Fig. 2) was done as intended. We believe it was NRC's intention to do a best-estimate calculation for CVTR and determine the best value to use for revaporization rate. For the CVTR data, the actual CVTR heat-transfer coefficients are the best estimate. We acknowledge that it was unfortunate that the heat-transfer coefficient that was used was not reported.

We do note that, in looking at all of the other figures in Ref. 5, the heat-transfer coefficient being used (where appropriate) is stated, and in all cases it is the Tagami and/or Uchida correlation. It is easy to see why TVA would have assumed that Tagami and Uchida had been used for Fig. 2.

Los Alamos concludes that the supporting analyses for NUREG-0588[1] were done correctly.

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7. CONCLUSIONS

1. NUREG-0588 requires Category I plants, which include BLN, to analyze their MSLBs for equipment qualification purposes using the Uchida heat-transfer correlation when condensing conditions exist. The analysis should use a wall-to-atmosphere temperature difference based on the saturation temperature of the vapor at the vapor partial pressure. For this analysis, 0% revaporization should be used.

2. The TVA MONSTER analysis fails to comply with the requirements of NUREG-0588 for Category I plants and fails to comply with the requirements spelled out in NUREG-0588 for Category II plants, which was for plants being licensed in 1981. TVA proposes using a scaled CVTR heat-transfer coefficient that is greater than the Uchida-calculated coefficient. It proposes using a revaporization rate of 10%, which exceeds the 8% allowed for Category II plants and the 0% for Category I plants that a strict interpretation of NUREG-0588 would require. TVA proposes using the bulk atmosphere temperature instead of the lower saturation temperature on which to base its heat-transfer calculations; this is less conservative than required by NUREG-0588.

3. TVA uses these methods to predict the experimental results for CVTR. TVA contends that the results are a conservative analysis for CVTR. Los Alamos disagrees. We consider it a best-estimate calculation. In light of the nonhomogeneous experimental results in CVTR, TVA's overprediction of the peak temperature by 4°F is not a conservative analysis.

4. TVA proposes a scaling method to enable them to use the CVTR results for the BLN. The scaling method is based on the Tagami empirical correlation done for a completely different scale. It has been shown that the Tagami correlation did not scale well for the CVTR results. No independent experimental data are presented that would justify the use of the proposed scaling equation.

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5. Los Alamos reviewed the literature to investigate what would be an orthodox scaling approach. We found five authors plus ourselves that support a physical approach based on the vapor/gas boundary layer dynamics. Comparisons with CVTR data by ourselves and other authors have shown reasonable results, but the authors that have analyzed these data believe the nonhomogeneous effects limit the applicability of the analytical methods.

6. The result of these arguments is that Los Alamos does not believe that TVA has proposed a demonstrably conservative alternative to the NRC method of NUREG-0588 for calculating environmental conditions inside containment during an MSLB for qualification of safety-related electrical equipment.

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