APPENDIX B

Heat Effects From
Burning Natural Gas

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HEAT EFFECTS FROM BURNING NATURAL GAS AT MIDLAND PLANT

Prepared for

CONSUMERS POWER COMPANY

by

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November 1, 1982

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1.0 INTRODUCTION

This report describes the analysis of the effects of burning natural gas from a postulated break in the pipeline. The heat and overpressure effects on plant safety-related structures are considered in the analysis. Included are direct radiation from the gas flames, convective heat transfer from the combustion plumes, and overpressures from gas cloud deflagration (including delayed ignition).

2.0 TECHNICAL DISCUSSION OF PROBLEM AND APPROACH

2.1 Pipeline Description

A six inch pipeline at 375 psig feeds the onsite pressure reducing station. From this station, low pressure lines at approximately 35 psig supply boilers in the Evaporator and Combination Shop buildings. The pipeline flow is restricted to 20 lbs/sec. The pipeline layout is shown in Figure 1.

The natural gas pipeline has an automatic isolation feature. Following a pipeline break and automatic isolation a total of about 800 lbs [1] of natural gas escapes from the line. In the analysis here, this number is conservatively rounded up to 1,000 lb of gas. At a constant flow rate of 20 lb/sec, the entire transient lasts for 50 seconds.

2.2 Deflagration Overpressures

Unconfined methane-air clouds will not detonate, though rapid burning or deflagration can occur [2]. Some measurements have been made of deflagration overpressures[3] in a burning cloud.

In the cloud, the measured overpressures are less than 0.1 bar and are not measurable beyond the cloud. For this reason, overpressures from rapid deflagrations are no hazard to the plant.

2.3 Radiant Heat Loading and Flame Size

Bennett and Finley[4] recommend a value of 100 kW/m^2 as the mean radiative power for LNG flames. The text explicitly refers to turbulent methane flames, therefore, the mean value quoted is adopted here as the flame edge heat flux.

The flame size used in the estimation of the heat flux is the visible flame height. The size of a sustained flame from a pipeline rupture is calculated using fluid dynamics. In this analysis a conservative approach, described below, was used to determine the jet dimensions.

Thomas[5] and Steward[6] give correlations for flame heights. Thomas's correlation is for "uncontrolled fires where the initial momentum of the fuel is low compared with the momentum produced by buoyancy". Steward's correlation is derived from a mathematical modeling of a free burning fire from a circular source assuming mixing controlled combustion. Steward correlated the available experimental data as a visible flame height that is the sum of a stoichiometric mixing height and an additional height to entrain four hundred percent excess air. The calculated flame height is (after Thomas) 164 feet, or (after Steward) 185 feet. The 185 feet was used since it is the larger, more conservative value.

The flame's horizontal dimension is conservatively assumed to be defined by the distance of 45 feet between the Evaporator and Combination Shop buildings. This dimension, and the 185 ft flame height, are used with the shape factor for parallel planes, to calculate the radiant heat loading on the face of the Auxiliary and Containment buildings.

2.4 Convective Heat Loading

The hot air plume from the break considered here is very buoyant. A strong wind is required to sufficiently suppress this buoyancy for the hot plume to impact on the safety-related structures. This strong wind will cause considerable mixing of the plume with cooler ambient air resulting in a reduction in the temperature of the plume.

The analysis of the transport and mixing of the plume is carried out using conventional Gaussian dispersion and Brigg's plume rise modeling.(7) All of the heat of combustion is conservatively assumed to be in the plume for this calculation (i.e., no losses to radiation).

2.5 Break Location Selection and Affected Safety-Related Structures

2.5.1 Low Pressure Pipeline

A break in the low pressure line between the Evaporator and Combination Shop buildings was determined to be the worst case onsite break based on engineering judgement. It is the nearest location to safety-related structures and there are no large intervening structures.

The heat loading from this break was found to have no adverse effect on the following safety-related structures:

1. The Auxiliary Building (North Face)
2. The Reactor Containment Buildings (North Faces)
3. The Borated Water Storage Tanks

All other safety-related structures are farther away and less affected. Similarly, breaks in other locations are bounded by this worst case break.

2.5.2 High Pressure Pipeline

Since a break in the high pressure pipeline will result in approximately the same total release of natural gas and since the high pressure pipeline is further from safety-related structures, the heat loadings from a high pressure pipeline break are bounded by the break results for the low pressure pipeline.

3.0 RESULTS OF ANALYSIS

3.1 Borated Water Storage Tanks (BWST)

There is a minimum of 300,000 gallons of borated water available in each BWST according to the MIDLAND FSAR, Section 9.2.8.2.2. Conservatively assume that all of the heat of combustion from burning the entire 1000 lbs of natural gas goes into heating the tank contents. This results in a temperature rise for the tank contents of less than 5°C. This is acceptable.

3.2 Auxiliary Building North Face

The north face of the Auxiliary building is 250 feet from the pipeline break location. The radiative shape factor for two equal parallel planes of dimension 45 ft - by -185 ft and separated by 250 ft is $F_{1-2} = 0.033$. The transmissivity of 20% humidity air is 80%. Thus, the radiant heat loading on the Auxiliary building is (100x.033x.8=) 2.64 kW/m^2.

A convective heat loading may also occur at the north face of the Auxiliary building if the wind is blowing from the north with a speed greater than 12 m/sec (26 mph). (For lower wind speeds the hot air plume rises over the Auxiliary building and no convective heat load occurs). Under the worst case conditions, hot plume air with a temperature of 160°C impinges on the north face for 50 seconds. The north face of the Auxiliary building consists of a steel siding section and a concrete section. These sections are considered separately below.

3.2.1 Auxiliary Building North Face-Steel Siding

The top portion of the north face of the Auxiliary building is insulated steel siding. The height of the siding is roughly 40 feet and the width is about 82 feet. Under worst case conditions this steel siding is heated by convective and radiative heat transfer from the burning natural gas to a temperature of 208°C. The temperature difference between the steel siding and the building interior (assumed to be at 27°C) causes heat to be conducted through the steel and insulation into the interior of the Auxiliary building. During the 50 second accident a total of 16,000 BTU's enter the Auxiliary building. This much heat will cause the 500,000 ft^3 of air in the interior of the Auxiliary building to rise an average of 1.0°C. This is an acceptable temperature rise. Thus, the effect of radiant and convective heat loading on the steel siding is acceptable.

3.2.2 Auxiliary Building North Face - Concrete Wall

The lower portion of the Auxiliary building north face is reinforced concrete 1 foot thick. The temperature rise over the outer first inch of this concrete because of a radiant heat loading of 2.64 kW/m^2 for 50 seconds is less than 3°C. The radiant heat loading will cause the temperature of the inner surface of the 1 foot thick concrete wall to rise a maximum of 0.21°C.

Under worst case conditions the lower concrete portion of the Auxiliary building will also be subjected to a convective heat loading because of the hot plume impinging on the concrete for 50 seconds. At the end of 50 seconds, the average temperature of the first inch of concrete is 70°C and the inner 11 inches of concrete are still at ambient temperature (38°C). Recall that wind speeds greater than 12 m/sec are required for there to be any convective heat load on the Auxiliary building. At the end of 50 seconds this wind would continue to blow and cool the outer concrete surface. However, if no credit is taken for this cooling then several hours after the accident the inner surface of the concrete would rise in temperature a maximum of 2.7°C because of the convective heat loading.

Thus, the combined effects of radiant and convective heating of the concrete portion of the Auxiliary building north face are acceptable. The outer first inch would have a maximum average temperature of ($70^{\circ}C + 3^{\circ}C =$) $73^{\circ}C$. For comparison, NUREG/CR-1748 quotes an allowable short term temperature of $194^{\circ}C$ for concrete following an accident. The interior surface of the concrete undergoes a maximum temperature rise of ($2.7^{\circ}C + 0.21^{\circ}C \approx$) $3^{\circ}C$. This is also acceptable.

3.3 Containment Buildings

The Containment buildings are 344 feet from the pipeline break location. The radiant heat loading on them is 1.54 kW/m^2. This loading lasts for 50 seconds.

A convective heat loading may also occur if the wind is blowing from the north with a speed greater than 8 m/sec (17 mph). (For lower wind speeds the hot air plume rises over the containment). Under worst case conditions, hot plume air with a temperature of $149^{\circ}C$ impinges on the containment walls for 50 seconds.

The containment wall is reinforced concrete 3.5 feet thick. The temperature rise over the outer first inch of this concrete because of a radiant heat loading of 1.54 kW/m^2 for 50 seconds is $1.5^{\circ}C$. The radiant heat loading will cause the temperature of the inner surface of the 3.5 foot thick concrete wall to rise a maximum of $0.04^{\circ}C$.

Under worst case conditions the containment walls will also be subjected to a convective heat loading because of the hot plume impinging on the concrete for 50 seconds. At the end of 50 seconds, the average temperature of the first inch of concrete is $66^{\circ}C$ and the inner 41 inches of concrete are still at ambient temperature ($38^{\circ}C$). Recall that wind speeds greater than 8 m/sec are required for there to be any convective heat load on the containment. At the end of 50 seconds this wind would continue to blow and cool the outer concrete surface. However, if no credit is taken for this cooling then several hours after the accident the inner surface of the concrete would rise in temperature a maximum of 0.67°C because of the convective heat loading.

Thus, the combined effects of radiant and convective heating of the Containments are acceptable. The outer first inch would have a maximum average temperature of (66°C + 1.5°C =)67.5°C. For comparison, NUREG/CR-1748 quotes an allowable short term temperature of 194°C for concrete following an accident. The interior surface of the concrete undergoes a maximum temperature rise of (.04°C + 0.67°C =)0.71°C. This is also acceptable.

4.0 REFERENCES

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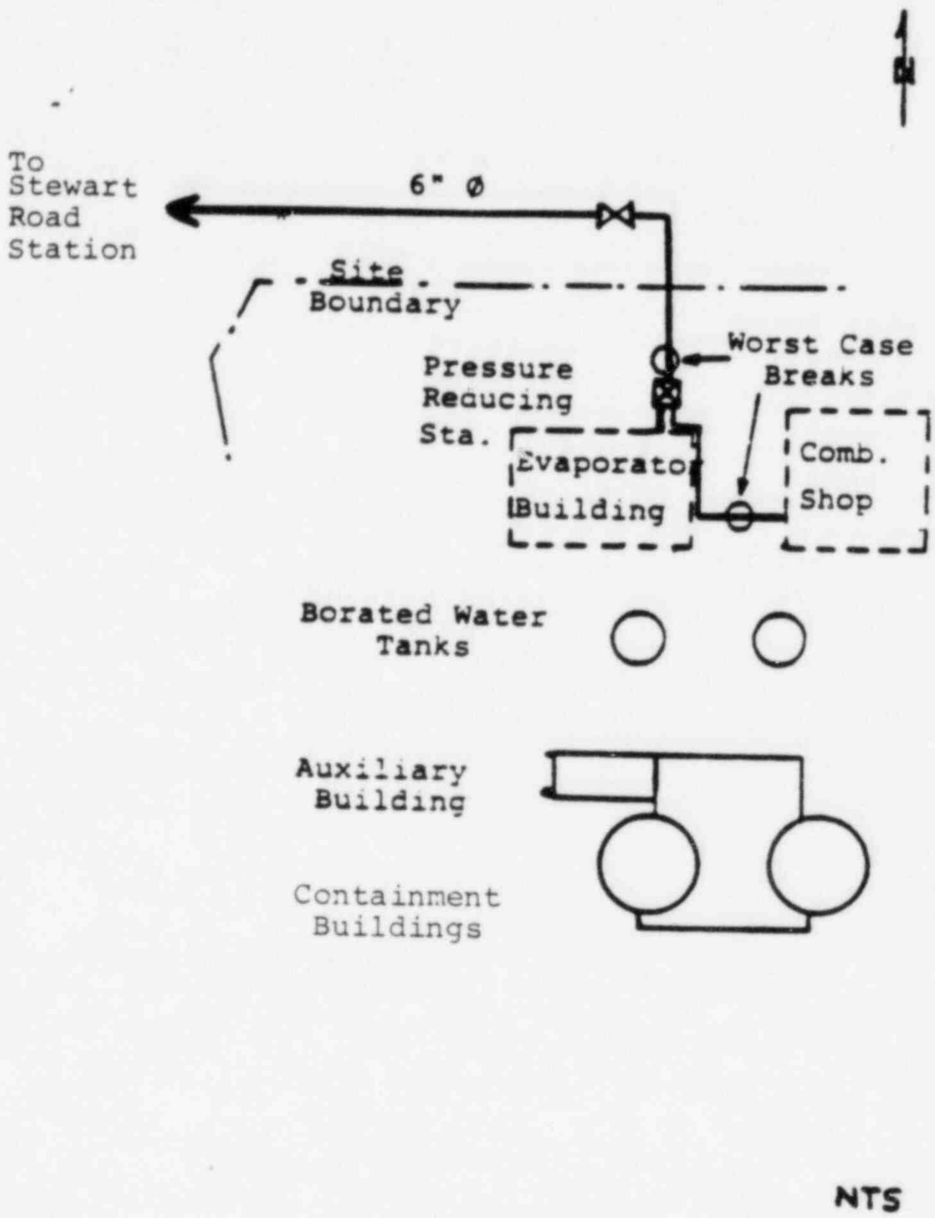

FIGURE 1

LOCATION OF WORST CASE PIPELINE BREAKS

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APPENDIX C

ANALYSIS OF LEAKS INTERNAL TO THE EVAPORATOR BUILDING AND THE COMBINATION SHOP

COMBINATION SHOP TEST BOILER ROOM
CALCULATION OF PROBABILITY OF GAS PIPELINE BREAK

This calculation is to confirm that the probability of a pipeline break within the test boiler room is acceptably low.

Pipe Within Test Boiler Room - 250 ft (estimated)

Frequency of Rupture - 3.3×10^{-8} Ruptures/ft-yr*

Availability of Leak Detection System - 98%

$P = (3.3 \times 10^{-8}$ Ruptures/ft-yr$) \times (250$ ft$) \times (2 \times 10^{-2})$

$P = 1.65 \times 10^{-7}$ Undetected Ruptures/yr

*The frequency of pipe rupture is determined from data collected by the American Gas Association (AGA). Since this piping is contained within a building it is assumed that a rupture due to an outside source is not applicable. An outside force is defined by the AGA as the encroachment of mechanical equipment, such as bulldozers and backhoes, from earth movements such as settlement or washout, from weather effects, such as thermal strains, and from willful damage. None of these reflects faults in the pipeline itself or in the operating or maintenance procedures. A detailed explanation of the calculation is provided in Section 3.0 of the NUS Report "Analysis of Flammable Concentrations at the Midland Plant from Natural Gas Pipeline Breaks."

Evaporator Building

Auxiliary Boiler Room

The auxiliary boiler room has been constructed so as to result in minimal effects to the plant in the event of an internal explosion. The south and west walls are block construction while the north and east walls are of butler construction which will act as blow-out panels and relieve to the north and east. Therefore, in the event of an explosion in the auxiliary boiler room, the potential air shock and missiles generated will be directed to the north away from safety related structures.

Laboratory Area

An investigation into the possibility of a natural gas leak in the evaporator building laboratory area was performed. The objective was to determine if in the event of a natural gas leak a flammable concentration (5% volume) could be reached. The only rooms with gas jets are the prep room and the sample room.

The maximum flow rate for gas jets was conservatively taken as 5 cu ft of gas an hour. The prep room has a volume of 13,100 cu ft; therefore, 655 cu ft of gas would be needed to reach a flammable concentration. With a leak flow of 5 cu ft an hour it would take 131 hours (5-1/2 days) to attain a flammable concentration. The sample room has a volume of 17,500 cu ft, therefore, 875 cu ft of gas would be needed to reach a flammable concentration. With a leak flow of 5 cu ft an hour, it would take 175 hours (7 days) to reach a flammable concentration.

The natural gas has an odor that can be detected at concentrations of 1% by volume. The laboratory will be manned 24 hours a day. The laboratory personnel will have ample time to detect any gas leaks. Also this calculation has not taken any credit for the HVAC system for the rooms in question. The HVAC system for the prep and sample rooms run 24 hours a day, 7 days a week. Therefore, with the air exchange that this would provide, it would take a longer time for the gas to build up to the concentrations calculated above.

Based on the above calculation and information, a leak in the evaporator building laboratory area will be detected before it could reach a flammable concentration.