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H. B. ROBINSON STEAM ELECTRIC PLANT, UNIT NO. 2
DOCKET NO. 50-261/LICENSE NO. DPR-23
ADDITIONAL INFORMATION CONCERNING INDIVIDUAL PLANT EXAMINATION

Gentlemen:

The purpose of this letter is to submit additional information concerning the H. B. Robinson Steam Electric Plant, Unit No. 2 Individual Plant Examination as discussed in recent conference calls between Carolina Power & Light Company and the NRC. Enclosure 1 is the information requested by the NRC during the December 13, 1993, and December 14, 1993, conference calls.

Questions regarding this matter may be referred to Mr. Jan S. Kozyra at (803) 383-1872.

Very truly yours,

Warren J. Dorman
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File: R-2-0529 (J. S. Kozyra)

Response to Additional Questions on The Level II Analysis For H.B. Robinson

In the IPE submittal a major contributor to release frequency is PDS 13Q. This sequence involves a loss of offsite power with the failure of the emergency diesel generators to run for the mission time. AC power is not restored prior to core damage. A latent human error or valve failure results in a containment bypass path. The lack of RWST injection and containment sprays reduces the potential for scrubbing of radionuclides prior to exiting the containment. The release path, however, is restrictive and provides a means for the radionuclides to plate out on surfaces prior to being released.

During the review of the analysis it was determined that the value assigned to the latent human error was an initial screening value. The actual probability for this event is estimated to be a factor of 10 less than that used in the IPE. Further examination found that the value for the event in the IPE submittal was incorrectly set at 1.0 instead of the 0.1 screening value. As a result, CET event CI was assigned a value of 1.0. This resulted in the entire PDS frequency for 13Q and similar plant damage states being assigned to small isolation failure.

The corrected value (0.01) was input into the CET database and resolved. The result was a sizable reduction in the small isolation failure and a corresponding increase in frequency for other outcomes. The effected failure modes are discussed below.

Early Containment Failure

If the containment remains intact, other early containment challenges that could result in containment failure are considered. Challenges from HPME/DCH hydrogen burning, and liner attack are considered. The reduction in the potential for isolation failure results in an increased probability of the containment failing due to an early containment challenge.

Due to the RPV failing at an elevated pressure, the potential for DCH exists. In the submittal no contribution was calculated since the isolation failure was already present. Due to the containment design and other factors, the potential for containment failure is small. Due to the high steam concentrations throughout the event, hydrogen burning is only remotely possible and does not contribute significantly to containment failure.

If the debris is released as a coherent film and not fragmented, the potential for liner attack is considered. This results in a small contribution to early failures. Additional discussion on how DCH is addressed in IPE is provided below.

Late Containment Failure

With only a small chance of early failure, the most likely challenges involve late containment failure. Late containment failure can occur due to late hydrogen burns, containment overpressure due to gas generation, or basemat failure.

The RWST will not be injected into the containment and will limit the water available to cover the debris. The high pressure release should send most of the debris out of the cavity to the RCP pump bay which has a small quantity of water. Steam will be generated as the water is boiled off and the containment pressure will increase. The lack of containment sprays and fan coolers will result in the containment pressure increasing at a rate directly proportional to the steam generation rate. After the water supply is exhausted, the debris will begin to attack the concrete basemat. Based on the ablation rates, determined by MAAP, basemat failure cannot occur prior to containment overpressure and is not considered as a containment failure mechanism without other events occurring.

The rate of steam generation will change once the water is depleted such that the containment will pressurize at a slower rate. The time to containment failure for this type of sequence is on the order of 35-40 hours. This allows time for the operators to recover containment cooling and preclude failure. Since the containment cooling systems are available but are without ac power, the operators need only to restore ac power to restore containment cooling.

The level I ac power recovery assessment accounted for the time until the core was uncovered. Considerable time is available between the time the core becomes uncovered and the time the containment fails due to overpressure.

Considering the time available, sufficient resources could be brought in to make it very likely that power could be restored. The later that cooling is restored, however, the less likely that it would provide adequate and the potential for recovery is adjusted to account for unknown factors. A somewhat conservative value, 0.5, is assigned for the probability of recovering ac power prior to containment failure. About 50% of the time the containment will fail late in the sequence due to containment overpressure.

For the other 50% of the time, containment cooling would be restored prior to containment failure. After restoration of containment cooling, the containment steam concentration will decrease. It is possible that a hydrogen burn will occur when the steam concentration is reduced below that necessary to inert the containment. The size of the hydrogen burn is related to the hydrogen source term present at the time of recovery. The IPE discusses the estimation of the hydrogen source term present and the resultant potential for containment failure. Based on this information, the potential for failure is small. A more detailed discusion of the recovery analysis is provided below.

Although basemat failure will not occur prior to containment overpressure if cooling is not restored, it is possible that debris cooling cannot be re-established after containment cooling is restored. In this case, the debris will continue to ablate concrete. Containment cooling will maintain containment pressure below that necessary for failure. Eventually, about 100 hours for the case of interest, the basemat will be breached and failure will occur. Given the estimated debris depth and other factors, this contribution is considered to be negligible and encompassed by overpressure failures already accounted for.

The results of the assessment are provided in Table 1 in terms of containment failure modes and Table 2 in terms of the release categories.

Table 1
Revised Containment State Frequencies

Sequence Type	Frequency (/yr)	Base Case (/yr)
Early Failure	4.18E-6	3.9E-6
Late Failure	4.71E-5	3.2E-5
Isolation (small)	3.47E-7	3.8E-5
Isolation (large)	1.00E-8	1.9E-8
Bypass (small)	5.61E-6	5.6E-6
Bypass (large)	7.70E-7	7.7E-7
Failure with IV recovery	5.00E-7	1.6E-6

As the results show, the net effect is to shift early small isolation failures to late containment failure. The resultant releases are somewhat higher due to the direct release path and the potential for revaporization but are still low. The timing of the release is substantially later which provides considerable time to recovery and evacuation that should reduce overall offsite population doses.

Table 2
Revised Release Category Contributions

Release Category	Frequency (/yr)	Base Case (/yr)
RC-1	1.62E-5	1.5E-5
RC-1A	1.80E-6	1.7E-6
RC-1B	2.61E-5	1.4E-5
RC-1BA	2.90E-6	1.6E-6
RC-2	3.54E-7	3.8E-7
RC-2B	4.72E-6	4.7E-6
RC-3	3.86E-7	3.9E-5
RC-4	4.7E-6	4.7E-6
RC-4C	1.3E-6	1.3E-6

Assessment of Direct Containment Heating

If the RCS is at high pressure at the time of RPV failure, the core debris will be ejected energetically. The debris at the bottom of the RPV will be pushed out first and into the cavity. At one point it was believed that a substantial fraction of the debris would be retained in the cavity. Recent experiments using scale model cavities similar to HBR2, however, do not support this belief and substantial retention is not expected. A more likely outcome is that the debris will be transported from the cavity to the instrument room as the gases which will follow the debris entrain the debris. The phenomena associated with RPV failure at high pressure is called high pressure melt ejection (HPME) and results in containment pressurization during RCS blowdown.

Given that retention of the debris cannot be assured based on geometry, other retention phenomenon are important. Although it is not precisely known, there is a direct relationship between RCS pressure and the potential for significant HPME. If the RCS pressure is low, the gases are not capable of entraining the debris and the debris would be retained in the cavity and preclude HPME.

To address this pressure dependency, the accident sequences are divided into three classifications. Sequences which involve RCS pressure near operating pressure at RPV failure have the highest potential for HPME. At the other extreme, HPME is not expected at the lowest RCS pressure range and is not considered. Between these two ranges is the medium pressure range. This range is provided under the idea that the potential for significant HPME is not a binary process and that the likelihood of significant HPME decreases with decreasing RCS pressure.

Using the above considerations the probability of significant HPME is determined. For the case of high pressure sequences it is considered to be certain and no factor is included. Similarly, HPME is not considered plausible for low pressure cases and a complement term is used to turn the event off for low pressure sequences. Finally, an event, MEDPRESS, is added to the medium pressure sequences to weight the likelihood of HPME. A value of 0.5 is chosen to accommodate uncertainty and the reduced potential for burning.

For some plant configurations excellent communication exists between the cavity and the upper compartment. In this case, the exhausting gases which entrain large quantities of the debris may transport the debris to the upper containment where energy released from the debris particles to the containment may cause rapid heating and increase in the containment pressure. Additionally, unoxidized zirconium found in the debris may be oxidized by steam present in the containment generating additional hydrogen and energy.

The proximity of the hydrogen to the hot debris may result in hydrogen burning which will further increase the containment pressurization. The draft NUREG-1150 study and other studies on large dry containments have indicated that this phenomenon, known as direct containment heating (DCH), may pose a serious threat to early containment integrity for large dry containments. The HBR2 containment is similar to the Surry which based on the NUREG/CR-4551 analysis, could have loads from DCH capable of failing the containment. The potential for DCH at HBR2 is considered and a qualitative assessment of the potential for DCH is performed.

As previously stated, it is believed that for high pressure sequences the cavity will not retain the quantities of debris necessary to preclude DCH. The expected path of the debris to the upper containment is graphically illustrated by Figure 1 and discussed below.

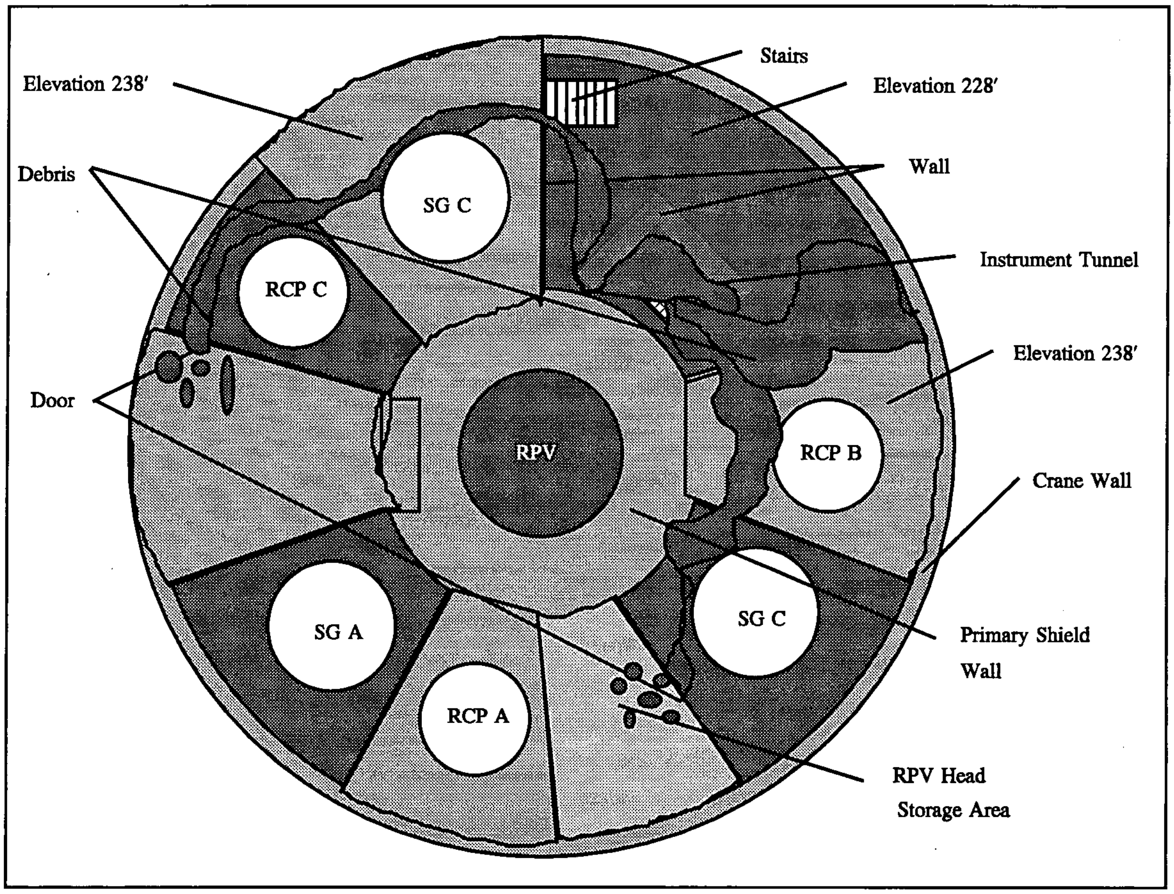

Figure 1. Simplified Diagram of Debris Transport Following HPME

The debris will be transported to the RCP B pump bay by way of the instrument tunnel. The entry point into the pump bay is partially shielded from the rest of the bay area by two walls and a ceiling exists directly overhead. The debris would enter this area and strike several different structures which would promote separation of the debris from the gas and reduce the potential for DCH. In fact, tests performed at Sandia support this point and found that the efficiency of DCH was substantially reduced if the debris strikes concrete surfaces.[38] With most of the debris being retained in the lower compartment, only a small amount of the debris would move in a lateral direction within the lower compartment and additional debris would be separated from the gas during the travel time. It is believed that very little debris will reach the small entry door located at the RPV head storage area and additional heating of the upper containment gases is expected.

The force of the exhaust gas would be sufficient to blow the door open and the gases would transported to the upper containment. Since the majority of the debris will be trapped in the lower compartment the potential for energy transfer from the debris to the upper containment will be limited to the energy transmitted to the gases during the flight time in the lower compartment and greatly reduces the potential for containment heating.

Hydrogen generation, however, may still occur and raise the potential for hydrogen burning. As the debris and gases exhaust from the RPV, the existing gases will be pushed from the cavity and the pump bay area. This may result in these areas becoming oxygen depleted and combustion may be prevented in these regions.

In this case, the hydrogen would be transported from lower regions of the containment to the upper containment. Once transported to the upper containment, this hydrogen could be burned. The debris could serve as the ignition source. It is generally believed that steam inerting would not be effective in this situation due to the proximity of the source to the hydrogen. It is possible, however, that steam present in the containment may suppress the pressure and could reduce the efficiency of the burn.

In quantifying the potential for a hydrogen burn coincident with HMPE some credit is for a reduced burn is given for cases where the steam concentration in the containment at the time of RPV failure is high. If the steam concentration is high, the likelihood for hydrogen burn and HPME was reduced by a factor of 0.5 (event H2@DCH). For cases with low steam concentration not credit was given and a value of 1.0 is used.

MAAP runs were performed to address the pressure rise due to HPME and limited DCH. Because the energy transmitted to the containment is limited to the energy transmitted by the gas, the time that the debris is interactive with the gas is important. One key parameter in assessing this relationship is the percentage of the debris which fragments and is entrained in the gas. The baseline assumption is that 3% of the escaping debris is entrained in the gas. This assumption is used for all PDS runs. The potential for hydrogen burning is based on relative hydrogen concentrations. These PDS runs provide a first cut at a median expected pressure rise due to HPME and DCH.

Alternative fragmentation values are used to study the effect of different fragmentation assumptions. Cases are ran which involve between 3% and 25% of the debris being fragmented and entrained in the gases. A limited number of high pressure PDS sequences which are candidates for HPME and DCH are examined. The results of these runs are provided in Table 3.

Table 3

MAAP Comparison of Containment Pressure Rises for Varying Debris Fragmentation and Accident Sequences

MAAP PDS Case	Containment Pressure Rise Given 3% Fragmentation (psi)	Containment Pressure Rise Given 10% Fragmentation (psi)	Containment Pressure Rise Given 25% Fragmentation (psi)
CA-4SBO	30	34.2	37.6
CA-4B-01	17	18.6	23.6
CA-5B	14	17.4	19
CA-6B	25	30.9	39
CA-11B	25	29	32.4
CA-2B-IS-1	18.6	27	42.9

In addition to varying the debris fragmentation, additional calculations are made which examine the extreme range of potential pressurization and use bounding conditions in which large quantities (in most cases 100%) of debris is assumed to be entrained in the gases and hydrogen burning is forced to occur. The results from these runs are believed to represent the 95 percentile for pressurization due to HPME and DCH. The results of these runs are provided in Table 4.

Table 4
MAAP Bounding Calculations for HPME and DCH

Percent Fragmentation	Time Scale for Dispersal (sec)	Hydrogen Burn Occurs	Resultant Pressure Rise (psia)
1	0.5	Yes	80
1	2	Yes	38
1	4	Yes	75
1	8	Yes	63
1	0.5	No	60
0.5	0.5	No	54

The highest pressure rise is 80 psi and represents the upper 95 percentile. The amount of debris fragmented depends on many factors including the debris participating in the melt, the RCS pressure, and the potential for quenching by the water found in the cavity at RPV failure.

As the two tables indicate the postulated pressure rise due to HPME and DCH ranges from as little as 14 psi to as much as 80 psi depending on the specifics of the sequence and how much debris is entrained. The MAAP runs selected to exam this phenomenon include a wide range of potential sequences and plant configurations. Consideration of the containment sprays, RCS pressure at RPV failure, injection and recirculation failures, and the water available in the containment are all included in the selected sequences. The resultant information is used to develop an average containment pressure rise for sequences following RPV failure. Based on these assessments, the median pressure rise is 27 psi and the 95 percentile is 80 psi. Figure 2 reproduces the HBR2 DCH pressure distribution. For comparison an equivalent NUREG-1150 curve is provided.

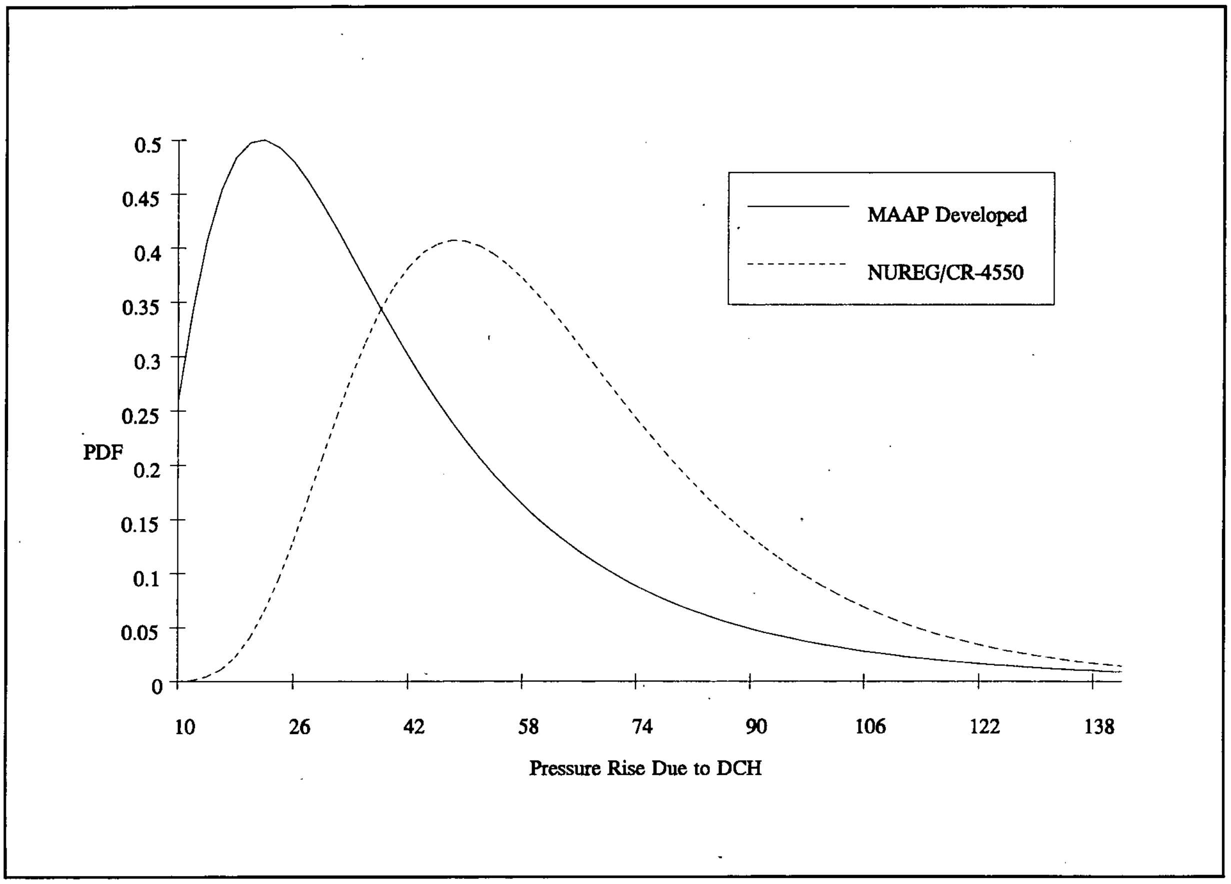

Figure 2. DCH Distribution Based on MAAP

In addition to the plant-specific assessment, information obtained during the expert opinion effort of NUREG-1150 was factored into the analysis. NUREG/CR-4551 examined the potential containment pressure increases at Surry due to loads which occur at RPV breach. Nineteen different cases are identified. These cases are grouped into three pressure regimes and two cavity states and are aggregated to develop four cases for use in the HBR2 assessment. The pressure cases corresponded to those developed for the plant-specific DCH cases. Since the HBR2 cavity is flooded for all sequences, only wet cavities are of interest.

A special case for SGTR sequences is developed to represent bypass sequences which have only limited water in the cavity. The presence of water in the cavity is believed to have an effect on the potential for DCH and a separate case was required. The high pressure bypass case provides the highest potential for containment pressure rise and containment failure. In contrast, the low pressure bypass case does not result in a significant loading (median is less than 20 psi).

In a method similar to that used for hydrogen generation, the HBR2 pressure distribution for HPME and DCH is treated as evidence which is used to update the NUREG-1150 results. The appropriate case derived from the NUREG-4551 study is chosen based on the PDS characteristics. The containment pressure at the time of RPV failure is also determined based on the PDS state. Since the loads associated with HPME and DCH are short term, the effect can be approximated by adding the base pressure to the expected HPME and DCH load. Figure 3 provides an example of the updated distribution for high pressure sequences.

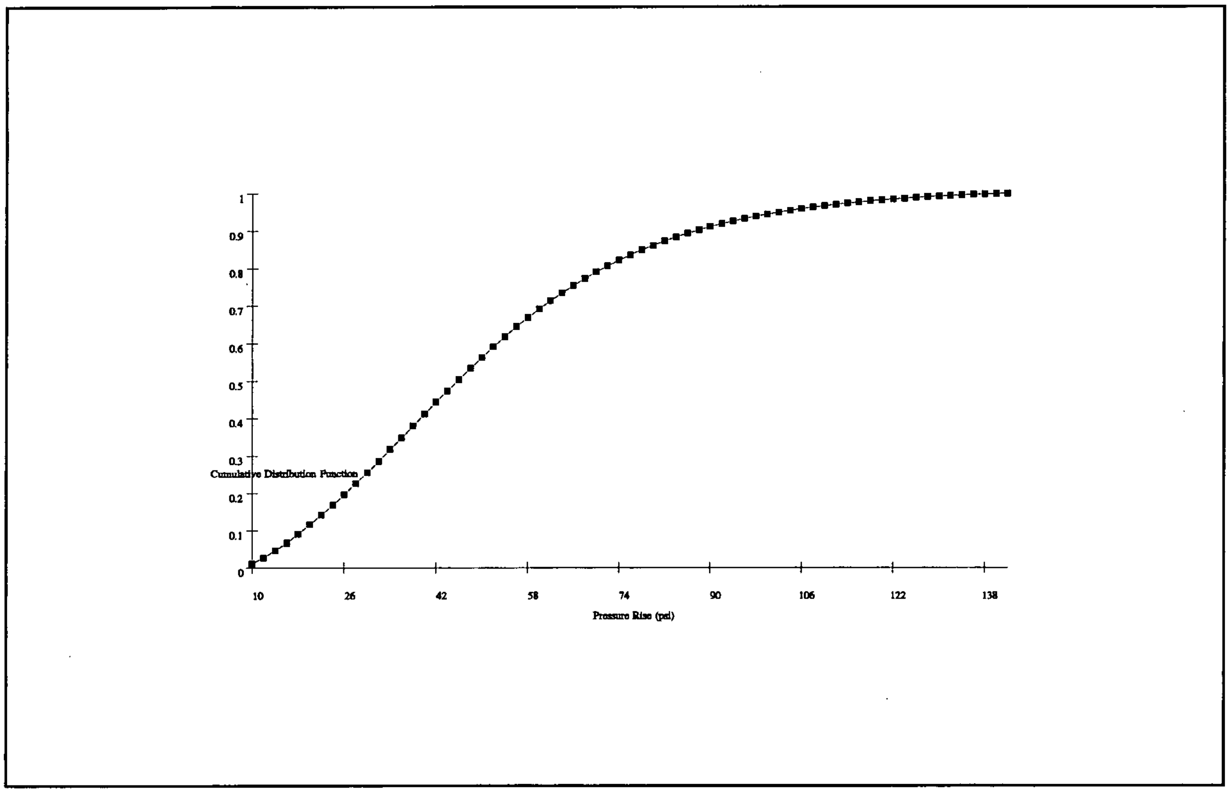

Figure 3. Updated DCH Pressure Rise Distribution

The pressurization is combined with the containment failure curve by discrete integration and using the probability of a pressure as a weight factor. The result is a distribution for the probability of containment failure given a load at RPV breach. The assumption of additive pressurization is slightly conservative since the operation of containment cooling and the presence of heat sinks in the containment may reduce the peak pressure. This assumption, however, is not considered to be significant given the uncertainties in the phenomenon. The potential for containment failure due to loads at RPV breach and other issues pertaining to RCS pressure and hydrogen burning are included in the model. The values for these events are summarized in Table 5.

Table 5
Event Values for HPME/DCH Related Events

PDS Condition	Probability of Containment Failure due to loading at RPV failure	Probability of Significant Fragmentation	Probability of Global Hydrogen Burn During DCH
High RCS Pressure, High Steam Concentrations	CFAIL-HDH - 0.2	DEBFRAG - 0.99	H2@DCH - 0.5[1]
High RCS Pressure, Low Steam Concentrations[2]	CFAIL-HDL - 0.017	DEBFRAG - 0.99	1
Medium RCS Pressure, High Steam Concentrations	CFAIL-IDH - 0.188	MEDPRESS - 0.5[3]	H2@DCH - 0.5
Medium RCS Pressure, Low Steam Concentrations	CFAIL-IDL - 0.012	MEDPRESS - 0.5	1
High RCS pressure, dry cavity[4]	0.046	MEDPRESS - 0.5	H2@DCH - 0.5

1. Based on MAAP assessments, the steam concentration will be in excess of 60% at the time of RPV failure. Some credit is provided for precluding complete hydrogen burns. Based on MAAP assessments, the base containment pressure will be near 45 psi at the time of failure.
2. The base containment pressure is less than 20 psi for cases with low steam concentrations.
3. The containment pressure is less than 1000 psi and credit is taken for reducing the potential for significant entrainment and energy transfer.
4. The nature of a bypass sequence results in early containment failure. Although containment overpressure is possible following a bypass sequence, the likelihood is much less than unity and, therefore, much less important than the bypass path. Thus, the potential for HPME/DCH is not quantified in the CET and the values shown in the table are provided for information only.

Late Hydrogen Burn Evaluation

Sequences which maintain containment integrity early in the sequence may still result in radionuclide releases if a late hydrogen burn occurs. This is especially true for cases involving prolonged concrete attack which results in additional combustible generation. An important issue related to late hydrogen burning is steam inerting. Based on MAAP analysis, the containment steam concentration is expected to be above the inerting limit for all cases which involve a loss of containment cooling prior to RPV failure. The early presence of large quantities of steam in the containment prevents hydrogen burning for sequences without containment cooling.

If containment cooling is present, then the potential for late hydrogen burns increases due to the lower steam concentration. The increased likelihood of late burning is offset somewhat by the potential for early burns at reduced hydrogen concentrations. If hydrogen burning occurs early, in-vessel production will be burned and late burns will be dominated by ex-vessel generation. The net effect is a series of smaller hydrogen burns and containment loads.

Late recovery is another possible situation. Initially the containment steam concentration is above the steam concentration necessary to prevent hydrogen burns. Hydrogen is generated during the accident progression from in-vessel and possibly ex-vessel sources. Containment cooling is restored and containment pressure is gradually decreased. As the containment cooling systems lower the steam concentration to reduce pressure, the potential for hydrogen burning is increased. Sufficiently rapid condensation could result in a hydrogen concentration which could lead to a hydrogen detonation.

These cases are examined to determine the potential for a late hydrogen burn and containment pressurization. Hydrogen detonation was considered and excluded based on the results of plant-specific MAAP analysis. The most likely situation involving the potential for detonation is a station blackout sequence with a late recovery of ac power. Two different cases are examined. The first deals with the restoration of containment sprays (RNP-005B2). The failure to inject the RWST results in concrete attack which generates additional combustible gases. Ac power is restored at 15 hours into the event and steam concentration decreases. The second case examined the recovery of containment sprays. Fifteen hours was also chosen as the recovery time for this case. It is the rate of decrease and the potential for burning during this period that is of interest. The results of the runs are summarized in Table 6.

Table 6
Late Recovery Sequence Assessment

	Steam Concentration		Hydrogen Concentration			
Case	Start	End	Start	End	Period	Rate
Fans	85%	30%	2%	10%	12 hr	0.67%/hr
Sprays	85%	30%	2%	10%	7 hr	1.14%/hr

As the results show, the steam concentration is decreased slowly. After the initiation of sprays, four hours are required to reduce the containment steam concentration below the level necessary to inert the containment. At the point where the containment is no longer steam inert, the global concentration is near 7% concentration and is near global burn concentration. If the minimum hydrogen concentration required to support detonation is assumed to be 16%, then the time available for a global burn to occur prior to reaching this concentration is 8 hours for the limiting case. This time is almost doubled for the case involving fans. In either case, sufficient time is available that a global burn is much more likely than a detonation. Therefore, no event for detonation is provided.

For cases without steam removal the potential for hydrogen burning late in the event is very unlikely (event LH2BURNS = 0.01). As was the case for early burning, the steam concentration precludes hydrogen burning. The model combines this event with conditional events which indicate that containment heat removal is initially failed and is not recovered.

If steam removal is restored late in the sequence the potential for hydrogen burning is almost assured (H2BURNR = 0.99). An event is provided to address the operator's ability to preclude a late hydrogen burn following containment cooling recovery. It is unlikely that the operators will be able to preclude a burn (OP-H2REC = 0.1). This value may be somewhat pessimistic and is chosen to address the limited operator training in mitigation of severe accident scenarios. These two events are combined with events to address the two possible recovery sequences and the early failure of containment cooling.

The last possibility is that hydrogen generation will continue during core melt progression but a burn will not occur until late in the sequence. If an early burn does not occur, it is likely (LH2BURNL = 0.9) that a late burn will occur. The model accounts for the possibility that an early burn has occurred and reduce the hydrogen concentration to preclude late burns.

Given that a burn occurs, the resultant pressurization must be considered to determine the potential for containment failure. Because of the variables involved, a range of hydrogen source terms is possible depending on several factors, e.g., early burn status, debris coolability, ablation rate, etc., and the time at which the burn occurs. As will be discussed in the next section, an upper bound can be identified. If steam generation remains unchecked, containment pressure will reach the mean ultimate strength in about 10 hours after RPV failure. A slightly longer time, 11 hours, is predicted for cases involving debris dryout. Using these estimates, hydrogen production after this time is not important since containment failure would be expected due to steam overpressure.

An important consideration in estimating the ex-vessel hydrogen source term is whether the RWST is injected into the containment. MAAP analysis of HBR2 indicates that only very limited ex-vessel hydrogen generation occurs for cases with the RWST. An average of 50 lbm is typical. If the RWST is injected, the in-vessel generation will dominate the source term and the values provided under early containment failure cases will apply. A example sequence which meets this criterion is any LOCA initiating event with a failure of recirculation. The RWST will be injected during the first phase of the response and the containment sprays will be unavailable at recirculation. Containment steam concentration will increase and limited hydrogen generation will occur.

If the RWST is not injected the potential exists for debris bed dryout and concrete attack. Unlike in-vessel generation, hydrogen generated during concrete attack is not limited by material. Sufficient metals exist within the basemat to generate large amounts of hydrogen given adequate time and energy. Station blackout sequence provide a good example of this situation. The debris is initially covered until water boils away and core concrete interaction begins. MAAP analyses of the important PDSs are used to develop the ex-vessel source term.

MAAP cases ran for station blackout and other cases indicate that approximately 1750 lbm of hydrogen is generated between RPV failure and the time that the containment reaches the mean containment capacity (Figure 4). Because no significant hydrogen generation occurs while the debris is covered, ex-vessel hydrogen production is limited to the period after concrete attack starts, typically five to six hours after RPV failure.

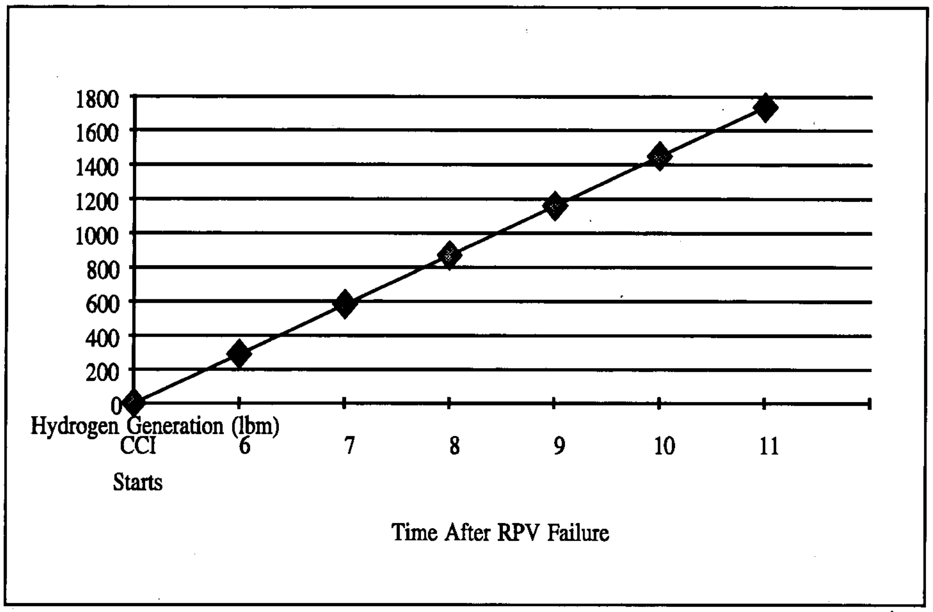

Figure 4. Ex-Vessel Hydrogen Generation for Station Blackout Sequences

The slope of the data identifies the rate of hydrogen generation as 290 lbm/hr. Since the operators could recover containment cooling at any time over the period, a range of source terms is possible based on the ex-vessel generation and the existing source term due to in-vessel production.

The degree of understanding related to recovery of equipment and the large uncertainties associated with hydrogen generation, however, does not necessarily support a detailed evaluation and a more conservative approach is used. The total production is taken as the combination of ex-vessel source term (1750 lbm) and the mean value in-vessel source term (~750 lbm). This equates to a maximum hydrogen source term of about 2500 lbm if no prior burns have occurred.

It is clear that the most likely source term is not the total amount possible. It is more likely that recovery would occur prior to reaching the point of maximum hydrogen generation. If the assumption is made that recovery is equally likely over the interval the most likely recovery time will occur at the midpoint of the time available (5.5 hours after RPV failure). Next it is important to recognize that hydrogen production is delayed after RPV failure. MAAP analyses predicts that the debris will not attack the concrete until the debris bed is dry. For the most limiting case (RWST not injected and debris dispersed to RCP pump bay) the time required to boiloff the pool over the debris is 5 hours. Thus, on average, only 30 minutes of hydrogen generation ex-vessel would be expected prior to recovery. Conservatively, one hour of hydrogen production is used. The ex-vessel production is graphically presented in Figure 5.

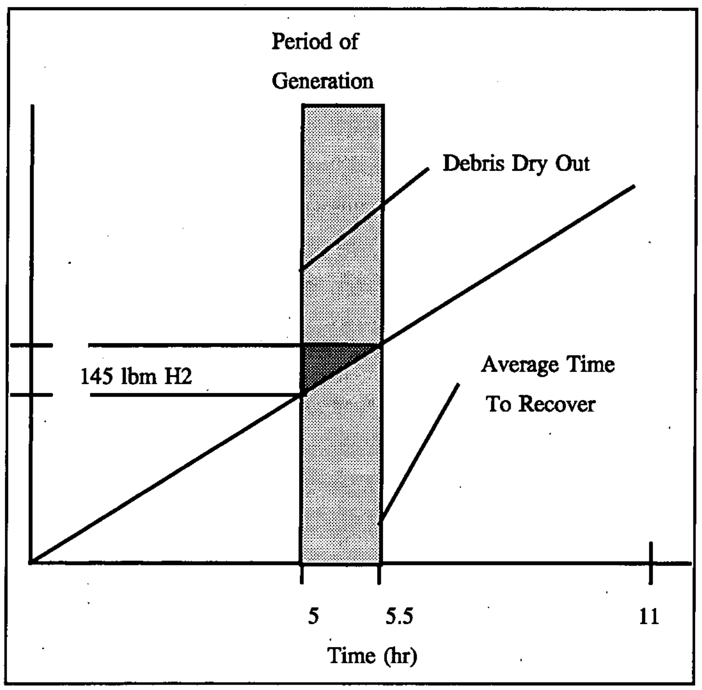

Figure 5. Assessment of Ex-Vessel Generation

Combining ex-vessel and in-vessel production results in a total hydrogen source term of 1050 lbm. The global burning of this quantity of hydrogen will result in a pressure rise of about 65 psi. When combined the expected containment pressure prior to a hydrogen burn (20 psi), a final pressure of 85 psi is calculated. This corresponds to a probability of late containment failure due to hydrogen burning (CFAIL-R) of 0.1 and is adopted for cases without RWST injection and late containment cooling recovery.

Another more rigorous examination can be used which weights the hydrogen source terms and the associated probability of containment failure. The total time is split such that each time increment is given the same weight and the hydrogen source terms are weighted by this value. The resultant burn pressurization, including in-vessel hydrogen, is used to calculate the containment failure probability for each source term and then the results are summed over the available times. The use of this approach yields a value of 0.12 (see Table 7) which, given the uncertainties present, is essentially the same as the value generated by the less rigorous method. This leads to the conclusion that using the simple method essentially does not affect the potential source term or any assumptions about ex-vessel generation and is adopted for all cases for the probability of containment failure given recovery.

Table 7
Calculation of Weighted Containment Failure Probability

Hour	Generated	Total H2	%MWR	H2 Mole Cont.	Weight Factor	Burn	Final Pressure	Cont. Failure Probability	Joint Prob.
No CCI	0	750	40%	11%	4.55E-1	35.83	55.83	5.33E-4	2.42E-4
0.5	145	895	48%	13%	4.55E-2	42.75	62.75	2.40E-3	1.09E-4
1	290	1040	56%	14%	4.55E-2	49.68	69.68	7.88E-3	3.58E-4
1.5	435	1185	64%	16%	4.55E-2	56.61	76.61	2.03E-2	9.23E-4
2	580	1330	72%	18%	4.55E-2	63.53	83.53	4.34E-2	1.97E-3
2.5	725	1475	80%	19%	4.55E-2	70.46	90.46	8.02E-2	3.64E-3
3	870	1620	87%	21%	4.55E-2	77.38	97.38	1.32E-1	5.99E-3
3.5	1015	1765	95%	22%	4.55E-2	84.31	104.31	1.97E-1	8.95E-3
4	1160	1910	103%	24%	4.55E-2	91.24	111.24	2.73E-1	1.24E-2
4.5	1305	2055	111%	25%	4.55E-2	98.16	118.16	3.56E-1	1.62E-2
5	1450	2200	119%	26%	4.55E-2	105.09	125.09	4.41E-1	2.00E-2
5.5	1595	2345	126%	28%	4.55E-2	112.02	132.02	5.24E-1	2.38E-2
6	1740	2490	134%	29%	4.55E-2	118.94	138.94	6.02E-1	2.73E-2
								Probability:	1.22E-1

In the case of no containment heat removal, the potential for global burns is remote due to the high steam concentrations. Partial burning may occur which could result in containment failure if the steam generated pressurization is sufficiently high. It is, however, highly unlikely (CFAIL-LHR=0.001) that a partial burn would result in containment failure. Similarly, if containment heat removal is present throughout the event the containment pressure will be low and, most likely, the debris will be coolable. This leads to the conclusion that late burns would be dominated by the in-vessel source term. Given low containment pressure and the average hydrogen source term, it is highly unlikely (CFAIL-LLR=0.001) that containment failure will occur.

Late Containment Failure Precluded

The quantification of this event addresses issues related to late containment failure sequences due to either steam generation or basemat meltthrough. These events occur late in the sequence and are considered exclusive. If the occurrence of one results in containment failure, the importance of the other is diminished to the point where no further analysis is necessary. There is a strong link between this event, the ability to cool the debris ex-vessel, and to hydrogen burning.

After the initial blowdown and assuming no major DCH loads, the pressure will be on the order of 4 to 5 atmospheres. At this point, long-term steam production will commence and gradually raise the containment pressure.

If the RWST is not injected, pressurization due to steam will be slower. For these cases, late pressurization comes from steam and gases generated during concrete attack. Once the debris is dry the stored energy in the debris will be used to attack the concrete containment structure.

The ablation of the concrete results in gases and some water vapor being generated and released into the containment.

Prior assessments have shown that considerable amount of gas can be produced for some concrete compositions, i.e., limestone aggregates. The HBR2 concrete uses a quartz based aggregate which is similar to basalt in relation to the production of noncondensable gases. Because of this, the pressurization from noncondensable gas is slow. This results in a two step pressurization process for sequences which do not have the RWST injected.

The best example of this type of sequence is station blackout (Figure 6). Based on MAAP assessments, RPV failure for a station blackout will occur at about 3.5 to 4 hours after the total loss of power. At this point, following blowdown, the containment pressure is near 80 psi. The majority of the debris is located in the pump bay area and is covered by a limited amount of water. This water is steamed away in about five hours and the containment pressure has risen to about 115 psi. At this point, concrete ablation begins. Over the next six hours, the containment pressure rises an additional 20 psi (3.3 psi/hr). Thus, the total time between RPV failure and the containment reaching the mean failure pressure is 11 hours for station blackout cases.

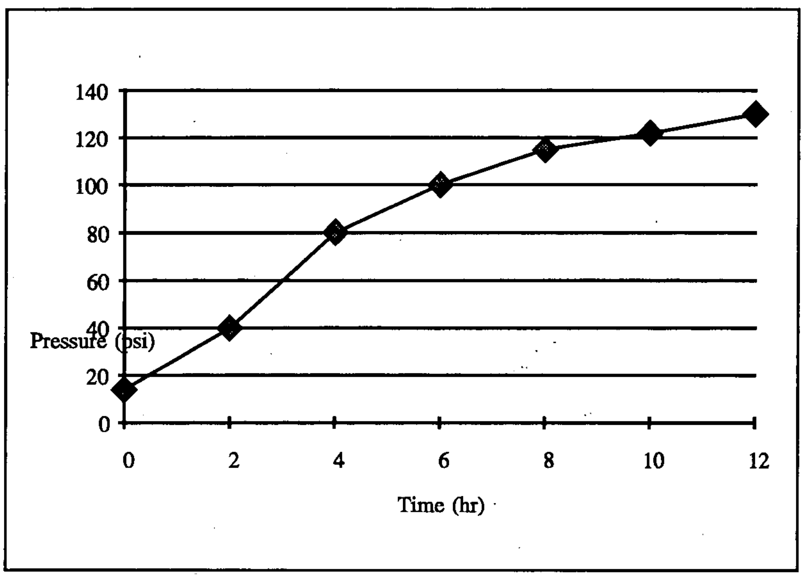

Figure 6. Containment Pressurization During Station Blackout Sequence

As an additional figure of merit, the containment reaches 85 psig shortly after RPV failure, which is included as an early containment load. Ac power must be restored in order to establish containment heat removal prior to containment failure.

In considering the potential for ac power recovery, the credit already included in the model must be addressed. Embedded in the probability of core damage is the non-recovery probability for ac power restoration. This accounts for actions which could be taken prior to the onset of core damage. Based on the historical evidence, the potential for recovering ac power over an interval is large for early times and quite small for later recovery times. This provides two insights. The likelihood of recovering power early is high and that if offsite power is lost for a considerable time, it is likely that a major problem exists which will require considerable action to correct.

In addition, if offsite power is restored to the site, it may not be possible to quickly restore power to the important loads. The evidence provided in the historical data does not address prolonged ac power loss which have also depleted onsite emergency batteries. Controlling the restoration process may be difficult. After considering these factors, the use of the standard ac power recovery curve was not considered appropriate and would overstate the potential for recovery. It is believed possible that ac power will be restored but it is not likely. A value of 0.5 was chosen to represent the potential for not recovering ac power in the time available (event RECPAC).