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January 9, 1981

Mr. James Milhoan, P. E.
Office of Policy Evaluation
Nuclear Regulatory Commission
1717 H Street N. W.
Washington, D. C. 20555

Dear Jim:

Please find enclosed the report that you requested.

If you have any questions, please feel free to contact me.

Sincerely yours,

Roger

Roger A. Strehlow
Consultant, N. R. C.

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Evaluation of the
Glow Plug
Igniter Concept
for use in the
Sequoyah Nuclear Plant

Prepared for

Mr. James Milhoan, P. E.
Office of Policy Evaluation
Nuclear Regulatory Commission
Washington, D. C. 20555

Prepared by

Roger A. Strehlow
Consultant

January 9, 1981

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Overall Evaluation

In my opinion, a well designed and maintained glow plug igniter system which is energized only for testing or during an event which has the potential of generating hydrogen is an effective way to protect the Sequoyah nuclear plants from the possibility of breaching the containment vessel due to the inadvertent combustion of accumulated hydrogen. Furthermore, it is my opinion that the implementation of this glow plug igniter technique will have no negative effects on overall safety in such a nuclear plant. I base this opinion on the following information that was supplied to me by the Nuclear Regulatory Commission:

Tennessee Valley Authority, Sequoyah Nuclear Plant Core Degradation Program, Volume I, Hydrogen Study, September 11, 1980.

News Release No. 80-159, USNRC, September 11, 1980.

News Release No. 80-163, USNRC, September 18, 1980.

Safety evaluation report related to the operation Sequoyah Nuclear Plant, Units 1 and 2, Docket No. 50-327 and 50-328, Tennessee Valley Authority, NUREG-0011, Supplement No. 3, September, 1980.

Memorandum for: ACRS members, from: J. C. Mark, Subject Notes on hydrogen burn with igniters, December 4, 1980.

Memorandum to: ACRS members, from: H. Etherington, Subject Memorandum P. G. Shemwon to ACRS members: "Quantity of H_2 at TMI-2 and source."

Tennessee Valley Authority, Sequoyah Nuclear Plant Core Degradation Program, Volume 2, Report on the Safety Evaluation of the Distributed Ignition System, December 15, 1980.

Tennessee Valley Authority, Sequoyah Nuclear Plant, Research Program on Hydrogen Combustion and Control, Quarterly Progress Report, December 15, 1980.

Draft copy of Supplement No. 4 to the Safety evaluation report by the Office of Nuclear Reactor Regulation, U. S. Nuclear Regulatory Commission in the matter of Tennessee Valley Authority Sequoyah Nuclear Plant Units 1 and 2, Docket No's. 50-327 and 50-328, undated.

Attendance at the ACRS subcommittee meeting held in Washington, D. C. on January 6, 1981.

A meeting with Mr. Tinkler and Mr. Butler of the NRC staff on the morning of January 7, 1981.

Other open literature references which helped me form my opinion will be referenced in the detailed supporting statement that follows. I also have opinions concerning the dynamics of a combustion explosion in a Sequoyah type containment and new research and data accumulation efforts which would be necessary to strengthen and quantify the justification for using glow plug igniters as the only hydrogen control technique. These will also be disucssed below.

Effectiveness of the Glow Plugs.

The Singleton Lab., Fenwal and LLNL tests have shown the glow plugs that are being considered for the Sequoyah plant to be very effective igniters down to 5% hydrogen even in the presence of 15% dry steam. Thus, in a real accident we now know that the igniters would initiate a partial burn at 5% H_2 in the CV. Furthermore, the Singleton lab tests show that in a small vessel even with 3.5% H_2 present initially a five minute "burn" reduces the H_2 concentration to about 0.1%. This is very encouraging because it shows that a hot glow plug will act as an H_2 scavenger even outside the flammability limit for upward propagation of about 4% H_2. Furthermore, sparks of the type that undoubtedly initiated the Three Mile Island burn are not effective at such a low hydrogen concentration.

It is important to note that glow-plug initiated burns will be much less dangerous than spark initiated burns. This is because between 4-8% hydrogen in air burns with a very lazy upward propagating flame which spreads at a maximum half angle of about 20 degrees and extinguishes when it reaches the top of the vessel. This means two things: 1) the pressure rise will be minimal for such a burn, and 2) the hot product gases will be confined to this cone-shaped volume and subsequently will spread along the ceiling. In other words, the flame will not contact and therefore not heat most equipment that is in the containment vessel. Also, if the rate of hydrogen generation were slow so that the fans produced a rather uniform hydrogen concentration, the burn would be almost continuous once the hydrogen content reached 4-5%.

On the other hand, a fast leak which caused a localized higher concentration of hydrogen would also not be dangerous when ignited by the glow plug. This is because glow plugs strategically placed above potential hydrogen sources would ignite a high hydrogen concentration plume on contact and only a localized high temperature burn would occur. It is well documented (Cubbage and Marshall, 1972) that such a partial burn yields a pressure rise in a vessel which is proportional to the energy released by the localized burn (Joules) divided by the <u>total</u> volume of the vessel (m^3). Thus, a small localized burn cannot cause a really large pressure rise.

In my opinion, properly located and functioning glow plug igniters would reduce the probability of a burn leading to a transition to detonation to virtually zero. This is because the very weak flames produced by a 4-5% hydrogen burn cannot generate significant pressure waves or significant flow velocities ahead of the flame. This means that the mechanisms that lead to flame acceleration do not exist under these conditions. In other words, the weak 4-5% hydrogen flames will remain weak irrespective of the environment that they encounter.

Combustion dynamics in the Sequoyah containment vessel.

The Sequoyah containment contains three main compartments: 1) the upper compartment, 2) the lower compartment, and 3) the ice condenser. The upper and lower compartments both have a rather low length-to-diameter (L/D) ratio and therefore if they could be treated as independent vessels they would be capable of supporting only a simple over-pressure explosion. The containment at Three Mile Island was essentially of this type and that is what happened there when the hydrogen concentration reached about 8%. In such a case, the flame propagates slowly enough such that the pressure is relatively uniform spatially in the vessel during the burn and simply rises with time (approximately as a cubic of time; see Bradley and Mitcheson, 1978 a, b). This is true even if there is some acceleration due to turbulence generation. Under these conditions, there are essentially no pressure waves generated. Note that at TMI the transit time of a sound wave from top to bottom to top is about 0.2 seconds and the burn took about 10 seconds.

Unfortunately, in the Sequoyah configuration the upper and lower compartments are not independent but are connected by the ice condenser. In my opinion, this is a very dangerous configuration because it would generate pressure waves which could possibly lead to local over pressures that could breach the containment. This is because the ice condenser contains hundreds of tubes (the spaces between the baskets) which have a very large L/D and which could cause significant flame acceleration and possibly even transition to detonation. This mechanism has been adequately documented by Urtiew et al (1965, 1967) and could occur after primary ignition at or above 8% in either the lower or upper compartment. The sequence, without detonation, is as follows: ignition in one compartment causes a slow pressure rise and starts a flow through the condenser, pressurizing the second compartment. The flame then gets into the ice condenser at some location and accelerates in this turbulent flow causing large turbulent jets to enter the second compartment. Once the flame reaches the second compartment, it is already pre-pressurized and the burning velocity is now so large that combustion in this compartment produces pressures that are up to a factor of 2-4 above the calculated maximum adiabatic constant volume pressure (Heinrich, 1974).

There is another more recently discovered combustion dynamics possibility. Knystantas et al (1979) have shown that large scale eddy folding of hot combustion products into an already turbulent jet of reactants can produce shockless initiation of detonation. Here the mechanism is that radicals in the product gases trigger combustion reactions in the mixing volume and as the system explodes the pressure increase augments the combustion process. This coupled augmentation eventually culminates in a detonation wave. For hydrocarbon-air mixtures, the critical eddy size is large, about three meters in diameter. Note that at the exit of the ice condensus, conditions would be right for the formation of such a large mixing region. The required eddy size for hydrogen-air is not known but it would probably be smaller than the critical size for a hydrocarbon-air mixture.

Thus, in my opinion, the combustion dynamics of an explosion in which a continuous flame is able to propagate (i.e., in a mixture containing greater than 8% H_2) is a very dangerous situation and would have the potential to breach the containment vessel. We know that glow plugs have been shown to yield partial burns when the flame is lazy and not dangerous. This, coupled with the vulnerability of the facility to a dynamic combustion explosion, is one more point in favor of using glow plug igniters to protect the containment vessel from the adverse consequences of an accidental spark-ignited burn.

Research Needs.

Glow plug testing should be continued. Specifically, I agree with the LLNL recommendations for further work that was presented at the ACRS subcommittee meeting of January 6, 1981. I would also like to see some continuous burn tests at concentration less than 4% to determine how rapidly a glow plug will scavenge hydrogen at these low concentrations. In these tests, the effect of fan-induced flow across the plug should also be investigated.

Even though I feel that the glow plugs will virtually eliminate the possibility of detonation in the containment vessel, I still feel that some work on detonation limits should be performed.

I do not believe the 18% figure that is in the reports. I feel that the limit is much lower, possibly 12%. At any rate, this uncertainty can be relatively easily answered by a few rather simple tests that should be performed.

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Cubbage, P. A. and Marshall, M. R. (1972), "Pressures generated in combustion chambers by the ignition of air-gas mixtures", I. Chem E. Symposium Series #33, Inst. of Chemical Engineers, London, pp. 24-31.

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Utriew, P. A., Laderman, A. J. and Oppenheim, A. K. (1965), "Dynamics of the Generation of Pressure Waves by Accelerating Flames", 10th Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pa., pp. 797-804.