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# ANALYSIS OF BWR/MARK III DRYWELL FAILURE DURING DEGRADED CORE ACCIDENTS *

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This paper presents an evaluation of the impact of drywell failure during potential degraded core accidents in a typical 1000-MWe boiling water reactor (BWR) plant with a MARK III containment. The MARK III containment design consists of a pressure barrier (the drywell) and a fission barrier (the containment), which are interconnected through the suppression pool. The reactor vessel and its coolant system are located in the drywell region. During a degraded core accident initiated by a loss-of-coolant through a break in the primary system, a large amount of hydrogen could accumulate in the drywell region. A potential hydrogen detonation could threaten the drywell integrity.

The potential for hydrogen accumulation and detonation are best illustrated by considering a typical degraded core accident sequence, such as a small pipe break with a failure of the Emergency Core Cooling Injection System (designated as $S_1E$ in the Reactor Safety Study[1]). The $S_1E$ (equivalent break diameter=3 inches) sequence was analyzed by using the MARCH[2] computer code. Starting from the initiation of the accident, steam released from the reactor vessel gradually pushes all of the air from the drywell into the containment. The drywell is saturated with steam prior to the release of hydrogen. As hydrogen is released from the vessel, it is accumulated in

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large concentrations in the drywell without burning because of oxygen deficiency. For example, at 86 minutes, the mole concentrations of hydrogen and steam in the drywell are 45% and 55%, respectively. Meanwhile, a portion of the hydrogen has been transported through the suppression pool into the containment region. At 86 minutes, the mole concentration of hydrogen in the containment has reached 8% (the flammability limit assumed in this study) and ignition of hydrogen is assumed to occur in the containment. The pressure rise due to the hydrogen ignition in the containment causes air to reenter the drywell. The reentry of air reduces the concentrations of steam and hydrogen but increases the oxygen concentration in the drywell. Shortly after the hydrogen burn in containment, the concentrations of steam, hydrogen and air in the drywell are 33%, 27% and 40%, respectively. These concentrations are close to the detonation region as defined in the Shapiro and Moffette diagram[3] reproduced in Figure 1. There is uncertainty in applying the Shapiro and Moffette diagram (which is developed for atmospheric pressure and low temperature) to high pressures and temperatures, but nevertheless the potential for a hydrogen detonation in the drywell cannot be excluded. The shock wave generated by the postulated detonation may be much stronger than the MARCH computed peak pressure. The shock wave could threaten the drywell integrity. Other scenarios assuming different primary system break areas exhibit a similar (Figure 1) potential for $H_2$ detonations, which may induce failure of the drywell wall.

For the purpose of estimating the consequences of hydrogen detonation in the drywell, the MARCH code was modified to model the postulated failure of the drywell boundary. It is assumed that the hydrogen detonation causes loss of integrity of the drywell wall above the suppression pool surface.

The consequence of this failure is calculated by making a modification to the MARCH logic and computation procedure. In the modification, an initially two-volume model (drywell and containment) is changed into a one-volume model at a specific time when the postulated hydrogen detonation occurs. It is assumed that the suppression pool can be completely bypassed and the atmosphere in the drywell is directly mixed with the atmosphere in the containment. The results of computed containment pressure for the $S_1E$ (D=3) scenario are shown in Figure 2 and may be compared with the base case (no drywell failure). The first pressure spike (in both graphs) represents a hydrogen burn in the containment followed immediately by a hydrogen burn of large concentration in the drywell. If no hydrogen detonation is assumed, the MARCH model predicts a peak pressure of 44 psia (Figure 2a). Another hydrogen ignition is predicted immediately after the ECCS is restored at 94 minutes. The integrity of the drywell is maintained during the transient. However, if a detonation in the drywell is assumed (in Figure 2b) rather than a deflagration, it could result in drywell failure. The failure of the drywell results in a direct redistribution of all gases between the drywell and containment without passing through the suppression pool. A second hydrogen burn is predicted 5 minutes later in the combined volume of containment and drywell as the hydrogen concentration reaches 8% (the flammability limit assumed in this study). Both cases assume that the ECC systems are restored at 94 minutes prior to core slumping in order to prevent a full core meltdown accident. The continued ECC injection after core recovery results in a continuous flow of steam from the pipe break location. The break flow from the pressurized vessel (at about 900 psia) flashes into steam and is added directly to the drywell and containment atmospheres without being condensed in the suppression pool. Hence, a continuous increase in containment pressure is predicted if the drywell wall is assumed to fail (compared with no pressure increase if the wall remains intact). A peak pressure of 56 psia is predicted at 152 minutes. The peak containment pressure is above the design pressure (30 psia) but is within the estimated failure pressure (110 psia) for a steel-lined containment wall. MARCH results show that steam condensation in the containment and continuous cooling in the pressure vessel eventually reduces the containment pressure.

In summary, the potential for a hydrogen detonation due to the accumulation of a large amount of hydrogen in the drywell region of a BWR MARK III containment is analyzed. Loss of integrity of the drywell wall causes a complete bypass of the suppression pool and leads to pressurization of the containment building. However, the predicted peak containment pressure does not exceed the estimates of containment failure pressure.

# References

[1] "An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants," WASH-1400, NUREG-75/014, October (1975).

[2] Wooton, R. O. and Arei, H. I., "MARCH Code Description and User's Manual," NUREG/CR-1711, BMI-2064, Battelle Columbus Laboratories, October (1980).

[3] Shapiro, Z. M. and Moffette, T. R., "Hydrogen Flammability Data and Application to PWR Loss-of-Coolant Accident," WAPD-SC-545 (1957).

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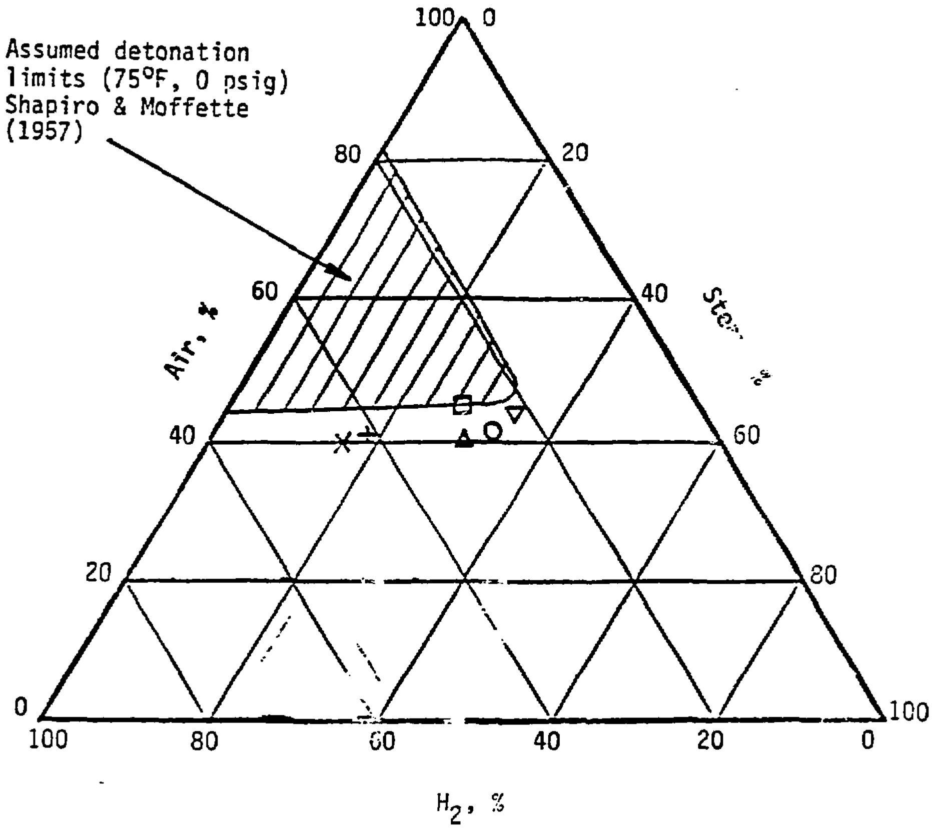


MARCH Predicted % of $H_2$ Burn in Drywell

| | |
|---|---|
| ▽ | $S_2E$ (D=2) Water Break |
| o | $S_1E$ (D=3) Water Break |
| □ | $S_1E$ (D=5) Water Break |
| Δ | $S_2E$ (D=2) Steam Break |
| + | $S_1E$ (D=3) Steam Break |
| x | $S_1E$ (D=5) Steam Break |

Figure 1 Potential for hydrogen detonation in drywell.

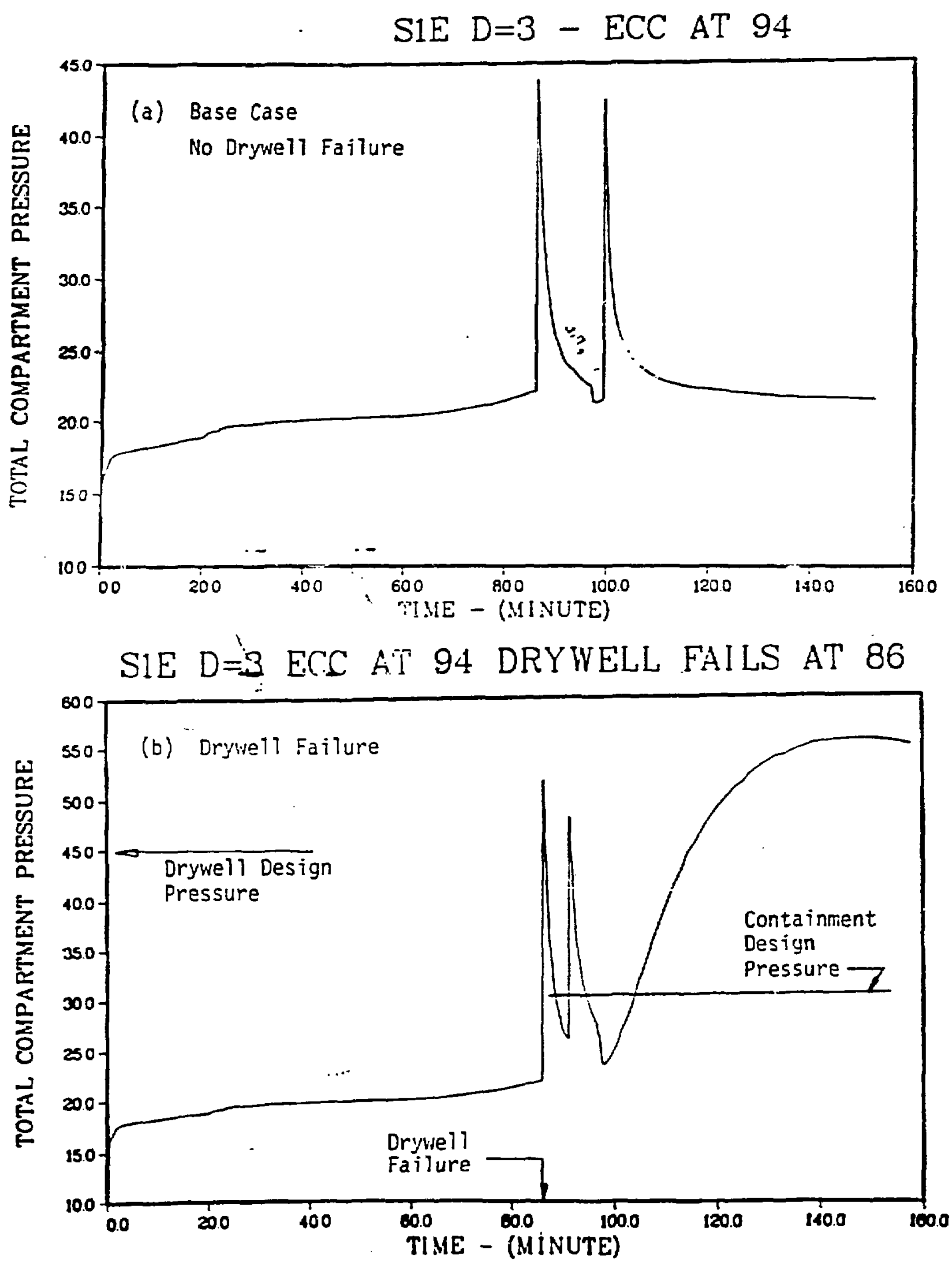


Figure 2 Effect of drywell failure on containment pressure for $S_1E$ (D=3) sequence.