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October 5, 1981

Dr. David Okrent, Chairman
Grand Gulf Nuclear Station Subcommittee
Advisory Committee on Reactor Safeguards
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Dr. Okrent:

Having participated as a consultant in the Grand Gulf Nuclear Station Subcommittee Meeting at Jackson, Mississippi, and toured the reactor site nearby on September 17, 1981, I submit the following observations and opinions regarding intended hydrogen control mechanisms in the air-filled Mark III containment system.

Largely, this submittal responds to particulars in the typewritten "Final Report on the Grand Gulf Nuclear Station Hydrogen Ignition System" (Sections 1.0 through 6.0 and Appendices A through D), submitted by Mississippi Power and Light Company (MP&L) to the Division of Licensing, NRC, by letter (to R. L. Tedesco from L. F. Dale) dated June 19, 1981. To a small extent, I consider the related materials presented in the September 17 subcommittee meeting by J. D. Richardson (MP&L) and C. G. Tinkler (NRC/Containment Systems Branch). I also draw for perspective upon my reaction to related questions regarding hydrogen control measures in reactor containments of the ice condenser type, as assembled in my letter to J. C. Mark, Sequoyah Reactor Subcommittee, ACRS, dated May 7, 1981.

I. HYDROGEN CONTROL BY BURNING IN MARK III CONTAINMENT

A potentially large amount of elemental hydrogen can be produced unintentionally as a consequence of certain nuclear reactor accidents, as a result of chemical reaction between necessarily present steam and metallic zirconium. Being both noncondensable and combustible in air, such hydrogen would

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pressurize and might threaten to burst an otherwise unvented containment vessel in which it were to accumulate and suddenly burn. Mitigation of such a threat is sought by deliberate burning of smaller volumes and/or concentrations of hydrogen in air than could otherwise accumulate throughout the containment and ignite, perhaps even detonate.

Four main mechanisms must combine to effect the desired mitigation. These are:

(a) dispersal of hydrogen by convection from its release location(s) into significant volume(s) of flammable mixture with air;
(b) ignition of propagating flame by deliberately energized devices exposed to the free volume at numerous and suitable locations throughout the containment;
(c) expansion of burned gases, with consequent intercompartmental displacement and compression of unburned (or previously burned) atmosphere, to delocalize the prompt pressurizing effect of combustion and maintain a uniform containment-wide pressure; and
(d) removal from the containment atmosphere of steam and sensible heat produced during burning by interaction with heat sinks in the form of passive concrete, steel, and water and actively injected water spray, so as to restore a nearly unheated, unpressurized atmosphere in the containment in tens of seconds or less after burning of an incremental accumulation of hydrogen.

It is qualitatively apparent from the information given on the Grand Gulf Nuclear Station that all of these mechanisms are operable in the Mark III containment in a mutually compatible fashion. Mechanisms (a), (c) and the passive portion of (d) are inherently present in the blowdown path configuration comprising drywell, wetwell, and upper containment. Active water sprays are engineered safety features serving the upper containment and partially carrying over into the wetwell free volume, where they augment mechanism (d) and also promote the intracompartmental homogenization aspect of mechanism (a). The newly added Hydrogen Ignition System (HIS) employs the same types of glow plugs, electrical supplies, and housings that have previously been selected for the corresponding modification of ice-condenser containments. I believe the HIS accomplishes mechanism (b) deliberately, with a degree of thoroughness comparable to that provided by the Emergency Hydrogen Mitigation System of the McGuire Nuclear Station. MP&L correctly identifies both the HIS hardware and the containment spray system as necessary active systems to mitigate a TMI-2 Degraded Core release of hydrogen.

I interject here my belief that a desirable improvement is possible in the design of the spray shields situated above each of the several igniters. The width and length of these flat, horizontal shields with turned-down edges are presently several times greater than the vertical clearance above the igniter, so as to provide almost hemispherical shielding from above. This configuration promotes the candle snuffer effect under circumstances where slow accumulation of hydrogen and inadequate forcing of convection may lead to surface burning of a very lean composition by contact with the igniter. Stagnation of warmed, burned-out material beneath the broad shield would tend to prevent later propagation of ignition from the igniter into the free volume. To avoid this possibility, I would prefer to see the shield configured as an upright V, with an included angle of perhaps 120-150° and about the present projected area, such that spray from above would drain out the free end of the trough at some distance beyond the igniter.

The circumstances for operation of the deliberate burning mechanisms for mitigating an excessive accidental release of hydrogen are remarkably similar in the two commercial designs of pressure-suppression containment for light-water reactors, the ice condenser and the Mark III (water suppression pool). Both containments have similar total free volumes and design pressures, and both are structurally divided into compartments. Both have a major compartment beneath a hemispherical dome, whose construction determines the designed and ultimate pressure capacities of the system. Both also have two or more other, smaller compartments within or below the major one. In each containment type, the reactor pressure vessel is centrally situated in the largest and sturdiest of these minor compartments, with egress to the major containment volume through an annularly situated pass-through chamber, where either liquid or solid water presents a major sink for condensing steam.

From the standpoint of hydrogen control, the most fundamental difference between the Mark III and the ice condenser is that the Mark III lacks a high-capacity or continuously operating mechanism that allows directed recirculation of the containment atmosphere through the reactor compartment and the heat-sink chamber under accident conditions. Because of this we note several differences in operating detail between the two containment types. Thus, in Mark III hydrogen may accumulate in substantial amount in the drywell, but not ordinarily be burned there, owing to prior expulsion and lack of replacement of air. In contrast, ice condensers replenish the air in the reactor compartment and preferentially accumulate and ignite threshold concentrations of hydrogen in that compartment, with the escape path for burned gases leading directly into the system's main heat sink, the ice gallery. In Mark III, accumulation and ignition of combustible mixtures of hydrogen and air would occur preferentially in the wetwell and/or the annular space above it, downstream of the main heat sink, the suppression pool. The quantity of combustible hydrogen that may accumulate and burn is the main factor governing the system-wide pressure excursions. It is a fortuitous compensating effect that the Mark III wetwell accommodates a smaller amount of hydrogen than does the reactor compartment of the ice condenser, in proportion to the free volumes of these compartments in their respective containments.

In the modeling of deliberate ignition in the ice condenser containments, it has been supposed that the fan-forced recirculation was important in justifying the presumption of rapid (indeed instantaneous) homogeneous mixing of the gases in each of the compartments. This feature is conspicuously absent in the Mark III, and I am presently unable to estimate whether or under what circumstances the presumption of complete mixing in the important compartments, particularly in the drywell and wetwell, might be significantly unreliable on this account. In this connection, I reemphasize the previously noted role of the upper-containment and carry-over sprays in promoting mixing in the air-containing compartments. Likewise, in the absence of fan-forced circulation, the ability of the wetwell to be recharged with air from the upper containment following greater or lesser consumption of its previous oxygen inventory in a burn is notably dependent upon spontaneous suction from the upper containment through shrinkage of the burned gases caused by heat transfer and condensation of steam. The considerable height of the annular containment volume above the wetwell, and the presence of obstructions at levels higher than the base of this volume, may actually translate the locus of accumulation of burnable hydrogen-air mixtures to a zone higher than the wetwell, with only a secondary effect on the quantities of hydrogen consumed in each burn.

II. CLASIX-3 MODELING RESULTS

Three observations are notable in regard to the calculated results of operation of the Hydrogen Ignition System and Containment Sprays under assumed accident circumstances in the Grand Gulf Mark III containment, as presented in Appendix D of the previously specified MP&L Final Report of June 19, 1981.

First, the model itself contains the conspicuously arbitrary simplification of instantaneous compartment-wide mixing, as a consequence of which burning is not begun in a particular compartment unless enough fuel and air are present to produce a combustible mixture throughout the entire volume of that compartment. Partially burned material transported between compartments such as from the wetwell into the upper containment, is apparently presumed to be extinguished immediately upon dilution in the receiving compartment. Depending on buoyant transport of hydrogen upward through the wetwell in competition with mixing, delivery of hydrogen to the upper containment may be underestimated or seriously overestimated. The mixing assumption thus influences the accounting of accumulation of hydrogen in the upper containment, which may become seriously inaccurate after the sequence of hydrogen burns in the wetwell predicted in the first three cases modeled. I believe that effects of such inaccuracy may not be wholly indicated by the range of results produced by the variation of parameters made between the different cases.

Second, it is significant that in Case 4 a containment-wide burn sequence was modeled whose most severe pressurization occurs from burning throughout the upper containment of a mixture bearing 1149 lb of hydrogen, which by my computation would constitute 13.2% of the gas in its 1.25 x 10^6 ft^3 volume at a preburn temperature of 135°F (330 K) and absolute pressure of 21 psia (1.5 atm). Such a composition, with one-third greater hydrogen content than the assumed threshold for ignition, was produced by sudden displacement of a large gulp of hydrogen through the wetwell from its previous accumulation in the oxygen-starved drywell, as the result of a burn in the latter location. From the standpoint of the amount of hydrogen assumed to be ignited in the containment, Case 4 is thus a quite conservative one. The 42 psig excursion accompanying such a burn obviously exceeds the design overpressure of 15 psig, but is apparently 20 psi below the minimum estimate of rupture pressure, 62 psig.

The essential mitigating effect of the containment water spray is a very important factor in the calculated upper containment burn of Case 4. To gain perspective on the severity of this case, I have estimated the pressure potential in adiabatic burning in Case 4 to be approximately 21 (13.2/5.9) (43/14.7) = 137 psia, or 122 psig, by scaling from the TMI-2 data. In the latter situation, a pressure increase from 14.7 psia to 43 psia (28 psig) is considered to have occurred by adiabatic burning of 590 lb of hydrogen, which was 5.9% of the larger volume of air involved.

The third noteworthy feature of the CLASIX-3 modeling results is the large predicted amounts of hydrogen accumulated in the air-filled upper containment in Cases 1, 2, and 3, (7.5%, 8.6%, and 7.9%, respectively), as well as in the air-starved drywell (62%) in Case 1. These upper containment accumulations of hydrogen are sufficiently above the physically known threshold for partial burning (4% H_2) and close to the regime of essentially complete burning (9 ± 1% H_2) that uncertainty in their accounting, together with the inherent physical absence of a precise go - no go threshold for burning, leaves open the possibility of single or even multiple burning events in the upper containment under the conditions of hydrogen release associated with Cases 1, 2, and 3. By the same reasoning, the apparent association in Case 4 of a major upper containment burn with a sequence originated by opening of the vacuum breakers and readmission of air to the hydrogen-charged drywell cannot be taken as a unique cause-and-effect relationship. Presence of air in the drywell is a prerequisite for burning in the drywell, but such presence is only one possible factor, neither necessary nor sufficient, which can contribute to burning in the upper containment.

III. SURVIVAL AND OPERATION OF SAFETY EQUIPMENT

Deliberate ignition mechanisms mitigate the possible threat from sustained and ultimately large accidental release of hydrogen by limiting each pressure surge to a system-wide amplitude and duration small enough not to overstress the air-filled containment. In part, this mitigation is to be accomplished by localized burning in compartments where much larger excursions in gas temperature would occur than could be accommodated simultaneously throughout the system. Transient pressure differentials and high-speed flows between compartments would also accompany these deliberate burn events. Thus, mechanical as well as thermal threats may be posed to essential equipment whose location coincides with the locally severe portion of combustion events, even though system-wide consequences are benign. I note that the local mechanical severity of a flame which traverses a compartment of an unvented system at an average speed of 6 ft/sec is not obvious from this average speed. Confined flames accelerate nonlinearly as their area and the system pressure increase; flow speed of gas displaced through intercompartmental channels is amplified by the ratio of flame area to channel area.

A confined flame can become a detonation by action of an accelerating flame front coupled with accelerating material flow; but these accelerations occur and are influenced by obstructions in all flammable gas mixtures which are confined, without regard to whether the gas composition is ultimately capable of sustaining a steady detonation. The impulsive loading on hardware from these transitional events is quantitatively less severe in gas mixtures outside the detonable limits than the corresponding loadings in more energetic, steadily detonable gases, but no qualitatively distinct separation exists between the transitional behavior exhibited by detonable and nondetonable compositions. Hence, the concern for localized damaging effects from a "transition to detonation", and thus for hardware configurations which promote transition, are a legitimate part of the safety analysis of deliberate ignition as a means for hydrogen control. However, local formation and burning of detonable gas mixtures is not much greater a threat to containment integrity than is the formation and burning of flammable but nondetonable mixtures. Likewise, localized internal equipment must be resistant to possible gas detonation if such equipment is to survive immersion in the localized fireball of a deliberate ignition. This consideration of localized or transitional detonation processes should be distinguished from the threat posed by a containment-wide detonation, whose transient forces would be applied over a substantial portion of the internal surface of the containment shell, and whose uncooled, stagnant products might exert a larger static pressure than the containment could withstand.

With regard to the ability to withstand locally violent combustion, the Mark III containment compares favorably to the ice condenser design. The latter has large, exposed moving parts in the form of check-valve doors and active fans, which are an integral part of the intercompartmental convection pathways that regulate the occurrence of hydrogen-air mixtures and allow dispersal of the energy of their batchwise ignition .

On the basis of these considerations, it appears to me that the Mark III containment as implemented at Grand Gulf presents an inherently rugged setting for deliberate localized ignition of hydrogen. The main intercompartmental pathways are the multiple holes in the base of the drywell wall, which are submerged in a few feet of water, and the gratings and other openings in the floors above the wetwell. Moreover, the Hydraulic Control Unit floor and items in the wetwell beneath it are designed to withstand erratic hydrodynamic loads of splashing, frothy water during a blowdown of primary reactor coolant. These items are thus inherently resistant to higher-speed, lower density flow transients which might occur in the terminal phase of a hydrogren-air burn ignited in the free volume of the wetwell.

The Mark III containment has two items of engineered safety equipment whose interaction with the deliberate ignition mechanism of hydrogen control became conspicuous during the September 17 meeting. These are the six vacuum breakers, whose areas are each only 0.55 ft^2 (3.26/6, from Table D-7 of the

MP&L Final Report), and the drywell purge system of nominal 1000 ft^3/min capacity. Survival of these items in an upper containment burn such as that modeled in Case 4 (discussed in the previous section) may be an issue. I recognize here the point made by J. D. Richardson that the perceived utility of these items arises in recovery from LOCA situations within the design basis, and that if an accident were to progress to Class 9 severity and lead to massive production of hydrogen by metal-water reaction, the vacuum breakers and purge pump(s) might be superfluous.

Actually, the Case 4 modeling calculations showed that these low-flux, one-way pathways from the upper containment into the drywell could adversely influence the intended control of hydrogen late in an accident by readmitting air and enabling previously suppressed combustion in the drywell. The possible hazard seems aggravated when/if these pathways open automatically. I thus suggest that consideration be given to precluding such <u>automatic</u> operation at any time when the Hydrogen Ignition System is energized or when a high hydrogen concentration is sensed in the drywell.

IV. NRC STAFF/CONTRACTOR REVIEW

I find the matters listed under the heading "Combustion/-Analysis Issues" by C. G. Tinkler during the September 17 subcommittee meeting to represent generally the right questions to be investigated in depth in NRC's review of the developing provisions for control of excessive hydrogen in the Mark III containment. In the foregoing sections, I have simplistically prejudged some of these issues, and expressed my own perspective for approaching their detailed analysis.

Sincerely,

Garry L Schott

Garry L. Schott

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