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March 12, 1985

Mr. Harold R. Denton, Director
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Subject: Dresden Station Units 2 and 3
Response to Questions on
Liquid Hydrogen Storage
NRC Docket Nos. 50-237 and 50-249

Reference (a): Letter dated February 27, 1985 from
J. A. Zwolinski to D. L. Farrar.

Dear Mr. Denton:

As requested by the referenced letter, enclosed in the form of an attachment to this letter is our response to your questions on our liquid hydrogen storage system.

If you have any further questions, please contact this office.

One signed original and forty (40) copies of this transmittal is provided for your use.

Very truly yours,

J. D. Marshall

For B. Rybak
Nuclear Licensing Administrator

lm

cc: R. Gilbert - NRR
NRC Resident Inspector - Dresden

Attachments

A001
1/40

9852N

DRESDEN 2/3 NRC QUESTIONS ON HYDROGEN STORAGE TANK

Question 1:

311.5 (Section 2.2.3) The H_2 tank failure analysis indicates that the Dresden safety related structures are designed to withstand overpressures of 6.3 PSI without damage. Figure 2 of your analysis shows that with Pasquill "D" stability (wind velocity u is not specified) and with a vapor cloud drift of 650 feet, the TNT equivalent of the flammable hydrogen mixture is 30,000 lbs of TNT. The distance from the center of this cloud to produce an overpressure of 6.3 PSI is stated to be 404 feet.

Indicate if this overpressure is the peak positive incident pressure (P_{SO}) or the peak positive normal reflected pressure (P_r) as defined in the Department of the Army Technical Manual TM 5-1300 "Structures to Resist the Effects of Accidental Explosions" - (Reference NO. 1 of Standard Review Plan 2.2.1 - 2.2.2 Identification of Potential, Hazards in Site Vicinity). Indicate the H_2 - TNT conversion factor used and its basis.

Response to Question 1:

Figure 2 shows the TNT equivalent vs. distance from release. For the "puff" or instantaneous Gaussian model, the amount in the flammable range at a given distance is only a function of the amount released and the weather stability. The wind speed only determines when the cloud will reach a particular distance (the time being universely proportioned to the wind speed). Since the probability of delayed ignition, P_I, was not taken as a function of time but of distance, the wind speed was not a factor in this analysis.

The overpressure used was the "peak positive incident pressure" (P_{SO}) as defined by TM 5-1300. It was assumed that the quoted strength of safety-related structures (6.3 psi for no damage, 21 psi for threshold of rebar yielding) accounted for any amplification due to shockwave reflections from the structure's geometry. Most references that list damage estimates for various structures use incident overpressure because the amount of shockwave amplification is a function of the structure geometry.

If the peak positive normal reflected pressure (P_r) is used, the distance from the epicenter of a 30,000 lb TNT equivalent explosion to a P_r of 6.3 psi is 640 ft. The included angle of wind directions that would translate the flammable cloud within 640 ft. of safety-related structures is 150^o. The probability of the "wind blowing towards plant" would be.

$$P_W = \frac{150^o}{360^o} = 0.42$$

This change would increse the frequency of threatening safety related structures due to tornadoes from 2.5×10^{-8} to 4.2×10^{-8} yr^{-1}.

The "H_2 - TNT conversion factor" used in the analysis is, one pound of H_2 in flammable range equates to 5.20 lbs. of TNT. The basis for this was that 20% of the available combustion energy was used in the shockwave formation. That is,

$$\frac{\text{lbs TNT}}{\text{lbs } H_2} = \frac{0.2(H_f)\ \text{cal/lb } H_2}{5 \times 10^5\ \text{cal/lb TNT}} = 5.20$$

where

$$H_f = \text{heat of combustion of } H_2 = 1.3 \times 10^7\ \text{cal/lb}$$

Question 2:

311.6 (Section 2.2.3) Provide a drawing of the flammable portion of the postulated hydrogen cloud path on an up-to-date plot plan of the Dresden Nuclear Station (assuming PASQUILL "F" and wind velocity (u) = 1 meter/second). Indicate on a scaled "Side View" of the Dresden complex the path of the flammable portion of the hydrogen plume considering the bouyancy of the hydrogen gas. Indicate the distance from the centroid of the hydrogen plume explosion to the nearest vertical and horizontal surfaces of safety related structures.

Response to Question 2:

The Pasquill F stability class is not the worst case for the postulated release. The D stability class results in a rate of dilution that maximizes the quantity of release in the flammable range for distances within 640 ft. of safety related structures (see attached Figure 1). The analysis is considered very conservative because it assumes that for all cases 88% of the total release will be in the flammable range. If 100% of the total mass released contributed to a blast wave, the distances would only increase by 4.4% (using $W^{1/3}$ scaling).

The saturated vapor from the flashing and evaporating liquid hydrogen release would have approximately neutral buoyancy (unlike ambient temperature hydrogen gas which has a specific gravity of 2/29). Because of this fact, the cloud was modeled using standard Gaussian with no credit taken for any vertical displacement. Since this assumption results in the shortest distances from the epicenter to safety-related structures, the results are considered to be conservative.

Question 3:

311.7 (Section 2.2.3) Figure SK-2 shows the H_2 truck delivery route. Indicate the maximum quantity of hydrogen contained in the transport vehicle. Figure SK-2 also indicates a 30,000 gal fuel oil storage tank and a 3 ft. earth dike surrounding it, near the proposed location of the H_2 storage area.

Provide an analysis of the peak positive normal reflected pressure on the oil tank and dike and the Thermal Flux (Kw/M_2) on the oil storage tank due to a detonation and a fire at the H_2 storage. In the event of failure of the dike indicate the flow of released fuel oil based on the topography of the site around the fuel storage tank.

Weight Percent of Release in Flammable Range vs Distance From Release

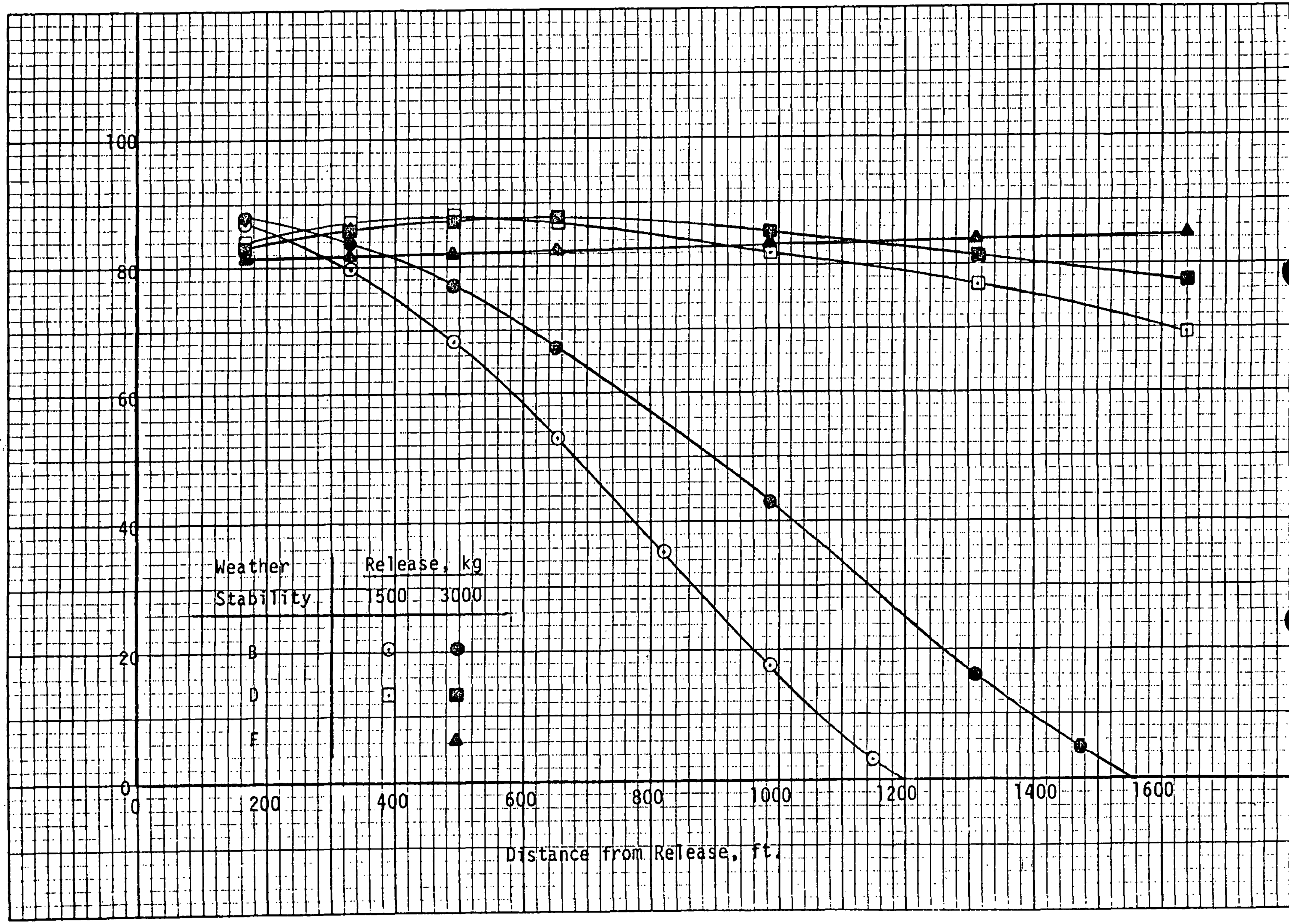

Figure 1

311.10 (Section 2.2.3) In the event of a fire at the hydrogen storage facility, calculate the Thermal Flux on the surfaces of safety related structures. Indicate the duration of the fire.

Response to Question 3:

The maximum mass of liquid hydrogen in the transport vehicle is 3660 kg.

The maximum peak positive normal incident overpressure from a hydrogen vapor cloud explosion is approximately 8 bar at the edge of cloud. Since the cloud could drift and ignite adjacent to the 30,000 gallon fuel oil storage tank this would be the maximum incident pressure. The maximum reflected pressure would be some multiple of the incident pressure depending on the tank geometry and shockwave angle of incident. Therefore, it should be assumed that if the postulated hydrogen vapor cloud explosively ignited near the oil storage area, the tank would fail in such a manner that some, if not all, of the fuel oil would be washed over the dike.

The most probable consequence of a sizable liquid hydrogen release would be a fireball-type combustion centered at the point of release. Since the majority of the heat radiated from the fireball occurs while it is spherical or near spherically shaped, damage estimates are most often made assuming a spherical fireball of constant diameter with a specified duration. Estimates for fireball diameter and durations taken from various sources in the literature are listed below.

Hardee & Larson,

Thermal Hazards from Hydrogen Fireballs[1]

Fireball Diameter, $D = 0.64\ (w_f T)^{1/3}$, m
w_f = weight of fuel, kg
T = flame temperature, ^{o}K

assuming adiabatic flame temperature, $T = 2318^{o}K$

$$D = 8.47\ w_f^{\ 1/3}$$

Hord,

How Safe is Hydrogen[2]

$$D = 7.93\ w_f^{\ 1/3}, \text{ m}$$

Fireball Duration, $t = 0.47\ w_f^{\ 1/3}$, sec

Crawley,

Effect of Ignition of a Major Fuel Spillage[3]

$$D = 26\ \frac{W_f}{MW}^{1/3}, \text{ ft; } w_f, \text{ lbs}$$

for hydrogen,

$$D = 8.186\ (w_f)^{1/3},\ m;\ w_f,\ kg$$

High,

<u>The Saturn Fireball</u>[4]

$$D = 9.82\ w_p^{\ 0.320},\ ft$$

w_p = weight of propellant (fuel + oxidant), lbs

for hydrogen

$$w_p = 8.94\ w_f$$

$$D = 7.77\ w_f^{\ 0.320}, m;\ w_f,\ kg$$

$$t = 0.232\ w_p^{\ 0.320}, sec;\ w_p\ lbs$$

$$t = 0.602\ w_f^{\ 0.320}, sec;\ w_f,\ kg$$

Gayle & Bransford,

<u>Size and Duration of Fireballs from Propellant Explosions</u>[5]

$$D = 9.56\ e_p^{\ 0.325}, ft;\ w_p,\ lbs$$

$$D = 7.677\ w_f^{\ 0.325}, m;\ w_f,\ kg$$

$$t = 0.196\ w_p^{\ 0.349}, sec;\ w_p\ lbs$$

$$t = 0.555\ w_f^{\ 0.349}, sec;\ w_f\ kg$$

Table I summarizes the estimated fireball dimensions for a release of 3000 kg of hydrogen. Since there is excellent agreement between the various sources, it would seem reasonable to use the average dimensions for damage estimates.

The thermal flux from a fireball, I, as a function of the distance from the center of the fireball as follows.

$$I = \varepsilon \sigma T^4 \frac{d^2}{4r^2},\ r > \frac{d}{2}$$

where

ε = emissivity of flame 0.1

σ = Stefan-Boltzmanns Constant = $5.67 \times 10^{-11} kw/m^2\ {}^{o}K$

T = flame temperature 1600 ^{o}K

d = fireball diameter = 112 m

r = distance from center of fireball, m

$$I = \frac{4.66 \times 10^5}{r^2}, \; kw/m^2, \; r > 56m$$

Since the 30,000 gallon fuel oil storage tank is approximately 60 meters from the liquid hydrogen storage vessel, the maximum expected thermal flux would be 130 kw/m^2 for a duration of 7.3 seconds.

The oil tank and the 3A earth dike were built on virtually flat ground. If we assume a leak in the oil tank and selectively fail the dike in such a way to direct the flow toward the liquid hydrogen facility, a fire could reach this facility.

Additional fire protection has been added in the area to protect against fires of this nature.

If we assume the additional fire protection is ineffective, the overpressure protection system of the Liquid Hydrogen Storage facility can adequately relieve the vaporization rate of a tank engulfed in a hydrocarbon fire. (See response to Question 4).

The thermal flux on the surfaces of safety-related structures can also be calculated using:

$$I = \varepsilon \sigma T^4 \frac{d}{4r^2}, \; r > \frac{d}{2}$$

ε = emissivity of flame 0.1

σ = Stefan-Boltzmanns constant = 5.67×10^{-11} kw/M^2 ^oK

T = flame temperature = 1600^oK

d = fireball diameter = 112m

r = distance from center of fireball, m

Since the liquid hydrogen tank is approximately 235 meters (700 ft) from the nearest safety-related structure, the maximum expected thermal flux would be 2.11 Kw/m^2 for a during of 7.3 seconds.

Table I

Fireball Dimensions

for 3000 kg of Hydrogen

	Diameter, m	Duration, sec
Hardee & Larson	122	-
Hord	114	6.78
Crawley	118	-
High	101	7.80
Gayle & Bransford	103	
Average Estimates	112	7.29

1. Hardee, H.C. and Larson, D.W., Thermal Hazard From Hydrogen Fireballs, U.S. Dept. of Commerce Report #SAND 78-1589, 1979

2. Hord, J., How Safe is Hydrogen, Symposium Hydrogen for Energy Distribution, Chicago, Illinois, 1978

3. Crawley, F.K., The Effects of the Igniting of a Major Fuel Spillage, I. Chem. E. Symposium Series #71 1982

4. High, R.W., The Saturn Fireball, Annals New York Academy of Sciences, Vol. 152, 1968

5. Gayle, J.B. and Bransford, J.W., Size and Durations of Fireballs from Propellent Explosions, NASA TMX-53314, 1965

Question 4:

311.8 (Section 2.2.3) In the event of a fire in the fuel oil storage tank calculate the Thermal Flux on the Hydrogen Storage Tank. Indicate the consequences of a fuel oil fire on the evaporation rate of hydrogen liquid in the storage vessel.

Response to Question 4:

The liquid hydrogen storage tank overpressure protection system is designed to relieve the vaporization rate caused by a hydrocarbon fuel fire engulfing the outer shell with a loss of vacuum and hydrogen (highest thermal conductivity) in the annulus of the double wall tank (as per Compressed Gas Association S1.3 and ASME Section VIII requirements). Under these conditions the shell reaches 1200^{o}F and the required relieving capacity is 9727 lbs/hr of H_2 at 59^{o}R which has a factor of safety of four. The actual venting rate under these conditions would be 2432 lbs/hr. The venting capacity of the 2 inch rupture disk is 22,952 lbs/hr of H_2 at 59^{o}R, over nine times the maximum venting rate. Since the overpressure protection system can adequately relieve the vaporization rate of a tank engulfed in a hydrocarbon fire, any fire at the 30,000 gallon fuel oil tank 200 ft. away will also be accommodated.

The liquid hydrogen storage tank at Dresden is provided with redundant 2 inch rupture disks.

Question 5:

311.9 (Section 2.2.3) Calculate the P_r on the roof and walls of the building containing the Units 2/3 control room and other safety related structures from a hydrogen cloud detonation considering the buoyancy of the gas and assuming Pasquill "F" stability with a wind speed of 1 M/sec. and a wind direction towards the Units 2 and 3 control rooms.

Response to Question 5:

The answers to these questions are incorporated into responses to Questions 2 and 3.

EJR/bmb/5785D*