SAND84-0807C

HECTR Results for Ice-Condenser Containment Standard Problem

F. Eric Haskin
Vance L. Behr
Allen L. Camp

Sandia National Laboratories
Albuquerque, NM 87185

ABSTRACT

We have performed calculations to study the Ice-Condenser Containment Standard Problem for the NRC Containment Loads Working Group (CLWG). This problem is based on a TMLB' accident sequence. TMLB' denotes a transient-initiated accident in which there is total failure of both AC power and feedwater to the steam generators. We used MARCH 2 and CORCON Mod2 to predict the steam, hydrogen, carbon dioxide, and carbon monoxide sources. We employed HECTR to predict the containment pressure temperature response. The results of our calculations include quantitative indications of the sensitivity of containment pressure-temperature loadings to the gas source terms, the ignition criteria, and the magnitude of the steam spike following vessel breach.

STANDARD PROBLEM DESCRIPTION

To generate the steam-hydrogen source term, we employed MARCH 2[1] and an input deck provided for the standard problem by Battelle Columbus Laboratories (BCL). Table 1 summarizes the key events predicted by MARCH 2 prior to vessel breach for the base case input deck provided by BCL. Natural circulation through the steam generators permits removal of decay heat by boiling and relief of steam through the atmospheric dump valves on the secondary side until 3885 s when the steam-generators boil dry. The primary system then rapidly heats up and the primary system relief valves open, discharging primary coolant to the containment. Core uncovering is predicted to begin at 5550 s. This is followed by core heatup, melting, slumping into residual water in the bottom head, and bottom head heatup and failure. While one can postulate events which would depressurize the primary, the standard problem did not consider these and the primary system is predicted to remain pressurized at the relief valve setpoint until vessel breach at 9465 s.

---

*This work was supported by the U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, and performed at Sandia National Laboratories which is operated for the U.S. Department of Energy under Contract Number DE-AC04-76DP00789.

CODES AND MODELS

BCL Version 111 of MARCH 2 was used to provide the steam-hydrogen sources to containment. We replaced the INTER core-concrete-interactions subroutine in MARCH 2 with CORCON Mod2[3]; however, this change had little impact since gases generated from core concrete interactions have a negligible impact on containment loadings during the first hour following vessel breach.

We used HECTR[4] to predict containment pressure-temperature loadings. HECTR is a lumped volume code developed specifically to compute containment pressure and temperature loadings associated with hydrogen deflagrations (detonations are not modeled). HECTR models for intercompartment gas flows, combustion, heat transfer, containment sprays, and the ice-condenser are more mechanistic than corresponding MARCH models. HECTR has been shown to agree well[5] with two other lumped volume codes of comparable complexity (CLASIX and COMPARE) in predicting ice-condenser containment loadings for a small-break LOCA.

The nodalization of the ice-condenser containment for our HECTR calculations is shown in Figure 3. The nine compartments include the dome; the lower compartment (which contains the reactor coolant system); an annular, dead-ended compartment; the ice-condenser upper and lower plenums; and four ice regions of the ice-condenser. HECTR includes models for the recirculation fans and containment sprays; however, both are inoperable due to failure of AC power in TMLB' accidents. The models used for the ice-condenser lower-plenum and intermediate-deck doors block downward flow through the ice-condenser. However, there is a small "bypass" flow area around the intermediate deck doors which (coupled with finite door closing times) permits downward burn propagation and limited downward flow.

We employed HECTR default values for 1) inerting due to high (>55%) steam and carbon-dioxide mole fractions, 2) inerting due to low (<5%) oxygen mole fraction, 3) flame speed, 4) burn completeness, and 5) burn propagation (4.1% upward, 6.0% horizontal, 9.0% downward).

CASE DESCRIPTIONS AND RESULTS

In order to examine the sensitivity of the containment pressure-temperature loadings with respect to variations in source term, ignition criteria, and steam spike magnitude, we examined twenty cases. Each case has been assigned an identifier consisting of a single letter prefix and a two digit suffix. Each distinct prefix denotes a different steam-hydrogen source term obtained with a different set of MARCH inputs chosen to vary such things as the amount of Zr oxidation and magnitude of the steam spike. Parameters affecting combustion and intercompartment flows were varied by changing HECTR inputs thus, each case required a separate HECTR run. Results for all cases are compiled in a table at the end of the paper. Specific sensitivities indicated by these results are discussed below.

Steam and hydrogen accumulate in the dome thereby decreasing the oxygen mole fraction. However, inerting does not occur in the dome at any time either due to high (>55%) steam or low (<5%) oxygen mole fractions. By 3 s after vessel breach upward burn propagation into the dome becomes possible (>4.1% hydrogen).

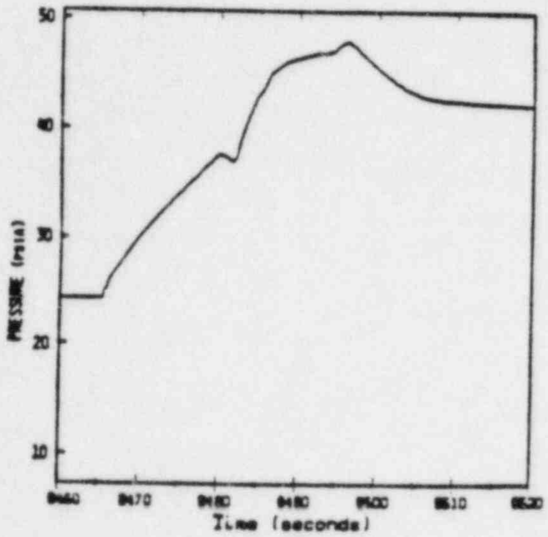

Figure 4
Dome Pressure, Case Q.06

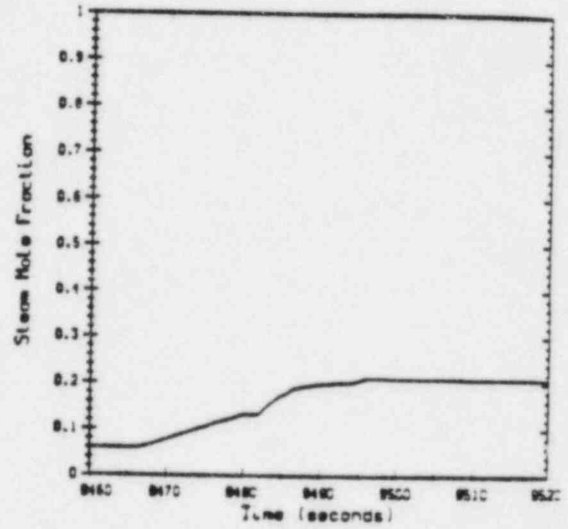

Figure 5
Dome Steam, Case Q.06

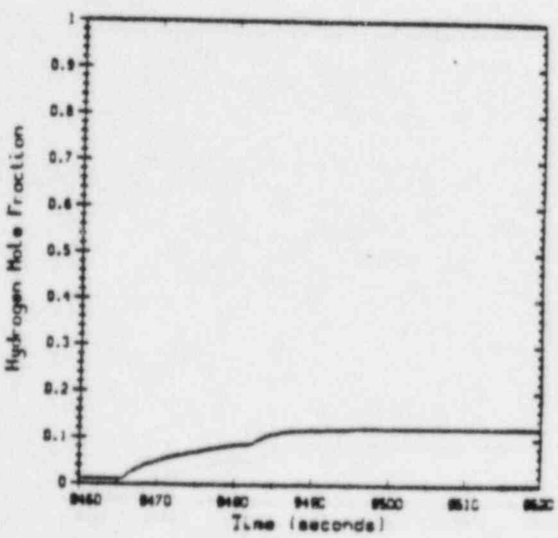

Figure 6
Dome Hydrogen, Case Q.06

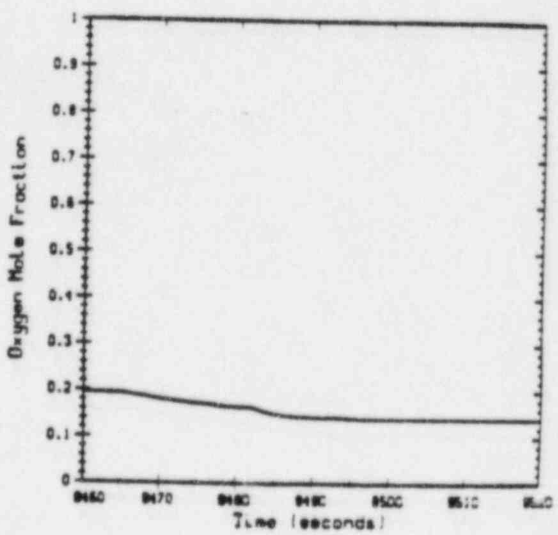

Figure 7
Dome Oxygen, Case Q.06

Figure 8 shows the temperature in the lower compartment which initially receives the steam and hydrogen from the primary system and from the steam spike. The peak temperature in containment in the absence of combustion occurs in the lower compartment. The peak during the first hour following vessel breach is 440 K (330 F).

Results for the upper ice regions, Compartments 8 and 9, are similar to those for the upper plenum. Prior to vessel breach, detonable concentrations occur in Compartments 8 and 9; however, following vessel breach these compartments rapidly inert. Table 2 summarizes the combustibility conditions in all of the compartments following vessel breach.

Table 2. Inerting During the Hour Following Vessel Breach (VB), Case Q.06--No Burning

Compartment	Time Period During Which There is		
	<5% O_2	>55% H_2O	<4.1% H_2
1 Dome	None	None	<VB+ 3s
2 IC Upper Plenum	>VB+ 17s	>VB+ 18s	None
3 IC Lower Plenum	>VB- 720s	>VB-5300s	>VB+18s
4 Lower Compartment	>VB-5330s	>VB-5920s	>VB+18s
5 Dead-ended Region	None	None	<VB
6 Bottom Ice Region	>VB- 720s	>VB- 720s	>VB+19s
7 Next-To-Bottom Ice Region	>VB- 660s	>VB- 660s	>VB+21s
8 Next-To-Top Ice Region	>VB+ 1s	>VB+ 3s	None
9 Top Ice Region	>VB+ 6s	>VB+ 10s	None

Note that the lower a compartment is in the ice-condenser, the more rapidly it inerts. Compartment 8 is inerted within one second, Compartment 9 within six seconds, and Compartment 2 within 17 seconds of vessel breach. The lower compartment (Compartment 4), the lower plenum (Compartment 3), and the lower ice regions (Compartments 6 and 7) are inert both before and after vessel breach. The dead-ended region (Compartment 5), although not inert, has a relatively low (<5.3%) hydrogen concentration at all times.

IGNITION FOLLOWING VESSEL BREACH

Currently planned or installed deliberate ignition systems for ice-condenser containments are powered by the AC systems which fail by definition in TMLB' accident scenarios. Failure of the AC power systems might also preclude other ignition sources, that is, electrical discharges from operating equipment inside containment. It is, therefore, not unreasonable to postulate that ignition could be delayed until after vessel breach. The ejection of hot gases or particles during vessel depressurization might serve as a source of ignition. Alternatively, ignition might be delayed indefinitely.

Based on Case Q.06 in which combustion was precluded, we developed several cases to examine the sensitivity of containment loading to the timing and threshold for ignition following vessel breach. Table 3 summarizes the sensitivity of containment loading to the timing of ignition. Ignition was assumed to be possible starting at the times indicated and was precluded again 30 s later. An ignition threshold of 8% hydrogen was

back into the ice-condenser permitting simultaneous burns in Compartments 8 and 9. The pressure resulting from the initial dome burn and concurrent burns in Compartments 2, 8, and 9 is 690 kPa (100 psia). The peak temperature of 1460 K (2170 F) occurs in Compartment 8.

Case Q.10 postulates ignition 20 s after vessel breach. As indicated in Table 2, all of the compartments in the ice-condenser (including Compartment 2, the upper plenum) are inerted at this time. However, 9.8% hydrogen has accumulated in the dome and is ignited. The baseline pressure at ignition is 300 kPa (43 psia). The burn in the dome forces enough oxygen back into the ice-condenser to permit simultaneous and subsequent burns in Compartments 2, 9, and 8. The peak pressure of 850 kPa (120 psia) results from the initial burn in the dome. The peak temperature of 1300 K (1890 F) occurs during the first burn in Compartment 2.

The maximum load we can conceive of during the hour following vessel breach would occur if ignition were delayed until the end of this one hour time interval. The longer the delay until ignition, the more hydrogen will accumulate in the dome. The source term considered for Case S.02 postulates 100% in-vessel Zr oxidation. With ignition delayed until one hour after vessel breach, the dome mixture at time of ignition is composed of 22.7% hydrogen, 14.5% oxygen, and 7.9% steam. This is clearly a detonable mixture; however, HECTR treats only deflagrations. The HECTR-predicted peak loadings for Case S.02 are 1459 kPa (212 psia) and 2369 K (3804 F) in the dome. A detonation of the same mixture would result in even more severe loadings.

Based on the preceding discussion, the results in Table 3 can be explained as follows. If ignition is delayed until after vessel breach, the peak loadings will be sensitive to the time interval between vessel breach and ignition. The peak loadings are, in general, determined by the dome hydrogen content and the pressure prior to burning in the dome. For early ignition (near the time of vessel breach) burning in the dome will not occur until the dome hydrogen mole fraction is sufficient to permit upward propagation (4.1%). Early burning in the ice-condenser can delay the buildup of hydrogen in the dome while increasing the pressure. Thus, ignition at vessel breach (Case Q.07) yields higher peak loadings than ignition which is delayed 5 s (Case Q.08). However, with more delay (Cases Q.09, Q.10) the hydrogen content in the dome begins to dominate the resulting peak loads, and, for an indefinite delay, detonable mixtures can be achieved in the dome (Case S.02).

IGNITION THRESHOLD

Table 4 shows the effect of reducing the ignition threshold from 8% to 4.1% for cases in which ignition follows vessel

Table 5. Sensitivity to Deliberate Ignition (DI)

Case No.	Ignition Type	Limit $\%H_2$	Peak Pressure kPa (psia)	Peak Temperature K (F)
Q.01	DI ex IC	8.0	730 (110)	1628 (2470)
Q.02	DI all	8.0	570 (83)	1177 (1660)
Q.08	VB + 5s	8.0	540 (78)	1305 (1890)

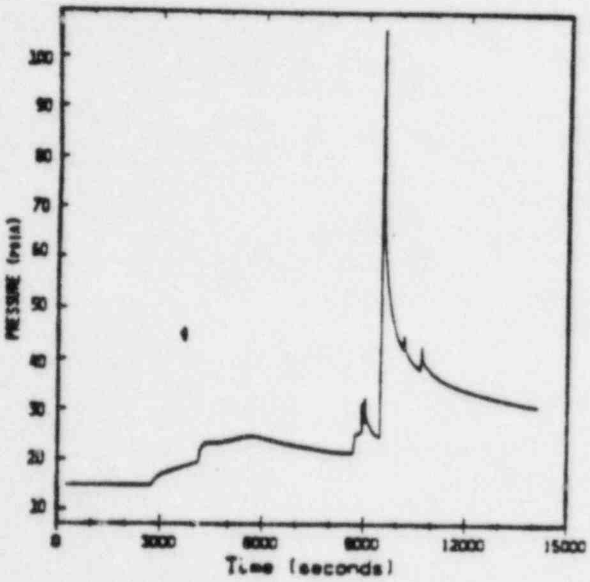

Figure 12
Dome Pressure for Case Q.01

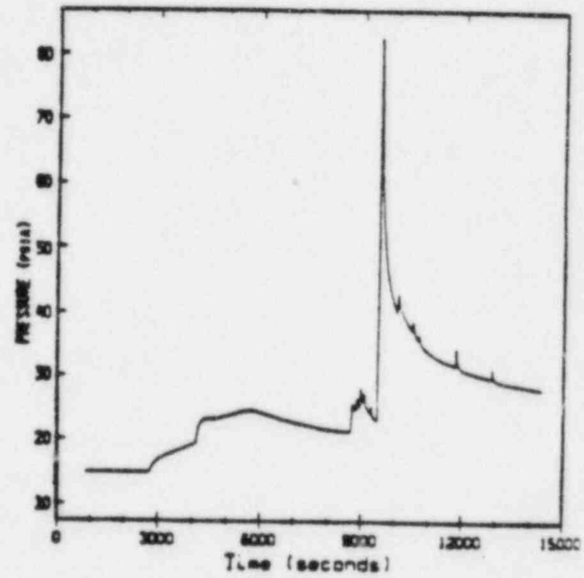

Figure 13
Dome Pressure for Case Q.02

NONMECHANISTIC IGNITION THRESHOLD

To permit comparisons with results obtained by others, in four cases (Q.00o, Q.01, Q.02o, and Q.03o) ignition is assumed to occur whenever the hydrogen mole fraction in non-inerted compartments outside the lower plenum and ice regions reaches an arbitrary threshold. The arbitrary ignition thresholds for these runs are 10%, 8%, 12%, and 30%. Our opinion is that only one of these runs (Q.01 with ignition at 8% hydrogen) has any physical significance. As discussed above, Case Q.01 simulates a deliberate ignition system which is independent of AC power. Such a deliberate-ignition system would most realistically yield ignition at ≤8% hydrogen, well before 10%, 12%, or 30% hydrogen. Without deliberate ignition, a single random ignition could certainly occur at 8%, 10%, 12%, or even 30% hydrogen; however, there is no mechanism which would make all subsequent ignitions occur at the same threshold.

There are two reasons for excluding ignition in the ice compartments in Cases Q.00o, Q.01, Q.02o, and Q.03o. First,

when MARCH predicts the core will collapse into residual water in the bottom head. Relief through the stuck open relief valve reduces the primary-system pressure to below the accumulator setpoint and delays vessel breach until 10150 s as opposed to 9465 s for the Q cases. Table 7 compares the peak containment loadings predicted by HECTR with and without depressurization prior to vessel breach.

When ignition is postulated shortly after vessel breach (Cases V.00 and Q.08) primary system depressurization prior to vessel breach allows hydrogen to accumulate to significant levels in the dome before ignition. In Case V.00 HECTR predicts 14.5% hydrogen, 15.6% oxygen, and 11.0% steam in the dome at time of initial ignition, 5 s after vessel breach. Obviously, if ignition is postulated shortly after vessel breach, primary system depressurization before vessel breach yields higher loadings (Case V.00 versus Case Q.08). However, early primary system depressurization would also eliminate the high pressure ejection of hot core debris particles which could serve as ignition sources.

Table 7. Sensitivity to Depressurization Prior to Vessel Breach

Case No.	SRV Sticks Open	Ignition Type	Peak Pressure kPa (psia)	Peak Temperature K (F)
Q.02	No	DI all	570 (83)	1180 (1660)
Q.08	No	VB+5s	540 (78)	1300 (1890)
V.01	Yes	DI all	660 (96)	1800 (2790)
V.00	Yes	VB+5s	1050 (150)	1680 (2560)

When deliberate ignition is postulated (Cases V.01 and Q.02), early primary system depressurization shifts both the hydrogen release and associated burning to before vessel breach. In Case V.01, an initial series of burns occurs in Compartments 2, 8, and 9 after the relief valve sticks open at 8640 s. This initial series of burns results in the inerting of Compartments 2, 8, and 9 due to insufficient oxygen. Subsequent ignition occurs when the hydrogen concentration in the dome reaches 8% at 9340s. The dome burn forces sufficient oxygen back into the ice-condenser to result in simultaneous burning in Compartments 2, 8, and 9. The pressure preceeding the dome burn is 270 kPa (39 psia). The peak pressure for Case V.01 is higher than for the corresponding deliberate-ignition case (Case Q.01) with no primary system depressurization prior to vessel breach. In Case Q.01 the dominant dome burn was ignited by propagation from Compartment 2 when the dome pressure was 300 kPa (44 psia) and the dome contained only 5.1% hydrogen.

EXTENT OF IN-VESSEL Zr OXIDATION

Table 8 indicates the sensitivity of peak containment loads to the extent of in-vessel Zr oxidation. In all of the cases in

to occur in the interval from 5 s to 35 s after vessel breach, and the ignition threshold is taken to be 8% hydrogen. By eliminating the steam spike, the baseline pressure for hydrogen burning and the resulting peak pressures are significantly reduced.

CONCLUSIONS AND CAVEATS

A summary of all the cases and the key results from HECTR can be found in Table 10. For comparison, the estimated failure pressures for ice condenser containments range from 51 psia[6] (a lower bound for Sequoyah) to 155 psia[7] (an upper bound for Watts Bar). The HECTR results discussed above indicate that for TMLB' accidents in an ice-condenser, the peak containment loads are strongly influenced by four factors:

1) The timing of ignition which is difficult to predict due to failure of AC power and consequent failure of present deliberate ignition systems.
2) The extent of in-vessel Zr oxidation.
3) Primary system depressurization prior to vessel breach.
4) The magnitude of any ex-vessel steam spike.

A lower bound to the containment loadings during the hour following vessel breach corresponds to Case U.01 in which a low steam spike is postulated and burning is precluded. An upper bound to the containment loadings during the hour following vessel breach corresponds to Case S.02 in which 100% in-vessel Zr oxidation is postulated and ignition is delayed until one hour after vessel breach to maximize the buildup of hydrogen in the dome prior to ignition. These are very wide bounds of uncertainty and are due largely to the uncertainty in the time of ignition and amount of zirconium oxidation. However, the loads calculated by HECTR for Case S.02 are not absolutely conservative because they are based on deflagrations, whereas a detonation in the dome is possible.

We have no "best guess" as to the containment loading which would actually arise in a TMLB' accident in an ice-condenser containment mainly because of uncertainties regarding the factors (listed above) which strongly influence predicted loadings.

The HECTR predictions show that detonable mixtures could occur in the ice compartments; however, HECTR cannot calculate the loadings which might result from detonations of such mixtures. Independently powered deliberate ignition throughout the containment including the ice regions would virtually eliminate the possibility of detonations and permit a lowering of the upper bound on containment loadings. However, we have not determined that such a deliberate ignition system would be feasible or warranted from a cost-benefit (risk reduction) perspective.

HECTR results presented herein assume that the intermediate-deck doors and the lower-plenum-inlet doors on the ice-condenser would continue to function to block backflow through the ice-condenser. In some cases in which burning occurs in the dome, substantial differential pressures are predicted across these doors when they shut to block backflow. Based on previous calculations, failure of the doors to block backflow would alter predicted containment loadings; however, more complete analyses would be required to firmly establish the significance of door failure.

Finally, we can state that the temperature loadings calculated in the dead-ended region (Compartment 5) do not appear severe when compared to the typical 450 K (350 F) qualification temperature for electrical penetrations located there. Higher atmospheric temperatures are predicted for some cases during burns in the dead-ended regions; however, these temperatures are short-lived (<10 sec) and could not be transmitted to the electrical penetration seals within the time frame of the burns.

REFERENCES

1. R. O. Wooton and P. Cybulskis, MARCH 2 (Meltdown Accident Response CHaracteristics) Code Description and User's Manual, Battelle Columbus Laboratories, October 1983 DRAFT.

2. R. O. Wooten and H. I. Avci, MARCH (Meltdown Accident Response Characteristics) Code Description and User's Manual, NUREG/CF-1711, U.S. Nuclear Regulatory Commission, Washington, D.C., 1980.

3. R. K. Cole, D. P. Kelley, and M. A. Ellis, CORCON-Mod2: A Computer Program for Analysis of Molten Core Concrete Interactions, Sandia National Laboratories, in preparation.

4. A. L. Camp, M. J. Wester, and S. E. Dingman, "HECTR: A Computer Program for Modeling the Response to Hydrogen Burns in Containments," SAND82-1964C, Procedings of The Second International Workshop on the Impact of Hydrogen on Water Reactor Safety, U.S. Nuclear Regulatory Commission, October 1982.

5. A. L. Camp, V. L. Behr, and F. E. Haskin, MARCH-HECTR Analysis of Selected Accidents in an Ice-Condenser Containment, Sandia National Laboratories, in preparation.

6. Safety Evaluation Report related to the operation of Sequoyah Nuclear Plant, Units 1 and 2, NUREG-0011 Supplement No. 6, U.S. Nuclear Regulatory Commission, Draft Copy, November 1982.

7. F. E. Haskin, V. L. Behr, J. Jung, "Containment Management Study for Severe PWR Accidents," SAND82-2120C, Proceedings of Tenth Water Reactor Safety Research Information Exchange Meeting, Gaithersburg, Maryland, October 15, 1982.

9.d.1

bnl

BROOKHAVEN NATIONAL LABORATORY

ASSOCIATED UNIVERSITIES, INC.

Upton, Long Island, New York 11973

Department of Nuclear Energy

(516) 282
FTS 666 2147

July 2, 1984

Mr. John Telford
U.S. Nuclear Regulatory Commission
Containment Systems Research
7915 Eastern Avenue
Silver Springs, Maryland 20910

Dear Mr. Telford:

I am enclosing a summary of the calculational results performed at Brookhaven in support of the CLWG Standard Problem 4 (BWR Mark I).

A detailed report describing the BNL contributions to the CLWG is in preparation and will be published late this fiscal year. Comparisons of BNL results with that of BCL and SNL are reported in the Appendix D of the Consensus Report. A copy of the report has been sent to you under separate cover.

Very truly yours,

Kenneth R. Perkins

Kenneth R. Perkins
Accident Analysis Group

KRP:tr
Encl.

Sandia National Laboratories

Albuquerque, New Mexico 87185

(9.C3)

June 29, 1984

Peter Cybulskis
Battelle Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

Dear Pete:

Vance Behr and I reviewed your draft of the "PWR Standard Problem - Ice Condenser Design". Enclosed is a markup with our comments. Also enclosed are better copies of figures for the no-combustion case.

We suggest that References 1, 2, and 3 be cited along with BMI-2104 as "earlier analyses". We request that Reference 4 (attached), which is the Sandia writeup for the ice condenser standard problem, be included as an appendix to your writeup.

Some of the major differences in the results are attributable to the fact that the models in HECTR allow some steam to pass through the ice-condenser during the steam spike whereas in MARCH nearly all the steam is forced to condense in the ice condenser. In our previous analysis[1] of a small break LOCA accident, the through-flow of steam in the ice condenser as predicted by HECTR was seen to fall between predictions of two other ice-condenser containment codes (CLASIX and COMPARE). Considering the good agreement we have seen in comparing HECTR CLASIX, and COMPARE and the general lack of agreement between HECTR and MARCH, we question the implied appropriateness of the MARCH pressure-equilibration model for mass and energy transfer in ice condenser containments undergoing combustion events.

Please telephone if you have questions regarding our comments.

Sincerely,

F. E. Haskin

F. E. Haskin
Reactor Safety Technology
Division 6411

VLB:6411:cgt
Enclosure
0264B

B/12

References:

1. A. L. Camp, V. L. Behr, F. E. Haskin, "MARCH-HECTR Analysis of an Ice-Condenser Containment," Proceedings of International Meeting on Light Water Reactor Severe Accident Evaluation, Vol. 1, American Nuclear Society, 1983.

2. V. L. Behr, A. L. Camp, F. E. Haskin, "Ice-Condenser Containment Loadings During Severe Accidents," Proceedings of the Eleventh Water Reactor Safety Research Information Meeting, NUREG-0047, 1983.

3. A. L. Camp, V. L. Behr, and F. E. Haskin, MARCH-HECTR Analysis of Selected Accidents in an Ice-Condenser Containment, Sandia National Laboratories, in preparation.

4. F. E. Haskin, V. L. Behr, and A. L. Camp, "HECTR Results for Ice-Condenser Containment Standard Problem," Proceedings Second Workshop on Containment Integrity, Sandia National Laboratories, June, 1984.

Copy to:

NRC J. Larkins
[redacted]
NRC C. Tinkler
NRC M. Silberburg
NRC T. J. Walker
6410 J. W. Hickman
6411 A. S. Benjamin
6411 V. L. Behr
6411 A. S. Camp
6411 S. E. Dingman
6415 D. C. Aldrich
6415 J. M. Griesmeyer
6420 J. V. Walker
6427 M. Berman
6440 D. A. Dahlgren
6442 W. A. Von Riesemann
6449 K. D. Bergeron