April 5, 1979

NOTE TO: EH01/Mr. Schwinghamer

FROM: EH31/Mr. Riehl

SUBJECT: Technical Support to Three Mile Island Nuclear Power Plant Incident

Pursuant to a request from the Center Director on April 1, I provided technical support as a "combustion expert" at the Three Mile Island Nuclear Power Plant, Pennsylvania.

Most of Sunday, April 1, was spent at the site, where I met and provided technical advice on the flammability of hydrogen in air and oxygen to the Chairman of the Nuclear Regulatory Commission, Mr. Joseph Hendrie; the Chairman of the Board of Metropolitan Edison Power Company, Mr. William Kunz; and several other officials - as Mr. Howard Dietkamp and Mr. Jack Herbein (Metropolitan Edison Power Company).

Sunday evening I was taken to the National Guard Armory, Middletown, Pennslyvania (1.5 miles away) where technical advisory support groups were being set up. There I met Mr. Ed Zebrowski, to whose group I was assigned. For the next several days I provided support in four major areas:

(1) <u>Establishment of "Redline" Flammability Limits for the Gas in the Bubble in the Reactor</u>

Several different sets of numbers have been reported by different groups. I investigated these in the literature, by discussion with several technical organizations, and prepared a "white paper" of recommended limits. Prior to issuance, the contents were coordinated with and unofficially approved by each of the groups. A copy of this report is attached (Attachment No. 1) and has been sent to each of the participants therein (per their request).

(2) <u>Review of Flammability Aspects of Hydrogen in Containment Room</u>

Some of the contents of the bubble in the reactor were being transferred into the surrounding containment room (normally air at -1.1 psia). The hydrogen content therein was between 2 and 2.7

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percent (by volume). Methods of removal were considered, and a "recombiner" selected. Flammability and fire prevention aspects of installation and use of the recombiner were reviewed and evaluated. A summary report was prepared (Attachment No. 2).

(3) Waste Gas Storage Tank Flammability Hazards

In addition to transfer into the containment room, some of the reactor bubble gases were transferred to waste gas storage tanks. The contents therein were reported to be 53% hydrogen (46% nitrogen, 1% other). These tanks have relief valves which could vent the radioactive gas mixture. In order to preclude filling the tanks to relief venting, methods of transfer of some of the contents are under consideration (by Burns and Rowe, Inc.).

The long term approach is by transfer through a suitable piping system and a charcoal absorber (for removal of most of the radioactive components) to additional storage tanks. At a later date, the remaining gas would be burned in a flare stack.

Suggestions were made to minimize flammable hazards to Mr. Frank Patti, Chief Nuclear Engineer of Burns and Rowe, Inc. (responsible for design, fabrication, and installation of this system).

Purge procedures will be prepared within several days, and will be provided subsequently for my review and comments.

Mr. Patti also inquired whether I may be able to assist in inspection of the piping after installation and prior to activation on-site at the Three Mile Island Plant. I informed him that this probably can be arranged and I would consult NASA Management along this line.

It is understood that it will be at least a week before the above system could be used. Contingency planning, in the event of approach of relief venting prior to the above measure, is also underway. In that case relief venting back to the containment room rather than the atmosphere is under consideration. Flammability aspects of this operation also were discussed and suggestions and maximum flow rates provided (Attachment No. 3).

(4) Fire Suppression of Hydrogen Flammable Mixtures

As a contingency, pursuant to a request for recommendation of a method of suppressing a fire if a flammable mixture of hydrogen in air or oxygen should develop, I am currently doing a literature search and personal contacts. It currently appears that for <u>these</u> particular applications, bromotrifluoromethane (Freon 1301, Halon 1301, etc.) probably would be more suitable, requiring only about 6% by volume for fire suppression. This has been established for aircraft (jet fuel) and normal industrial type fires. However, test data of "1301" with hydrogen/air or hydrogen/oxygen mixtures has not yet been located. A separate report on this will be prepared subsequently.

W. A. Riehl
Non-Metallic Materials Division

3 Enclosures

April 3, 1979

TO: Ed Zebrowski, Group Leader
Technical Advisory Support for Three Mile Island
Nuclear Power Plant Incident

FROM: W. A. Riehl

SUBJECT: Flammability Limits for Hydrogen and Oxygen in Nuclear Reactor Vessels

A limited literature review has been done, and technical discussions held, with several groups with expertise in the area of flammability of hydrogen in reactor vessels. Primary literature sources included:

(1) NACA Report No. 1383, "Survey of Hydrogen Combustion Properties," I. E. Drell and F. E. Belles - Lewis Flight Propulsion Laboratory - 1957.

(2) "Hydrogen Flammability Data and Application to PWR Loss of Coolant Accident," WAPD-SC-545, Westinghouse Corp., Contract AT-11-1-Gen 14 - September 1957.

(3) "Hydrogen Flammability and Burning Characteristics in BWR Containments," B. C. Slifer and T. G. Peterson, General Electric Company Report No. NEDO-108012 - April 1973.

(4) Private experimental data from J. Smiley, J. Conine, E. Vencrus, and D. Krommenhoek, April 2, 1979, General Electric Company, Knolls Atomic Power Laboratory, Schenectady, New York.

(5) Yeaw, J. S. and Schnidman, L., "The Extinction of Gas Flames by Steam," A. G. A. Proceeding, 1938, pp. 717-745.

(6) Zabetakis, M., "Research on the Combustion and Explosion Hazards of Hydrogen-Water-Air Mixtures," AECU-3377, September 4, 1956.

Attachment No. 1

Persons contacted include:

(1) Bob Tedesco, Nuclear Regulatory Commission, Bethesda, Maryland.

(2) E. Venerus, J. Conine, D. Krommenhoek, and J. Smiley, General Electric Company, Schenectady, New York. (Reference 4).

(3) Thomas G. Peterson, General Electric Company, San Jose, California. (Reference 3).

The consensus of recommended flammability limits for use in hydrogen/oxygen mixtures at 1000 psi and 300°F is as follows:

	% by Volume		Zone
	Hydrogen	Oxygen	Safe
Safe Limit (Upward flame propagation)	4	6	Marginal
Flammable Limit (Deflagration - stable burning)	8	6	Hazard
Detonable Limit	15	12	Detonation

To be in a given zone above, both the respective hydrogen and oxygen limits must be exceeded. Some clarification of the limits and zones therein is as follows:

Safe Limit: Absolutely no fire hazard below these values.

Flammable Limit: Minimum quantities required for sustained combustion or flame. Between 4 and 8% hydrogen is a marginal zone or "gray" area, in which flames propagate upward and then extinguish, presenting a limited fire hazard.

Between the flammable and detonable limits, stable combustion and explosion can occur in confined spaces. The shock wave pressure difference will normally be only about 5 to 8 times across the front. However, this could cause significant damage.

Detonable Limit:

Above the detonable limits, "high order" explosions can occur, with shock wave pressure differences of 18-20 times or more in confined areas.

These limits are for hydrogen and oxygen only, with no other gases present - as nitrogen, air, or water. Naturally their presence is beneficial to varying degrees on the limits above. However, these limits are recommended to be on the conservative side.

For example, in air at ambient temperature the flammable limit for hydrogen may be raised to 9%, and for detonation to 18%.

In high water contents (50%), the flammable limit for oxygen rises to 7%, and for detonation to 18%.

It is to be stressed that the variation of these limits with the presence of additional gases is complex. Any deviations to the limits in the above table must be discussed with technical experts on specific individual case by case situations.

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April 3, 1979

TO: Ed Zebrowski, Group Leader
Technical Advisory Support for Three Mile Island
Nuclear Power Plant Incident

FROM: W. A. Riehl

SUBJECT: Hydrogen in Containment Room

Potential hydrogen hazards and removal measures in the containment room have been reviewed and currently appear safe and in control.

The concentration of hydrogen (by volume) has been in the range of 2 to 2.7% within the past several days. This is considered safe - whether in air or in the reactor vessel. However, in order to prevent the composition from approaching a marginal hazard zone at 4%, "recombiners" have been installed to remove the hydrogen.

The recombiners function by heating the gas to over 1300°F, thereby reacting hydrogen with oxygen to produce water and evolving additional heat. Since the autoignition temperature of hydrogen in air is 1080°F, this device could function as an igniter.

However, a safety cutout is provided. The temperature drop is monitored across the unit (inlet and exit). This is indicative of the performance of the unit as well as the precent hydrogen present at the inlet. When the hydrogen concentration exceeds 5%, the unit is automatically cut off.

In the 4 to 5% hydrogen range, unstable flames could occur. However, this could not propagate upstream against the 50 ft/sec flow velocity in the unit. This feature has been confirmed by testing the unit with 5.5% hydrogen.

As an additional backup safety feature, the unit is reportedly designed so that between 5.5% and 9% hydrogen the heat evolved from combustion would be sufficient to burn out the heater coils.

Attachment No. 2

Regarding flow rates and reduction times, the unit is designed to operate at 100 cfm with a minimum guaranteed flow rate of 50 cfm. Upon installation and checkout, the single unit now in operating is providing a 90 cfm flow. For an approximately two million cubic feet room volume, fifteen days would be required to drop the concentration from 2 to 1% (assuming no additional hydrogen input).

At an initial concentration of 2% hydrogen, approximately 2600 cubic feet of hydrogen would be removed per day. Thus, this is the limit of hydrogen input in order to prevent a rise in concentration, whether the source is from the reactor or venting of the waste gas storage container.

These values are for the single recombiner now in operation. Activation of the second unit (already installed) would naturally provide a benefit proportional to the additional flow rate.

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April 3, 1979

TO: Ed Zebrowski, Group Leader
Technical Advisory Support for Three Mile Island
Nuclear Power Plant Incident

FROM: W. A. Riehl

SUBJECT: Transfer of Hydrogen from Waste Gas Storage Tanks

It is understood that two waste gas storage tanks contain approximately 25,000 cubic feet of 53% hydrogen, 46% nitrogen (1% other) gas mixture. These tanks have relief valves which could vent the radioactive gas mixture. In order to preclude filling the tanks to relief venting, methods of transfer of some of the contents are under consideration (by Burns and Rowe, Inc.).

The long term approach is by transfer through a suitable piping system through a charcoal absorber (to remove most of the radioactive components) to additional storage tanks. At a later date, the remaining gas would be burned in a flow stack.

I have made suggestions to minimize flammable mixtures during installation purge and checkout upon the request of Mr. Frank Patti, Chief Nuclear Engineer of Burns and Rowe, Inc. Some of the major precautions include:

(1) Eliminate or minimize potential deadends or pockets.

(2) Provide for nitrogen purge flow through all lines.

(3) Verify adequate nitrogen purge by sampling several points, either by chemical or instrumental analysis.

(4) 1.0% maximum oxygen content prior to entry of waste gas (53% hydrogen).

The transfer system is now in design, and purge procedures will be prepared within several days. A copy of these will be provided subsequently for my review and comments (at Marshall Space Flight Center).

Attachment No. 3

Mr. Patti also inquired whether I may be able to assist in inspection of the piping after installation and prior to activation on-site at the Three Mile Island Plant. I informed him that this probably can be arranged and I will consult NASA Management along this line.

It is understood that it will be at least a week before the above system could be used. Contingency planning, in the event of approach of relief venting prior to the above measures, is also underway. In that case, relief venting back to the containment room rather than the atmosphere is under consideration.

A separate memorandum cited the maximum allowable hydrogen input to the containment room as 2600 cubic feet per day to prevent a concentration increase under current conditions therein (2% hydrogen by volume - one recombiner at 90 cfm flow). This would allow 4900 cubic feet per day of 53% hydrogen mixture (3.4 cfm). An additional safety margin obviously exists in that a second recombiner also has been installed but not yet activated in order to provide a higher permissible flow.

During entry of the 53% hydrogen mixture into the containment room, a flammable zone will occur and spurious ignition cannot be ruled out. Thus, there is a reasonable possibility that a flame may exist at the waste gas entry point. However, this should be a localized stable flame, without propagation into the general room volume or propagation back toward the waste gas tank. Potential hazards would be limited to overheating of adjacent items. At a flow rate of 3.4 cft (NTP), the maximum rate of heat evolution (from 53% hydrogen gas) would be 126 kilocalories per minute. This aspect should be considered by engineers familiar with the system.

This approach and contingency plan is considered safe and reasonable with respect to flammability hazards, subject to the review and precautionary conditions and limits cited above.

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