DRAFT
TECHNICAL EVALUATION REPORT ON U.S. COMMERCIAL POWER REACTOR HYDROGEN TANK FARMS AND THEIR COMPLIANCE WITH SEPARATION DISTANCE SAFETY CRITERIA

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March 1990
SCIENTECH, Inc.
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Prepared for the
U.S. Nuclear Regulatory Commission
Washington, DC 20555
Under DOE Contract DE-AC07-76IDO1570
FIN No. D6198

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PREFACE

This draft report is a preliminary assessment prepared for the U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, by SCIENTECH, Inc., of Idaho Falls, Idaho, under subcontract to EG&G Idaho, Inc., NRC Regulatory Technical Assistance Group. Included in this report are recommendations for further study and evaluation directed at resolving hydrogen tank farm concerns related to Generic Safety Issue 106.

ABSTRACT

An evaluation of hydrogen tank farm facilities at commercial nuclear reactor plants was made to determine compliance with safety-related building distance separation requirements. The separation requirements were those previously established by Electric Power Research Institute (EPRI) NP-5283-SR-A, 1987. [redacted]

In addition, a calculated hydrogen tank farm explosion frequency of 1E-03/RY was established from both existing operational experience data and from inquiry of hydrogen and related gas industry sources. This explosion frequency provided a basis for a preliminary risk assessment and recommendations for further evaluations of the core damage risk posed by hydrogen tank farm facilities.

SUMMARY

This report is a preliminary assessment of risk to commercial nuclear power plants from onsite hydrogen tank farms. This assessment of risk is part of a larger evaluation of the risks from combustible gases [redacted] Generic Safety Issue 106 (GI-106). Most of the risks associated with GI-106 are attributed to hydrogen gas.

This report uses input supplied by the Office of Nuclear Reactor Regulation (NRR) of the U.S. Nuclear Regulatory Commission (NRC) on existing reactor hydrogen tank farms. The separation criteria used are from the Electric Power Research Institute (EPRI) Report (NP-5283-SR-A) on hydrogen water chemistry installations at boiling water reactors (BWRs). This interim tank farm report serves as a general overview of this topic, but does not estimate risk to the individual plants. The data are sufficient to reasonably portray the general status of hydrogen tank farms for 119 reactors, even though some tank farm location detail is missing.

[redacted]

NRR compiled the requested storage information supplied by the five NRC regions. The purpose of this study by SCIENTECH, Inc., is to assess the general safety significance of the tank farm storage of hydrogen at commercial nuclear plants relative to the EPRI report guidelines. Compliance with explosion, ventilation air intake, and thermal flux separation distance criteria for both gas and liquid hydrogen storage near safety-related buildings is addressed. A preliminary assessment is also made of the frequency and damage consequences of hydrogen tank farm explosions.

The review of the hydrogen tank farm storage installations at commercial nuclear power plants shows that for explosion damage separation [redacted] review of separation from ventilation air intakes shows that [redacted] meet this criterion. For the thermal flux separation distance, [redacted] meet the criterion. Further evaluation of plant [redacted]

Based on operating experience data, the frequency of hydrogen tank farm explosions was determined to be 1 E-03/reactor year (RY). In the absence of more detailed plant-specific evaluations, conditional probabilities of wall-failure and subsequent damage to safety systems were conservatively estimated to approach one. [redacted]

[redacted]

It is recommended that further efforts toward the resolution of this issue include evaluations of core damage risk posed by hydrogen storage facilities in a manner similar to the individual plant examination (IPE) process. Further plant-specific evaluations [redacted]

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TECHNICAL EVALUATION REPORT ON U.S. COMMERCIAL POWER REACTOR HYDROGEN TANK FARMS AND THEIR COMPLIANCE WITH SEPARATION DISTANCE SAFETY CRITERIA

1. INTRODUCTION

This report is on the assessment of risk to commercial nuclear power plants from onsite hydrogen tank farms. This assessment of risk is part of a larger evaluation of the risk to commercial nuclear power plants from combustible gases in vital areas. That topic is covered by the Nuclear Regulatory Commission's (NRC) Generic Safety Issue 106 (GI-106), Piping and Use of Highly Combustible Gases In Vital Areas (Reference 1-1). Most of the risk is caused by the most prevalent combustible gas, hydrogen. This report deals only with the risk posed by the hydrogen tank farm as opposed to other areas of risk associated with the distribution of hydrogen gas into the [redacted] building of pressurized water reactors (PWRs) and the [redacted] building of both PWRs and boiling water reactors (BWRs). These other areas have been addressed in two earlier EG&G Technical Evaluation Reports (References 1-2 and 1-3) and will be the subject of a future NUREG/CR.

This draft report uses input supplied by the NRC's Office of Nuclear Reactor Regulation (NRR) on hydrogen tank farms at commercial nuclear power plants. The separation criteria are from the Electric Power Research Institute (EPRI) Report NP-5283-SR-A (Reference 1-4, from now on called the EPRI report) on hydrogen water chemistry installations at BWRs. This draft report is preliminary in nature, and therefore simplifying assumptions are made to estimate risk to the plant. A more detailed assessment of the risk resulting from the hydrogen tank farm will be made in a future probabilistic risk assessment for a typical PWR.

1.1 Background

[redacted]

1. Distance from the hydrogen storage facility to the nearest safety-related structure or air intake.

2. Maximum volume of gaseous or liquid hydrogen stored onsite in scf or gallons (gal), respectively.

NRR compiled information received from each of the five regions (detailed in Appendix A, Reference 1-7). This regional information is preliminary and needs significant interpretation. Some detail is missing. However, it is the best available information without establishing a more precise data base.

1.2 Purpose

This study is to assess the safety significance of the tank farm storage of hydrogen at commercial nuclear plants. It does not attempt to provide definitive analyses of each plant's hydrogen storage system, rather it only identifies whether plants meet separation distance criteria for hydrogen storage near safety-related buildings or air intakes. An assessment is made of the possible frequency of accidental hydrogen release and potential damage. A more detailed subsequent analysis may show that plants [redacted] used in this study can meet the individual plant examination (IPE) screening criteria (Reference 1-8).

1.3 Contractor's Study

EG&G Idaho, the prime contractor for the evaluations of GI-106, authorized SCIENTECH, Inc. as a subcontractor to compile and analyze the information supplied by NRR. Also, SCIENTECH was asked to determine the frequency of hydrogen tank farm explosions, fires and uncombusted releases; and provide an indication of the likelihood of resulting damage to safety systems. Extensions of this information will assist the NRC in determining the need for further action.

1.4 Limits of the Study

This study is limited to outdoor hydrogen tank farms. Small hydrogen gas storage or distribution systems inside buildings are not addressed. The only concern is potential plant damage which may affect the reactor core damage frequency. The expected consequences of economic losses and personal injuries or fatalities from the small gas storage inside buildings are not addressed. Both the small gas storage inside buildings and the distribution of hydrogen gas inside buildings will be covered in a later NUREG/CR.

1.5 Relevant Guidelines

Guidelines for hydrogen water chemistry (HWC) installations at BWRs are addressed in the EPRI report. These EPRI guidelines have been reviewed and accepted by the NRC. The non-HWC storage installations are similar to installations addressed in the EPRI guidelines, which are therefore considered applicable to non-HWC storage installations. Regulatory Guide 1.91 (Reference 1-9) addresses transportation of hydrogen as a hazardous material, and is considered less applicable than the EPRI report. Other relevant guidelines, such as the NRC Fire Protection Standard Review Plan 9.5-1, are noted in Appendix A, Table A-1.

1.6 Methodology for this Study

SCIENTECH tabulated the data supplied by NRR (in Appendix B). Because of the difficulty in interpreting the data, judgement was used to complete the table found in Appendix B. The ground rules used are included as footnotes to the table. Once the data values were tabulated, the spreadsheet calculations, described in Appendix C, were made and logical comparison functions of the spreadsheet were applied to determine compliance and noncompliance.

The site storage information for liquid hydrogen was separated from that for gaseous hydrogen. Each type of storage requires a different calculation to determine the trinitrotoluene (TNT) energy equivalence used in the separation calculation. For the final comparison and summary, the gas only, liquid only, and liquid plus gas sites were totaled.

The hydrogen facility [redacted] experience was secured by telephone contacts with industry representatives and by consulting known literature sources. The results were then extended based on engineering judgement and experience.

2. SCENARIO SELECTION AND ACCEPTANCE CRITERIA

In the event of an accidental hydrogen leak from a tank farm, there are three possible results of concern: (1) a fireball, (2) an explosion (detonation being more severe than deflagration), and (3) transport of uncombusted hydrogen through ventilation air pathways into safety-related buildings. The EPRI report addresses all three possibilities for storage tanks. Each of the three basic scenarios is discussed in greater detail for both gaseous and liquid storage installations. Blast-generated missiles and hydrogen events caused by earthquake or tornado are specifically excluded from consideration.

2.1 Assumptions and Conservatism

In this report, effort has been made to be reasonably conservative. This is reflected in the following considerations:

1. All building walls are considered to be 18-in.-thick reinforced concrete, while in reality many walls are [redacted]
2. All reinforcing steel in the concrete is assumed to be [redacted] of the wall volume while in practice it may be significantly greater.
3. All concrete is assumed to have a μ (mu) level of ductility of [redacted]
4. 100% of the hydrogen mass contributes to the blast wave.
5. The effects of [redacted] in lessening the effects of a blast are not considered.
6. [redacted] is considered the normal situation.

As no attempt was made to individually characterize each plant's construction, it is assumed here that all safety-related buildings have reinforced concrete walls and are designed to withstand the pressure criteria of the Tornado Zone III. This is the same assumption used in the EPRI report for a typical commercial nuclear power plant. This assumption is generally conservative, but experience shows there may be plants where this assumption is not valid [redacted]. As stated, data are not readily available to allow identification of the limited cases where this assumption is not valid.

2.2 Gaseous Storage Installation Scenarios

Simultaneous failure of multiple storage tanks is not addressed in the EPRI report "because the inherent strength of the vessels make them unsusceptible to failure from outside forces" (Reference 1-4). This evaluation treats only

2 [redacted] failure. The total gas inventory release can result from a leak or rupture of the header piping which is supplied from each individual tank, but is limited by the jet gas discharge model.

2.2.1 Fireball

The fireball scenario involves combustion of the entire contents of the largest single storage or unit vessel. The EPRI report established that this scenario is not a major concern for safety-related buildings because of the resistance of concrete structures to thermal flux. The size and duration of thermal fluxes experienced during a fireball associated with a tank or pipe leak "will not adversely affect safety-related structures" (Reference 1-4). The thermal flux criteria in the EPRI report show only whether wooden surfaces would be charred from the thermal flux and in no way show potential wall failure. Separation guidelines were taken from the EPRI report and are tabulated in Appendix B of this report for completeness. Again, no safety-related building wall damage is expected from the fireball thermal flux. Figures C2-3, C2-4 and Table C2-1 in Appendix C were the source of the values for thermal flux separation distances.

2.2.2 Explosion

The explosion scenario involves the contents of a [redacted] 2
An explosion involving the total contents of one tank is expected only with a unit tank failure. Leakage from pipe failure is restricted due to jet dispersion models which show that hydrogen leaks to the atmosphere slowly, resulting in leakage which is dispersed too quickly for large quantities of hydrogen to accumulate in an explosive concentration in an outdoor environment. Also, Figure C2-1 of Appendix C shows the smallest needed separation distance for explosions resulting from pipe ruptures. This assumes the safety-related structure has a wall thickness of greater than [redacted] This separation distance is far less than the separation distance associated with the uptake of hydrogen by ventilating air intakes of the safety-related buildings. Therefore, explosions associated with pipe failure are dismissed from further consideration in this report.

Blast damage separation guidelines are found in the EPRI report. The actual values result from calculations following procedures given in Appendix B, "Separation Distances Recommended for Hydrogen Storage to Prevent Damage to Nuclear Plants Structures From Hydrogen Explosions," of the EPRI report. But, they follow generally the values that can be found from Figure C2-2 of Appendix C. (Figure C2-3 can be used to make a qualitative check the accuracy of the computations and the tabulated values.)

The EPRI report does not address explosive missiles. The reason for not including missiles is based on Regulatory Guide 1.91 (Reference 1-9) which states, "The effects of blast-generated missiles will be less than those associated with blast overpressure levels considered in this guide. If the overpressure criteria of this guide are exceeded, the effects of the missile must be considered." Missiles associated with explosions therefore, are not specifically addressed in the SCIENTECH evaluation. Safety-related buildings are designed to withstand tornado-generated missiles. [redacted] ←—2

The single tank separation criterion is used in this evaluation. [redacted] —2 In each installation, the vessels are designed to be capable of withstanding tornado missiles and site-specific seismic loading. These features tend to eliminate common cause vessel failures so that the maximum postulated instantaneous release [redacted] —2 Figure C2-2 of Appendix C was used for the blast damage evaluation. The 18-in.-thick concrete wall assumptions used are the same assumptions recommended in the EPRI report. These are considered conservative for the typical concrete safety-related facility wall. These assumptions include a static pressure allowable of 1.5 psi, a ductile factor μ of 3.0 and a tensile steel factor (ρ x yield strength of steel/ 100%) of 0.12 ksi. These assumptions are reflected in case (a) of Figure C2-2 and correspond to the first equation shown in Figure C2-5 in Appendix C.

2.2.3 Presence of Unburned Hydrogen Gas in Ventilation Air Intakes

The presence of unburned hydrogen gas in the ventilation system air intake is addressed for a tank farm-related pipe break. This is described by the separation distance needed to maintain a hydrogen concentration less than 4% by volume nearest to any safety-related building ventilation air pathway. Migration of hydrogen from a pipe rupture is not addressed in the EPRI report because hydrogen gas release is governed by a jet release model described earlier in this section and is therefore not addressed here. The low density and high diffusion rate of hydrogen make closeness to the ventilation air pathway more important than the volume available, decreasing the importance of a tank leak or rupture. Figure C2-1 of Appendix C presents the needed separation distance between hydrogen piping and the air intakes to safety-related buildings as a function of the pipe inside diameter.

2.3 Liquid Storage Installation Scenarios

There are differences in the storage and handling of liquid and gaseous hydrogen. These differences are reflected in the storage vessel design and construction, both in configuration and materials. Because of the differences in behavior of structural materials at low temperatures (brittle fracture), special choice of materials is necessary for liquid storage vessels. Also, to limit heat transfer, the vessels are insulated to maintain their low temperatures (-408°F). Liquid hydrogen is stored in vessels at a working pressure of 150 pounds per square inch gauge (psig); gas is stored at a pressure of [redacted] psig. Liquid storage offers the advantage of greater storage density and a resulting storage volume reduction.

The EPRI report (page 4-8) points out that "Design basis tornado-generated missiles are capable of breaching all known commercially available liquid hydrogen storage vessels." [redacted]

2.3.1 Fireball

The fireball scenario assumes instantaneous combustion of the contents of the [redacted]. This scenario is not a major concern for safety-related buildings because of the resistance of concrete structures to heat. The size and duration of fireball thermal fluxes from a tank or pipe leak "will not adversely affect safety-related structures" (Reference 1-4). The thermal flux criteria show whether a wooden surface would be charred by a thermal flux and do not necessarily show potential wall failure. The guidelines used for separation are from Figures C2-6 and C2-7 of Appendix C.

[redacted] A fireball at the tank location is an expected result. The reasons cited are [redacted] Excluding the possibility of missile-caused multiple tank failure, the report states that thermal fluxes and their durations will not adversely affect equipment or personnel in concrete/steel safety-related structures. The facility operators must review both the site and equipment to be sure all equipment will be operable in the event of a fireball.

2.3.2 Explosion

[redacted] As mentioned in Section 2.2, explosions associated with pipe failure are not important. [redacted] However, for liquid hydrogen storage tanks as discussed above in Section 2.2, the missile issue should be given more attention.

The single tank separation criterion presented in Figure C2-8 was used for this evaluation. The concrete wall assumptions used here are the same assumptions recommended in the EPRI report. These are considered conservative for the typical concrete safety-facility wall. These assumptions include a static pressure capability of 1.5 psi, a ductile factor μ of 3.0 and a tensile steel factor of (ρ x steel yield strength/100%) of 0.12 ksi. These assumptions are reflected in case (a) of Figure C2-2, and correspond to the first equation shown in Figure C2-5 in Appendix C.

3. DESCRIPTION OF PLANT STORAGE

Plant storage information is taken from two sources: the NRR data presented in Appendix A and personal communication with EG&G personnel about their visits to 14 plants.

3.1 Observations on Hydrogen Tank Farm Plant Storage

Based on the examination of the plant information supplied by NRR, the following observations have been made about hydrogen tank farm plant storage.

1. There are a wide variety of containers used for the bulk storage of gaseous hydrogen. Hydrogen vendors indicated there is no current industry standardization of the containers. The preference of the architect-engineer for the plant generally determined the container size. Vessel sizes other than standard 215 scf cylinders, range from 1000 to 40,000 scf. For the most part, the size is limited to what is convenient to transport or build. It has been noted from the data supplied by NRR that sizes of [redacted] 2

2. Several [redacted] storage configurations are in use. The [redacted] 2 are often used as reserve capacity and are less permanent than the conventional anchored storage units. They range from ganged standard 215 scf cylinders [redacted] 2

3. For the liquid hydrogen storage, there are several basic configurations. The smallest is 1500 gal and the volumetric capacity of the largest reported is [redacted] A hydrogen vendor reported that standard sizes are 1500, 3000, 4500, 6000, 9000, and 20,000 gal. Each gallon of liquid hydrogen results in 110 scf of hydrogen gas. In the NRR data, only three sizes are represented. These are [redacted] 2 gal capacity.

3.2 Specific Configurations

A sketch of the [redacted] 2 has been included as representative and is Figure 3-1. The sketch was secured by EG&G during a recent inspection visit. [redacted] 3

4. SEPARATION DISTANCE COMPLIANCE

The discussion of separation distance criteria is based on the understanding that the EPRI HWC damage criteria are governing, i.e., some cracking is allowed before failure. If there is much cracking, the wall is considered to have failed and equipment near the wall is considered to be damaged. Wall thickness, reinforcing materials, the allowable static pressure judged to result from the blast, and elasticity designed into the wall system all form the basis of the separation distance criteria.

4.1 Separation Distance Calculations

As noted in Sections 2.1 and 2.2, specific acceptance criteria were determined from referenced figures and formulas in the EPRI report. The derived values used for this study are supplied in the figures in Appendix C.

[redacted]

The EPRI report shows that a different TNT equivalent should be used for liquid hydrogen from that used for gaseous hydrogen. Calculations were made using this TNT equivalent for liquid hydrogen to determine the minimum separation distance. Comparisons were then made between what was calculated and what was reported to determine compliance or noncompliance.

All reported and calculated values were tabulated with the derived values and the compliance information. The data are illustrated graphically and summarized in Table 4-1 and in Figure 4-1.

4.2 Special Considerations for Liquid Hydrogen Storage

In the design of the reactor facilities, it has been assumed that the tornado design (for missiles and wind loading) of the walls and structures is enough to prevent damage to hydrogen tanks. [redacted]

TABLE 4-1

SUMMARY OF POWER REACTOR
HYDROGEN TANK FARM SEPARATION COMPLIANCE

REGION	EXPLOSIVE		AIR INTAKE		THERMAL FLUX		NUMBER OF REACTORS
	YES	NO	YES	NO	YES	NO	
1	[redacted]						31
2	[redacted]						36
3	[redacted]						29
4	[redacted]						12
5	[redacted]						11
TOTAL	[redacted]						119
PERCENT	[redacted]						
RESPONSES	118		118		118		

The EPRI compliance assessment was performed for a total plant population of 119 reactors. [redacted]

SUMMARY OF POWER REACTOR HYDROGEN TANK FARM SEPARATION COMPLIANCE

BLAST DAMAGE SEPARATIONS

[redacted]

Figure 4-1

Summary of Graphs for Gas for All Plants

5. ESTIMATE OF EVENT FREQUENCY

The approaches used to estimate the frequency of tank farm events included: (1) evaluating nuclear reactor experience, (2) surveying the hydrogen supply industry for their experience, (3) using published data for the hydrogen industry, and (4) using published data for related-industries [e.g., Liquified Natural Gas (LNG)]. Each of these approaches met with limited success. The results of each approach are discussed in this section.

An alternate approach, which was not attempted, is the summation of each individual component's failure rate to arrive at a system failure (rupture) rate. The difficulty of this approach lies in arriving at a representative system model and in getting proper failure data. The system description information supplied was insufficient to allow a representative system model to be developed. There may be considerable deviations in system design depending on such factors as whether small bottles or larger tanks are used for storage.

5.1 Nuclear Power Industry Experience

Reference 1-3 contains the results of a previous search of nuclear power experience data bases for hydrogen-related events. Many events were identified in the Licensee Event Reports (LERs), NRC Information Notices, and Nuclear Power Experience Reports. A review of these events determined that none of the events involved tank farms, but did involve equipment in the [redacted] Tank farm events may not be events for which reporting is needed, and therefore, the lack of data was not alone conclusive.

The results of other previous searches for hydrogen-related experience can be found in References 5-1 and 5-2. NUREG/CR-3551 (Reference 5-2) identifies two events involving tank farms at nuclear power plants (pages 25 and 26). Other hydrogen-related events are discussed, but none was considered suitable to the problem addressed here since they did not involve nuclear plant tank farms. Nuclear plant events associated with the [redacted] are not suitable to the outdoor tank farm situation. An incident at [redacted] involving liquid oxygen and liquid hydrogen at a compressed gas facility was also determined to be not relevant.

The two events identified in NUREG/CR-3551 happened during tank refilling operations and were the result of premature failure of safety pressure relief disks. In both cases, water had entered the pressure relief mechanisms and produced corrosion or deformation (because of freezing). [redacted] The other cylinders in the reserve bank were isolated after the fireball and were not affected. It is not possible to determine if a true detonation occurred, but this is assumed to be the case. It is also not possible to determine the volume of gas involved in the explosion or fire (each cylinder was reported to have a filled capacity of [redacted]

Both nuclear plant tank farm events involved flow through the safety relief rupture discs. It is expected that hydrogen involved in the explosion/fireball was less than the equivalent of a full tank (because of the low release rate and hydrogen's high buoyancy). In neither case was damage to safety-related structures or equipment reported. It is, therefore, conservative to assume these events were of the same size as the models used in the deterministic analysis (i.e., the detonation of [redacted]
The nuclear experience identified can therefore be summarized as one explosion with a fireball, and one fireball.

There are 1287 reactor years (RY) of operating experience for commercial PWRs and BWRs through October 17, 1989. Some reactors may have multiple tank farms, and in other cases multiple reactors may share a single tank farm. It is assumed these cases have a general cancelling effect and there is an average of one tank farm per reactor. This assumption is believed to be reasonable, but it could not be verified with the information available.

The estimated mean rates of major tank farm explosion, fire, and uncombusted release are shown in Table 5-1.

Table 5-1 Nuclear Industry Frequency Estimate

	Frequency (per tank farm per RY)
Explosion	[redacted]
Fire	
Uncombusted Release	

Appendix D provides a detailed discussion of the derivation of these values.

5.2 Survey of the Hydrogen Supply Industry

A survey was made of the hydrogen supply industry to determine if they recorded failure rates. This data would allow rates for tank farm explosions, fires, and unburned hydrogen releases to be calculated. Five contacts were made without success. Risk assessments within the hydrogen industry seem to be based upon specific installation designs and are based on failure rates not hydrogen-specific (e.g., WASH 1400).

One respondent showed that the type of events addressed here can only result from the single catastrophic failure of a storage tank. Line ruptures, pressure relief failures, etc., will lead to a release which is too gradual for the equivalent of one tank to be involved instantly. Hydrogen gas bottles are considered to be very robust and resistant to rupture. A rough estimate of 1E-05/tank-year was given for a "generic hydrogen tank" rupture. [redacted]

5.3 Published Hydrogen Industry Data

The Factory Mutual Study, dated 1977 (Reference 5-4), is the only reference identified which provides any data on hydrogen explosions and fires. The Factory Mutual study discusses and characterizes the hydrogen events experience, but does not provide any estimate of operating history addressed. It is not possible, therefore, to arrive at an explosion or fire event rate.

This report does provide valuable insights which are itemized below:

1. About 1/3 of the outdoor hydrogen events involved explosions, 1/3 involved fires, and 1/6 involved uncombusted releases (see page 49).

2. Use of data associated with indoor releases of hydrogen is not suitable to outdoor applications. [redacted]

3. Based on steel industry data, the volumetric hydrogen release incident rate is 6.4 times the corresponding volumetric release incident rate for natural gas. Based on data from the oil refining industry, the volumetric release incident rate for hydrogen is 1.4 times the corresponding rate for natural gas. However, "the higher reported damages because of hydrogen losses are explainable in terms of differences in occupancy categories and deductible values of insurance coverage, instead of any inherent differences between hydrogen and natural gas."

5.4 Published Data from Related Industries

The most suitable published data found is from the liquified natural gas (LNG) industry (Reference 5-5). A summary of these data are presented with the reservation that the LNG facilities addressed are much different from the nuclear plant hydrogen storage installations. The LNG storage systems are much larger and do not use the same size or type of tanks. The LNG values may be used as a reasonableness check and may be expected to have a higher failure rate than the nuclear plant installations.

No safety-related failures were experienced from 1.18E+06 hours of LNG storage system experience. As explained in Appendix D, the LNG incident rate data provides the results presented in Table 5-2. The uncertainty associated with these values is quite large since no events happened.

Table 5-2 Published Related Industry Frequency Estimate

	Frequency (per storage facility-year)
Explosion	[redacted]
Fire	
Uncombusted Release	

These values for explosion and fire agree very well with the values based on nuclear experience.

5.5 Recommended Values

The most suitable data found is considered to be the nuclear experience. It is, therefore, recommended that the values shown in Table 5-3 be used. These values are verified as reasonable based on the LNG experience.

Table 5-3 Recommended Frequency Estimate

	Frequency (per tank farm per RY)
Explosion	[redacted]
Fire	
Uncombusted Release	

The frequency of events of the "full tank" size is expected to be significantly lower than these recommended values; more than an order of magnitude lower. No data were found which would allow such a determination, so these conservative (pessimistic) values are recommended for use until better information becomes available.

6. EXPLOSION DAMAGE

Damage from explosion involves two factors, blast pressure and thermal effects of a fireball. Blast pressure in the EPRI report discussion is assumed to be about 1.5 to 4.5 psi and depends on the material and its equivalent mass of TNT explosive. The radiating blast wave was conservatively assumed to impinge on the building all at once, essentially treating the building as a flat plate. The blast separation calculation will determine the distance needed for the wall to stay intact for the given mass of hydrogen involved. [redacted]

The second factor involves the damage that would result from a fireball (thermal flux). In the case of a fireball, the separation distance is found from distances at which wood would be charred (specified in the EPRI report). For the most part, the heat or thermal flux effect does not appear to be a problem for concrete or metal structures because of their resistance to burning. Thermal flux effects from a fireball or explosion were also dismissed in Section 2.2.1, but the calculations were performed for information. As explained in Section 5, most of the plants would even comply with the conservative wood-charring separation distance criterion. Therefore, only the effects of explosions will be addressed here.

Estimating the damage from potential hydrogen events is very difficult because of uncertainty and variability in the explosion size, the building wall overpressure capacity, the varying vulnerability of different components, and the location of safety-related equipment within the building. Also of concern are the types of core-damage threatening sequences which may happen and the varying systems which must respond in each case. This section on explosion damage is qualitative in nature because of lack of scientific data, and merely tries to provide a conservative bound for the potential significance of a hydrogen event.

The equipment vulnerability and safety implications for the auxiliary and turbine buildings are discussed below.

6.1 Equipment Vulnerability

A subjective, qualitative estimate of equipment vulnerability was made based on the presumed relative locations of each type of equipment in any safety-related building. It was assumed that an explosion led to failure of the wall. The resulting potential mechanisms affecting the equipment include: overpressure, loss of physical support, thermal flux, and debris/missile loadings. Table 6-1 presents an estimate of whether the equipment vulnerability is judged "high" or "low."

[redacted]

The [redacted]

6.2 Equipment Location Considerations

[redacted] The information resulted from EG&G personnel visits to these sites. While the comparisons made in the figure refer to different concerns, this tabulation is useful in that relative locations and elevations of safety-related equipment are presented. The conversations with the persons who made these visits suggest that many, though not all, of the items of equipment mentioned are below grade level. The purpose for using this figure was to take advantage of a compilation that enumerated the items of interest. The report from which the figure came [redacted] also mentions that safety equipment in addition to being at different levels is also enclosed in separate concrete cubicles to prevent common cause failures from fire, flooding, pipe whip, explosions, etc. It was noted that concrete cubicle wall thickness was generally a minimum of [redacted] Concrete floors and ceilings between elevations usually approached [redacted] in thickness. Equipment items located

2 [redacted]

The safety-related equipment found at or above grade level generally involves tankage or mechanical components. These components (pumps, heat exchangers, and tanks) are by their usage in nuclear plants ruggedized to conform to seismic and tornado hardening and therefore have the ability to resist blast effects. They are also generally found away from walls. Their location depends on the need to have access to piping systems and clearances for maintenance. Therefore, damage predicted to result from wall failure is judged to be small.

2 2 2 2 [redacted] 2

6.3 Damage Assessment

Safety-related equipment and systems are vulnerable to blast damage to varying degrees. [redacted]

7. ESTIMATE OF RISK

This section addresses the risks associated with plants that [redacted] The safety significance of hydrogen tank farm explosions at these plants is examined in three ways: (1) explosion frequency, (2) safety system damage frequency, and (3) core damage frequency.

7.1 Explosion Frequency Criterion

As discussed in Section 4, [redacted] Regulatory Guide 1.91 (Reference 1-9) states that acceptability can also be demonstrated by showing:

> "...that the rate of exposure to a peak positive incident overpressure above 1 psi (7kPa) is less than 10^{-6} per year, when based upon conservative assumptions, or 10^{-7} per year, when based on realistic assumptions."

Although this Regulatory Guide 1.91 criterion does not apply directly, it is addressed here since it deals with a similar facet of the general external explosion damage concern.

The frequency of hydrogen tank farm explosions is conservatively estimated in Section 5 to be 1E-03/RY, which clearly exceeds the Regulatory Guide 1.91 criterion of 1E-06/RY. [redacted] Therefore, further efforts toward compliance with with the frequency criterion of this regulatory guide are not recommended.

7.2 Safety System Damage Frequency

The frequency of hydrogen storage installation explosions is estimated to be 1E-03/RY (see Section 5). In the absence of more detailed evaluations, the conditional probabilities [redacted] Further plant-specific evaluations to refine these conditional probabilities and potentially reduce the concern at some plants are recommended. In the interim, the frequency of safety system damage is conservatively estimated to be 1E-03/RY. [redacted]

7.3 Core Damage Frequency Criterion

Generic letter No. 88-20 (Reference 1-8) addresses the requirements for IPEs, but it also states that while:

"... resolution of several unresolved safety issues (USIs) and generic safety issues (GSIs) may need an examination of the individual plant, it is reasonable to use the current IPE process for that examination."

The screening criterion for the IPE is 1E-06/RY for core damage. This is a less demanding criterion than Regulatory Guide 1.91, [redacted]

Assessment of core damage frequency is beyond the scope of this study. A suggested approach for this assessment is outlined in Appendix E for information.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

A preliminary review of the hydrogen storage installations at commercial nuclear power plants has been performed. The following conclusions have been reached relative to compliance with the EPRI separation criteria:

1. The EPRI report separation distance criteria [redacted] 2

2. The EPRI report separation distance criteria for [redacted] The NRR supplied data (forming the basis for these compliance determinations) were often imprecise or missing. Therefore, the air intake distance determinations are judged less reliable than those for explosion distance.

Additional efforts were made to assess the level of risk for those plants that [redacted] The following conclusions were reached relative to the risks at these plants: 2

1. The calculated frequency for hydrogen storage installation explosions is [redacted]

2. [redacted] 2

3. The calculated frequency for hydrogen storage installation explosions resulting in [redacted] conservatively estimated to be 1E-03/RY. Further plant-specific evaluations could significantly reduce this estimated frequency.

8.2 Recommendations

As a result of this preliminary assessment, the following recommendations for further study are suggested:

1. The importance of hydrogen tank farm events relative to the overall core damage frequency should be evaluated in a manner similar to the IPE methodology. (A suggested approach is outlined in Appendix E.)

2. Plant-specific evaluations of conditional wall failure probabilities should be performed [redacted] 2

3. Plant-specific evaluations of safety system vulnerabilities related to wall failure should also be performed [redacted] 2

4. The effects of blast-generated missiles merit further consideration and investigation. Although this concern is outside the scope of this study and is not addressed in the EPRI report, [redacted] —2

5. [redacted] —2

6. [redacted] —2

9. REFERENCES

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1-7. R. C. Iotti, W. J. Krotiuk, and D. R. DeBoisblanc, "Hazards To Nuclear Plants From On Site (Or Near) Gaseous Explosions," EBASCO Services Inc.

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1-9. U.S. Nuclear Reactor Regulatory Commission, Regulatory Guide 1.91, "Evaluations of Explosions Postulated to Occur on Transportation Routes for Nuclear Power Plants," Rev. 1, February 1978.

5-1. U.S. Nuclear Regulatory Commission, NRC Memorandum from J.E. Rosenthal to E. L. Jordan, Subject: "Operating Experiences Involving Combustible/Explosive Mixtures of Hydrogen," February 9, 1989.

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5-4. R. G. Zalech and T. P. Short, Factory Mutual Research Corp., "Compilation and Analysis of Hydrogen Accident Reports," October 1978.

5-5. D. W. Johnson and J. R. Welker of Applied Technology Corp. (Prepared for Gas Research Institute), "Development of an Improved LNG Plant Failure Rate Data Base," September 1981.

APPENDIX A

GOVERNING DOCUMENTS

TABLE A-1. CODES, STANDARDS, REGULATIONS, AND PUBLISHED GOOD ENGINEERING PRACTICES APPLICABLE TO PERMANENT HYDROGEN WATER CHEMISTRY INSTALLATIONS

This Table lists codes, standards, and regulations which may be applicable to specific permanent hydrogen water chemistry installations.

Reference	Standards and Regulations
10 CFR 20	Standards for Protection Against Radiation
10 CFR 50.48	Fire Protection
10 CFR 50.49	Environmental Qualification of Electric Equipment Important to Safety for Nuclear Power Plants
10 CFR 50	Appendix A, General Design Criteria for Nuclear Power Plants, General Design Criteria 54, 55, 56, or 57.
10 CFR 100	Reactor Site Criteria
29 CFR 1910	Labor - OSHA Health Standards
29 CFR 1910.103	Hydrogen
29 CFR 1910.104	Oxygen
40 CFR 190	Protection of Environment - Environmental Radiation Protection Standards for Nuclear Power Operations
ASME BPVC	Section VIII, Pressure Vessels
ASME BPVC	Section IV, Heating Boilers
ASME BPVC	Section IX, Welding and Brazing Qualifications
ANSI A13.1	Scheme for the Identification of Piping Systems
ANSI B31.1	American National Standards Institute, Power Piping
ANSI B31.3	American National Standards Institute, Chemical Plant and Petroleum Refinery Piping
ANSI Z35.1	Accident Prevention Signs, Specification for

TABLE A-1. (continued)

Reference	Standards and Regulations
API Standard 620	Design and Construction of Large, Welded, Low-Pressure Storage Tanks, America Petroleum Institute Recommended Rules for
ASTM G63-83a	Evaluating Nonmetallic Materials for Oxygen Service
ASTM G88-84	Designing Systems for Oxygen Service
AWS D1.1	Structural Welding Code
NFPA 50	Bulk Oxygen Systems
NFPA 50A	Gaseous Hydrogen Systems at Consumer Sites
NFPA 50B	Liquefied Hydrogen Systems at Consumer Sites
NFPA 53M	Fire Hazards in Oxygen-Enriched Atmospheres
NFPA 70	National Electrical Code
NFPA 78	Lightning Protection Code
CGA G-4	Oxygen
CGA G-4.1	Cleaning Equipment for Oxygen Service
CGA G-4.3	Commodity Specification for Oxygen
CGA G-4.4	Industrial Practices for Gaseous Oxygen Transmission and Distribution Piping Systems
CGA G-5	Hydrogen
CGA G-5.3	Commodity Specification for Hydrogen
CGA P-12	Safe Handling of Cryogenic Liquids

APPENDIX B

DATA COMPARISONS AND FIGURES

WITT DATA COMPILATION

YES/NO SUMMARY OF ALL PLANTS
HYDROGEN SEPARATION COMPLIANCE

REGION 1

	PLANT	[redacted]
1	BEAVER VALLEY 1	
2	BEAVER VALLEY 2	
3	CALVERT CLIFFS 1	
4	CALVERT CLIFFS 2	
5	FITZPATRICK	
6	GINNA	
7	HADDAM NECK	
8	HOPE CREEK	
9	INDIAN PT 2-A	
10	INDIAN PT 2-B	
11	INDIAN PT 3-A	
12	INDIAN PT 3-B	
13	LIMERICK 1	
14	LIMERICK 2	
15	MAINE YANKEE	
16	MILLSTONE 1	
17	MILLSTONE 2	
18	MILLSTONE 3	
19	NINE MILE POINT 1	
20	NINE MILE POINT 2	
21	OYSTER CREEK	
22	PEACH BOTTOM 2	
23	PEACH BOTTOM 3	
24	PILGRIM	
25	SALEM 1	
26	SALEM 2	
27	SEABROOK 1	
28	SHOREHAM	
29	SUSQUEHANNA 1	
30	SUSQUEHANNA 2	
31	TMI 1	
32	VERMONT YANKEE	
33	YANKEE ROWE	

REGION 2

	PLANT	[redacted]
34	BROWNS FERRY 1	
35	BROWNS FERRY 2	
36	BROWNS FERRY 3	
37	BRUNSWICK 1	
38	BRUNSWICK 2	
39	CATAWBA 1	
40	CATAWBA 2	
41	CRYSTAL RIVER 3	
42	FARLEY 1	
43	FARLEY 2	
44	GRAND GULF 1	
45	GRAND GULF 2	
46	HARRIS	
47	HATCH 1	
48	HATCH 2	
49	MCGUIRE 1	
50	MCGUIRE 2	
51	NORTH ANNA 1	
52	NORTH ANNA 2	
53	OCONEE 1	
54	OCONEE 2	
55	OCONEE 3	
56	ROBINSON 2	
57	SEQUOYAH 1	
58	SEQUOYAH 2	
59	ST. LUCIE 1	
60	ST. LUCIE 2	
61	SUMMER	
62	SURRY 1	
63	SURRY 2	
64	TURKEY PT. 3	
65	TURKEY PT. 4	
66	VOGTLE 1	
67	VOGTLE 2	
68	WATTS BAR 1	
69	WATTS BAR 2	

LEGEND

1 = GAS PLANTS EXPLOSION
2 = GAS PLANTS AIR INTAKE
3 = GAS PLANTS THERMAL FLUX
4 = LIQUID PLANTS EXPLOSION
5 = LIQUID PLANTS AIR INTAKE
6 = LIQUID PLANTS THERMAL FLUX

REGION 3

	PLANT	1	2	3	4	5	6
70	BIG ROCK PT	[redacted]					
71	BRAIDWOOD 1	[redacted]					
72	BRAIDWOOD 2	[redacted]					
73	BRYON 1	[redacted]					
74	BYRON 2	[redacted]					
75	CALLAWAY	[redacted]					
76	CLINTON 1	[redacted]					
77	COOK 1	[redacted]					
78	COOK 2	[redacted]					
79	DAVIS-BESSE	[redacted]					
~~80~~	~~DRESDEN 2~~	[redacted]					
~~81~~	~~DRESDEN 3~~	[redacted]					
82	DUANE ARNOLD	[redacted]					
83	FERMI 2	[redacted]					
84	KEWAUNEE	[redacted]					
85	LA SALLE 1	[redacted]					
86	LA SALLE 2	[redacted]					
87	MONTICELLO	[redacted]					
88	PALISADES	[redacted]					
89	PERRY 1	[redacted]					
90	PERRY 2	[redacted]					
91	POINT BEACH 1	[redacted]					
92	POINT BEACH 2	[redacted]					
93	PRAIRE ISL 1	[redacted]					
94	PRAIRE ISL 2	[redacted]					
95	QUAD CITIES 1	[redacted]					
96	QUAD CITIES 2	[redacted]					
97	ZION 1	[redacted]					
98	ZION 2	[redacted]					

REGION 4

	PLANT	1	2	3	4	5	6
99	ANO 1	[redacted]					
100	ANO 2	[redacted]					
101	COMANCHE PK 1	[redacted]					
102	COMANCHE PK 2	[redacted]					
103	COOPER	[redacted]					
104	FORT CALHOUN	[redacted]					
105	FT ST. VRAIN-A	[redacted]					
106	FT. ST. VRAIN-B	[redacted]					
107	RIVER BEND	[redacted]					
108	SO TEX 1	[redacted]					
109	SO TEX 2	[redacted]					
~~110~~	~~WATERFORD 3~~	[redacted]					
~~111~~	~~WOLF CREEK~~	[redacted]					

REGION 5

	PLANT	
112	DIABLO CANYON 1	[redacted]
113	DIABLO CANYON 2	[redacted]
114	PALO VERDE 1	[redacted]
115	PALO VERDE 2	[redacted]
116	PALO VERDE 3	[redacted]
117	RANCHO SECO	[redacted]
118	SAN ONOFRE 1	[redacted]
119	SAN ONOFRE 2	[redacted]
120	SAN ONOFRE 3	[redacted]
121	TROJAN	[redacted]
122	WNP-2	[redacted]

The EPRI compliance asssment was performed for a total plant population of 119 reactors.

FOOTNOTES FOR THE HYDROGEN TANK FARM TABLE

1. The data making up this table came from information supplied by Mr. Frank Witt, NRC as compiled by each individual regional staff.

2. Some of the data was difficult to interpret. For example, at multiple reactor sites, where only one system served the site, the table credited each reactor with a system of the same size. This could be in error, but there was no way to clarify the issue without going back to the source of the original data.

3. The distances noted in the table are sometimes estimated or extended from the data presented in the NRC source information in order to put a value in the table.

4. The category, "closeness to the air intake" [redacted] used the terminology "> 50 feet", which has little meaning. The value of 50 feet was placed in the table. Thus, closer attention to measurement data might have resulted in a larger proportion of compliance in this area.

5. The values used to provide the comparisons were calculated or taken from figures provided by the EPRI NP-5283-SR-A, September 1987, document that serves as a guideline to Industry for Hydrogen Water Chemistry systems.

6. The data in the table is displayed alphabetical by region, similar to the manner in which the data was reported by NRC.

7. Note that reactors are grouped as gaseous storage or liquid storage.

8. The criteria of a single bottle represents a single bottle or tube as the unit bulk gas storage container. This ranged from [redacted]

9. Where there was no bulk storage indicated, either a [redacted] container was identified in the table representing the inventory of unit bottles in use.

10. This table does not address single or multiple use of standard 215 scf gas cylinders of hydrogen. Gas cylinder use in plant will be the subject of a report evaluating the used of combustible gases at the reactor site.

11. One ground rule was that the only tank farm system was the subject of this evaluation.

12. The results are summarized in the summary chart which shows all the categories examined. These have been shown as pie charts to show the proportions of the tank farm systems that complied with the separation distance requirements.

13. The 4 columns at the far right of the table are descriptive information. The first column is a record number, the second column is the region number, the third number is the type of reactor (1=BWR, 2=PWR), and the fourth column is the size (1=0-400 MW, 2=401-900 MW, 3=901-1300 MW)

14. The air intake calculations were based on the assumptions that all tanks farms used 1 in. diameter supply piping. Using that information the data is then extracted from the figure in the appendix either for gas or liquid.

15. Note that four of the liquid hydrogen reactors had no gas component.

TABULATION OF NRR ALL HYDROGEN SEPARATION DATA

REGION 2
(38 PLANTS) (38 ENTRIES)

	PLANT	BULK VOLUME	DISTANCE (ACTUAL)	TNT # EQUIVALENT	DISTANCE REQUIRED	COMPLIANCE	AIR INTAKE	DISTANCE EPRI	COMPLIANCE	DISTANCE (ACTUAL)	THERMAL FLUX EPRI	COMPLIANCE	NUMBER	REGION	TYPE	SIZE
1	BROWNS FERRY 1	[redacted]											41	2	1	3
2	BROWNS FERRY 1	[redacted]											42	2	1	3
3	BROWNS FERRY 3	[redacted]											43	2	1	3
4	BRUNSWICK 1	[redacted]											37	2	1	3
5	BRUNSWICK 2	[redacted]											38	2	1	3
6	CATAWBA 1	[redacted]											44	2	2	3
7	CATAWBA 2	[redacted]											45	2	2	3
8	CRYSTAL RIVER 3	[redacted]											46	2	.	2
9	FARLEY 1	[redacted]											47	2	2	2
10	FARLEY 2	[redacted]											48	2	2	2
11	GRAND GULF 1	[redacted]											49	2	1	3
12	GRAND GULF 2	[redacted]											50	2	1	3
13	HARRIS	[redacted]											51	2	2	2
14	HATCH 1	[redacted]											52	2	1	2
15	HATCH 2	[redacted]											53	2	1	2
16	MCQUIRE 1	[redacted]											54	2	2	3
17	MCQUIRE 2	[redacted]											55	2	2	3
18	NORTH ANNA 1	[redacted]											56	2	2	3
19	NORTH ANNA 2	[redacted]											57	2	2	3
20	OCONEE 1	[redacted]											58	2	2	1
21	OCONEE 2	[redacted]											59	2	1	2
22	OCONEE 3	[redacted]											60	2	1	2
23	ROBINSON 2	[redacted]											63	2	2	2
24	ST. LUCIE 1	[redacted]											61	2	2	2
25	ST. LUCIE 2	[redacted]											62	2	2	2
26	SEQUOYAH 1	[redacted]											64	2	2	3
27	SEQUOYAH 2	[redacted]											5	2	2	3
28	SUMMER	[redacted]											66	2	2	2
29	SURRY 1	[redacted]											67	2	2	2
30	SURRY 2	[redacted]											68	2	2	2
31	TURKEY PT. 3	[redacted]											69	2	2	2
32	TURKEY PT. 4	[redacted]											70	2	2	2
33	VOGTLE 1	[redacted]											73	2	2	3
34	VOGTLE 2	[redacted]											74	2	2	3
35	WATTS BAR 1	[redacted]											71	2	2	3
36	WATTS BAR 2	[redacted]											72	2	2	3

2

TABULATION OF NRR ALL HYDROGEN SEPARATION DATA

	REGION 1 (31 PLANTS) (33 ENTRIES) PLANT	BULK VOLUME	DISTANCE (ACTUAL)	TNT # EQUIVALENT	DISTANCE REQUIRED	COMPLIANCE	AIR INTAKE	DISTANCE EPRI	COMPLIANCE	DISTANCE (ACTUAL)	THERMAL FLUX EPRI	COMPLIANCE	NUMBER	REGION	TYPE	SIZE
1	BEAVER VALLEY 1	[redacted]											1	1	2	2
2	BEAVER VALLEY 2	[redacted]											2	1	2	2
3	CALVERT CLIFFS 1	[redacted]											3	1	2	2
4	CALVERT CLIFFS 2	[redacted]											4	1	2	2
5	FITZPATRICK	[redacted]											5	1	1	1
6	GINNA	[redacted]											6	1	2	2
7	HADDAM NECK	[redacted]											7	1	2	2
8	HOPE CREEK	[redacted]											8	1	1	1
9	INDIAN PT. 2-A	[redacted]											9	1	2	2
10	INDIAN PT. 2-B	[redacted]											9	1	2	2
11	INDIAN PT. 3-A	[redacted]											10	1	2	2
12	INDIAN PT. 3-B	[redacted]											10	1	2	2
13	LIMERICK 1	[redacted]											11	1	1	1
14	LIMERICK 2	[redacted]											13	1	1	1
15	MAINE YANKEE	[redacted]											14	1	2	2
16	MILLSTONE 1	[redacted]											15	1	2	2
17	MILLSTONE 2	[redacted]											16	1	2	2
18	MILLSTONE 3	[redacted]											17	1	2	3
19	NINE MILE POINT 1	[redacted]											18	1	1	2
20	NINE MILE POINT 2	[redacted]											19	1	1	3
21	OYSTER CREEK	[redacted]											20	1	2	2
22	PEACH BOTTOM 2	[redacted]											21	1	2	3
23	PEACH BOTTOM 3	[redacted]											22	1	2	3
24	PILGRIM	[redacted]											23	1	1	1
25	SALEM 1	[redacted]											24	1	2	3
26	SALEM 2	[redacted]											25	1	2	3
27	SEABROOK 1	[redacted]											26	1	2	3
28	SHOREHAM	[redacted]											28	1	1	2
29	SUSQUEHANNA 1	[redacted]											29	1	1	3
30	SUSQUEHANNA 2	[redacted]											30	1	1	3
31	TMI 1	[redacted]											31	1	2	2
32	VERMONT YANKEE	[redacted]											33	1	1	1
33	YANKEE ROWE	[redacted]											34	1	2	1

TABULATION OF NRR ALL HYDROGEN SEPARATION DATA

REGION 3
(29 PLANTS) (29 ENTRIES)

	PLANT	BULK VOLUME	DISTANCE (ACTUAL)	TNT # EQUIVALENT	DISTANCE REQUIRED	COMPLIANCE	AIR INTAKE	DISTANCE EPRI	COMPLIANCE	DISTANCE (ACTUAL)	THERMAL FLUX EPRI	COMPLIANCE	NUMBER	REGION	TYPE	SIZE
1	BIG ROCK PT	[redacted]											75	3	2	1
2	BRAIDWOOD 1	[redacted]											76	3	1	3
3	BRAIDWOOD 2	[redacted]											77	3	1	3
4	BYRON 1	[redacted]											79	3	1	3
5	BYRON 2	[redacted]											78	3	1	3
6	CALLAWAY	[redacted]											80	3	1	3
7	CLINTON 1	[redacted]											81	3	2	3
8	COOK 1	[redacted]											82	3	1	3
9	COOK 2	[redacted]											83	3	1	3
10	DAVIS-BESSE	[redacted]											84	3	1	2
11	DRESDEN 2	[redacted]											85	3	2	2
12	DRESDEN 3	[redacted]											86	3	2	2
13	DUANE ARNOLD	[redacted]											87	3	1	1
14	FERMI 2	[redacted]											88	3	1	3
15	KEWAUNEE	[redacted]											89	3	2	1
16	LA SALLE 1	[redacted]											91	3	1	3
17	LA SALLE 2	[redacted]											92	3	1	3
18	MONTICELLO	[redacted]											93	3	1	1
19	PALISADES	[redacted]											94	3	1	2
20	PERRY 1	[redacted]											95	3	1	3
21	PERRY 2	[redacted]											96	3	1	3
22	POINT BEACH 1	[redacted]											97	3	2	1
23	POINT BEACH 2	[redacted]											98	3	2	1
24	PRAIRE ISL 1	[redacted]											99	3	2	1
25	PRAIRE ISL 2	[redacted]											100	3	2	1
26	QUAD CITIES 1	[redacted]											102	3	1	2
27	QUAD CITIES 2	[redacted]											103	3	1	2
28	ZION 1	[redacted]											104	3	2	3
29	ZION 2	[redacted]											105	3	2	3

TABULATION OF NRR ALL HYDROGEN SEPARATION DATA

REGION 4
(12 PLANTS) (13 ENTRIES)

	PLANT	BULK VOLUME	DISTANCE (ACTUAL)	TNT # EQUIVALENT	DISTANCE REQUIRED	COMPLIANCE	AIR INTAKE	DISTANCE EPRI	COMPLIANCE	DISTANCE (ACTUAL)	THERMAL FLUX EPRI	COMPLIANCE	NUMBER	REGION	TYPE	SIZE
1	ANO 1	[redacted]											35	4	2	3
2	ANO 2	[redacted]											109	4	2	3
3	COMANCHE PEAK 1	[redacted]											110	4	2	3
4	COMANCHE PEAK 2	[redacted]											110	4	2	3
5	COOPER	[redacted]											112	4	1	2
6	FORT CALHOUN	[redacted]											113	4	2	1
7	FT ST. VRAIN - A	[redacted]											114	4	2	1
8	FT ST. VRAIN - B	[redacted]														
9	RIVER BEND	[redacted]											115	4	1	3
10	SO TEX 1	[redacted]											116	4	2	3
11	SO TEX 2	[redacted]											117	4	2	3
12	WATERFORD 3	[redacted]											118	4	2	3
13	WOLF CREEK	[redacted]											119	4	2	3

REGION 5
(11 PLANTS) (11 ENTRIES)

	PLANT	BULK VOLUME	DISTANCE (ACTUAL)	TNT # EQUIVALENT	DISTANCE REQUIRED	COMPLIANCE	AIR INTAKE	DISTANCE EPRI	COMPLIANCE	DISTANCE (ACTUAL)	THERMAL FLUX EPRI	COMPLIANCE	NUMBER	REGION	TYPE	SIZE
1	DIABLO CANYON 1	[redacted]											126	5	2	3
2	DIABLO CANYON 2	[redacted]											125	5	2	3
3	PALO VERDE 1	[redacted]											121	5	2	3
4	PALO VERDE 2	[redacted]											122	5	2	3
5	PALO VERDE 3	[redacted]											123	5	2	3
6	RANCHO SECO	[redacted]											120	5	2	2
7	SAN ONOFRE 1	[redacted]											128	5	2	1
8	SAN ONOFRE 2	[redacted]											129	5	2	3
9	SAN ONOFRE 3	[redacted]											130	5	2	3
10	TROJAN	[redacted]											131	5	2	3
11	WNP-2	[redacted]											124	5	1	3

TABULATION OF NRR LIQUID HYDROGEN SEPARATIONS DATA

	LIQUID INFORMATION / PLANT	BULK VOLUME	DIST (ACTUAL)	TNT # EQUIV	DIST REQUIRED	COMPLIANCE	AIR INTAKE	DIST EPRI	COMPLIANCE	DIST (ACTUAL)	THERMAL FLUX EPRI	COMPLIANCE	NUMBER	REGION	TYPE	SIZE
1	PEACH BOTTOM 2	[redacted]											21	1	2	3
2	PEACH BOTTOM 3												22	1	2	3
3	BRUNSWICK 1												37	2	1	2
4	BRUNSWICK 2												38	2	1	2
5	CRYSTAL RIVER 3												46	2	2	2
6	FARLEY 1												47	2	2	2
7	FARLEY 2												48	2	2	2
8	HARRIS												51	2	2	2
9	MONTICELLO												93	3	1	1
10	PERRY 1												95	3	1	3
11	PERRY 2												96	3	1	3
12	QUAD CITIES 1												102	3	1	2
13	QUAD CITIES 2												103	3	1	2

2

I

UNITED STATES
NUCLEAR REGULATORY COMMISSION
REGION I
475 ALLENDALE ROAD
KING OF PRUSSIA, PENNSYLVANIA 19406

MAY 09 1989

MEMORANDUM TO: William T. Russell
Regional Administrator

FROM: Thomas T. Martin, Director
Division of Reactor Safety

SUBJECT: HYDROGEN STORAGE SURVEY AT REGION I
NUCLEAR POWER PLANTS
(ACTION ITEM NO. 89-76)

Attached are the summary sheets from the survey of Hydrogen storage facilities at each of the Nuclear Power Plants in Region I.

This summary information has been telecopied to Conrad McCracken at NRR. Action Item No. 89-76 is closed.

Thomas T. Martin

Thomas T. Martin, Director
Division of Reactor Safety

cc:
W. Johnston
W. Kane
S. Collins
J. Strosnider
P. Eapen
J. Trapp
D. Moy
A. Lopez
C. McCracken
F. Witt

SAFEGUARDS INFORMATION

NAME	[redacted]
Beaver Valley 1	
Beaver Valley 2	
Calvert Cliffs 1	
Calvert Cliffs 2	
Fitzpatrick	
Ginna	
Haddam Neck	
Hope Creek 1	
Indian Point 2	
Indian Point 3	
Limerick 1	
Limerick 2	
Maine Yankee	
Millstone 1	
Millstone 2	
Millstone 3	
Nine Mile 1	
Nine Mile 2	
Oyster Creek	
Peach Bottom 2	
Peach Bottom 3	
Pilgrim	
Salem 1	
Salem 2	
Seabrook 1	
Shoreham	
Susquehanna 1	
Susquehanna 2	
Three Mile Island 1	
Vermont Yankee	
Yankee Rowe	

* See individual sheets for all equipment in the vicinity

3

SAFEGUARDS INFORMATION

[redacted]

Hydrogen Tanks	Gas or Liquid	Volume (ft3)or (gal.)	Pressure (psig)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that If a Detonation were to Occur, It would be Adversely Impacted	Distance From Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustable Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
Bank of 8 seamless pressure vessels (tubes) manifold together	Gas	[redacted]	2300 psig Normal 2450 psig Max.	[redacted]	[redacted]	None	

[redacted]

[redacted]

Hydrogen Tanks	Gas or Liquid	Volume (ft^3) or (gal)	Pressure (psi)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that if a Detonation were to Occur, it would be Adversely Impacted	Distance From Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustible Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
Bank of 8 seamless pressure vessels (tubes) manifold together 20'L x 20'D each	Gas	[redacted]	2300 Normal 2450 Max.	[redacted]	[redacted]	[redacted]	[redacted]

[redacted]

Hydrogen Tanks	Gas or Liquid	Volume (ft3) or (gal.)	Pressure (psig)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that If a Detonation were to Occur, It would be Adversely Impacted	Distance From Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustible Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
1) Bulk storage tanks - 9 bottles	1) Gas	[redacted]	1) 2100 psig	[redacted]	[redacted]	[redacted]	[redacted]
2) H_2 calibration gas for H_2 analyzer 2 bottles	Gas	[redacted]	2300 psig max	[redacted]	[redacted]	[redacted]	[redacted]

[redacted]

Hydrogen Tanks	Gas or Liquid	Volume (ft3) or (gal.)	Pressure (psi)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that if a Detonation were to Occur, it would be Adversely Impacted	Distance From Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustible Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
30 (15 for operation, 15 for backup)	Gas	[redacted]	2450	[redacted]			

[redacted] 2

Hydrogen Tanks	Gas or Liquid	Volume (ft3)or (gal.)	Pressure (psi)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that if a Detonation were to Occur, it would be Adversely Impacted	Distance From Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustible Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
44 Bottles	Gas	[redacted]	2200	[redacted]			

2

2

[redacted]

Hydrogen Tanks	Gas or Liquid	Volume (ft3)or (gal.)	Pressure (psi)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that if a Detonation were to Occur, It would be Adversely Impacted	Distance From Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustible Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
6 Cylinders -4 active -2 reserve	Gas	[redacted]	2200 psig	[redacted]			
Alternate hydrogen storage facility: 5 cylinders currently not in use	Gas		2200 psig [redacted]sed				

[redacted]

Hydrogen Tanks	Gas or Liquid	Volume (ft3)or (gal.)	Pressure (psi)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that if a Detonation were to Occur, It would be Adversely Impacted	Distance From Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustible Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
.) H_2/O_2 analyzer and recombiner 1 bottle manifold	Gas	[redacted]	2500	[redacted]			
:) Generator bulk H_2 storage 2 bottles on skid	Gas		2300				

[redacted]

Hydrogen Tanks	Gas or Liquid	Volume (ft3)or (gal)	Pressure (psi)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that if a Detonation were to Occur, it would be Adversely Impacted	Distance From Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustable Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
1) H_2 storage 3 standard tanks	Gas	[redacted]	2000	[redacted]	[redacted]	[redacted]	[redacted]
2) Compressed gas storage tanks	Gas	[redacted]	2000	[redacted]	[redacted]	[redacted]	[redacted]
3) H_2 supply to main generator 45 tanks (18 active, 18 reserve, 9 emergency)	Gas	[redacted]	1500	[redacted]	[redacted]	[redacted]	[redacted]
4) H_2 supply to Nuclear equipment 12 standard gas tanks	Gas	[redacted]	2000 9	[redacted]	[redacted]	[redacted]	[redacted]
5) Instrument calibration H_2 2 standard gas tanks	Gas	[redacted]	2000	[redacted]	[redacted]	[redacted]	[redacted]

[redacted]

Hydrogen Tanks	Gas or Liquid	Volume (ft3) or (gal.)	Pressure (psi)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that if a Detonation were to Occur, it would be Adversely Impacted	Distance From Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustible Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
6) Instrument calibration 2 2 standard gas tanks	Gas	[redacted]	2000	[redacted]	[redacted]	[redacted]	[redacted]
7) Instrument calibration 3	Gas	[redacted]	2000	[redacted]	[redacted]	[redacted]	[redacted]
8) Instrument calibration 4	Gas	[redacted]	2000	[redacted]	[redacted]	[redacted]	[redacted]
9) Several hydrogen cylinders	Gas	[redacted]	2000 psig	[redacted]	[redacted]	[redacted]	[redacted]

[redacted]

Hydrogen Tanks	Gas or Liquid	Volume (ft3) or (gal.)	Pressure (psig)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that if a Detonation were to Occur, it would be Adversely Impacted	Distance From Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustible Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
10 cylinders	Gas	[redacted]	2000 psig	No safety structures/ equipments sufficiently close to the hydrogen cylinders	[redacted]	No safety related air intake structure sufficiently close to the hydrogen cylinder	[redacted]
12 cylinders	Gas	[redacted]	2000 psig	No safety structures/ equipments sufficiently close to the hydrogen cylinders	[redacted]	No safety related air intake structure sufficiently close to the hydrogen cylinder	[redacted]

[redacted]

Hydrogen Tanks	Gas or Liquid	Volume (ft)3 or (gal.)	Pressure (psi)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that if a Detonation were to Occur, It would be Adversely Impacted	Distance From Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustible Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
6 gas cylinders	Gas	[redacted]	2000 psig	No safety structured equipment sufficiently close to hydrogen cylinders	[redacted]	No safety related air intake structure sufficiently close to the hydrogen cylinders	[redacted]

Hydrogen Tanks	Gas or Liquid	Volume (ft3)or(gal.)	Pressure (psig)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that If a Detonation were to Occur, It would be Adversely Impacted	Distance From Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustible Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
6 gas cylinders	Gas	[redacted]	2000 psig	No safety structure/ equipment sufficiently close to hydrogen cylinders	[redacted]	No safety related air intake structure sufficiently close to the hydrogen cylinders	[redacted]

[redacted]

Hydrogen Tanks	Gas or Liquid	Volume (ft3) or (gal.)	Pressure (psi)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that if a Detonation were to Occur, it would be Adversely Impacted	Distance From Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustible Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
1)75 Standard Bottles (4' tall)	Liq.		2400 psi each	[redacted]			
2)Tube Truck	Liq.	[redacted]	2500				

[redacted]

Hydrogen Tanks	Gas or Liquid	Volume (ft3) or (gal.)	Pressure (psi)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that If a Detonation were to Occur, It would be Adversely Impacted	Distance From Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustible Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
Bulk hydrogen storage facility	Gas	[redacted]	2000	[redacted]			

[redacted]

Hydrogen Tanks	Gas or Liquid	Volume (ft3)or (gal.)	Pressure (psig)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that if a Detonation were to Occur, It would be Adversely Impacted	Distance From Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustible Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
8 storage cylinders 16-active 2-reserve	Gas	[redacted]	2450	[redacted]			

[redacted]

Hydrogen Tanks	Gas or Liquid	Volume (ft3)or (gal.)	Pressure (psig)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that if a Detonation were to Occur, it would be Adversely Impacted	Distance from Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustible Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
5 bottles ~51 CFT each	Gas	[redacted]	1800	[redacted]			

[redacted]

Hydrogen Tanks	Gas or Liquid	Volume (ft3)per [tank]	Pressure (psig)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that If a Detonation were to Occur, It would be Adversely Impacted	Distance from Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustible Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
5 bottles ~51 CFT each	Gas	[redacted]	1800	[redacted]			

[redacted]

Hydrogen Tanks	Gas or Liquid	Volume (ft3)or (gal.)	Pressure (psi)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that if a Detonation were to Occur, it would be Adversely Impacted	Distance from Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustible Concentration of H2 with a Potential to Detonate	Distance from Each Air Intake Structure to the H2 Storage Tank
Bank of 7 Bottles ?1 CFT each	Gas	[redacted]	2250	None within 200 ft.		None within 200 ft.	

[redacted]

Hydrogen Tanks	Gas or Liquid	Volume (ft3)or gal.)	Pressure (psi)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that if a Detonation were to Occur, It would be Adversely Impacted	Distance From Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustible Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
1) 96 Cylinders	Gas	[redacted]	2000	[redacted]			
2) 15 Tubes Normal Supply	Gas		2400	None within 200 ft.		None within 200 ft.	
15 Tubes Backup Supply							

2

2

[redacted]

Hydrogen Tanks	Gas or Liquid	Volume (ft3)or (gal.)	Pressure (psig)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that if a Detonation were to Occur, it would be Adversely Impacted	Distance From Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustible Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
1) Hydrogen water chemistry system	Liq.	[redacted]	150	None Safety concerns addressed in the base design set forth by EPRI NP-5283		None	
2) 24 bottles for generator	Gas		2400	[redacted]		None	

[redacted] — 2

Hydrogen Tanks	Gas or Liquid	Volume (ft3) or (gal.)	Pressure (psi)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that if a Detonation were to Occur, it would be Adversely Impacted	Distance from Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustible Concentration of H2 with a Potential to Detonate	Distance from Each Air Intake Structure to the H2 Storage Tank
Compressed hydrogen gas storage facility 8 tanks	Gas	[redacted]	2400 psig	[redacted]	[redacted]		

[redacted]

Hydrogen Tanks	Gas or Liquid	Volume (ft3) or (gal.)	Pressure (psig)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that if a Detonation were to Occur, it would be Adversely Impacted	Distance From Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustible Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
) 1 bank of 5 cylinders main H_2 Storage	Gas	[redacted]	2000	[redacted]	[redacted]	[redacted]	[redacted]
) U-2 10 ottles U-1 12 ottles	Gas	[redacted]	2200 each	[redacted]	[redacted]	[redacted]	[redacted]
) Emergency ain generato- bottles er unit		[redacted]	2200	None in vicinity		None in vicinity	

[redacted]

Hydrogen Tank	Gas or Liquid	Volume (ft3)or (gal.)	Pressure (psig)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that if a Detonation were to Occur, it would be Adversely Impacted	Distance From Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustible Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
Hydrogen bottle truck	Gas	[redacted]	2200 psig	No safety structures/ equipments sufficiently close to the hydrogen bottle truck	[redacted]	[redacted]	[redacted]
Hydrogen bottles up to 5 bottles in outside storage area	Gas	[redacted]	2200 psig	No safety related equipments	[redacted]	[redacted]	[redacted]
Hydrogen bottles up to 6 bottles for main generator makeup	Gas	[redacted]	2200 psig	No safety related equipment	[redacted]	[redacted]	[redacted]

[redacted]

Hydrogen Tanks	Gas or Liquid	Volume (ft³) or (gal.)	Pressure (psi)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that If a Detonation were to Occur, It would be Adversely Impacted	Distance From Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustable Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
3 tanks hooked up 3 reserved 35 additional tanks for H_2 addition	Gas	[redacted]	2400 psig	[redacted]			

[redacted]

Hydrogen Tanks	Gas or Liquid	Volume (ft3)or (gal.)	Pressure (psi)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that if a Detonation were to Occur, it would be Adversely Impacted	Distance From Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustible Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
1) Bulk tube trailers (2)	Gas	[redacted]	Max = 2450 Normal = 2300	[redacted]	[redacted]	[redacted]	[redacted]

[redacted]

Hydrogen Tanks	Gas or Liquid	Volume (ft3)or (gal.)	Pressure (psig)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that if a Detonation were to Occur, it would be Adversely Impacted	Distance From Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustable Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
ble-up tank wer pressur-ization l cylinders	Gas	[redacted]	2000 psig max each			[redacted]	[redacted]

[redacted]

Hydrogen Tanks	Gas or Liquid	Volume (ft3)or (gal.)	Pressure (psi)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that if a Detonation were to Occur, it would be Adversely Impacted	Distance From Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustable Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
66 Tanks	Liq.	[redacted]	2015	[redacted]			

[redacted] 2

Hydrogen Tanks	Gas or Liquid	Volume (ft3)or (gal.)	Pressure (psi)	Safety Related Structure(s) or Equipment Sufficiently Close to a H2 Storage Tank that if a Detonation were to Occur, it would be Adversely Impacted	Distance From Each Structure to the H2 Storage Tank	Safety Related Air Intake Structure(s) Sufficiently Close to a H2 Storage Tank to Uptake a Combustible Concentration of H2 with a Potential to Detonate	Distance From Each Air Intake Structure to the H2 Storage Tank
'O Cylinders	Gas	[redacted]	2000	[redacted]			

2

2

F. Witt

II

MAY 09 1989

MEMORANDUM FOR: Thomas E. Murley, Director
Office of Nuclear Reactor Regulation

FROM: Stewart D. Ebneter
Regional Administrator

SUBJECT: REVIEW OF HYDROGEN STORAGE ON THE ROOF OF THE CONTROL ROOM INFORMATION NOTICE NO. 89-44, APRIL 27, 1989

As requested by your memorandum dated May 2, 1989, we have performed a review of the subject matter. The results have been tabulated and shown in the matrix attached.

If you should have any questions, please advise.

(Original signed by A. Gibson)

Stewart D. Ebneter

cc: C. E. Rossi, NRR
J. W. Roe, NRR
B. Sheron, RES
W. F. Kane, Region I
E. G. Greenman, Region III
L. J. Callan, Region IV
D. F. Kirsch, Region V

bcc: K. D. Landis
S. J. Vias

CONTACT:
S. Vias
FTS: 242-5350

RII	RII	RII
S. Vias		
SVias:vyg	KLandis	HErnst
5/9/89	5/9/89	5/9/89

MAY 09

IEN 89-44

REGION II DATA FOR IEN 89-44: HYDROGEN STORAGE ON THE ROOF OF THE CONTROL ROOM

PLANT	CLOSEST SAFETY RELATED FACILITY	DISTANCE (FEET)	GAS (SCF)	LIQUID (GAL)
BRUNSWICK	[redacted]			
CATAWBA				
CRYSTAL RIVER				
FARLEY				
GRAND GULF				
HARRIS				
HATCH				
McGUIRE				

PLANT	CLOSEST SAFETY RELATED FACILITY	DISTANCE (FEET)	GAS (SCF)	LIQUID (GAL)
NORTH ANNA	[redacted]			
OCONEE	[redacted]			
ROBINSON	[redacted]			
ST LUCIE	[redacted]			
SUMMER	[redacted]			
SURRY	[redacted]			

3

SAFEGUARDS INFORMATION

MAY 09 1989

PLANT	CLOSEST SAFETY RELATED FACILITY	DISTANCE (FEET)	GAS (SCF)	LIQUID (GAL)
TURKEY POINT	[redacted]			
VOGTLE				

3

SAFEGUARDS INFORMATION

UNITED STATES
NUCLEAR REGULATORY COMMISSION
REGION III
799 ROOSEVELT ROAD
GLEN ELLYN, ILLINOIS 60137

MAY 10 1989

MEMORANDUM FOR: Conrad McCracken, Chief, Chemical Engineering Branch

FROM: Edward G. Greenman, Director, Division of Reactor Projects

SUBJECT: HYDROGEN STORAGE [redacted] 2

This is in response to the May 2, 1989, memorandum from T. E. Murley to the Regions regarding whether other facilities may have similar safety problems such as were identified at [redacted]. Enclosed is Region III's response to the specific information you requested regarding hydrogen capacity and distance to the nearest safety related structure or air intake. In addition to this information, I have also asked our Residents to examine the licensee's administrative and physical controls for explosive materials stored onsite to reaffirm these external hazards will not affect any safety related components, equipment or facilities. Should any additional safety concerns become evident, we will promptly notify you.

Edward G. Greenman

Edward G. Greenman, Director
Division of Reactor Projects

Enclosure: As stated

cc w/ enclosure:
A. B. Davis, RIII
Regional Administrators,
RI, RII, RIV, RV
T. E. Murley, NRR
F. J. Miraglia, NRR
L. C. Shao, NRR
C. E. Rossi, NRR
G. M. Holahan, NRR
M. J. Virgilio, NRR
J. E. Richardson, NRR
F. J. Witt, NRR
W. D. Lanning, NRR 8H9

BIG ROCK POINT

[redacted]

3

BRAIDWOOD

[redacted]

3

BYRON

[redacted]

2

CALLAWAY

[redacted]

3

CLINTON

[redacted]

3

DAVIS BESSE

[redacted]

2

D. C. COOK

[redacted]

3

DRESDEN

[redacted]

3

DUANE ARNOLD

[redacted]

3

FERMI 2

[redacted]

3

KEWAUNEE

[redacted]

3

LASALLE

[redacted]

3

MONTICELLO

[redacted]

3

SAFEGUARDS INFORMATION

3

[redacted]

PALISADES

3

[redacted]

PERRY

2

[redacted]

POINT BEACH

3

[redacted]

PRAIRIE ISLAND

3

[redacted]

QUAD CITIES

3

[redacted]

SAFEGUARDS INFORMATION

withhold all

2

[redacted]

ZION

2

[redacted]

UNITED STATES
NUCLEAR REGULATORY COMMISSION
REGION IV
611 RYAN PLAZA DRIVE, SUITE 1000
ARLINGTON, TEXAS 76011

IV

MAY - 9 19[illegible]

MEMORANDUM FOR: C. E. McCracken, Chief, Chemical Engineering Branch, NRR

FROM: L. J. Callan, Director, Division of Reactor Projects

SUBJECT: RESPONSE TO NRR REQUEST FOR INFORMATION ON HYDROGEN STORAGE

This is in response to the memorandum dated May 2, 1989, from Mr. Thomas E. Murley, requesting information on the location and quantity of hydrogen storage at Region IV plants.

The information requested is summarized in the enclosed attachment.

L. J. Callan, Director
Division of Reactor Projects

Enclosure: As stated

cc w/enclosure:
R. D. Martin, RA
T. Murley, NRR
F. Miraglia, NRR
E. Rossi, NRR
J. Milhoan, RIV
A. Beach, RIV
T. O. Martin, EDO
DRP Section Chiefs

ATTACHMENT

RESPONSES TO SURVEY ON HYDROGEN STORAGE

REGION IV

Question No. 1

What is the distance from the hydrogen storage facility to the nearest safety-related structure or air intake?

Responses:

Arkansas Nuclear One - Units 1 and 2

[redacted]

3

Cooper Nuclear Station

[redacted]

3

Fort Calhoun Station

[redacted]

3

Fort St. Vrain

[redacted]

3

River Bend Station

[redacted]

3

South Texas Project - Units 1 and 2

3 [redacted]

Waterford 3 SES

3 [redacted]

Wolf Creek

3 [redacted]

Question No. 2

What is the maximum volume of gaseous or liquid hydrogen stored onsite in standard cubic feet or gallons, respectively?

Responses:

Arkansas Nuclear One - Units 1 and 2

2 [redacted]

Cooper Nuclear Station

2 [redacted]

Fort Calhoun Station

2 [redacted]

Fort St. Vrain

[redacted]

River Bend

[redacted]

South Texas Project - Units 1 and 2

[redacted]

Waterford 3 SES

[redacted]

Wolf Creek

[redacted]

V

Please note that this is a revision to the 5/4/89 information
[illegible signature]

5/5/89
REV. 1

HYDROGEN STORAGE AND PROXIMITY INFORMATION FOR RV PLANTS

PLANT	H_2 VOLUME (SCF)	NEAREST SAFETY STRUCTURE OR EQUIPMENT	NEAREST AIR INTAKE
Rancho Seco	[redacted]		
Palo Verde For each of 3 Units	[redacted]		
WNP-2	[redacted]		
Diablo Canyon	[redacted]		
San Onofre Unit 1	[redacted]		
For each of Units 2 and 3	[redacted]		
Trojan	Info already submitted		

3

463

Information compiled by [illegible], RV, 31744

[illegible] information provided by Palo Verde

APPENDIX C

EPRI NP-5283-SR-A FIGURES USED FOR SEPARATION INFORMATION

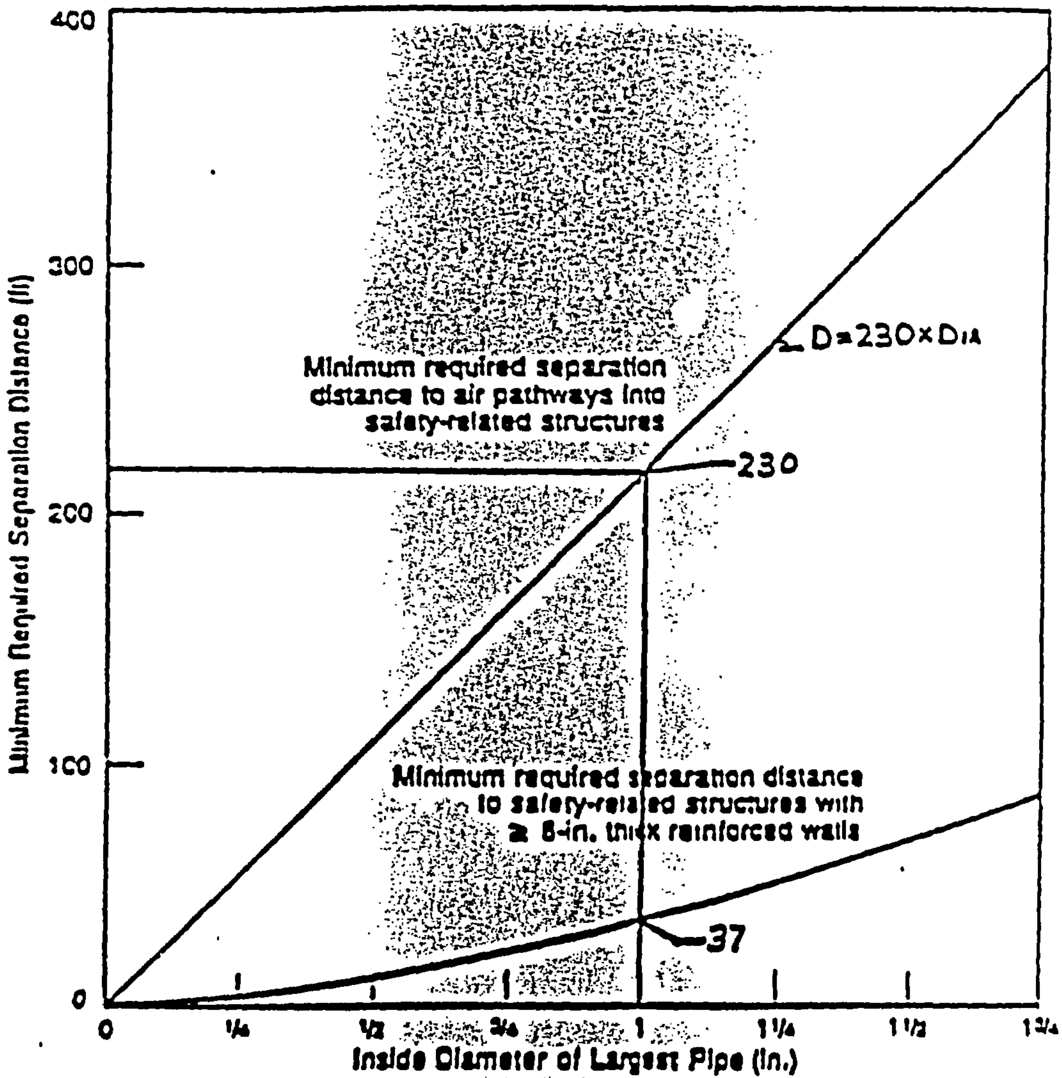


Figure 4-3. Minimum required separation distance versus ID of pipe for releases from 2450 psig gaseous hydrogen storage systems.

Figure C2-1
Pipe Releases Separation Distances For Gas

RELATIONSHIP (2) WAS USED. THE EQUATION IDENTIFIED ON PAGE B-15 PROVIDED THE EXACT VALUES USED AND EXTENDED THE CURVE FOR GREATER STORAGE QUANTITIES.

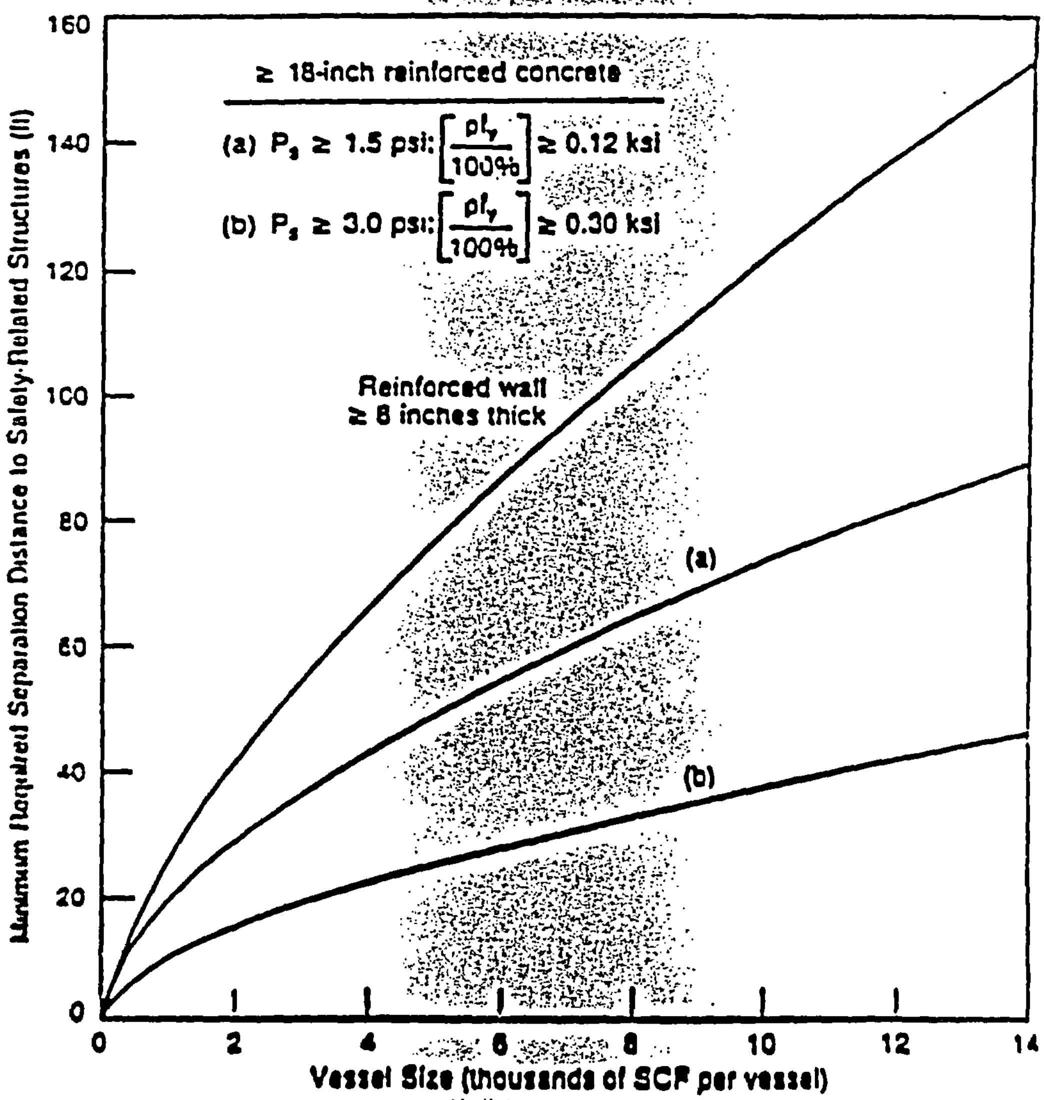


Figure 4-2. Minimum required separation distances to safety-related structures versus vessel size for gaseous hydrogen storage system.

Figure C2-2
Blast Separation Distances For Gas

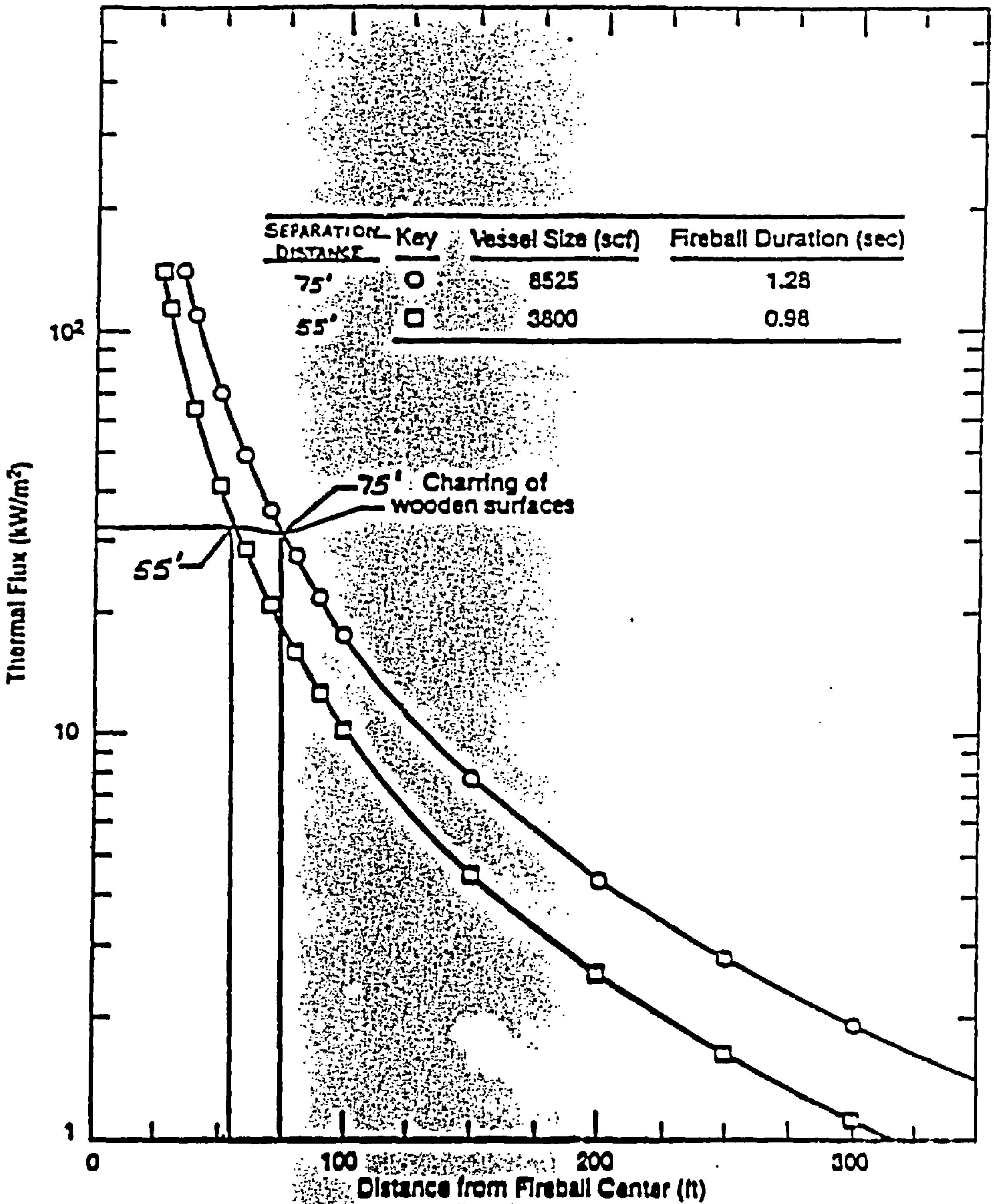
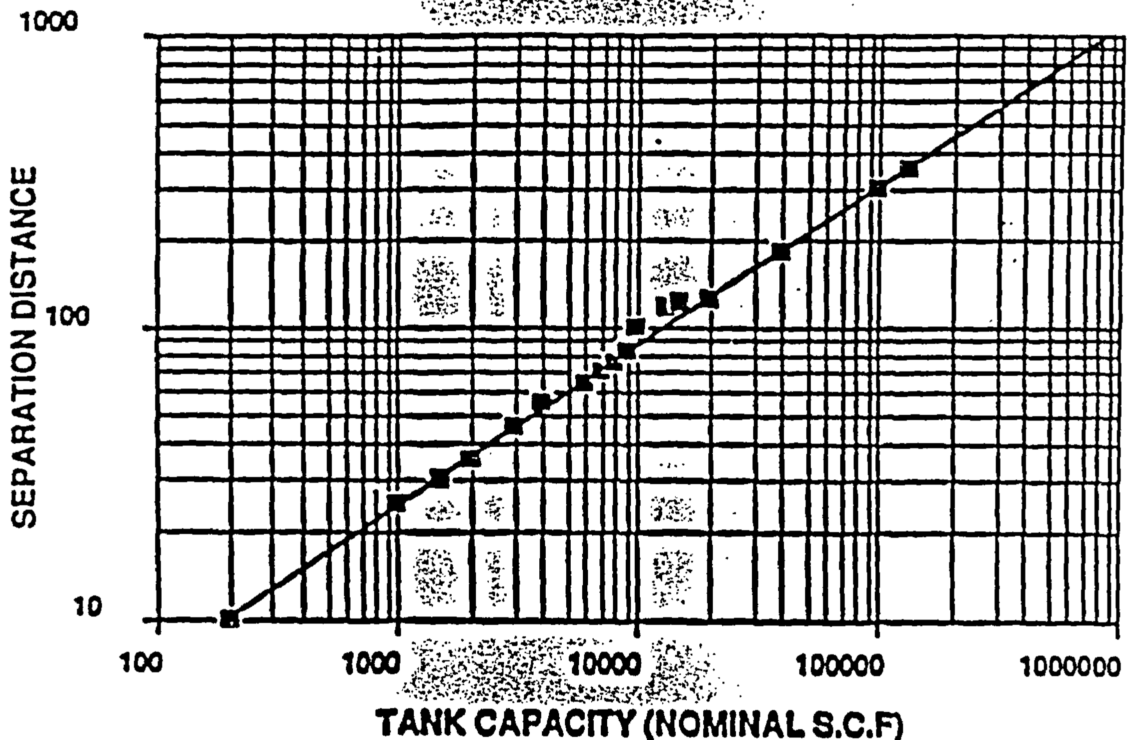


Figure 4-1. Thermal flux vs. distance from fireball center for gaseous hydrogen storage system.

Figure C2-3
Thermal Flux Separation Distances For Gas

LOG-LOG PLOT OF THERMAL FLUX SEPARATION DISTANCES



SOURCE: THIS IS A DERIVED CHART TAKING THE TWO POINTS FROM THE CHART C2-3 AND A LOWER LIMIT FOR THE SINGLE GAS BOTTLE AND THEN PLOTTING AS A LOG-LOG PLOT. THE VALUES FROM THE TABLE ARE THEN TAKEN OFF THE CHART AND TABULATED

Figure C2-4
Thermal flux separations distances

TABLE C2-1

TABLE OF THERMAL FLUX SEPARATION DISTANCE

NOMINAL TANK CAPACITY (SCF)	SEPARATION DISTANCE (FEET)
200	10
1000	25
1500	30
2000	35
3000	45
4000	55
6000	65
7000	70
8000	75
9000	82
10000	100
13000	118
15000	120
20000	125
40000	180
100000	300
130000	350

SOURCE: VALUES TAKEN FROM LOG-LOG PLOT SEEN IN THE PREVIOUS FIGURE

μ	$\left(\frac{\rho\, f_y}{100\%}\right) = 0.12\text{ksi}$		$\left(\frac{\rho\, f_y}{100\%}\right) = 0.30\text{ksi}$	
	f_μ	B_μ	f_μ	B_μ
1.0	87	5.2	80	2.7
3.0	54	2.8	50	1.45
5.0	51	2.2	44	1.2

The use of Egn (7) requires one to estimate:

1) Minimum static capacity, P_s
2) Tensile steel factor, $\left(\frac{\rho\, f_y}{100\%}\right)$
3) Permissible wall ductility, μ

Some representative cases are:

$P_s = 1.5\text{psi}$; $\left(\frac{\rho\, f_y}{100\%}\right) = 0.12\text{ksi}$; $\mu = 3.0$

$$R = \frac{41\, W^{1/3}}{\left[1 + \left(\frac{47{,}000}{W}\right)^2\right]^{1/8}}$$

THIS EQUATION WAS USED TO EXTEND FIGURES 4-2, 4-5 CURVE (2) AND TO PREDICT EXACT VALUES.

$P_s = 4.5\text{psi}$; $\left(\frac{\rho\, f_y}{100\%}\right) = 0.12\text{ksi}$; $\mu = 3.0$

$$R = \frac{20\, W^{1/3}}{\left[1 + \left(\frac{2{,}500}{W}\right)^2\right]^{1/8}}$$

$P_s = 3.0\text{psi}$; $\left(\frac{\rho\, f_y}{100\%}\right) = 0.12\text{ksi}$; $\mu = 1.0$

$$R = \frac{42\, W^{1/3}}{\left[1 + \left(\frac{4{,}200}{W}\right)^2\right]^{1/8}}$$

$P_s = 3.0\text{psi}$; $\frac{\rho\, f_y}{100\%} = 0.30\text{ksi}$; $\mu = 3.0$

$$R = \frac{24\, W^{1/3}}{\left[1 + \left(\frac{75{,}000}{W}\right)^2\right]^{1/8}}$$

Tables 2 thru 5 present minimum required separation distances based upon Egn (7) for various explosive yields, W, ranging from 40 lbs. to 1×10^7 lbs. for these 4 representative cases.

Figure C2-5
Appendix B Calculations Sheet

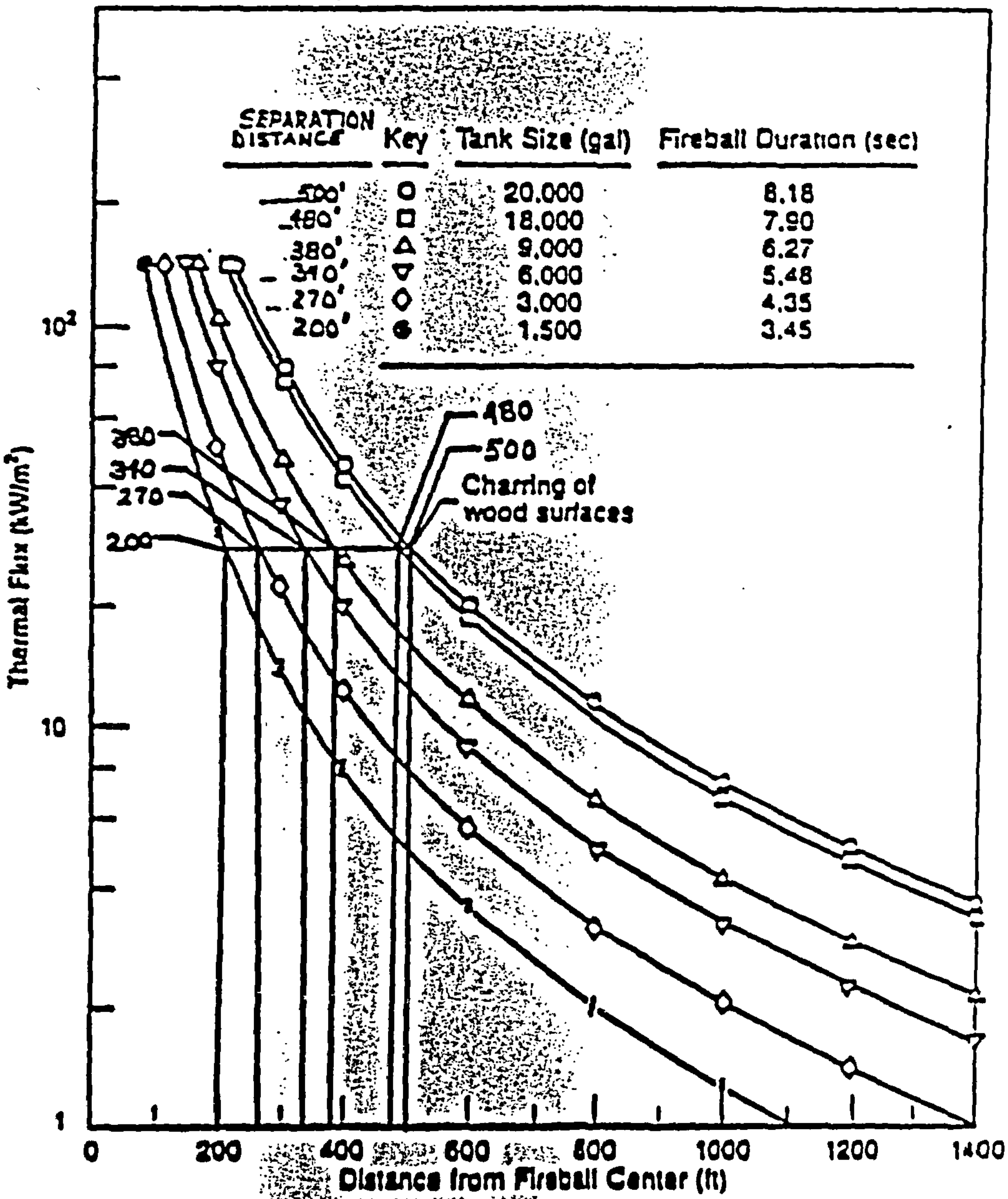


Figure 4-4. Thermal flux versus distance from fireball center for liquid hydrogen storage system.

Figure C2-6
Thermal Flux Separation Distance For Liquids

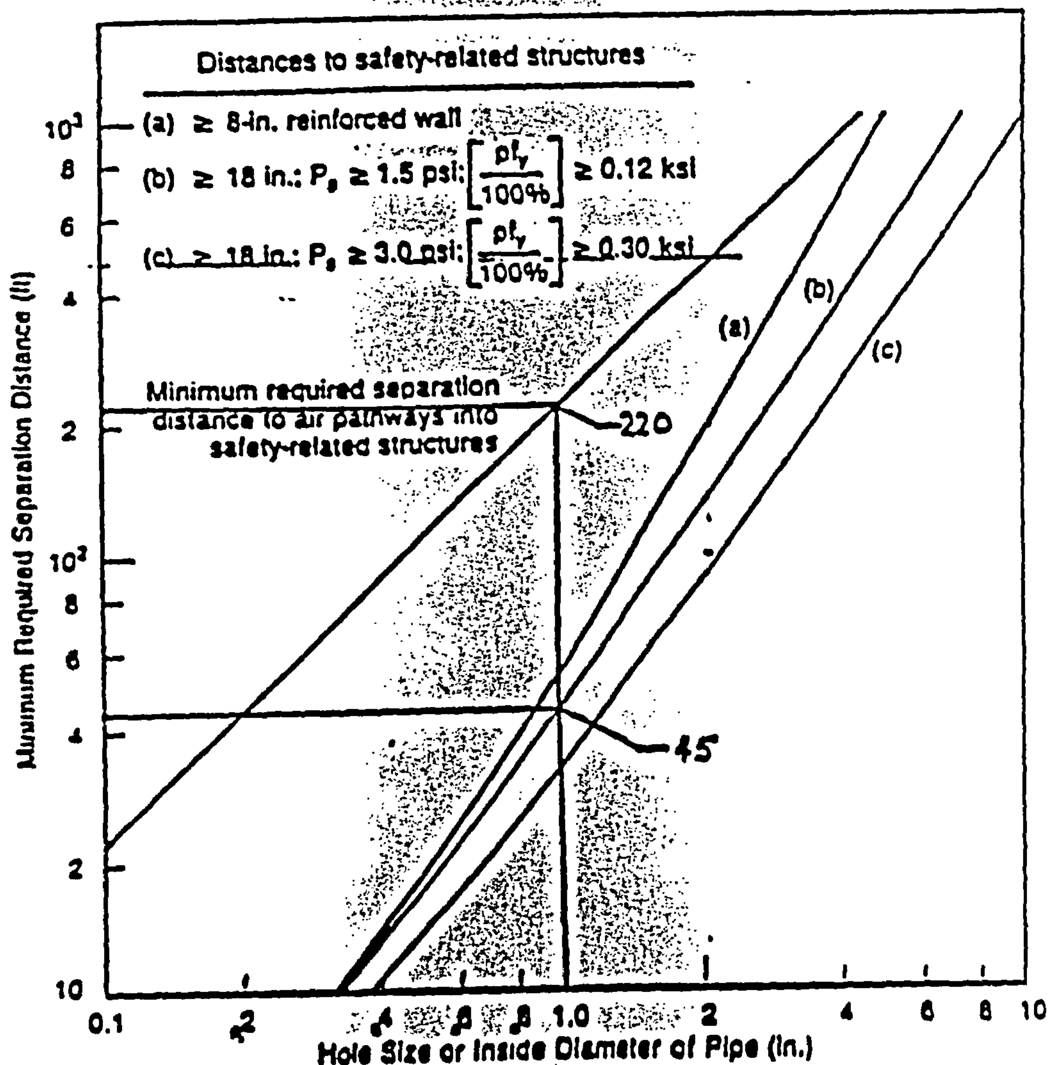


Figure 4-6. Minimum required separation distance versus hole size and ID of pipe for gaseous releases from 150 psig liquid hydrogen storage tank.

Figure C2-7
Pipe Releases Separation Distance For Liquids

RELATIONSHIP (2) WAS USED. THE EQUATION IDENTIFIED ON PAGE B-15 PROVIDED THE EXACT VALUES USED.

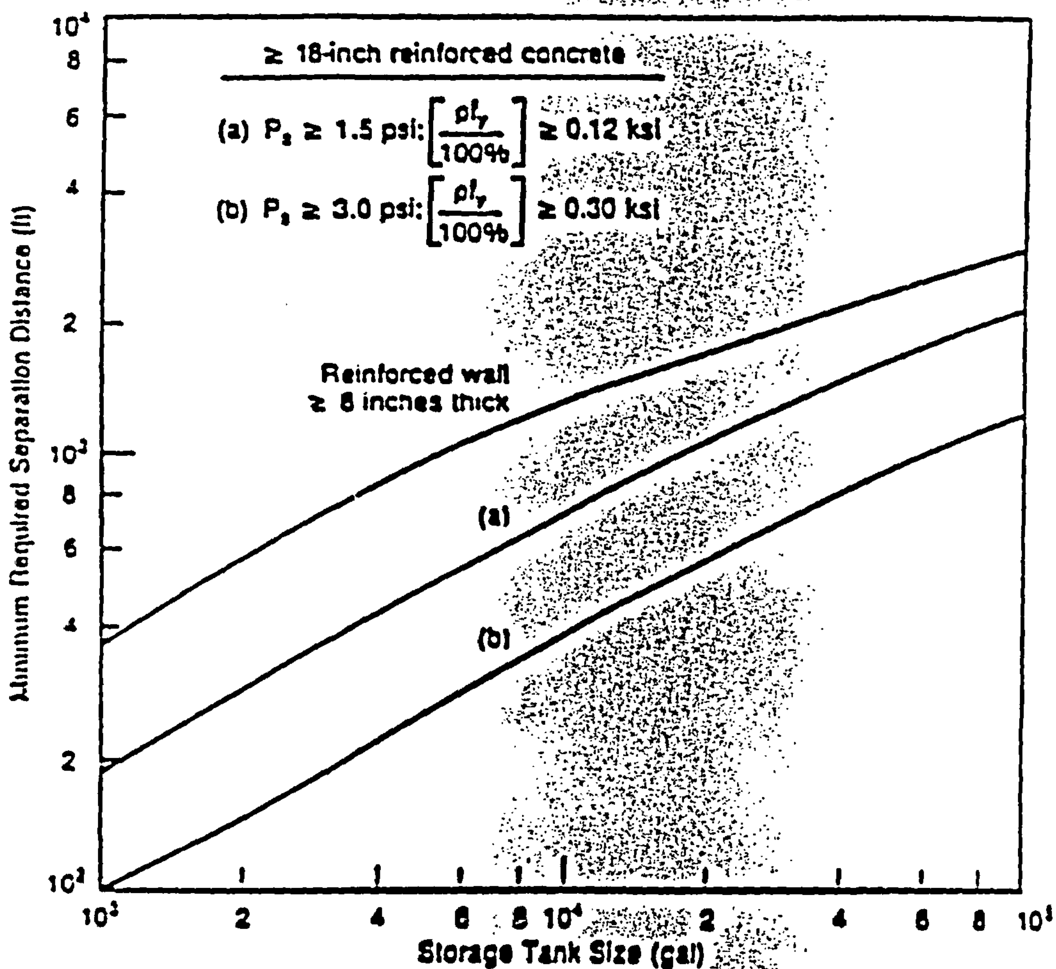


Figure 4-5. Minimum required separation distance versus liquid hydrogen storage tank size for instantaneous release of entire tank contents and explosion at tank site F weather stability.

Figure C2-8
Blast Separation Distances For Liquids

APPENDIX D

FREQUENCY CALCULATIONS

APPENDIX D. FREQUENCY ESTIMATE CALCULATIONS

D.1. Introduction

The hydrogen explosion, fireball and uncombusted release experience was described in section 5.1 of the report. There have been one explosion, two fireball and no uncombusted release events in the 1287 reactor-years of power reactor operating experience. Even though the "instantaneous"* events do not appear to have involved a full tank equivalent of hydrogen, it will conservatively be assumed that they are of the magnitude being considered. No uncombusted leak events were identified, which is not inconsistent with the Factory Mutual study (Reference 5.5), which indicates that uncombusted releases of hydrogen are about half as frequent as explosions or fires.

The PRA Procedures Guide (Reference J.1) outlines two basic methods for analyzing data, the classical method and the Bayesian method. Both methods will be used here.

D.2 Classical Method

The classical method mean and interval frequency estimates for a Poisson distribution are defined for n events in T years by (Reference J.1, p. 5-23 and 5-26):

Lower Confidence Limit: $X^2(2n; \alpha)/2T$

Mean: n/T

Upper Confidence Limit: $X^2(2n+2; 1-\alpha)/2T$

The quantities $X^2(2n+2; 1-\alpha)$ and $X^2(2n; \alpha)$ are chi-square percentiles obtained from the cumulative chi-square distribution. The percentile values are presented below for the cases where zero, one and two events have occurred (see Reference J.2).

	5%	95%
0 Event	-	5.991
1 Event	0.103	9.488
2 Events	0.711	12.592

---

* An instantaneous event is defined here as a single large explosion or fireball involving the hydrogen released, as opposed to a series of explosions or fireballs. Prolonged flames and multiple small explosions or fireballs are not equivalent to one "instantaneous" event in terms of the peak overpressure, thermal flux, or hydrogen concentrations at the air pathway.

For the case where no events have occurred (e.g. uncombusted hydrogen releases), the mean frequency will be zero, which does not convey any real meaning. A common technique where a significant amount of experience exists is to arbitrarily assume 0.5 events have occurred. This technique will not be used here, but it would produce the same mean as the Bayesian method. The lower confidence limit cannot be calculated for the case where no events have occurred.

D.3 Bayesian Method

The Bayesian mean and symmetrical probability intervals for a noninformative prior distribution are defined for n events in T years by (Reference J.1, p. 5-50):

5th percentile:	$X^2(2n+1; 0.05)/2T$
Mean:	$(2n+1)/T$
95th percentile:	$X^2(2n+1; 0.95)/2T$

The quantities $X^2(2n+1; 0.05)$ and $X^2(2n+1; 0.95)$ are chi-square percentiles obtained from the cumulative chi-square distribution. The percentile values are presented below for the cases where zero, one and two events have occurred.

	5%	95%
0 Event	0.00393	3.841
1 Event	0.352	7.815
2 Events	1.145	11.07

D.4 Results

Using both the classical and the Bayesian methods, the resulting frequencies are as follows:

	UNCOMBUSTED RELEASE FREQUENCY (per RY)	EXPLOSION FREQUENCY (per RY)	FIRE FREQUENCY (pe· RY)
Classical Method:			
5% Confidence Interval	--	4.0E-05	2.8E-04
Mean	--	7.8E-04	1.6E-03
95% Confidence Interval	2.3E-03	3.7E-03	4.9E-03
Bayesian Method:			
5 Percentile	1.6E-06	1.4E-04	4.4E-04
Mean	3.9E-04	1.2E-03	1.9E-03
95 Percentile	1.5E-03	3.0E-03	4.3E-03

The Bayesian method produces slightly more conservative results, and it is recommended that these more conservative results be used.

D. 5 LNG Frequency Estimates

Reference 5.6 (p. 18) indicates that there were no safety-related failures of LNG storage systems in 1.8E+06 hours of experience. This results in the following frequency estimates utilizing the techniques (methods) described above.

	UNCOMBUSTED RELEASE FREQUENCY (per RY)	EXPLOSION FREQUENCY (per RY)	FIRE FREQUENCY (per RY)
Classical Method:			
5% Confidence Interval	–	–	–
Mean	–	–	–
95% Confidence Interval	1.5E-02	1.5E-02	1.5E-02
Bayesian Method:			
5 Percentile	9.6E-06	9.6E-06	9.6E-06
Mean	2.4E-03	2.4E-03	2.4E-03
95 Percentile	9.3E-03	9.3E-03	9.3E-03

As discussed in section 5, the LNG data are not considered to be directly applicable to the nuclear power plant storage installation because of the differences in size and the fact that it is liquified. The LNG experience base is much smaller (205 years versus 1287 years of nuclear experience), which makes its results more uncertain.

The LNG mean results are 1 to 6 times greater than the nuclear experience results for hydrogen. This result appears at first to be in conflict with the Factory Mutual finding that hydrogen release events may be 4.5 times more frequent than LNG events. This apparent discrepancy can easily be explained by the larger LNG uncertainty and the much larger LNG storage capacity. Taking these factors into account, the LNG results confirm that the nuclear experience values are reasonable.

D.6 References

1. U. S. Nuclear Regulatory Commission, "PRA Procedures Guide - A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants," USNRC NUREG/CR-2300, January 1983.

2. T.T. Soong, Probabilistic Modeling and Analysis in Science and Engineering, John Wiley & Sons, 1981.

APPENDIX E

AN APPROACH FOR ASSESSING CORE DAMAGE SIGNIFICANCE

APPENDIX E:
AN ALTERNATE APPROACH FOR ASSESSING
THE SIGNIFICANCE OF HYDROGEN STORAGE TANK EVENTS

by
KENNETH D. BULMAHN
Consultant

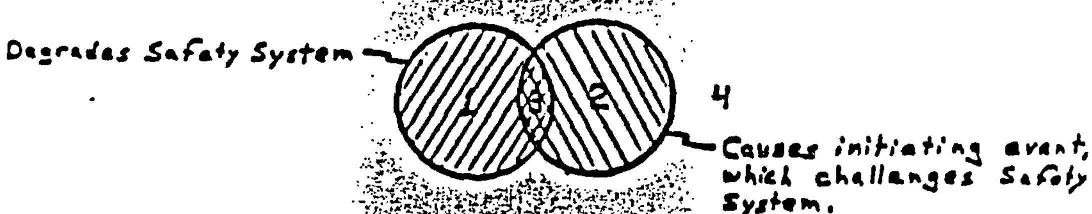
E.0 Introduction

This appendix presents an alternate methodology for assessment of the significance of potential tank storage system events. This methodology builds upon the work already performed and develops a more complete perspective of the issue. This presentation outlines potential future efforts which would more dEfinitively assess the significance of hydrogen storage installation risks.

Specifically deleted from this discussion are initiating events which may cause a hydrogen explosion (i.e. earthquake and tornado). This dependent failure mechanism deserves attention, but it is beyond the scope of this effort.

E.1 Potential Impacts of Hydrogen Storage Tank Events

The potential impacts associated with a hydrogen tank explosion or fire can be one of four possibilities, as demonstrated in the Venn diagram of Figure K-1. Each of the four possiblities, as represented in the diagram, are described below:



Region 1 represents the case where a hydrogen event results in the degradation of the plant's ability to respond to another independent initiating event. In this case, the hydrogen event does not challenge the safety systems, it only decreases the safety system's ability to respond to other challenges. An example of an event in this region is a hydrogen explosion which fails an auxiliary building wall and results in a loss of a high pressure safety injection pump. Loss of HPI capability does not directly threaten the plant, but it impairs the plant's ability to respond.

Region 2 represents the case where a hydrogen event results in an initiating event which directly challenges the plant's safety systems. An example of an event in this region is a hydrogen explosion which fails an auxiliary wall and results in the loss of all component cooling water flow. Loss of CCW is a direct challenge to the reactor.

Region 3 represents the case where a hydrogen event results in both the degradation of the plant's ability to respond and a direct challenge to the plant's safety systems. This would require impacting at least two systems.

Region 4 represents the case where the explosion does not challenge the safety systems or degrade safety system ability to respond. In other words, these events have no significance from a nuclear incident perspective. There may be damage to walls and there may be monetary loss. Events in this region are dismissed from further consideration.

These four regions describe all possible significant outcomes of a hydrogen event. Each of the regions which may affect core damage frequency (Regions 1, 2 & 3) will now be discussed in greater detail.

E.2 Degradation of the Plant's Ability to Respond

Hydrogen events which degrade safety systems are only of concern if a potential core damage initiating event occurs while the system is vulnerable. The window of vulnerability for region 1 includes both the case where an independent initiating event occurs before the hydrogen event, and the case where the independent initiating event occurs after the hydrogen event. If the independent intiating event occurs first, it will be assumed that the core can be cooled to a safe configuration within 24 hours. If the hydrogen event occurs first and a safety system is impaired, the plant must be brought to safe configuration within 86 hours (per Westinghouse Tech Specs based upon a discussion with J. C. Stachew). The window of vulnerability is conservatively considered to be 110 hours.

The frequency for a given Region 1 event (F_{R1}) is therefore the product of the annual independent initiating event frequency (F_{IE}) times the probability (P(SI)) that an essential safety system will be impaired due to a hydrogen event during the window of vulnerability.

$$F_{R1} = F_{IE} * P(SI)$$

P(SI) is the product of the rate of explosions (λ) times the duration of vinerability (t), using the λt-approximation. This conservatively assumes that all explosions will result in impairment of the essential safety system. This conditional probability of damage is certainly less than 1 (0.1 may be more realistic). The rate of explosions was found in section 5.5, the explosion rate is 1.4E-07/hr. The window of vulnerability is 110 hrs, so:

$$\begin{aligned} F_{R1} &= F_{IE} * \lambda * t \\ &= F_{IE} * 1.4E\text{-}07/hr * 110\ hrs \\ &= 1.5E\text{-}05\ F_{IE} \end{aligned}$$

Based upon the NRC Generic Letter GL 88-20 (Reference 7.2), the overall screening frequency for functional sequences is 1E-06/yr. This 1E-06/yr screening frequency will be used here for the region 1 screening frequency, recognizing that in the worst case the functional sequence screening frequency now beomes 2E-06/yr. This non-conservatism is offset by the conservative assumption that all explosions result in damage to an essential safety system. The only initiating events for region 1 which must be addressed are those independent initiating events where:

$$F_{R1} > 1.0E\text{-}06/yr$$
$$1.5E\text{-}05\ F_{IE} > 1.0E\text{-}06/yr$$
$$F_{IE} > 6.6E\text{-}02/yr$$

These initiating events will include loss of offsite power, turbine/reactor trip, etc. All other initiating events can be dismissed. Generic initiating event frequencies can be obtained from sources such as EPRI NP-2230 (reference K.1). The train and system unavailabilities which result from hydrogen explosions can be compared to the sytem unavailabilities due to all other causes to determine which systems may experience a significant increase in unavailability due to the tank farms.

E.3 Initiating Events Caused By Hydrogen Explosions

For Region 2 events, hydrogen explosions are only going to increase the frequency of the initiating events already identified (e.g. loss of CCW frequency). The "new" frequency (F'_{IE}) is:

$$F'_{IE} = F_{IE} + F_{HE}$$

where F_{IE} is the initiating event frequency excluding hydrogen explosions and F_{HE} is the frequency of hydrogen explosions which produce this initiating event. An initiating event will not occur each time a hydrogen explosion occurs, but is dependent upon the conditional probability that an initiating event occurs given a hydrogen event has occured (P(IE|HE)):

$$F'_{IE} = F_{IE} + F_{HE} * P(IE|HE)$$

If the new frequency (F') is not significantly different from the original frequency, then the hydrogen event can be ignored since it will not significantly increase the frequency of core damage. GL 88-20 states that functional sequences must be addressed if they contribute more than 5% of the core damage frequency. It will arbitrarily be assumed here that hydrogen-initiated events can be ignored if they contribute less than 10% of the given initiating event's overall frequency. Any given initiating event will contribute less than 100% of the total core damage frequency, and therefore a 10% increase in a given initiating event's overall frequency will have less than a 10% impact on the total core damage frequency.

If this <10% sreening criterion is used, then the initiating events which can be dismissed are those where:

$$F'_{IE} < 1.1 * F_{IE}$$

$$F_{IE} + F_{HE} * P(IE|HE) < 1.1 * F_{IE}$$

$$F_{IE} > 10 * F_{HE} * P(IE|HE)$$

Since section 5.5 recommends a hydrogen explosion frequency of 1.2E-03/yr, the only initiating events which must be considered for region 2 are those initiating events with a frequency greater than 1.2E-02/yr (assuming P(IE|HE) = 1). Generic sources for initiating event frequencies (e.g. References K-1) can be reviewed to identify the initiating events of concern and those that can be dismissed. This means that initiating events such as reactor/tubine trip, loss of offsite power, etc. can be dismissed. Those initiating events which must be addressed further include loss of DC power, steam generator tube rupture, LOCAs, etc. By looking at each case, it will be possible to screen further by using the following guidelines:

1) Dismiss initiating events which occur inside containment (e.g. most LOCAs) since the containment is typically not the safety related building in violation of separation distance and the reactor containment is considered much more blast worthy.

2) Dismiss initiating events when the screening criteria would be met if a more reasonable P(IE|HE) were used. Arriving at this conditional probability may not be easy, but in some case it will be obvious (e.g. certainly fewer than half of the explosions will result in a steamline/feedline break).

There are some additional factors which must be considered before the screened initiating events are finally dismissed. Consideration must also be given to the possiblity that a hydrogen explosion will produce some distinguishing difference from the initiating events caused by other sources. For example, a hydrogen explosion near a switchyard may interrupt offsite power for an abnormally long duration, which is a more severe scenario than typical LOOPs.

E.4 Concurrent Initiating Event and Safety System Degrading Events

Region 3 events can be handled in a manner similar to the methods outline above in sections K.2 and K.3. Due to time constraints, this effort could not be undertaken at this time.

E.5 Conclusion

The methodology described above is only one approach to assessing the significance of hydrogen tank farm explosions. This approach does offer a thorough, well defined strategy for attacking the problem. Initiating events which cannot be screened by the above approach are not necessarily major contributors to core damage frequency, but further refinements are required to demonstrate that this is not the case.

E.6 References

K.1 A. S. McMlymont and B. W. Poehlman, ATWS: A Reappraisal, Part 3: Frequency of Anticipated Transients, EPRI NP-2230, Research Project 1233-1, Interim Report January 1982.

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

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HOR(S)

J. L. BALLIF
K. D. BULMAHN
R. G. NEVE

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Division of Safety Issue Resolution
Office of Nuclear Regulatory Research
U. S. Nuclear Regulatory Commission
Washington, DC 20555

LEMENTARY NOTES

RACT (200 words or less)

SCIENTECH, Inc., evaluated data on hydrogen tank farms supplied by the NRC Regional staff to make a qualitative assessment of the commercial nuclear reactor plants that comply with building separation requirements. The separation requirements were those previously established by Electric Power Research Institute (EPRI) NP-5283-SR-A, 1987. In addition, a frequency of occurrence of hydrogen release from tank farms was established from both existing data and data from inquiry of hydrogen and related gas industry sources.

[redacted] The information supplied was sufficiently accurate to allow a general assessment of the tank farm location/separation status. A frequency of hydrogen plant explosion is 1E-03/reactor year was determined from both hydrogen vendors and safety information.

WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)

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