APPENDIX A

Methane Explosion Evaluation for
Overpressure and Missile Effects
at Safety-Related Structures

NUS-4235

MIDLAND NUCLEAR POWER STATION METHANE EXPLOSION EVALUATION FOR OVERPRESSURE AND MISSILE EFFECTS AT SAFETY-RELATED STRUCTURES

Prepared for

Consumers Power Company

By

M. R. Fallin

October 1982

Approved: Steven J Nathan
S. J. Nathan, Manager
Radiological Analysis Department
Consulting Division

NUS CORPORATION
910 Clopper Road
Gaithersburg, Maryland 20878

TABLE OF CONTENTS

1.0 INTRODUCTION

The natural gas pipeline which is present in the immediate vicinity of the Midland Nuclear Power Station presents a concern in the event of its rupture. The Condensate Return Pumphouse and Mechanic Shop locations and ventilation system designs are such that a buildup of the natural gas could result within these buildings if a pipeline rupture were to occur. Although unconfined natural gas is not considered to be an explosive hazard, within the confines of a building, an explosive hazard may exist. An analysis was performed postulating that such an explosion did take place subsequent to the rupture of the natural gas pipeline and the resultant buildup of natural gas within the Pumphouse and the Mechanic Shop. The purpose of the analysis was to confirm that there is no hazard to any of the safety-related structures due to the generation of overpressure or missiles from an explosion in either buillding.

2.0 TECHNICAL DISCUSSION OF PROBLEM AND APPROACH

The magnitude of the postulated explosion is determined by equating the energy generated by the combustion of a given volume of gas to the mass of TNT that would release the same energy upon explosion. To do this, a volume of gas had to be determined. Since natural gas is over ninety percent methane (Reference 1), the gas trapped in the Condensate Return Pumphouse and the Mechanic Shop was considered to be all methane. From Reference 2, the mix concentration of methane in air that results in the highest overpressure if it is exploded, is the stoichiometric mixture of 9.5 percent by volume. Knowing the volume of the two structures, the gas volume is easily obtained. Because the volume of the Mechanic Shop is greater than the volume of the Condensate Return Pumphouse (67,000 cubic feet vs. 30,000 cubic feet, as indicated on Reference 3), a postulated Mechanic Shop explosion was evaluated since it would produce the larger explosion of the two buildings. With the gas volume determined, the equivalent TNT mass and the resultant overpressure from the explosion of that volume at any given distance from the explosion center can also be determined.

The missile hazards evaluation was performed utilizing the same missiles used in the Midland FSAR (Reference 2) for the tornado missile analysis. These missiles are a 12 ft x 12 in x 4 in wooden plank, a 1 inch diameter steel rod, three feet in length, a 4000 lb automobile and a 13.5 inch diameter utility pole, thirty-five feet in length. Knowing the explosive yield and the aerodynamic characteristics of the missiles, the dynamic impulse imparted to the missile by the kinetic energy of the exploded gas and accelerated air is used to determine the initial missile velocity. The trajectory of the missiles is then determined.

3.0 DESCRIPTION OF METHOD OF ANALYSIS

As described in the previous section, the first step was to equate the energy released by the combustion of the methane to an equivalent mass of TNT. This was accomplished using the following equation.

$$W_i = \left[(Q \cdot \rho \cdot \Delta H_c \cdot E)/A \right] \Big/ 500 \text{ Kcal/lb}_m\text{-TNT}$$

where

W_i = equivalent mass of TNT (lb_m)

Q = maximum quantity of vapor (ft^3)

ρ = density of gas (g/ft^3) - taken from Reference 1

A = molecular weight (g/mole)

ΔH_c = heat of combustion (Kcal/mole) - taken from Reference 5

E = yield of explosion (assumed to be 20% on an energy basis - maximum expected TNT equivalency for gas in symmetrical geometry from Reference 6)

Once the equivalent TNT mass has been determined, the parameter Z, called the scaled distance, is calculated by the equation:

$$Z = R_A/W_i^{1/3}$$

where

Z = scaled distance ($ft/lb_m^{1/3}$)

R_A = distance between point of detonation and the location of interest (ft)

W_i = equivalent mass of TNT (lb_m)

In this case, the value of R_A is the distance from the Mechanic Shop to the closest safety-related structure which is the closer of the two Borated Water Storage Tanks to the Mechanic Shop. From Reference 3, this distance is about 575 feet.

In determining the peak incident and peak reflected overpressures at the Borated Water Storage Tank, a hemispherical explosion propagation was assumed, as opposed to a spherical propagation, since higher overpressures were realized with the hemispherical propagation assumption. For hemispherical explosion propagation and for the calculated scaled distance, Z, the peak incident and reflected overpressures are read from Figure 4-12 of Reference 7. Due to the distance of the Borated Water Storage Tank from the explosion center, the peak incident overpressure is less than 1.0 psig and is, therefore, off the scale of Figure 4-12. The peak incident overpressure can be determined, however, by solving the following equation taken from paragraph 3.50 of Reference 8.

$$p_r = 2p \left[(7P_o+4p)/(7P_o+p) \right]$$

where

p_r = peak reflected overpressure, (psig)
p = peak incident overpressure, (psig)
P_o = atmospheric pressure, (14.7 psia)

For the missile hazards analysis, spherical explosion propagation is conservatively assumed. The building (Mechanic Shop) is assumed to be a sphere of radius 25.20 feet which is equivalent to the given volume of 67,000 ft^3. A hemispherical explosion propagation assumption at the same radius would produce greater initial velocities; however, a hemisphere of the equivalent 67,000 ft^3 volume would have a radius of 31.74 feet. Since the missiles are assumed to be generated from the surface of the equivalent sphere or hemisphere, assuming a hemispherical explosion propagation with a radius of 31.74 feet results in less conservative initial missile velocities than the spherical propagation case. Also, the dynamic impulse calculation is for a spherical charge configuration.

explosion propagation was assumed, as opposed to a spherical propagation, since higher overpressures were realized with the hemispherical propagation assumption. For hemispherical explosion propagation and for the calculated scaled distance, Z, the peak incident and reflected overpressures are read from Figure 4-12 of Reference 7. Due to the distance of the Borated Water Storage Tank from the explosion center, the peak incident overpressure is less than 1.0 psig and is, therefore, off the scale of Figure 4-12. The peak incident overpressure can be determined, however, by solving the following equation taken from paragraph 3.50 of Reference 8.

$$p_r = 2p \left[(7P_o+4p)/(7P_o+p) \right]$$

where

p_r = peak reflected overpressure, (psig)
p = peak incident overpressure, (psig)
P_o = atmospheric pressure, (14.7 psia)

For the missile hazards analysis, spherical explosion propagation is conservatively assumed. The building (Mechanic Shop) is assumed to be a sphere of radius 25.20 feet which is equivalent to the given volume of 67,000 ft^3. A hemispherical explosion propagation assumption at the same radius would produce greater initial velocities; however, a hemisphere of the equivalent 67,000 ft^3 volume would have a radius of 31.74 feet. Since the missiles are assumed to be generated from the surface of the equivalent sphere or hemisphere, assuming a hemispherical explosion propagation with a radius of 31.74 feet results in less conservative initial missile velocities than the spherical propagation case. Also, the dynamic impulse calculation is for a spherical charge configuration.

The missile hazards evaluation begins with the determination of the positive dynamic impulse created at the boundary of the equivalent sphere from the postulated explosion. From Reference 9, the following equation is taken.

$$I_u^+ = \int (\eta \cdot \beta^2/2)\,d\tau$$

where

η = reduced density = ρ / ρ_o, (dimensionless)

β = reduced velocity = V/C_o, (dimensionless)

τ = reduced time = $C_o \cdot t/\alpha$, (dimensionless)

α = reduced yield = $(E_o/P_o)^{1/3}$, (ft)

E_o = energy yield of explosion, (ft-lb_f)

P_o = atmospheric pressure, (14.7 psi)

ρ_o = atmospheric density, (1.293 Kg/m^3)

C_o = sonic velocity, (1086 ft/sec)

I_u^+ = dimensionless impulse parameter which is a function of the parameter λ

λ = reduced radius = R/α , (dimensionless)

R = radius of the sphere

Substituting the above expressions into the equation you get the following relationship.

$$I_u^+ \cdot \rho_o \cdot C_o \cdot \alpha = \int (\rho \cdot V^2/2)\,dt = I_D$$

The above integral is known as the positive dynamic impulse, I_D, and is the impulse imparted to a missile by the kinetic energy of the exploded gas and accelerated air. The dimensionless impulse parameter, I_u^+, is taken from Figure 26 of Reference 9.

Once the positive dynamic impulse is calculated, the initial velocity of the missile can be calculated from the following equation taken from Reference 10.

$$V_f/\bar{V}_g = 1-e^{-R}, \text{ where } R = \left[(g_c \cdot I_D)/(\beta \cdot \bar{V}_g)\right]$$

and

V_f = initial missile velocity, (ft/sec)
$\bar{V}_g$ = gas particle velocity (taken from Figure 4-5 of Reference 6), (ft/sec)
g_c = gravitational constant, (32.17 lb_m-ft/lb_f-sec^2)
I_D = positive dynamic impulse, (lb_f-sec/ft^2)
β = ballistic coefficient = $m/(C_D \cdot A)$, (lb_m/ft^2)
m = missile mass, (lb_m)
C_D = missile drag coefficient, (dimensionless)
A = missile presented cross-sectional area, (ft^2)

This expression gives the initial velocity generated as an integral over the total duration of the gas and air movement past the missile. Making the appropriate substitutions, the equation now becomes the following.

$$V_f = \bar{V}_g \left\{1-\exp\left[-(g_c \cdot I_D \cdot C_D \cdot A)/(m \cdot \bar{V}_g)\right]\right\}$$

The missile presented cross-sectional areas, A, and the missile drag coefficients, C_D, are selected such that the greatest cross-sectional areas and, therefore, the greatest drag coefficients are utilized for the calculation. This results in the greatest possible initial velocity.

Having established the initial velocity for each of the missiles, the NUS computer code NUSTRAJ is used to determine the maximum distances that the missiles will travel. For the purposes of this portion of the analysis, the missiles are assumed to reorient themselves to the lowest cross-sectional area and drag coefficient during flight in order to attain their maximum possible flight distance. It is also assumed that the dynamic impulse serves only to induce an initial velocity and does not cause any of the missiles to break up; i.e., they survive the explosion intact.

4.0 RESULTS OF THE ANALYSIS

The peak reflected overpressure at the closer of the two Borated Water Storage Tanks to the Mechanic Shop is 1.3 psig. The peak incident overpressure at the same storage tank is 0.64 psig.

The maximum velocities attained by the missiles as a result of the explosion are as follows:

- 12 ft wooden plank - 92.84 ft/sec
- 3 ft steel rod - 15.57 ft/sec
- 4000 lb automobile - 12.77 ft/sec
- 35 ft utility pole - 13.17 ft/sec

The maximum distances traveled by the missiles from the Mechanic Shop are as follows:

- 12 ft wooden plank - 254 ft
- 3 ft steel rod - 7.5 ft
- 4000 lb automobile - 5.1 ft
- 35 ft utility pole - 5.4 ft

5.0 CONCLUSIONS

Based on the results of the analysis, it is concluded that there is no hazard presented to any of the safety-related structures by an explosion in either the Condensate Pumphouse or the Mechanic Shop based on the following points:

- o The 0.64 psig peak incident and 1.3 psig peak reflected overpressures, which were calculated to occur at the closest safety-related structure to the Mechanic Shop after the postulated explosion, are below the peak incident and peak reflected overpressure criteria found in NRC Regulatory Guides 1.91 and 1.76, respectively. The explosion would, therefore, cause no damage to any of the safety-related structures.

- o The closest safety-related structure to the Mechanic Shop is about 575 feet away and the maximum distance traveled by any missile is 254 feet; therefore, there would be no missile hazard to any of the safety-related structures.

6.0 REFERENCES

1. Lab Report from E. L. Rice to R. T. Sarrine, "Natural Gas Analysis Report", August 27, 1982.

2. Nagy, John, Earl C. Seiler, John W. Conn, Harry C. Verakis, "Explosion Development in Vessels," Report of Investigations 7507, U. S. Department of the Interior, Bureau of Mines, 1969.

3. Marked-up, to-scale, unnumbered Midland blueprint, entitled "Trailer Layout", provided by client. Last updated 12/16/81.

4. Midland 1 & 2 FSAR, Volume 10, Section 3.5.

5. Matheson Unabridged Gas Data Book - Methane, Matheson Gas Products, 1974.

6. Eichler, T. V. and H. S. Napadensky, H.S., "Accidental Vapor Phase Explosions on Transportation Routes Near Nuclear Power Plants," Final Report J6405, IIT Research Institute, Chicago, Illinois, April 1977.

7. "Structures to Resist the Effects of Accident Explosions", TM5-1300/NAVFAC P-397/AFM 88-22, Departments of the Army, Navy and the Air Force, June 1969.

8. Glasstone, S., Ed., The Effects of Nuclear Weapons, United States Atomic Energy Commission, February 1964.

9. Brode, H. L., "A Calculation of the Blast Wave from a Spherical Charge of TNT", P-975 (AD605113), The Rand Corporation, May 1958.

10. TRW Systems Group, Transit RTG Final Safety Analysis Report, Volume II, "Accident Model Documentation", TRW(A)-11464-0492, 1971.

NUS CORPORATION

A Halliburton Company