APPENDIX D

Natural Gas Build Up In
Selected Non-Safety-Related
Structures At The Midland Site

NUS-4242

NATURAL GAS BUILDUP IN SELECTED MIDLAND PLANT STRUCTURES

Prepared for
CONSUMERS POWER COMPANY

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1.0 INTRODUCTION

This analysis was performed to determine the maximum buildup of natural gas in five buildings at the Midland site following a postulated rupture in the natural gas pipeline. These five buildings are the permanent structures closest to the natural gas pipeline. The pipeline runs adjacent to the plant's northern boundary with a spur extending onto the site, (See Figure 1-1). The five buildings are:

- Evaporator building
- Combination Shop building
- Warehouse No. 1
- Mechanic Shop building
- Condensate Return Pumphouse

Consumers Power Company (CPCo) will install a computerized leak detection system and two isolation valves, one approximately one half mile from the pressure reducing station, and the other in the flood plain, approximately 165 feet from the pressure reducing station (See Figure 1-1). This system will shutoff the natural gas flow within 5 seconds following a guillotine rupture. In addition, a flow limiter will be installed to restrict the steady flow to 20 lbs/sec.

A computer analysis was carried out to determine the mass flow rate resulting from a rupture of the natural gas line adjacent to the Midland site. A basic Gaussian plume dispersion model was then used to determine cloud centerline concentration at the air intakes of the five buildings using 0.5 percentile directionally dependent meteorological conditions [(1)].

HVAC characteristics were reviewed to develop a ventilation flow model for each of the structures identified above. Based on these models differential equations for gas buildup were developed. These equations were numerically integrated to determine the peak natural gas concentration in each building.

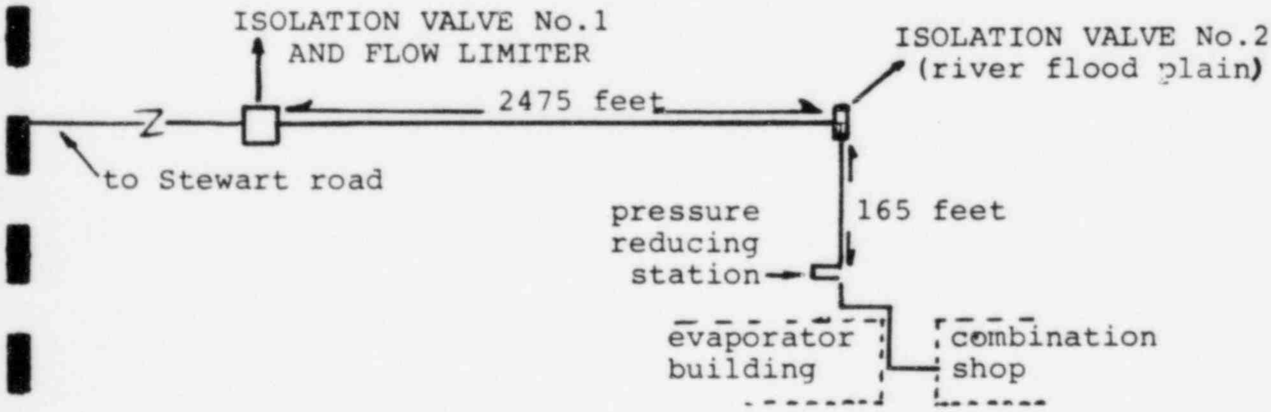
2.0 TECHNICAL APPROACH

2.1 Break Mass Flow Rate Analysis

In order to evaluate the break flow rate as a function of time, a model for the natural gas line was developed for the COMPARE-MOD1 code.[2] COMPARE uses ideal gas parameters R and C_p to describe the fluid. Calculation of parameters for CPCo's natural gas constitutive mixture was performed using the procedures of the American Petroleum Institute Data Book.[3]

Separate models were used to evaluate the transient prior to isolation valve closure and after isolation valve closure. Prior to isolation valve closure, a 25 node model (each node 528 feet long) was used. Only the last six nodes were analyzed after isolation.

The geometric description of the pipeline is as follows:



At the beginning of the event, the gas pressure in the break node was taken as 390 psia (based on the known reservoir pressures and the pipeline lengths) and the temperature is $45^{o}F$ based on CPCo operating experience.

For these conditions and assuming adiabatic, isentropic flow, the choked maximum flow rate can be analytically predicted as:

$$\frac{G_c^2}{g_c \ \rho_o \ P_o} = k\left[\frac{2}{k+1}\right]^{\frac{k+1}{k-1}}$$

where

k = the dimensionless ratio of the specific heats
ρ_o = density
G_c = specific critical mass flow rate
g_c = gravity term
P_o = initial pipeline pressure

2.1.1 Guillotine Rupture

For a 6 inch pipe at these conditions the theoretical maximum flow rate is 220 lbs/sec and, in fact, COMPARE does predict approximately 210 lbs/sec immediately following the initiation of the transient.

However, as the fluid is accelerated and the frictional losses become significant, the pressure loss upstream of the break increases. These losses decrease the pressure and the gas density, causing the break flow rate to decrease.

After the initial break, a decompression wave travels upstream at sonic velocity. Approximately two seconds after the break this decompression wave will have reached the flow limiter and shutoff valve and will continue to travel back to the reservoir. Shortly after two seconds the fluid at the flow limiter has been accelerated to its maximum of 20 lbs/sec and the rate of the pressure change will decrease.

At five seconds, the isolation valve closes. The remainder of the transient is simply the evacuation of the remaining gas in the pipeline after isolation. By thirty one seconds, the break flow terminates. Natural gas flow versus time is presented graphically in Figure 2-1.

2.1.2 Smaller Breaks

The maximum concentration inside each structure is a function of the intake ventilation flow rate and the natural gas release rate. The guillotine rupture, for example, may result in too rapid a release for structures whose ventilation flow is too small to ingest the entire passing cloud. Very small natural gas releases will be exhausted from the buildings as fast as they are ingested, resulting in only a modest buildup of natural gas. Parametric studies of natural gas concentration vs. break flow size were performed to determine the worst break for each structure. The break flow rate was conservatively held constant for the duration of the release.

From the COMPARE analysis performed above, it was determined that the total release of natural gas resulting from any size break is simply the inventory of gas in the pipeline plus the amount of gas passing the flow limiter up to isolation, minus the small amount of gas which remains in the pipeline after the pressure has equalized. The isolation time is a function of break size. CPCo supplied data[7] for isolation time vs. break flow rate is presented graphically in Figure 2-2. The duration of the release may, therefore, be determined from the following relationship:

$$T_{rel} = \frac{M + W*T_{ISO}(Q) - R}{Q}$$

where

T_{rel} = duration of the release (sec)

Q = release rate (lb/sec)

M = initial inventory of natural gas in segment of pipeline beyond isolation valve (lbs)

W = refill flow into segment beyond isolation valve (lbs/sec)

$T_{ISO}(Q)$ = isolation time (sec)

R = natural gas remaining in pipeline after blowdown (lbs)

The refill W, is constrained by the flow limiter to a maximum of 20 lbs/sec.

2.1.3 Breaks Inside Structures

An eight inch natural gas line extends into the auxiliary boiler room and a ten inch pipeline branches into the high pressure boiler rooms. These lines are downstream of both the pressure reducing station and the second isolation valve which is located in the flood plain (See Figure 1-1). The maximum pressure in these lines is 50 psia. Using the critical flow formula in Section 2.1 above, the maximum flow rate from a 10 inch low pressure line is 71 lbs/sec. Conservatively assuming that this maximum flow rate persists for the period up to isolation of the valve in the flood plain (5 seconds), the mass available for release is 400 lbs. The release of this mass of gas will not result in an explosive concentration in either boiler room.

2.2 Gas Concentration at Intakes

This analysis was performed using 0.5 percentile directionally dependent X/Q's developed for the Midland site.[1] The intake concentration is determined using a Gaussian dispersion model. For intakes less than 165 feet (50 meters) from the release point, the concentration at the intake is conservatively assumed to be the density of the gas at ambient conditions. The natural gas ingested with the intake air was limited such that no more than the amount of gas contained in the passing cloud was admitted into the building.

The distance from the break to the air intakes was conservatively chosen to be the shortest distance to the pipe for each intake. For buildings with natural inleakage only, the distance used was the shortest distance from the pipe to the building of interest. The assumed natural inleakage was conservatively taken as two air exchanges per hour.[6]

Free volumes and air intake characteristics for the buildings considered are shown in Table 2-1. This table is based on information provided in References 4 and 5.

2.3 Gas Buildup Inside Structures

The HVAC systems of the nearby structures were studied to determine the ventilation flow paths. For those structures where the air can freely mix, a single volume model was used. All other structures were modeled as two interconnected compartments, with one volume representing the potentially limiting (e.g., highest air exchange rate) subcompartment. Some of the structures have several independent HVAC systems. For these structures, each independent HVAC zone was modeled separately.

The buildup of natural gas in the two compartments can be determined from the following equations:

$$V_1 \frac{dC_1}{dt} = X_1(q_{I1}) - (q_L + q_{01}) C_1$$

$$V_2 \frac{dC_2}{dt} = X_2(q_{I2}) + (q_L)C_1 - (q_{02})C_2$$

X = cloud concentration at distance D_i (lbs/cubic feet)

q_I = intake rate (cubic feet/sec)

q_L = flow rate from volume 1 to volume 2 (cubic feet/sec)

q_0 = exhaust rate (cubic feet/sec)

V = volume (cubic feet)

C = concentration in compartment (lbs/cubic feet)

D = distance in feet (from postulated break site)

These equations were solved numerically using a forth order Runga-Kutta-Gill procedure. The volumes of the buildings were reduced 10% to 15% account for equipment and interior structure.

The Evaporator building has several zones served by independent HVAC systems. For modeling these zones have been divided into the Northern Zone (Control Room, Laboratory, and equipment areas), the Auxiliary Boiler area, and the Evaporator area which occupies the south half of the building. The Evaporator building north has the subvolume with the highest air exchange rate. The remaining spaces have been grouped together. The Evaporator building south is taken as one, freely mixed volume with the two air intake locations. The Auxiliary Boiler area is represented as a single volume structure.

The Combination Shop building and Warehouse No. 1 both consist of two noncommunicating compartments.[5] The Combination Shop building and its High Pressure Boiler Room are both modeled as simple one volume structures. The east side of the Warehouse No. 1 has as its second compartment the Auxiliary Diesel-Generator Room. This room has the highest air exchange rates of the compartments which draw air from the Warehouse No. 1 east. The Warehouse No. 1 west side is modeled as a simple one volume structure.

The Mechanic Shop and the Condensate Return Pumphouse are also modeled as simple one volume structures.

3.0 RESULTS

The maximum concentration of natural gas inside each of the five structures analyzed is presented in Table 3-1. Based on these results four structures have potentially hazardous natural gas concentrations: the Condensate Return Pumphouse, the Mechanic Shop, the High Pressure Boiler room and the Auxiliary Boiler room. None of these structures are safety-related. The Mechanic Shop and the Condensate Return Pumphouse have been analyzed elsewhere[8] and were shown to present no hazard to any safety-related structure.

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. The HVAC for the Auxiliary Boiler room operates at a reduced capacity ($<$ 40,000 cfm) when the boiler is not producing, therefore, the peak percent concentration during this time will be less than 8.5 lbs/sec shown in Table 3-1. When the HVAC is operating at full capacity the boiler is also fired up and natural gas drawn in from a postulated pipeline break would ignite and result in a deflagration which would not be expected to cause damage to any safety-related structures.

The high pressure boiler room is located on the southwest corner of the Combination Shop building. The predicted frequency at which a natural gas cloud of 5% concentration reaches this building is $3.7x10^{-7}$.[9] Since the High Pressure Boiler and the HVAC for the Combination Shop building only operate one third of the time, the expected frequency of ingesting a 5% concentration is reduced to $1.2x10^{-7}$.

$(3.7x10^{-7}/3=1.2x10^{-7})$ When the Combination Shop building HVAC is not operating the expected in-leakage results in a peak concentration of approximately 0.7 volume percent (See Table 3-1) which is well below the flammable limit. Again, when the HVAC is operating so is the boiler, and as with the Auxiliary Boiler room, natural gas drawn into the building from a postulated pipeline break would ignite and result in a deflagration. Such a deflagration, combined with the low probability $(1x10^{-7})$ that a flammable natural gas cloud concentration from a postulated pipeline break reaches the Combination Shop building air intake while the HVAC and boiler are operating, is not expected to pose a hazard to any safety-related structures.

It should be noted that the criterion for flammability is a 5% gas concentration which corresponds to the lower flammability limit for methane. The criterion for a highly explosive mixture is 9.5% gas concentration, which is approximately the stoichiometric mixture of methane in air.

4.0 REFERENCES

1. Report NUS-3963, "Off-Site Hazardous Chemical Definition Program for the Midland Plant", Appendix B, dated January 29, 1982.

2. LA-7199-MS, "COMPARE-MOD1", R. G. Gido, et.al., LASL, MARCH 1978.

3. "Technical Data Book, Petroleum Refining", American Petroleum Institute, Third Edition 1976.

4. Bechtel Drawing - Trailer Layout Annotated by Haldon Smith, August 6, 1982.

5. Personal communication M. Ferens, Consumers Power Company, to K. Toth, NUS Corporation, August 20, 1982.

6. 1981 ASHRAE Fundamentals Handbook, ASHRAE, 1981.

7. Personal communication M. Ferens, Consumers Power Company, to K. Toth, NUS Corporation, October 28, 1982.

8. Report NUS-4235, "Midland Nuclear Power Station Methane Explosion Evaluation for Overpressure and Missile Effects at Safety-Related Structures," October 1982.

9. Report NUS-4146, Rev. 1, "Analysis of Flammable Concentrations at the Midland Nuclear Plant from Natural Gas Pipeline Breaks," October 1982.

TABLE 2-1
BUILDING FREE VOLUMES AND AIR INTAKE CHARACTERISTICS[4,5]

Building	Compartment	Free Volume $10^3 FT^3$	AIR INTAKE CHARACTERISTICS Source	Nearest Distance From Pipeline (FT)	Flow Rate (10^3 CFM)
Evaporator	a) north storage tank cubicle	25	outside	50	3.2
	b) remainder of north area	144	outside	10	14.6
	c) auxiliary boiler area	143	outside	10	40
	d) south area	1672	a) outside (No.Wall)	225	101
			b) outside (So.&W.Wall)	40	587
Combination Shop	a) shop area	622	outside	50	23
	b) high pressure boiler room	151	outside	10	75
Warehouse No. 1	a) east area	1995	outside	375	73
	b) diesel room	8.7	from east area	-	35.5
	c) west area	194	outside	250	8
Mechanic Shop	-	60	outside	25	2.2
Condensate Return Pumphouse	-	27	outside	15	22

TABLE 3-1
MAXIMUM CONCENTRATION OF NATURAL GAS INSIDE STRUCTURES
FROM A POSTULATED PIPELINE BREAK

Building	Compartment	Peak % Concentration	Comments
Evaporator	a) north storage tank cubicle	4.5	4.6 lbs/sec break flow
	b) remainder of north area	3.7	4.6 lbs/sec break flow
	c) auxiliary boiler area	8.5	8.4 lbs/sec break flow
	d) south area	1.0	guillotine break
Combination Shop	a) shop area	2.8	11.0 lbs/sec break flow
	b) high pressure boiler room	8.9/0.7*	guillotine break
Warehouse No. 1	a) east area	0.5	guillotine break
	b) diesel room	0.5	guillotine break
	c) west area	3.5	guillotine break
Mechanic Shop	-	22.0	1.0 lbs/sec break flow
Condensate Return Pumphouse	-	47.0	16.3 lbs/sec break flow

* When HVAC is not operating

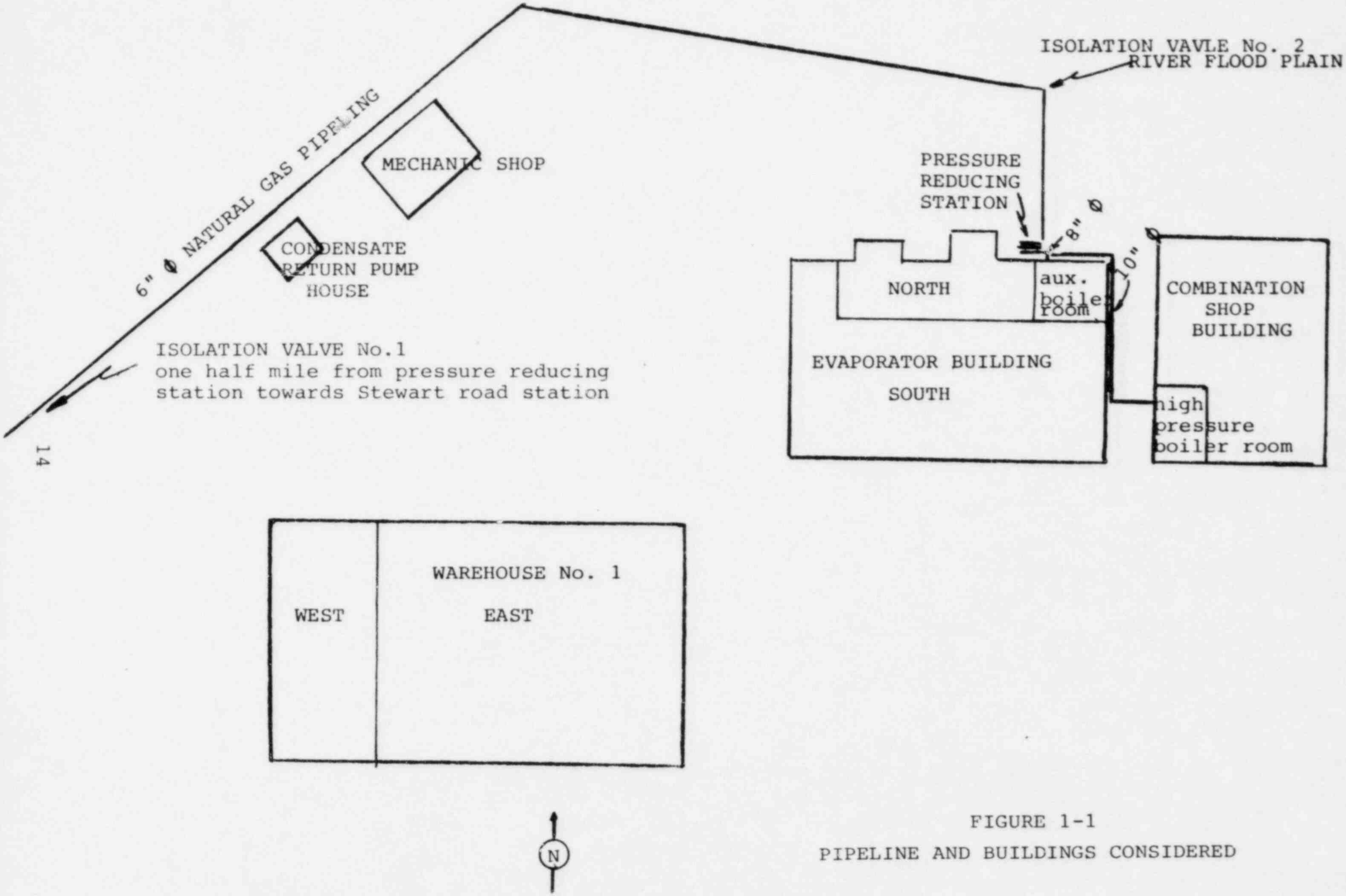


FIGURE 1-1

PIPELINE AND BUILDINGS CONSIDERED

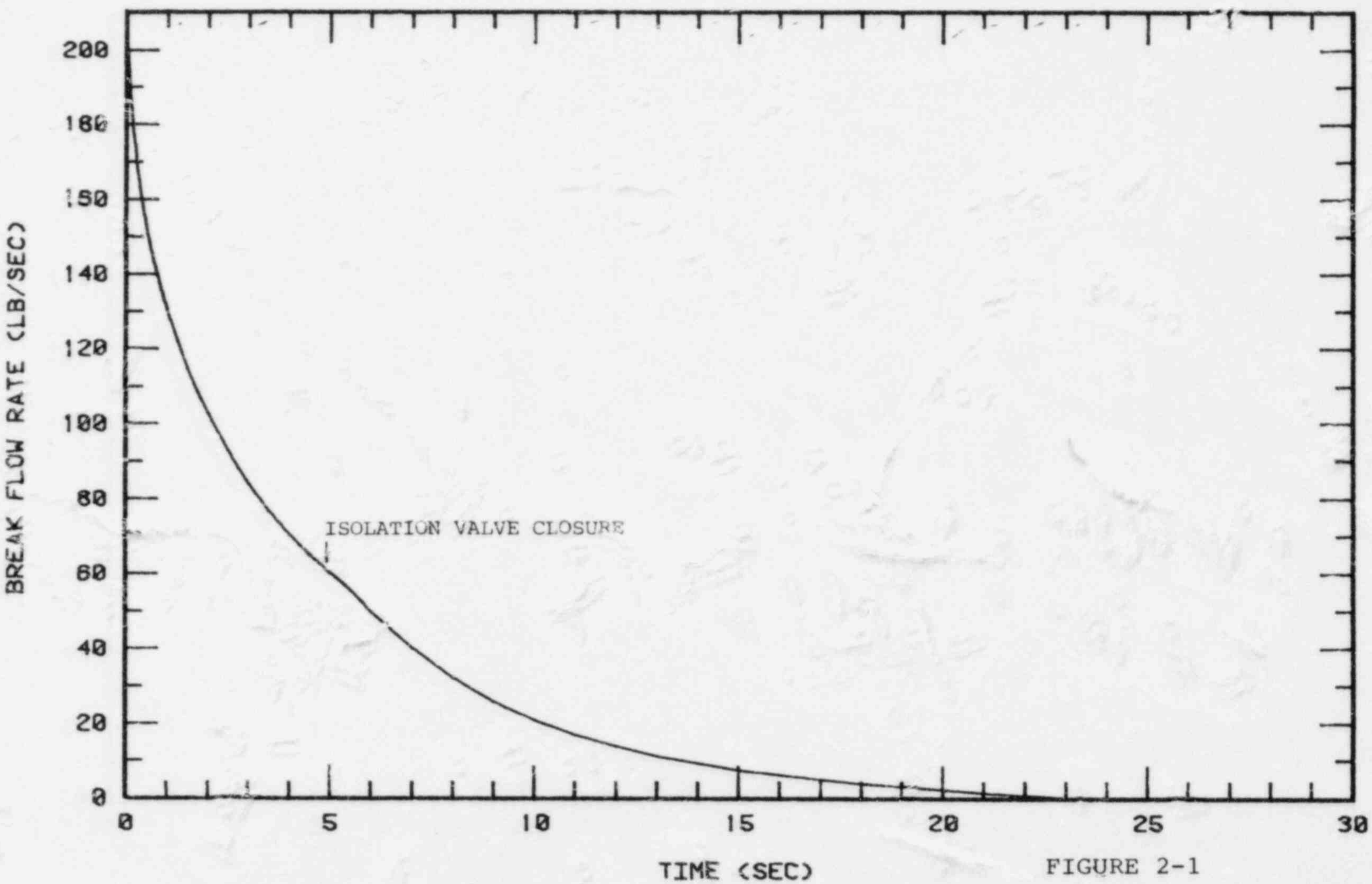


FIGURE 2-1

TIME VERSUS BREAK FLOW RATE FROM PIPELINE NEAR THE MIDLAND PLANT

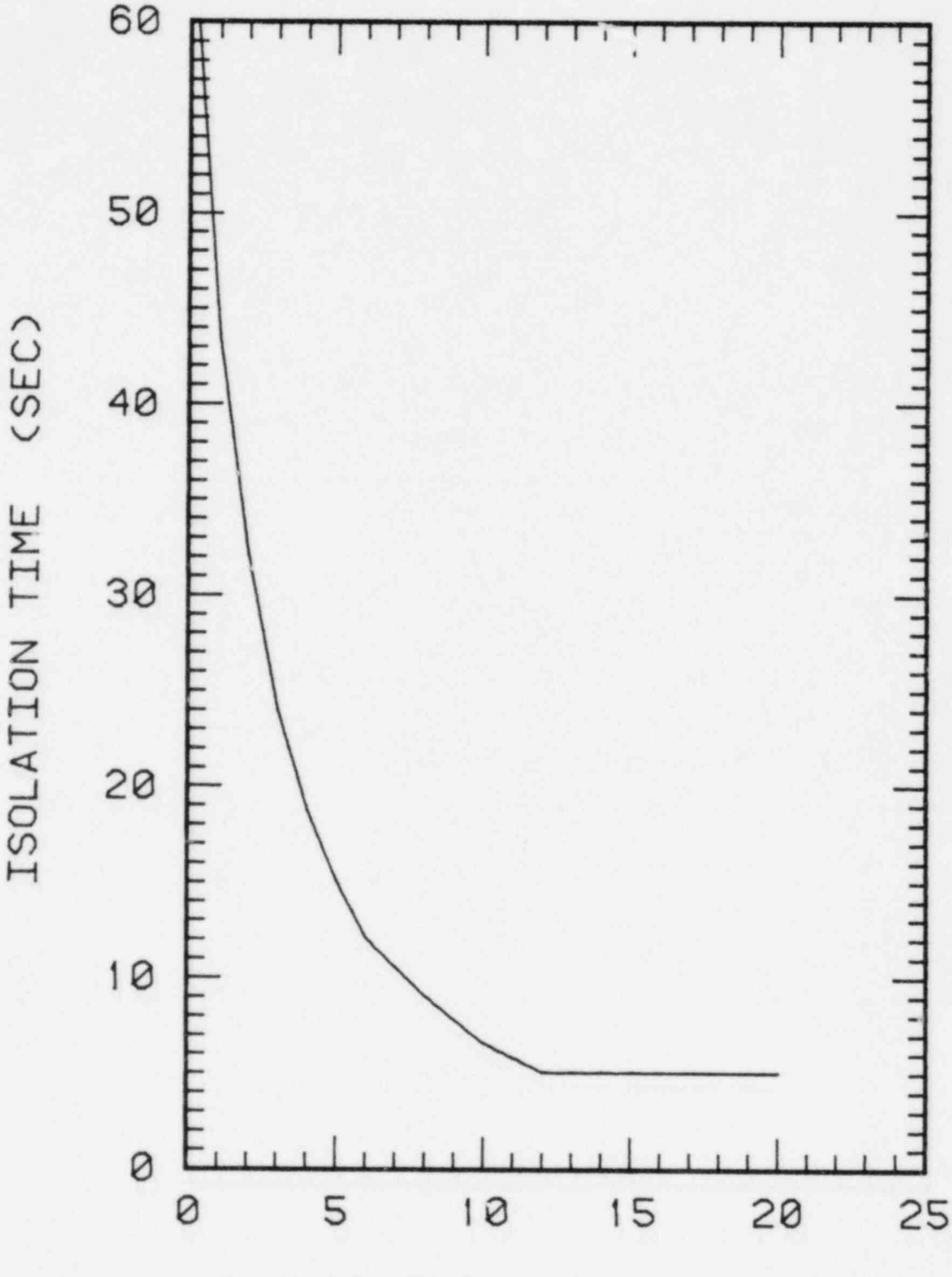


FIGURE 2-2

TIME VERSUS BREAK FLOW RATE FROM PIPELINE BREAK NEAR THE MIDLAND PLANT

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